SWELLING POTENTIAL OF EXPANSIVE SOILS WITH A CRITICAL APPRAISAL OF THE IDENTIFICATION OF SWELLING OF ANKARA SOILS BY METHYLENE BLUE TESTS

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DEDICATED TO MY MOTHER AND FATHER

Approval of the Graduate School of Natural and Applied Sciences.

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ABSTRACT

Swelling properties and especially swelling potential characteristics of Ankara soils by using different swelling potential classification methods developed by different researchers were investigated.

Studies of previous researchers for Ankara soils with regard to swelling have been summarized.

The influence of the mineralogical composition on swelling potential of expansive clayey soils and the use of Methylene Blue Test in order to predict their swelling potential were studied.

A new swelling potential classification method based on the methylene blue test result and clay content was tried to develop.

Data given by previous researchers for Ankara soils and data given by foreign researchers on methylene blue test have been evaluated with regard to swelling potential. Data obtained from tests which were performed on commercially pure samples (kaolinite, illite, montmorillonite) by the Author were also evaluated.

Atterberg limits, hydrometer, X-ray, PVC meter, methylene blue tests were performed to determine swelling potential of remolded samples mostly taken from Pliocene-Pleistocene age fluvial lacustrine deposits (terrace deposits) and recent alluvium deposits in various parts of Ankara region. Swelling potential of these soils were evaluated by using different swelling potential classification methods. For the same soil sample these classification methods may give different swelling potential values.

Omay (1970)'s field swell observations have been compared with the percent swell equation proposed by the Author. In one of the stations estimated % heave values are approximately two times higher than the measured % heave values; for the other station estimated and measured % heave values are close to each other.

A new swelling potential classification method has been proposed by using clay content versus methylene blue value chart.

Key Words: Expansive soils, Ankara clays, Ankara soils, clay minerals, methylene blue tests.

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ŞİŞEN ZEMİNLERİN ŞİŞME POTANSİYELİ VE ŞİŞEN ANKARA ZEMİNLERİNİN METİLEN MAVİSİ DENEYİ İLE TANIMLANMASININ İRDELENMESİ

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ÖZET

Ankara zeminlerinin şişme özellikleri ve bilhassa, değişik araştırmacılar tarafından geliştirilmiş farklı şişme potansiyeli sınıflandırma metodları kullanılarak, şişme potansiyeli özellikleri araştırılmıştır.

Önceki araştırmacıların Ankara zeminlerinin şişmesini dikkate alarak yapmış oldukları çalışmalar özetlenmiştir.

Mineral kompozisyonunun şişen killi zeminlerin şişme potansiyeline etkisi ve Metilen Mavisi Deneyinin bunların şişme potansiyelinin tahmininde kullanılması incelenmiştir.

Metilen mavisi deneyi neticesi ve kil muhtevasına bağlı yeni bir şişme potansiyeli sınıflandırma metodu geliştirilmeye çalışılmıştır.

Önceki araştırmacıların Ankara zeminleri üzerinde yapmış oldukları deneylerin verileri ve yabancı araştırmacıların yayımlamış oldukları metilen mavisi deneyi verileri şişme potansiyelini dikkate alarak değerlendirilmiştir. Bunlardan başka Yazar tarafından ticari olarak saf numuneler (kaolin, illit, montmorillonit) üzerinde yapılmış olan deneylerin verileri de değerlendirilmiştir.

Ankara 'nın çeşitli bölgelerinden, çoğunlukla Pliosen-Pleistosen yaşlı akarsu göl çökelleri ile alüvyon çökellerinden alınan örselenmiş numuneler üzerinde kıvam limitleri, hidrometre, x-ışını, PVC metre ve metilen mavisi deneyleri bu zeminlerin şişme potansiyelini belirlemek için yapılmıştır. Bu zeminlerin şişme potansiyelleri değişik şişme potansiyeli sınıflandırma metodları kullanılarak bulunmuştur. Aynı zemin numunesi için değişik sınıflandırma metodları farklı değerler verebilmektedirler.

Omay (1970)' in arazi kabarma ölçümleri, Yazar tarafından önerilen şişme (%) denklemi sonuçlarıyla karşılaştırılmıştır. İstasyonlardan birinde tahmin edilen % kabarma değerlerinin ölçülenlerin iki katı olduğu ; diğerinde ise tahmin edilen ve ölçülen % kabarma değerlerinin birbirine yakın olduğu gözlenmiştir.

Kil muhtevası - metilen mavisi değeri abağı kullanılarak, yeni bir şişme potansiyeli sınıflandırması metodu önerilmiştir.

Anahtar Kelimeler: Şişen zeminler, Ankara killeri, Ankara zeminleri, kil mineralleri, metilen mavisi deneyi.
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LIST OF SYMBOLS

A^{o}	Angstrom.. one hundred millionth of a centimeter
Ac	Activity
Ama	Clay with moderate activity
Apa	Clay with low activity
Ata	Clay with high activity
Ca^{++}	Calcium ions
Cc	Coefficient of curvature
CC	Clay content (clay size fraction)
c.e.c.	Cation exchange capacity
Ch	Chlorite
Cs	Swelling index
Cu	Coefficient of uniformity
e	Void ratio
e_o	Natural void ratio
f'	Dry weight of soil sample used
Gs	Specific gravity
H	Sample height
I	Illite
I_s	Shrinkage index (I_s=LL-SL)
K	Kaolinite
$\overset{*}{Ko}$	= (Lateral preloading load)/ (Vertical preloading load)
LI	Liquidity index
LL	Liquid limit

LIST OF SYMBOLS (CONT'D)

Lma	Silt with moderate activity
Lpa	Silt with low activity
Lta	Silt with high activity
M	Montmorillonite
M_{BM}	Molecular mass of methylene blue
meq	Miliequivalent
n	Number of observations in statistical analysis
N	Hazard Coefficient
PI	Plasticity index
PL	Plastic limit
PR	Plasticity ratio (PR= PI/PL)
Ps	Swell pressure
$\%_{o/d}$	Proportion of the granular part in total soil
Q	Quartz
r	Coefficient of correlation in simple linear regression
S %	Swell percent
S_{BM}	Active area of methylene blue molecule
Se	External surface area of a particle
SI	Swell index
Si	Internal surface area of a particle
SL	Shrinkage limit
SP	Swell Potential
t	Time
V	Vermiculite

LIST OF SYMBOLS (CONT'D)

Vcc	Volume of methylene blue injected
$VB_{o/d}$	Methylene blue value measured on granular part
$VB_{o/D}$	Methylene blue value measured on total soil
Wi	Initial water content
Wn	Natural water content
α	Lateral restraint factor
Δe	Change in void ratio
ΔH	Change of sample height
ΔS	Change in specific surface area
$\Delta\sigma$	Change of pressure
γ	Unit weight of soil
γ_d	Dry unit weight of soil
ρ_d	Dry density of soil
σ_1	Major principal stress
σ_3	Minor principal stress
σ_o	Applied pressure
ζ	Soil suction
$\mathcal{N}$	Avagadro number=$6.02*10^{23}$
µm	Micron ..One thousandth of a milimeter
1 nm=	0.001 µm
rpm	Revolution per minute

Abbreviations Used in the Text:

AFNOR	L'Association Francaise de Normalisation
ALLUV.	Samples taken from Alluvial soils
ANIT	Anıttepe sample tested in the present study

LIST OF SYMBOLS (CONT'D)

ANK.	Soil samples taken from different regions of Ankara tested in the present study
AOC	Ataturk Orman Ciftligi sample tested in the present study
AOC-KOP	Atatürk Orman Çiftliği (Köprü) sample tested in the present study
BAHC-BES	Bahçelievler- Beşevler sample tested in the present study
BATIKE	Batıkent sample tested in the present study
BILK-KAV	Bilkent kavsağı sample tested in the present study
BLS	Bar linear shrinkage
CPAT	Cement Producers Association of Turkey
DEMET	Demetevler sample tested in the present Study
DOM	Double oedometer method
DOT	Double oedometer test
DTA	Differential Thermal Analysis
EYMIR(G)	Eymir lake sample (its colour is gray) tested in the present study
EYMIR(Y)	Eymir lake sample (its colour is green) tested in the present study
FATIH C	Fatih caddesi sample tested in the present study
F.M.E.	Field Moisture Equivalent
MB	Methylene blue

LIST OF SYMBOLS (CONT'D)

MBV	Methylene blue value
METU	Middle East Technical University
MTA	Maden Tetkik ve Arama Enstitüsü
ODTU	Orta Dogu Teknik Üniversitesi sample tested in the present study
PVC	Potential volume change
SSA	Specific surface area
SPT	Standard penetration test
TERR.	Samples taken from Pliocene- Pleistocene age Fluvial Lacustrine deposits (Terrace Deposits)
TPAO	Türkiye Petrolleri Anonim Ortaklığı
UMIT-KA	Umitkoy kavsağı sample tested in the present study
USBR	United States Bureau of Reclamation

CHAPTER 1

INTRODUCTION

1.1. General

Unsaturated clay soils that undergo a volume increase when the water content is increased are referred to as swelling or expansive soils. Such soils exert a pressure upon saturation when volume change is prevented .

Increase in water content by rainfall , build-up of moisture beneath impervious pavements, leakage of pipes, clogging of drains and poor drainage of surface water may all cause expansion of soil which results in differential movements under the structures. Especially lightly loaded structures like single storey houses, road and airport pavements, parking areas, pipelines, canal linings, spillway structures (Peterson and Peters, 1963) and earth retaining structures may suffer distress if founded on expansive soils. Hardy (1965) states that, in connection with swelling soils, modification may occur in the shearing strength of the soil due to swelling pressures in the soil mass.Damage related to expansive soils is most severe in arid and semi-arid regions. Özmelek (1974) states that Central Anatolia and Ankara shows a semi-arid type of climate according to Thornthwaite Moisture Index. Documented evidence of problems associated with expansive soils is world-wide having occurred in some foreign countries (Schreiner, 1987; Dhowian et. al, 1984 ; Means, 1959 ; Jones and

Holts, 1973 ; Holts , 1959) and in Turkey . Ordemir et. al,(1977) presented two case stories; one dealing with the water supply line construction for Ankara , where a section of the 2.20 m diameter pipeline substantially heaved during its installation. In the other case a design scheme developed on the basis of preliminary laboratory and field investigations for the foundation of the city's new water treatment plant is described . The merits of the direct approach of replacing the surfacial potentially expansive clay soil with a non-expansive selected fill, incorporating an impervious barrier are noted, considering economy as well as technological limitations of developing countries such as Turkey.

Birand (1976) presented a case of airfield pavement failure due to swelling subgrade soil.

The Ankara clay is generally thought of as a suitable foundation material because of its capacity to stand unretained to great depths temporarily, to carry fairly heavy loads without excessive settlement, and to support structures safely on individual or continuous footings; however swelling of the Ankara clay is a problem (Ordemir et. al, 1965).

During the past decade , damage due to swelling action has been observed more clearly in the greater Ankara region where rapid expansion of the city led to the construction of various kinds of structures.

The magnitude of in-situ heave depends on many factors such as the degree of expansibility of the soil involved,thickness of the strata, availability of water, initial density and water content, surcharge load, tree influence (Driscoll, 1953; Ward, 1953), water table and depth of seasonal moisture change. But for any amount of heave to take place the soil has to be a potentialy swelling soil.Therefore awareness of existence and identification of such soils is very important.

The mineralogical composition and clay fraction content are main factors governing the swelling characteristics of expansive clayey soils.However,the determination of mineralogical composition needs relatively sophisticated test equipment and elaborate test procedures which may not be generally available for practical purposes. Therefore, indirect, simple methods were developed to avoid these difficulties.Various research studies showed that expansive clays can be recognized from their plasticity characteritics (e.g. El-shoby and Mazen, 1983). Further the activity of clay as defined by Skempton (1953) was used for the determination of potential expansiveness of clayey soils (e.g. El-Shoby and Mazen, 1983).

A number of emprical approaches, based on the index tests such as Atterberg Limits, Activity, Hydrometer, Linear Shrinkage, and so forth, have been developed as an aid to predict swelling potential of a soil. However, as Seed et. al (1962) pointed out, these approaches for the most part have been based on limited experimental data and have provided approximate correlations between index properties and swelling characteristics.

An accurate ,rational method would have to be based on extensive field exploration and sampling , elaborate laboratory testing,together with the accumulation of climatic, hydrologic data with compatible theories interrelating this information. Such an aproach ,being impractical for most jobs (Ladd and Lambe, 1961), builders of small structures such as single-family residential buildings are, not surprisingly , often reluctant to enter into a full-scale investigation regarding the evaluation of the swelling potential of foundation soil.In such cases , prediction of swelling potential for natural soils based on simple and inexpensive tests (these tests must be handled easily and routinely by a technician, they must be conducted even in small soil mechanics laboratories and they must be conducted rapidly) is very helpful and rewarding (Bandyopadhyay, 1981).

1.2. Objective of the Study:

The first objective of this study is to investigate the swelling properties and especially swelling potential characteristics of Ankara soils by using different swelling potential classification methods developed by different researchers (Dhowian et. al, 1984; Lambe ,1960). Two different data sets were used to get this result:

a) Data set I : Available data from previous researchers on Ankara Soils (index, hydrometer test results).

b) Data set II: Data obtained by the Author on Ankara soils (index, hydrometer, swell index and X-ray test results). These tests were performed on remolded samples taken mostly from Pliocene- Pleistocene age fluvial lacustrine deposits (terrace deposits) and recent alluvial deposits which are expected to exhibit volume changes (generally, terrace deposits show swelling , alluvial deposits show settlement, but if alluvial deposits are dry they may show swelling (Birand, 1978 a) when subjected to variances in water content. There are two samples taken from residual soils just to get an idea about the magnitude of the swelling properties.

The Swell Index values of the soils were determined by Potential Volume Change (PVC) Meter test (Lambe, 1960). Chen (1975) pointed out that the PVC meter test in itself does not measure the swell potential. The true swell potential of clay studied can be much greater than the indicated value. In this study the PVC meter test was used only as a basis of comparison between various swelling soils.

The results of these tests were evaluated and a critical review of the swelling problem as it pertains to the Ankara region is made.

The second objective of this work is to study the influence of the mineralogical composition on swelling potential of expansive clayey soils and critically reviewing, for practical purposes, the possible use of an indirect simple procedure (Methylene Blue Test (AFNOR, 1980)) for the identification of the mineralogical composition of such soils in order to predict their swelling potential (i.e.by assuming the following relationship: Methylene Blue Test result ----→ ----→ Mineralogy ----→ Specific Surface ----→ Swelling Potential). Three different data sets were used to get this result:

a) Data Set III: It contains data from the studies of Lautrin (1987) and Magnan and Youssefian (1989):

i. Lautrin (1987) gives data (index properties, clay fractions, x-ray, methylene blue values) of 79 soil samples.

ii. Magnan and Youssefian (1989) give data (index properties, clay fractions, methylene blue values) of 160 soil samples.

b) Data set IV : Data (index, hydrometer, swell index, methylene blue, X-ray tests results) obtained from tests which were performed on commercially pure samples (kaolinite, illite, montmorillonite) and a mixture of these samples by the Author.

c) Data set V : Data set II and methylene Blue test results of these samples.

As a result, the merits of methylene blue test as a possible means of identification of swelling soils is investigated in comparison to other existing methods.

CHAPTER 2

EXPANSIVE SOILS

2.1.Expansive Soils-Problems

Swell of an unsaturated clay soil may be described as the volume increase that results from an increase in moisture content.

The engineering significance of expansive soils is widely recognized and is well demonstrated by the case histories of failures (Chen, 1975; Schreiner, 1987; Dhowian et. al, 1984; Lambe, 1960; Ordemir et. al, 1977; Birand,1978 a; Birand, 1963; Doruk, 1968; Omay, 1970; Schming, 1984; Daksanamurthy and Raman, 1973; Damla, 1976). Damage caused by expansive soils is almost entirely restricted to light structures such as single storey houses, pipelines, canal linings, surface coverings such as road, airport pavements, parking areas, factory floors (Means, 1959; Öner and Birand, 1978;Jones and Holtz, 1973; Gromko, 1974; Birand, 1976 a; McDowell, 1959; Dawson, 1959; Holtz, 1959). Such damage usually occurs due to the swelling of soil especially in countries where seasonal variations of climatic conditions are great.In the region of Ankara having expansive soils with its semi-arid climate, swell is an important problem.

2.2.Swelling Mechanism and Factors Affecting Swelling Properties.

In its general form an expansive soil is composed of non-clay particles,different clay minerals with pore water solution including charged ions

2.2.1.Clay soil:

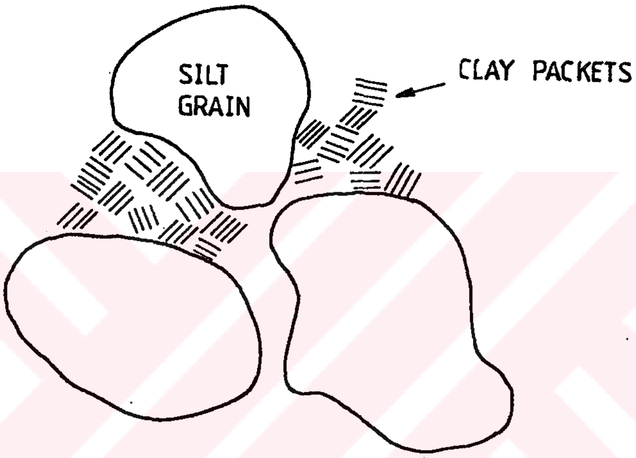


Fig. 2.1.Model of a Desiccated Clay Soil

It is suggested that in principle a partly saturated clayey soil can be considered as being made up of a number of grains as depicted in Fig. 2.1 . Some of the grains consist of silt and sand particles. The other grains may be thought of as " packets" of clay particles. The grains and " packets " are bonded together by the high curvature menisci acting at their contact points.

Volume changes can take place not only as result of grain contact slippage but also by the distortion , shrinkage and swelling properties of the clay "packets". The extent to which either effect predominates will depend on many factors, the chief one being the clay content, the magnitude of the applied loads and the moisture content. In some areas settlement, termed "structural collapse" may take place instead of swelling (Çalışan, Ö.,1987), this phenomenon is outside of the scope of this thesis.

2.2.2.Clay Minerals, Structure and Swelling Mechanism

Most soil classification systems define clay particles as having an effective diameter of two microns (0.002 mm) or less. Particle size alone does not determine the behaviour of the clay fraction. Probably the most important grain property of fine grained soils is the mineralogical composition (Chen,1975). For small size particles, the electrical forces acting on the surface of the particle are much greater than the gravitational force . These particles are said to be in the colloidal state ,the colloidal particles consist primarily of clay minerals that were derived from parent rock (igneous or sedimentary) by weathering (Schreiner, 1987) .

The three most important groups of clay minerals are montmorillonite, illite , and kaolinite, which are crystalline hydrous alumino-silicates. Montmorillonite is the clay mineral that presents most of the expansive soil problems.The type of exchangeable ion also plays a predominant role.

2.2.2.1.Formation of Clay Minerals

The clay minerals are formed through a complicated process from assortment of parent materials through a "weathering" cycle depicted in Fig.2.2. The parent materials include feldspars, micas, and limestone. The alteration process that takes place on land is referred to as weathering. The alteration process includes disintegration, oxidation, hydration, and leaching (Chen, 1975).

The formation of montmorillonite is the result of extreme disintegration, strong hydration, and restricted leaching. Such conditions are favorable in semi-arid regions with relatively low rainfall or highly seasonal moderate rainfall, particularly where evaporation exceeds precipitation (Chen, 1975).

2.2.2.2.Cation Exchange

Clay minerals have the property of sorbing certain anions and cations and retaining them in an exchangeable state.The exchangeable ions are held around the outside of the silica-alumina clay mineral structural unit, and the exchange reaction does not affect the structure of the silica-alumina pocket. In clay minerals, the most common exchangeable cations are Ca^{++} , Mg^{++}, H^{+}, K^{+}, NH_4^{+}, Na^{+} , frequently in about that order of general relative

COMPACTED CLAY
PLACEMENT VARIABLES:

Compaction type and amount

Pore fluid nature and amount

Temperature

SEDIMENTARY CLAY
DEPOSITION VARIABLES

Transporting agent

Deposition process

Nature of deposition environment

INITIAL
SOIL
STRUCTURE

\+

CHANGES IN SOIL STRUCTURE
CAUSED BY:
PRESSURE
TIME
ENVIRONMENTAL CHANGES
- Pressure
- Water content
- Eloctrolyte concentration
- Valence of cation
- Size of cation
- Dielectric constant
- Anion
- Ph
- Temperature
- Disturbance

=

FINAL
SOIL
STRUCTURE

Fig.2.2. Development of Soil Structure (After Lambe, 1958)

abundance.

The existence of such ions are indicated by the ability of clay to adsorb ions from the solution. Cations (positive ions) are more readily adsorbed than anions (negative ions); hence, negative charges must be predominant on the clay surface. Montmorillonites are 10 times as active in adsorbing cations as kaolinites. This is caused by the large net negative charge carried by the montmorillonite particle and its greater specific surface as compared with kaolinite and illite (Chen, 1975). A cation such as Na^+, is readily attracted from a salt solution and attached to a clay surface. However, the adsorbed Na^+ ion is not permanently attached; it can be replaced by K^+ ions if the clay is placed in a solution of potassium chloride KCl. The process of replacement by excess cations is called cation exchange.

Lambe and Whitman (1959) stated that the composition of clay minerals and type of exchangeable ion affect clay thirst. They studied the influence of the exchangeable ion on expansion characteristics of clays by using consolidation test and determined the swell index values (i.e. slope of the e-logP curve). They stated that swellability depends considerably on exchangeable ion, but not in the same way with each mineral. Generally, Li^+ and Na^+ clays are the most expansive forms; Fe^{++} is the least expansive form (Table 2.1; After Lambe and Whitman, 1959)

Table 2.1. Swell Index Values of Clay Minerals

Clay	Exchangeable Ion	Swell Index
Montmorillonite	Na^+	2.5
	Li^+	2.0
	Ca^{+2}	0.51
	Mg^{+2}	0.44
	H^+	0.34
	K^+	0.3
	Ba^{+2}	0.2
	Fe^{+3}	0.03
Illite	K^+	0.27
	Ca^{+2}	0.21
	Mg^{+2}	0.18
	Fe^{+3}	0.15
	Na^+	0.15
	H^+	0.10
Kaolinite	Na^+	0.20
	Mg^{+2}	0.08
	K^+	0.06
	Ca^{+2}	0.06
	Fe^{+3}	0.06
	H^+	0.05

2.2.2.3.Clay Structure

There are two fundamental molecular structures as the basic units of the lattice structure.These are the silica tetrahedron and the alumina octahedron.

The silica tetrahedron consist of a silicon atom surrounded tetrahedrally by four oxygen ions as shown in Fig.2.3.a,b. The alumina octahedron consist of aluminum atom surrounded octahedrally by six oxygen ions as shown on Fig.2.4.a,b. When each oxygen atom is shared by two tetrahedra, a plate-shaped layer is formed. Similarly, when each oxygen atom is shared by two octahedran, a sheet is formed.

The silica sheets and the alumina sheets combine to form the basic structural units of the clay particle (Fig.2.5;after Mitchell, 1976).

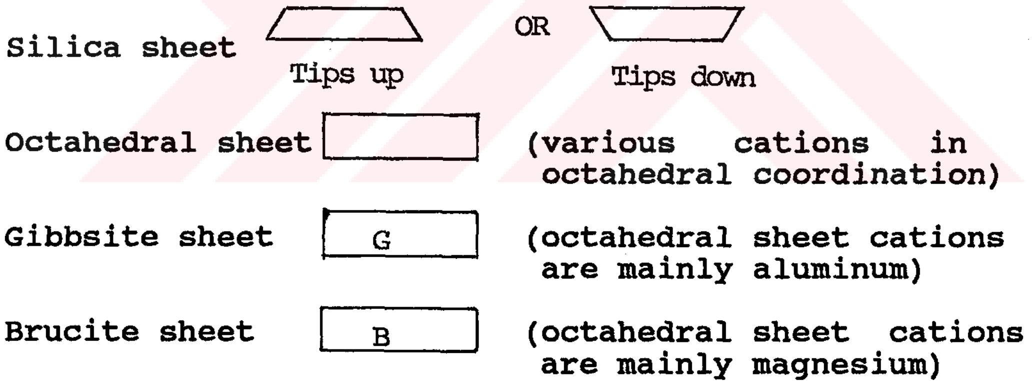
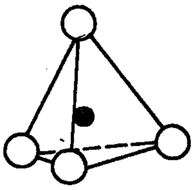
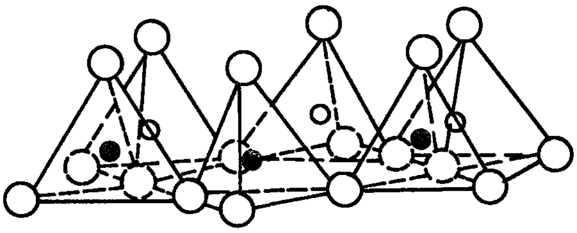


Fig. 2.5. Schematic Representation of Clay Mineral Structures (After Mitchell, 1976)

In montmorillonite, a single particle may be made up of only three such units, and consist of a gibbsite unit between two silicate units. Most other clay mineral particles consist of repeating sequences of two or three structural units (Fig.2.6 and Figs.2.7.a,b,c).



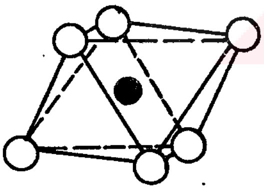
a. Single Silica
Tetrahedron



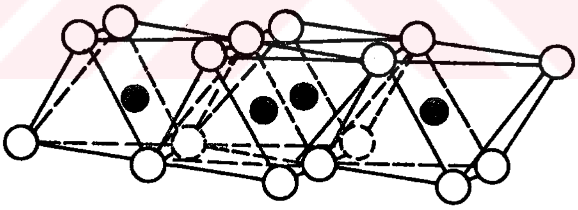
b. Sheet Structure of
Silica Tetrahedrons
in Hexagonal Network

○ ○] Oxygens ● ○] Silicons

Fig. 2.3.a. Single Silica Tetrahedron
(After Grim, 1953)
Fig. 2.3. b. Sheet Structure of Silica Tetrahedrons in
Hexagonal Network (After Grim, 1953)



a. Single Octahedral
Unit



b. Sheet Structure of
Octahedral Units

● ○] Aluminums, magnesiums, etc.
○ Hydroxyls

Fig. 2.4.a. Single Octahedral Unit (After Grim, 1953)
Fig. 2.4.b. Sheet Structure of Octahedral Units
(After Grim, 1953)

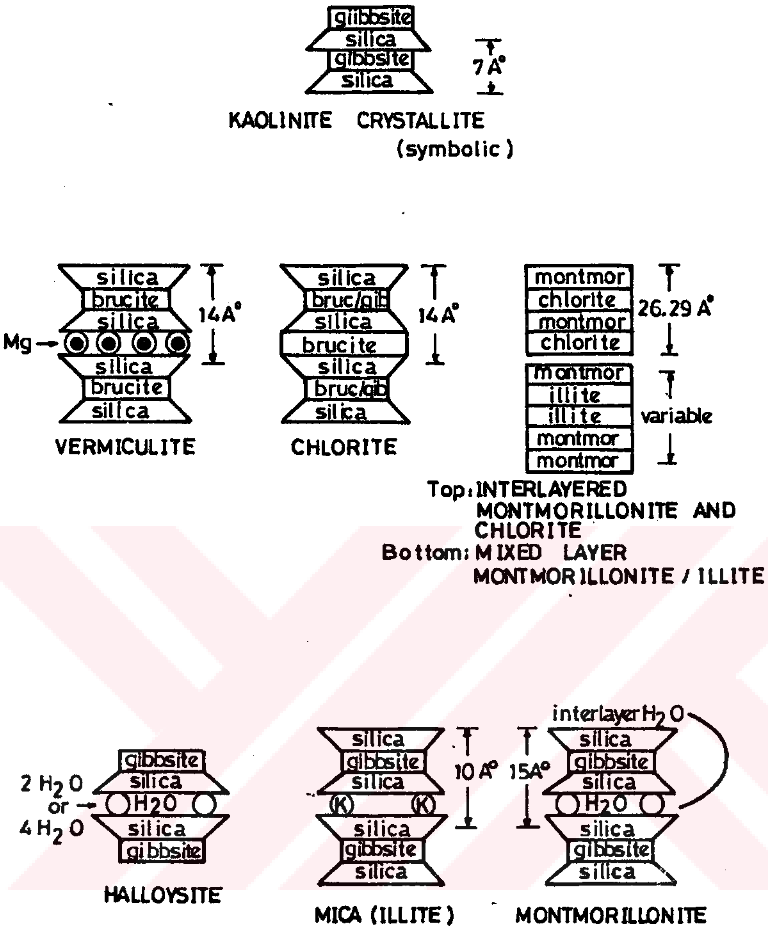


Fig. 2.6. Symbolic Composition of Common Clay Minerals
(After Schreiner, 1987)

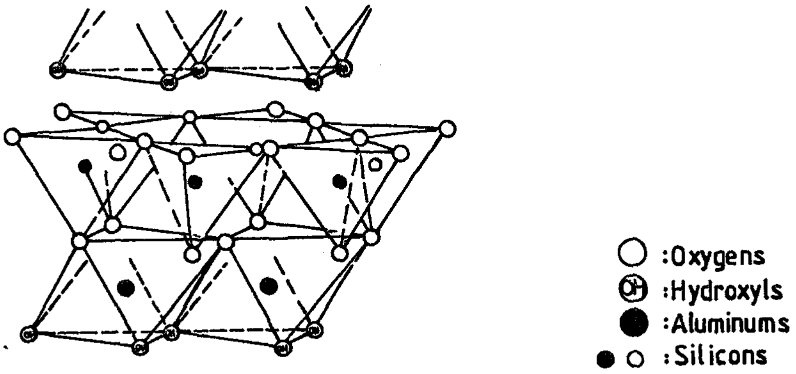


Fig. 2.7. a. Structure of Kaolinite

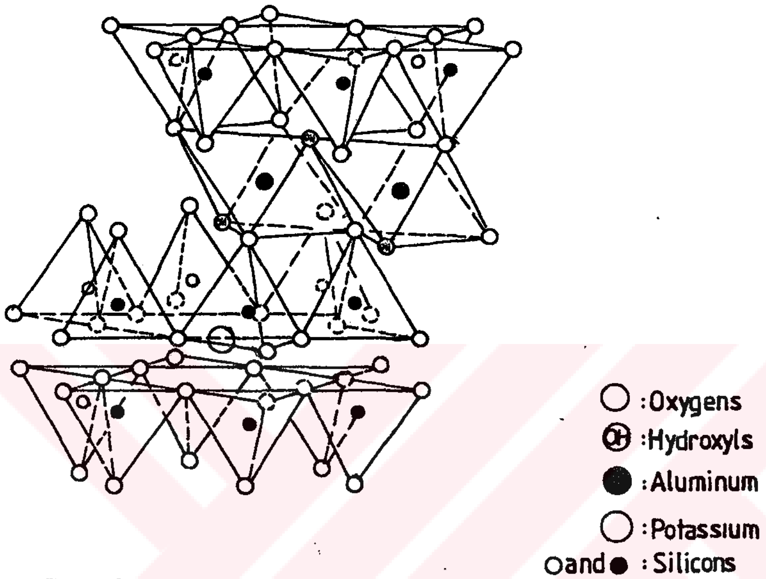


Fig. 2.7. b. Structure of Illite

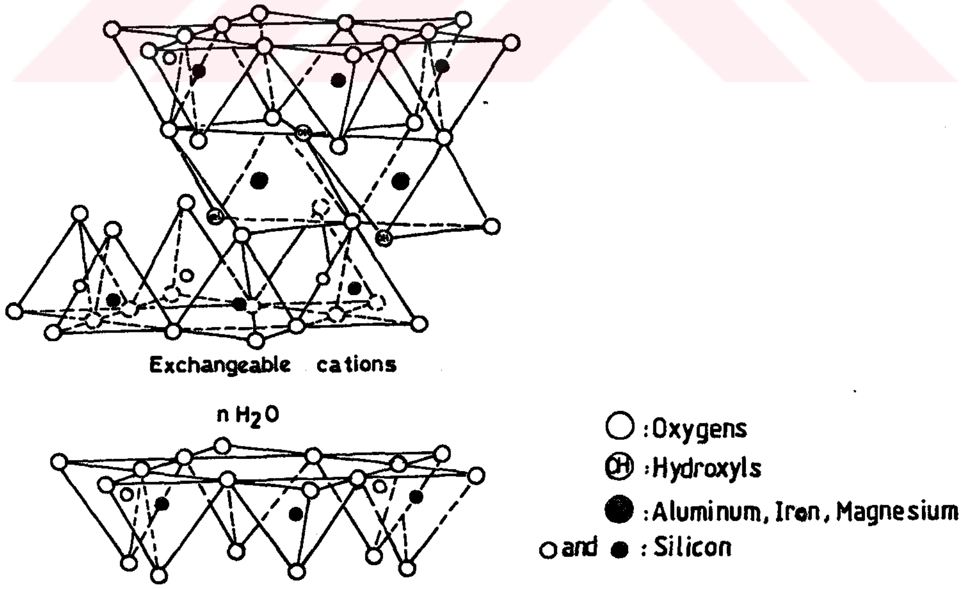
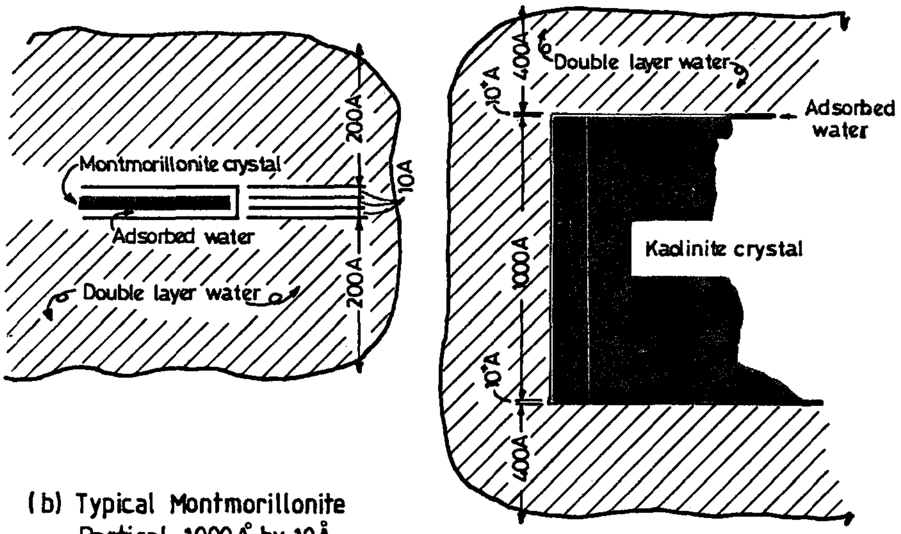


Fig. 2.7. c. Structure of Montmorillonite
(After Grim, 1953)

Thus a kaolin particle may have more than 100 sequences of silicate and gibbsite, chemically bonded to form a single crystal structure up to 1000 A^{o} thick.The montmorillonite particle by comparison may be as little as 10 A^{o} thick.

In the case of clay minerals in civil engineering it is generally water that is immediately adsorbed onto the clay mineral surface. Up to four mono-molecular layers of water may be adsorbed. The thickness of the fully developed, four molecule thick, adsorbed layer is about 10 A^{o}(or $10*10^{-10}$ m) (Figs.2.8.a,b and Figs.2.9.a,b). Adsorbed water is relatively strongly held to the solid particle. Less well bound and ordered water exists with the exchangeable cations outside the adsorbed layers, and is referred to as the diffuse double layer or Gouy-Chapman layer. It is the variation in the thickness of the adsorbed and double layers that is effective in causing swelling of clayey soils (Schreiner , 1987) . Two forces exist in the system,the attractive and the repulsive forces.



(b) Typical Montmorillonite Partical 1000Å by 10Å

(a) Typical Kaolinite Particle 10000 Å by 1000Å

Fig. 2.8.a. Typical Kaolinite Particle
Fig. 2.8.b Typical Montmorillonite Particle
(After Lambe, 1958)

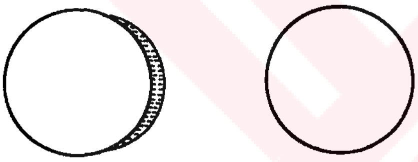


Fig. 2.9.a Adsorbed Water Film

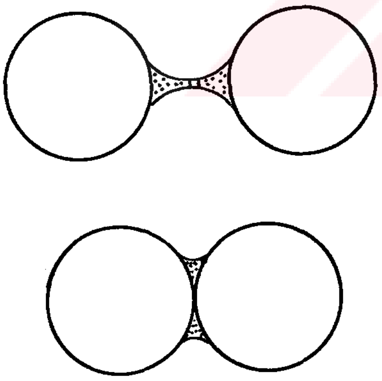


Fig. 2.9.b. Interparticular Water
(After Beaulieu, 1979)

The closer the dipolar water molecules and cations are to the flat plate surface, the more strongly they are attracted (Fig. 2.10; after Birand , 1965). At small interlayer distances, two attractive forces predominate.

1. Electrostatic force - depends on the composition of the mineral.

2. Van Der Waals' force - depends on the distance between the layers.

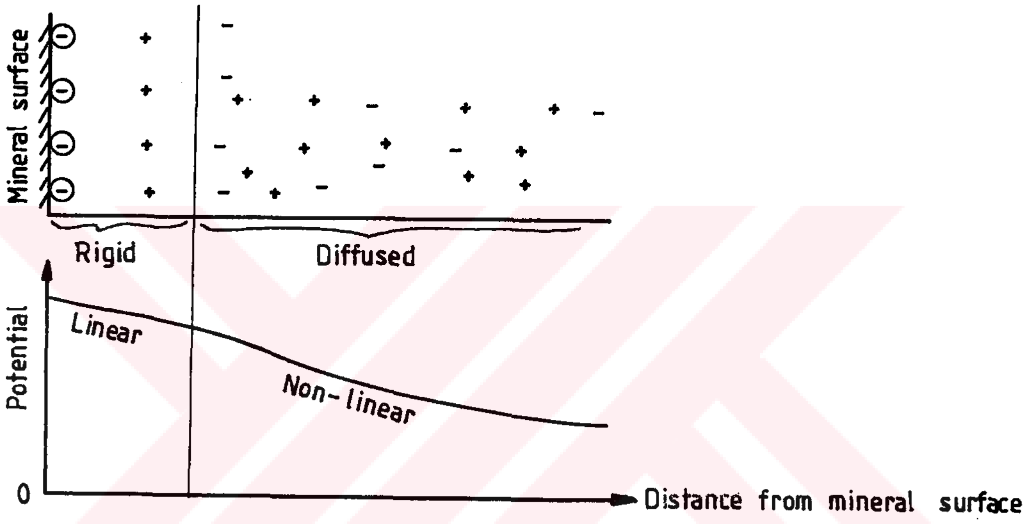


Fig. 2.10. Nature of Variation of Potential with Distance from the clay Surface (After Birand, 1965)

2.2.2.4.Osmotic Pressure and Swelling Mechanism

Osmosis is the passage of solvent through a semi-permeable membrane from a solution of lesser concentration to one of higher concentration, and osmotic pressure is the pressure which must be applied to the solution to prevent the flow of solvent which tries to dilute the solution.

It is well recognized that osmotic pressure can be expected to take place in the soil water system. Assuming that the double layer system exists in the soil lattice, the concentration of ions being held by the attractive force prevents the ions from moving away from the double layer. However, water is able to move in and dilute the concentration, and , consequently, a semi-permeable membrane effect is achieved.

Research made after about 1965 (in the last decade) strongly suggest that osmotic pressure indeed develops in the soil water system and is one of the factors responsible for the swelling mechanism (Chen, 1975).

Since all clay minerals have silicate layers and exchangeable cations, it is reasonable to expect similarities in their interaction with water. Lambe and Whitman (1969) show that individual particles of kaolinite and montmorillonite will develop double layers of similar thickness. However, since the kaolinite particle is about 10000 times the volume of the montmorillonite particle, the water contents of the particle plus double layer water will be very different. For montmorillonite particle the volume of water is about 40 times the solid particle volume for a 200 $\mathring{A}$ double layer thickness (Lambe, 1958). The water volume for the kaolinite however is only 0.8 times the solid particle volume (Fig. 2.8). This indicates a theoretical potential volume change for montmorillonite of 50 times that of kaolinite from completely dry to saturated conditions. Thus the expansiveness can be seen to be significantly dependent on the clay mineral type due to the size of particle typical of that mineral.

Interaction between clay particles takes place through the double layer water and not by solid to solid contact (Schreiner ,1987).

Besides osmosis, there are other natural microscale mechanisms causing volume change in expansive soils (Dhowian et al, 1984) (Table 2.2).

2.2.3. Factors Affecting Swelling Properties

The amount of volume change in expansive soils primarily depends on the soil properties and the environmental conditions as shown in Table 2.3 (Dhowian et. al, 1984) . Of the properties listed, the soil composition which reflects the amount and type of clay mineral, determines the potential for volume change. The remaining intrinsic properties and ambient environmental conditions determine the magnitude and rate of volume change. Some authors presented emprical equations for the prediction of the amount of swell percentage and swell pressure, e.g. Brackley (1983) presented an equation for the prediction of the potential percentage swell of compacted expansive clay samples in terms of

Table 2.2. Natural Microscale Mechanisms Causing Volume Change in Expansive Soils
(Dhowian et. al, 1984)

MECHANISM	EXPLANATION	INFLUENCE ON VOLUME CHANGE
Osmotic Repulsion	Pressure gradients developed in the double layer water due to variations in the ionic concentration in the double layer. The greatest concentration occurs near the clay particle and decreases outward to the boundary of the double layer.	The double layer boundary acts as osmotic membrane when exposed to an external source of free water; that is, it tries to draw the water into the double layer to reduce the ionic concentration. The result is an increase in the double layer water volume and the development of repulsive forces between interacting double layers. The net result is an increase in the volume of the soil mass
Clay Particle Attraction	Clay particles posesses a net negative charge on their surfaces and edges which result in attractive forces for various cations and in particular for dipolar molecules such as water. This makes up the major " holding" force for the double layer water.	In an effort to satisfy the charge inbalance, the volume of water in the double layer will continue to increase until a volume change of the soil mass occurs.
Cation Hydration	The typical hydration of cations substituted into or attracted to the clay particle.	As the cations hydrate, their ionic radii increase, resulting in a net volume change of the soil mass.
London-Van Der Waal Forces	Secondary valence forces arising from the interlocking of electrical fields of molecule associates with movements of electrons in their orbits. The phenomenon frequents molecules in which the electron shells are not completely filled	The interlocking of electrical fields causes a charge inbalance which creates an attractive force for molecules such as water.
Capillary Inhibition	Movement of water into a mass of clay particles resulting from surface tension effects of water and air mixtures in the pores of the clay mass. Compressive forces are applied to the clay particles by the menisci of the water in the pores.	As free water becomes available to the clay mass, the pore water menisci begin to enlarge and compressive forces are relaxed. The capillary film will enlarge resultingina volume change or supply water for one of the other mechanisms.
Elastic Relaxation	A readjustment of clay particles due to some change in the diagenetic factors	Volume change results from particle reorientation and/or changes in soil structure due to changes in the diagenetic factors.

Table 2.3 . Factors That Influence Heave (Dhowian et. al,1984)

FACTOR	DESCRIPTION
Soil Properties	
Composition of Solids :	Active clay minerals include montmorillonite and mixed layer combinations of montmorillonites and other clay minerals.
Concentration of Pore Fluid Salts :	High concentration of cations in the pore fluid tend to reduce magnitude of volume change: swell from osmosis can be significant over long periods of time.
Composition of Pore Fluids :	Prevalance of monovalent cations increase shrink-swell; divalent and trivalent cations inhibit shrink-swell.
Dry Density :	Larger dry densities cause closer particle spacings and and larger swells.
Structures :	Flocculated particles tend to swell more than dispersed particles; cemented particles tend to reduce swell; fabrics that slake readily may promote swell.
Environmental Conditions	
Climate :	Arid climates promote desiccation while humid climates promote wet soil profiles.
Groundwater :	Fluctuating and shallow water tables provide a source of moisture for heave.
Drainage :	Poor surface drainage leads to moisture accumulation or ponding.
Vegetative Cover :	Trees, shrubs, and grasses are conducive to moisture depletion by transpiration; moisture tends to accumulate beneath areas denuded of vegetation.
Confinement :	Larger confining pressures reduce swell; cut areas are more likely to swell; lateral pressures may not equal vertical overburden pressures.
Field Permeability :	Fissures can significantly increase permeability and promote faster rates of swell.

initial void ratio, plasticity index, external pressure and initial water content; Furtun (1989) developed an emprical equation to gain a general idea about the swell pressure of the Alluvial soils and Terrace deposits of the Ankara region in terms of liquid limit, initial water content and dry density.

Birand (1963) also states that, based on the results of laboratory consolidation tests on Ankara soils, the effect of precompression of the clays on swelling is to reduce the swelling potential.

2.3. Cracks and Fissures By Shrinkage and Swelling

In reviewing literature on expansive soil,it was noted that much attention has been focused by various investigators on the mechanics of shrinkage. It has been claimed that shrinkage is the mirror reflection of expansion (Chen, 1975).

Blight and Williams (1971) studied the theory of cracking in a shrinking soil by using the Griffith criterion (Appendix A) and stated that cracking occurs at the surface when the relationship between $\overline{\sigma}_v$ and $\overline{\sigma}_h$ is such that the soil fails or fractures. To investigate the failure conditions, two assumptions are made;

i. $\overline{\sigma}_v$ and $\overline{\sigma}_h$ are principal stresses*

$$\overline{\sigma}_v = -[\gamma . z + \alpha . \gamma_w (h-z) \} \quad [1]$$

$$\overline{\sigma}_h = \gamma_w (h-z)(\beta-\alpha) - k . \gamma . z \quad [2]$$

$$u_z = \alpha . \gamma_w . (h-z) \quad [3]$$

* compression is negative

where,

$\bar{\sigma}_v$ = Effective overburden stress at depth z

γ = Unit weight of soil

z = Depth from ground surface

α = is a factor that increases above unity as the rate of evaporation increases. If evaporation ceases , α tends to unity.

γ_w = Unit weight of water

h = Depth of water table from the ground surface

$\bar{\sigma}_h$ = Effective horizontal stress at depth z

β = is a factor which depends on the stress-strain characteristics of the soil in the horizontal plane. β will probably be equal to or greater than α .

k = σ_h/σ_v (4)

u_z= Pore water pressure at depth z.

ii. Griffith criterion is appropriate to this problem. (Fig.2.11)

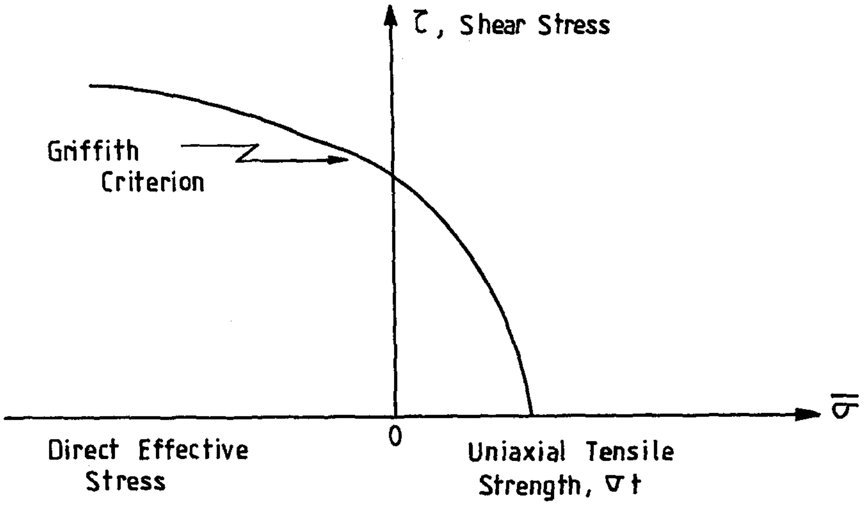


Fig.2.11. Griffith Failure Envelope For Drained Tension Test on London Clay (After Blight and Williams, 1971)

If shrinkage cracks become filled with material washed down from the surface and the soil subsequently swells, horizontal swelling will be restrained and large horizontal swelling pressures will develop. If the horizontal stresses become large enough in relation to the overburden stresses, the clay will fail in passive compression. Under these conditions, the horizontal stress becomes the major principal stress and the vertical stress the minor principal stress.

Clays that alternatly shrink and swell can be expected to contain two sets of fissures, one corresponding to shrinkage, the other to swelling. The shrinkage fissures must, of course, form first and swelling fissures will not form unless open shrinkage fissures become filled with extraneous material.

Özkan (1987) studied the directions of fissures and cracks of Eymir Lake clay by using the Griffith criterion and stated that the Griffith criterion gives the change of the crack orientations with depth reasonably.

CHAPTER 3

METHODS OF IDENTIFICATION AND CLASSIFICATION OF EXPANSIVE SOILS

The purpose of an identification and classification technique for expansive soils is to qualitatively characterize the potential volume change behaviour of suspected problem soils. The need for qualitative characterization of potential volume change is valuable as a forewarning to the engineer during early stages of potential problems with expansive soils.

In current identification and classification techniques one or more of the related intrinsic properties are measured to provide indicators of potential volume change (Dhowian et. al, 1984).

According to Snethen (1984), evaluation of expedient methods for identification and classification of potentially expansive soils is very difficult because none of the techniques provides a universally applicable criterion for assessing or categorizing volume change behaviour.

The following are some of the published classification systems commonly used in current practice:

3.1. General Methods

3.1.1. PVC Meter: (see also Chapter 6)(Lambe, 1960)

The determination of the potential volume change (PVC) of soil was developed by Lambe (1960). Remolded samples were specified. In the standard procedure the sample is first compacted in a fixed ring consolidometer with compaction effort of 55000 ft.-lbs per cu. ft (=2633.28 m.KN/m3). Then an initial pressure of 200 psf (=9.576 KN/m2) was applied, and water added to the sample which is partially restrained from vertical expansion by a proving ring. The proving ring reading is taken at the end of 2 hours. The reading (0.0001 inch division) is converted to pressure (psf) and is designated as Swell Index. From Fig.3.1 ,the swell index can be converted to potential volume change. Lambe established the following categories of PVC rating:

PVC rating	Category
<2	non-critical
2-4	marginal
4-6	critical
>6	very critical

3.1.2. Louisiana Department of Transportation: (Dhowian et. al, 1984)

In this method, Atterberg limits (LL and PI) are used to identify potentially expansive soils as follows:

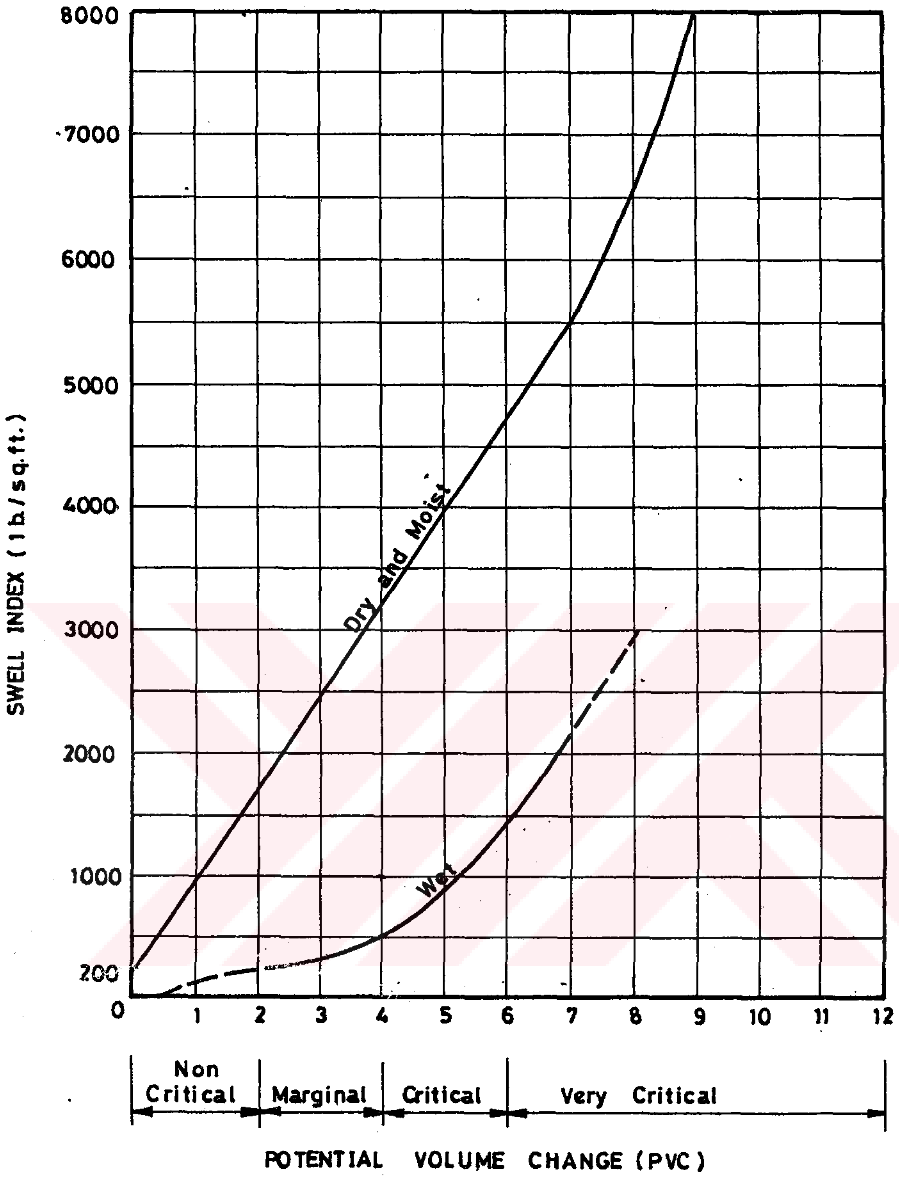


Fig. 3.1. Swell Index Versus Potential Volume Change
(After Lambe, 1960)

LL %	PI%	Potential Swell Classification
20-49	15-24	low to medium
50-70	25-46	high
>70	>46	very high to severe

3.1.3. Kansas Highway Commission (Dhowian et.al, 1984)

This institution also uses Atterberg Limits (PI) to indicate potentially expansive soil in the following way:

PI(%)	Potential Swell Classification
<15	low or none
15-35	moderate
>35	high

3.1.4. Raman Method: (Dhowian et. al, 1984)

This method uses the Atterberg Limits (LL, PI and SL) with a different configuration as follows:

PI(%)	I_s=LL-SL (%)	Degree of Expansion
<12	<15	low
12-23	15-30	medium
23-32	30-40	high
>32	>40	very high

3.1.5. Sowers Method: (Dhowian et. al, 1984)

Sowers uses the combination of PI with SL as an indicator of potential swell.

PI %	SL(%)	Potential Volume Change
>12	15	probably low
10-12	15-30	probably moderate
<10	>30	probably high

3.1.6. Dakshanamurthy and Raman: (Dhowian et. al, 1984)

The Authors present a method for identfiying expansive soils from its LL, PI and I_s values Fig.3.2.

3.1.7. Andersen and Thomson: (Dhowian et. al, 1984)

The authors use the PI alone with the addition of measured potential swell. The criteria is as follows:

PI(%)	Potential Swell	Degree of Expansion
<20	<1.5	Low
20-31	1.5-4.0	Medium
31-39	4.0-6.0	High
>39	>6.0	Very High

LL%	Potential swell classification
0 - 20	non swelling
20 - 35	low swelling
35 - 50	medium swelling
50 - 70	high swelling
70 - 90	very high swelling
>90	extra high swelling

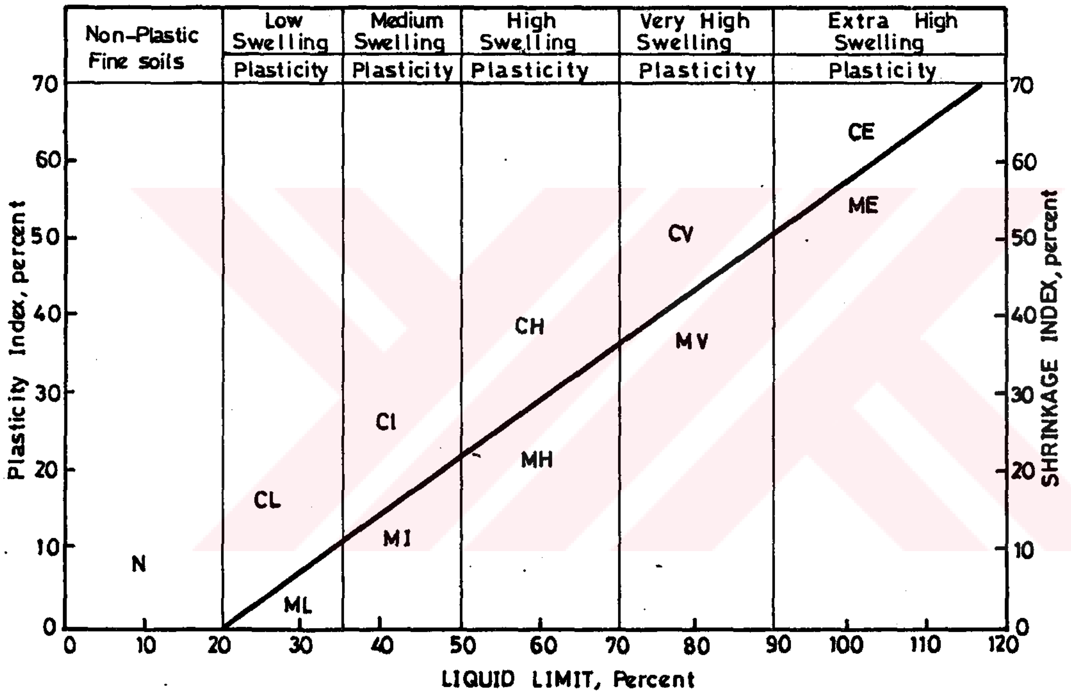


Fig. 3.2. Chart for Potential Expansiveness of Soils (After Daksanamurthy and Raman, 1973)

3.1.8. Ranganatham and Satyanarayana: (Dhowian et. al, 1984)

These authors were the first to use $I_s = (LL-SL)$ for identification of expansive soils. The criteria are:

I_s (%)	Potential Swell Classification
<20	Low
20-30	Medium
30-60	High
>60	Very High

3.1.9. Saita and Miki :(Dhowian et. al, 1984)

This method defines the plasticity ratio (PR) as the PI divided by the PL and uses this ratio to correlate with measured swell. The corresponding criteria for potential swell are:

PR	Potential Volume Change, %	Potential Swell Classification
<0.6	<3	Low
0.6-1.0	3-10	Medium
1.0-2.0	10-50	High
>3.0	>50	Very High

3.1.10. US Bureau of Reclamation (USBR): (Dhowian et. al,1984)

This method involves direct correlation of observed volume change with colloidal content, PI and SL. The degree of expansion and limits of correlated properties are shown in the following tabulation:

Data From Index Tests			Probable	Expansion
Colloid Content %<2 m	PI %	SL %	Expansion %	
<15	<18	15	<10	Low
13-23	15-28	10-16	10-20	Medium
20-31	25-41	7-12	20-30	High
>28	>35	<11	>30	Very High

This method correlates reasonably well with expected behaviour and provides a good indicator of potential volume change (Dhowian et. al, 1984).

3.1.11. Altmayer : (Dhowian et.al, 1984)

The author suggests a method based on correlation between percent swell and the SL, and linear shrinkage. The results of this recommendations are as follows:

Linear Shrinkage %	SL %	Probable Swell, %	Degree of Expansion
<5	<12	<0.5	Non-critical
5-8	10-12	0.5-1.5	Marginal
>8	10	>1.5	Critical

The limitation of the method is noted as the fact that the data were collected on remolded samples only, and therefore the method is not applicable to in-situ behaviour.

3.1.12. Seed, Woodward and Lundgren: (Seed et.al, 1962)

The potential swell of expansive soil is defined from correlations of percent swell from PVC Meter tests using laboratory prepared and compacted samples with percent clay size (-2 μm)and soil activity. The recommended classification system is shown in Fig. 3.3 . The authors also propose the following relationship for percent swell (S %) calculations:

$$S\ \% = 0.00216 * PI^{2.44}$$

In this method potential swell can be categorized in the following way

Potential swell, %	Degree of Expansion
0-1.5	Low
1.5-5.0	Medium
5.0-25.0	High
>25	Very High

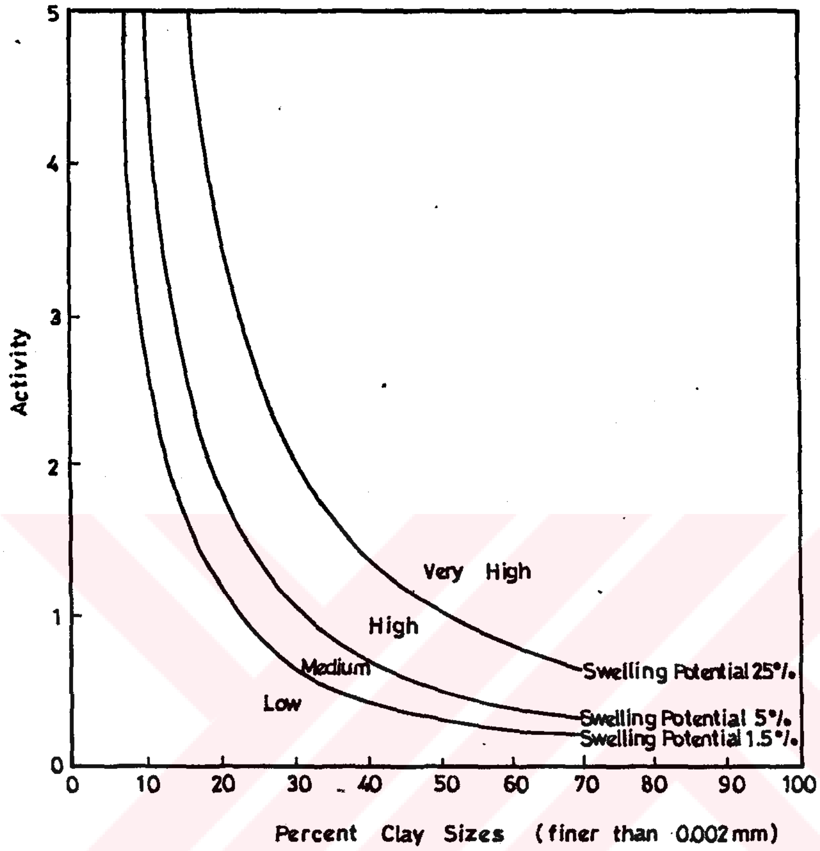


Fig. 3.3. Swell Potential Classification with Clay Fraction and Activity (After Seed et. al, 1962)

3.1.13. Chen: (Dhowian et. al, 1984)

In an effort to simplify the USBR method (i.e. eliminate the need for hydrometer analysis) the following classification is proposed:

Laboratory and Field Data				
%< No.200	LL,%	SPT, N Value	Probable Expansion	Degree of Expansion
<30	<30	<10	<1	Low
30-60	30-40	10-20	1-5	Medium
60-95	40-60	20-30	5-10	High
>95	>60	>30	>10	Very High

3.1.14. Vijayvergiya and Ghazzaly:
(Vijayvergiya and Ghazzaly, 1973)

The method defines a swell index for an expansive soil as the ratio of natural water content w_n to the LL and correlates it with oedometer swell and swell pressure data. The limits of probable swell and swelling pressure are defined as shown in the following tabulation:

w_n/LL	Probable Swell Pressure tsf	Probable Swell %
>0.5	<0.3	<1
0.37-0.5	0.3-1.25	1-4
0.25-0.37	1.25-3.0	4-10
<0.25	>3.0	>10

3.1.15. Vijayvergiya and Sullivan :(Dhowian et. al, 1984)

The method is a correlation of oedometer swell data with LL and dry density. The degree of expansion is not defined, instead a family of curves relates the parameters with quantitative volume change as shown in Fig. 3.4.

3.1.16. Sorochan (Dhowian et. al,1984)

The correlation involves relating the swelling index (void ratio,e, after free expansion divided by the initial sample void ratio, e_0) to PI. The degree of expansion categories are as follows:

Swelling Index e/e_0 Plasticity index, PI					Degree of Expansion
15-20	20-25	25-30	30-35	35-40	
<1.12	<1.11	<1.09	<1.08	<1.07	Non swelling
(1.12-1.23)	(1.11-1.21)	(1.09 1.19)	(1.08-1.17)	(1.07-1.15)	Slight
(1.23-1.39)	(1.21-1.30)	(1.19-1.28)	(1.17 1.25)	(1.15-1.22)	Medium
>1.39	>1.30	>1.28	>1.25	>1.22	High

The method considers two of the properties important to volume change; however, an expansion test must be conducted to use the method. Also, the upper limits of PI are less than PI values encountered in many naturally occuring expansive soils (Dhowian et. al, 1984).

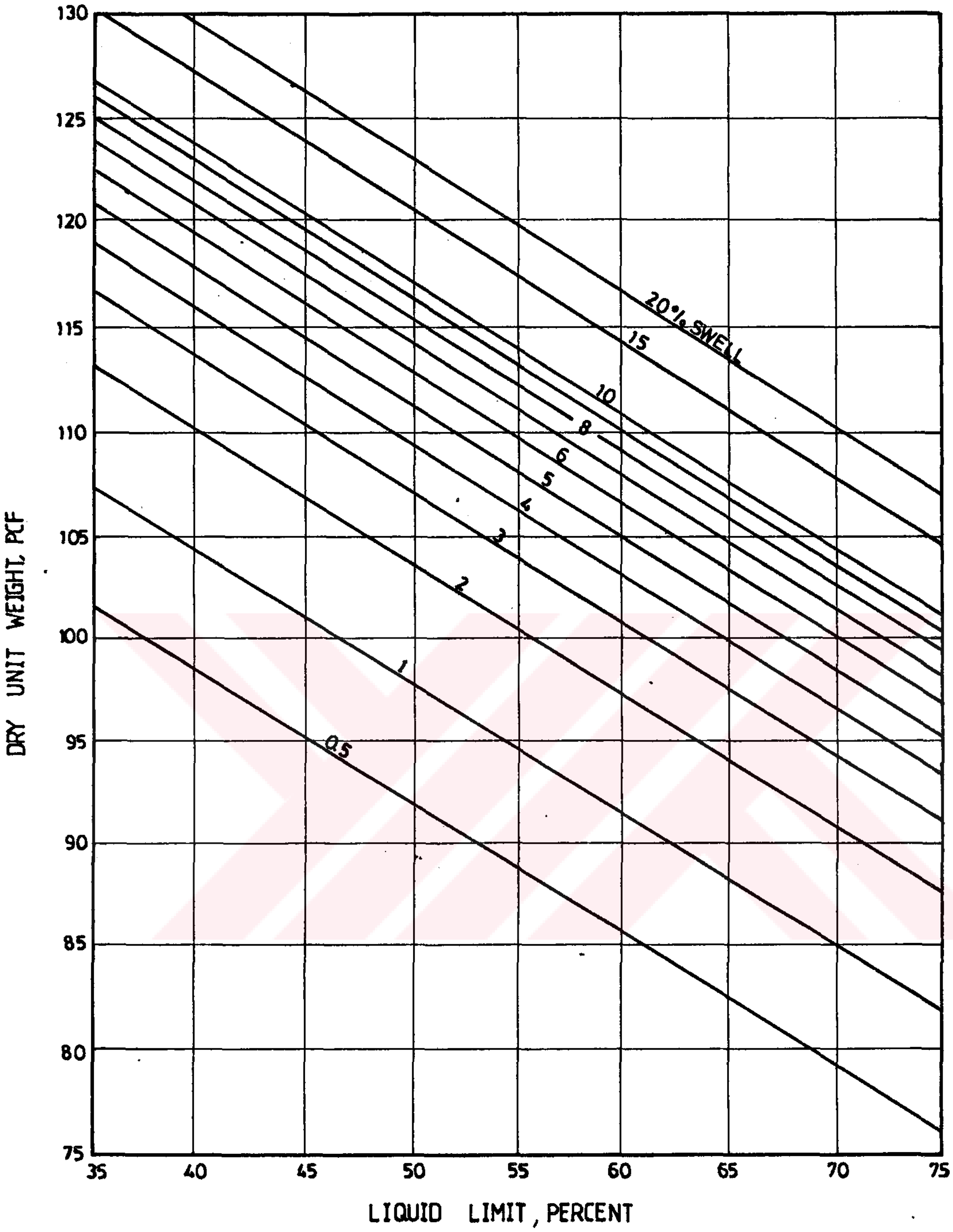


Fig. 3.4. Correlation of Percent Swell with Liquid Limit and Dry Unit Weight (After Dhowian et. al, 1984)

3.1.17. Van der Merve : (Dhowian et. al, 1984)

The simpler method involves the determination of the plasticity index (PI) and the clay content of the suspect soil (Fig.3.5) .

3.1.18. Snethen and Johnson: (Dhowian et.al,1984)

The author includes soil suction, ζ , in addition to LL and PI as a key parameter to indicate the swell potential of the expansive soils. The proposed classification system is as follows:

LL,%	PI,%	ζ,(tsf)	Potential Swell,%	Potential Swell Classif.
>60	35	>4	1.5	High
50-60	25-35	1.5-4	0.5-1.5	Marginal
<50	25	<1.5	0.5	Low

The evaluation of existing techniques on the basis of a large number of laboratory swell measurement indicates that the most consistent indicators of potential swell are first, the LL and PI; second the LL and w_n combined; third, SL and PI; and the SL and linear shrinkage. Further analysis of the laboratory data using correlation studies of potential swell versus 31 independent variables showed that the most consistent

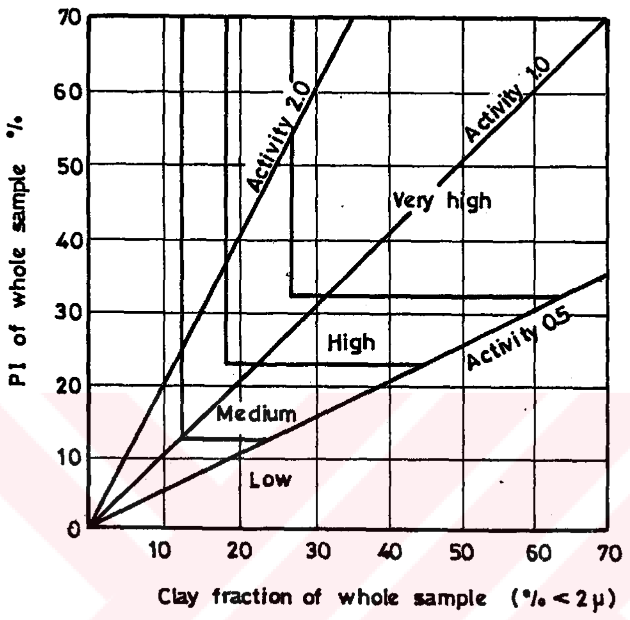


Fig. 3.5. Van der Merve Potential Swell prediction
(After Dhowian et.al, 1984)

indicators of potential swell are LL, PI, I_s, BLS and ζ (soil suction) (Dhowian et.al, 1984).

After the determination of swelling potential in the laboratory, as outlined above, the prediction of the amount of total heave can be made. Numerous methods have been proposed for heave predictions, however there is a lack of standardization and agreement among the methods. Dhowian et. al (1984) categorized the heave prediction methods into three groups:

i. Oedometer tests and prediction procedures (also Double Oedometer test method)

ii. Methods based on soil suction

iii. Emprical methods

Since the prediction of amount of total heave is out of this thesis subject, details of these methods are not given here.

As it can be seen from Appendix B , for the same soil, different swelling potential classification methods may give different swelling potential classes.

CHAPTER 4

IDENTIFICATION OF EXPANSIVE SOILS BY SPECIFIC SURFACE AREA VALUES

In 1957, De Bruyn et al. studied the specific surface area- potential expansiveness relationship. In order to be potentially expansive the soil must be able to bind a certain amount of water that does not drain away by the force of gravity. Water affinity is thus a necessary condition for potential expansiveness, which can be related to the specific surface. Expansive soils generally contain appreciable amounts of montmorillonite and illite types of clay minerals (De Bruyn et. al, 1977) and clay mineral analysis is therefore a further approach for the study of expansive soils.

Dyal and Hendrics determined the specific surface area by the glycol method (De bruyn et. al, 1957). This method has the advantage of being much simpler than the clay mineralogical analysis.Total, external and internal specific surface areas (total specific surface area of a particle corresponds to external and internal surface areas of the particle) of most of the samples were determined by means of the glycol retention method.

From Table 4.1 , it would appear that soils with total specific surface areas of less than 70 m2/g and equilibrium moisture contents (at 85 % humidity)of less than 3 % may be classified as good (non- expansive) and those with total specific surface areas of more than 300 m2/g and equilibrium moisture contents (at 85 % humidity) of more than 10 % as bad, the intermediate group being classified as medium.

Table 4.1 . Summary of Test Results (After De Bruyn et. al, 1957)

Sample No.	Locality	% Moisture at 85 % Humidity	Specific Surface Area In m2/ g (Total)	Comments
Bentonite	Wyoming	19.3	671	B
1126	Rustenburg	16.6	433	B
1643	"	10.4	326	B
1125	"	11.6	324	B
	Vereeniging	-	913	B
1124	Rustenburg	9.0	173	M
1119	"	5.8	89	M
1123	"	2.0	69	G
1120	"	2.1	53	G
1300	"	2.3	48	G
1122	"	1.6	46	G
1050	Lusaka	-	38	G
Kaolinite	Kloof	2.3	36	G

B=Bad, M= Medium, G=Good

The use of the total specific surface area was preferred to that of the internal specific surface area of montmorillonite content for comparison purposes, because the fine grained particles of kaolinite and illite might also contribute to potential expansiveness. Shiming (1984) also stated that the value of specific surface area (SSA) is a better comprehensive index of material composition for identification of expansive soils.

From the physical and chemical point of view , the soil will expand due to an increase of the thickness of double layer when the soil meets water, so the surface area of the particle of the soil will be enlarged. The soil with large c.e.c. has a strong tendency for water adsorption.

Owing to the fact that the property of the clay mineral in various kinds of soils is not the same, the surface area values of the particles of the soils are quite different (Table 4.2), thus the characteristics of the soils can be distinguished.

Table 4.2. C.E.C and Specific Surface Areas of Different Clay Minerals

Clay Mineral	Total Specific Surface Area (m2/g)	C.E.C meq/100 g
Montmorillonite	810	80-150
Illite	67-100	10-40
Kaolinite	2-30	3-15

* c.e.c.= cation exchange capacity

Table 4.3 . shows the measured results for the (Specific Surface Area)SSA of the expansive soils and kaolinite from different sites and the corresponding composition of clay mineral, c.e.c. free swell (%), liquid limit (%) and plasticity index (%).

According to the Schiming (1984)'s opinion SSA can reflect the types of main clay minerals in the soils and constitute a good index for the identification of expansiveness of soils.

It can be seen from Table 4.3 that as SSA increases, the c.e.c. and LL will also increase.

Schiming (1984) suggests that th preliminary classification of the expansive soils could be done according to the test results in Table 4.4.

Table 4.4 . Preliminary Classification of Expansive Soils

Main Clay Mineral in the Soil	Specific Surface Area (m2/g)	Liquid Limit(%)	Water Adsorption
Montmorillonite	280	55	Strong
Montmorillonite-Illite	150-280	45-55	Medium
Illite	60-150	35-45	Weak
Kaolinite	60	35	Very Weak

Table 4.3 . Test Results of the Soil Properties (After Schming, 1984)

No.	Appraisal of the Composition of Mineral M=Montmorillonite I=Illite K=Kaolinite V=Vermiculate Q=Quartz	Specific Surface Area (m2/g)	CEC (meq/100 g)	Free Swell (%)	LL (%)	PI (%)
1	M, small amount of mica	748.8	92.5	74	81.0	30.0
2	I(60%),K(33%),M(7%)	452.4		70	60.8	34.5
3	M, small amount of K	290.6	63.9	62	58.6	28.5
4	I mainly, K and M	217.6	48.0	51	44.8	19.5
5	M mainly, small amount of K,hydromica	205.4	43.1	55	58.9	28.0
6	I mainly, M and V	205		60	36.0	13.0
7	I mainly, M and V	196		60	37.0	16.0
8	I mainly, M and V	170.5		50	38.0	17.0
9	I mainly, M and K	156.4	27.5	39	36.7	17.5
10	I mainly, small amount of M	137.5	32.04	51	40.5	20.6
11	K(50%),I and Chlorite	136.8	11.0	33	38.5	18.1
12	I mainly, M and V	128.8		29	34.0	13.0
13	I mainly, small amount of M and Q	125.1	32.6	56	42.4	18.6
14	I mainly, small amount of K	118.6	32.4	41	44.2	21.9
15	K mainly	101.8	14.9	28	55.5	29.6
16	K containing small amount of Q	53.0	5.9	16	40.5	14.4

CHAPTER 5

METHYLENE BLUE TEST

5.1. Studies by Foreign Researchers on Methylene Blue Test

Studies on dye adsorption or methylene blue adsorption by clay minerals have been carried out for a long time by various researchers .Jones (1964) used methylene blue test to measure the bentonite content of the drilling mud for petrolium drillings. Phelps and Harris (1968), Nevins and Weintritt (1967), used this test to characterize ceramic material. Fairbairn and Robertson (1957) used this test to as complementary to the Atterberg Limits test results. Methylene blue test was developed in France for the suitability of the granular materials (i.e. to detect the clay in the granular material).

In chronological order, some of these studies can be summarized as follows:

Emodi in 1946 studied the "adsorption of dyestuff by montmorillonite" and stated that the adsorption of dyestuff by montmorillonite can be attributed to two different processes, namely (1) base exchange and (2) Van Der Waals adsorption. There are some mixed cases, but usually one of the two effects is predominant and can be easily distinguished by one of the following features:

Base exchange reaction	Van Der Waals adsorption
Almost instanteneous	Slower
Only the positive group of the dye is adsorbed and some simple cation such as Ca, Na, Mg,etc., released from the montmorillonite	The molecule is adsorbed as a whole. There is no release of cations

Robertson and Ward (1951) stated that the methylene blue is unfortunately unobtainable as a chemical of constant and known impurity. Not only may chemical impurities be present, but the water of hydration is not constant, though the compound is sometimes given in textbooks as being $C_{16}H_{18}N_3SCl.3H_2O$ (for the methylene blue substance used in this study, MERCK, $C_{16}H_{18}N_3SCl.3\text{-}4H_2O$) The equivalent weight of the pure unhydrous dye is 319.6.

For experimental work he recommends estimating the moisture content of the dye and neglecting the small amount of chemical impurity which is found in the best grades of methylene blue.

Fairbairn and Robertson (1957) studied the correlation between the LL and dye adsorption.They concluded that for a given engineering site methylene blue can be used as as a convenient substitude for LL provided that the two methods are calibrated. Since the relationship varies with clays of different geological types, methylene blue results should be kept in groups according to the geological age of the specimens.

It follows that where the rocks show great variation, or where the site is very large, and a great many plasticity tests are needed, it would be economical to do many methylene blue tests and few LL tests Figs.5.1, 5.2 (After Fairbairn and Robertson, 1957).

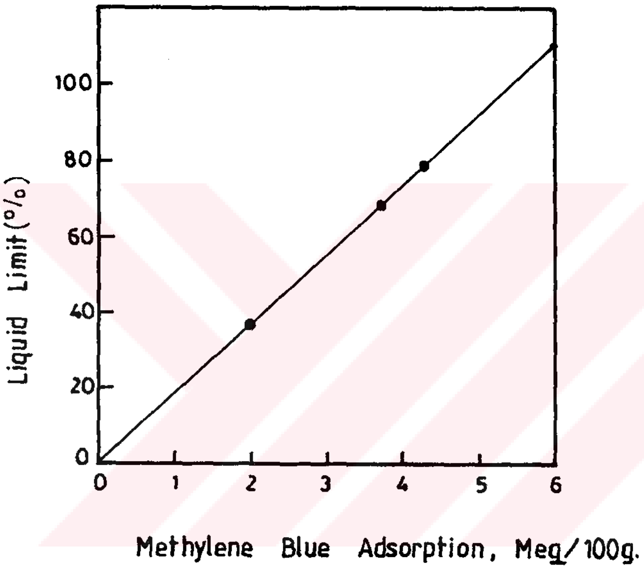


Fig.5.1. LL of Buckland Pit (Cretaceous) Samples Compared With Methylene Blue Adsorption (After Fairbairn and Robertson, 1957)

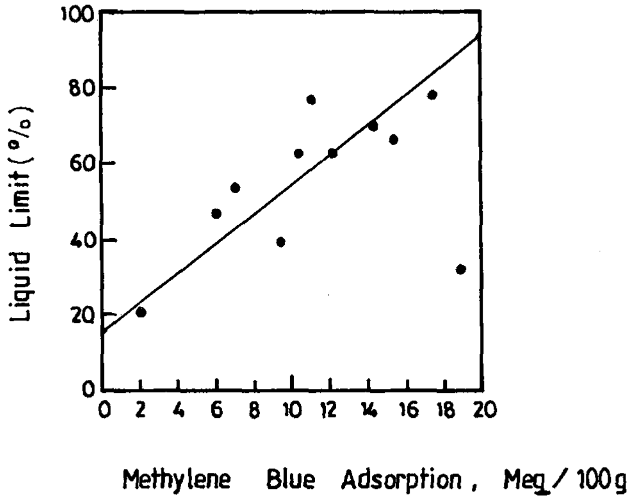


Fig.5.2 . LL and Methylene Blue Adsorption of Marchwood Samples.(After Fairbairn and Robertson, 1957)

Worrall (1958) studied the adsorption of basic dyestuff by clays and stated that the commercial dyes of the basic type, of which methylene blue hydrochloride is a good example, consists of an organic base combined with an acid. When this dye is dissolved in water, methylene blue cations and chloride anions are formed and these (i.e. Methylene Blue and Chloride) can then replace the existing cations associated with a given clay.

Calcium$^{(+)}$ Clay$^{(-)}$+Methylene Blue$^{(+)}$ Hydrochloride$^{(-)}$ -----→

----→ Methylene Blue Clay + Calcium Chloride

Most of exchange reactions are reversible, but whilst this is true for inorganic ions, organic cations such as methylene blue appear to be exceptional.

Brooks (1964) studied the mechanism of methylene blue dye adsorption on siliceous minerals. In case of clays (montmorillonite and kaolinite), he attributed the saturation dye adsorption capacity to two mechanisms: first to cation exchange resulting from isomorphous substitution in the alumina silicate lattice and, second, to an adsorption mechanism which might be either physical (Van Der Waals) adsorption or chemisorption (hydrogen bonding) with the surface SiOH and AlOH of the alumina silicate lattice.

Nevins and Weintritt (1967) determined the Cation Exchange Capacity (c.e.c.) by methylene blue adsorption. The methylene blue dye adsorption capacities of various commercial bentonites and other clays used in ceramic, foundry and oil field applications are shown in Table 5.1. These results are compared with the c.e.c. determined by standard ammonium acetate method and values cited in literature. Since the methylene blue capacity was determined by direct titration of clay suspension, calculations were simply expressed as follows:

$$\begin{array}{l}\text{Methylene Blue}\\ \text{Capacity (MBC)}\\ \text{or c.e.c.,}\\ \text{meq/100 g clay}\\ (105^\circ\text{C})\end{array} = \frac{100}{\begin{array}{c}\text{sample weight}\\ \text{gr } (105^\circ\text{C basis})\end{array}} * \begin{array}{l}\text{volume}\\ \text{titrant}\\ \text{(ml)}\end{array} * \begin{array}{l}\text{Normality}\\ \text{(meq/ml)}\end{array} \quad [5]$$

Results show that the methylene blue dye method gave values reasonably close to those determined by ammonium acetate method and differences were usually less than 5 meq/100 gr . This similarity is particularly noteworthy when the simple and rapid methylene blue test was contrasted to the time consuming, tedious ammonium

Table 5.1 .Cation Exchange Capacities of Various Clay Minerals by Methylene Blue Adsorption in Comparison with the Ammonium Acetate Method and Values Reported in the Literature (After Nevins and Weintritt, 1967)

Literature	Range, meq/100
Montmorillonite	80-150
Vermiculate	100-150
Halloysite-$4H_2O$	10-40
Illite	10-40
Chlorite	10-40
Sepiolite-Attapulgite	20-30
Halloysite-$2H_2O$	5-10
Kaolinite	3-15

Experimental

Sample Designation	Moisture %(105 °C)	Methylene Blue Adsorption Method CEC, meq/100 g (105 ° C)	Ammonium Acetate Method CEC, meq/ 100 g (105 ° C)
EG 28 Wyoming Bentonite	10.3	76.6	77.5
NE 98 Wyoming Bentonite	9.1	74.5	74.9
EG 20 Wyoming Bentonite	8.9	77.8	81.9
MI 19 Centrifuged Bentonite	2.6	101.0	91.9
EG 16 Low Yield Bentonite	9.4	71.8	76.4
EG 24 Low Yield Bentonite	11.6	69.2	73.2
EG 21 Texas Bentonite	10.7	62.2	65.5
EG 21 Treated Texas Bentonite	11.5	85.2	83.3
NE 93 Centrifuged Hectorite	4.0	117.0	85.5
BI 52 Attapulgite	9.3	25.7	22.3
NE 96 Native Clay	7.1	46.2	47.4
NE 97 Drilled Cuttings	3.1	7.9	8.3

acetate method.

Where small differences in the adsorptive capacities were observed, the methylene blue dye values were generally lower than the capacities obtained by the ammonium acetate method. This trend was attributed to premature reading of the end point, but might have resulted from the arbitrary premise that the values obtained experimentally with the ammonium acetate method were correct in all instances.

Where discrepancies were larger, such as with centrifuged bentonite, MI19 and hectorite, NE93, such anomalous behaviour was difficult to explain.It suggests supplemantary adsorptive effects which were not revealed by the ammonium acetate method. The methylene blue adsorptive test did show the increased adsorption associated with processing and concentrating of the active clay fraction and the elimination of the non-clay constituents.

Fig.5.3. shows the methylene blue dye capacities, expressed in ml, for various concentrations of Wyoming bentonite in Ottawa 50-70 mesh sand. The sand was free of clay originally and behaved as an inert diluent here. The graphs show that the methylene blue dye test readily determined different clay concentrations in various sample weights taken.

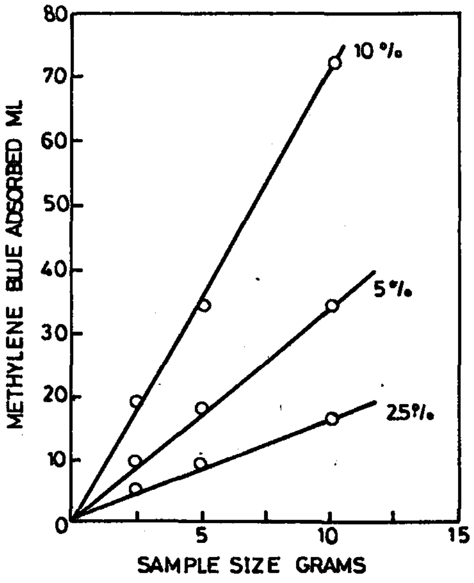


Fig.5.3. Dye Adsorption vs Sample Size for Mixtures of Ottawa Sand and 2.5%, 5% and 10% Bentonite
(After Nevins and Weintritt, 1967)

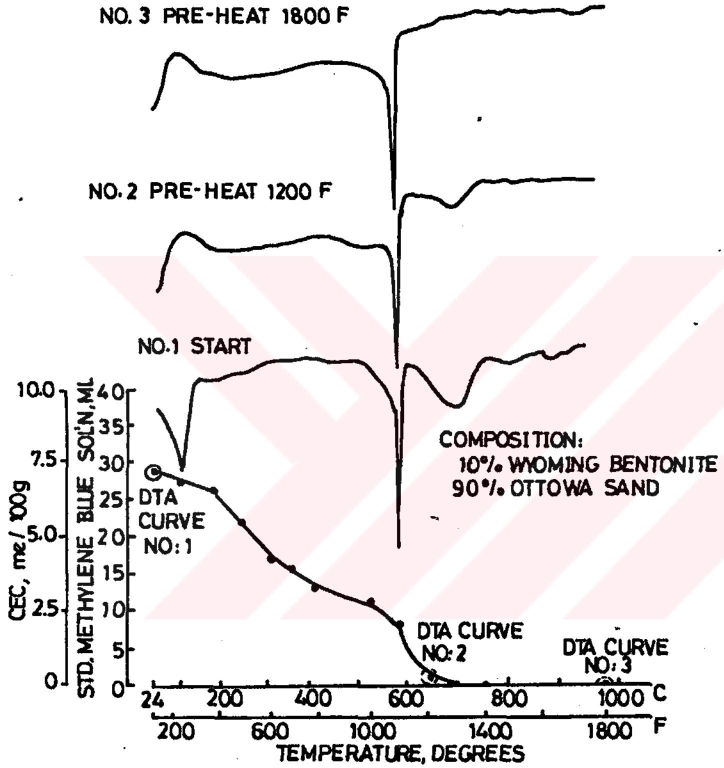


Fig.5.4. Methylene Blue Adsorption and Differential Thermal Curves for Bentonite Sand Mixtures Heated to Various Temperatures
(After Nevins and Weintritt, 1967)

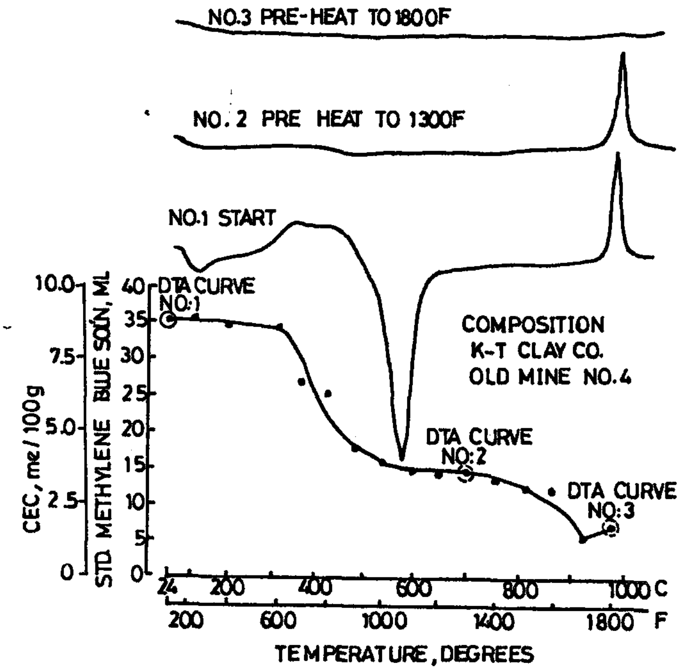


Fig.5.5. Effect of Thermal Dehydration on the Methylene Blue Adsorption and Differential Termograms of Old Mine No.4 Ball Clay
(After Nevins and Weintritt, 1967)

For typical bentonites, methylene blue adsorption tests permit a rapid estimation of clay content. Organic materials were either not troublesome or could be readily eliminated with hydrogen peroxide. Clays containing naturally-occurring adsorptive organic material were boiled with acidified hydrogen peroxide, 3% solution strength, to remove these impurities.

The test was also effective with ceramic clays as well as with bentonite.

The effect of heating a foundary sand and a kaolinitic clay at various temperatures upon resultant methylene blue capacity was also explored. Results were related to the thermal changes shown by differential thermal analysis. Indications were that the changes in methylene blue capacity [eqn.5] were related to the structural changes in the clay.

The graphs in Figs.5.4 and 5.5 show the changes in adsorptive capacities of a bentonite foundary sand and a kaolinitic ball clay which had been systematically heated at various temperatures. Differential thermal analysis of material heated at the cited temperatures were superimposed on the methylene blue capacity-temperature graphs.

As might be anticipated when clays are heated to a structural destruction, methylene blue adsorptive capacities decreased.

Phelps and Harris (1968) tested 29 representative whitewares ceramic clays. Each clay was dried at 90 C for 24 hours in an electric oven and, where not already pulverized, crashed and ground to pass a 200 mesh testing sieve.

Four of the kaolins were described by their producers as containing no montmorillonite. Their respective nitrogen adsorption and water vapour adsorption specific surfaces were plotted against c.e.c. as determined by methylene blue adsorption. Regression lines were calculated for nitrogen cation exchange and water vapour cation exchange and drawn as shown by Fig.5.6.

A number of the clays were known to contain montmorillonite. Fig.5.7 gives water vapour specific surface data against nitrogen adsorption specific surface data for 9 clays representing a range of montmorillonite contents.

The data of Figs.5.6 and 5.7 show that nitrogen and water vapour specific surfaces for montmorillonite free clays are very close to one another but where any great quantity of montmorillonite is involved this relation disappears. The inability of nitrogen adsorption to adequately reflect the true surface area of montmorillonite is shown clearly in Fig.5.7. On the other hand water vapour specific surfaces gave a good straight line relation with their respective c.e.c. for 9 clays involved.

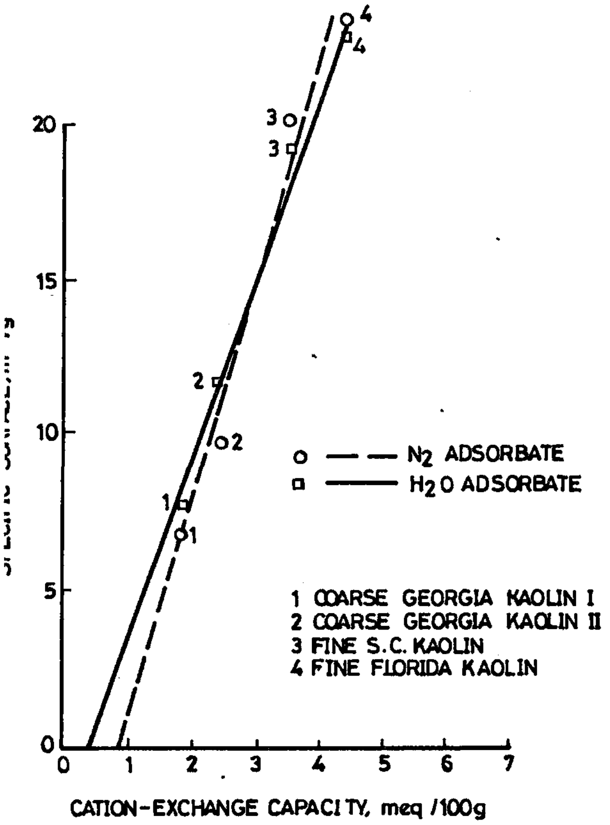


Fig. 5.6. MB C.E.C. for Four Kaolins vs Specific Surface Area by N_2 and H_2O Adsorption (After Phelps and Harris, 1968)

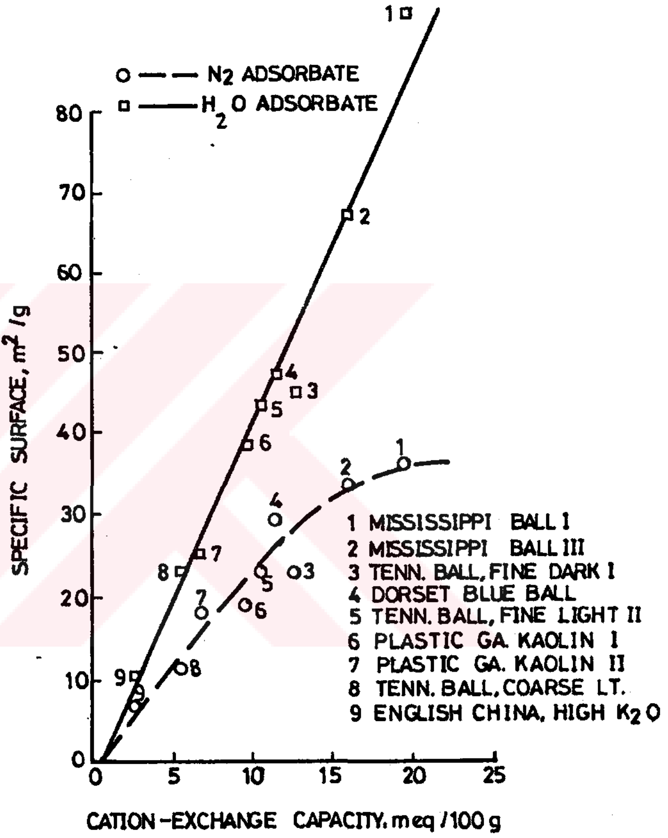


Fig. 5.7. MB C.E.C of Various Montmorillonite Clays vs Specific Surface Area by N_2 and H_2O Adsorption (After Phelps and Harris, 1968)

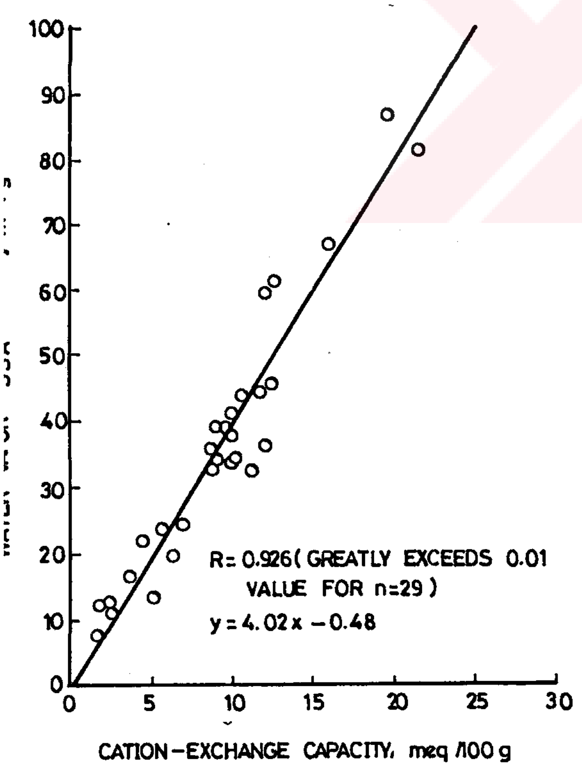


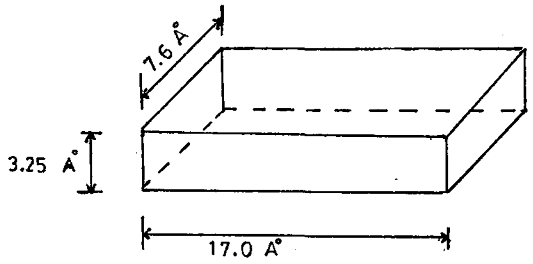
Fig. 5.8. MB C.E.C. of 29 Whiteware Clays vs Specific Surface Area by H_2O Adsorption (After Phelps and Harris, 1968)

Specific surfaces for non-expanding kaolinite and illite are obtained from low temperature adsorption of nitrogen . However, attemts to determine specific surfaces of montmorillonite by inert low temperature gas adsorption give values much too low to account for high surface area connected performance of such clay minerals.

Techniques based on desorption of glycerol and glycols and of water vapor from montmorillonitic clays provide surface area data of an order of magnitude that accord with values calculated from unit cell dimensions.

Fig.5.8 is a plot of water vapor specific surfaces against methylene blue c.e.c. for all 29 clays investigated. The rank correlation R greatly exceeds the value required for 99 % assurance of a relation between specific surface area and c.e.c.. The regression line calculation for these data provided an excellent straight line relation.

The projected area of methylene blue molecule has been given as 130 $Å^2$ by Hang and Brindley (1970). The molecule can be regarded approximately as a rectangular volume of dimensions 17*7.6*3.25 Å .



Brindley and Thompson (1970) made the methylene blue adsorption measurements as follows: A stock solution of methylene blue, 2.67 m moles/ liter, was prepared by dissolving 1 g of material in 1 liter of deionized water. Adsorptions were carried out in polypropylene beakers using 2 ml of various clay suspensions (about 10 mg/ml) diluted with 200 ml of deionized water and with various additions of the stock solution. Samples were stirred at intervals and left overnight to equilibrate. The range of methylene blue concentrations was about $2-13*10^{-5}$ moles/liter. Concentrations of supertanant solutions were determined with a Beckman DU-spectrophotometer at 6650 Å. The adsorption isotherm for the Wyoming montmorillonite clay , saturated with various cations prior to methylene blue adsorption is shown in Fig.5.9 where the adsorbed methylene blue in meq/100 g dry clay is plotted against the amount of methylene blue supplied expressed in the same units. The initial parts of all the isotherms are straight lines at 45° to the axes and correspond to the complete adsorption of the methylene blue by the clays; beyond the linear range, less is adsorbed than is supplied and a saturation state is reached, or is approached.

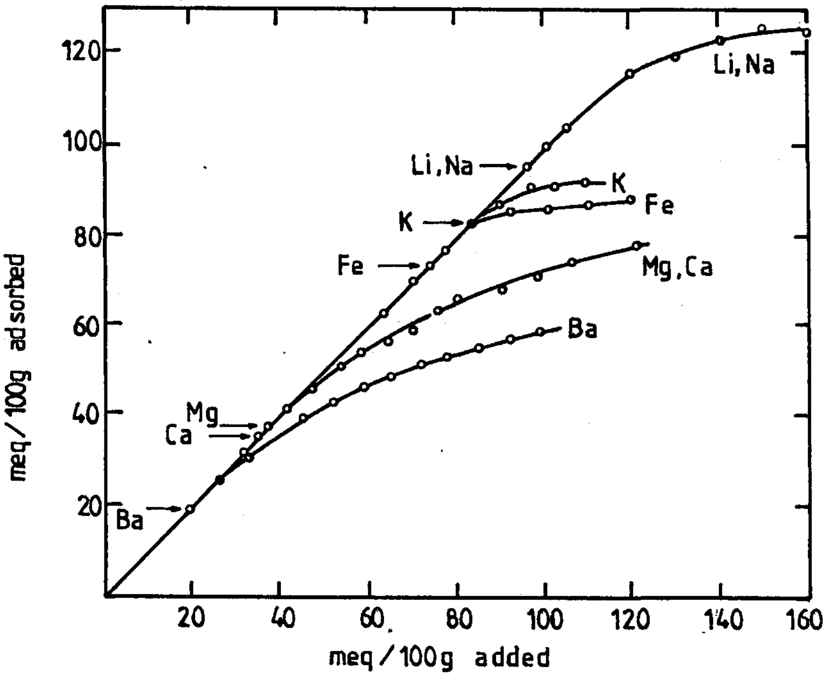


Fig. 5.9. Methylene Blue Adsorption by a Wyoming Montmorillonite Saturated with Various Exchangeable Inorganic Cations vs Amount of Methylene Blue Supplied
(After Brindley and Thompson, 1970)

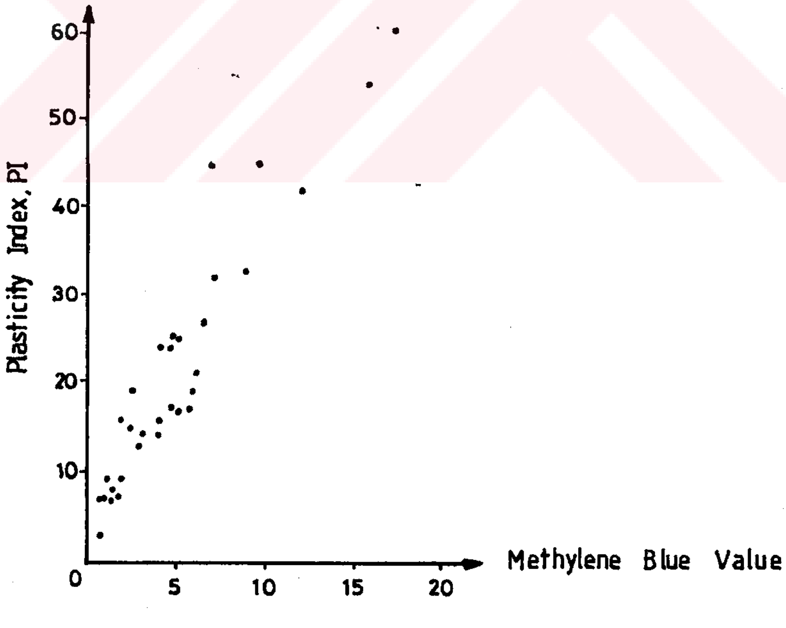


Fig. 5.10. Correlation between PI and Methylene Blue Value (After Lan, 1977)

Brindley and Thomson (1970) showed that surface measured by methylene blue is 100% for Na-montmorillonite, but only 20 to 75 % for Ca-montmorillonite where exchanges are limited due to limited expansion of sheets, but this expansion is very large for Na- montmorillonite.

Lan (1977) stated that methylene blue test measures the methylene blue adsorption capacity of soils and hence measures the specific surface (internal and external surfaces) of clay particles. Methylene blue value shows the quantity and activity of the clay fraction (<2 micron) of the soil (also called as activity coefficient of the clay fraction).This value is high when the clay is active.

Methylene blue test permits to qualify the clay fraction without separating clay fraction from the rest of the soil which is difficult in practice.

Lan (1977) gave a correlation between PI and methylene blue value (Fig.5.10)(see Section 5.2.1.3).

Beaulieu (1979) , in his Ph.D. thesis studied the relationship between methylene blue value and specific surface. He derived an equation for the specific surface area of a material (i.e. clay) as follows:

$$\text{Surface corresponding to 1cc MB} = \frac{S_{BM} x N x 10}{M_{BM} \quad 1000} \qquad [6]$$

S_{BM} = Active area of a methylene blue molecule=$130*10^{-20}$ m^2

$\mathcal{N}$ =Avagadro number =$6.02*10^{23}$

M_{BM} =Molecular mass of methylene blue= 374 gr

Surface corresponding to 1 cc MB=$\frac{130x10^{-20}x6.02x10^{23}x10}{374 \text{ x } 1000}$

=20.93 m2/cc

Specific surface of a material (i.e. clay)

$$S=20.93*N_{cc}*(1/P_s) \qquad [7]$$

S= Specific surface (m2/g)

N_{cc} = Volume of solution used

P_s =Dry weight of material (g)

water content of the material (because measurement can be made on humid material)=$W_e=\frac{P_H - P_s}{P_s}*100$ [8]

$$P_s=\frac{P_H}{W_e+100}*100 \qquad [9]$$

P_H =Humid (wet) weight of the material

P_S =Dry weight of the material

$$S= 20.93*N_{cc}*\frac{W_e+100}{100*P_H} \qquad [10]$$

Beaulieu (1979) showed the effect, on the surface,of time of immersion of the material in distilled water in Table 5.2.

Lan (1980) presented a new test method (Spot Test), based on the adsorption of MB, for the suitability of aggregates (clay particles are harmful for the granular materials used in highways). Methylene blue test measures the surface of clay fraction of the soil. This is a measure of the pollution of the soil by the clay

Table 5.2.Effect on the Surface Area of Time of Immersion of the Material in the Distilled (After Beaulieu, 1979)

Specimens	Surface (m2/g)		ΔS
	After 5 hours	After 12 hours	%
Kaolinite (Arvor)	15	18	+20
Kaolinite (Georgie)	39	43	+10
Montmorillonite (Kimolus)	243	296	+22
Montmorillonite (Mellila)	418	421	+1
Montmorillonite (Camp-Berteau)	670	731	+10
Illite (Brives)	147	121	-18
Illite - Kaolinite (C 40)	99	125	+25
Calcite (Prolabo)	<1	<1	0
Quartz (Fontainebleau)	<1	<1	0

fraction in quantity and quality. Duration of the test varies between 15 to 40 minutes depending on the type of the soil.

The quantity of methylene blue adsorbed by the mixture of clay minerals is equal to the summation of the methylene blue adsorbed by each mineral separately.

Comparison of specific surface values found by classical methods and methylene blue test are shown in Table 5.3

Table 5.3. Specific Surface Area of Different Clay Minerals (After Lan, 1980)

Method Used	Specific Surface Area (m^2/g)			Type of Surface Measured By the Method
	Kaolinite	Illite	Montmorillonite	
BET (After Escart,1952)	22	113	82	External Surface Area
Ethylene-Glycol (After Hendrics and Dyal, 1950)	45	90	750-800	Total Surface Area
Methylene Blue Test	48	74	860	Total Surface Area

Variation of methylene blue value with different mineral compositions are shown in Figs 5.11.a,b and c.

Sand and granular materials are a mixture of inert and active materials. Non clay type materials do not participate in the adsorption phenomenon; methylene blue

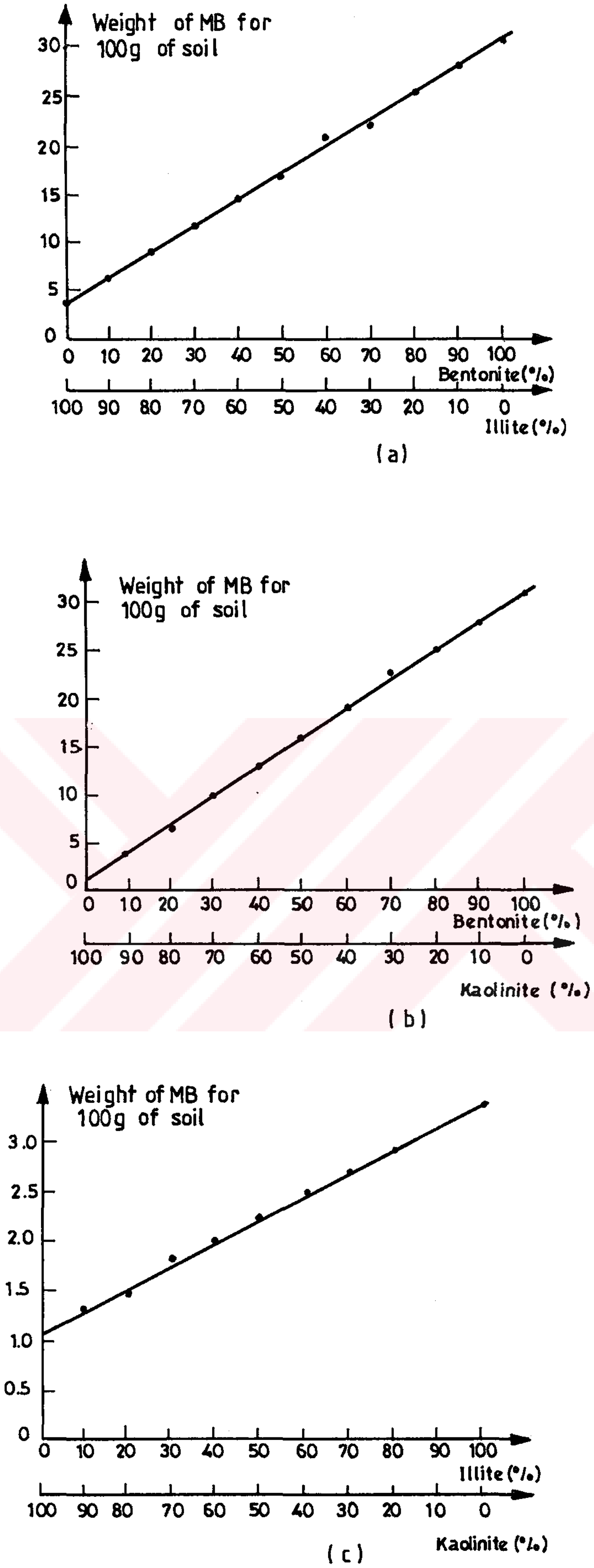


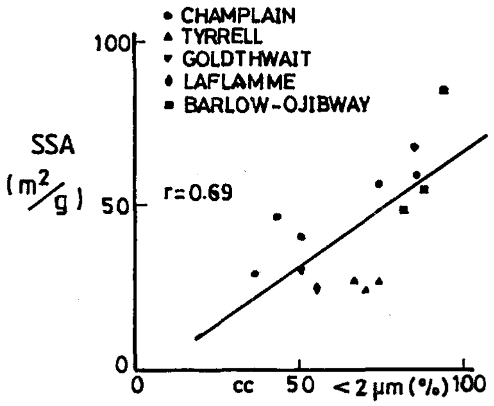
Fig. 5.11. Variation of Methylene Blue Value with Different Mineral Compositions (After Lan, 1980)

value of the sand or granular material is directly a function of total surface of clay fraction in 100 grams of material.

Bensted (1981) applied methylene blue test to cement raw materials and discovered that clay minerals adsorbed basic dyes from aqueous solution, whereas mica, quartz and other non clay minerals were virtually non staining. Bensted (1981) stated that clays adsorbed methylene blue from aqueous solution by a cation exchange mechanism. Although secondary adsorption effects involving Van Der Waals forces took place when the dye was present in excess quantity,such effects were found to be negligible at concentrations near the c.e.c.

Locat, Lefebvre and Ballivy (1984), describes the use of quantitative mineralogy and specific surface area (specific surface area (SSA) was measured by means of the methylene blue method (spot test)) in interpreting the index properties of clayey soils from 9 sites in eastern Canada. Samples representative of the Tyrrell, Laflamme, Champlain and Goldtwait marine seas and Lac Barlow - Ojibway have been studied.

Correlations between Atterberg limits and specific surface area are believed to be more useful than those between specific surface area and the grain size or clay fraction (Fig.5.12)



a) Relationship Between the clay content (cc) and specific Surface Area (SSA)

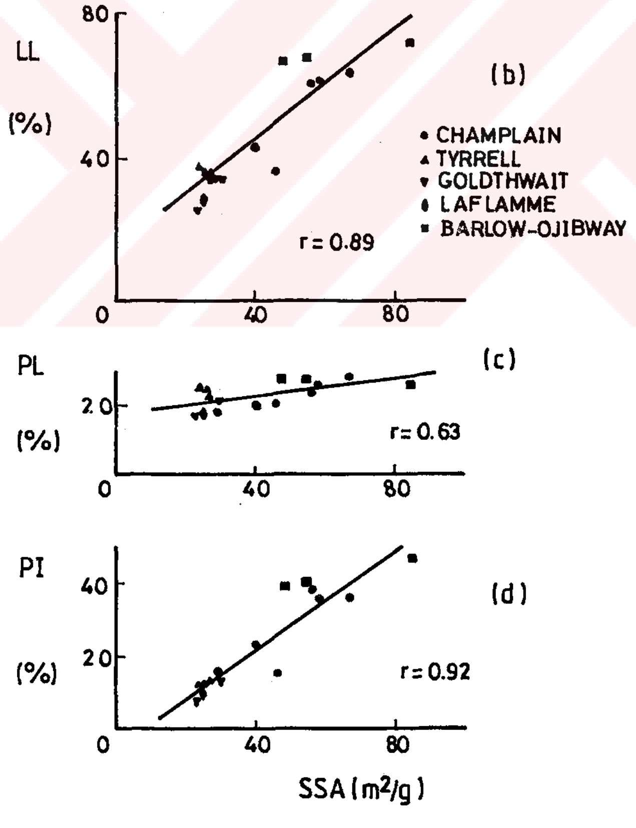


Fig. 5.12. Relationships between Specific Surface Area and CC, LL, PL and PI (After Locat et.al,1984)

Methylene blue adsorption has been adopted as a standard test in France for determining the presence of clay in aggregates, Taylor (1985). Clays such as smectites and vermiculates are made up of stacked sheets. Cations are therefore attracted to internal surfaces as well as external ones.

The methylene blue molecule consists of an organic base in combination with an acid. Its morphology is shown in Fig.5.13.

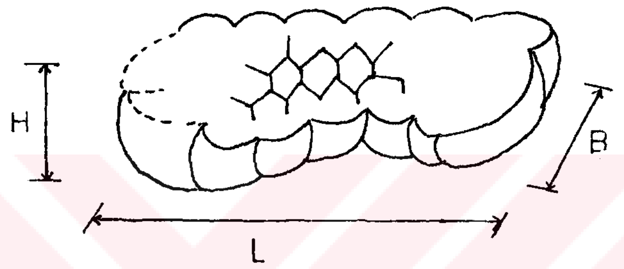


Fig.5.13. Methylene Blue Molecule (Diagrammatic) Modified From Kipling and Wilson (After Taylor,1984)

Approximate dimensions reported by a number of authors are also given in Table 5.4.

Table 5.4. Dimensions of Methylene Blue Molecule (After Taylor, 1985)

Author	L (nm)	B (nm)	L*B (nm2)	L (nm)	H (nm)	L*H (nm2)	B (nm)	H (nm)	B*H (nm2)
Hofman	-	-	1.95	-	-	-	-	-	-
White	-	-	1.95	-	-	-	-	-	0.25
Kipling	1.60	0.84	1.34	1.60	0.47	0.75	0.84	0.47	0.39
Hofman	1.25	0.57	0.71	1.25	0.51	0.64	0.57	0.51	0.29
Brindley	-	-	1.29	-	-	0.55	-	-	0.25

Methylene blue replaces natural cations irreversibly as indicated below. This is unlike the reversible exchange of inorganic cations:

Ca-Na CLAY + Methylene Blue Hydrochloride ------→
--→ Methylene Blue CLAY + Ca-Na Chloride

Experimental work on untreated clays suggest that with illite and kaolinite the methylene blue molecule may well be adsorbed on a small area of the aromatic ring. The molecule will thus have greater access to exchange sites on external surfaces. With smectites however, the molecule lies flat on the surface, so that if the lattice is not fully expanded there will be a cover up effect because the molecule has a larger surface area than that associated with the exchange site.

Hills and Pettifer (1985) studied the effect of the particle size of the test sample on the methylene blue value. To investigate this effect tests were carried out (in 13 cases) both on test samples ground to pass the 0.425 mm sieve and on test samples ground to pass 0.075 mm sieve. The methylene blue values for each size are plotted against each other in Fig.5.14. There is a linear relationship, and the methylene blue value for the coarser test samples is about 60 % that of the finer ones. This is not unexpected, however this result makes it clear that when a ground specimen is to be tested, the particle size of the test sample should be specified.

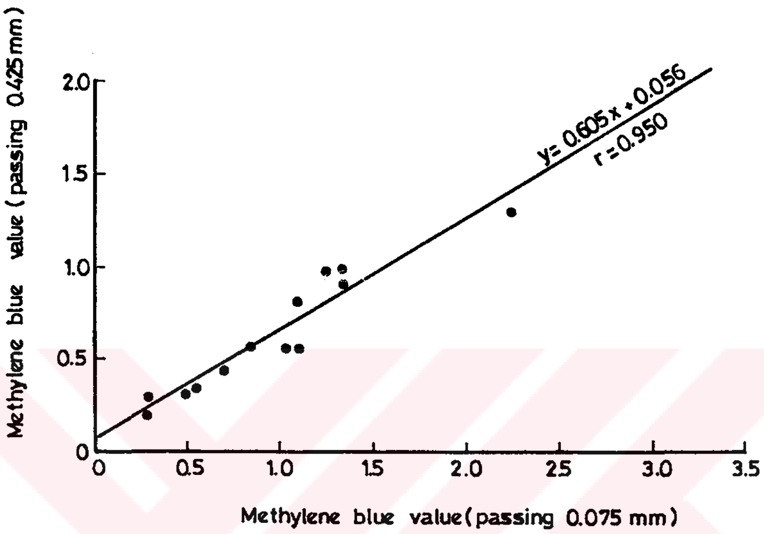


Fig.5.14. The Effect of the Particle Size of the Test Sam on the Methylene Blue Value (After Hills and Pettifer, 1985)

Lautrin (1987) states that the methylene blue test is a rapid method for the identification of clays. Behaviour of clayey soils depend on many factors, among these mineralogy and cation exchange are important. But mineralogical identification by using classical methods is a difficult task. He evaluates "Hazard cofficient " N by using methylene blue value,

N= Hazard coefficient = (100* MB value / CC) [11]
(MB value for the clay fraction)

He compares the methylene blue value with the mineralogical composition of the soil determined by X-ray method by using around 100 samples (Figs. 5.15, 5.16).

In Fig.5.16, variation of the Hazard coefficient as a function of the mineralogical concentration of clays is shown:

N=1 to 2 for pure kaolinite
N=4 to 5 for pure illite
N=18 to 20 for pure montmorillonite

by using the given data:

For N⩽1 --→ Silts, sands, gravels (there is no clay in the soil)

For 1<N⩽3--→ Inactive soils, clay fraction contain pure kaolinite or kaolinite + illite, there is no montmorillonite.

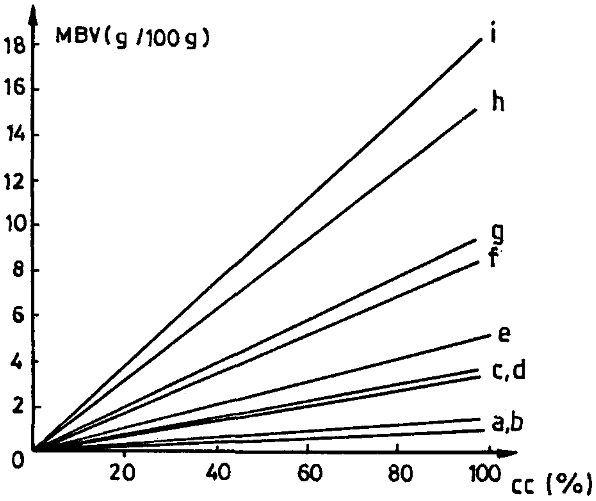
For 3<N⩽5 --→ Little active soils, clay fraction contains montmorillonite but it is less than 10% .

For 5<N⩽8 --→ Normal soils, the montmorillonite % in the clay fraction is up to 50% .

For 8<N⩽12 --→ Active soils, the montmorillonite % in the clay fraction is between 50% and 75 % .

For 12<N⩽18 --→ Harmful soils, the montmorillonite % in the clay fraction is between 75 and 90 % .

For N>18 --→ very harmful soils, the montmorillonite % in the clay fraction is higher than 90 % .



a 100% K + 0% I + 0% M

b 95% K + 5% I + 0% M

c 95% K + 0% I + 5% M

d 0% K + 100% I + 0% M

e 80% K + 0% I + 20% M

f 10% K + 45% I + 45% M

g 0% K + 98% I + 2% M

h 15% K + 0% I + 85% M

i 10% K + 0% I + 90% M

Fig. 5.15. Influence of Mineralogy of Clays on the MBV (After Lautrin, 1987)

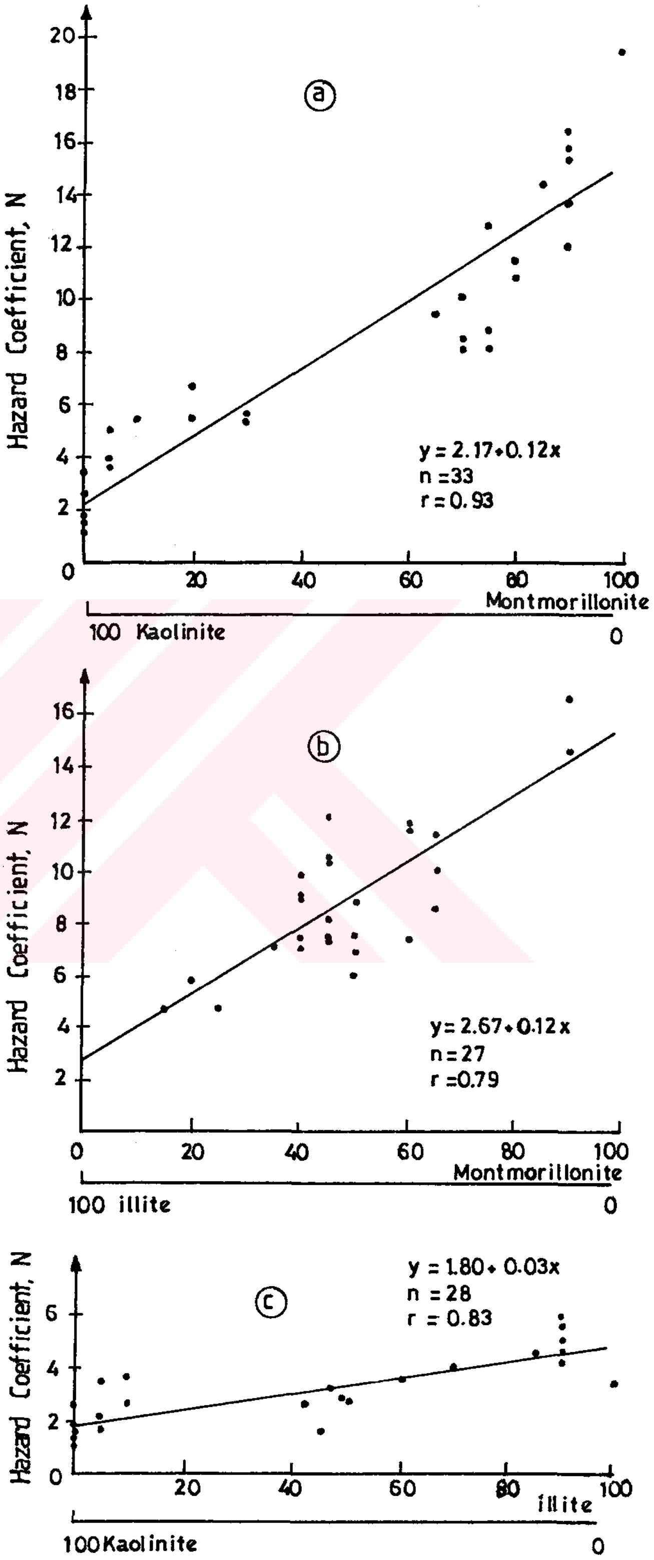


Fig 5.16. Variation of Hazard Coefficient as a Function of Concentration of Clay Minerals (After Lautrin, 1987)

For pure minerals:

MB value (kaolinite)< MB value (illite) <
< MB value (montmorillonite)

For the same mineralogical composition as CC increases MB value increases linearly, and the slope of the line is a function of the activity of the minerals (Figs 5.15, 5.16). In Fig.5.15 the slope of the line "i" (10 % K + 90 % M) is 10 times greater than the line "a" (100 % K) (i.e. the small amount of montmorillonite is more effective than higher percentages of kaolinite and illite).

Based on this observation Lautrin (1987) prepared a Hazard diagram (Hazard Coefficient=100*MBV/CC) (as he stated it is experimental and open to all readjustments) Fig.5.17. He classified soils in regions 1,2,3, as little active and the ones in regions 4,5,6,7, as active.

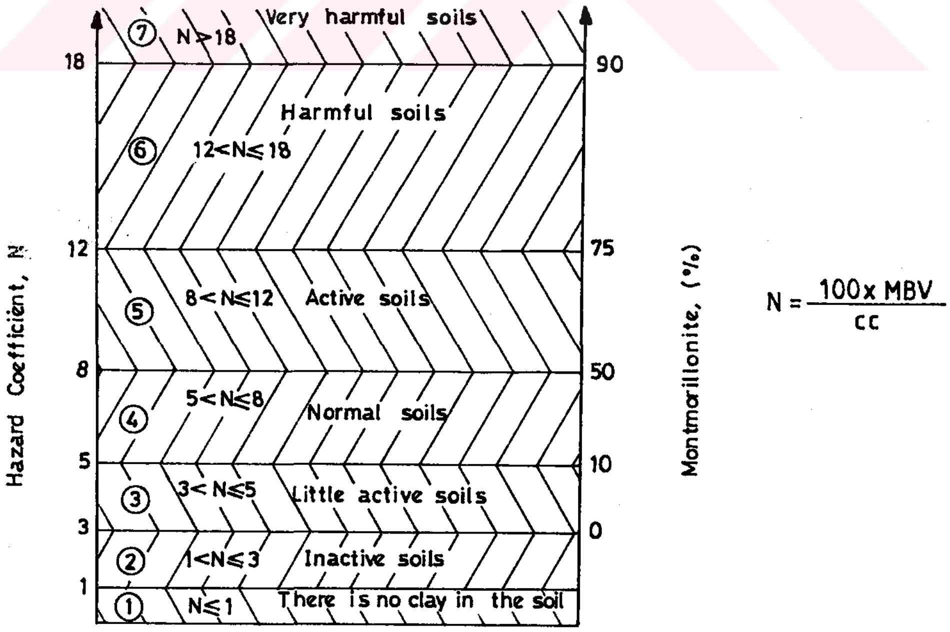


Fig.5.17. Hazard Coefficient Diagram

Specific surface area can be determined by using Eqn.7.

S= 20 to 40 m2/g for pure kaolinite

S= 80 to 100 m2 /g for pure illite

S= 400 to 450 m2 /g for pure montmorillonite

Lautrin (1987) states that for montmorillonite, a small external surface and a large internal surface is measured. But interlayer zones may not be reached by methylene blue molecules all the time.

Swelling depends on the grain size and activity of the clays. Montmorillonite swells more than illite and much more than kaolinite. Swelling is also related with the electrolyte content of the soil e.g. Na- Montmorillonite swells more than Ca- Montmorillonite.

Classical soil classification methods do not give an idea about the minerals in the soil (clay). But methylene blue test result also gives an idea about the mineralogy of the soil.

Methylene blue test allows the identification of harmful minerals without using X-ray diffraction tests, differential thermal analysis, base exchange capacity or chemical analysis which are expensive and time consuming.

Lautrin (1989) criticized Skempton's activity value (A_c=PI/CC) Skempton (1953) gives the following activity values for the following clay minerals:

Clay mineral	Coeff. of activity (A_c)
Kaolinite	0.33 to 0.46
Illite	0.90
Ca- Montmorillonite	1.50
Na - Montmorillonite	7.20

Lautrin (1989) defined 5 groups for activity: (Based on the original definition by Skempton)

Group 1	Group 2	Group 3	Group 4	Group 5
inactive soils	inactive soils	normal soils	active soils	very active soils
$A_C<0.5$	$0.5<A_C<0.75$	$0.75<A_C<1.25$	$1.25<A_C<2$	$A_C>2$

In Table 5.5, classification of soils as a function of coefficient of activity are given. It is seen that even when there is montmorillonite in high percentages in a soil, A value may be smaller than 1.25, this soil then would be expected to show a zero swelling value, which is contrary to what happens in reality.

Lautrin (1989) shows that Hazard coefficient [eqn.11] increases with the montmorillonite % and smaller values are obtained for the clay fractions which are little reactive or inert (Fig.5.18). In practice N is a better indicator of the colloidal activity of the clay fraction of a soil.

Table 5.5 . Classification of Soils as a Function of Skemptons Activity Value (After Lautrin , 1989)

	Mineralogical Composition of the Clay Fraction (< 2 μm)	Group 1 Inactive Soils $A_c<0.50$	Group 2 Inactive Soils $0.50<A_c<0.75$	Group 3 Normal Soils $0.75<A_c<1.25$	Group 4 Active Soils $1.25<A_c<2$	Group 5 Very Active Soils $A_c>2$
CC< 50%	75% K	2 *	2			
	100% K	4	1			
	75% I		3	1		
	100% I		3			
	75% M		5	1		
	100% M			1		
CC> 50%	75% K	2	1			
	100% K	4	1			
	75% I		1			
	100% I			1		
	75% M	1	6			
	100% M		6	2		

* Numbers show the number of samples

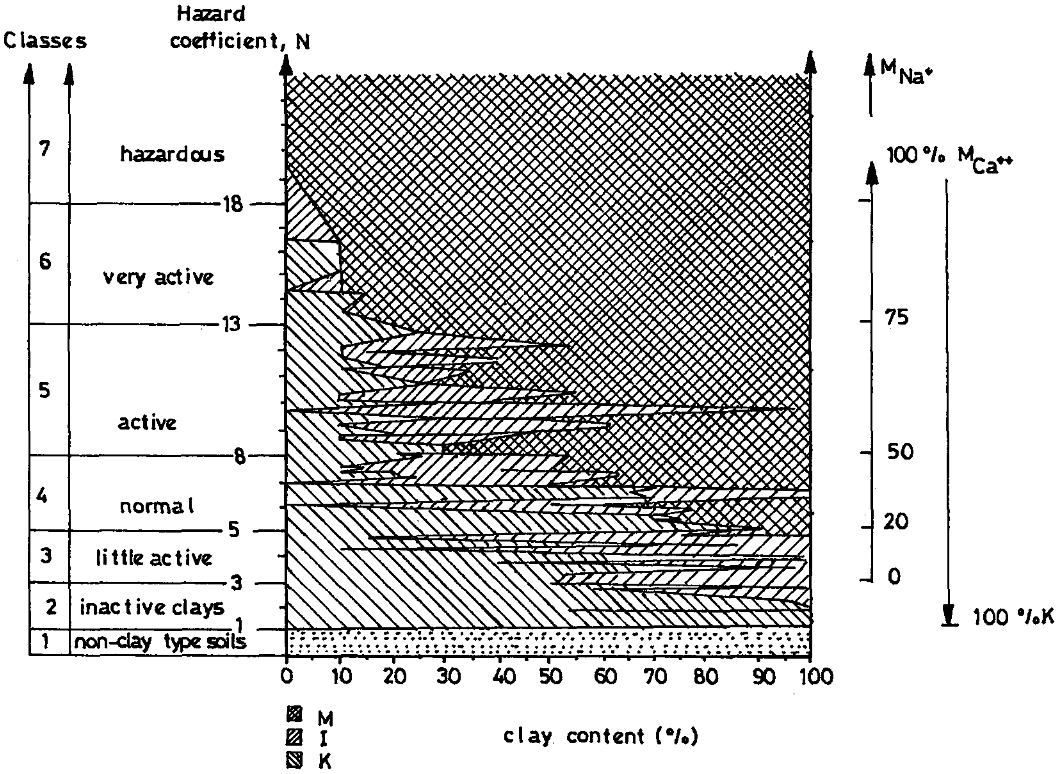


Fig.5.18 . Activity Diagram for Clays (After Lautrin,1989)

Lautrin also studied the variation of methylene blue value as a function of Atterberg Limits. Fig.5.19 shows that there is no significant correlation between Atterberg limits and methylene blue value.

Lautrin (1989) states that methylene blue is a very useful method for identification of soil fines, it gives exchange capacity and reactive surfaces which permit more precise identification of clays.

Tourenq and Lan (1989) tried to show the presence of clays in a soil by a methylene blue test. They

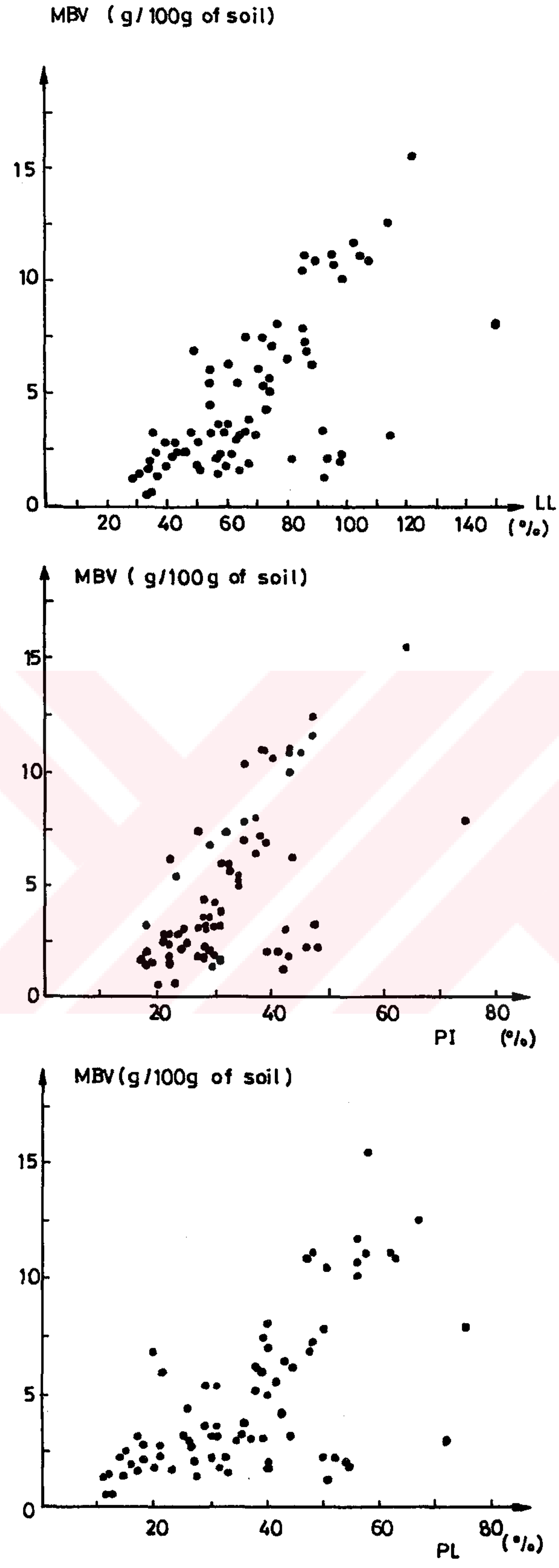


Fig. 5.19. Variation of Methylene Blue Value as a Function of Atterberg Limits (After Lautrin, 1989)

indicated the following points about the test:

a) Test duration is from 10 to 40 minutes depending on the type of the soil.

b) Any particular sample preparation is not necessary (large particles >10 mm which may cause trouble to the agitator should be removed)

c) The necessary material is easy to be obtained and not expensive: a container, a laboratory mixer and a filter paper.

They explained the significance of the test as follows:

The non-clay elements of the soil are practically not participant in the adsorption phenomena. Methylene blue value considers the clay fraction of the soil.It expresses the necessary quantity for covering a layer of its molecules , on the total surface developed by the clay fraction of the soil.

By definition, the surface developed by the particles is the product of the mass of the clay. This surface will be high when the clay is active. The methylene blue value is a global evaluation of the quantity and the activity of the clay fraction (<2 micron) of the soil.

The methylene blue test permits to qualify the clay fraction, without the necessity of separating the rest of the soil, the latter operation being difficult in practice.

The researchers found a good correlation between methylene blue value and PI (Fig.5.20) for the samples they used.

They stated that the methylene blue test verifies the additivity law (i.e. the quantity of the blue adsorbed by a mixture, is exactly equal to the sum of the quantities adsorbed respectively by the mass of clays present in the mixture)

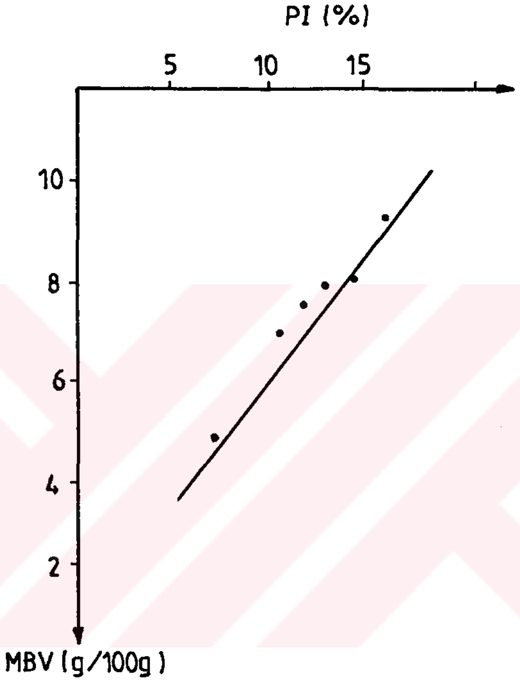


Fig.5.20. Variation of the Methylene Blue Value as a Function of PI (After Tourenq and Lan, 1989)

Magnan and Youssefian (1989) used methylene blue test for the classification of soils with the help of grain size distribution curve,which is not based on Atterberg limits any more and based on colloidal activity. This classification is given and explained in Appendix C since it is not directly related with the objective of this thesis work.

They propose to determine methylene blue value on the soil fraction of finer than 80 micron for granular soils, and on the soil fraction of finer than 400 micron for fine soils.

The possibilities offered by methylene blue test is that it can characterize physico- chemical properties of clays especially their ability to swell which is a major problem in geotechnical engineering.

Fourin, Millon-Devigne and Lan (1989) state that methylene blue value (obtained from spot test) is a good index to show the hazard potential of the soil in a long term(i.e. for some years).

5.2. Method and Test Procedure

5.2.1. Methlene Blue Test Method (Reference: AFNOR, P18-592, See Appendix D)

5.2.1.1. Apparatus, Equipment and Materials (see Fig.5.21)

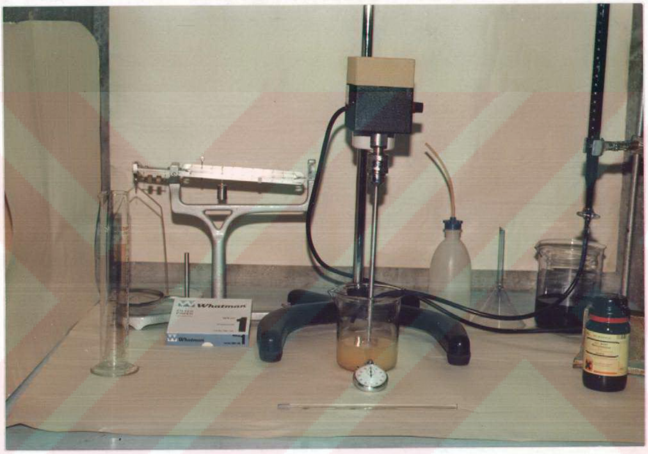


Fig.5.21. Methylene Blue Test Set-up

- A burette (capacity= 100 cc or 50 cc)
- Filter paper (Whatman No.1 was used in this study)
- A glass rod (length= 30mm, Diameter= 8 mm)
- Mixer (speed= 400 to 700 rpm)
- Glass container (capacity= 500 cc or 1000 cc, diameter= 100 mm)
- A balance (sensitivity= 0.01)
- A chronometer
- Medical quality Methylene Blue (MERCK, Art.6040 was used in this study)
- Distilled water
- Oven dry soil sample (sieved through No.40 sieve (400 micron))

5.2.1.2. Preparation of Methylene Blue and Soil Solutions

a. Methylene Blue Solution

Place 10 gr.± 0.1 gr. methylene blue in a glass container, add distilled water (1 lt) and mix very well

b. Soil Solution

Place 30 gr (or 7.5 gr) of soil sample (sieved through No.40 sieve) in a glass container, add 200 cc (or 50 cc in case of 7.5 gr soil sample) distilled water and mix by using a mixer at a speed of 700 rpm.

5.2.1.3. Test Procedure (see Fig. 5.22 (spot test))

The principle of the test consists of introducing an increasing quantity of the methylene blue solution to

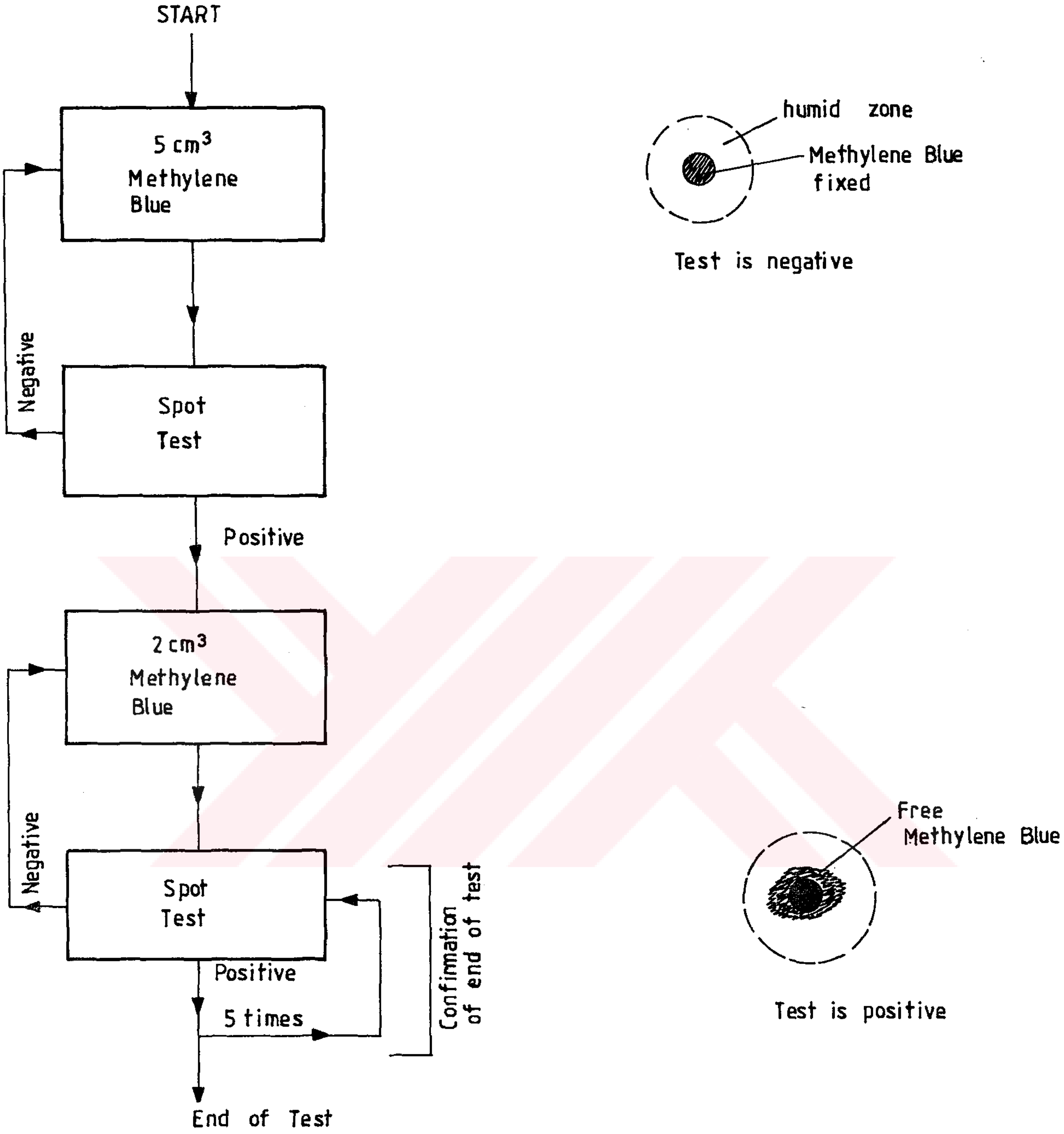


Fig. 5.22. Schematic Representation of Spot Test

the soil solution (mixing of soil solution at a mixer speed of 400 rpm is continuing throughout the test) and taking a drop from this solution and putting it on a filter paper. Initially a circle of dust is formed surrounded by an outer ring of clear water. The end point is reached when a permanent light blue coloration is observed in this ring of water, then Methylene Blue Value of soil can be calculated.

For 100 grams of fine soil, " methylene blue Value (MBV) " of the soil is given by the following formula

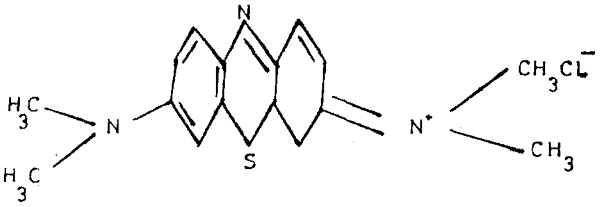
$$MBV = V_{cc} / f' \qquad [12]$$

V_{cc} = Volume of the methylene blue solution injected to the soil solution (cm3).

f' = Dry weight of soil sample used (g)

5.3. Adsorption of Methylene Blue by Clay Minerals

Methylene Blue (anhydrous) has the following formula $C_{16} H_{18} N_3 S Cl$



when methylene blue reacts with a clay solution:

Calcium Clay+ Methylene Blue Hydrochloride --→

---→ Methylene Blue Clay + Calcium Chloride

When Methylene Blue dye is dissolved in water, methylene blue cations and chloride anions are formed and these can then replace the existing cations associated with a given clay.

Now consider what happens when a solution of methylene blue hydrochloride is added, a little at a time, to a sample of clay. Until the c.e.c. of the clay has been reached, the amount of dye adsorbed is equal to the amount added. Additions of dye beyond the c.e.c.however are not entirely adsorbed (Fig.5.23).

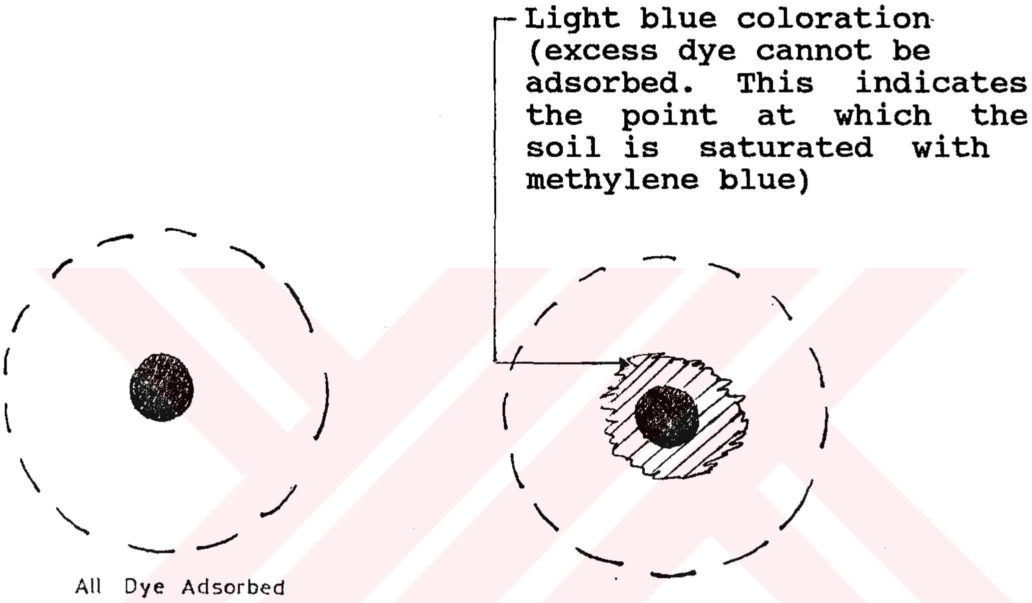

Light blue coloration (excess dye cannot be adsorbed. This indicates the point at which the soil is saturated with methylene blue)

Fig.5.23. Adsorption of Methylene Blue by Minerals

Methylene blue adsorpsion of clay minerals is also a function of the surface area (internal and external) of the mineral (i.e. bentonite can adsorb considerably more methylene blue dye from solution than low - yield clays because of its higher surface area) . Here, it is assumed that the methylene blue is spread over the soil particles as a monomolecular layer.

CHAPTER 6

POTENTIAL VOLUME CHANGE (PVC) METER

6.1. Introduction

Lambe (1960) developed a simple soil testing device (Potential Volume Change (PVC) Meter) suitable for use in identifying potential volume change of clay soils. PVC Meter was designed to measure the swell index of clay soils. This is a practical, simple and quick method for the purpose of identifying potentially dangerous soil conditions.

6.2. Equipment (Figs. 6.1 and 6.2)

a. Swell Index device
b. Compaction hammer and cylinder
c. Knife and straight edge
d. Water (squirt bottle)
e. Two dry porous stones
f. Brush (optional)
g. 1/8 inch pin
h. Teaspoon
i. No. 10 sieve (optional)
j. Wrenches

6.3.. Preparation for Compaction (refer to Appendix E , Fig. E.1)

a. Disassemble Swell Index Device , with the exception of Rods (7) which can remain screwed into the base (1). Place proving ring (13) and top bar (17) where it will not be jarred during compaction.

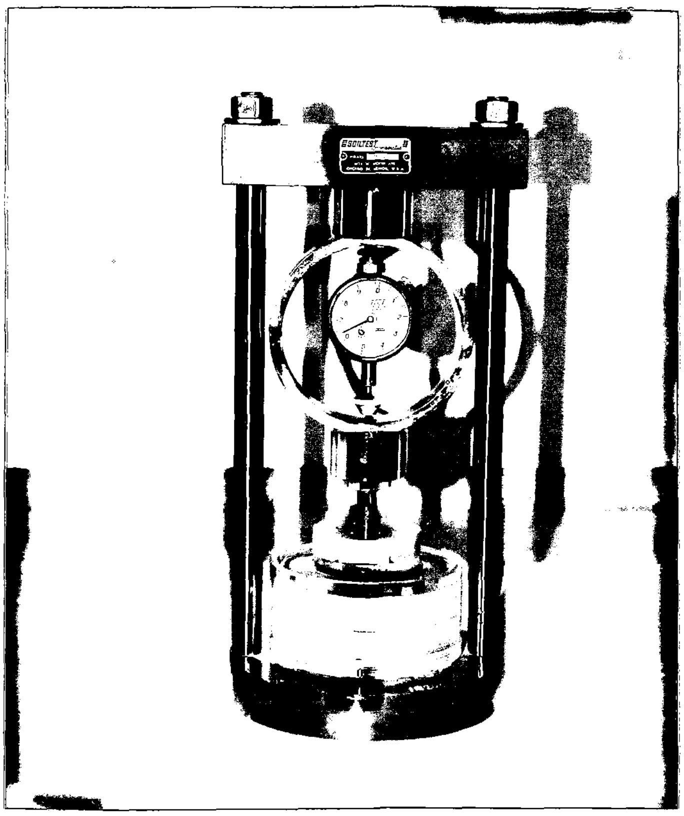


Fig.6.1. PVC Meter Apparatus

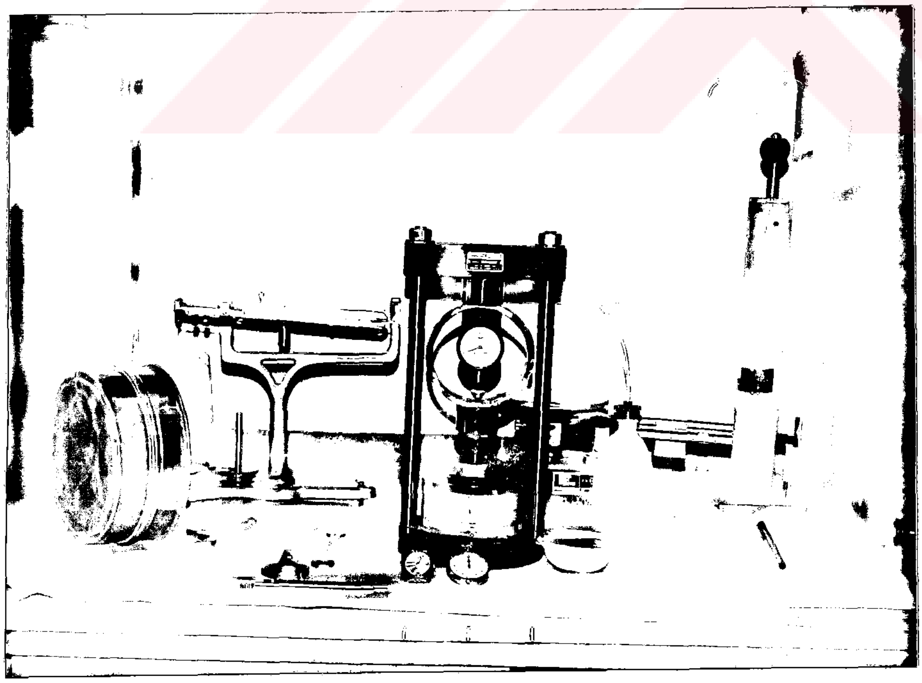


Fig.6.2. Necessary Equipment for PVC Test

b. Place compaction ring (3), with letters CO at the top, on the base and so that the No. 1 on the base is aligned with No.2 on the compaction ring. Place spacing ring (2), on compaction ring with letters CO at the bottom (radial groves are on top) and aligned with the letters CO on the compaction ring. Insert the 3 bolts (5) and tighten firmly.

c. The relative water content is adjusted to a dry or moist relative water content (sample was sieved through No.40 sieve), (Dry: This is equivalent to air drying a soil (assuming the relative humidity of the air is from 30 to 70 %) . Moist: can be obtained by placing air- dried soil in closed container with water at the bottom and allowing to equilibrate for several days).

6.4. Compaction

a. The compaction procedures to follow are shown below, along with the compactive efforts and their relation to modified AASHO compaction.

Relative water content	No of layers	No of blows per layer	Compactive energy * (ft.lb./cu. ft.)
Dry	3	7	55000 (modified AASHO)
MOist	3	4	31000 (1/2 " ")

* Compactive Energy (ft.lb./ cu.ft.) =

$$= \frac{(\#\text{ of layers}) * (\#\text{ of blows})/\text{Layer} * 5.5\text{ lb} * 1\text{ ft}}{2.15\text{ ft}^3} \qquad [13]$$

=2.55 * No. of layers * No. blows/layer

=122.478 * No. of layers * No. of blows/layer , (SI units), (i.e. m. N/m3)

b. Place the apparatus on the floor for compaction.

c. Add 2 to 3 heaping teaspoons per layer and press the soil with the hammer to smooth and firm up the surface before applying the blows (this reduces the amount of soil "jumping " out of the mold during compaction).Each layer of soil after compaction should have a thickness of about 1/4 inch so that the final compacted thickness before trimming is 1/8 to 1/4 inch above the compaction ring. The top of the first and second layers should be scarified to ensure a good bond between successive layers.

d. Disaasemble. Remove the three bolts. Rotate spacer ring and remove.

e. Trim the top of the sample. Start by trimming the edges of the sample first, gradually working towards the center of the sample. When the sample is almost level, do the final levelling by drawing a metal straight edge over the sample.

f. Rotate compaction ring and remove. Clean soil from base and from holes in compaction and spacer rings.

6.5. Assembly and Start of Test

a. Place spacer ring on base with No.2 on the ring (radial grooves are on top) aligned with No.1 on the base. Place a dry porous stone in the spacer ring. Above the porous stone place a filter paper. Place compaction ring, with recessed soil on top, on spacer ring and porous stone with letter S on compaction ring lined up with letter S on spacer ring. Insert 3 bolts and tighten firmly.

b. Place O-ring (20) and screw lucite container (6) firmly down onto o-ring to ensure water tightness.

c. Place a filter paper and a dry porous stone on top of sample inside compaction ring. Place the cover (4) , with the radial grooves on the bottom, on the porous stone.

d. Place top bar (17) with proving ring on the steel rods, add washers (19) and nuts (18) and tighten firmly.

e. Push up on proving ring dial to see that it appears to work properly.

f. Set proving dial to zero by moving the face of the dial, then clamp face to dial. Turn adjustable rod down into groove on top of the cover until a dial reading corresponding to 200 lb./sq.ft. (about 1 division) is attained.

g. Record the time and proving ring reading on the data sheet. Add water to the sample by squeezing water from the squirt bottle into one of the three vertical holes located at the top of the compaction ring until the water level in the lucite container has reached the cover.

6.6. Calculation of Swell Index

The proving ring reading is taken at the end of 2 hours. This reading is first converted to load by using calibration curve (Appendix E, Fig.E.2) and then pressure. This pressure is designated as Swell Index. From (Appendix E,Fig. E.3),the swell index can be converted to potential volume change (PVC).

According to Chen (1975), the PVC meter test in itself does not measure the swell potential. The true swell potential of clay measured can be much greater than the indicated value. The PVC meter test should be used only as a comparison between various swelling soils.

Ladd and Lambe (1961) stated that the PVC ratings proposed are tentative and since field behaviour varies with climate (among other things), the workers throughout the world will check and , if required, modify the proposed system to fit better the pattern of behaviour of "expansive" soils in their area.

6.7. Effects of Compaction Methods

Three compaction methods can be used in laboratory testing . The most common is the dynamic compaction as used in Proctor and British standard compaction testing. Static and kneading compaction are also used. Schreiner (1987) compared all three methods and found that static and dynamic compaction gave greater swell than kneading compaction for the same initial dry density and moisture content. Schreiner (1987) compared static and kneading compaction and also found slightly greater swell for the static compaction.

CHAPTER 7

GEOLOGY AND A REVIEW OF PAST RESEARCH ON SWELLING SOILS IN ANKARA REGION

7.1.Introduction

The occurence of swelling soils is generally a result of geological history, sedimentation and environmental conditions. The regions with the most severe problems are usually those with local climates that produce desiccation. In this connection geology of Ankara region is described briefly.

In a broad sense, soil may be thought of as an incidental material in the vast geological cycle which has been going on continuously and relentlessly throughout the hundreds of millions of years of geological time. This cycle may be considered as consisting of a number of phases.

The first step in the cycle is represented by igneous rocks- that is, rocks that have solidified from molten magma. Igneous rocks include the oldest rocks found on earth and represent the original or primordial sources for soils.

Igneous activity which involves uplift and exposure to the atmosphere initiates the other step in the cycle, slow chemical degradation or weathering. The gradual breakdown of hard rock into soil results in "RESIDUAL SOILS " .

In addition to exposing rocks to weathering, geologic uplift also initiates the forces of erosion. Erosion and transportation are followed by deposition in a different locale (Sürgel ,1976).

It should be noticed that the most important transporting agent which may be active in soil formation is running water, contributing to the formation of "ALLUVIAL SOILS " (Sürgel,1976).

Aggregates of particles that come to rest in some place after having been transported laterally or vertically for some distance are called "SEDIMENTS " . When first deposited, the particles are unconsolidated or essentially unconsolidated. Such deposits are called "RECENT SEDIMENTS ". With time the sediments consolidate and harden into rock. Such consolidated sediments are called "ANCIENT SEDIMENTS" (Sürgel,1976).

After deposition, most sediments immediately reenter the weathering - erosion - deposition cycle (Sürgel, 1976) . As a result of this, terraces are formed by running water in floodplains and deposition by floods on terraces are called "TERRACE DEPOSITS " (Sürgel 1976).

7.2. Regional Geology

Geology of Ankara region and geotechnical properties of Ankara soils have been investigated by several researchers.

Geology of Ankara region is quite complex. Formations encountered range from paleozoic (Appendix F) to Quarternary in age and incluede sedimentary, metamorphic and igneous rocks (Ordemir et al 1977).

The soil and rock formations and their ages are shown in Appendix G. The regional soils may be classified in three main groups; i) residual soils , ii) recent alluvial deposits , iii) deposits of Pliocene - Pleistocene age which are mostly terrace formations in the flood plains (also known as Ankara Clay). It can be seen from the map that the surface area of Pliocene and Quartenary age deposits are very large compared to other formations. By disintegration and weathering process a soil layer having a thickness about 0.5-2.0 meters has been formed on the outcrops which is called "RESIDUAL SOILS ". One would expect that since the residual soils have weathered in place or been moved small distances downslope, there is little reason to suspect that their overconsolidated behaviour is a result of overburden pressure.

The second group of Ankara soils is known as recent Alluvial Deposits formed in Quartenary age by the flood waters. These formations are encountered along the local streams. These are normally consolidated soft deposits and ground water level is close to the surface. Most of the alluvial soils are seen along the Ankara River 200-2000 meters in width and 10-45 meters in depth (Furtun

1989). The alluvium which has been deposited by the flood waters has not been in place long enough to show any appreciable effect of soil forming factors. The parent material within the alluvium will vary, depending upon the nature of rocks and soils in the areas drained by the streams (Sürgel, 1976).

Here, two different views for the formation and the cause of overconsolidation of Ankara clay will be discussed. First the studies of Kasapoğlu (1980) and Kiper (1983) (Kasapoğlu (1980) studied the region falling to the east of the Macun River and Kiper (1983) studied on the area at the west side of Macun River) will be given ; then the studies of Sürgel (1976) will be discussed. There are many other researchers whose studies were also collected and systematically evaluated by the researchers whose names are given above.

At the end of the Miocene age, as a result of Attic and Radonic phase movements several lakes have been developed. In the Middle Pliocene age, lakes have been filled by sand, silt, gravel and clay particles transported from the surrounding old formations like andesites, graywackes etc. At the same time, as a result of Epirogenic movements many lakes disappeared and at the beginning of the upper pliocene age the sediments were subjected to desiccation and preconsolidation. During upper pliocene, new deposits were formed and the previous deposits were subjected to second loading. At the beginning of the Quartenary age, as a result of uplift and erosion, sediments were preloaded for the second time. Calcareous concretions are present in the Ankara clay in some zones; these concretions occurred due to the dissolution of limestone formations (and in a smaller amount, due to the dissolution of the pyroclastic derivations of the andesites in the region (Kasapoğlu, 1980) in carbonic acid which is present in the water and seeping down into the soil, and in some other zones, during evaporation, the pressure of CO_2 gas in water which contains calcium ion reduces and this causes sedimentation (Birand, 1978 a).

Since the limestone formations cover a larger area in the south of Ankara river with respect to the north of Ankara river, occurence of calcareous concretions in the terrace deposits are higher in the south of Ankara river than in the north of Ankara river. This formation is generally called as Pliocene - Pleistocene age Fluvial Lacustrine Deposits or Terrace Deposits. Montmorillonite, illite, kaolinite are basic minerals in these formations. According to Kasapoğlu (1980), Pliocene deposits are not the same everywhere since their parent materials are different such as graywackes in the south and andesite in the north. Percentages of granular particles are higher at the sides of the basin where deltas of rivers are believed to exist. Kiper (1983) divided pliocene clay into groups : yellow or gray Macun member around Elvan village and reddish brown Balgat member which is the dominant one. From the data collected, it appears that reddish brown clay layer thickness reduces westward and beyond Macun river gray and yellow clay is encountered. Kiper (1983) states that the upper pliocene deposits of Etimesgut - Batikent area can be considered as overconsolidated soils which have been subjected to very high level of preloading. It is presumed that these deposits, first have been exposed to atmosphere right after their deposition at the beginning of Upper Pliocene; and have been subjected to preloading by superficial drying. Later they have been compacted under the weight of fluvial deposits piled on top of them. Subsequently, they have been unloaded by erosion which occurred during the Quartenary period; and underwent a second preloading process. Recent superficial drying and wetting activities form the last preloading process that the sediments have undergone since the beginning of the Quarternary. He stated that during the last preloading stage, due to the fissures in the drying depths, the traces of first two preloading stages may be diminished.

Kiper (1983) states that the liquidity index (LI=(Wn-PL)/PI) value for overconsolidated clays is around zero, for heavily overcosolidated clays is negative and for normally consolidated clays is around one. According to the depth - liquidity index (LI) diagram given by

Sürgel (1976) down to the 30 m depth LI value is around zero. If the soil at these depths were normally consolidated LI value should be around one (Birand (1977),based on observed variation of preconsolidation pressures with depth from consolidation tests on terrace deposits and alluvial soils , states that the soil samples after 15 m are normally consolidated).

By using the data collected from the previous studies on Ankara soils, depth versus liquidity index relationships are given. Fig. 7.1 shows the depth versus liquidity index relationship for alluvial soils (limits are given by Rominger and Rutledge, 1950). It can be seen from this figure that 17 % of the samples are heavily over consolidated, 67 % of the samples are overconsolidated, 14 % of the samples are normally consolidated and 2 % of the samples are sensitive. Similarly, for terrace deposits, depth versus liquidity index relationship is given in Fig. 7.2: 11 % of the samples are heavily overconsolidated, 86 % of the samples are overconsolidated, 3 % of the samples are normally consolidated.

Kiper (1983) used the overburden pressure versus void ratio chart given by Rieke and Chilingarian (1974). He found average void ratio value of his samples as 0.76 and from the above mentioned chart he found 15 kg/cm2 overburden pressure value. The average preloading pressure of his samples taken from Etimesgut-Batıkent area (from consolidation test results) was found as 3.6

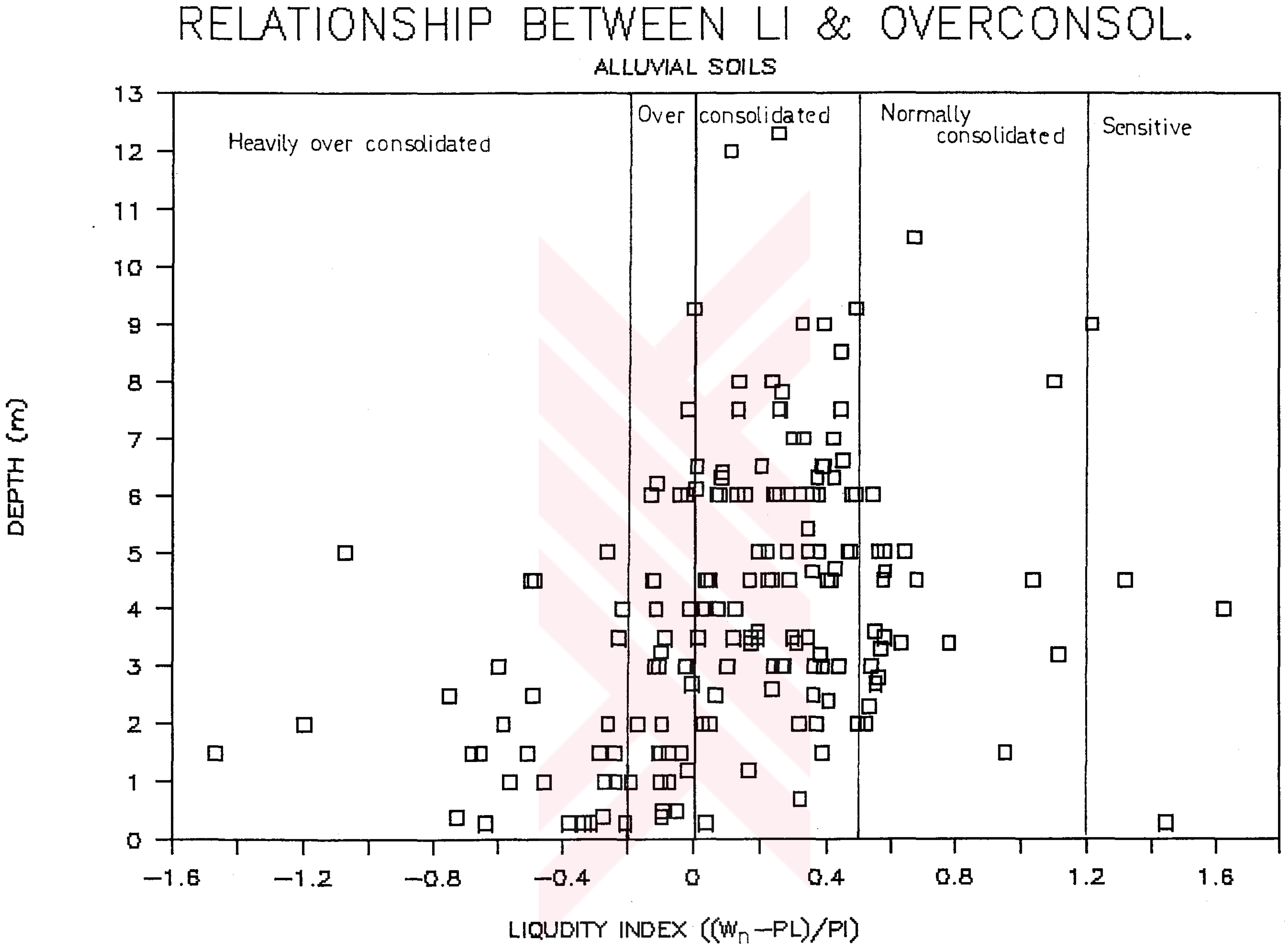


Fig.7.1. Depth vs LI Relationship for Alluvial Soils

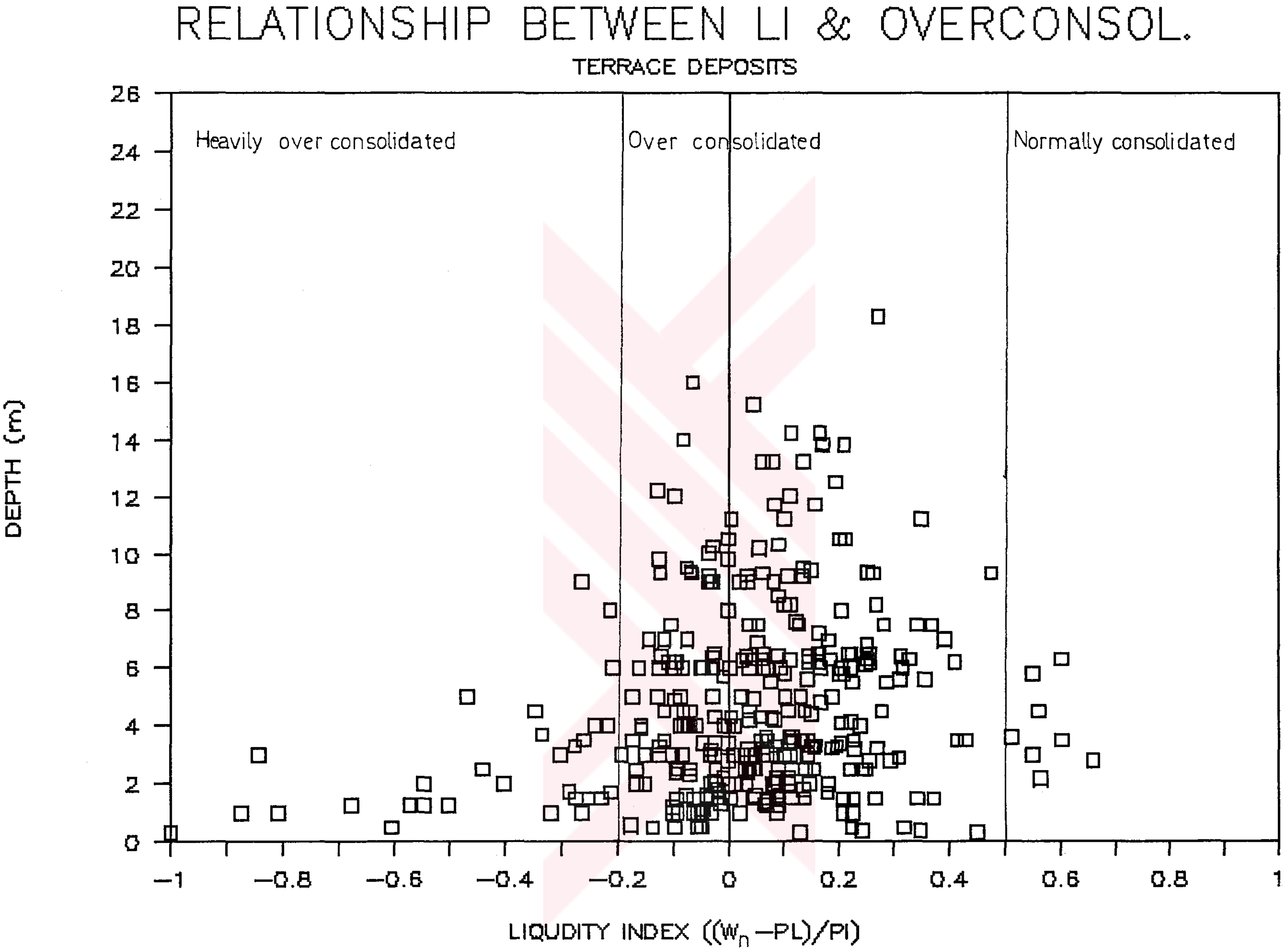


Fig.7.2. Depth ve LI Relationships for Terrace Deposits

kg/cm2 ; the difference between these two pressure values was indicated as an overburden load which had been there in the geological history of the soil and than eroded.

Kiper (1983) states that the permian clays which were under the overburden load of 30 kg/cm2 in their geological history show a 4 kg/cm2 preloading pressure due to the shrink - swell cycle that they were exposed to later on in their geological history (Fig.7.3). If the permian clays had only 4 kg/cm2 preloading pressure, at higher pressures the e- logP curve had to be straight, but at 30 kg/cm2 pressure level there is a slight outward curvature. The same behaviour was also observed by Kiper (1983) at 10 - 15 kg/cm2 pressure levels. As a result Kiper suggests that the preloading pressure value obtained from consolidation test results (i.e. e - logP curve) gives the preloading pressure value due to capillary forces depending on the surface drying.

Kiper (1983) states that the preloading pressure value obtained from the consolidation test result is not accurate if the geological history of the clay is complex.

According to Sürgel's (1976) study, the pliocene pleistocene terraces are the result of a cut and fill sequence and as such their parent surfaces are depositional rather than erosional and that the soils

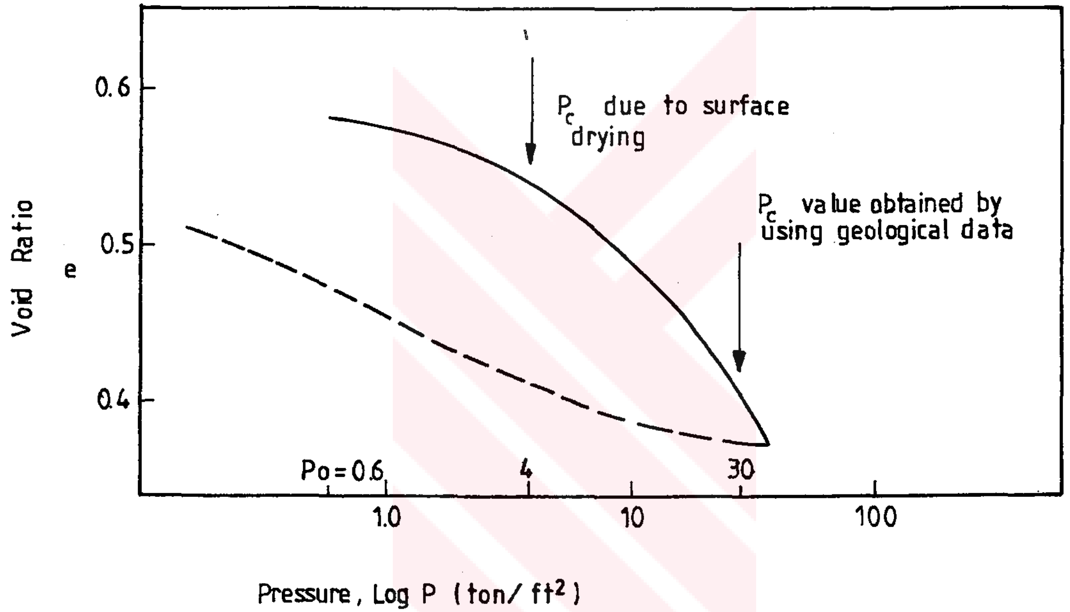


Fig. 7.3. e-log P Curve Belonging to the Overconsolidated Permian Clays in Kansas (After Kiper, 1983)

which lie beneath these surfaces have not experienced any overburden pressure much greater than that which exist at present.

The clay found in METU campus area has mainly the same properties as "Ankara Clay " defined earlier by Ordemir et. al (1965). This clay is described as friable with haircracks and slickensides as well as layers of lime formations (Sürgel, 1976).

Birand (1977) states that in Ankara soils the natural water content values are near to plastic limit values, this indicates the existence of preloading. Birand (1977) studied the cause of this overburden pressure. If a soil was preloaded by a geological load this effect should be seen along all depths. In other words if the unit weight of a soil is γ and if this soil was preloaded by a geological load σ_m , then the variation of preloading pressure with depth (z) should be $\sigma_m + \gamma * z$. In Fig.7.4 , variation of preloading pressure with depth is shown. From this figure it can be concluded that after 15 m depth, the soil is normally consolidated and near the surface the preloading is caused by capillary forces due to desiccation. If a soil has been preloaded by capillary forces, due to the isotropic character of capillary forces, the preloading load should be nearly isotropic.From Fig.7.5 it is seen that K_o^*=(Lateral Preloading Load) / (Vertical Preloading Load) value is around 1.0 . This indicates that the soil has been subjected to preloading loads which are

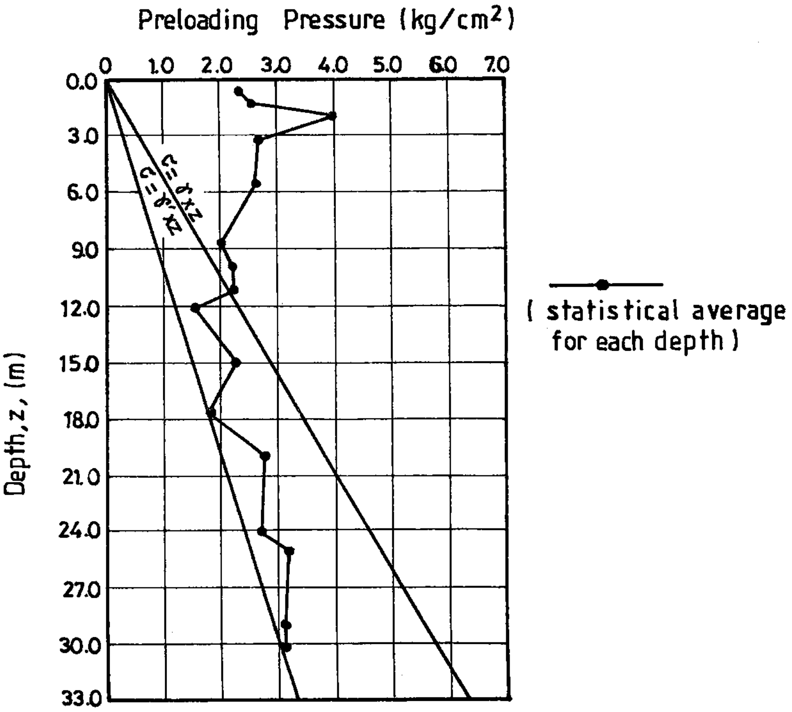


Fig. 7.4. Variation of Preloading Pressure with Depth
(After Birand, 1977)

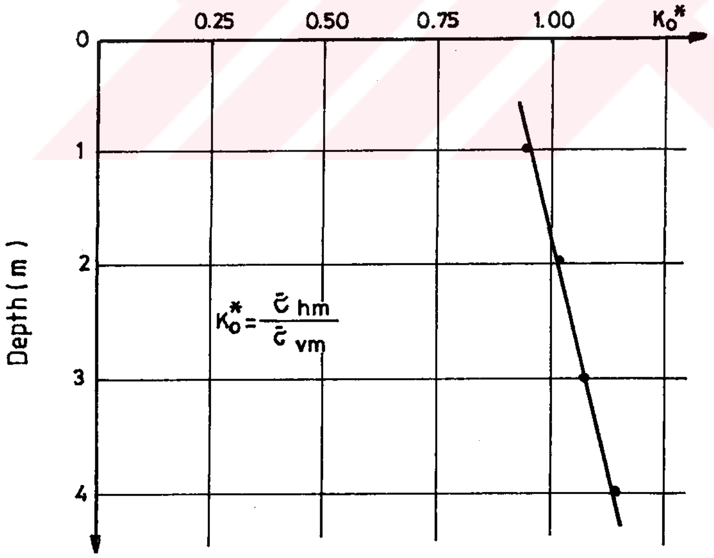


Fig. 7.5. Relationship Between K_o^* and Depth
(After Birand, 1977)

isotropic in character.At least for the 4.0 m depth in which vertical and horizontal preloads were determined in horizontally and vertically obtained samples. However, it is also possible that this behaviour may be due to the relaxation caused by alternate drying and wetting as suggested by Kiper (1983) ; so it seems that the controversy over the nature of preconsolidation needs to be studied further. Nevertheless, it is known that the swelling process is influenced by the actual preconsolidation as exists today, and such relaxation mechanism is instrumental in the explanation of the cause of preconsolidation.

7.3. Properties of Ankara soils and Reseach at METU on Swelling

The geotechnical properties of Ankara soils have been investigated by several researchers. The following conclusions have been reached in the studies made especially to study the swelling behaviour of Ankara soils:

Birand (1963) studied the swelling properties of compacted samples of Ankara clays, primarily focusing on the factors responsible for the expansion of soils and the available methods of classification and identification .

The effect of climate, the precompression of the clay, the chemical compounds within the clay were also investigated by Birand(1963). The conclusions that may be drawn from his study are:

a) The relationship $SP=K*CC^x$ (x and K are constants depending on the type of the clay) proposed by Seed et. al (1962) is valid for the natural Ankara clay.

b) There is a distinct variation in the behaviour of the natural and artificial clay samples as far as their swelling tendencies are concerned. The use of artificially prepared samples cannot reproduce all the field conditions.

c) Skempton's (1953) original definition of activity as $A_c=PI/CC$ for natural London clays is found to be equally applicable to natural Ankara clays, versus a suggestion of $A_c=PI/(CC-n)$ (Seed et. al, 1962).

d) The effect of precompression of the clays on swelling is to reduce the swelling potential.

e) It has been verified once more that the mineralogical composition of the clay affects the swelling of the clays.Clays with high ion exchange capacity have tendency to swell more upon soaking than those with lower ion exchange capacities.

f) The swelling potential of clayey soils is found to increase as the PI increases.

The method proposed by Lambe et. al(1960) (PVC test) should be used in estimating the potential heave of Ankara clays. Using this method, one would be on the safe side and also take the climatic factors into account.

Ordemir et. al, (1965) studied the properties of

Ankara clay. According to their report, the climate of Ankara is semi - arid. The alternate wetting and drying results in swelling and shrinking of the soil which in turn causes the cracking of light buildings. The structures resting on deep foundations are not harmed because the seasonal changes are not felt below a certain depth.

The properties of Ankara clay as a highly plastic and expansive soil resulting in a very poor performance of this clay as a subgrade material.

Arda (1966) studied the preconsolidation of Ankara clay by using undisturbed samples. According to the results of his study, Ankara clay has been preconsolidated in the past. The reason for this preconsolidation is the existence of overburden which has covered the basins in Ankara region during upper Pliocene and in early Quarternary.

There is also an effect of desiccation in certain depths. But the influence of this is relatively small in comparison to the geologic loading except at shallow depths from the surface.

For determination of the preconsolidation pressure of Ankara clay,the conventional test of 24 hour duration of load application with a pressure increment ratio of 1.0 is recommended. Schmertmann method is suggested for evaluating the preconsolidation pressures.

It is also recommended that laboratory consolidation tests of load increments up to 32 kg/cm2 be used for clays which are located at the middle parts of the basin since they have greater preconsolidation pressures. The virgin portion which is extremely important in the determination of preconsolidation pressure cannot be obtained satisfactorily with load increments only up to 16 kg/cm2.

Doruk (1968) conducted his study on the three kinds of clayey soils (compacted and undisturbed) from the METU. The factors affecting the swelling of soils were examined. The swelling potentials of the soils were measured, and the soils were classified with respect to the classification of the USBR, and the classification recommended by Seed et. al,(1962):

Soil structure has a paramount effect on swelling such that an increase in the degree of orientation of the particles decreases the swelling amount of soil.

Increases in the initial moisture content of the soil decreases swelling.

Increase in percentage of soil finer than 2 micron increases swelling amount and swelling potential.

Increase in plasticity index, which is related to clay type and its amount, also increases swelling.

Although the soils can be put into categories by means of the mentioned classifications, the swelling that the soils show under different natural conditions cannot be understood perfectly by means of their categories.

Increase in dry density increases swelling for soils having low initial water contents. For high initial water contents, increase in initial dry density may increase or decrease swelling.

According to Doruk (1968), it is very difficult, almost impossible to simulate natural conditions in laboratories. The best thing to do is to found stations at different places and to record the swelling of the soils under natural conditions for a long period of time, from which the actual swelling behaviour of soils can be predicted.

Following this last suggestion, the main purpose of Omay's (1970) study was to obtain a practical result by means of field observations (elevation changes which occur at various depths on two locations of METU campus at monthly intervals were recorded) and laboratory experiments on undisturbed samples. One of the practical aspects of the study is presented by figures showing the possible heave amount in the future for an initial water content. By these curves, for any soil having approximately the same soil characteristics, it is possible to be informed roughly about future heaving amount under a pressure equal to the overburden pressure.

Due to economical and sociological conditions in Turkey, light weight structures are the most common type of building which is the most sensitive to heaving.

As is done in some parts of Israel, the zone below which the moisture stays more or less constant may be determined. Since the small changes in moisture does not cause much swelling, foundations should lie below this zone.

In laboratory experiments, swelling pressures up to 1.52 t/m2 have been obtained (this is the minimum value and this can be extended up to 4 to 5 t/m2). In some regions of Ankara, if the types of the light- weight structures were observed,it can easily be calculated that the contact pressure may decrease to a value of 3 t/m2 . Under these conditions, test results show that some precautions should be taken for such type of light weight structures.

The main purpose of Abbasoğlu's (1971) study was to investigate the effects of inorganic chemical addition on the vertical swelling characteristics of compacted samples of Ankara clay. In this research , 146 samples, compacted under standard compactive energy and with various initial water contents have been used for one dimensional swelling tests. 32 samples have been tested without using any additive, and 114 samples have been treated with NaCl and $CaCl_2$ of various percentages by the dry weight of the soil specimen. The following conclusions were obtained:

Under a given compactive method and energy, Ankara clay specimens compacted at low initial water contents exhibit more vertical swelling than specimens compacted at higher initial water contents.

Samples compacted on the dry side of the optimum have higher initial rate of swelling than those compacted on the wet side.

Under a given initial water content and dry density, remoulded clay samples swell more than undisturbed samples.

Inorganic chemicals NaCl and $CaCl_2$ produce a net reduction in the rate and amount of vertical swelling.

Addition of NaCl and $CaCl_2$ reduces the optimum water content and increases the dry density.

Increasing amounts of NaCl and $CaCl_2$ cause a progressive reduction in the liquid limit of clay samples. The reduction caused by $CaCl_2$ is more than that of NaCl due to the valence of exchangeable ions.

Kocabayoğlu (1971) studied the contribution of desiccation to the preconsolidation of Ankara clay.

The purpose of this study is to try and estimate the contribution of desiccation to the preconsolidation of the upper layers of Ankara clay, and hence throw some light on the accuracy of predictions of the maximum height of geologic overburden in different locations of the city of Ankara.

Throughhout the world there exist areas of surface clays which are subjected to cycles of drying and wetting due to alternating dry and wet climatic conditions. The capillary forces in the drying clay subject the clay to an increase in effective pressures which produce overconsolidation to considerable depths.

Some of these clays have , in addition, been preconsolidated by heavy overburden which has subsequently been removed by erosion. The preconsolidation due to geologic overburden can be much greater than the preconsolidation produced by desiccation.

Studies have shown that in the upper layers of the Ankara clay desiccation is responsible for as much as 50 % of the preconsolidation pressure estimated from laboratory tests. This percentage is based on the assumption that at the greatest depth investigated, the effect of desiccation is negligible.

The predicted values of preconsolidation, in spite of the fact that they include the additional effect of desiccation, have been found to be lower than the values calculated on the basis of geomorphological data for four of the five sites investigated. This may have been partly due to the inaccuracy of laboratory predictions and partly due to the overestimate of the past elevation of the ground surface. That the soils tested(undisturbed samples) have been retransported after the initial deposition and preconsolidation is a further possibility.

Yüncü (1972) performed appropriate tests (on compacted samples) in the laboratory to evaluate the volume change behaviour of Ankara clay. These effects of various silt contents and of applied pressures to the volume change behaviour of the Ankara clay were found:

Increasing the surcharge decreases the swelling.

The value of swelling pressure decreases with increasing silt content.

Increasing the plasticity index increases Swelling Index .

Wetting after loading or loading and wetting at the same time give almost the same results for the swelling index and the swelling pressure for the same samples.

Increasing the silt content increases the volume reduction : the criteria given by Gibbs (1967) is applied to the samples and the sample having the highest silt content is closest to the region of collapsing soils.

The value of swelling pressure for Ankara clay having varying silt contents is obtained between 0.70 - 1.00 kg/cm2, this value can be higher (up to around 2.0 - 2.5 kg/cm2 (Omay, 1970)) generally. So light structures around Ankara are damaged seriously. When the structure loads are not sufficient to prevent expansion of the subgrade soils, the following measures may be adopted:

i) The natural subgrade expansive clays may be removed and replaced with non-expansive soils to a depth sufficient to provide loadings that will resist uplift.

ii)If the subgrade is a remolded expansive soil, the volume change may be controlled by compacting the soil at high moisture contents and low densities as predetermined in the laboratory.

iii)The saturation of the foundation soils may be prevented by shutting off all sources of water supply, although this may be difficult and impossible in some cases.

iv) Piles anchored in an inactive zone below a structure provide a reliable assurance against uplift if properly incorporated into the structure base.

Söylemez (1972) made an identification of the clay mineral composition for four remolded samples (2 samples from METU campus, one from Yücetepe and one from Ayrancı) of Ankara clay. A quantitative analysis of the clay mineral constituents of the samples was also made. X-ray powder diffraction method was used for the analysis.

The study showed that the clay fraction of the samples were composed, on the average, of illite 50 %, kaolinite 26 %, montmorillonite 12 %, and vermiculite 12 %.

The most abundant in the samples examined is illite. The ratio of its abundance to that of the total clay minerals is about 0.5. Therefore, the samples analyzed are to be identified as to be illitic clays. Kaolinite is also quite abundant in the samples. Its amount varies from 22 to 36 per cent. There is essentially no chlorite in the samples.

Expanding minerals (montmorillonite and vermiculite) are present in the samples in minor amounts. However it is believed that montmorillonite affects the physical properties of clay when present even in minor amounts.

The minimum percentage found for montmorillonite in this study is 9 % . The high values of LL and PI found for the samples are most probably due to the presence of montmorillonite.

Kaynar (1972) studied the ratio of swelling index to compression index in clay soils. As a part of his study he performed tests on 17 undisturbed samples of Ankara clay.

The following general conclusions were reached as a result of his study:

The ratio of swelling index to compression index increases with increasing plasticity.

Rate of increase of swelling index with PI becomes higher for more plastic soils.

An increase in plasticity causes soils to have higher void ratios.

There is a certain linear relationship between LL and the ratio of swelling index to compression index for clays. That is, this ratio increases when the LL is increased.

More plastic soils have high compression indices.

In the study by Akbay (1972) the volume change characteristics of undisturbed samples of Ankara clay with changes in moisture content under various applied loads were investigated. Comparison of the behaviour of the saturated and unsaturated clay samples was made.

Void ratio versus applied load curve of a soil differs depending upon the initial water content and degree of saturation. Changes in moisture content causes changes in volume, but the direction of this change in volume during change in moisture content is dependent on the magnitude of the applied load on the soil, i.e. soil may swell or collapse. Applied heavy loads tend to reduce swelling and for each soil there is a particular pressure which will just serve swelling but will not cause any collapse. This pressure may be defined as the swelling pressure.

It is known that when an area is covered by a structure or by any other means the moisture content of the soil increases. For such a case laboratory findings obtained from the natural moisture content sample should be less reliable, because the behaviour of the soil in the future will not be the same when its moisture content is increased. Therefore, any method of predicting partly saturated soil behaviour during change in moisture content must cover the extremes of collapse and swell, and any associated phenomena.

The quantitative prediction of partly saturated soil behaviour requires laboratory simulation of pressure and moisture conditions existing in the field.

The double oedometer test (Damla, 1976) may be used to predict the total collapse settlement or swell in partly saturated soils. By these tests the settlement at field moisture content and also the additional amount of settlement to be expected on saturation can be estimated. However as the tests do not completely reproduce the field conditions, the most accurate test would be the one conducted in the field with the actual load in place. So, the sampling errors would be eliminated. Any suitable test setup enabling the researcher to load the soil along the stress path in the field is more satisfactory.

As the soils above the water table do not reach 100 % saturation, the amount of volume change for degree of saturation they will attain should be determined, using as accurately as possible the stress path that the soil is expected to follow in the field.

Undisturbed samples taken from Kınık region, along Kurtboğazı dam - Ankara water line, have been tested in the laboratory by Damla (1976). The swelling of the clay was observed through studying the moisture variation against volume change behaviour of the clay under different loads. The swelling amount and the swelling pressure were determined by a series of double oedometer tests. The studies described in this thesis lead to the following conclusions:

Any partly saturated soil will undergo swelling under an applied stress when the suction is decreased and if void ratio or $\triangle H/H$ ratio versus applied pressure curves for the saturated condition is above the natural moisture content condition.

Double Oedometer Test (DOT) can be used to define the swelling amount and the swelling pressure for general engineering purposes. Prediction of swelling pressure according to double oedometer method (DOM) relies on the fact that the sample is allowed to swell fully under applied load, then compression occurs to its initial thickness. Also the final void ratio in swelling is estimated from the recompression curve by DOM easily.

Damla (1976) explained DOT as follows:

The applied vertical pressure on the sample in a desiccated condition is ;

$$\sigma_o = \gamma . z \qquad [14]$$

where z is the depth of the soil and γ is the average unit weight . If e_o is the void ratio which represents the applied pressure σ_o , then σ_o , e_o is plotted on Fig.7.6 .

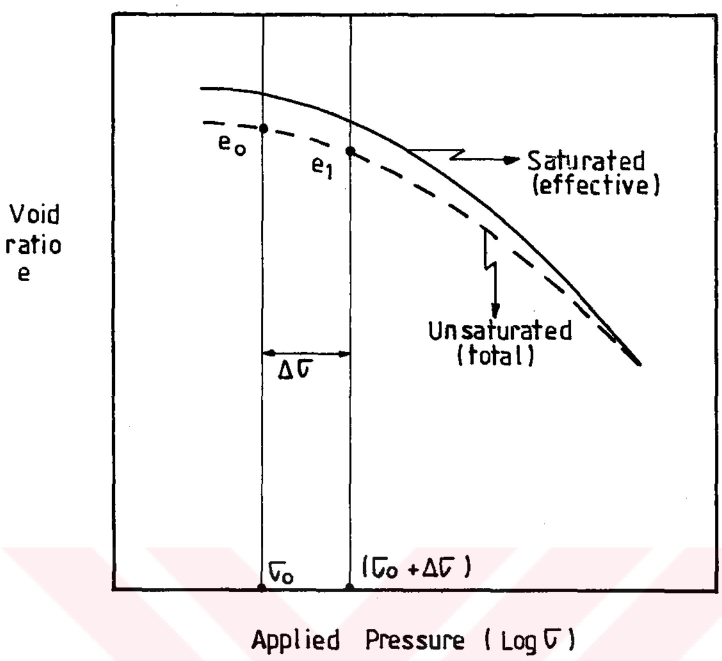


Fig.7.6. Application of Double oedometer Test

An additional load $\Delta\sigma$ is applied on the sample at depth z, the sample will compress under the applied pressure $(\sigma_o + \Delta\sigma)$, if no additional water enters. The new condition is represented by the point $(\sigma_o + \Delta\sigma)$ and e_1 on unsaturated curve. The amount of settlement is calculated making use of the usual settlement theory.

Instead of applying the load, if the surface of soil is covered with an infinite impermeable membrane, such as an airport base, the soil will gain moisture because evaporation is stopped completely. In case of the exitence of a ground water table at depth D, the final effective pressure at depth z will be,

$$\sigma'_{oe} = \sigma_o + \gamma_w \cdot (D-z) \qquad [15]$$

Jennings derived this equation for clay soils and up to 60 ft. water table depths encountered in South Africa.

Even if there is no ground water table, assuming atmospheric air pressure in the pores, this final effective pressure will be

$$\sigma'_{oe} = \sigma_o - X.u_w \qquad [16]$$

where u_w is the negative pore water pressure and is a parameter dependent on the degree of saturation of the soil. As water content begins to increase this equation holds true. The part $(X.u_w)$ is destroyed as the soil tends towards saturation. Then effective stresses are decreased and swelling occurs. To transfer from initial condition (σ_o, e_o) to final condition (σ_{oe}, e_2) is a swelling process (Fig.7.7)

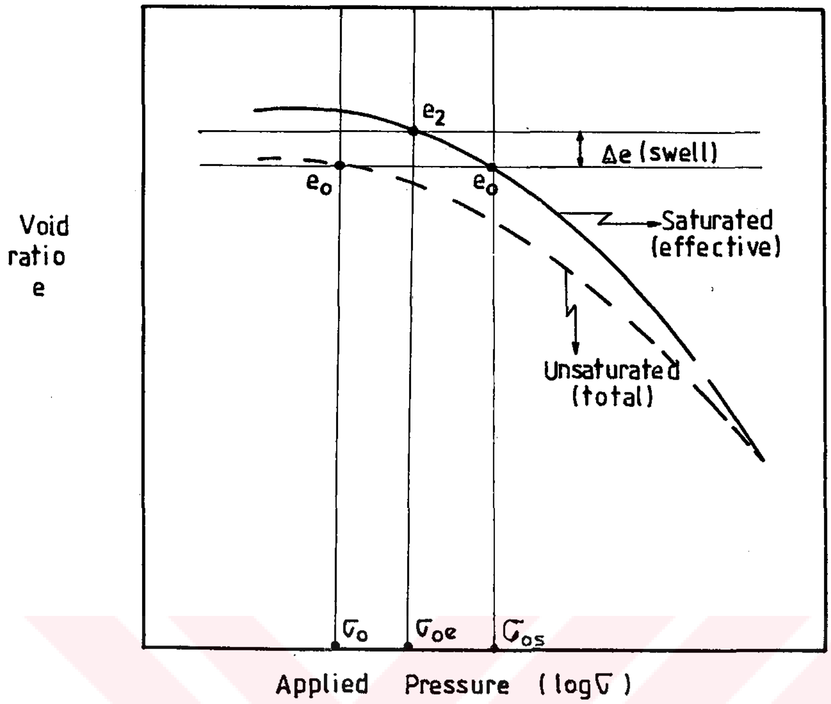


Fig.7.7.Aplication of DOT for a Swelling Soil

Δe represents the amount of change in void ratio due to swelling. If σ_{OS} is the pressure which recompresses the sample to the initial void ratio, " e_O", then (σ_{OS}-σ_O) is the swelling pressure under initial applied pressure σ_O.

DOT consists of testing in the oedometer a pair of soil samples obtained from the expansive soil, adjacent to each other so that their initial conditions such as void ratio, water content and physico - chemical properties are presumed to be identical. Prior to testing, a very small "seating " load of 5 to 10 KN/m2 is applied. Then the samples are loaded in conventional consolidation testing increments, one in its natural state and the other after having been soaked and allowed to swell freely.

The virgin portions of the resulting deformation - pressure curves are made to coincide (natural moisture content (unsaturated) curve is transferred upwards until the compression indices of two curves coincide) since the unsaturated sample reaches saturation by compression at a critical pressure increment.

The path independency is one of the big advantages of DOT.

Final void ratios in swelling are estimated from the DOT for each applied pressure under which the samples show swelling.

DOT loading must be carried out up to 32 kg/cm2 for Ankara clay to facilitate the coincidence of the virgin curves.

The time effect on expansive soils is a very important factor. For each stress increment time duration is changeable. Observation shows that samples under low stresses need more time to reach full swelling than the higher ones.

The amount of swelling pressure and swelling amount is directly related to the initial conditions, and indirectly related to the Atterberg Limits. Soils having high initial water content show less swelling pressure and less swelling amount.

The DOT provides a convenient measure for estimating the swelling amount and the swelling pressure.

Sürgel (1976) modified the boundaries of the soils on the Reconnaissance Engineering Soils Map of Ankara area reported by Dr.Lohnes (1974), and determined the general properties of the Ankara soils. He grouped Ankara soils into three different types named as "Alluvial Soils " , " Residual Soils " and " Terrace Deposits " based on Lohnes' Reconnaissance Soils Map. A frequency distribution analysis of engineering properties was made. Using these frequency analysis he modified the boundaries of soils on Lohnes' Reconnaissance Soil Map, He obtained the variation intervals of index and bulk properties of each soil and a PI - LL chart in order to differentiate the soils. He studied general properties of each class of soils by following an Engineering Parameters versus depth study.

He reached the following conclusions (based on the remolded and undisturbed soil data):

The parent material of Ankara area is composed of three different soils named as "Alluvial Soils ", "Residual Soils" and "Terrace Deposits" which is also known as "Ankara Clay".

Almost 75-85 % of the samples of all three types of Ankara soils fall above the A-line and a large part of it are classified as CH. Therefore, the soils of Ankara are mostly classified as CH.

Terrace deposits are a little more active than residual soils, and residual soils are more active than alluvial soils. METU campus clay, being a terrace deposit, gives results which fall within the limits of terrace deposits and is uniform.

All three types of soils have been subjected to surface drying and desiccation.

Considering the swelling potentials of differentiated soils it can be said that terrace deposits may swell a little more than residual soils and residual soils swell more than alluvial soils.

Surface materials of all three types of soils have been weathered and affected by fissures.

Consistencies of all types of soils are as follows;

i.Alluvial soils are in a semi- solid state and have medium to high plasticity.

ii. Residual soils are highly plastic. The soil within upper 3 meters is in a semi - solid or solid state, and after 3 meters the soil is in plastic state.

iii. Terrace deposits within the depths 0-4.0 meters are in semi-solid or solid state and have stiff consistency, the soils within the depths 4.0-19.0 meters are in plastic state and have stiff consistency, the soils within the depths 19.0-25.0 meters are in semi-solid or solid state and have high plasticity, and soils after 25.0 meters are in states varying from semi-solid to plastic and have high plasticity.

iv. METU campus clay has a plasticity varying from high to very high within upper 2.0 meters. After this depth the soil has equal chance to be in a semi-solid or plastic state.

All three types of soils appear to be preconsolidated mainly due to desiccation.

The parts of the all three types of soils remaining on the south side of Ankara river are more active than the soils remaining on the north side.

Plot of samples tested in this study on Birand(1978)'s Classification chart for Ankara soils is given in Fig.7.8. Terrace deposits samples fall in the terrace deposits region defined by Birand. But the range given for alluvial samples is not compatible with the Birand's range completely.

The properties of soils (remolded and undisturbed soil samples) in Ankara region was treated by Ordemir et al (1977) with special emphasis on their swelling properties. The predominant types of clay formations in the region were introduced and classified with respect to their expansiveness. Data on field volume changes were presented and it is shown that the so called 'Ankara Clay' exhibits a potentially expansive character.

They reached the following conclusions:

Residual soils which cover a relatively smaller area whose significance is not as great when city's development is considered.

Deposits of Pliocene - Pleistocene age which are mostly terrace formations in flood plains and, are referred

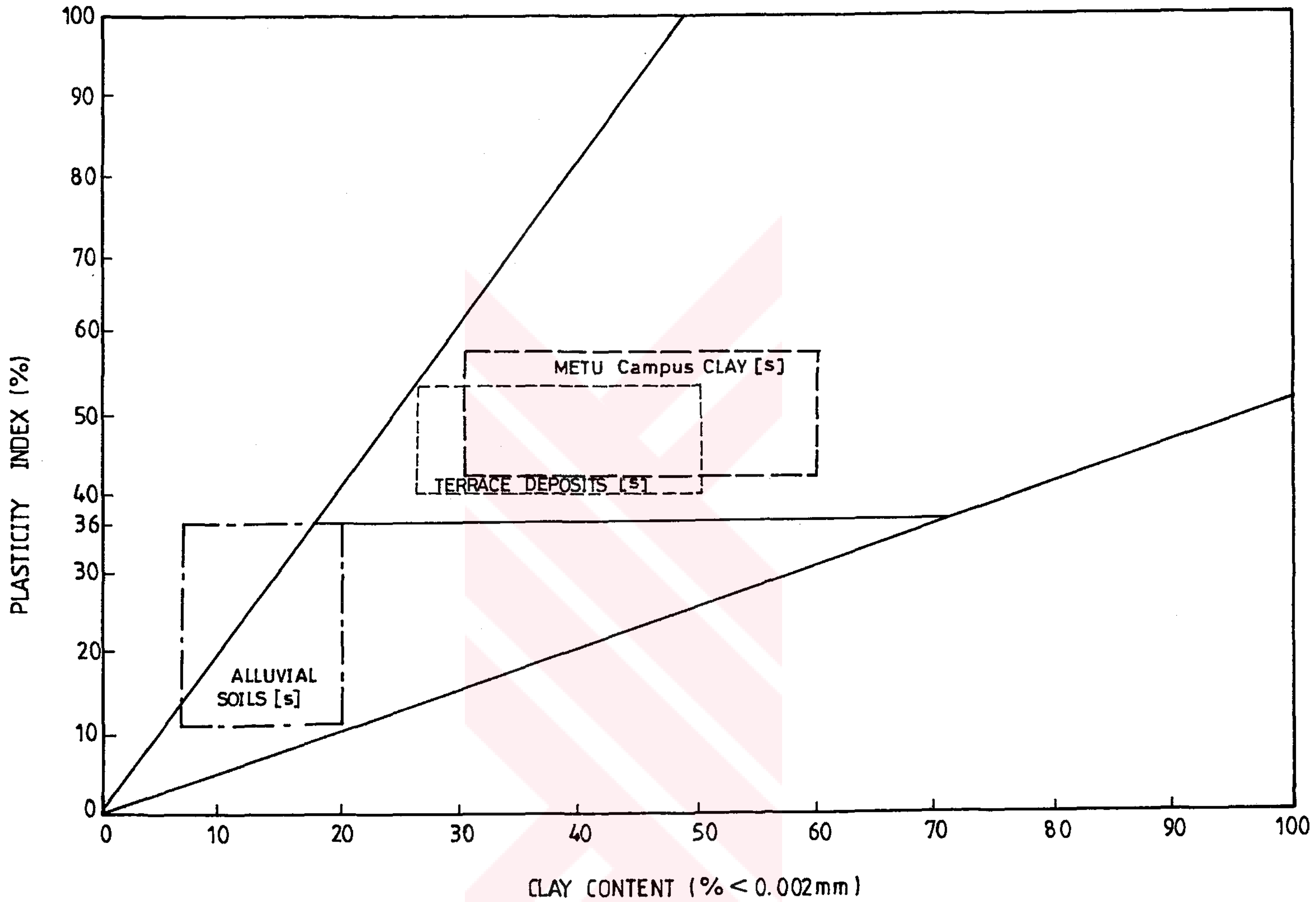


Fig.7.8. Plot of Ranges Given by Sürgel (1976) [s] on Birand's Classification Chart for Ankara Soils

to as preconsolidated, stiff, fissured "Ankara Clay ". These formations contain solution deposits and concretions of lime constituency which decrease in a north- north west direction. It has been noted in general that swelling potential decreases with increasing lime content.

Recent Alluvium deposits are encountered along local rivers and streams.

A recent statistical study by Sürgel (1976) on the index properties of these three subformations has lead to a tentative classification as shown in Table 7.1.

Table. 7.1.Index Properties of Residual Soils, Terrace Deposits and Alluvial Soils (After Ordemir et. al, 1977)

	Wn (%)	LL (%)	PI (%)
Residual Soils	25-32	49-71	21-41
Terrace Deposits (Ankara Clay)	25-36	60-80	39-53
Alluvial Soils	16-25	35-57	9-35

Ankara has a semi-arid climate according to Thorntwaite system (Özmelek, 1984). This is known to be a prerequisite for swelling problems which are further accentuated by geological setting and soil type.

Problems due to swelling are to be expected mostly in the case of "Ankara Clay ",though recent alluvium may also deserve special attention at certain places.

Double oedometer testing as suggested by Jennings and Knight (1957) have been found very useful and effective in the determination of swell pressures and amount for this soil.

Birand (1978 a) studied the geotechnical properties of Ankara soils and proposed the classification method as in Fig.7.8.

Mineralogical composition of Ankara clay is kaolinite- illite - montmorillonite. Kaolinite percent is higher and montmorillonite percent is lower. In general excangeable ion is calcium.

He states that Ankara clay is active for swelling and shrinkage and creates problems. If ground water table is near to the surface, Ankara clay and alluvial clay creates settlement and stability problems. Preconsolidation load was created due to capillary forces.

Swelling problems should be considered when using Ankara clay for embankments. Otherwise the structure that will be built on this embankment may be damaged due to swelling.

Birand (1978 b) states that the Double Oedometer Test is a valuable tool in geotechnical engineering for the solution of the problem of expansive soils. Its value derives not only from its ready applicability to engineering problems but also from the fact that its results can be closely related to the fundamental behaviour of partly saturated soils in terms of effective stresses. He estimated the swell pressure of Kınık clay samples by three different methods i.e., a)making use of the results of the DOT and reading off the value of swell pressure, b) letting the sample to swell and then compressing it by application of total stress increments until the initial thickness is obtained, c) increasing the total pressure continuously so as to prevent any swelling.

He observed that the values of swell pressures determined by the three methods are close, suggesting the exitence of a stress path independency of this clay.

He plotted the swell (%) versus total pressure (kN/m2) on several samples of Kınık clay; all samples had been taken very near to one another. He observed that the duration of swell measurements are important (i.e. 40 day swell amount value is higher than 24 hour swell amount value and the DOT curves plotted using the 40 day values would yield higher swell pressures than those that would be obtained if 24 hour values were utilized).

Furtun (1989) performed oedometer type swelling tests on undisturbed samples taken from Pliocene - Pleistocene age fluvial lacustrine deposits (terrace deposits) and recent alluvium deposits in various parts of Ankara region to assess their relative expansibility. He obtained the swelling pressure and percent swell values with initial water content and dry density. He compared the swelling pressures measured in constant volume swell and swell under overburden tests. An empirical equation giving swelling pressure in terms of LL, initial water content and initial dry density was developed based on the test results. Data given by previous researchers for Ankara soils was evaluated with regard to swelling.

The following main conclusions can be drawn on the basis of his study:

Terrace deposits have larger values of Atterberg Limits and Clay content than alluvial soils and the ranges of index properties of terrace deposits are very wide because of their heterogeneous structure which contains various sizes of silt, sand and gravel particles in the forms of bands and lenses. For example PI values change between 20 and 55 % while clay content values are between 10 % and 70 % . Another reason for this may be the wideness of the area and the differences in the parent materials of the terrace deposits formed in different locations. In order to gain an idea about the swelling properties of terrace and alluvial deposits data was also used in four different classification criteria which are Da Nilov , Modified Casagrande , Seed et. al and Van Der Merve charts. For all classifications between 70 - 86 % of the terrace deposits are classified as high to very high expansive while only 26 - 37 % of the alluvial deposits are classified as high to very high expansive.

According to Da Nilov's chart 68 % of the terrace deposits were found to be swelling while that value is 12 % for alluvial soils.

Terrace deposits have higher swell parameters than alluvial soils. Swell parameters increase as initial water content decreases and as dry density increases.

LL appears to be a good indicator of swelling (i.e. as LL increases swell parameters increase)

The average swell pressure for terrace deposits is 68 KN/m2 (weighted average) as opposed to 20 kN/m2 (weighted average) for alluvial deposits.

Damage due to swelling has been observed in Ankara basin where rapid expansion of the city led to the construction of various kinds of structures on the Ankara clay formation having a potentially expansive character.

Swell pressure values obtained by swell under overburden test is generally higher than the ones obtained from constant volume test.

The use of relationships given in the literature based on different soils and locations for swell parameters in terms of index properties can be misleading. Such correlations have to be derived locally.

Analysis has shown that swell pressure is strongly correlated with LL (%), W_i (%) and dry density(ρ_d mg/m3). In the analysis MINITAB Programme was used and the analysis of 30 CVS swell pressure test results from the present study on soils from 6 different locations in Ankara revealed the following emprical relationship to predict the swell pressure (P_s) in kg/cm2.

$$\log P_s = -4.161 - 0.059 w_i + 2.368 \rho_d + 0.036 LL \qquad [17]$$

(coeff. of correlation (r) is 0.90)

Erol (1990) found that the swell amounts calculated from oedometer test results (on undisturbed samples) are higher than the in-situ heave in an expansive shale from Saudi Arabia. This may be due to the inadequate wetting of the in-situ soil with respect to oedometer specimen and due to cracks and fissures in the in-situ soil which causes lateral deformations, these lateral deformations may decrease vertical swelling amounts. He defined " lateral restraint factor" α to reflect the effect of lateral deformations.

α = (In-situ heave amount/ Swell amount found from oedometer test)

α is a value between 1.0 (under the oedometer conditions, no lateral deformation) and 0.33 (lateral deformation is allowed). In the field, depending on the soil conditions, α value is in between these limits.

Although these tests were not performed on Ankara clay, due to the presence of cracks and fissures in

Ankara clay, they have a bearing on the results obtained on Ankara soils.

Yanıkömeroğlu (1990) studied the effect of lateral confinement on swell behaviour on compacted samples. He used Ankara clay and bentonite - sand mixture samples in his studies. Due to the fissured structure of Ankara clay , the results of his study are important.In conventional swell oedometer tests the influence of the cracks can hardly be simulated, since laboratory samples are usually prepared from smooth intact cores which do not include major discontinuities. Therefore the swell parameters obtained from oedometer tests tend to overestimate in-situ heave in such soils. A lateral restraint factor is then introduced to account for such structural effects.

A model study has been performed to simulate the cracks and fissures (macropores) in expansive soils with artificial holes drilled in two different samples. Free swell, swell pressure and swell under load tests have been performed for three restraining conditions (i. no lateral restraint, ii. partial lateral restraint, iii. full lateral restraint). An expression for lateral restraint factor in terms of percent macropore content and normal pressure has been derived.

On the basis of his study, the following conclusions have been drawn:

There is a linear relationship between percent swell and logarithm of normal pressure (percent swell decreases as logarithm of normal pressure increases).

The amount of swell as well as swell pressures increase with increasing values of dry density.

The swell and swell pressures are reduced with increasing values of macropore content. This reduction is due to crack closure and a possible reduction in lateral swell pressures.

The rate of swell is significantly increased by the presence of macropores which increase the permeability and consequently the rate of water intake.

The predicted heave based on experimental swell data obtained from intact samples should be corrected by multiplying with lateral restraint factor, α . If a reasonable estimate of this factor can be made for a real soil profile.

$$\alpha = -0.12*10^{-3} (P_m) - 0.19P+0.89 \qquad [18]$$

α = Lateral restraint factor

P_m = Percent macropore content by volume, %

P = Surcharge pressure, kg/cm2

This relationship is valid for $P_m > 0$, and α is unity for $P_m = 0$

$$P_m = \left(1-\left(\frac{\gamma_{d_{bulk}}}{\gamma_{d_{intact}}}\right)\right)*100 \qquad [19]$$

$\gamma_{d_{bulk}}$ = bulk dry density (with macropores)

$\gamma_{d_{bulk}}$ = intact dry density

The crack closure process is more efficient in the vertically oriented pores.

The magnitude of the index of propensity to water intake (P_w) (Birand, 1976) is reduced significantly due to the presence of macropores, where;

$$P_w = \frac{\Delta e}{\Delta w} \qquad [20]$$

Δe= change in void ratio during swell

Δw= change in water content that cause swell

7.4. General Observations for Ankara Soils Based on the Studies Reviewed

The parent material of Ankara area is composed of three different soils named as Alluvial Soils, Residual soils and Terrace deposits which is also known as Ankara clay.

Recent alluvium deposits are encountered along local rivers and streams.

Ranges of index properties of terrace deposits are very wide because of their heterogeneous structure which contains various sizes of silt, sand and gravel particles in the form of bands and lenses. Another reason for this may be the wideness of the area and the differences in the parent materials of the terrace deposits formed in different locations. Because of this, the engineering problems change from one location to another on terrace deposits. Therefore, terrace deposits may be divided into subgroups by future studies.

Residual soils and terrace deposits are mostly classified as CH.

Ankara soils appear to be preconsolidated. Agents causing preconsolidation need further study.

All three types of soils have been subjected to surface drying and desiccation to different extents.

Surface materials of residual soils and terrace deposits have been weathered and affected by fissures.

Skempton's original definition of activity as A_c=PI/CC for natural London clays is applicable to natural Ankara clay.

The parts of all three types of soils remaining on the south side of the Ankara river are more active than the soils remaining on the north side.

Terrace deposits are a little more active than residual soils, and residual soils are more active than alluvial soils. Since swelling potential depends on activity, it can be said that terrace deposits may swell a little more than residual soils and residual soils swell more than the alluvial soils.

Mineralogical composition of Ankara clay is kaolinite - illite - montmorillonite. Kaolinite percent is higher and montmorillonite percent is lower. Based on scarce data, it seems that the exchangeable ion is calcium.

The most abundant clay mineral in the samples examined by Söylemez (1972) is illite. Expanding minerals (montmorillonite and vermiculite) are present in the samples in minor amounts. However, Kasapoğlu (1980) reports that in Ankara soils the dominant mineral in clay fraction is montmorillonite. Kiper (1983) states that in Ankara clay montmorillonite and illite are the dominant minerals and chlorite and kaolinite are present in minor amounts. These results can give a general idea about the mineralogy of the Ankara soils, but these results are based on limited number of data, and therefore controversies exist.

Terrace deposits contain solution deposits and concretions of lime constituency which decrease in a north - north west direction. It has been noted in general that swelling potential decreases with increasing lime content (this behaviour was also observed by Kılıç, 1990). According to Kasapoğlu (1980), main source of the calcium is limestone formations present in the region and a minor source is andesites.

The effect of precompression of the clays on swelling is to reduce the swelling potential.

The method proposed by Lambe (1960)should be used in estimating the potential heave of Ankara clays. Using this method, one would be on the safe side and also take the climatic factors into account.

Swell pressure values obtained by swell under overburden test is generally higher than the ones obtained from constant volume test.

An emprical relationship based on 30 constant volume swell pressure tests on soils from 6 different location in Ankara to predict the swell pressure P_s [Eqn.17] in kg/cm2 can be used .

The value of swelling pressure decreases with increasing silt content.

The swell and swell pressures are reduced with increasing values of macropore content. This reduction is due to crack closure and a possible reduction in lateral swell pressures (this result is based on the tests performed on Ankara clay and bentonite - sand mixture).

Double oedometer test is useful and effective in the determination of swell pressures and amounts. In this test duration of swell measurements affects the test results.

The predicted heave based on experimental swell data (on Ankara clay and on bentonite - sand mixture samples) obtained from intact samples should be corrected by multiplying with the lateral restraint factor [Eqn.18], if a reasonable estimate of this factor can be made for a real soil profile.

Under a given compactive method and energy, Ankara clay specimens compacted at low initial water contents exhibit more vertical swelling than specimens compacted at higher initial water contents.

Under a given initial water content and dry density, remoulded clay samples swell more than undisturbed samples.

Mineralogical composition of the clay affects the swelling of clays: clays with high ion exchange capacity ha tendency to swell more upon soaking than those with lower ion excange capacities.

Increase in the initial moisture content of the soil decreases swelling for undisturbed and compacted samples.

Increasing the surcharge decreases the swelling.

Inorganic chemicals NaCl and $CaCl_2$ produce a net reduction in the rate and amount of vertical swelling.

Samples compacted on the dry side of optimum have higher initial rate of swelling than those compacted on the wet side.

The rate of swell is significantly increased by the presence of macropores which increase the permeability and consequently the rate of water intake.

Swell parameters (pressure and amount) increase as initial water content decreases and as dry density increases.

LL appears to be a good indicator of swelling.

Increasing PI increases swelling index C_s .

Ankara has a semi- arid climate according to Thorntwaite system. This is known to be a prerequisite for swelling problems which are further accentuated by geological setting and soil type.

Swelling problems should be considered when using Ankara clay for embankments. Otherwise the structure that will be built on this embankment may be damaged due to swelling.

The data on Ankara soils will be evaluated later on in sections 8.5.1 and 8.5.4.

CHAPTER 8

EXPERIMENTAL STUDY

8.1. General Information

As stated in Chapter I the first objective of this study is to investigate the swelling properties and especially swelling potential characteristics of Ankara soils (section 8.5.1), and the second objective is to investigate the merits of methylene blue test as a possible means of identification of swelling soils in comparison to other existing methods (sections 8.5.2, 8.5.3 and 8.5.4). Five different data sets were used to get the result, among these the results of tests (i.e. Atterberg Limits, sieve analysis, hydrometer, x-ray diffraction, PVC meter and methylene blue tests) belonging to Data sets II, IV and V were obtained .

Analysis by X-ray diffraction supplements microscopic examination in identifying the finest fractions and in determining semi-quantitatively the mineral constituents. The method depends on the manner in which the atomic structure of the compound diffracts X-rays of a certain wave length and it determines the arrangement of atoms within crystals (the X-ray diffraction technique measures the basal spacings, i.e. the distance between two layers of atoms in a crystal structure). Patterns of X-ray diffraction may be recorded on photographic film. Film patterns permit comparison with standard reference patterns for identification of mineral constituents.

X-ray tests of samples were carried out in Geological Engineering Department of METU , Geological Engineering Department of Hacettepe University, Turkish Petrolium Research Laboratory, Cement Producers Association Reseach Laboratory and MTA.

8.2. Field Sampling and Preparation of Specimens

The locations of sampling sites were selected considering the geology of Ankara region which contains mainly two types of formations, namely terrace deposits and alluvial deposits, and they are expected (according to the previous researchers) to exhibit different magnitudes of swell potential values. Because of their relatively small thickness and relatively small area they cover, residual soils were not included largely in the testing program (there are only 2 samples from residual soils just to give an idea about the magnitudes) ,(according to Ordemir et. al, 1977, the significance of this area is not as great when city's development is considered). Sampling area is shown in Fig. 8.1. Sampling locations are indicated on the geotechnical map of Ankara given in Appendix G (there are 4 samples taken from Sincan and 2 samples from Eymir lake region which are shown on Fig.8.1) . The sampling locations are described in Appendix H . 22 remolded samples were taken on terrace deposit regions which show high swell potential values according

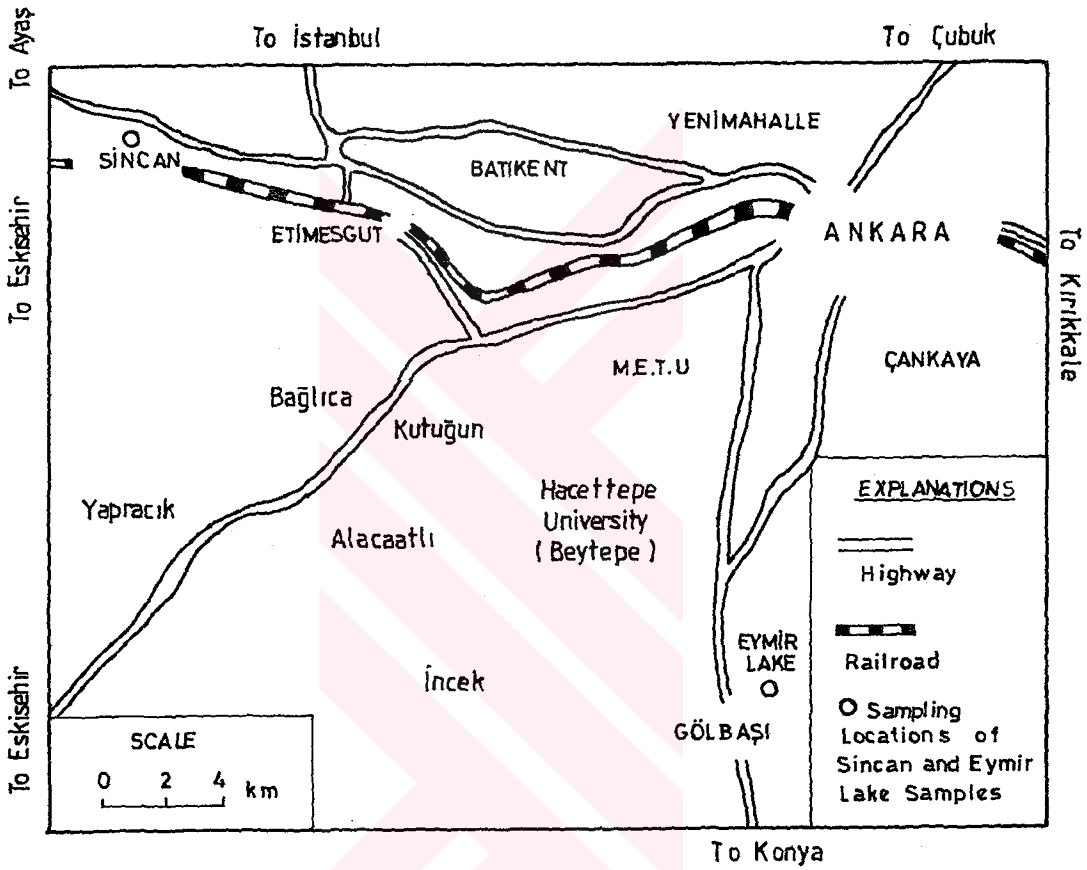


Fig. 8.1. Sampling Area

to the studies made by previous researchers. 16 remolded samples were taken from alluvial deposits. There are 2 remolded samples from residual soils.

Amongs the samples tested there are some commercial clays (kaolinite ,illite and montmorillonite) which are quite pure (taken from ceramic factories and MTA).

The samples were taken from the field (or from the factory in the case of pure clays), they were brought to the laboratory, dried in the oven for 24 hours, then ground and sieved through No.40 sieve (sieve opening is 400 micron).If the compaction of the soil sample can be done in dry condition it was not put into the desiccator, but if the compaction of the soil sample could not be done in dry condition it was put into the desiccator for at least 24 hours. For methylene blue test, samples were dried and sieved through No.40 sieve (sieve opening =400 micron).

8.3. Experimental Programme

For each sample, liquid limit (LL%), plastic limit (PL%), clay content (CC%), specific gravity (G_s), sieve analysis, PVC meter, methylene blue tests were performed. X-ray diffraction analysis for the samples were also made.

8.4. Test Results

Sample locations, clay content, specific gravity, Atterberg limits, soil classification, activity, swell potentials according to different classification methods, swell index, initial dry density, methylene blue value of the samples are given in Appendix I. Mineralogical composition of the samples (X-ray diffraction results) are given in Appendices J1 and J2 (mineral percentages of the samples were found according to the method given by Stoffers and Muller, 1972). Occurrance of a mineral in the samples are given in Appendix J3 and Fig.J1.

8.5. Evaluation of Data Obtained from Previous Studies and from the Present Study

8.5.1. Evaluation of Test Data Obtained by Different Researchers on Ankara Soils

At an early stage in any large scale investigation associated with expansive soils a qualitative characterization or classification of potential volume change should be made. The qualitative evaluation serves the purpose of warning the engineers of the potential problem at an early stage. In this section , swelling potential characteristics of Ankara soils are investigated by using Data Sets I and II.

Data which belongs to Data Set I has been collected from the studies of different researchers . Sampling locations of these data were also plotted on the geotechnical map (Appendix G). Variations in the properties of the Ankara soils are noted in terms of clay content, plasticity characteristics, swelling potential, water content and dry density.PI and CC values of the Alluvial Soils and Terrace Deposits samples were plotted on Birand (1978 a)'s classification chart (samples were taken from depths above 7 m) for Ankara soils in Figs. 8.2 and 8.3 respectively.This chart is used to determine the type of soil by plotting its clay content and plasticity index values . Sürgel (1976) gives activity ranges for alluvial soils as 0.26-

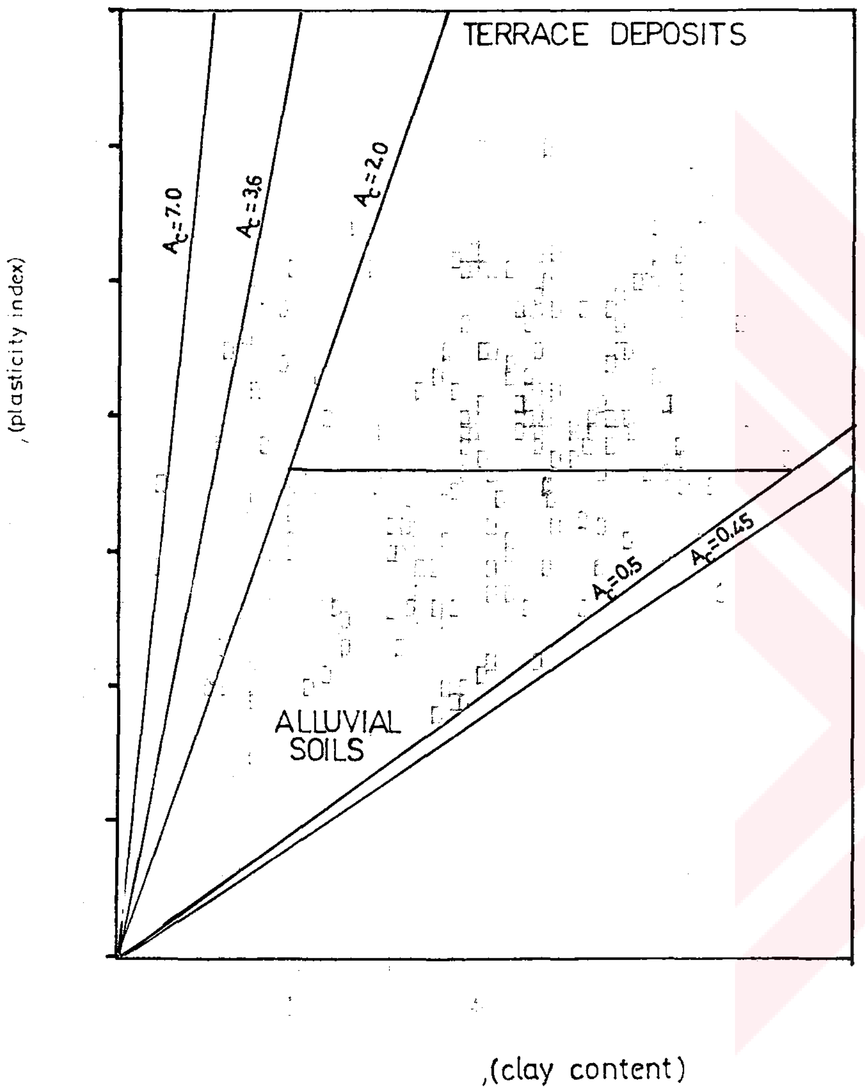


Fig. 8.3. PI vs CC Relationship for Terrace Deposits

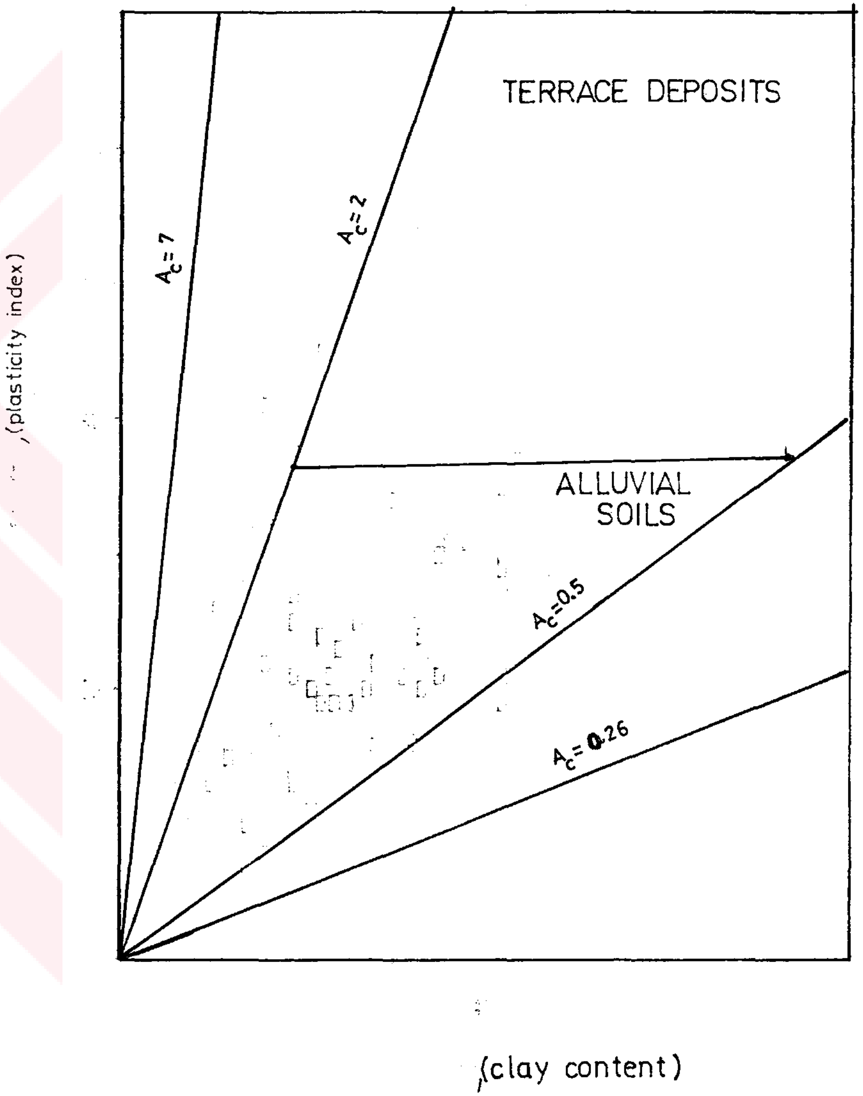


Fig.8.2. PI vs CC Relationship for Alluvial Soils

1.78 (maximum depth is 4 m)and for terrace deposits as 0.45-3.6 (maximum depth is 5 m).These ranges were also plotted on Birand (1978 a)'s chart. There are two regions in the chart. The region above the line passing from plasticity index of 36 % indicates terrace deposits. The region below this line indicates alluvial soils. From Fig. 8.2, it is seen that most of the alluvial soil samples are in alluvial soil range defined by Birand (1978 a). But , from Fig. 8.3 , it is seen that some of the terrace deposits samples are in alluvial soil range defined by Birand (1978 a) , the reason for that is explained by Furtun, (1989) as the presence of local alluvial deposits in the area .In Figs. 8.2 and 8.3 there are also some samples which are out of the ranges given by Birand (1978 a) and Sürgel (1976), these samples may have been taken from the depths lower than the maximum depth considered while preparing the Engineering Geology map . Also some Terrace deposit samples have activity numbers greater than 7 (activity number of Na-montmorillonite is 7), this seems to be an experimental error.

In Data Set II (data obtained by the author on Ankara soils), by using the geological map given in Appendix G as a guide, some sampling locations were selected on the alluvial soils (16 samples) and others (22 samples) were taken from the locations falling into terrace deposit classification. Two samples were taken from residual soils . PI and CC values of the samples were plotted on

Birand (1978 a)'s classification chart (Fig.8.4). In spite of the care taken in observing the real location of the samples the same trend occurs as in Figs. 8.2 and 8.3. Five samples taken from the terrace deposits fell into the region of alluvial deposits (the reason for that is believed to be the presence of local alluvial deposits in the area (Furtun, 1989)). One sample taken from the alluvial soils fell into the region of terrace deposits (its PI value is 37 % and close to the border between terrace deposits and alluvial soils).

Furtun (1989) states that the effect of presence of expansive clay minerals and their percentages are reflected in the consistency limits which correlate well with the swelling parameters.

In Figs. 8.5 a and b , plasticity index and liquid limit values of Alluvial Soils and Terrace Deposits are plotted on the plasticity index chart. From Fig.8.5.a it is seen that 91 % of the Alluvial Soil samples are above the A-Line (34 % of the samples are in CH range, 57 % of the samples are in CL range). From Fig.8.5.b, it is seen that 83 % of the Terrace Deposits samples are above the A-Line (69 % of the samples are in CH range, 14 % of the samples are in CL range).

In Fig.8.6.a range of changes of moisture content, LL, PL , shrinkage limit with depth (up to 10 m depth) for alluvial soils are shown .In Fig.8.6.b range of change of moisture content, plastic limit, shrinkage

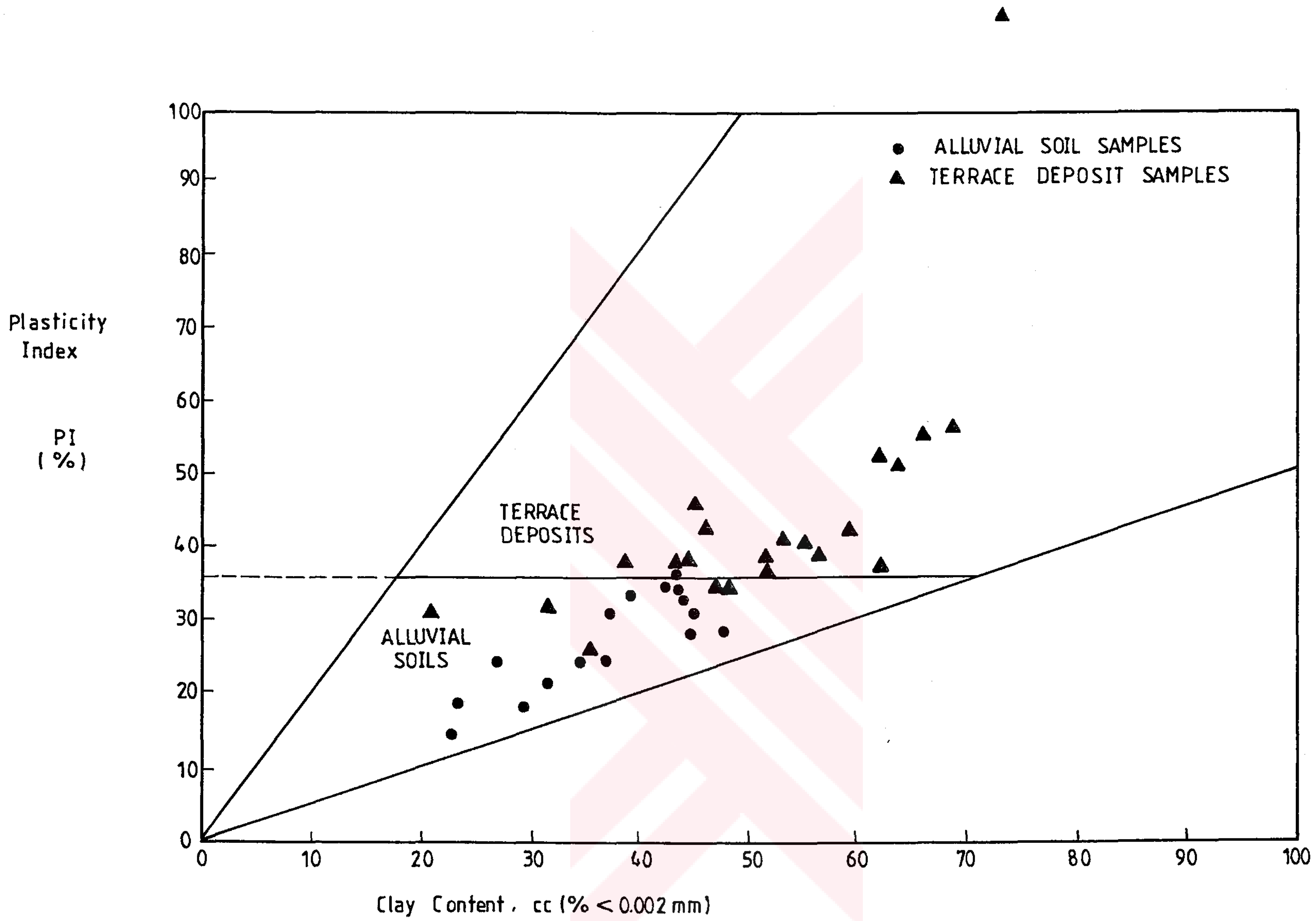


Fig. 8.4. PI vs CC Chart

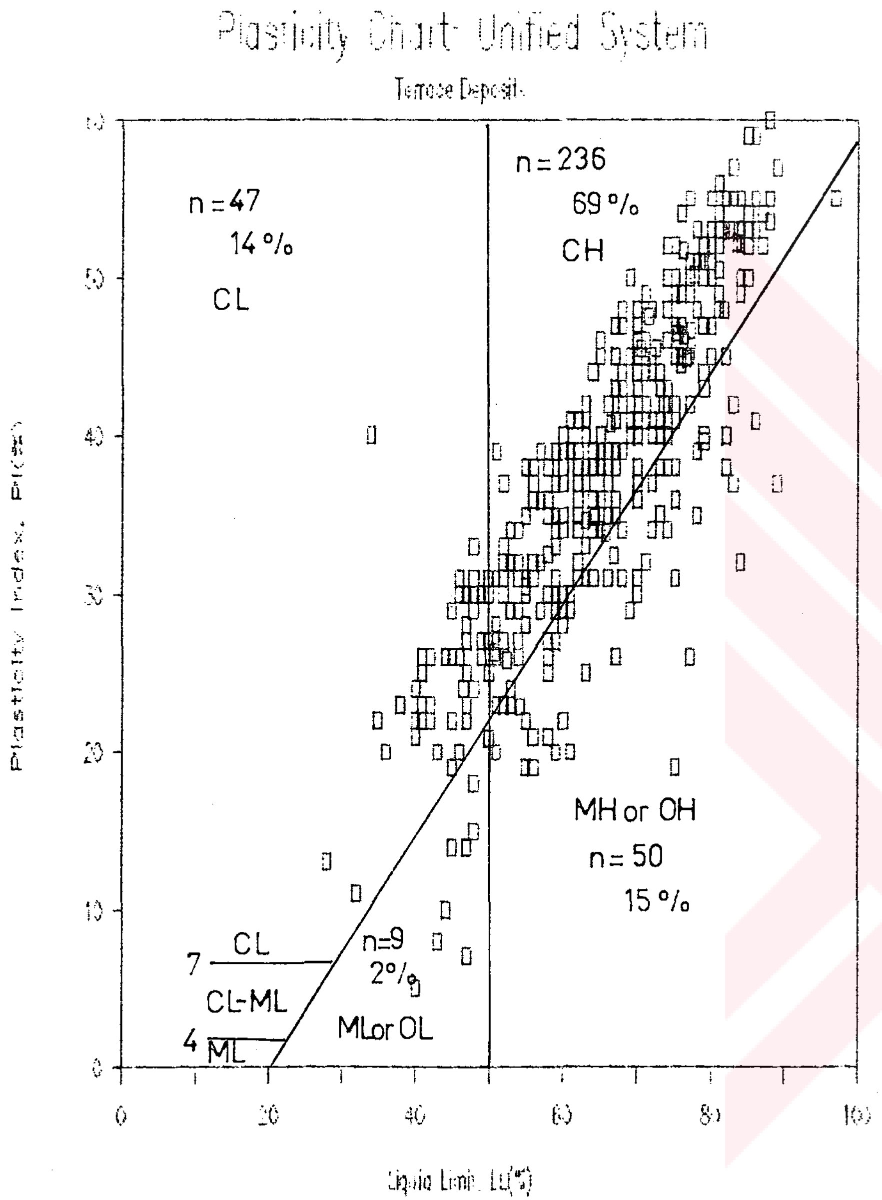


Fig.8.5.b. Plasticity Chart for Terrace Deposits

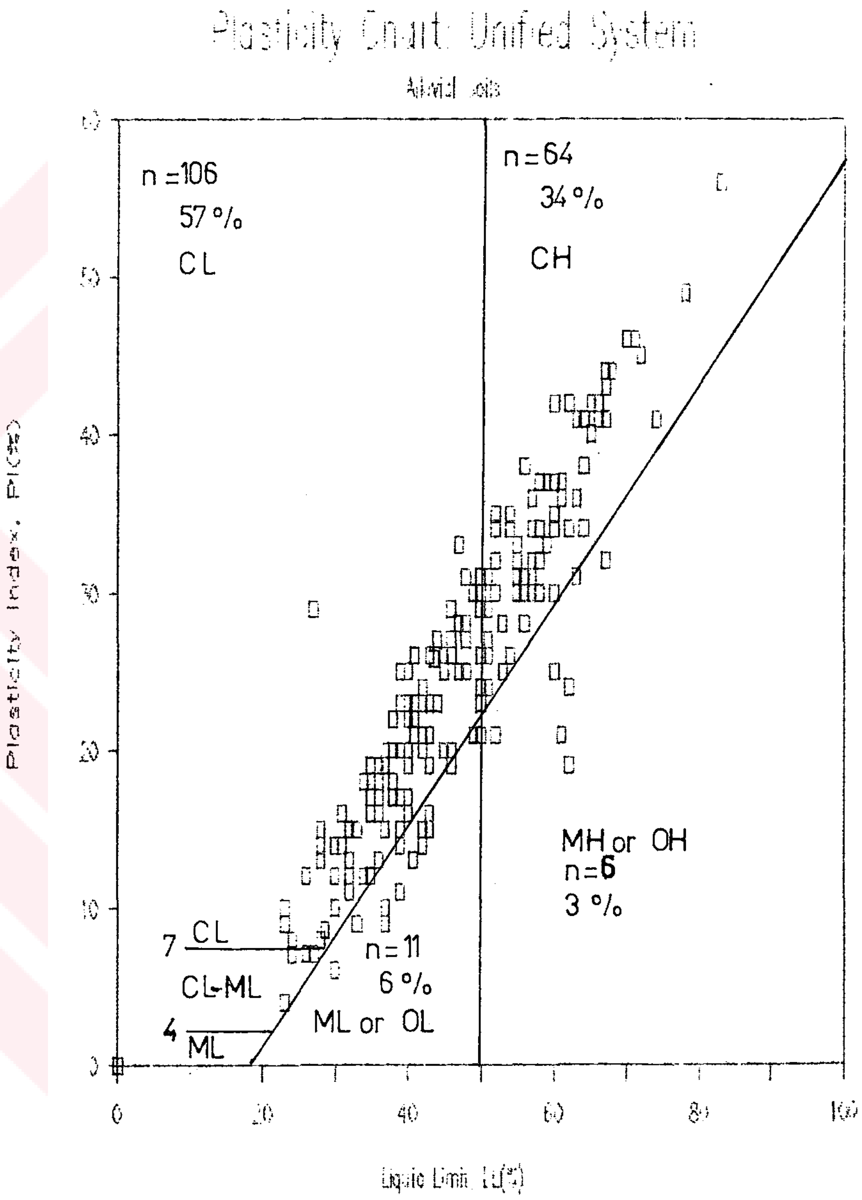
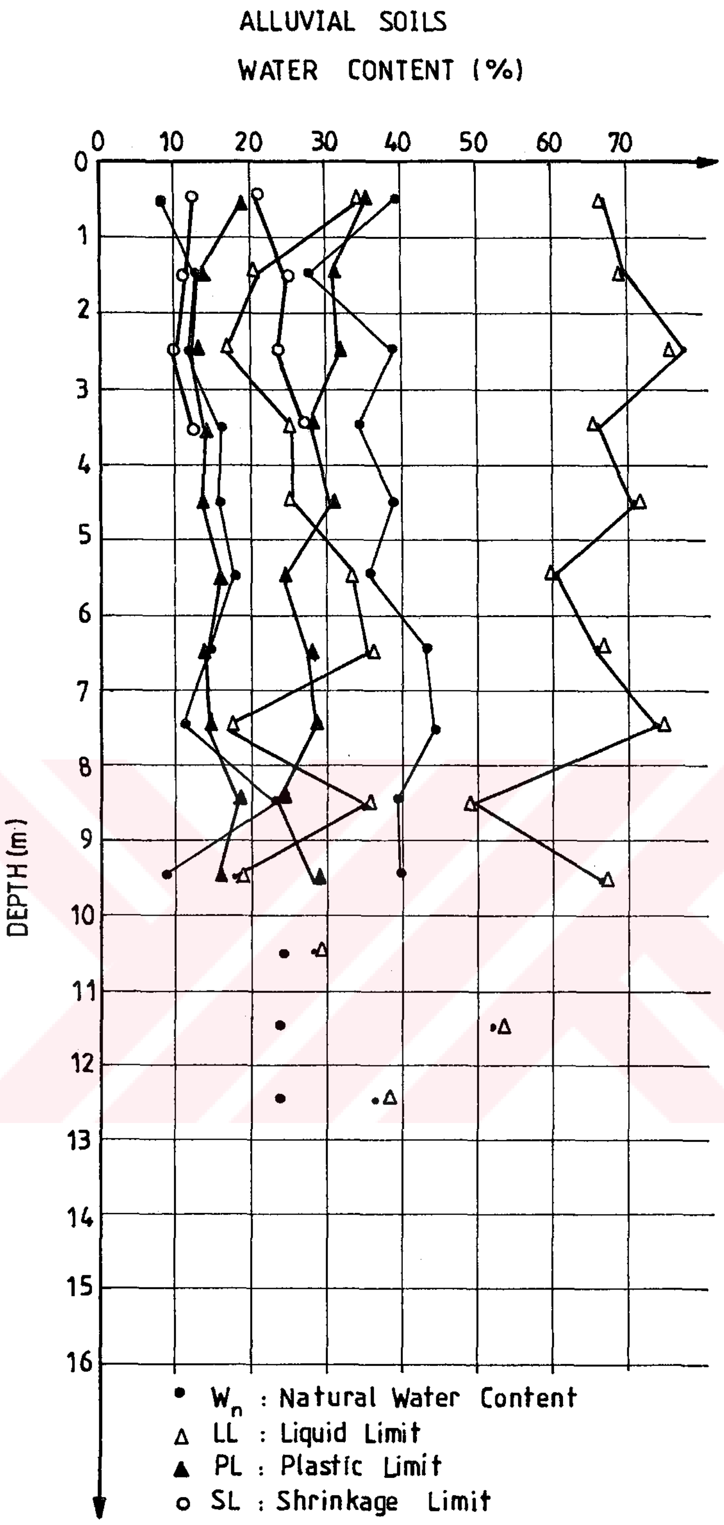
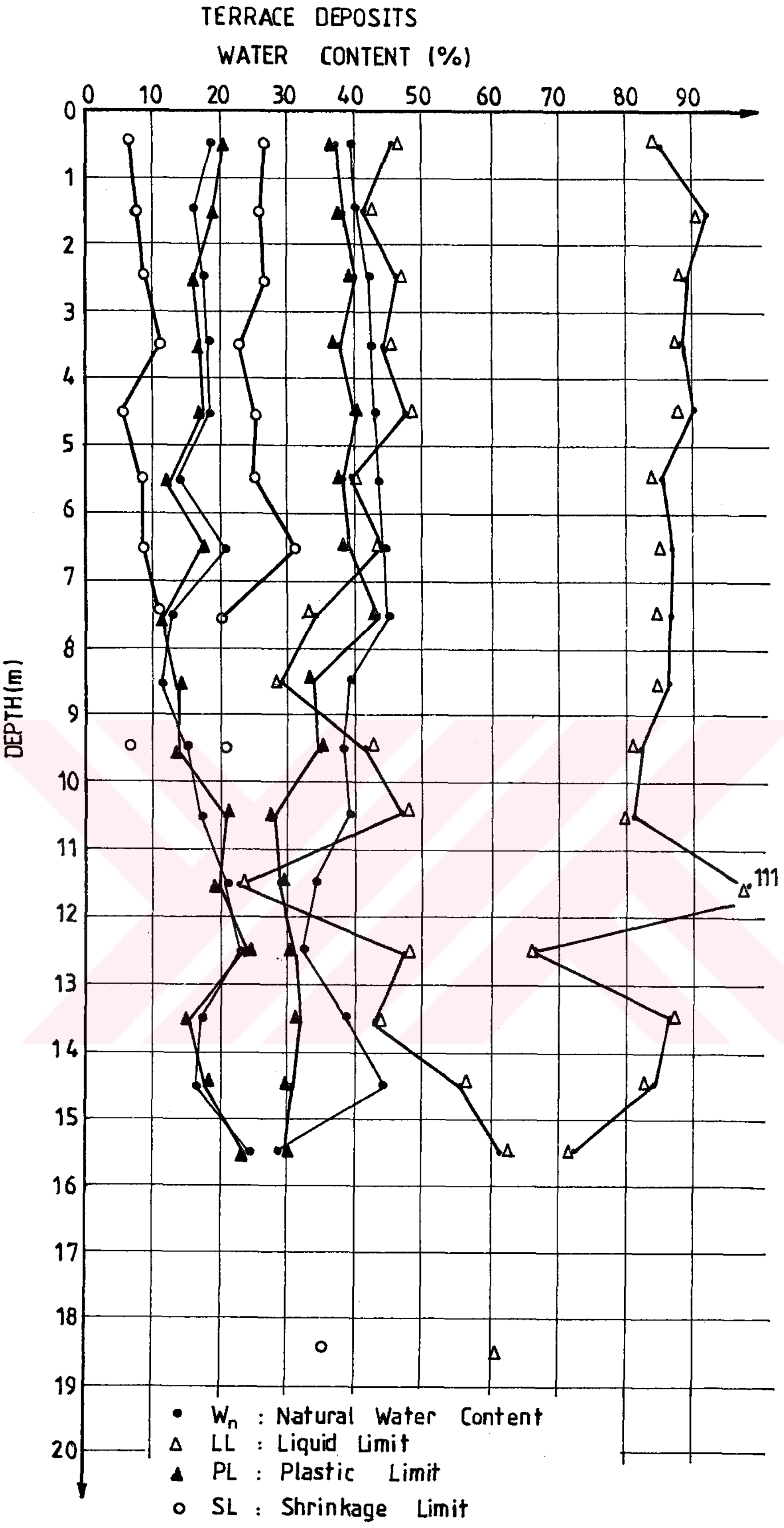


Fig.8.5.a. Plasticity Chart for Alluvial Soils



Note: Total no of samples = 188

Fig. 8.6.a. Depth vs W_n, LL, PL and SL Ranges for Alluvial Soils



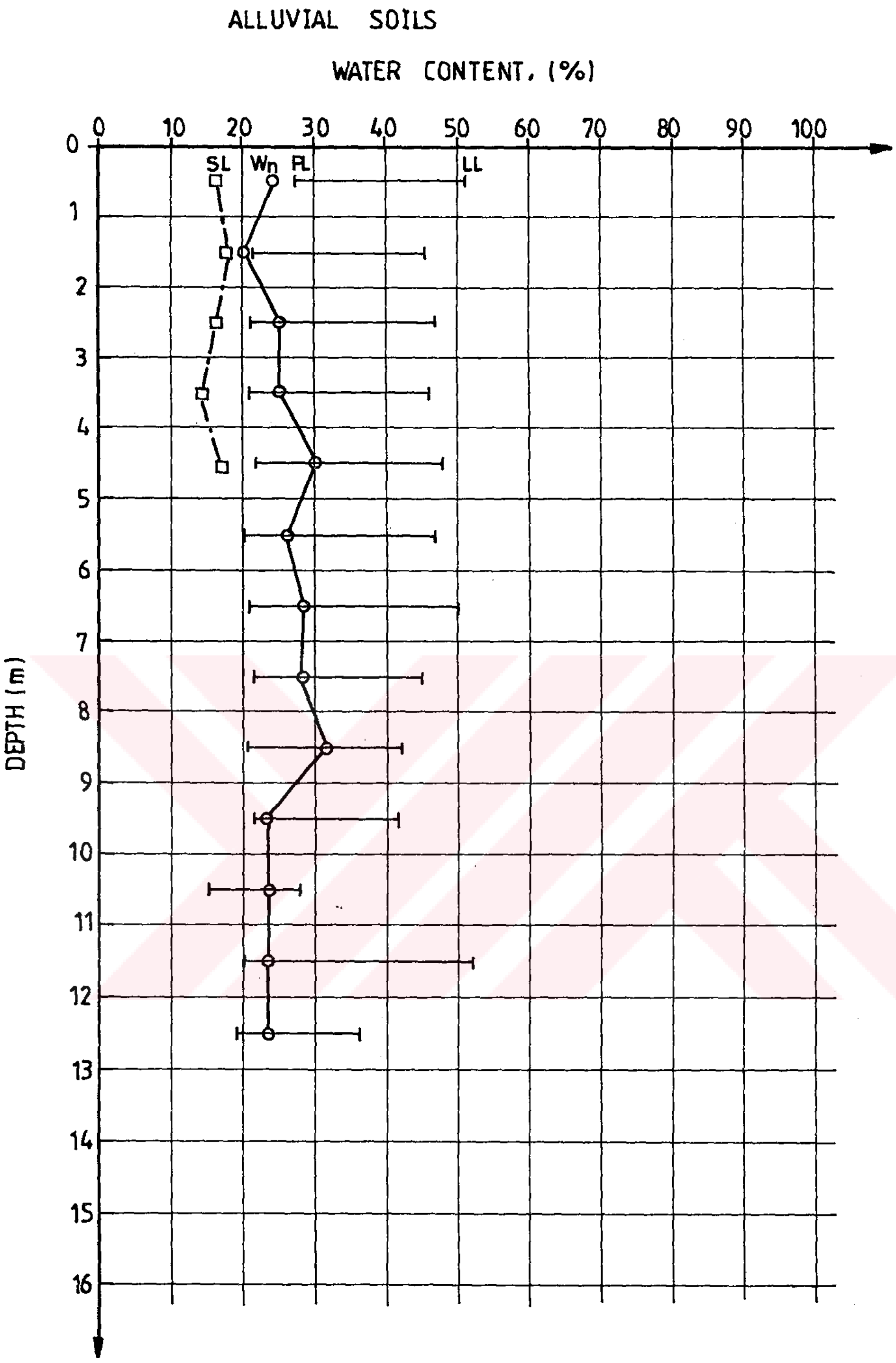
Note: Total no. of samples = 376

Fig. 8.6.b. Depth vs W_n, LL, PL and SL Ranges for Terrace Deposits

limit with depth (up to 16 m depth) for terrace deposits are shown (based on the data given by Furtun, (1989) and Author).

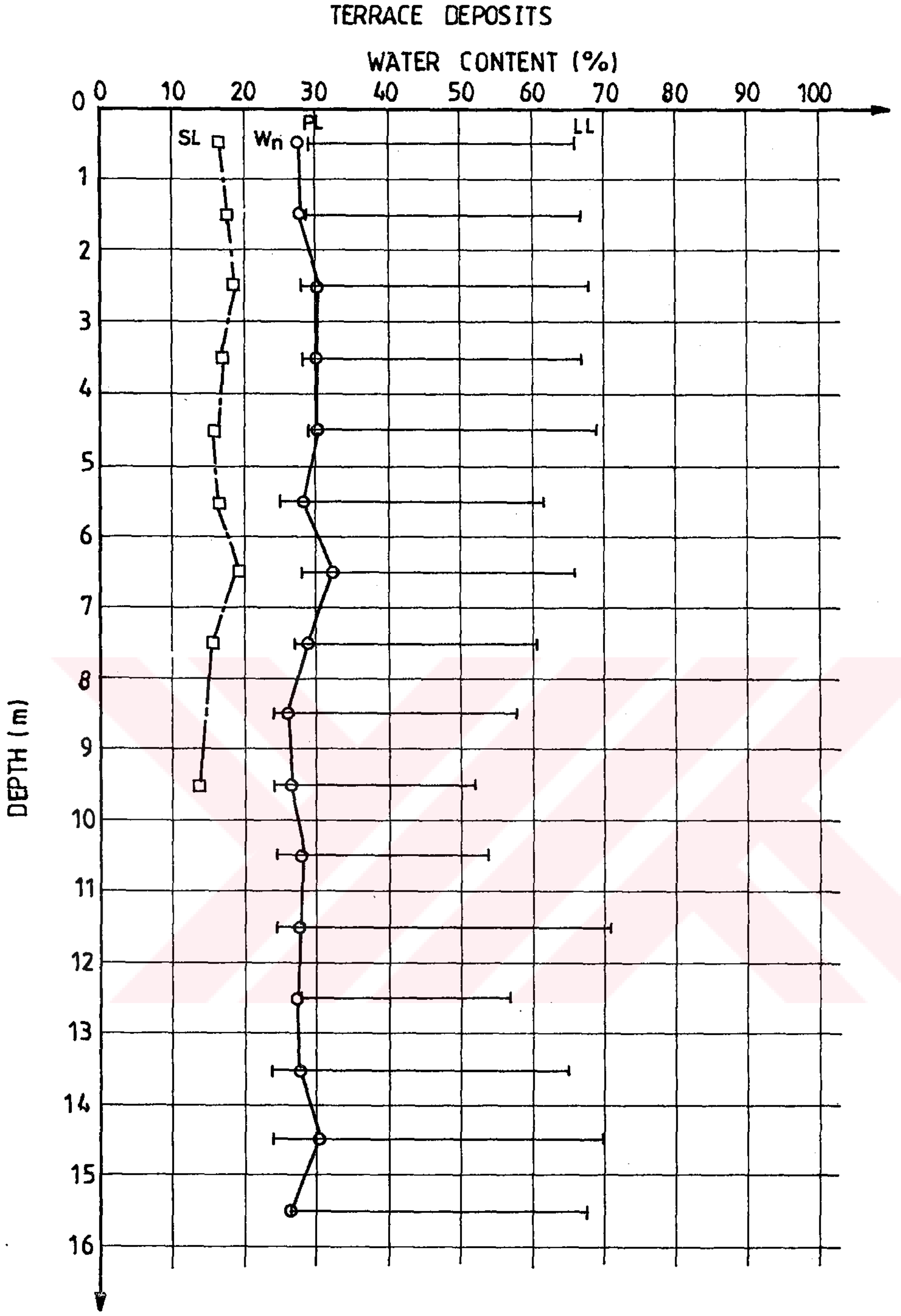
Typical in-situ moisture profiles from both alluvial soils and terrace deposits areas are shown in Figs.8.7.a and 8.7.b (based on the data given by Furtun, (1989) and Author) .Average values of SL,W_n , PL and LL are given for each depth interval. In general, natural water content values are near the PL values as stated by Ordemir et. al (1965). As stated by Lambe (1960) , soils most capable of large volume changes are plastic clays with high surface areas. In general, the more plastic the soil, the more water it can hold. Alluvial soils and terrace deposits satisfy this condition in their natural state.

Furtun (1989) states that terrace deposits have larger values of Atterberg limits and clay content than alluvial soils and the range of index properties of terrace deposits are very wide because of their heterogeneous structure which contains various sizes of silt, sand and gravel particles in the form of bands and lenses (reports of the data taken from the laboratories). For example plasticity index values change between 20 % and 55 % while clay content values are between 10 % and 70 %. Another reason for this may be the wideness of the area and the differencies in the parent materials of the terrace deposits formed in



* Average values are used

Fig. 8.7.a. Typical In-situ Water Content Profiles in Alluvial Soils

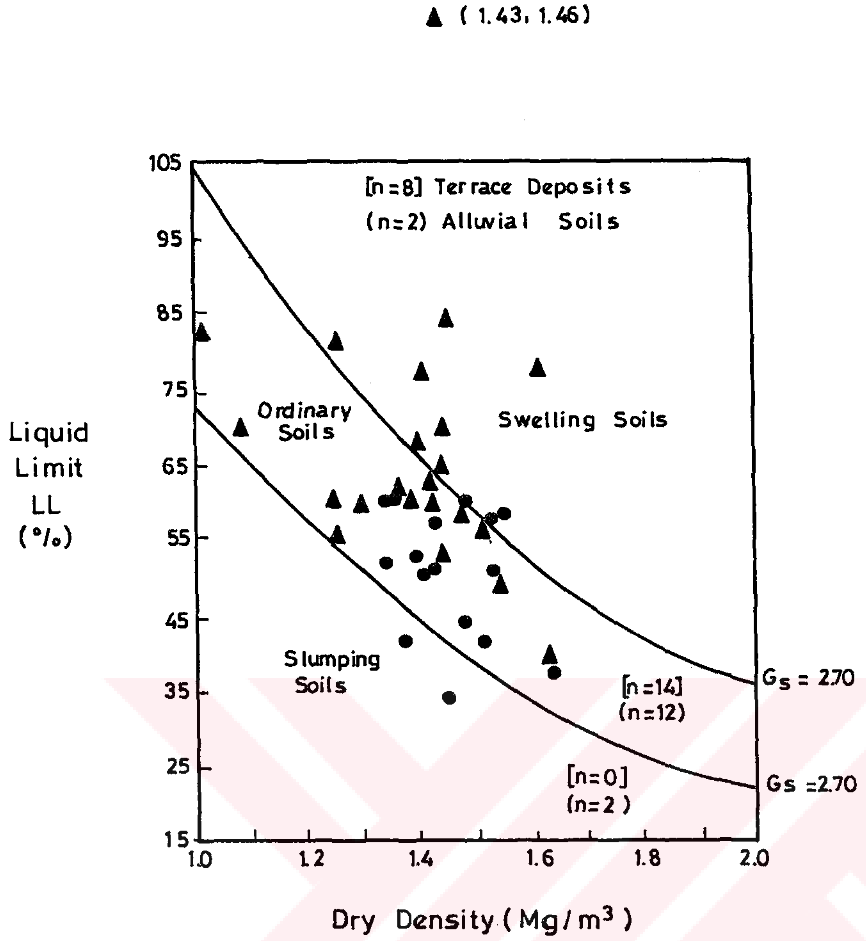


* Average values are used

Fig. 8.7.b. Typical In-situ Water Content Profiles in Terrace Deposits

different locations. In order to gain an idea about the swelling properties of terrace and alluvial deposits Furtun (1989) has also used the data in four different classification criteria which are Da Nilov (Fig. 8.8 for the samples taken by the Author), Modified Cassagrande (Fig.8.9 for the samples taken by the Author), Seed et. al (Fig.8.10 for the samples taken by the Author) and Van Der Merve (Fig.8.11 for the samples taken by the Author) charts. For all classifications between 70-86 % (77- 96 % for the samples taken by the Author) of the terrace deposits are classified as high to very high swelling while only 26- 37 % (43- 75 % for the samples taken by the Author) of the alluvial deposits are classified as high to very high swelling. According to the Da Nilov's chart 68 % (36 % for the samples taken by the Author) of the terrace deposits were found to be swelling while that value is 12 % (13 % for the samples taken by the Author) for alluvial soils.

The relationships between swelling potential (Seed et. al, 1962) and PI for Terrace and alluvial deposits are shown in Figs.8.12 and 8.13 .The swelling potential of these clayey soil samples is found to increase as the plasticity index increases. The dotted lines show the ranges of swell potential values for a given PI value (Seed et.al, 1962). Most of the terrace and alluvial soil samples fall in these ranges. So, this shows the compatibility of findings of Seed et. al, (1962) and those found by the Author.



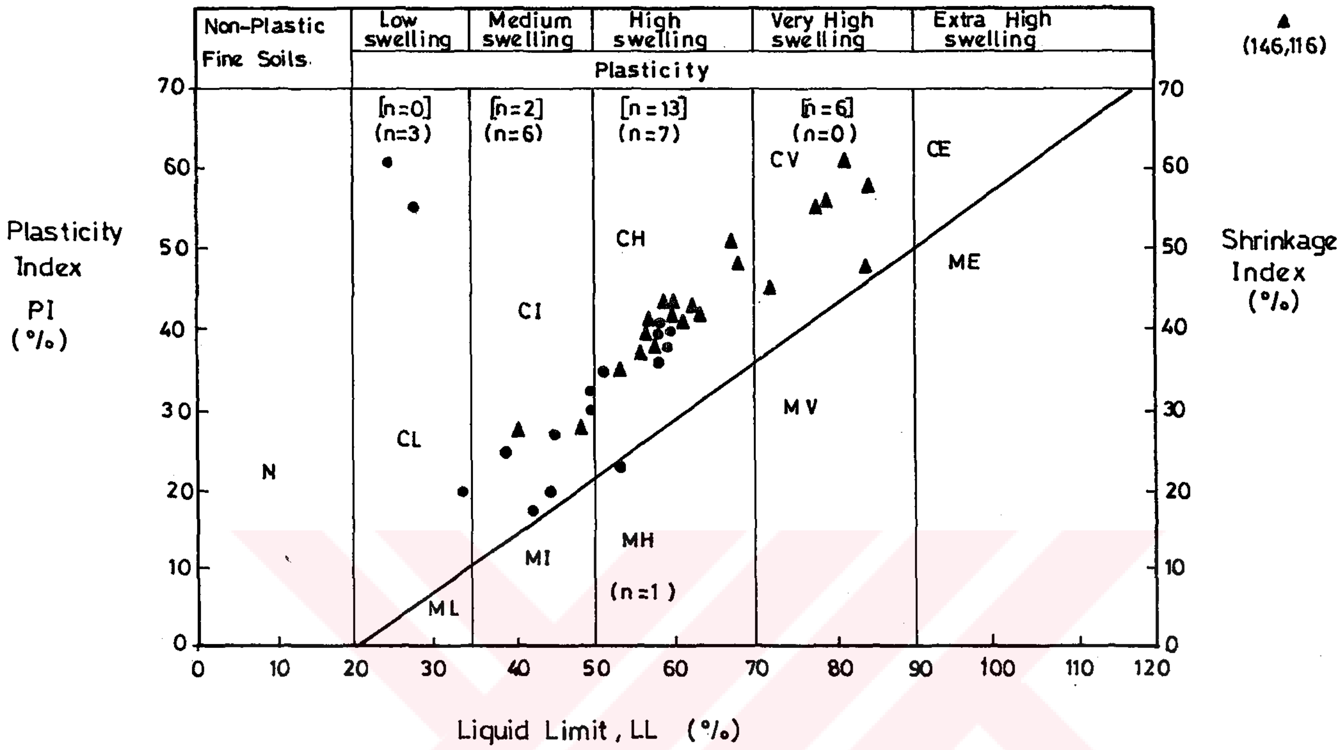
ALLUVIAL SOILS ● ( )

Swelling Soils : 13 %
Ordinary Soils : 75 %
Slumping Soils 12 %

TERRACE DEPOSITS ▲ [ ]

Swelling Soils : 36 %
Ordinary Soils : 64 %
Slumping Soils : -

Fig. 8.8. Da Nilov's Chart



ALLUVIAL SOILS ● ( )

Low Swelling : 18 %
Medium Swelling : 38%
High Swelling : 44%
Very High Swelling : -
Extra High Swelling : -

TERRACE DEPOSITS ▲ [ ]

Low Swelling : -
Medium Swelling: 9 %
High Swelling : 59 %
Very High Swelling: 27 %
Extra High Swelling: 5 %

Fig. 8.9. Dumbleton's Modified Casagrande Chart

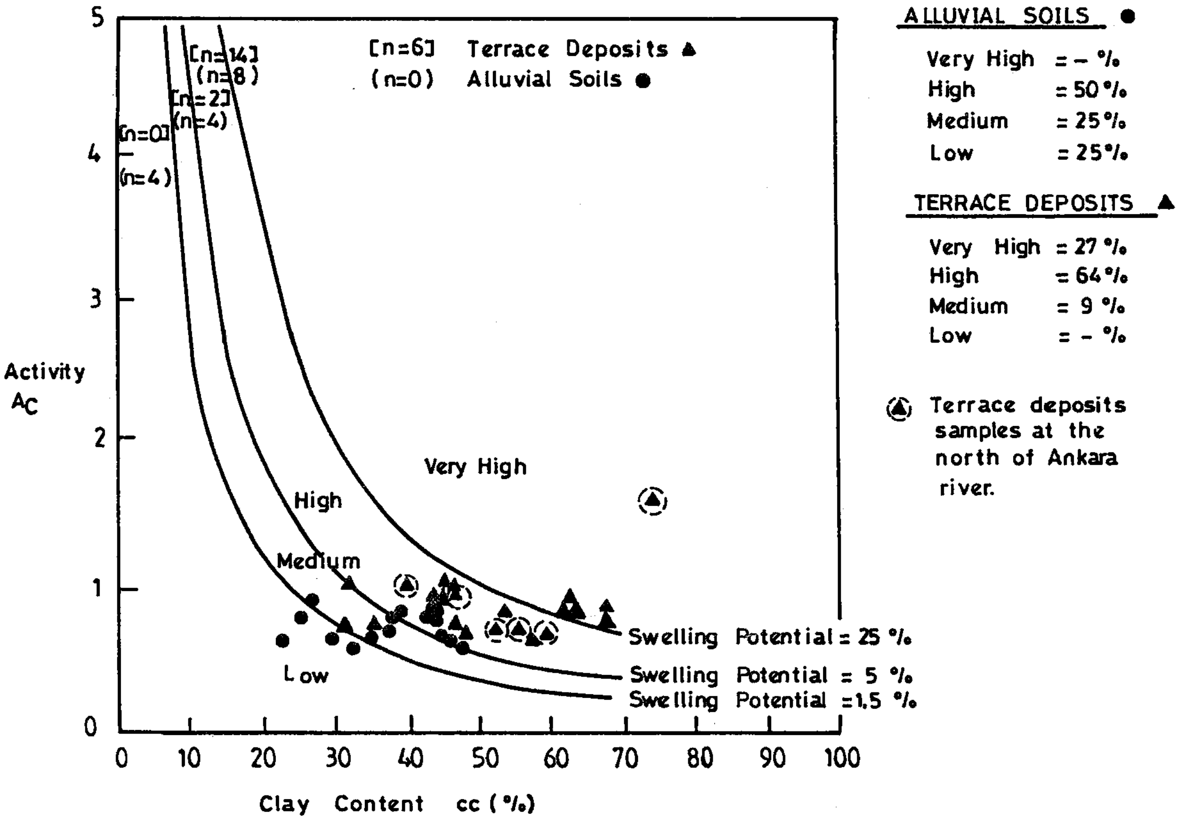


Fig. 8.10. Classification Chart for Compacted Soils

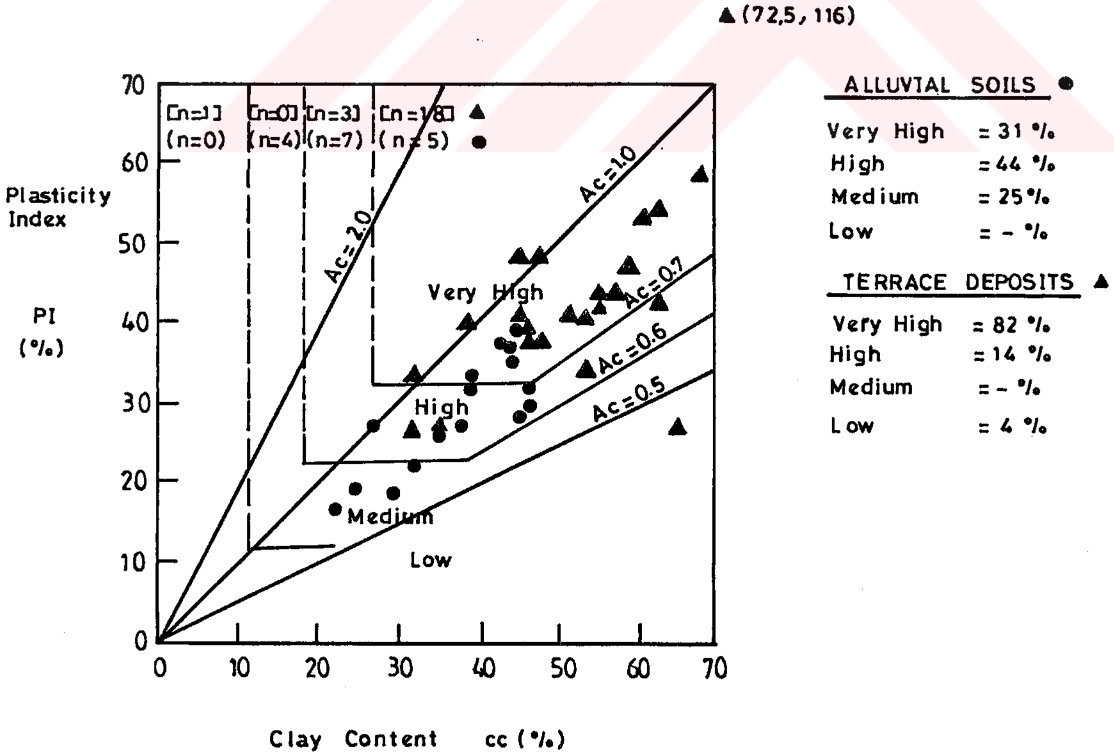


Fig. 8.11. Modified Van der Merve Chart

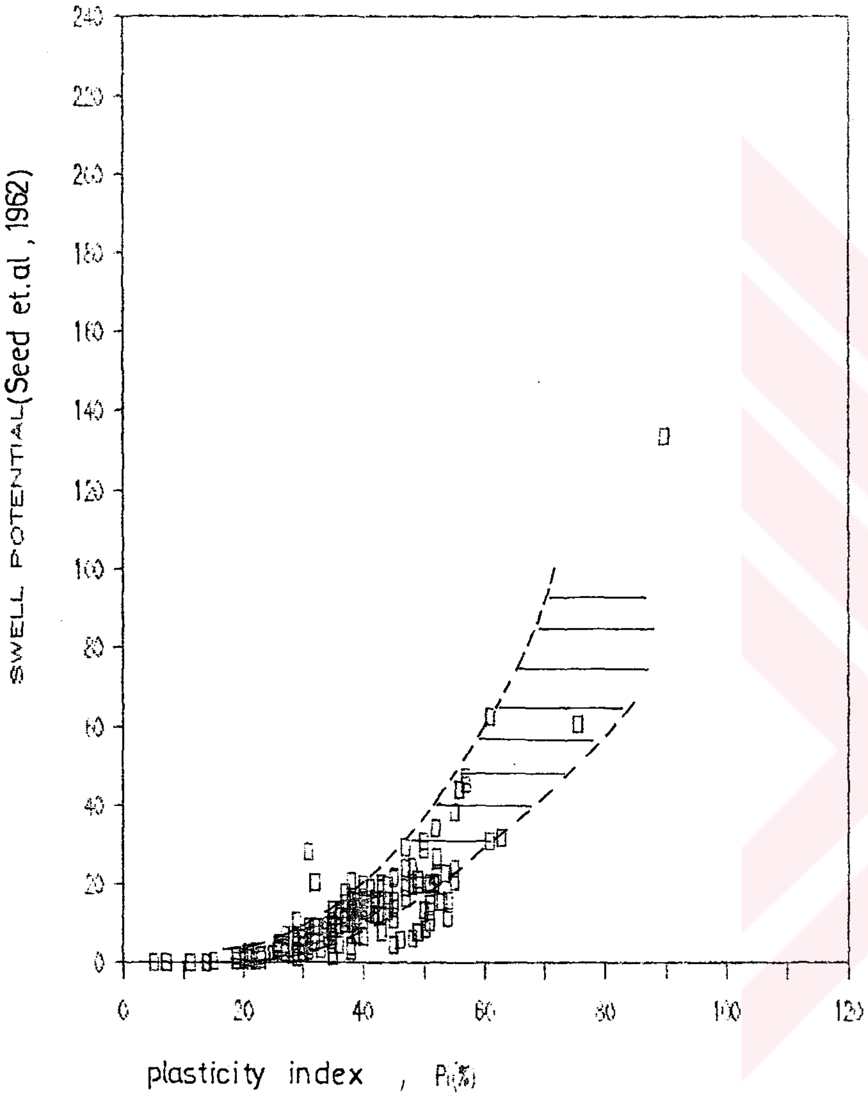


Fig.8.13.Swell Potential vs PI Relationship (Terrace Deposits)

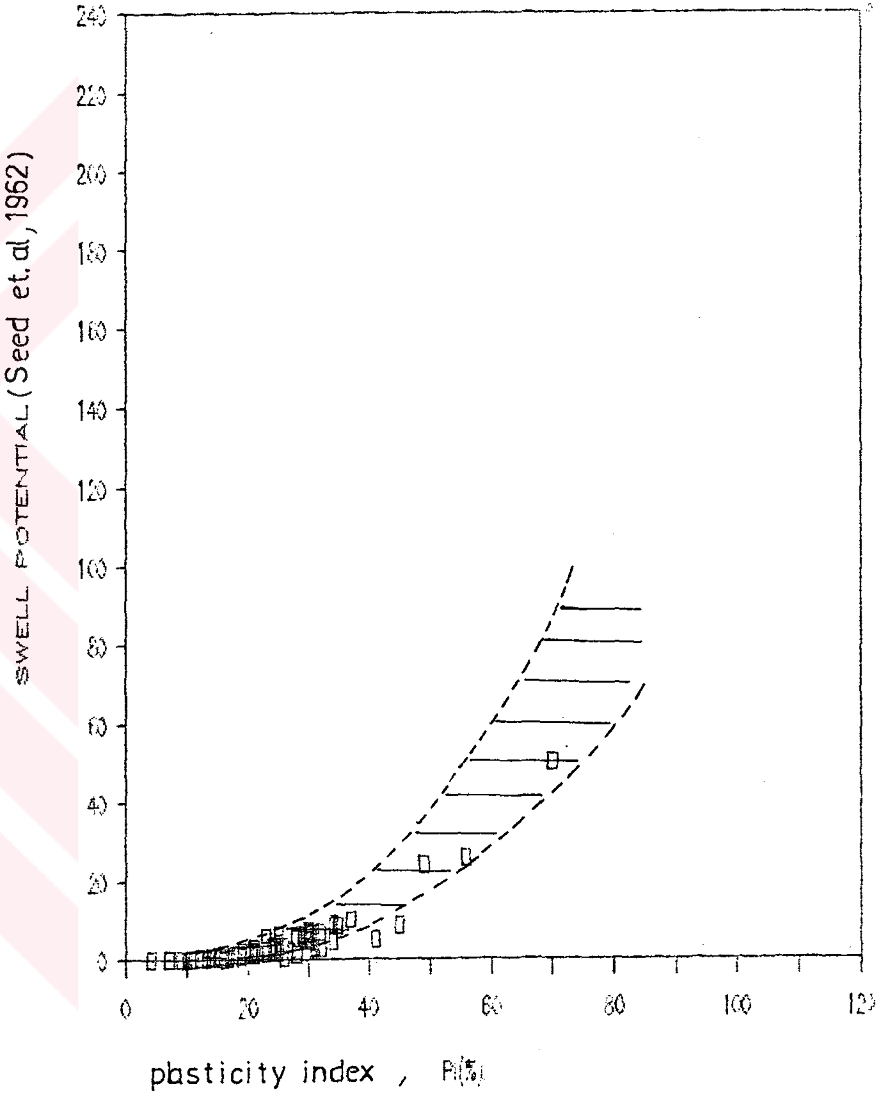


Fig.8.12. Swell Potential vs PI Relationship (Alluvial Soils)

In Appendix K , swelling potential classification of soil samples from Alluvial soils and Terrace Deposits were made by using different swelling potential classification methods (i.e. Seed et. al, 1962; Van der Merve, 1964; Snethen and Johnson, 1971; Dakshanamurty and Raman, 1973). From this table, it can be seen that , for the same soil sample, different swelling potential classification methods may give different swelling potential values.

In Figs.8.14.a and 8.14.b range of change of dry densities with depth for alluvial (up to 9 m depth) and terrace deposits (up to 15 m depth) are shown respectively .

In Figs. 8.15 and 8.16 typical dry densities of soil samples from alluvial soils and Ankara clay (obtained at various seasons through years) have been plotted against their water contents. Samples have been obtained from various depths. Correlation coefficients (r) of these relationships are 0.78 and 0.86 for Terrace Deposits and Alluvial Soils respectively.

From the water content versus dry density relationship an empirical equation for terrace deposits (i.e. Ankara clay) was obtained ($W_n = 79.5 - 34.67\ \rho_d$).By using this relationship and by making some assumptions a linear strain equation (i.e. estimated % heave) as a function of initial and final water contents was reached (Appendix L). This equation (i.e. linear strain

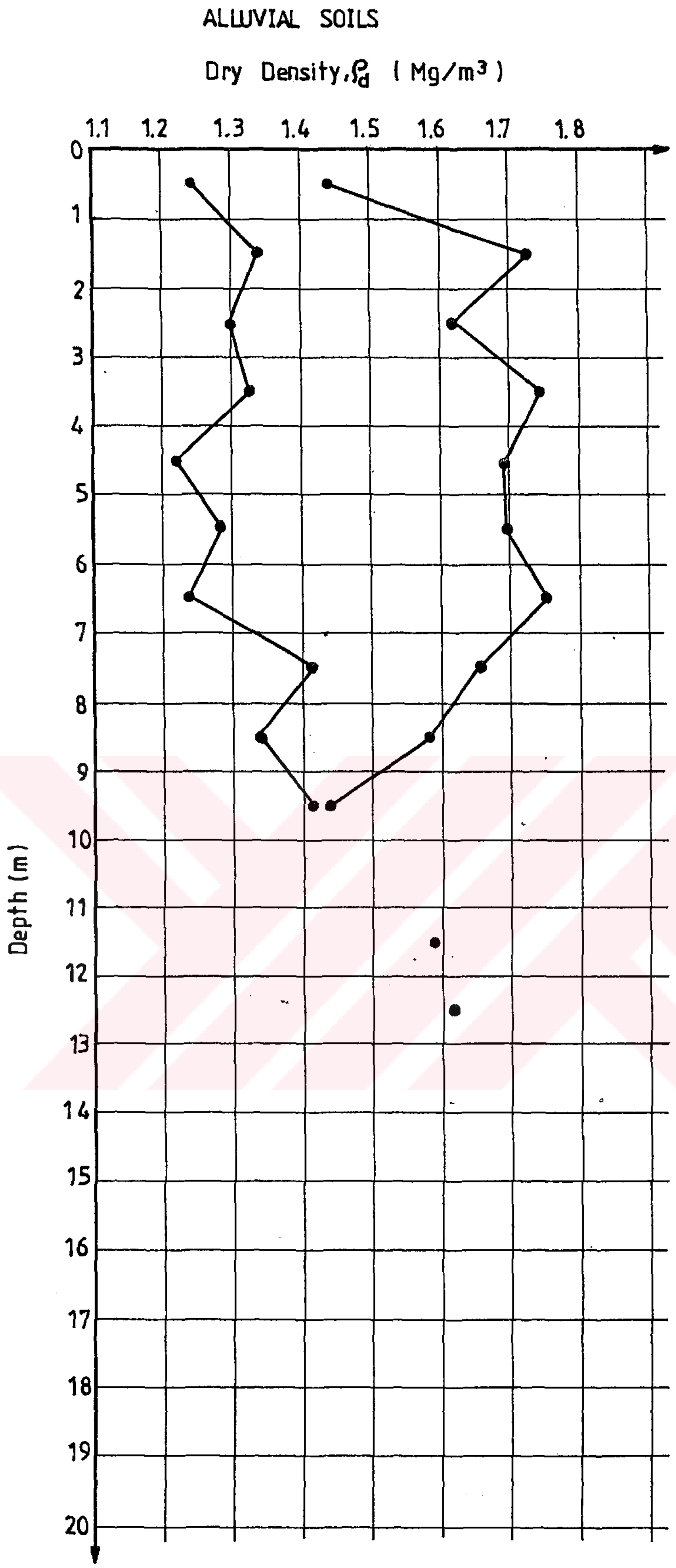


Fig. 8.14.a. Depth vs Dry Density Relationship
(Alluvial Soils)

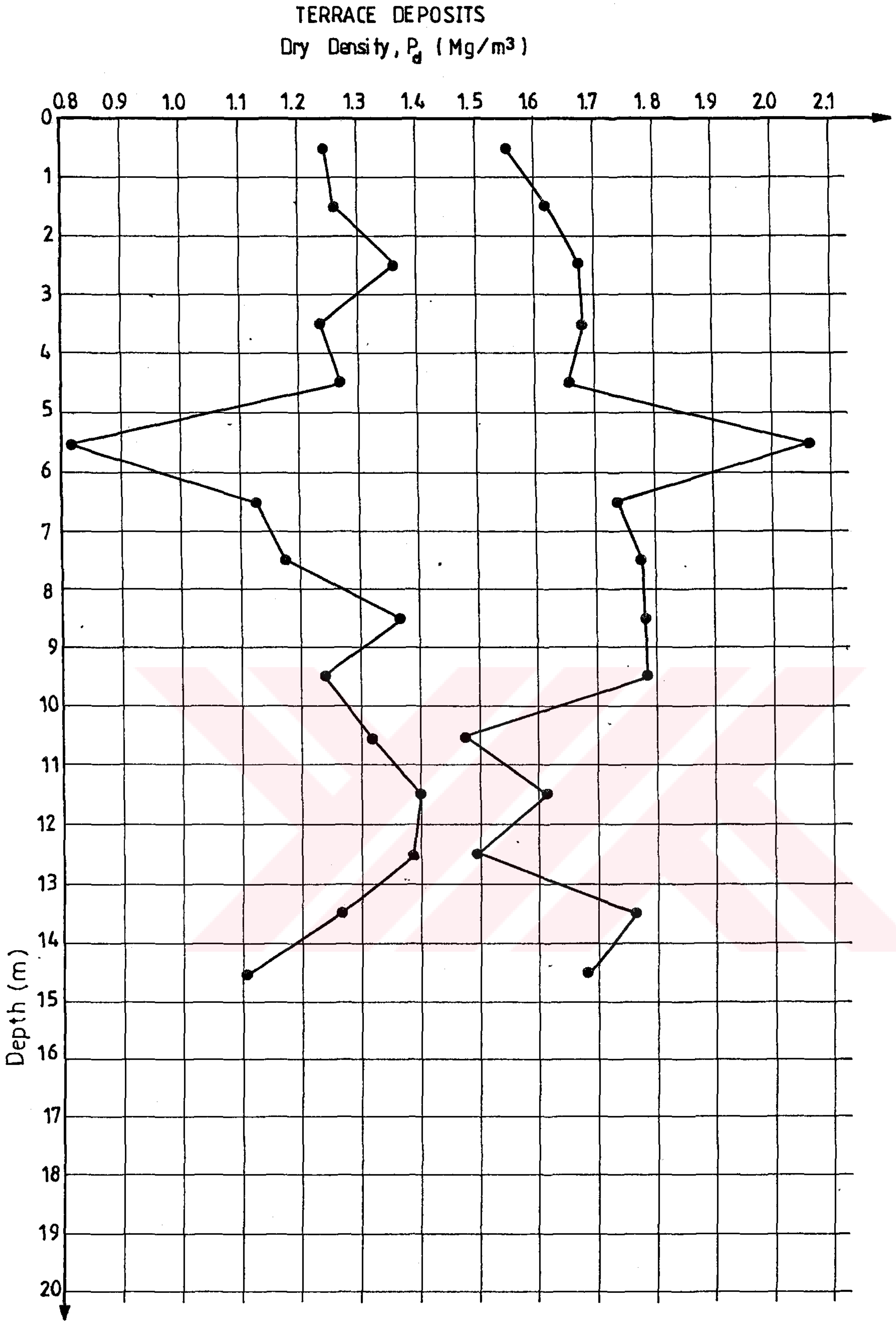


Fig. 8.14. b. Depth vs Dry Density Relationship (Terrace Deposits)

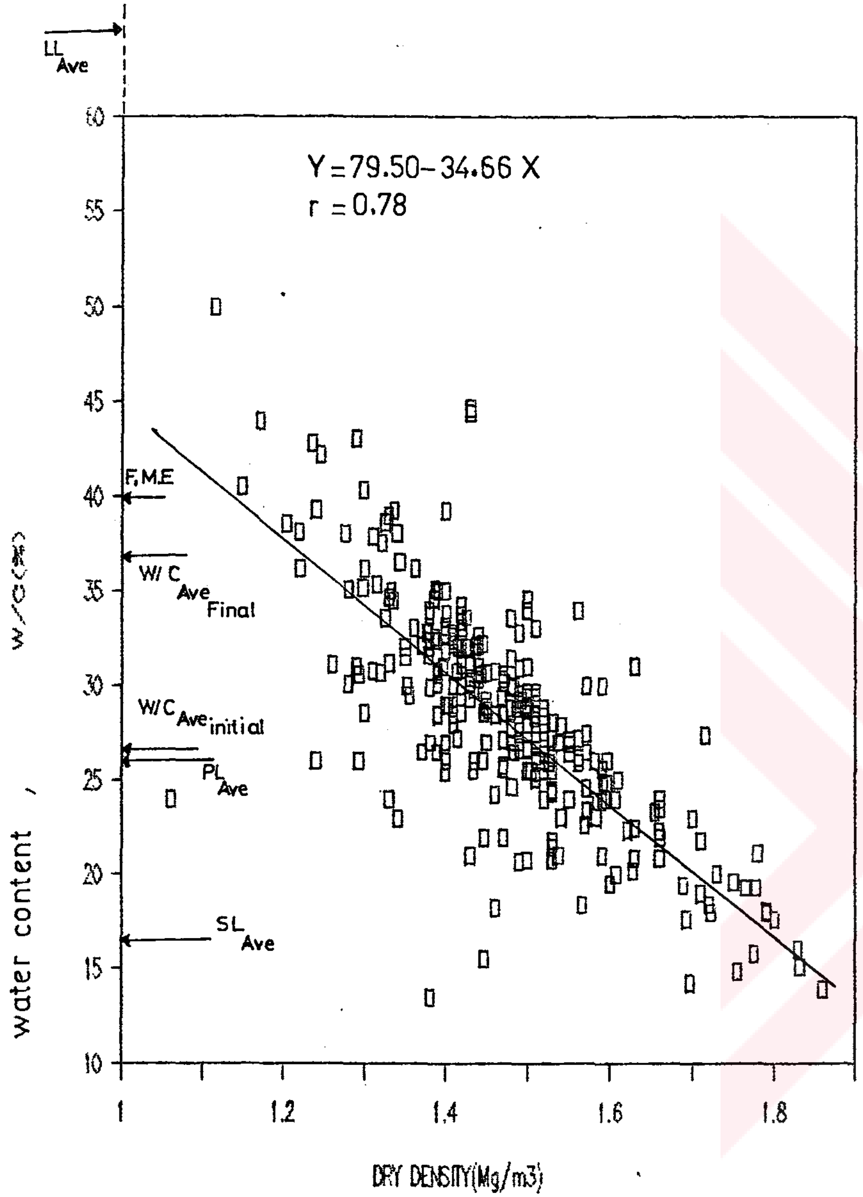


Fig.8.16. Wn vs Dry Density Relationship (Terrace Deposits)

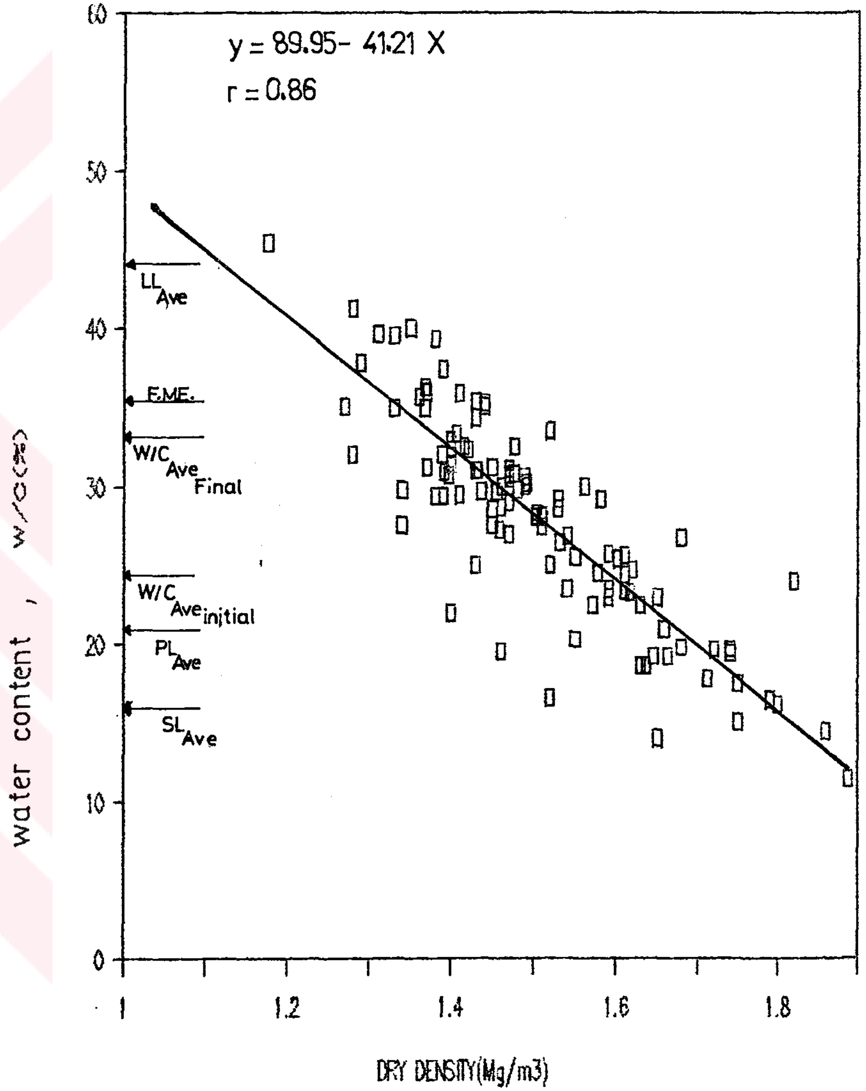


Fig.8.15. W_n vs Dry Density Relationship (Alluvial Soils)

equation) was checked by using the field measurements (i.e. measured % heave) performed by Omay (1970) at two stations in the METU campus area (on terrace deposits).

In Fig.8.17 measured % heave values were plotted against estimated % heave values for stations A and B. It is seen from Fig.8.17 that for station A, estimated % heave values are approximately 2 times higher than the measured % heave values; for station B estimated and measured % heave values are close to each other. The differences between the estimated and measured % heave values may be due to the assumptions made during the derivation of linear strain equation and due to the errors made during the field measurements.

In Fig. 8.18, for Ankara clay, average water content values for each depth were plotted against the maximum linear strain (i.e. estimated maximum % heave) determined by using the minimum and maximum water contents for that depth. On the same figure, estimated maximum % heave values belonging to Station A and B were also plotted. Since the maximum water content changes corresponding to depths (0 m-1 m) and (1 m- 2 m) are much greater than the field water content changes at station A and B , the estimated % heave values at stations A and B are much smaller than the estimated maximum % heave values at these depths.

It seems that the estimated % heave values are compatible with the measured % heave values for Ankara

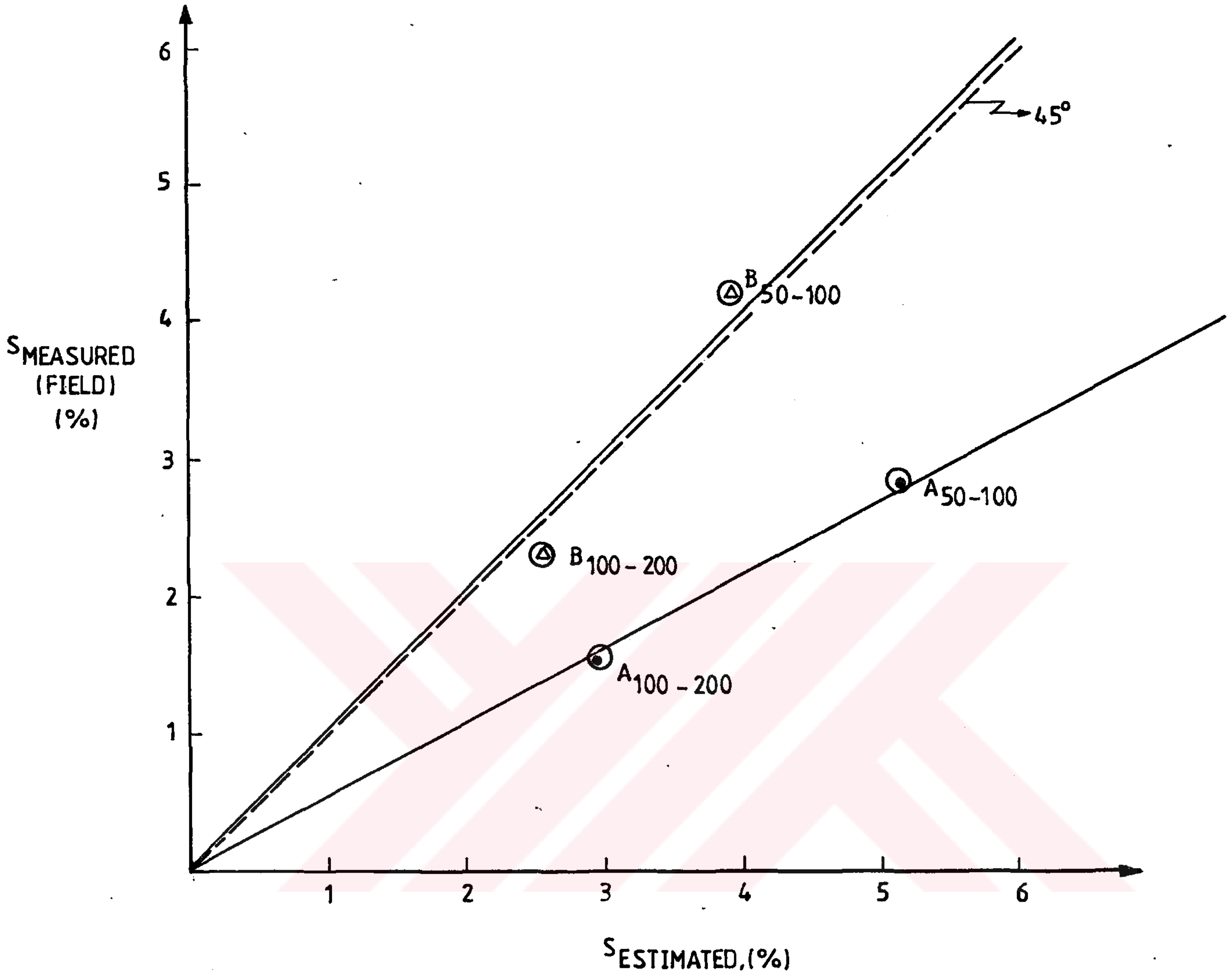


Fig. 8.17. Plot of Measured % Heave Against Estimated % Heave for Stations A and B

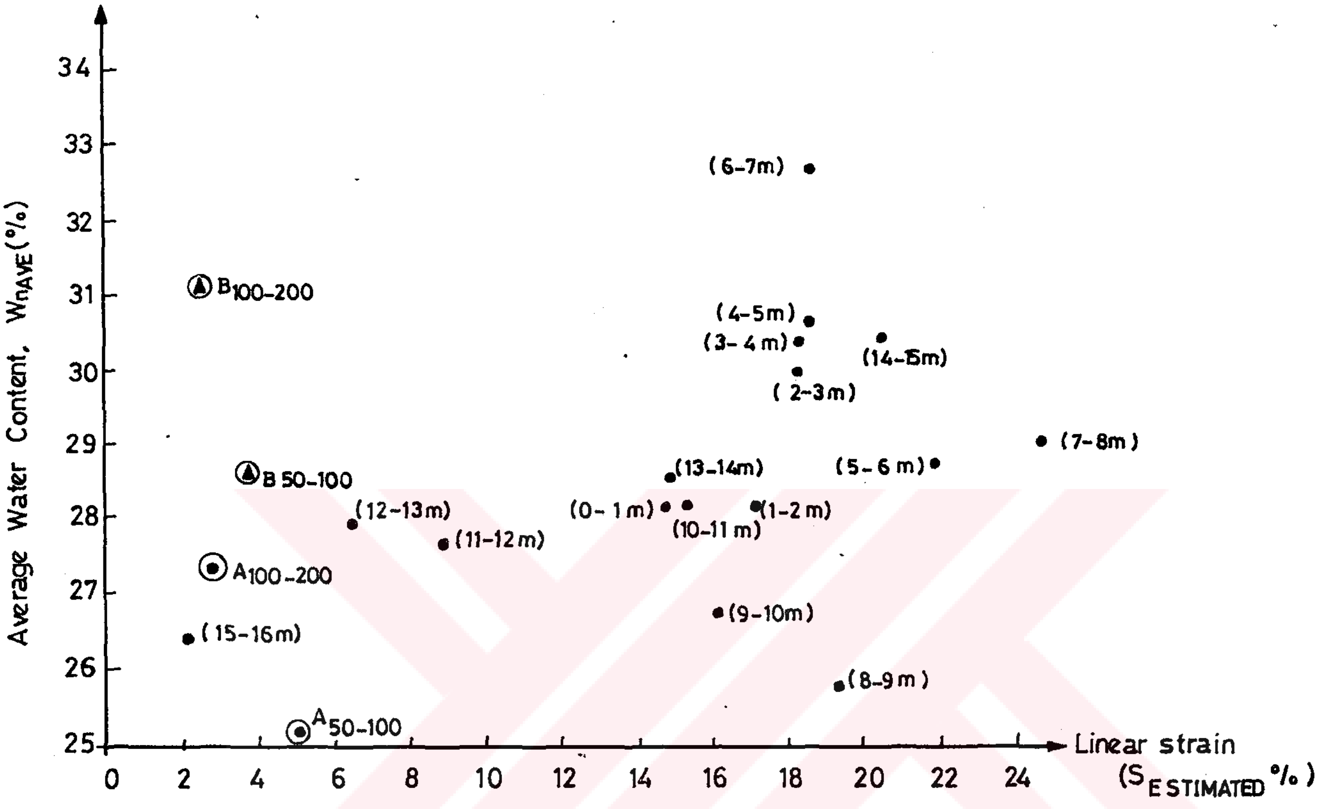


Fig. 8.18. Average Water Content vs Maximum Linear Strain Relationship

clay, but to be able to reach a more precise conclusion many more field heave measurements are needed.

* Swelling Potential (%)=S=$(3.6*10^{-5})*(A^{2.44})*(CC^{3.44})$ [21]

Potential Swell (%)	Degree of Expansion
0-1.5	Low
1.5-5.0	Medium
5.0-25.0	High
>25	Very High

** For each depth interval, arithmetic mean and standard deviation of the data were calculated. Then, limits within which 90 % of the values would be within were calculated by using :

$$\text{Limits}_{\substack{\text{max}\\\text{min}}} = (\text{arithmetic mean}) \pm 1.645*(\text{standard deviation}) \quad [22]$$

From normal distribution chart (Gürpınar, 1979)

$(0.10/2)=0.05 \longrightarrow N(z)=0.95 \longrightarrow z=1.645$

8.5.2. Evaluation of Test Data on Methylene Blue Test

In this part, the relationship between methylene blue value and swelling potential of soil samples was investigated by using Data Set III (see Appendix M). The above relationship was tried to be established by making use of the following statement and assumption:

a) Furtun, (1989) states that the effect of presence of expansive clay minerals and their percentages are reflected in the consistency limits which correlate well with the swelling parameters .

b) Methylene blue test result--→ Mineralogy --→ --→ Specific surface area --→ Swelling potential relationships were assumed.

For Lautrin (1987)'s data, the specific surface area values which were determined from methylene blue values are plotted against the ranges of specific surface area values of pure minerals given by Chen (1975) in Appendix N , it seems that specific surface area values of the samples, determined from methylene blue test results, generally fall into the expected ranges (i.e. this indicates the validity of the methylene blue test result ----→mineralogy --→ specific surface area relationship).

Under the light of above statement (a) and asssumption (b) , the relationships between methylene blue test results and Atterberg limits (i.e.LL, PL, PI), clay content, activity, hazard coefficient (N) were investigated (Figs.8.19, 8.20, 8.21, 8.22, 8.23, 8.24). The correlation coefficients (r) of these relationships are 0.65, 0.60, 0.65, 0.56, 0.27 and 0.82 respectively. Then the relationships between specific surface area values (which were determined from methylene blue values) and Atterberg limits, clay contents were investigated (Figs. 8.25, 8.26, 8.27, 8.28).

Locat et. al (1984) studied the soils from nine sites in Eastern Canada. They determined the correlation coefficients (r) of the relationships between specific surface area values (determined from the result of methylene blue test) and clay content, liquid limit, plastic limit, plasticity index . The correlation coefficients (r) of these relationships are 0.69, 0.89, 0.63 and 0.92 respectively. For Lautrin's (1987) and Magnan and Youssefian's (1989) data these values are 0.56, 0.65, 0.61 and 0.65 respectively.

For Lautrin's (1987) and Magnan and Youssefian's (1989) data, swelling potential (Seed et.al, 1962) versus activity relationship is given in Fig. 8.29 , the correlation coefficient of this relationship seems to be low (r=0.54).

Since the correlation coefficients (r) of the previous relationships in this section are not generally too high, finally, the swelling potential values of the soil samples in Data set III were found according to Seed et. al,(1962)** (different signs were

** see page 186

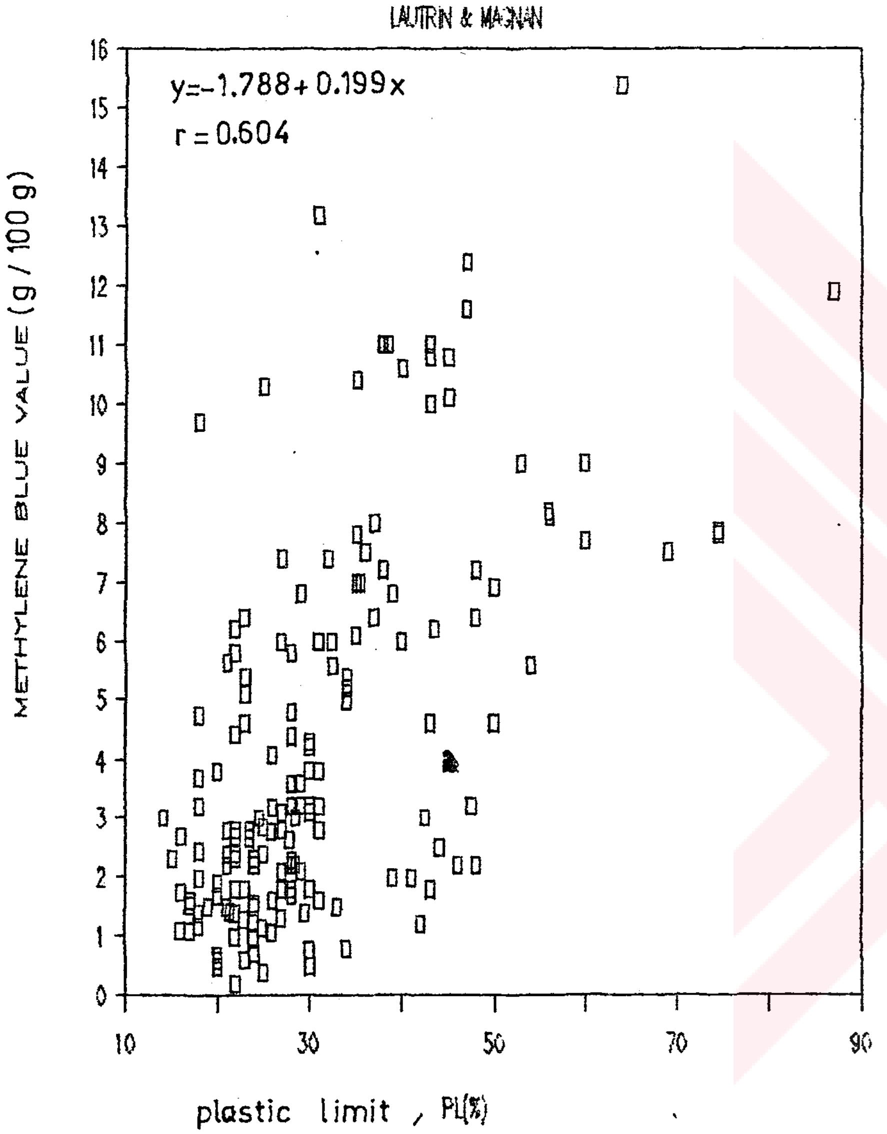


Fig.8.20. MBV vs PL Relationship

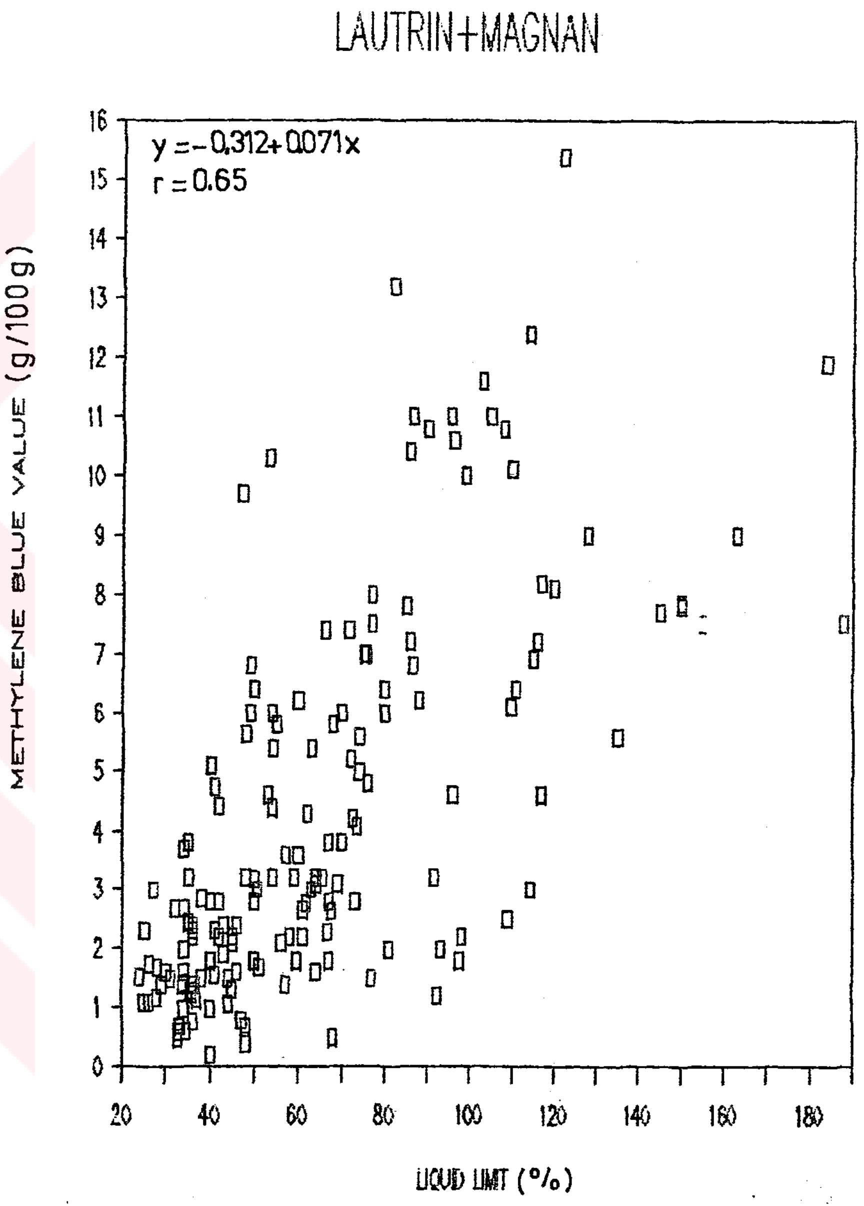


Fig.8.19. MBV vs.LL Relationship

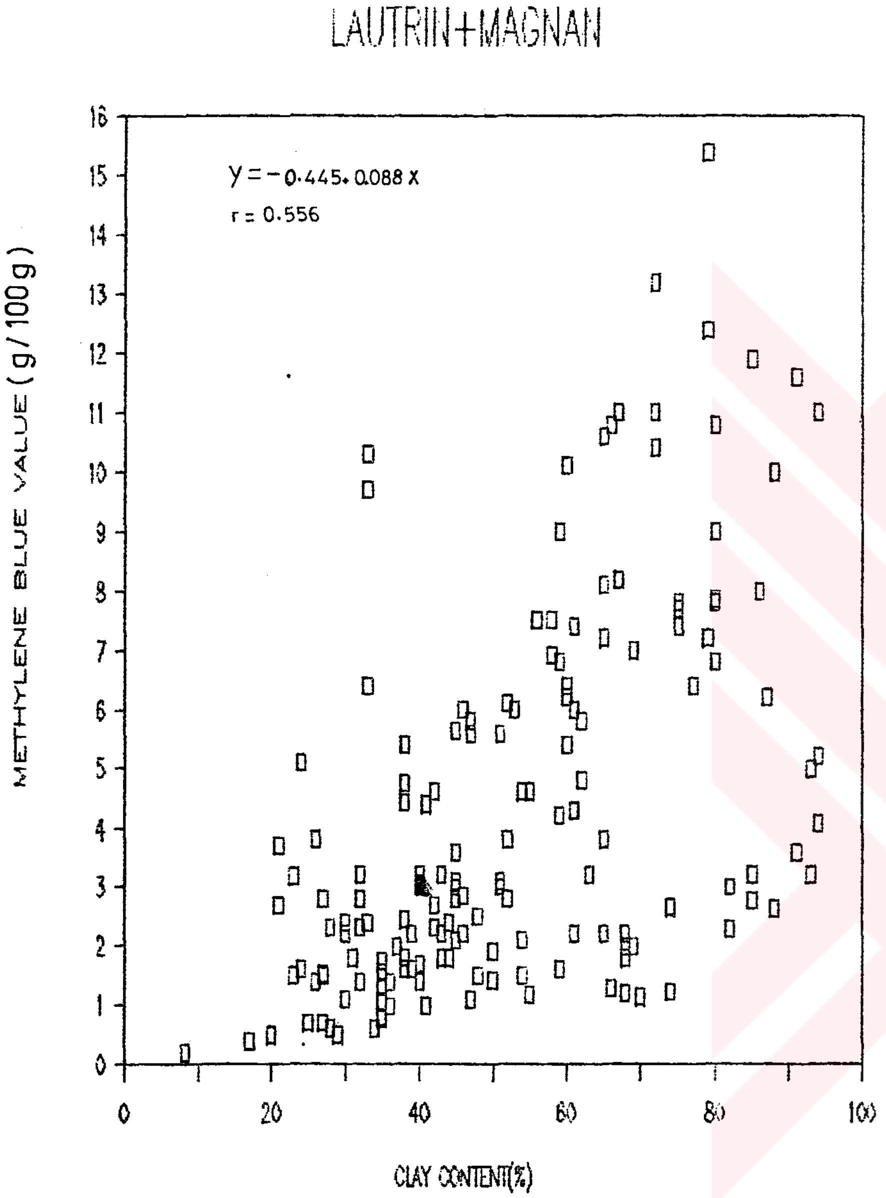


Fig.8.22. MBV ve CC Relationship

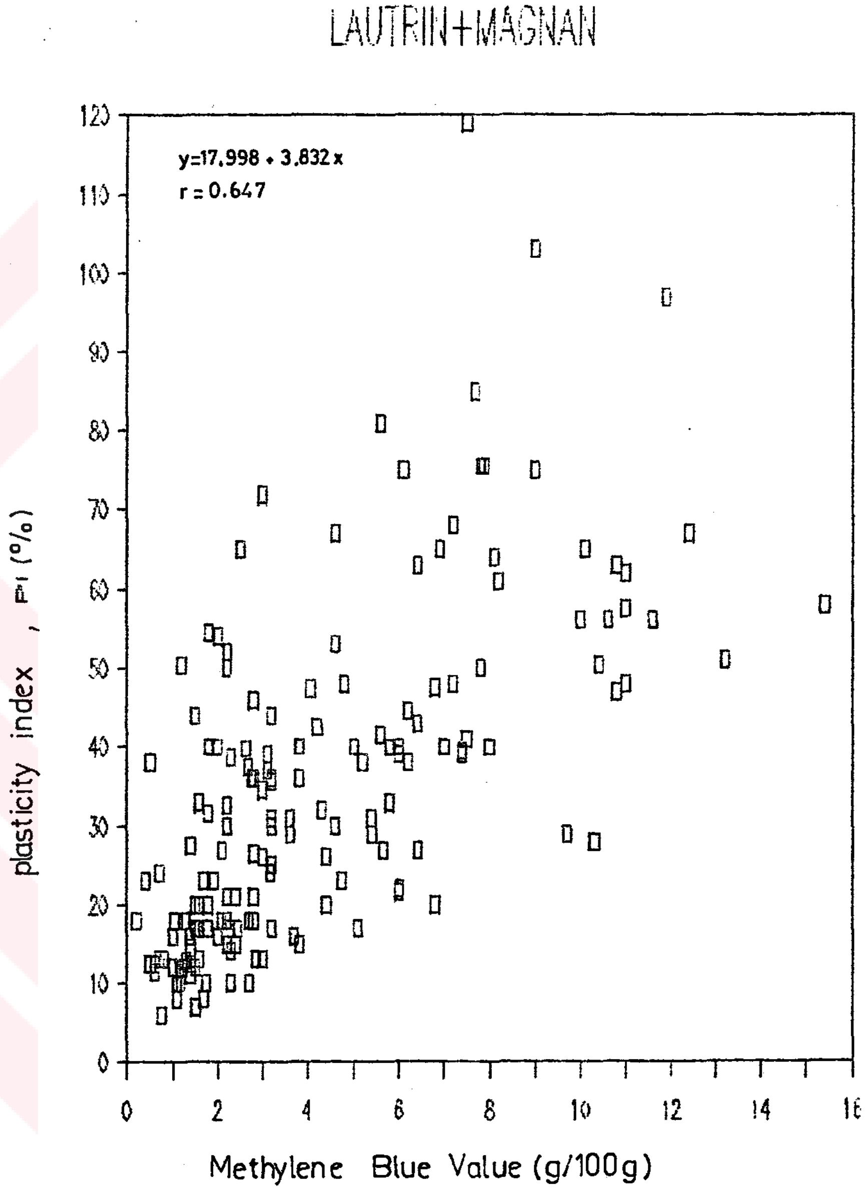


Fig. 8.21. PI vs MBV Relationship

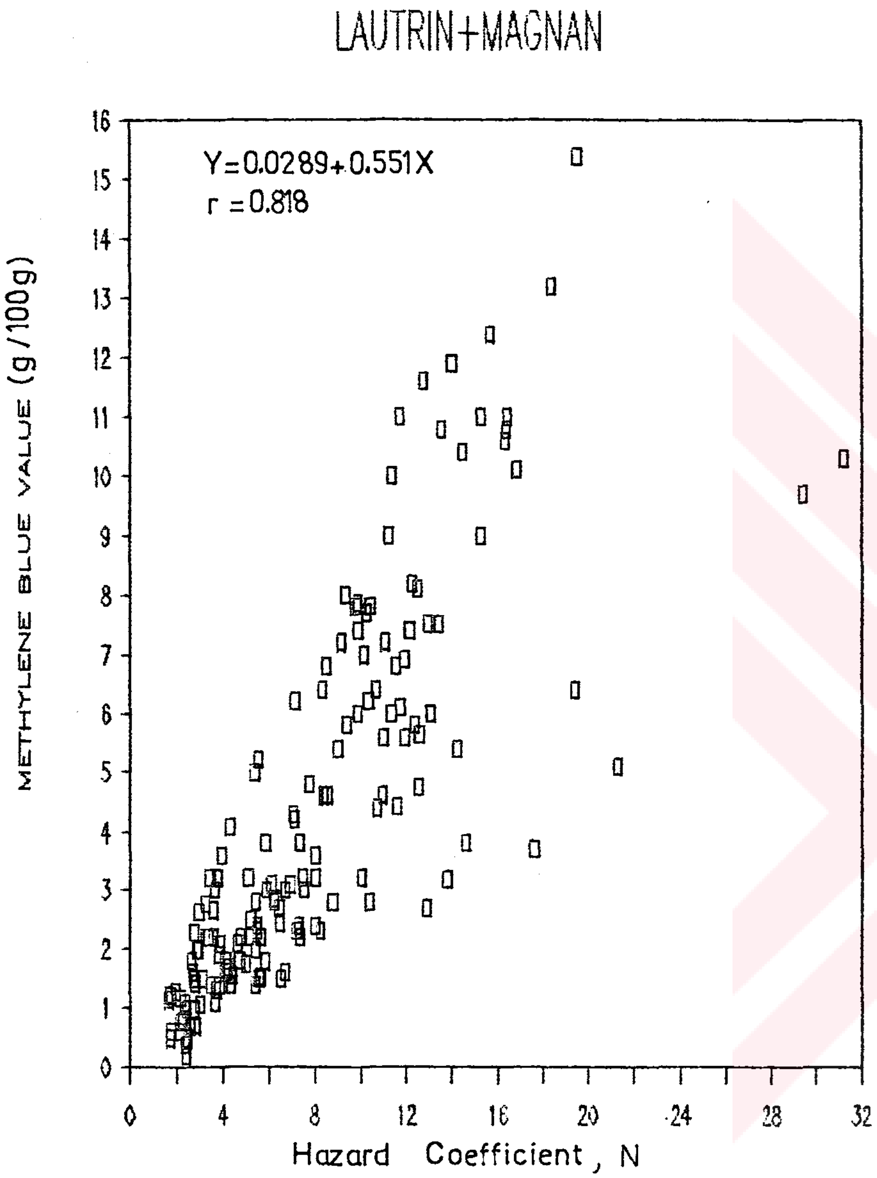


Fig.8.24. MBV vs Hazard Coefficient Relationship

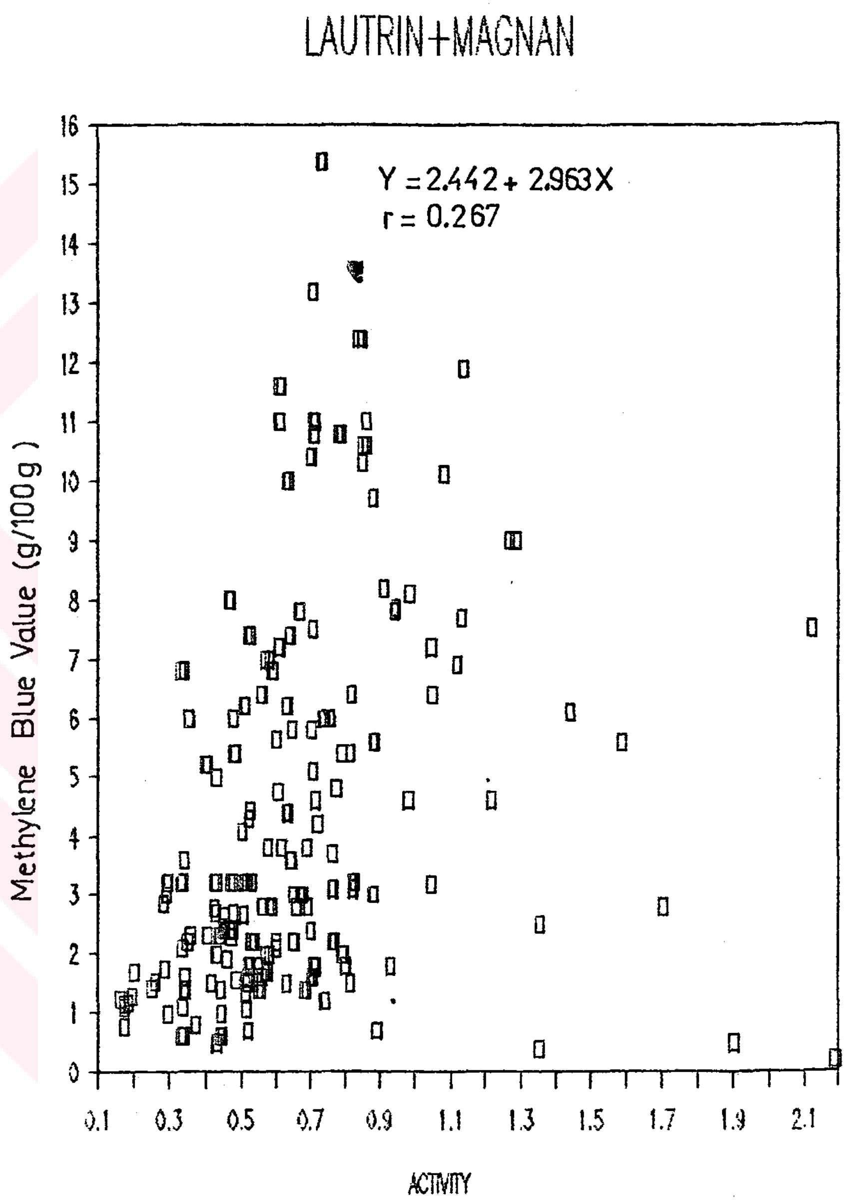


Fig.8.23. MBV vs Ac Relationship

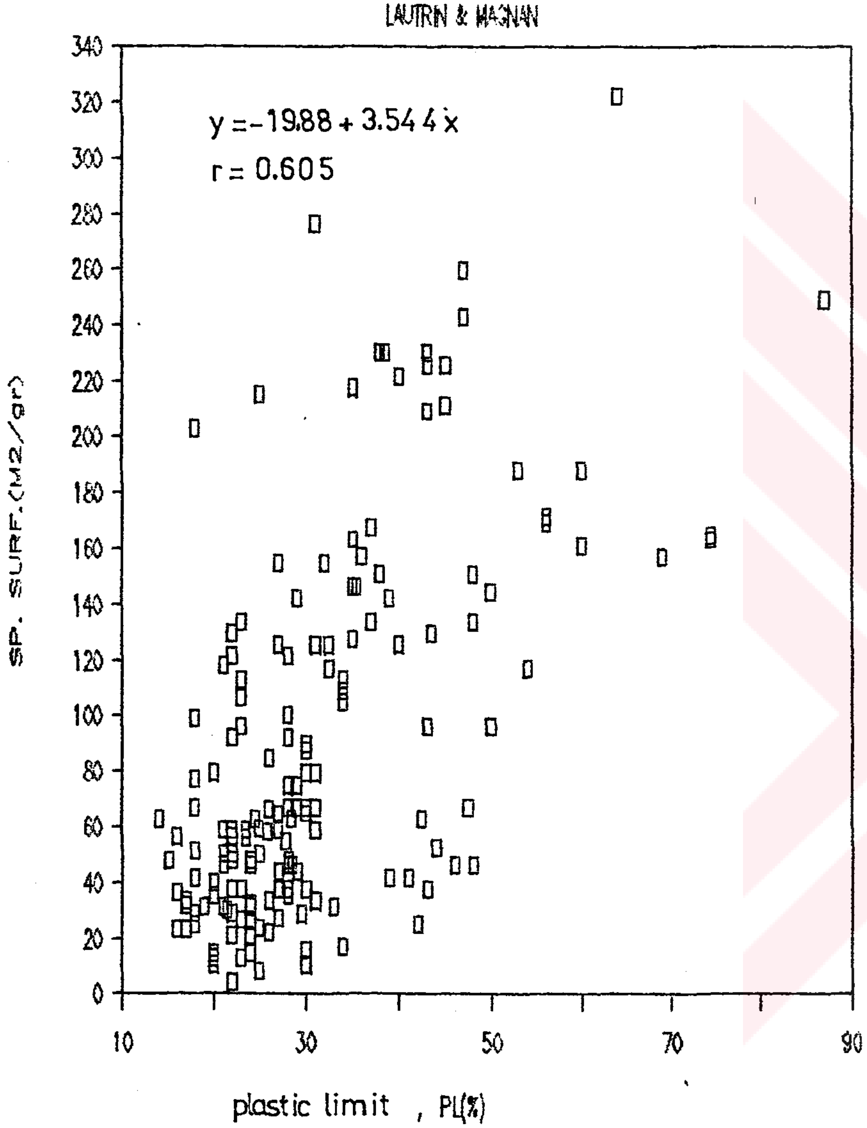


Fig.8.26. SSA vs PL Relationship

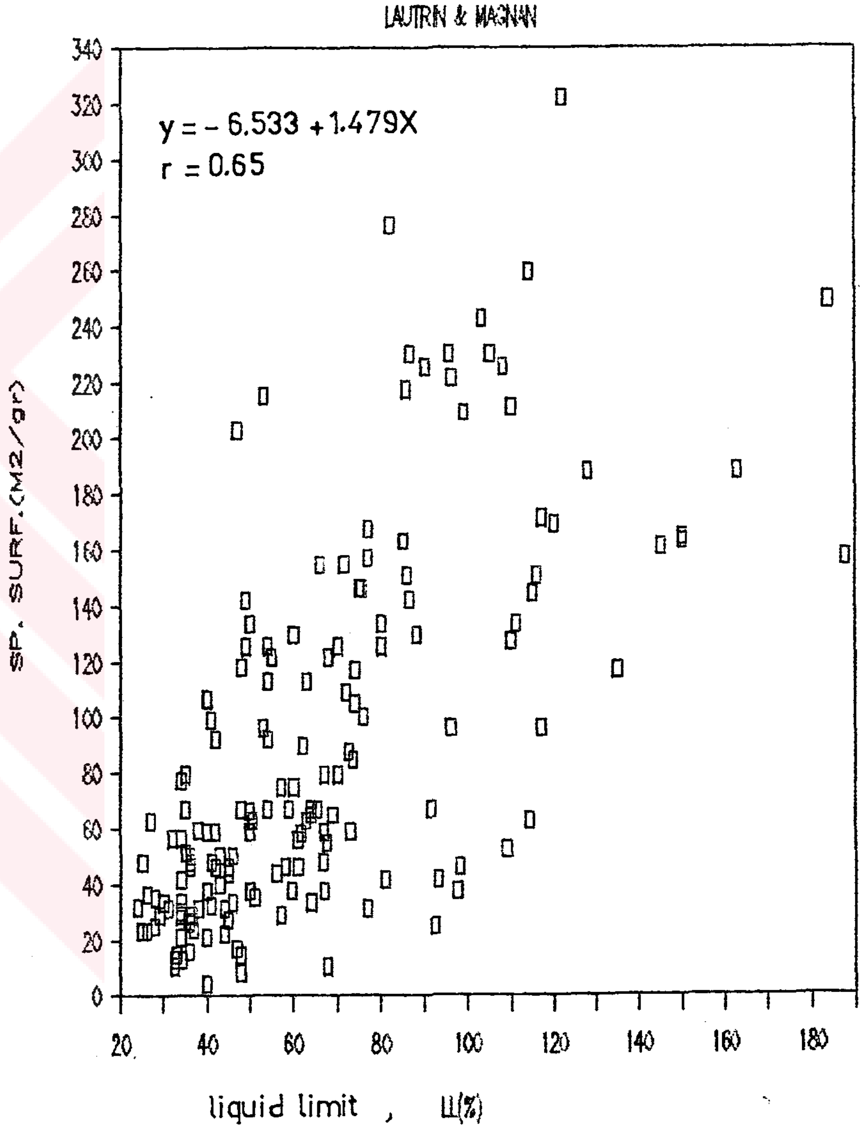


Fig.8.25. SSA vs LL Relationship

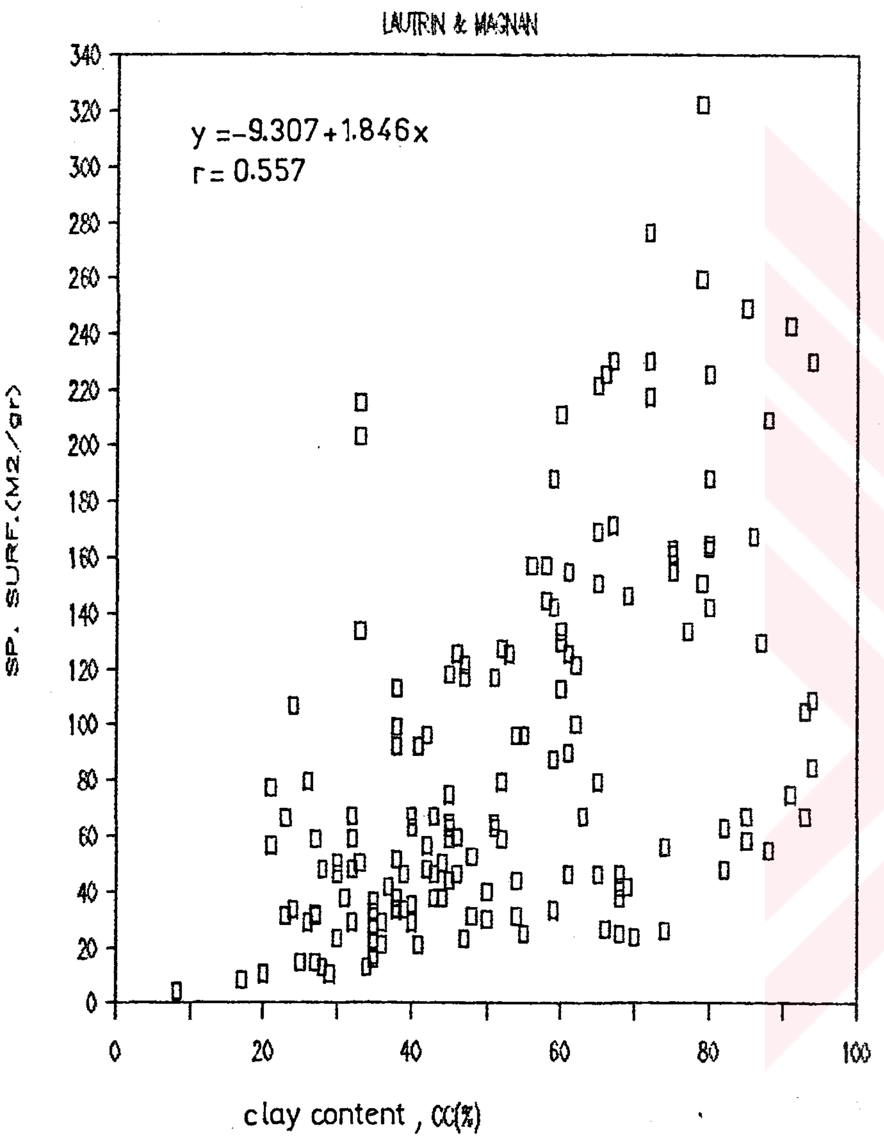


Fig.8.28. SSA ve CC Relationship

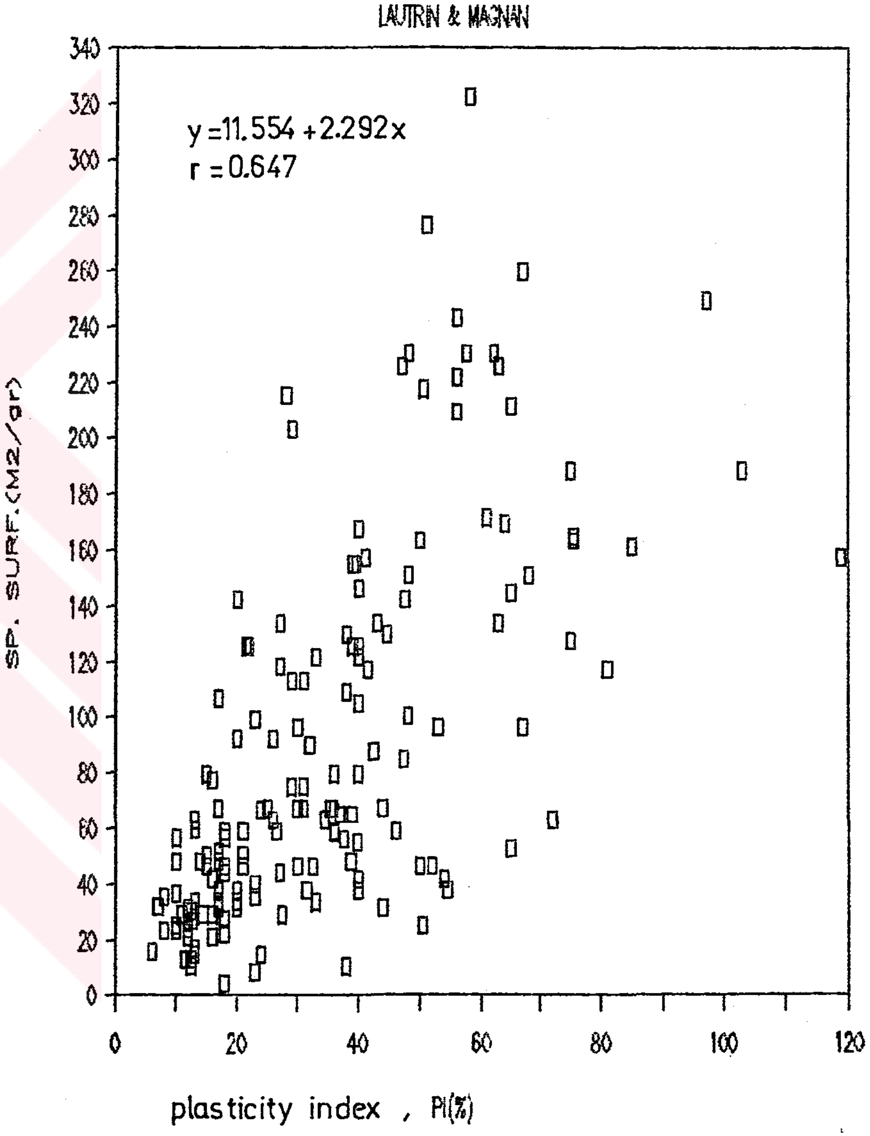


Fig.8.27 SSA ve PI Relationship

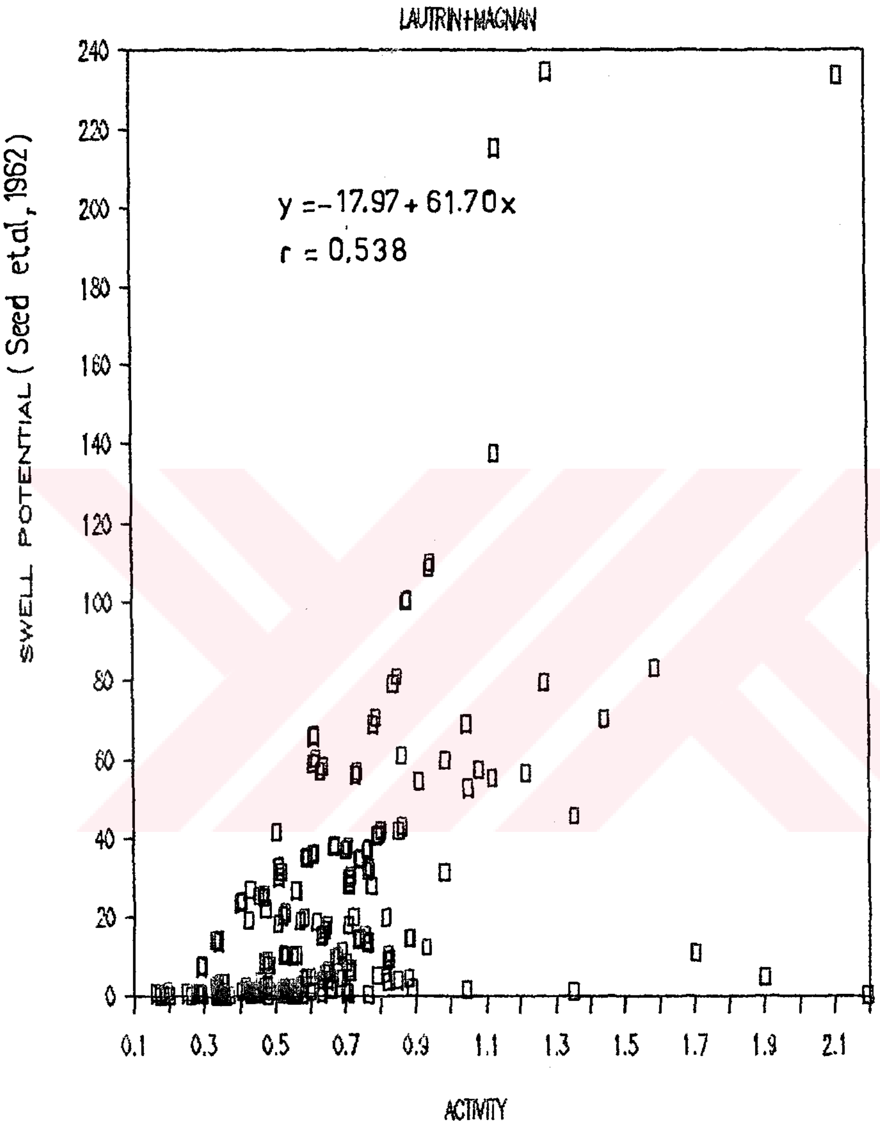


Fig.8.29. Swell Potential (Seed) vs A_c Relationship

used for different swelling potential ranges, see Table 8.1, p.185) and these data were plotted on the soil classification chart which was given by Magnan and Youssefian (1989) (Fig. 8.30). The regions Ata, Ama, Apa, Lta, Lma, Lpa were separated by Magnan and Youssefian (1984) as shown on the Fig. 8.30.

In Fig. 8.30 , very high swell potential** points are mostly in Ata* zone and a few are in Ama zone. High swell potential points are mostly in Ama zone and a few are in Ata zone (near the border between Ama and Ata zones) Lma zone (near the border between Ama and Lma zones) and Lta zone (near the border between Ata and Lta). Medium swell potential points are mostly in Lma, Lta zones and a few are in Ata, Ama zones. Low swell potential points are in Apa zone and in the middle portions of the Lta, Lma , Lpa zones.

The distribution of points given by foreign researchers in Magnan and Youssefian's (1989) chart according to their swelling potential (Seed et al, 1962) values is shown in Table 8.1.

As it can be seen from this chart, soils which show different swelling potential values ,generally fall into different regions on this chart. This shows the possibility of using this chart as a swelling potential classification of soils (i.e. this indicates the validity of methylene blue value --→ clay content --→ --→ swell potential relationship).

* See page 186

** See page 186

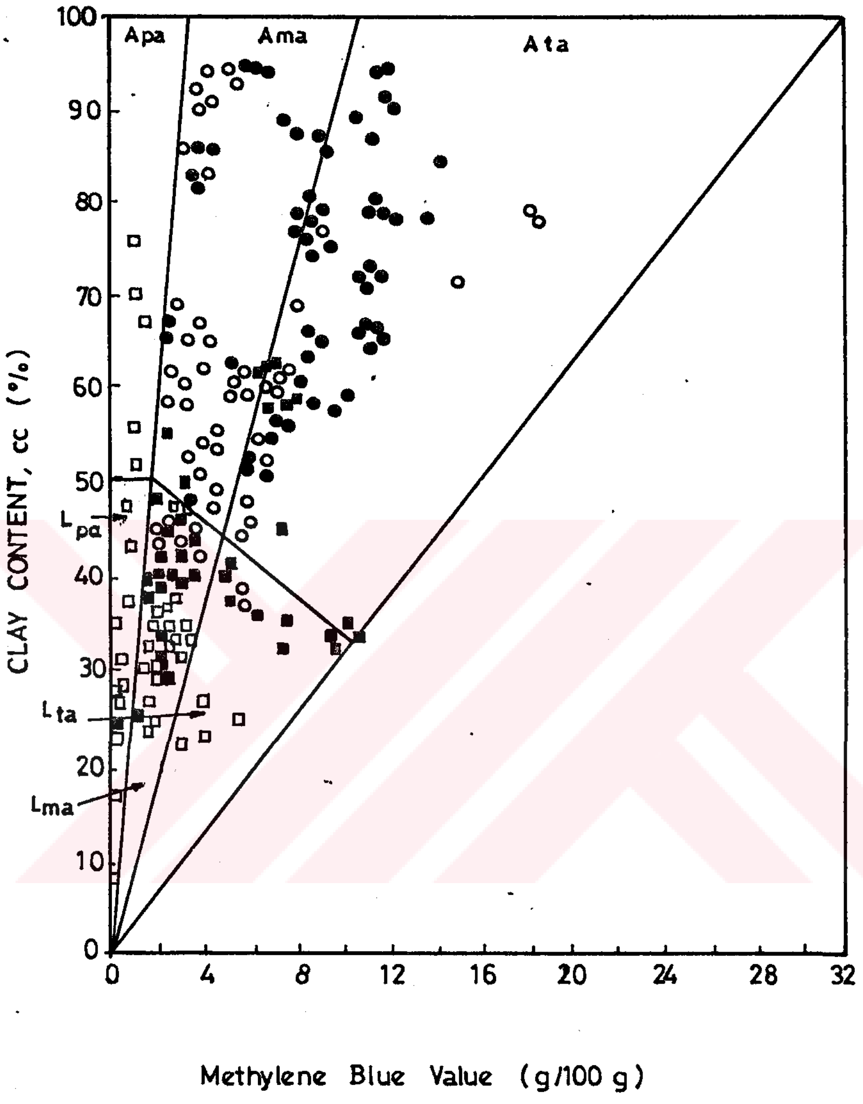


Fig. 8.30. CC vs MBV Chart**

Note : Data have been taken from Lautrin (1987), Magnan and Youssefian (1989)

Table 8.1. Distribution of Points Given by Foreign Researchers in Magnan and Youssefian (1989)'s Chart According to Their Swelling POtential (Seed et.al,1962) Values

Zone in Magnan & Youssefian (1989) Chart	Distribution of Points (%)			
	Very High Swell Potential	High Swell Potential	Medium Swell Potential	Low Swell Poten.
Ata	74	15	11	-
Ama	34	60	6	-
Apa	-	-	-	100
Lta	-	13	63	25
Lma	-	11	29	60
Lpa	-	-	6	94

*

Ata= clay with high activity

Ama= clay with moderate activity

Apa= clay with low activity

Lta= silt with high activity

Lma= silt with moderate activity

Lpa= silt with low activity

**

● very high swell potential

○ high swell potential

■ medium swell potential

□ low swell potential

8.5.3. Test Results on Commercially Pure Samples

Lan (1980) and Tourenq and Lan (1989) stated that the quantity of methylene blue adsorbed by the mixture of clay minerals is equal to the summation of the methylene blue adsorbed by each mineral separately (i.e. methylene blue test verifies the additivity law). An attempt to check this behaviour was made by using pure samples (i.e. by using 100 % pure kaolinite, 100 % pure illite, 100 % pure montmorillonite). Unfortunately 100 % pure samples could not be obtained. Commercially pure kaolinite (Bolu), illite (Uşak) and Na-montmorillonite were obtained from Söğüt Ceramic Factory, Çanakkale Ceramic Factory and MTA respectively (Data Set V) .

Index, clay content, soil classification, swell classification, swell index, methylene blue and X- ray test results of commercially pure samples are shown in Table 8.2. X-ray tests of the commercially pure samples were performed in the Geological Engineering Department of Hacettepe University and Cement Producers Association Laboratory.

Small amounts (approximately 5 grams) of kaolinite and Ca- montmorillonite samples were obtained from the Geological Engineering Department of METU. Since the amounts of samples are very small only methylene blue tests were performed on these samples. Test results are shown in Table 8.2.It can be noticed that MBV of Ca-

Table.8.2.Commercially Pure Samples

Name	Obtained From	% Clay	Gs	LL (%)	PL (%)	PI (%)	Class.	Ac Activity	Swell Seed et. al, 1962	Van Der Merve	PVC Rate	PVC Catg.	Swell Index KN/m^2	MBV g/100g	γ dry $\frac{KN}{m3}$	Swell Pot. Seed et. al,1962	Spec. Surf. Area (m2/g)	SI / CC
Kaolinite (Bolu)	Sögüt Ceramic Factory	20	2.616	39	23	16	CL	0.8	Low	Medium	0.1	Non-critic.	10.24	0.93	13.4	0.624	19.46	.512
Illite (Uşak)	Çanakkale Ceramic Factory	17	2.639	34	16	18	CL	1.059	Low	Medium	0.75	Non-critic.	30.71	2.67	16.04	0.708	55.88	1.81
Na-Mont.	MTA	100	2.08	466	38	428	CH	4.28	V.High	V.High	6.2	V.Crit.	214.9	33.0	10.2	9485	690.7	2.14
Mixture [(33.33 % kaolinite + +33.33 % illite + +33.33 Na-montmorillonite)]		40	2.345	212	16	196	CH	4.9	V.High	V.High	4.2	Critic.	148.4	12.34	13.34	564.2	258.3	3.71
Kaolinite	METU Geological Eng. Dept. (obtained in small amounts ,i.e. 3-5 grams)													1.33			27.84	
Ca-Mont.	METU Geological Eng. Dept. (obtained in small amounts ,i.e. 3-5 grams)													19			397.68	

montmorillonite is smaller than the MBV of NA-montmorillonite. This is due to inadequate expansion of layers of Ca- montmorillonite (this can be explained by the valence of exchangeable ions. The thickness of the double layer water decreases with the increasing value of ion valence due to the fact that the higher the ion valence, the less number of ions will be sufficient for neutralization, and the double layer thickness will be small). Methylene blue test results and X-ray test (for the determination of mineralogical composition) results seems to be compatible with each other.

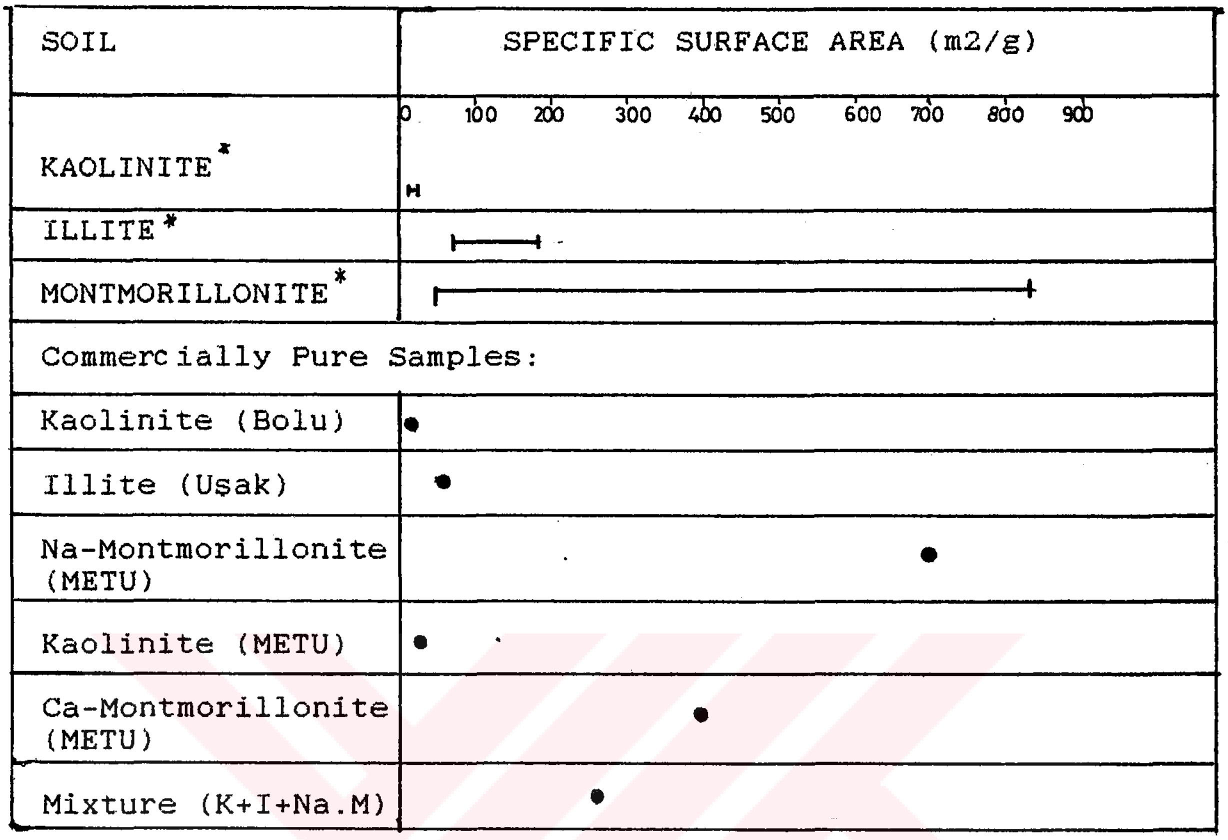
To verify the statement given by Lan (1980) and Tourenq and Lan (1989) the quantity of methylene blue adsorbed by 7.5 grams of these commercially pure samples were determined separately, then the quantity of methylene blue adsorbed by 22.5 grams of the mixture of these commertially pure samples (i.e. 7.5 grams of kaolinite (Bolu) + 7.5 grams of illite (Uşak) + 7.5 grams of Na-montmorillonite) were determined, the results are shown on the Table 8.3 . and confirms the above statement of additivity.

Table 8.3 . Quantity of Methylene Blue Adsorbed by the Specimens

The quantity of methylene blue adsorbed by 7.5 gr.of kaolinite (Bolu)	= 7 cc
The quantity of methylene blue adsorbed by 7.5 gr. of illite (Uşak)	= 20 cc
The quantity of methylene blue adsorbed by 7.5 gr of Na-montmorillonite	= 250 cc
The quantity of methylene blue adsorbed by a mixture of (7.5 gr kaolinite (Bolu) + 7.5 gr illite (Uşak) + 7.5 gr Na-montmorillonite)	= 275 cc

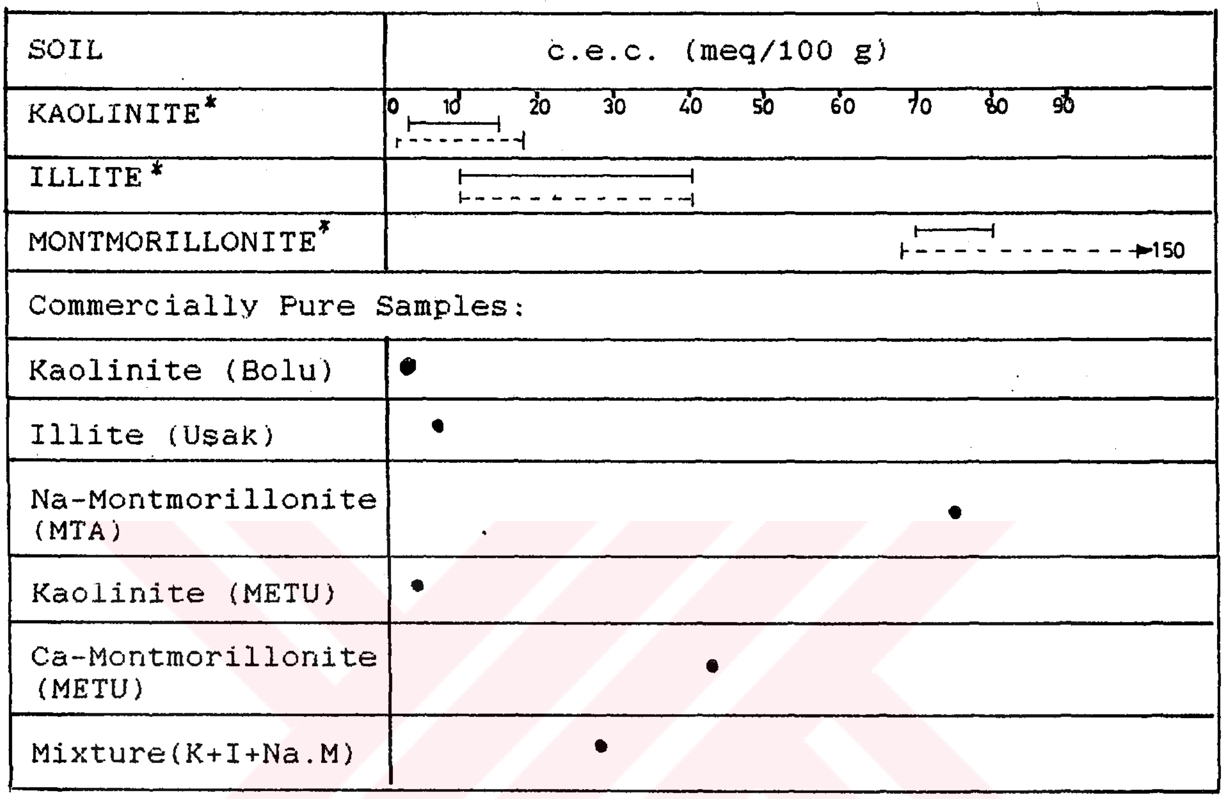
So, it was tried to see the behaviour of each commercially pure sample separately and then as a mixture of these samples (i.e. 33.33 % kaolinite (Bolu)+ +33.33 % illite (Uşak) + 33.33 % Na-montmorillonite).

The specific surface area of each sample (determined by methylene blue test) was compared with the specific surface area value of pure minerals given in the literature. The samples generally fall into the ranges given in the literature (Fig.8.31). Specific surface area value of the illite sample is a little smaller than the minimum value of illite range, this may be due to impurities in the sample. Also, the c.e.c. of each sample determined by methylene blue test (derivation of c.e.c equation is given in Appendix O) was compared with the c.e.c. value of pure minerals given in the literature (Fig.8.32). C.E.C of illite sample falls slightly out of illite range, this may again be due to



* Ref.: Chen, 1975 (After Woodward-Clyde and Associates, 1967)

Fig.8.31. SSA Values of Commercially Pure Minerals



* Ref.: —— Chen, 1975

---- Taylor, 1965

Fig.8.32. C.E.C. Values of Commercially Pure Minerals

impurities in the sample. C.E.C. of Ca- montmorillonite sample is also out of range, this may be due to inadequate expansion of layers of Ca- montmorillonite.

Swell index versus MBV graph is shown in Fig.8.33 for kaolinite (Bolu), illite (Uşak), Na- montmorillonite and Kaolinite-illite-Na.Montmorillonite mixture. With a limited number of data, it seems that the relationship between swell index and methylene blue value is good (r=0.97).

Swell index versus CC relationship is shown in Fig. 8.34.

Swell index/CC versus methylene blue value relationship is shown in Fig.8.35

Methylene blue value versus LL, PL, PI, CC and Activity relationships are shown in Figs.8.36,8.37,8.38, 8.39 and 8.40 respectively.

Specific surface area versus LL, PL, PI and CC relationships are shown in Figs.8.41,8.42,8.43 and 8.44 respectively.

By using the limited number of data, linear regression analysis results of various relationships are given for commercially pure samples. Correlation coefficients (r) of these relationships are generally high (i.e. $0.91<r<0.999$) except Swell Index/ Clay Content versus methylene blue value relationship.

Finally, the swelling potential values of the commercially pure samples were first found according to

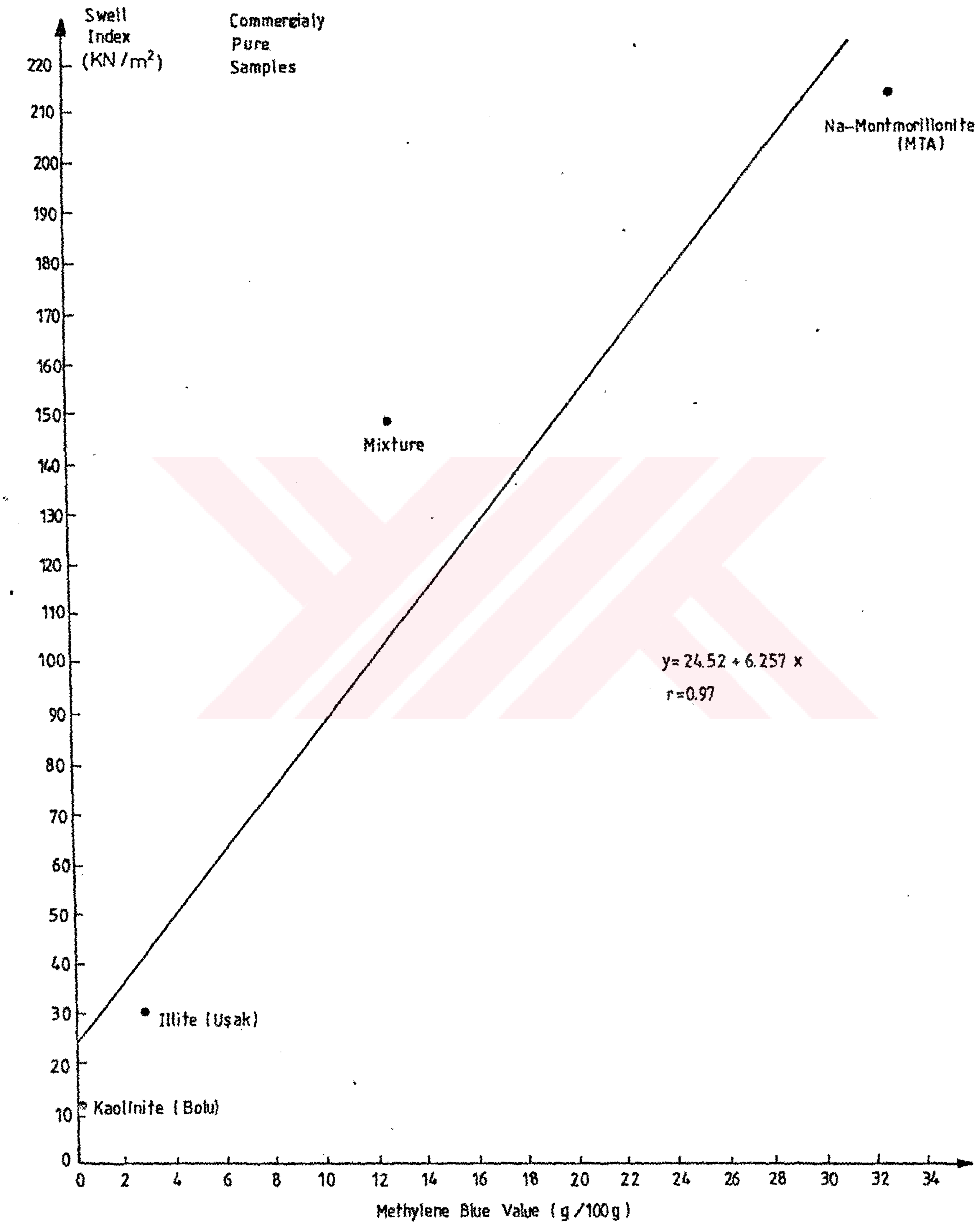


Fig. 8.33. SI vs MBV Relationship

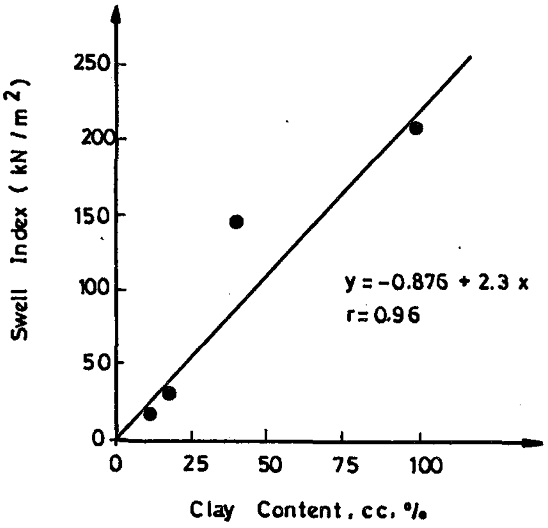


Fig. 8.34. SI vs CC Relationship

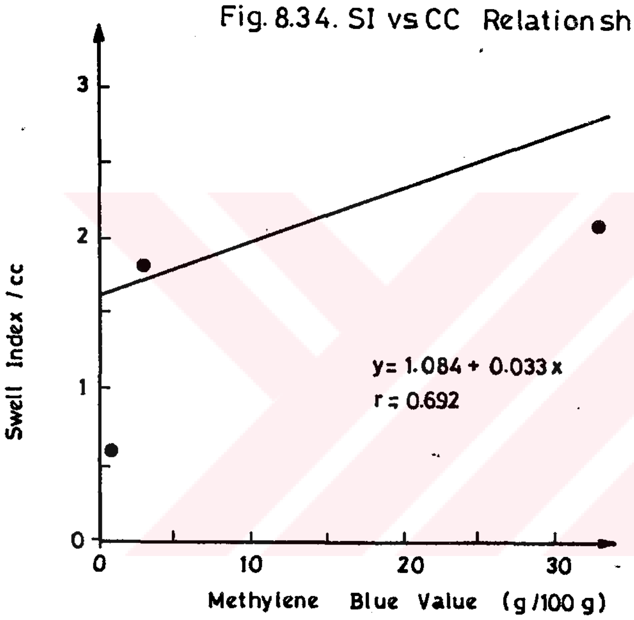


Fig. 8.35. SI/CC vs MBV Relationship

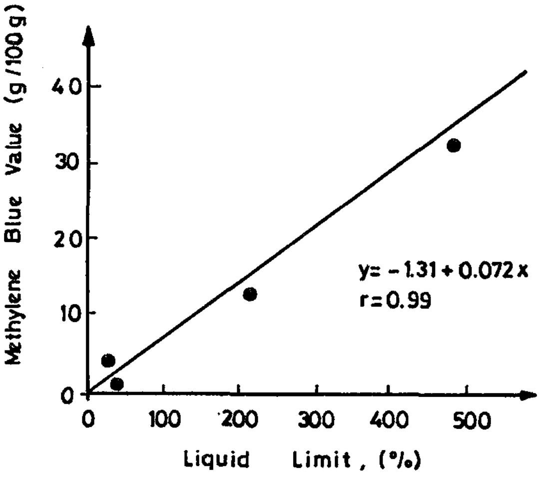


Fig. 8.36. MBV vs LL Relationship

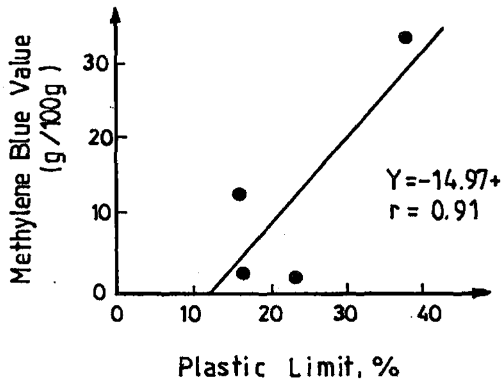


Fig. 8.37 MBV vs PL Relationship

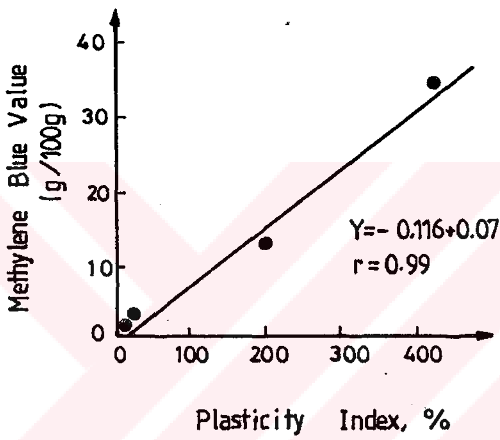


Fig. 8.38. MBV vs PI Relationship

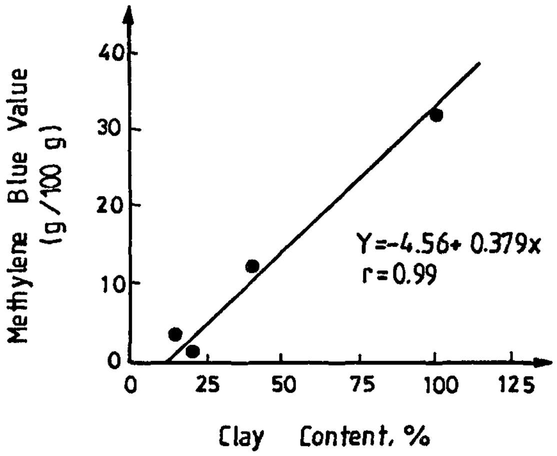


Fig. 8.39. MBV vs CC Relationship

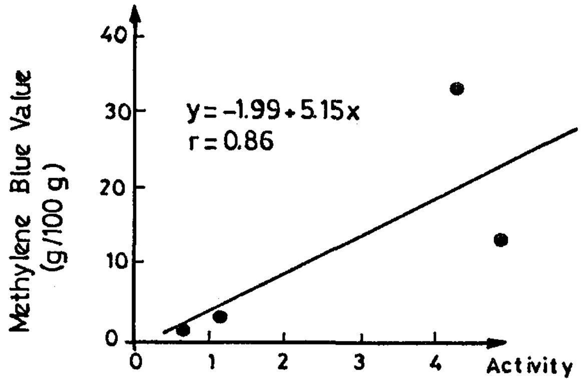


Fig. 8.40. MBV vs Ac Relationship

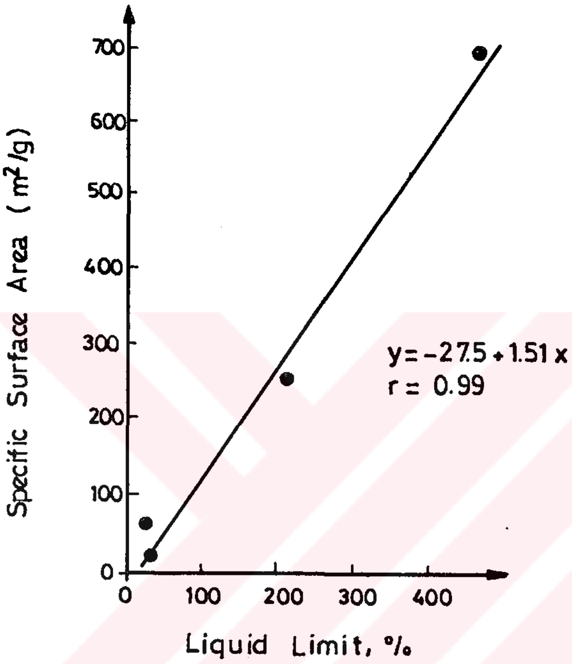


Fig. 8.41. SSA Value vs LL Relationship

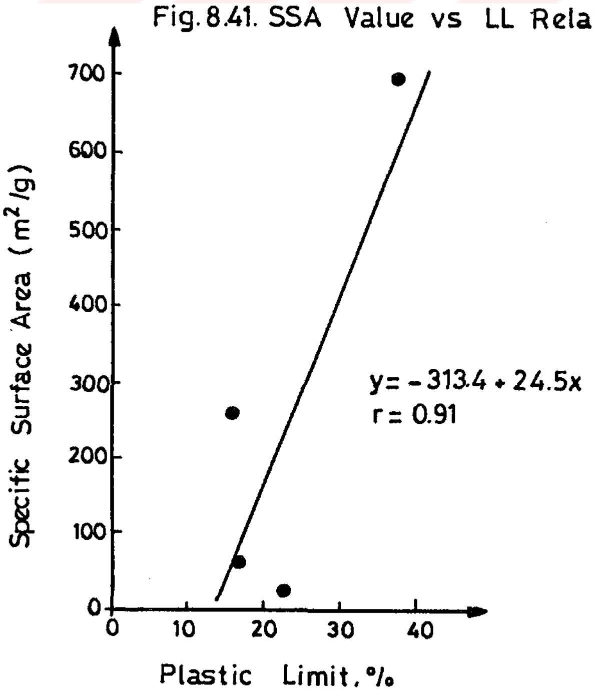


Fig. 8.42. SSA Value vs PL Relationship

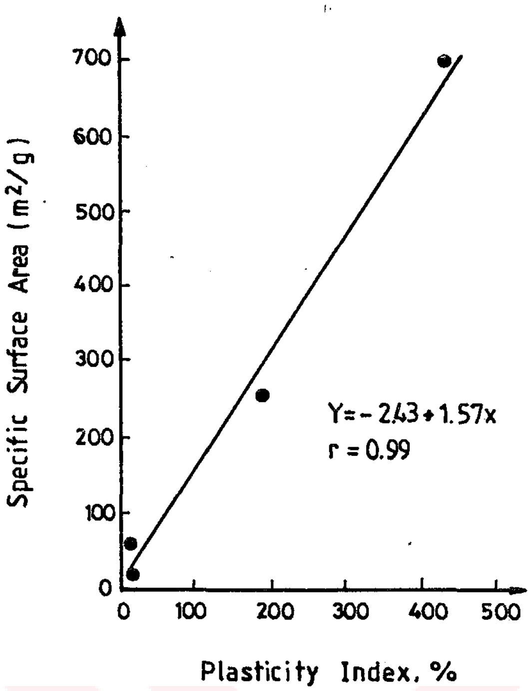


Fig. 8.43. SSA Value vs PI Relationship

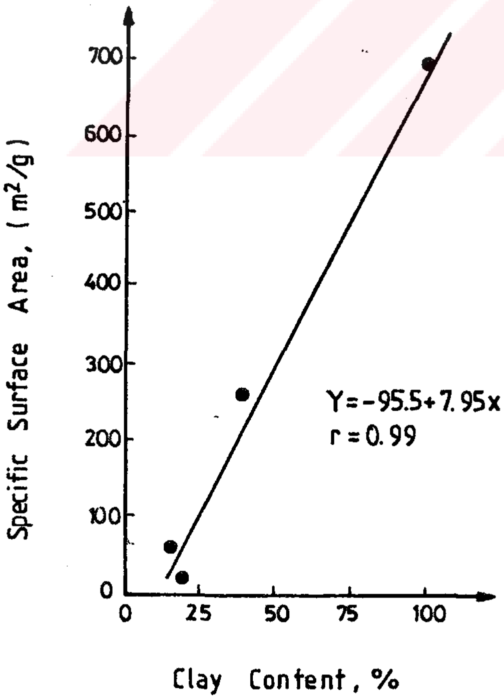


Fig. 8.44. SSA Value vs CC Relationship

Seed et. al (1962) and then clay content and methylene blue values of these samples were plotted on Magnan and Youssefian's (1989) chart (Fig. 8.45). Kaolinite (Bolu) and illite (Uşak) samples are in CL range and show low swell potential. Na-montmorillonite sample is out of CH range and shows very high swell potential. Kaolinite (Bolu)-illite(Uşak)-Na.Montmorillonite mixture sample is on the border of CH range and shows very high swell potential.

Tentatively, it seems that this original line of demarcation may be shifted towards the broken modified line as shown on the Fig.8.45.

Commercially Pure Samples

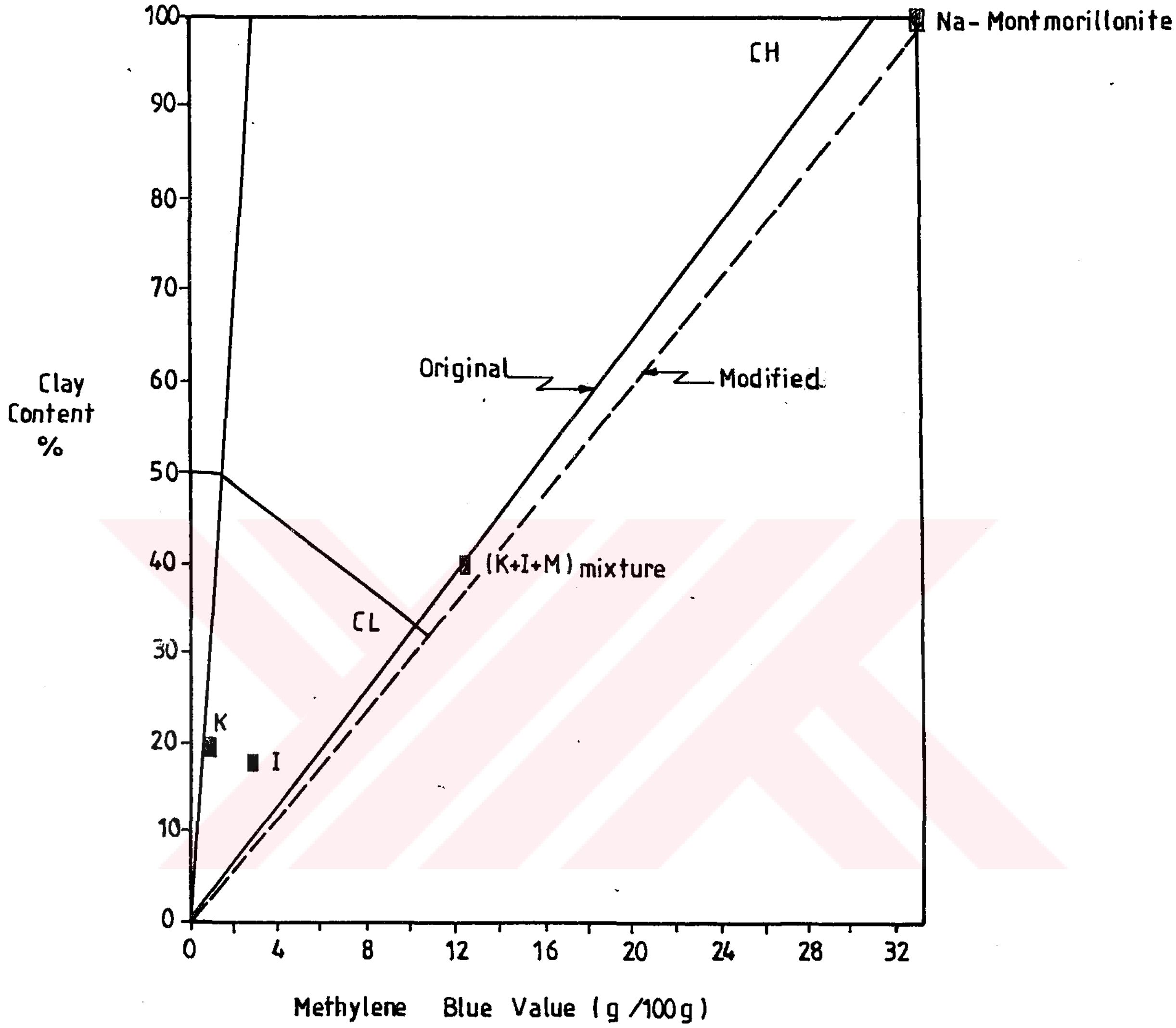


Fig. 8.45. CC vs MBV Chart

8.5.4. Evaluation of Data Obtained By the Author on Ankara Soils

In this section, the merits of methylene blue test as a possible means of identification of swelling potential of Ankara soils is investigated. For this purpose, by using Data Set V, some probable relationships were primarily searched and then a chart for the classification of swelling potential of Ankara soils was proposed.

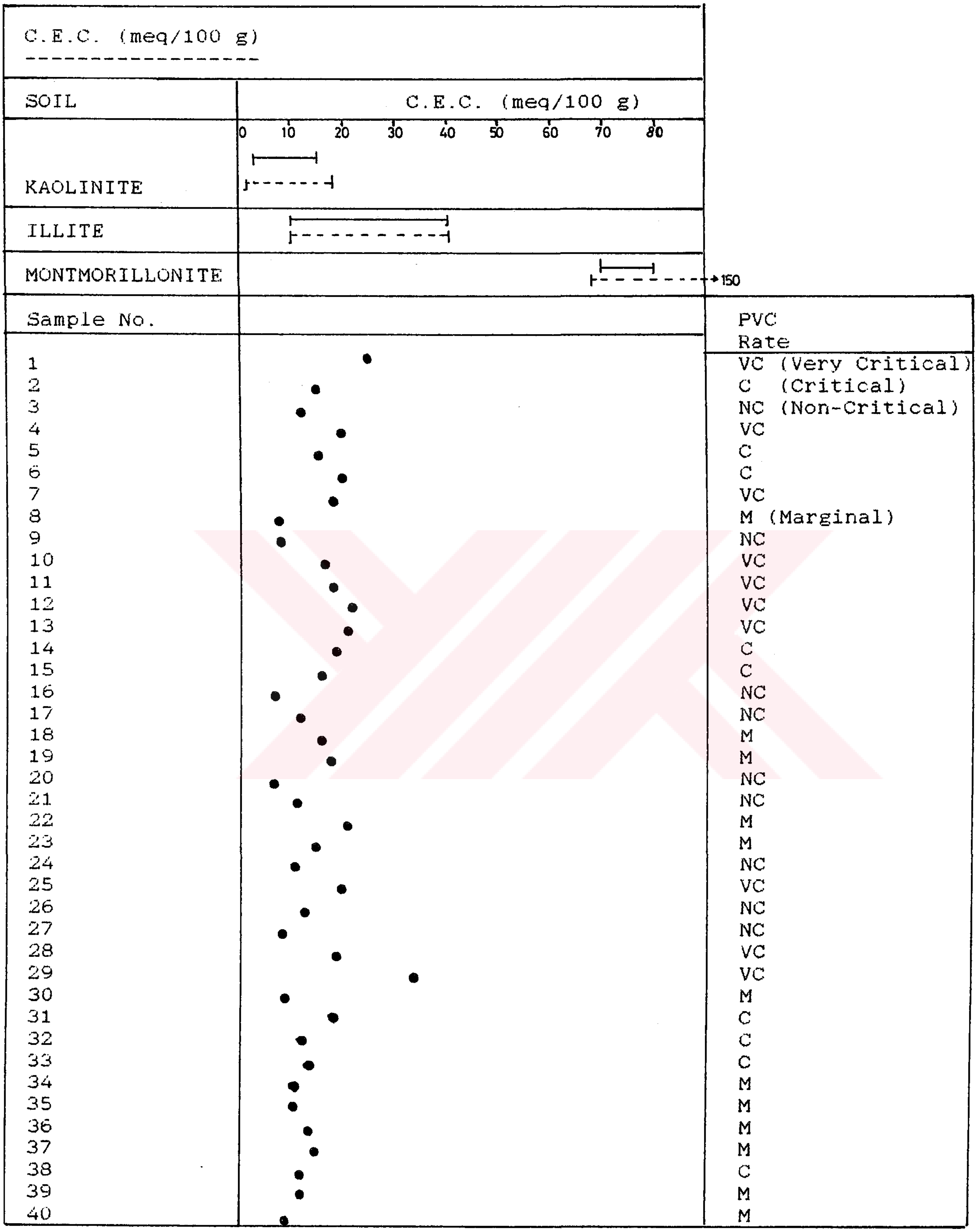
In Appendix J1 , X-ray test results of the soil samples taken from different locations of Ankara are given. These tests were performed in TPAO Research Center (5 samples, with mineral percentages), Cement Producers Association of Turkey (22 samples, without mineral percentages), Geological Engineering Department of METU (9 samples , with mineral percentages) and MTA (4 samples, without mineral percentages). Mineral percentages of 26 samples could not be obtained due to overlapping of X- ray peaks .

In Appendix J2, mineral percentages and methylene blue values of 14 samples are given (8 samples from terrace deposits, 4 samples from alluvial soils and 2 samples from residual soils (the X-ray test results and methylene blue test results of residual soils are given just to give an idea about the magnitude of these values)). As it can be seen from this table percentage of montmorillonite and the methylene blue values of terrace deposits are higher than alluvial soils. Due to limited number of data no definite conclusion could be reached for residual soils.

From (Appendix J3) it can be concluded that the occurrence of montmorillonite, quartz, calcite, illite and albite minerals are higher than the other minerals (similar findings were found by Kasapoğlu (1980)and Kiper (1983)). Almost 90 % of the samples contain montmorillonite;as it is known montmorillonite minerals, even in minor amounts, cause swelling of soils. Therefore it can be concluded that the Ankara soils essentially contain expanding lattice- structured clay minerals in their fines.

The c.e.c. of each sample , determined by methylene blue test was compared with the c.e.c. value of pure minerals (Chen,1975;Taylor, 1965) in Fig.8.46 . The specific surface area value of each sample was compared with the specific surface area value of pure minerals in Fig.8.47 . Except for the Macunköy sample, specific surface area values are in between 65-210 m2/g and c.e.c. values are in between 6.5 meq/100 g - 24.5 meq/100 g.

In Figs. 8.48.a,b, 8.49.a,b, 8.50.a,b, 8.51.a,b,, the relationships between methylene blue values and LL, PL, PI and CC are shown for alluvial soils and terrace deposits. The relationship between methylene blue value and activity are shown in Fig.8.52.a,b.



ig.8.46.Plot of c.e.c Values of Ankara Soils

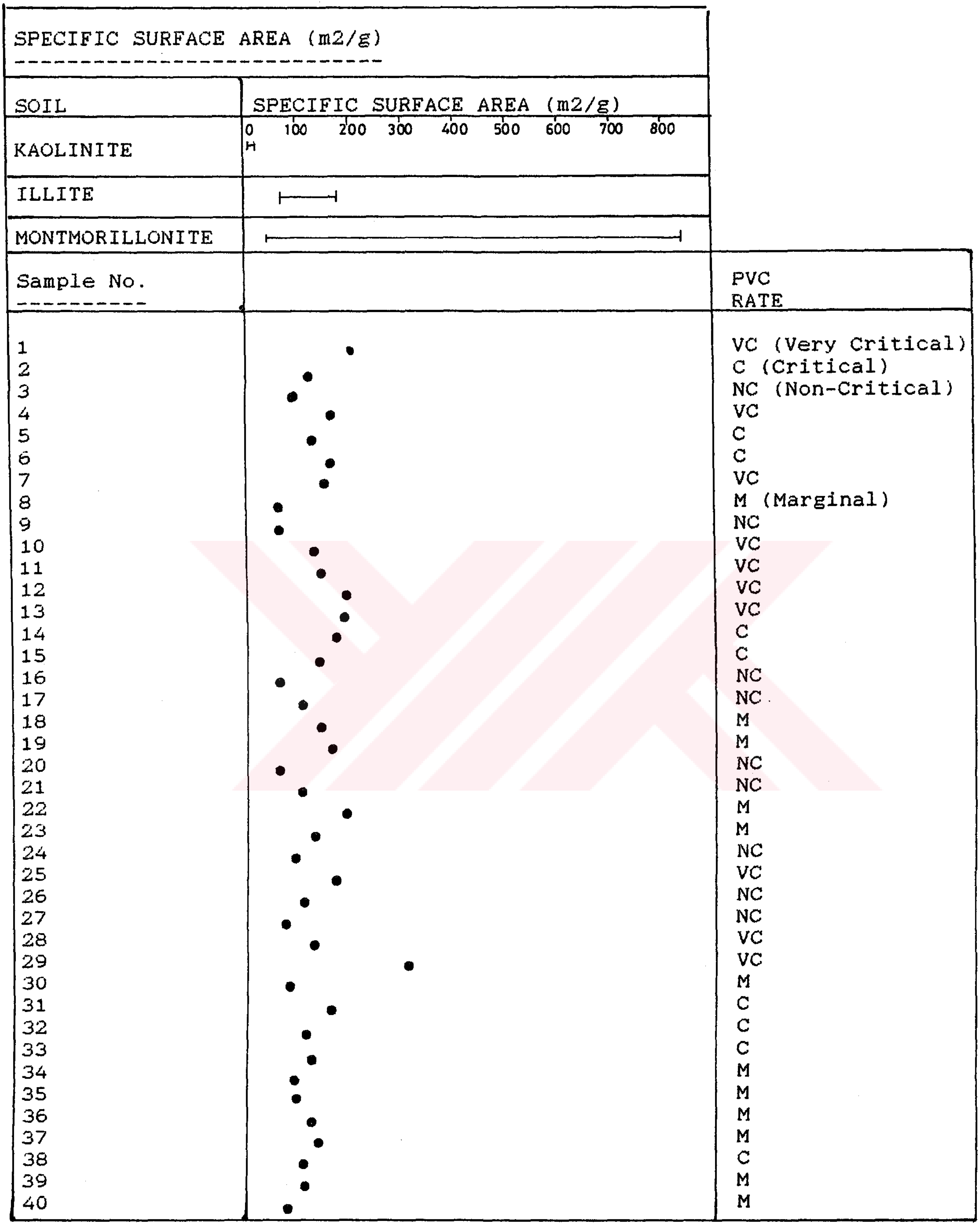


Fig.8.47. Plot of SSA Values of Ankara Soils

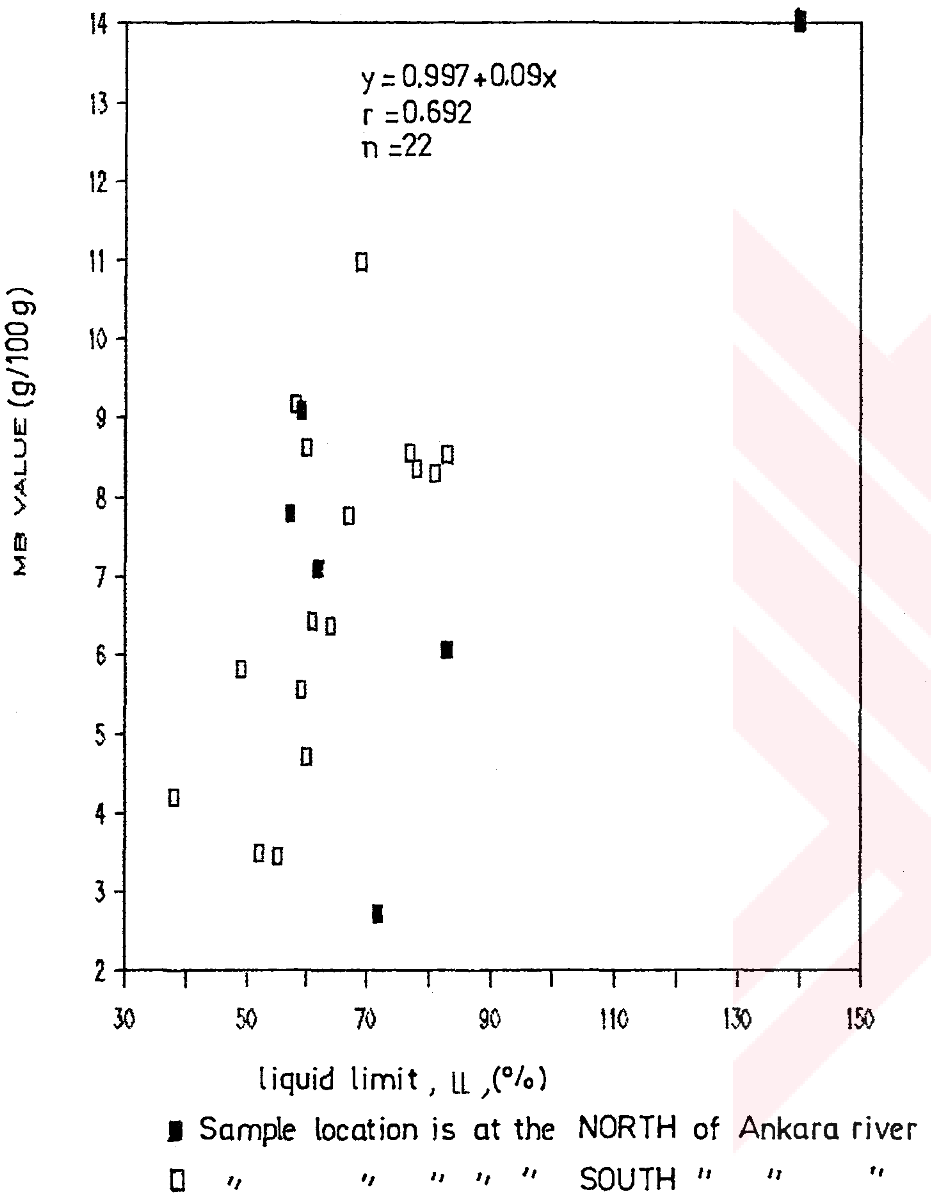


Fig.8.48.b.MBV vs LL Relationship for Terrace Deposits

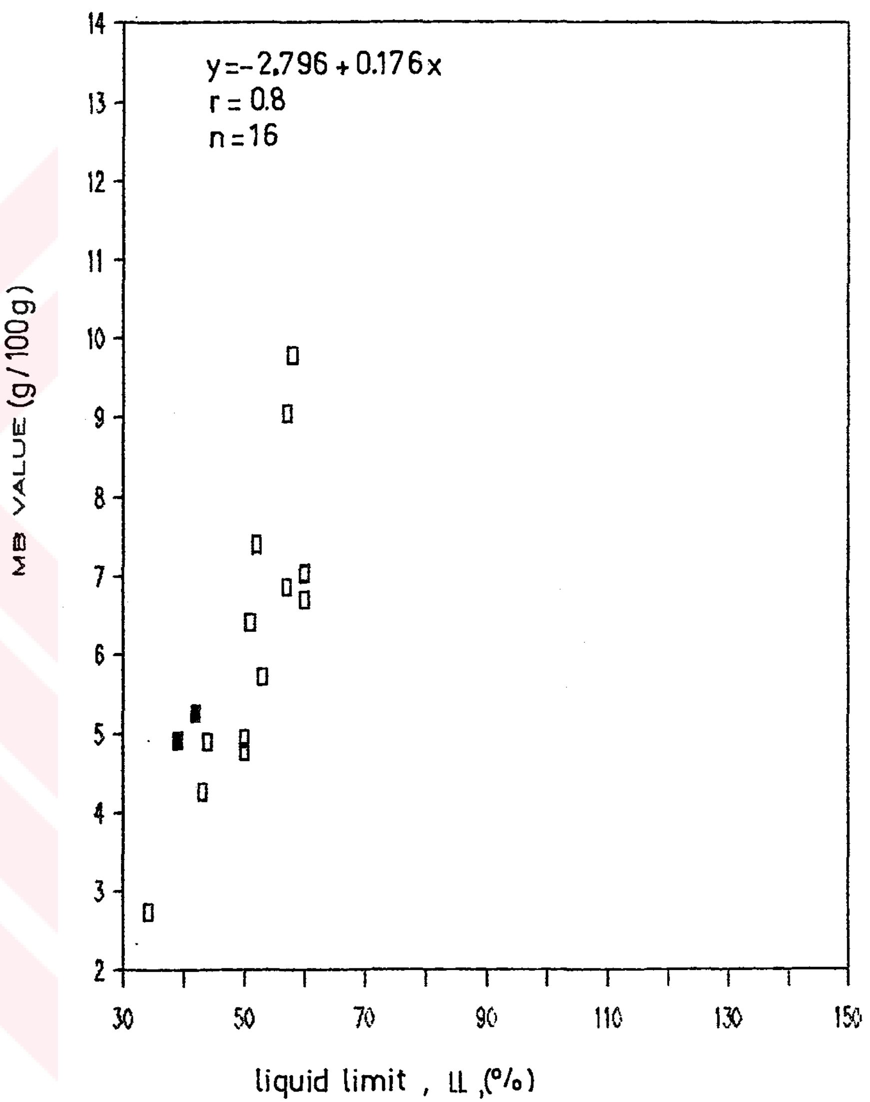


Fig.8.48.a.MBV vs LL Relationship for Alluvial Soils

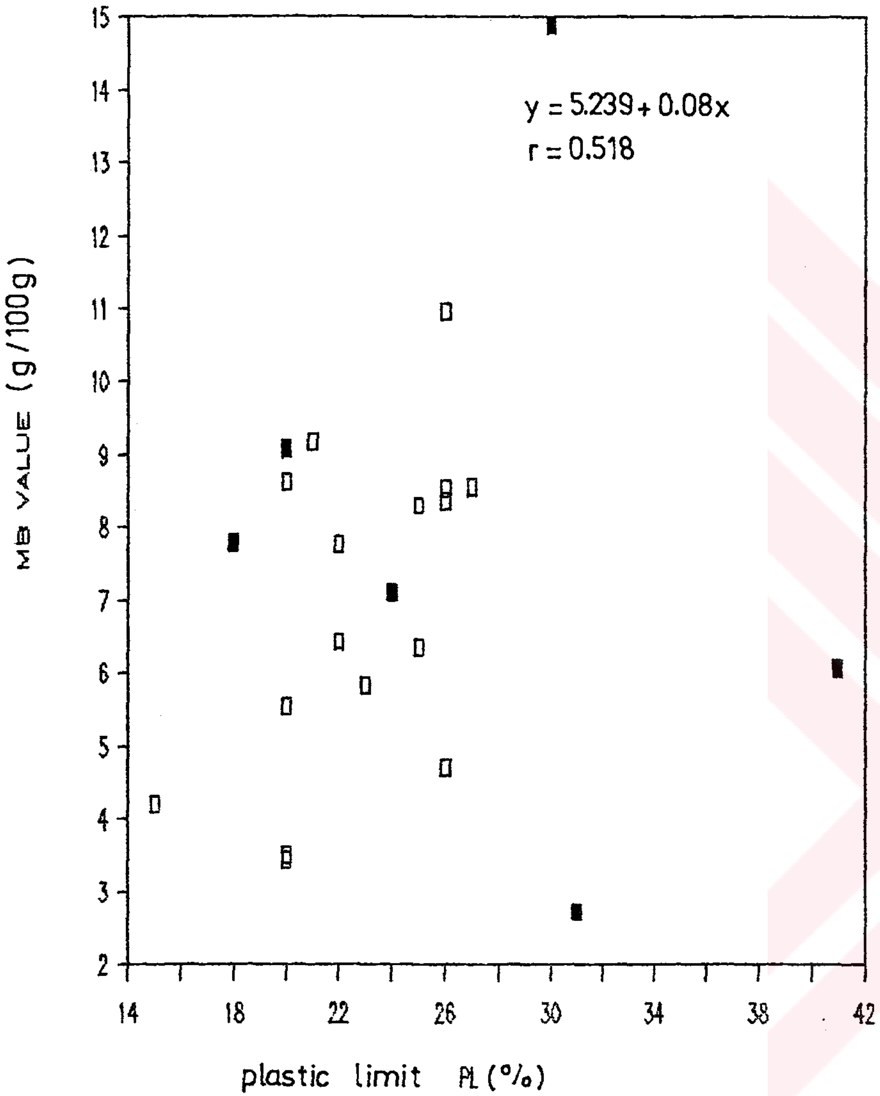


Fig.8.49.b.MBV vs PL Relationship for Terrace Deposits

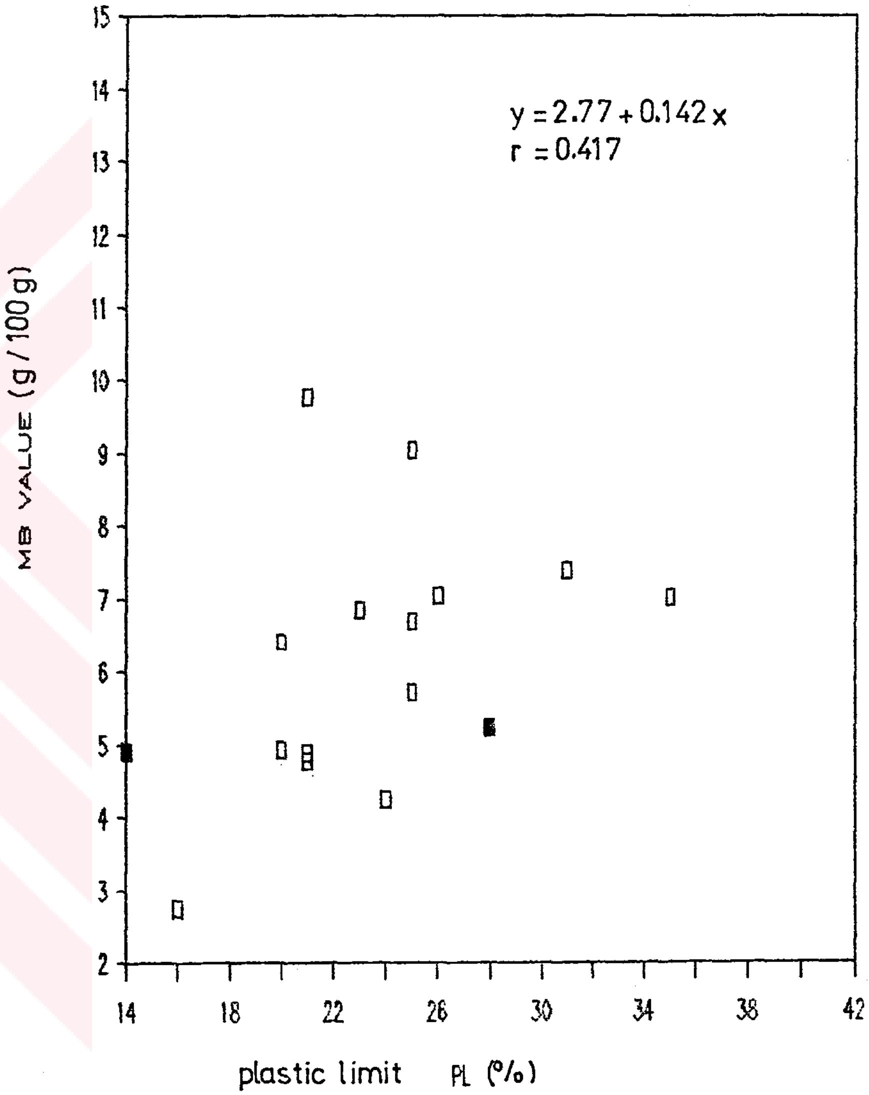


Fig.8.49.a.MBV vs PL Relationship for Alluvial Soils

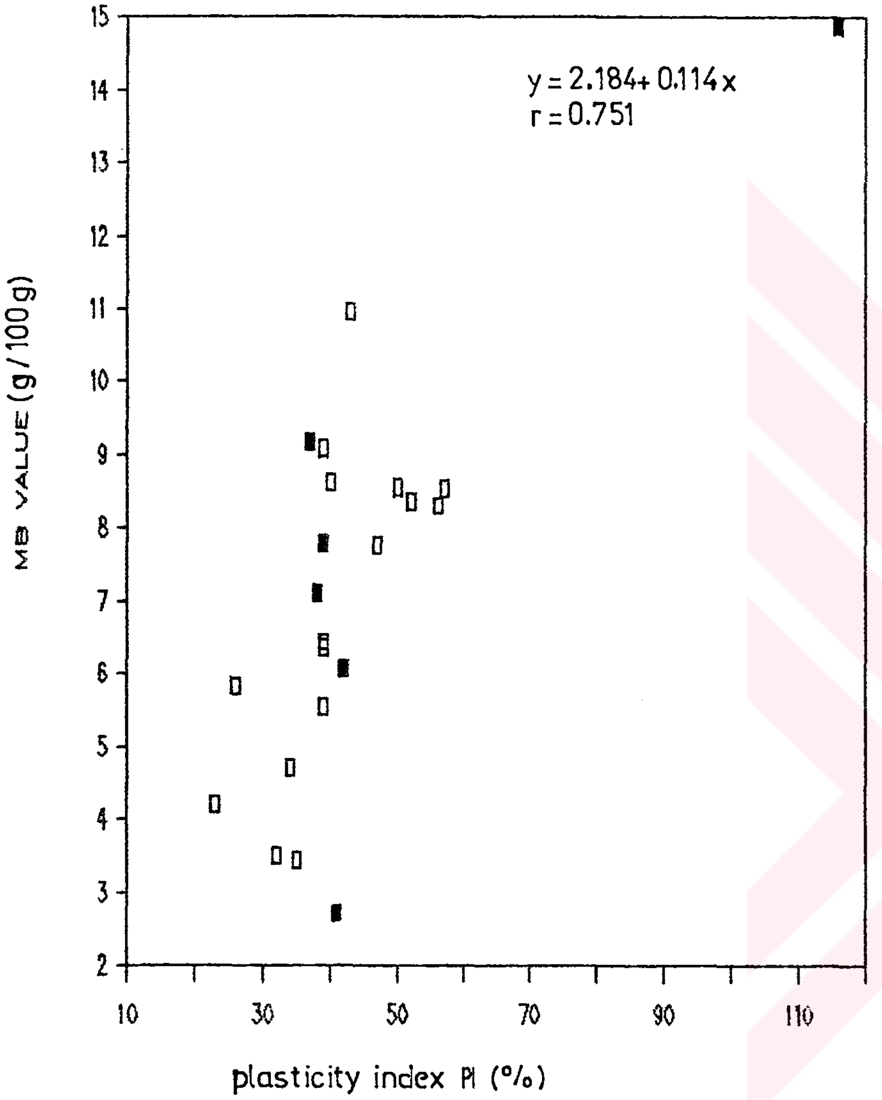


Fig.8.50.b.MBV vs PI Relationship for Terrace Deposits

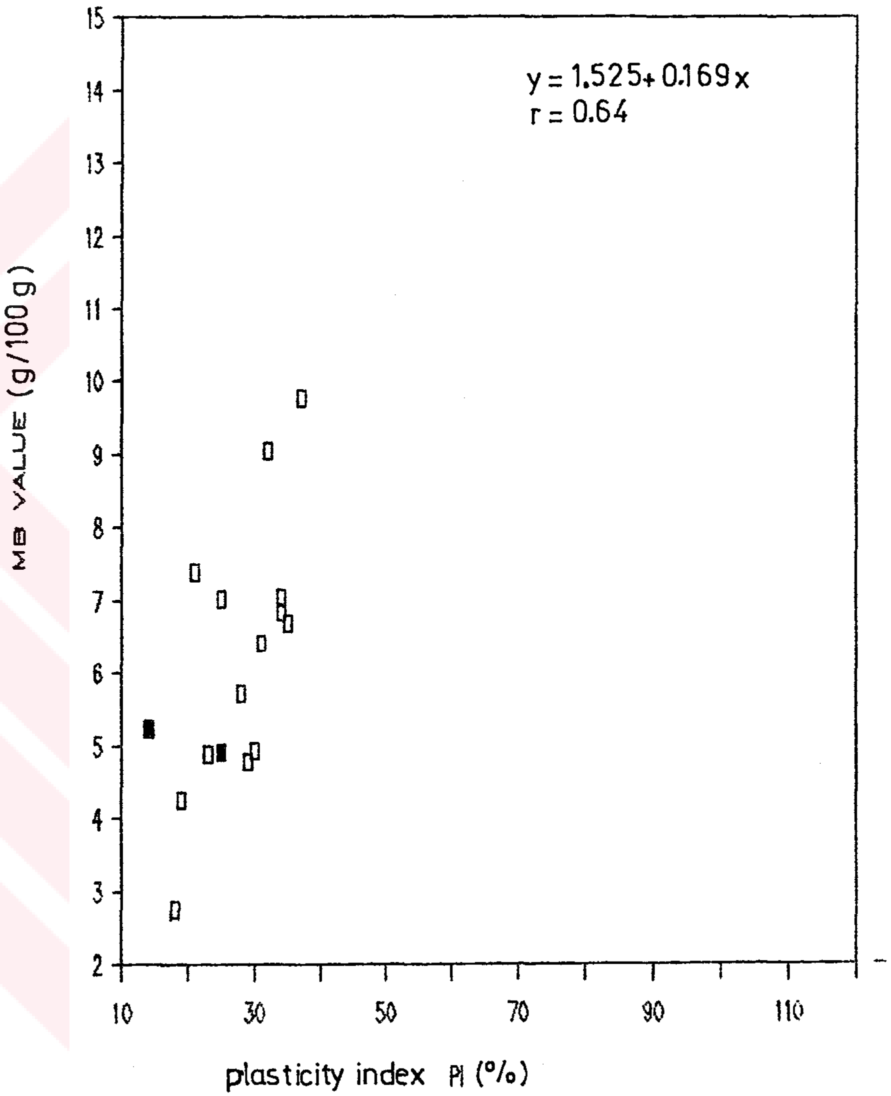


Fig.8.50.a. MBV vs PI Relationship for Alluvial Soils

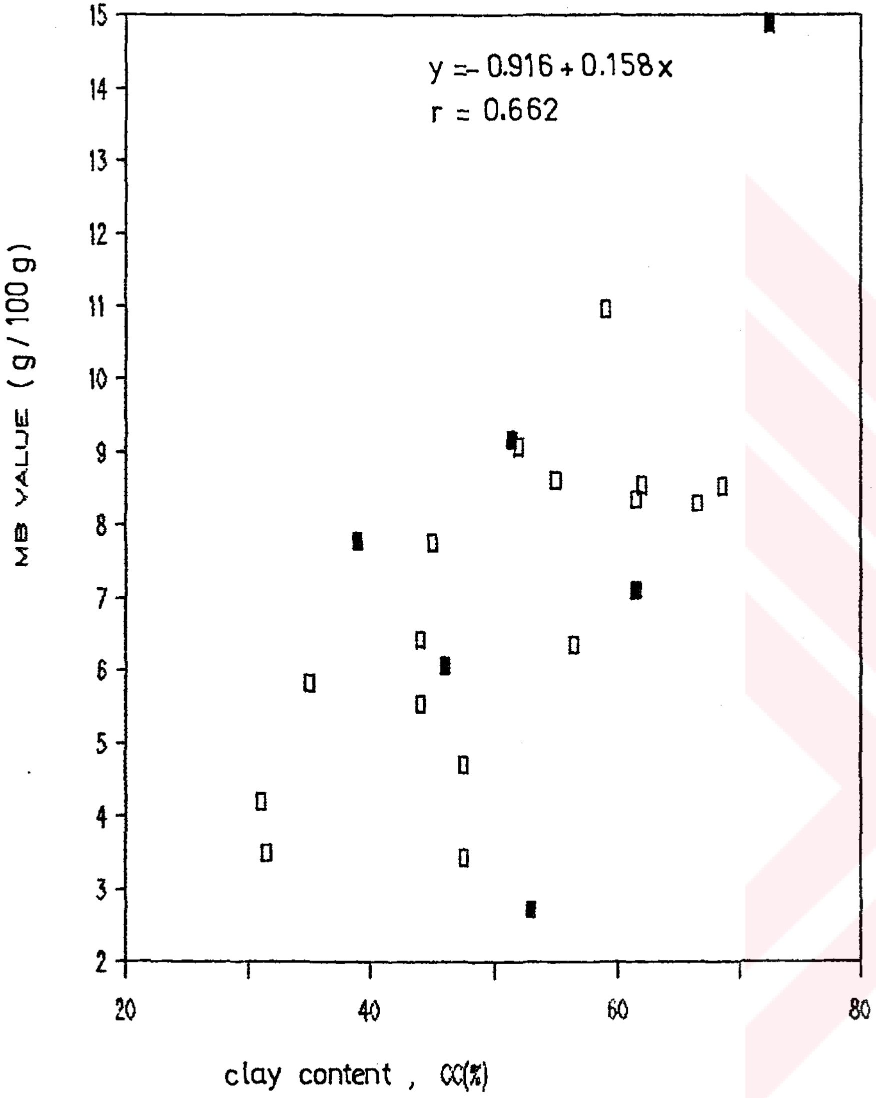


Fig.8.51.b. MBV vs CC Relationship for Terrace Deposits

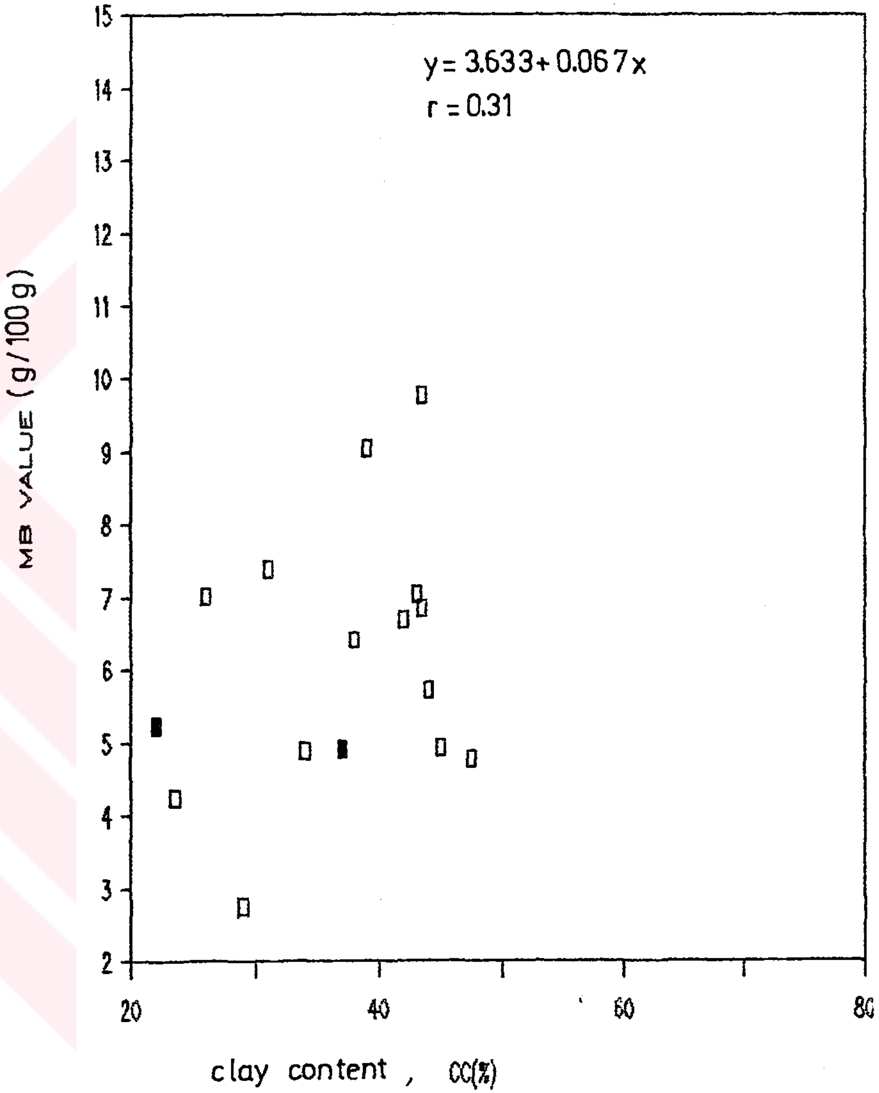


Fig.8.51.a. MBV ve CC Relationship for Alluvial Soil

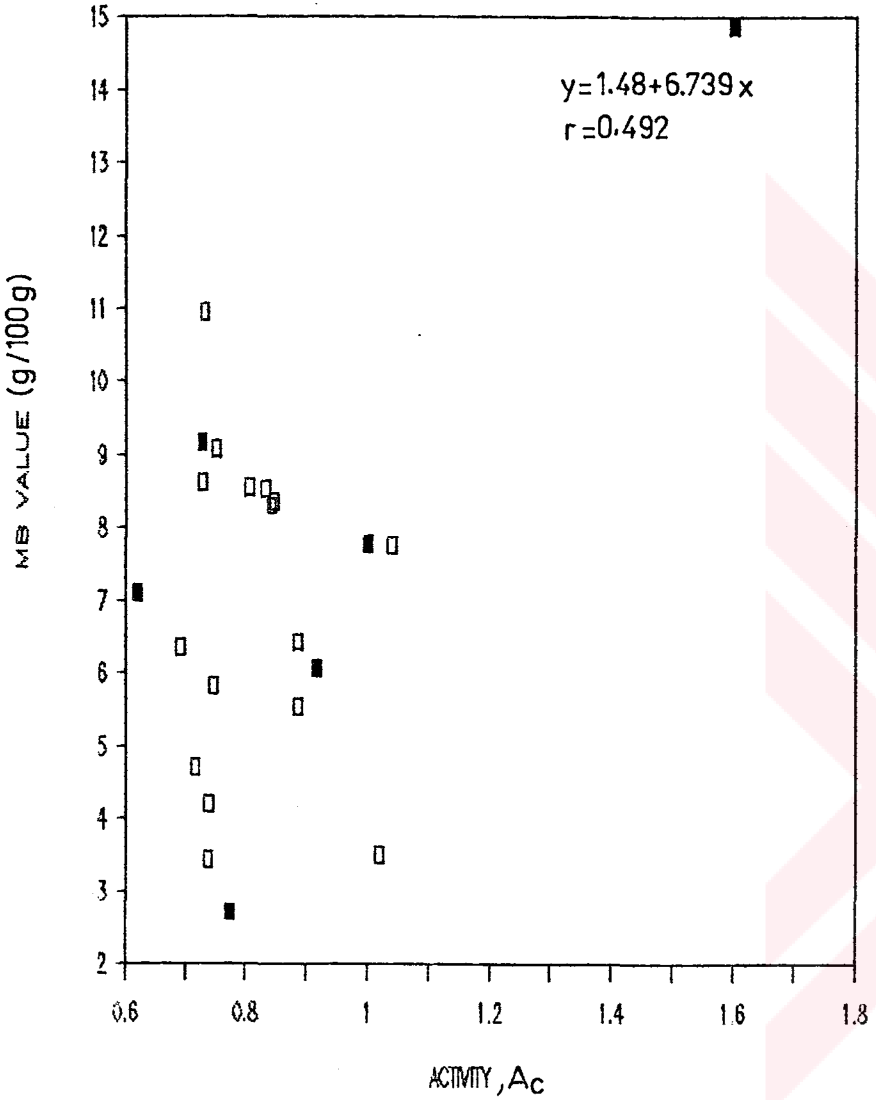


Fig.8.52.b. MBV vs Ac Relationship for Terrace Deposits

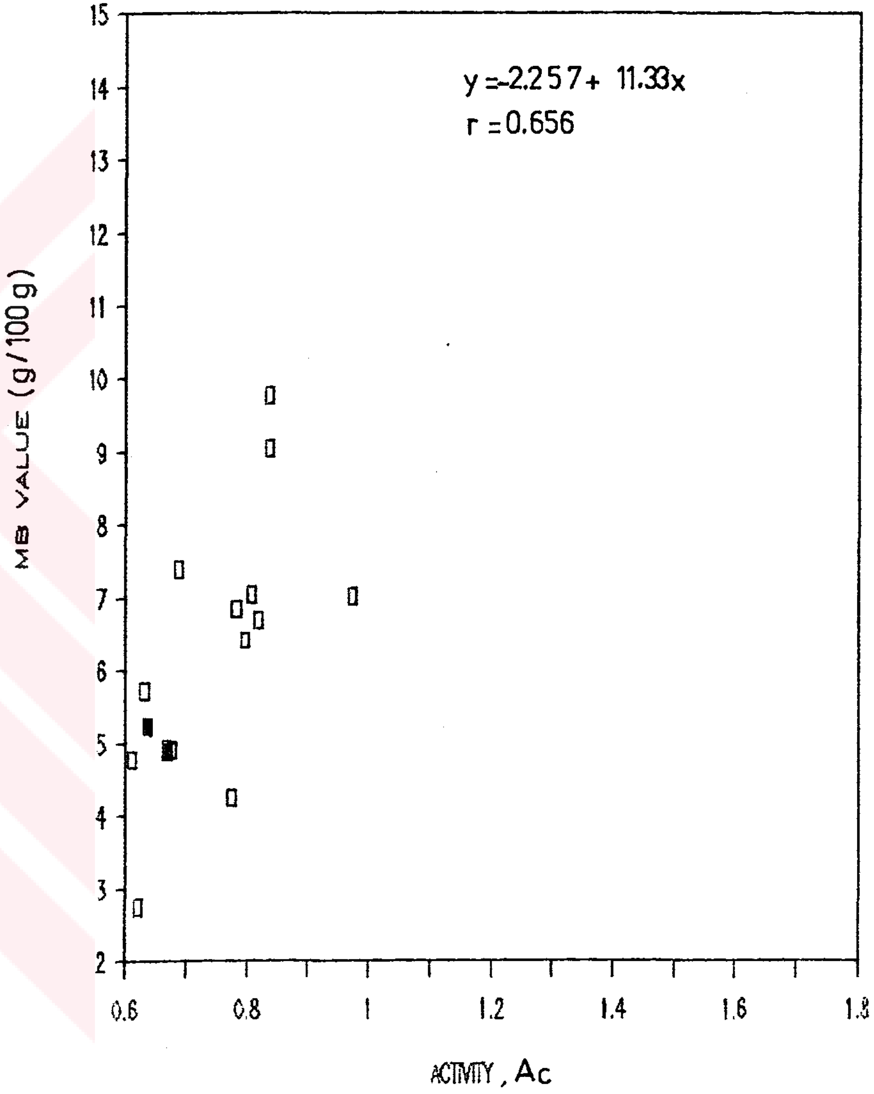


Fig.8.52.a. MBV vs Ac Relationship for Alluvial Soils

Specific surface areas of these samples were determined from methylene blue test results and their relationships between LL, PL, PI, CC are shown in Figs. 8.53.a,b, 8.54.a,b, 8.55.a,b, 8.56.a,b respectively.

Swell potentials were plotted against methylene blue value (logarithmic scale) for Lautrin (1987) and Magnan and Youssefian's (1989) data (Appendix M) and for Ankara soils (Appendix I) in Fig. 8.57. General trend of both data sets seem to be in accordance with each other, although no definite relationship is approached.

Swell index versus clay content, swell index versus methylene blue value, swell index/clay content versus methylene blue values are shown in Figs. 8.58.a,b, 8.59.a,b and 8.60.a,b respectively. The swell index versus PI relationship for alluvial soils and terrace deposits are given in Figs. 8.61.a and 8.61.b.

The correlation coefficients are also given for all of the above mentioned relationships.

In Table 8.4 comparison of correlation coefficients for various relationships on terrace deposits and on alluvial soils are shown. In half of the relationships correlation coefficients of terrace deposits are higher than the correlation coefficients of alluvial soils, and in the remaining half the opposite is true. Correlation coefficients of these relationships are not too high.

In Figs.8.62.a and 8.62.b ,clay content versus methylene blue values are shown for Ankara soils. When these plots

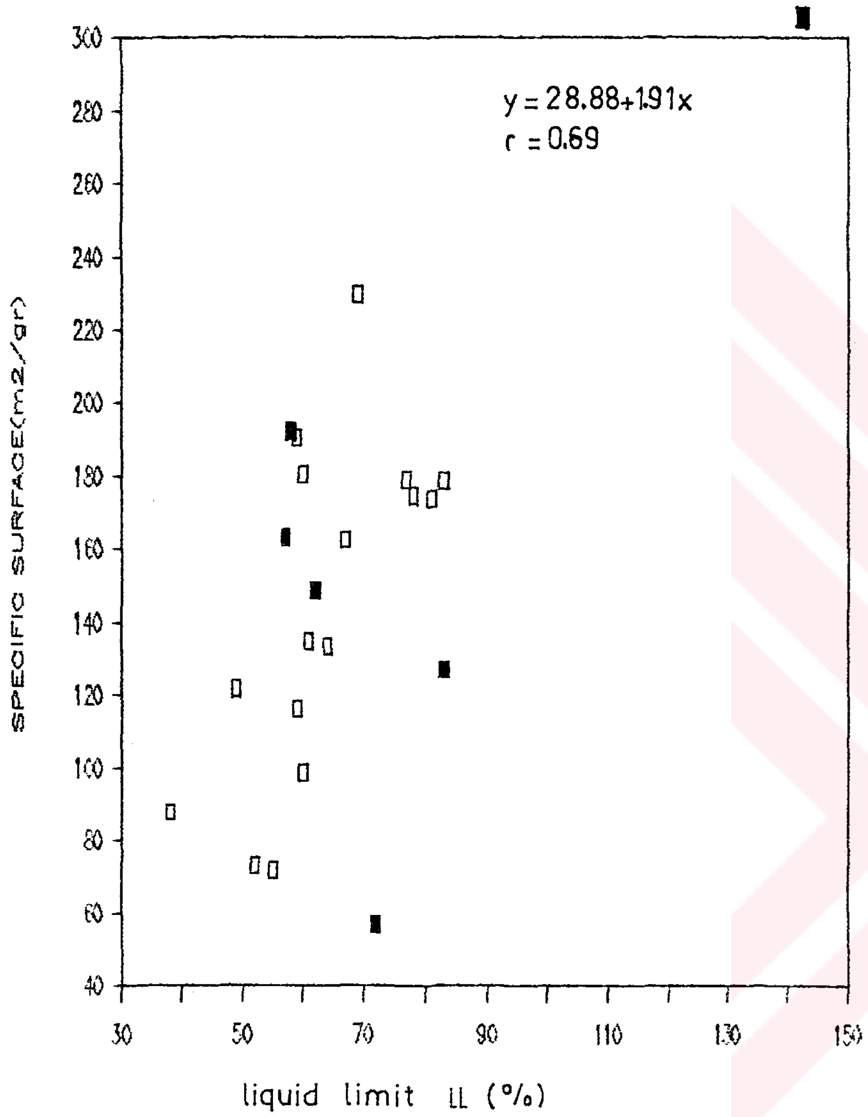


Fig.8.53.b. SSA vs LL Relationship for Terrace Deposits

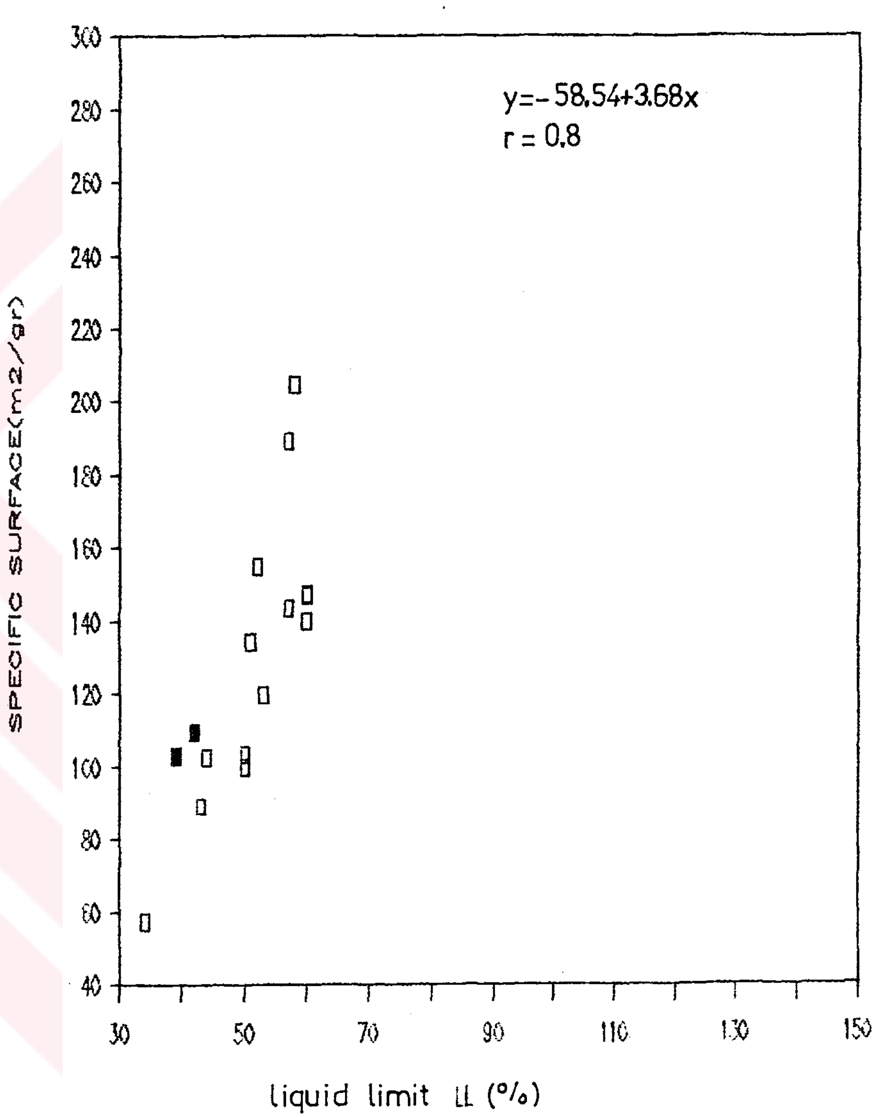


Fig.8.53.a. SSA vs LL Relationship for Alluvial Soi

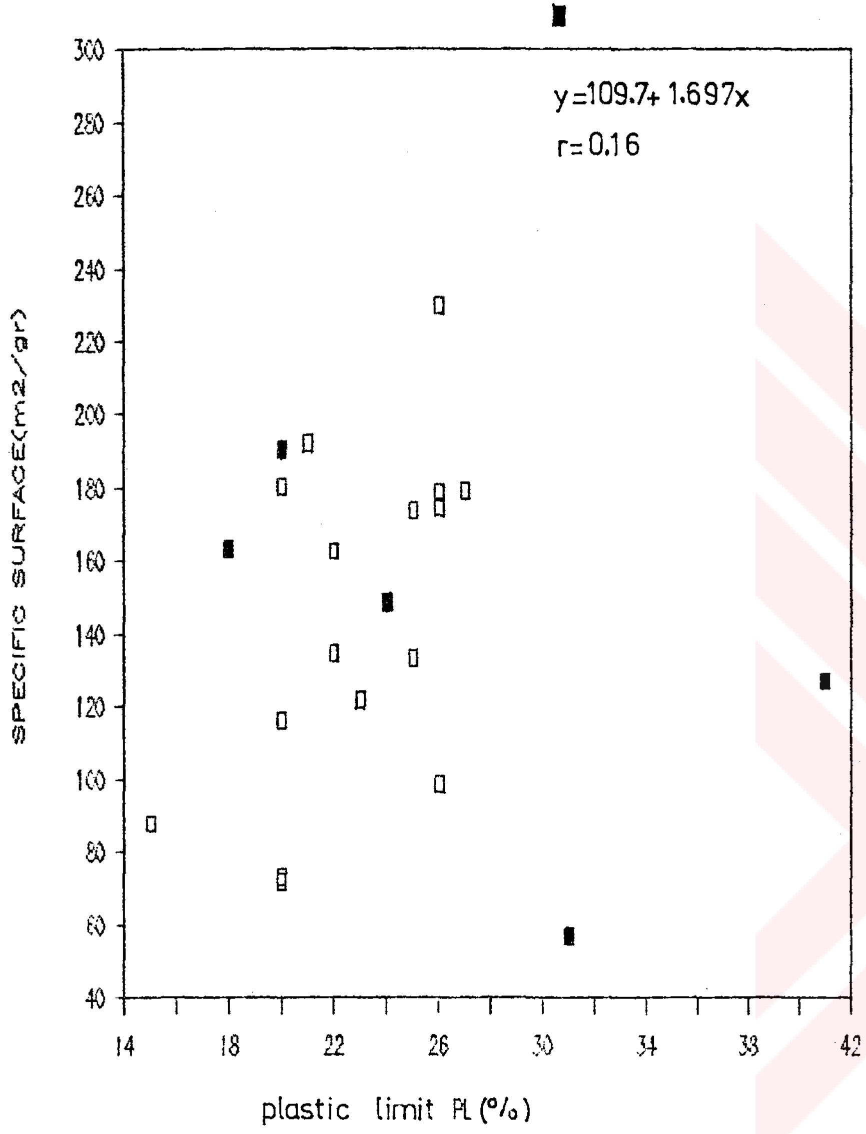


Fig.8.54.b. SSA vs PL Relationship for Terrace Deposits

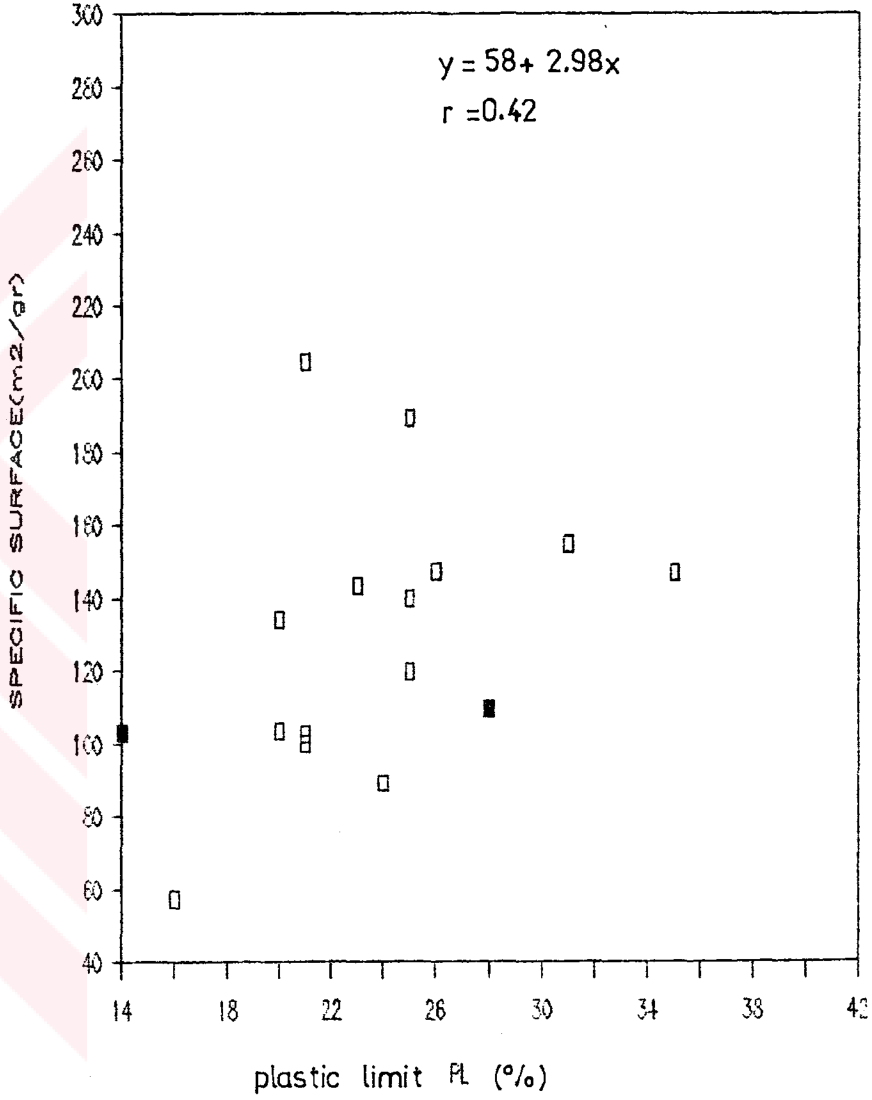


Fig.8.54.a. SSA ve PL Relationship for Alluvial Soils

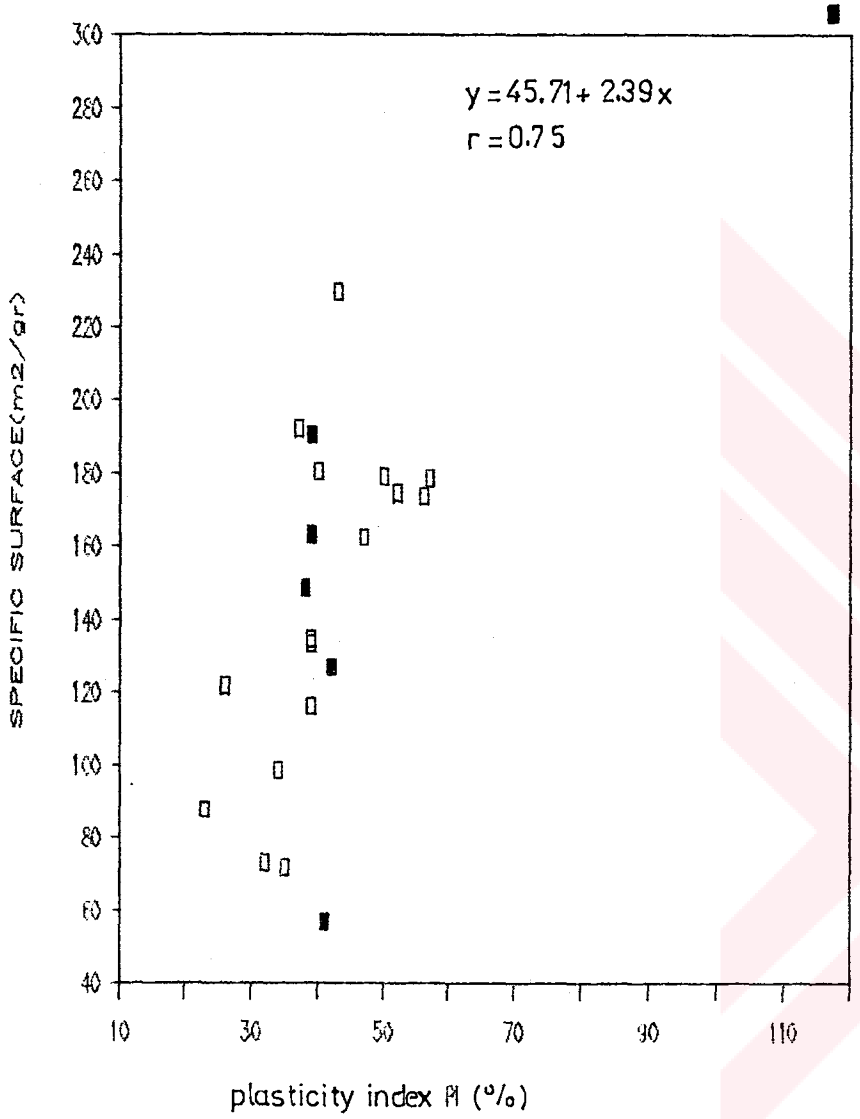


Fig.8.55.b. SSA vs PI Relationship for Terrace Deposits

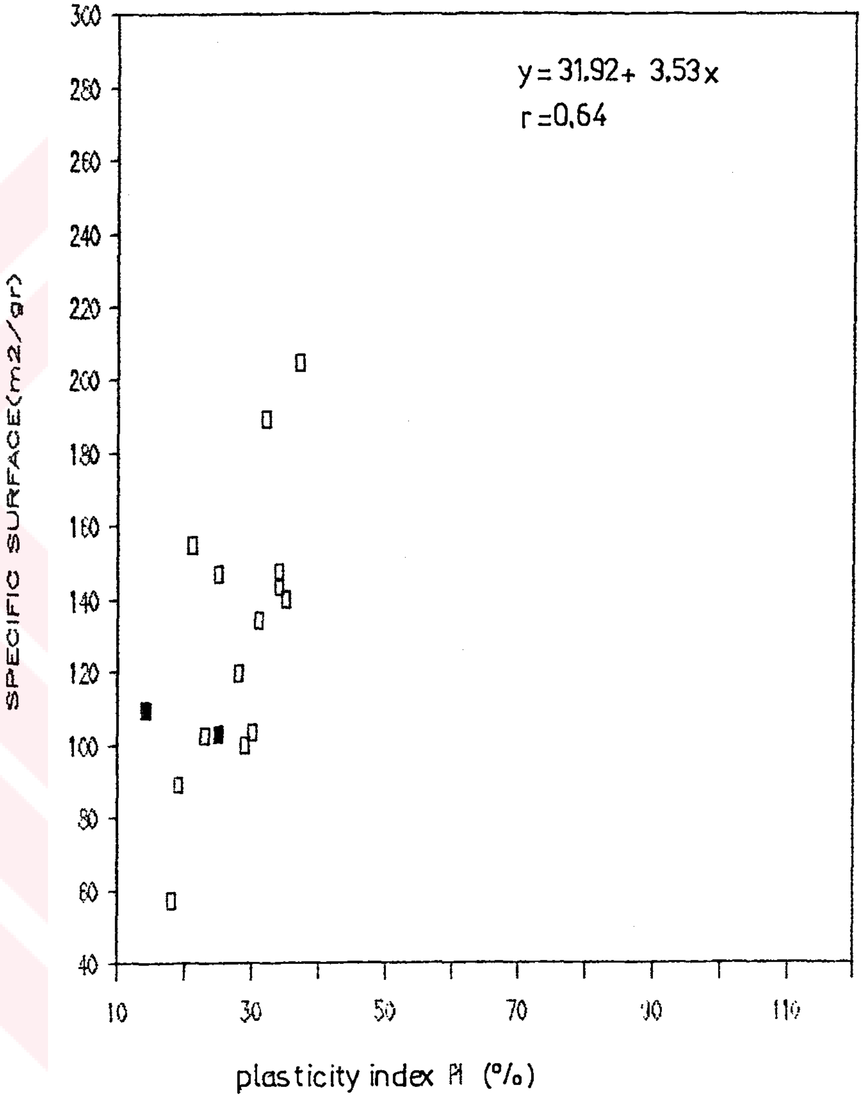


Fig.8.55.a. SSA vs PI Relationship for Alluvial Soi

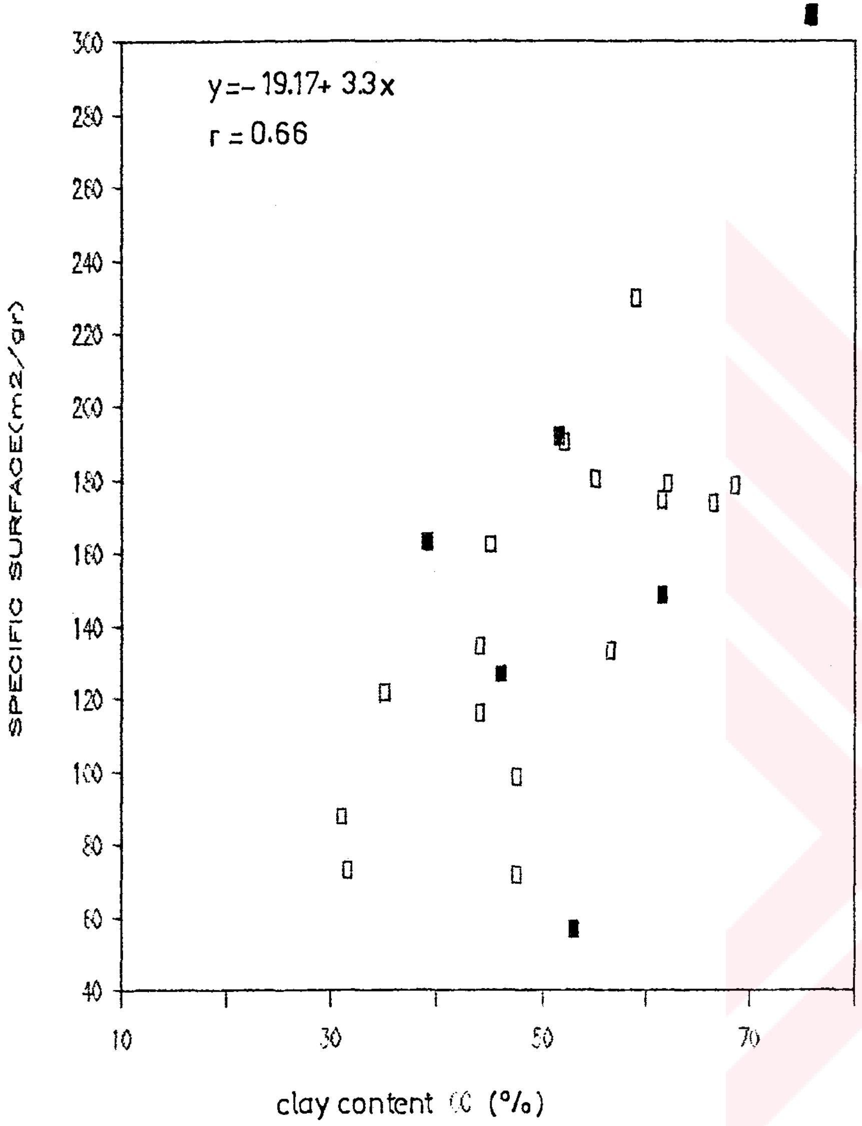


Fig.8.56.b. SSA ve CC Relationship for Terrace Deposits

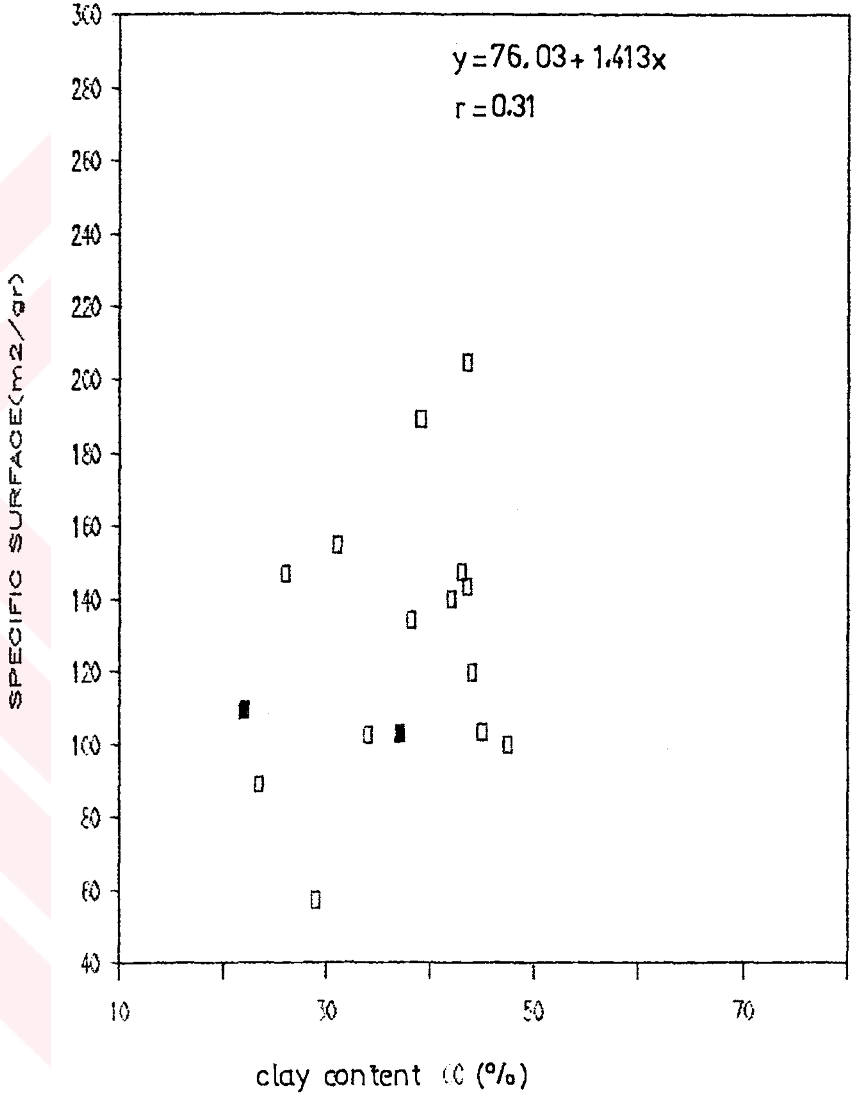


Fig.8.56.a. SSA ve CC Relationship for Alluvial Soils

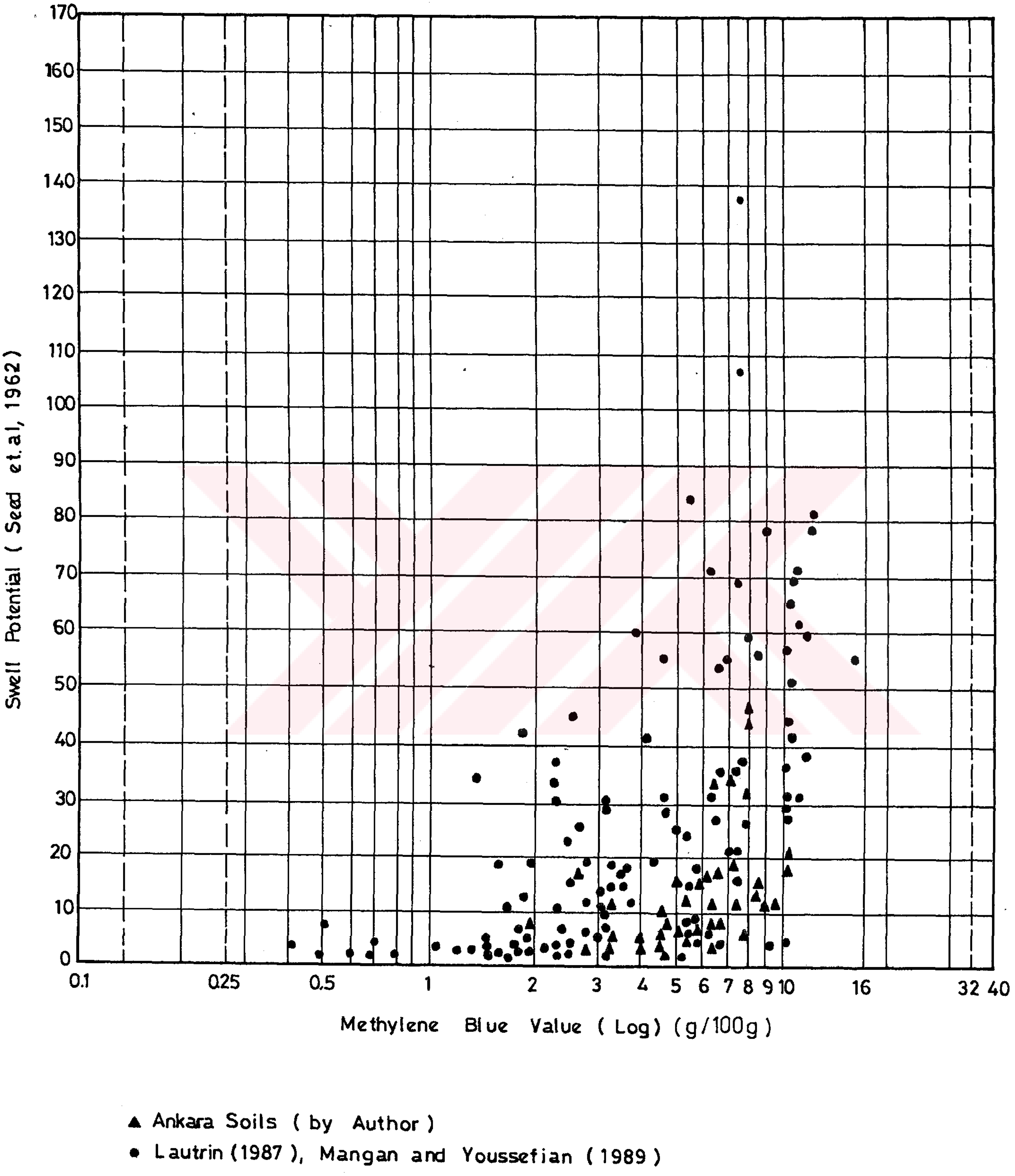


Fig. 8.57 Swell Potential vs MBV (log) Relationship

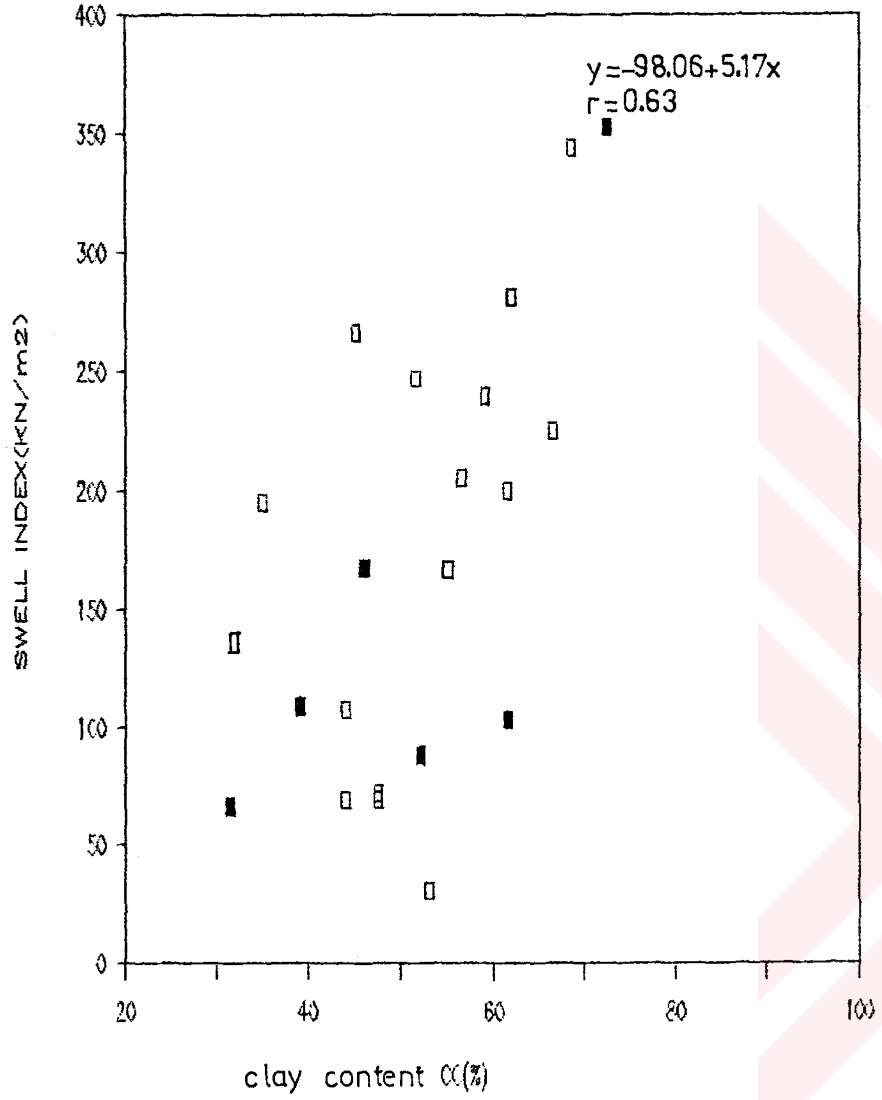


Fig.8.58.b. SI ve CC Relationship for Terrace Deposits

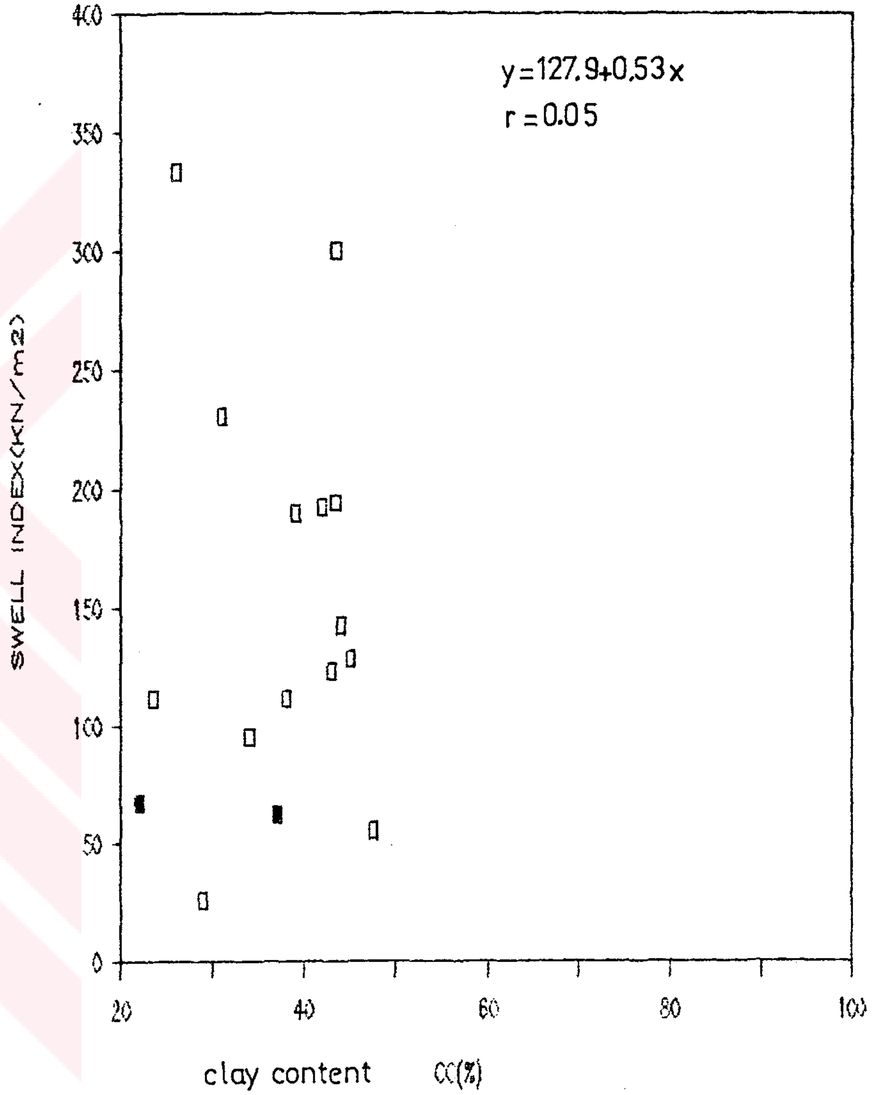


Fig.8.58.a. SI ve CC Relationship for Alluvial Soils

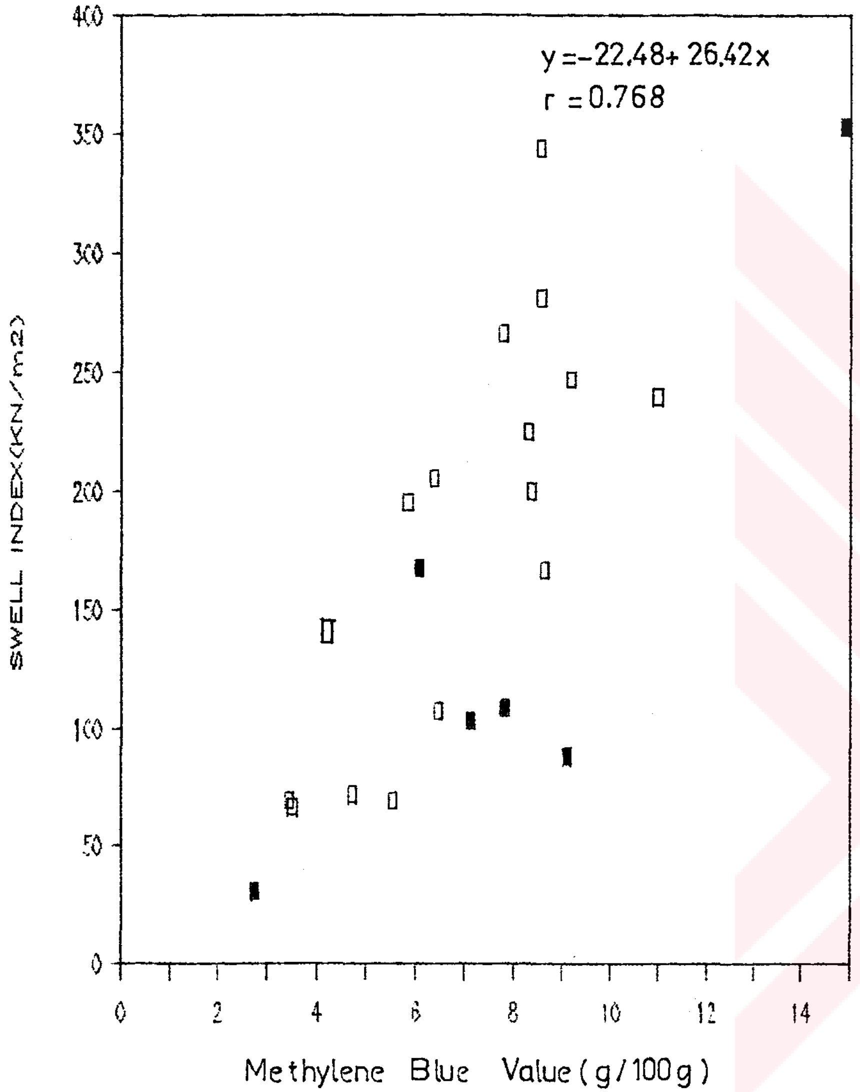


Fig.8.59.b. SI ve MBV Relationship for Terrace Deposits

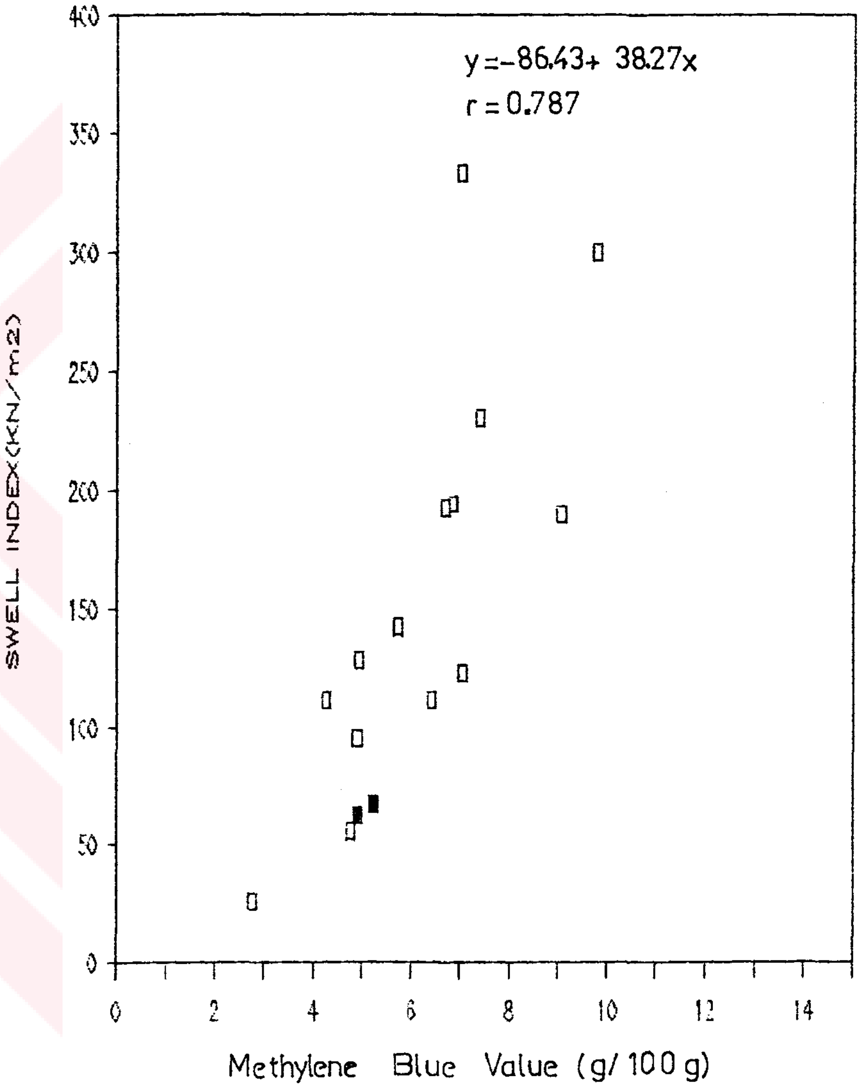


Fig.8.59.a. SI vs MBV Relationship for Alluvial Soi

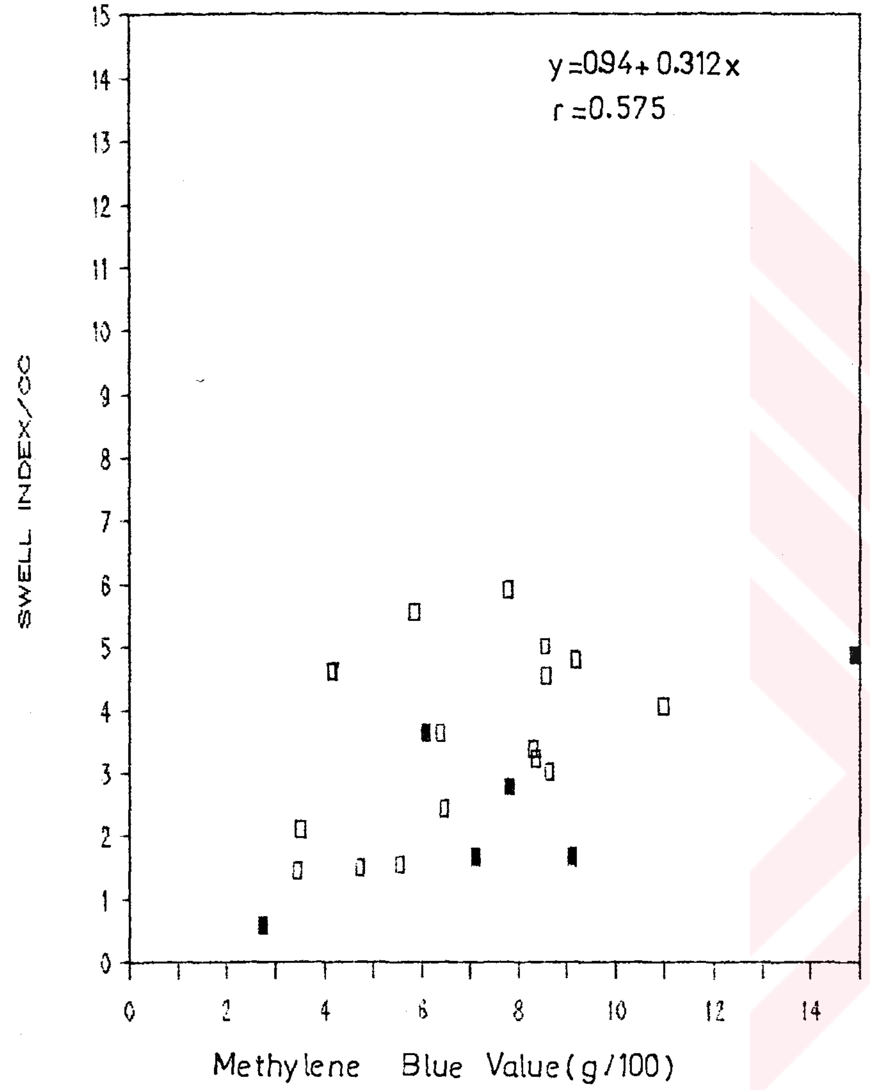


Fig.8.60.b.SI/CC vs MBV Relationship for Terrace Deposits

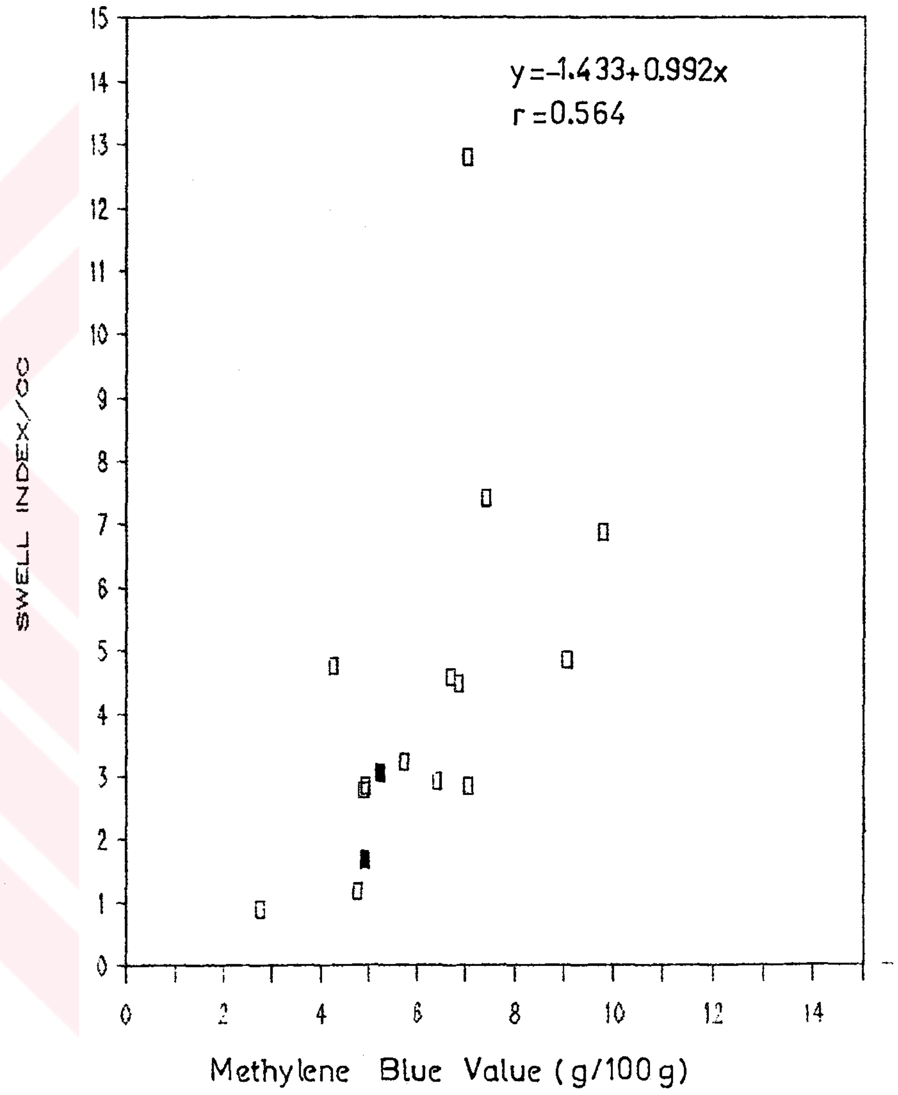


Fig.8.60.a.SI/CC vs MBV Relationship for Alluvia
Soils

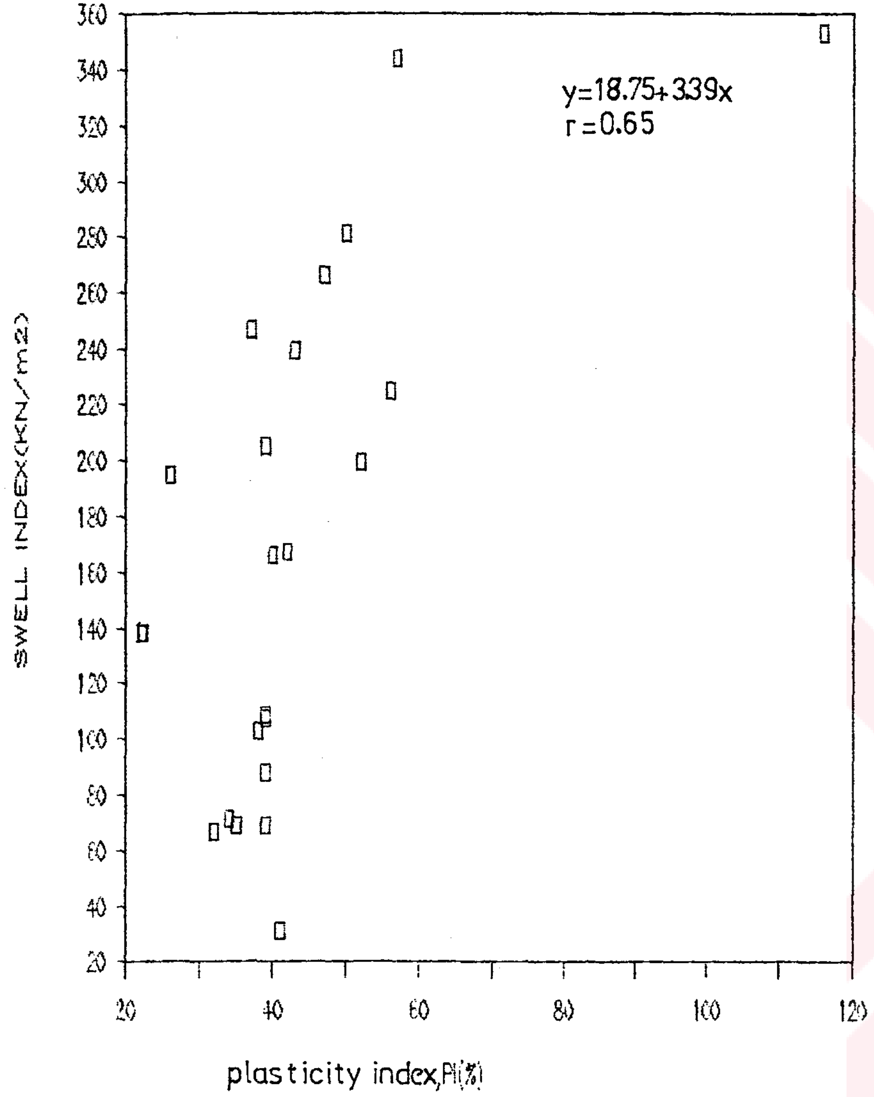


Fig.8.61.b. SI vs PI Relationship for Terrace Deposits

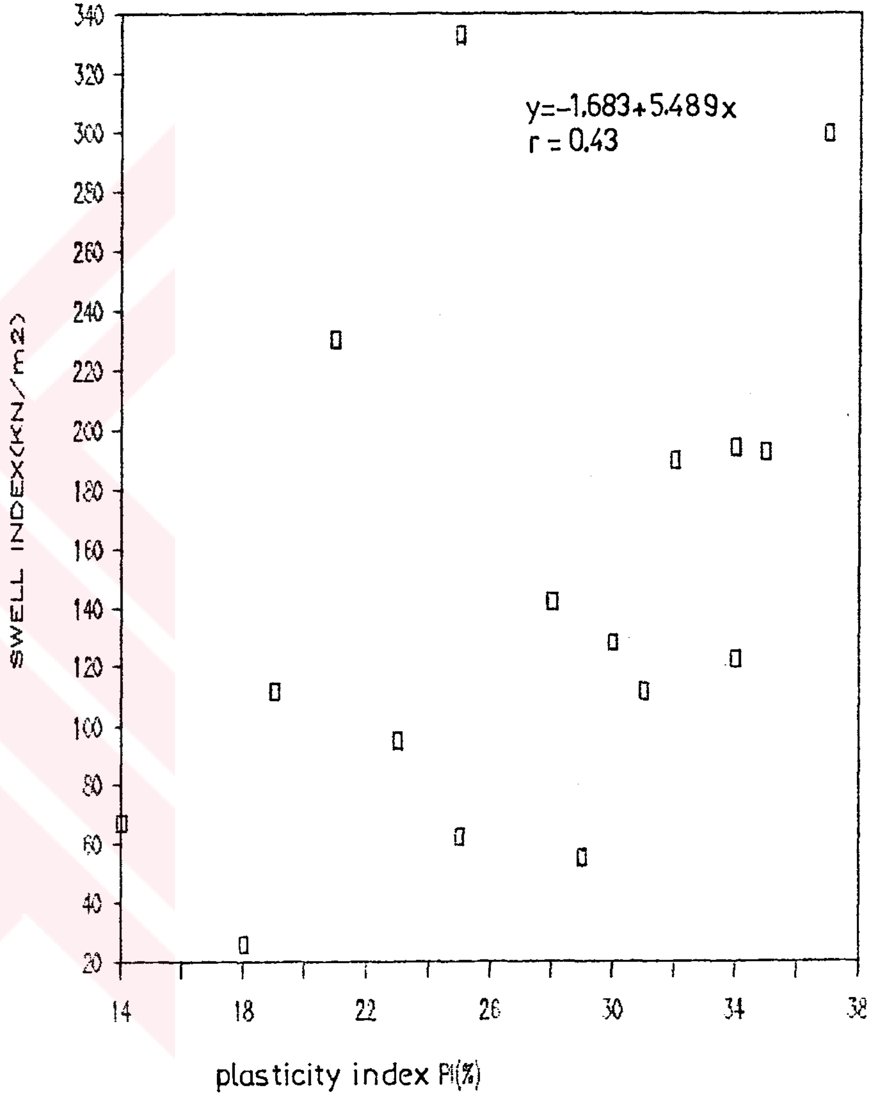


Fig.8.61.a. SI ve PI Relationship for Alluvial Soils

Table 8.4 . Comparison of Correlation Coefficients For Various Relationships on Terrace Deposits and on Alluvial Soils

Relationship	Correlation Coefficient (r)	
	Terrace Deposits	Alluvial Soils
MB Value-LL	0.69	0.80
MB Value-PL	0.16	0.42
MB Value-PI	0.75	0.64
MB Value-CC	0.66	0.31
MB Value-Activity	0.49	0.66
Spec.Surf.-LL	0.69	0.80
Spec.Surf.-PL	0.16	0.42
Spec.Surf.-PI	0.75	0.64
Spec.Surf.-CC	0.66	0.31
Swell Index-CC	0.63	0.05
Swell Index- MB Value	0.77	0.79
Swell Index/CC - MB Value	0.58	0.56

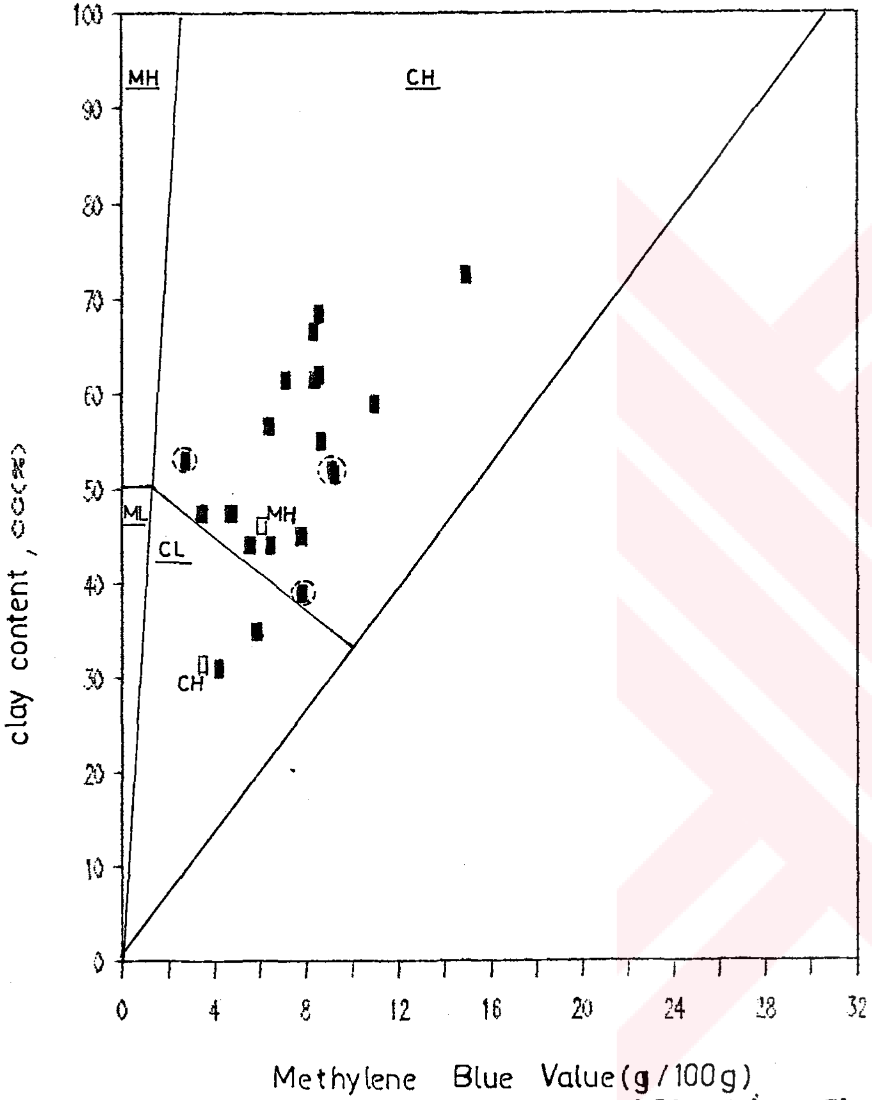


Fig.8.62.b. CC ve MBV Soil Classification Chart (Terrace Deposits)

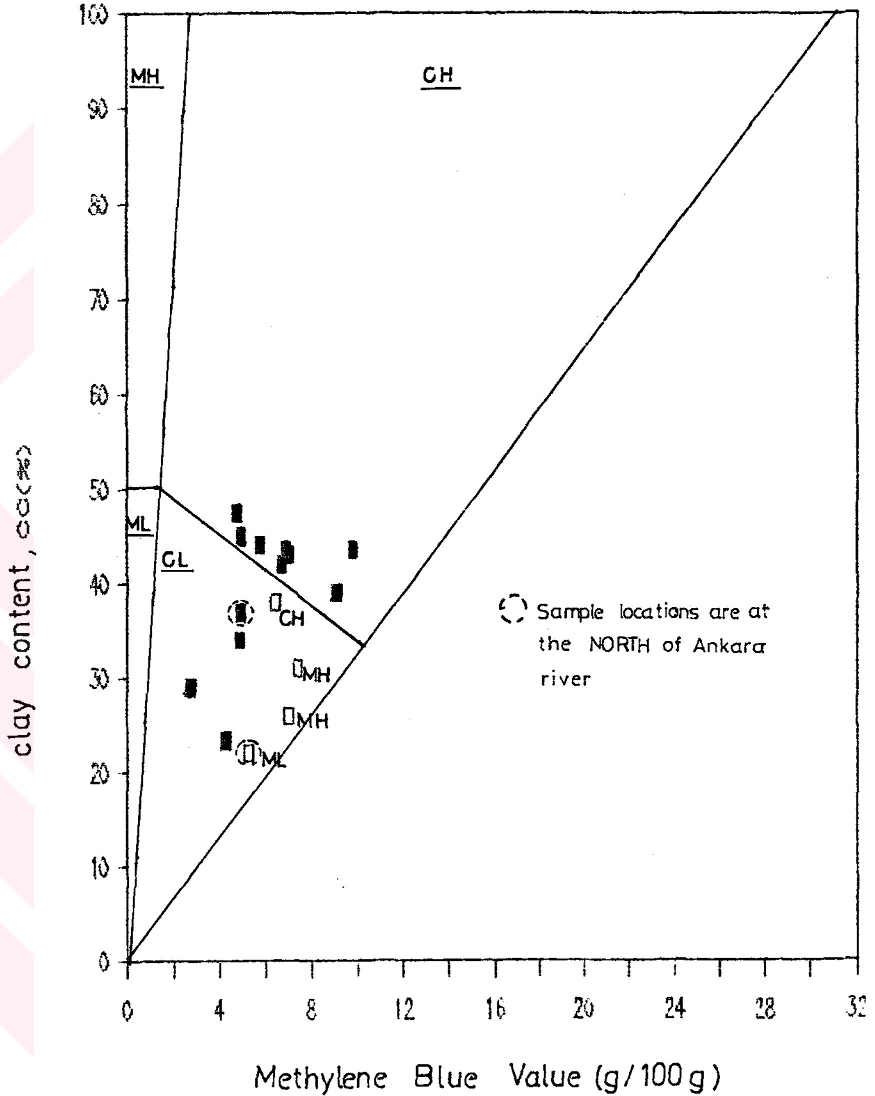


Fig.8.62.a. CC vs MBV Soil Classification Chart (Alluvial Soils)

were separated into regions according to Magnan and Youssefian (1989), in these figures ■ points show the accordance of unified soil classification and Magnan and Youssefian classification (84 % of the data), □ ones show the inaccordance between the two classification methods (16 % of the data).

In Figs. 8.63.a and 8.63.b soil samples were first classified according to Seed's (1962) swell potential classification. In general, the ■ points which show samples with very high swell potential are in the middle portion of clay with high activity zone (Ata), □ points which show samples with high swell potential are mostly in the lower portion of the clay with high activity zone (Ata), ● points show samples with medium swell potential are in the upper portion of the silt with high activity zone, o points which show the samples with low swell potential are in the middle portions of silt with high activity and silt with moderate activity zones.

Distribution of points given by Author in Magnan and Youssefian's (1989) chart according to their swelling potential (Seed et al., 1962) values are given in Table 8.5.

By the help of Figs. 8.30, 8.45, 8.63.a and 8.63.b (i.e. very high, high, medium and low swelling potential regions were separated by plotting all of the data on Magnan and Youssefian's (1989) chart), the Swelling Potential Classification Chart shown at Fig. 8.64 was proposed.

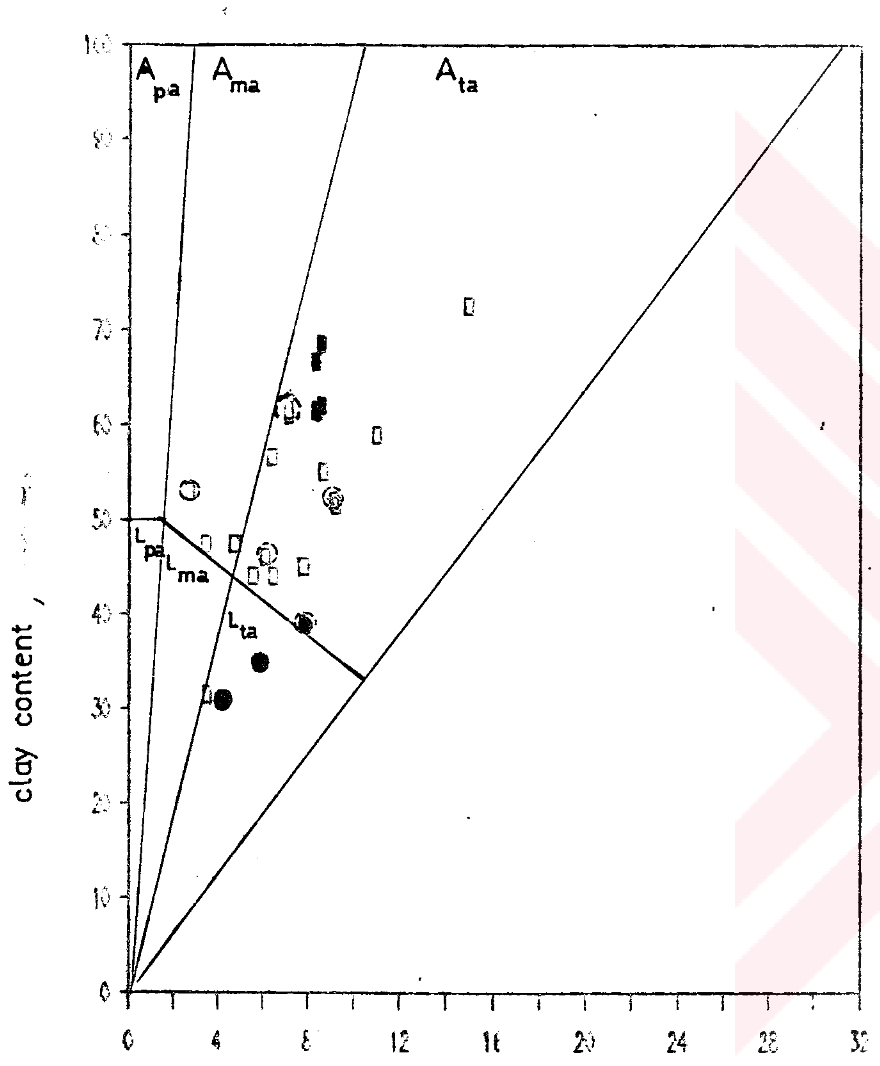


Fig. 8.63.b CC vs MBV Chart (Terrace Deposits)

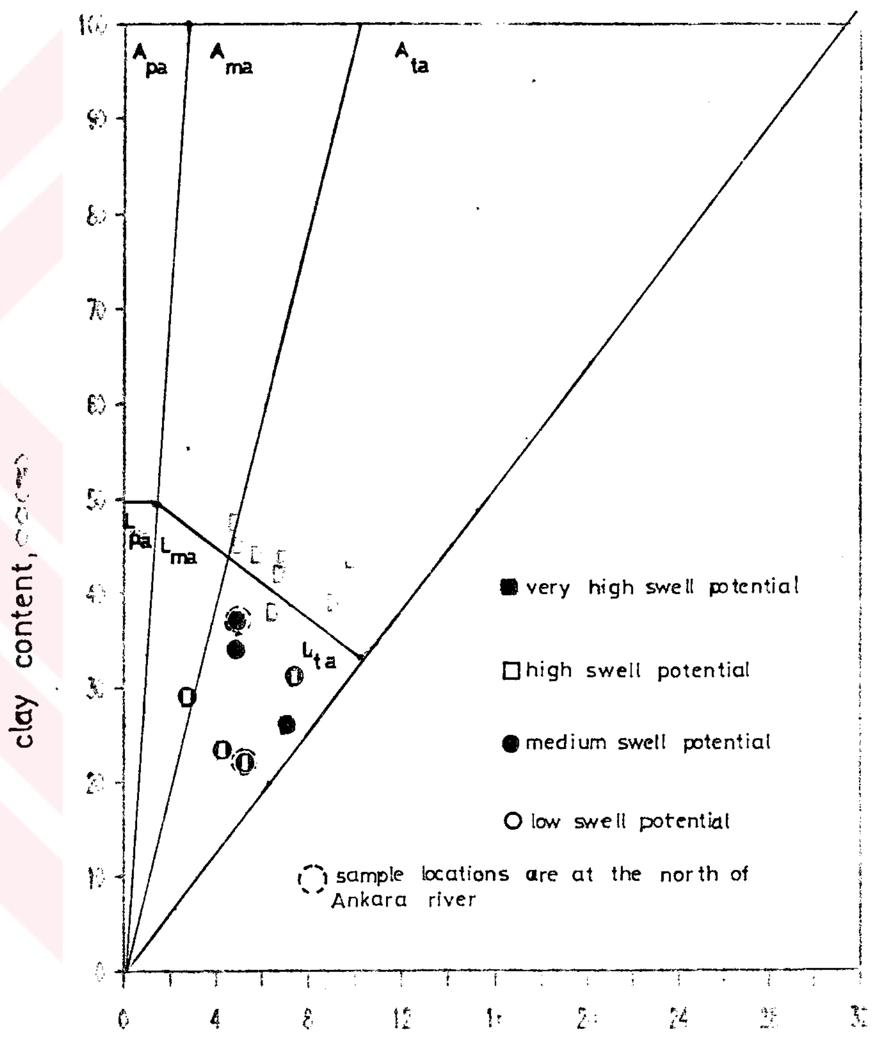


Fig. 8.63.a CC vs MBV Chart (Alluvial Soils)

Table 8.5. Distribution of Points Given by Author in Magnan and Youssefian's (1989) Chart According to Their Swelling Potential (Seed et al, 1962) Values

Zone in Magnan and Youssefian's (1989) Chart	Distribution of Points (%)			
	Very High Swell Potential	High Swell Potential	Medium Swell Potential	Low Swell Potential
Ata	17	78	5	-
Ama	-	100	-	-
Apa	-	-	-	-
Lta	-	20	50	30
Lma	-	-	-	100
Lpa	-	-	-	-

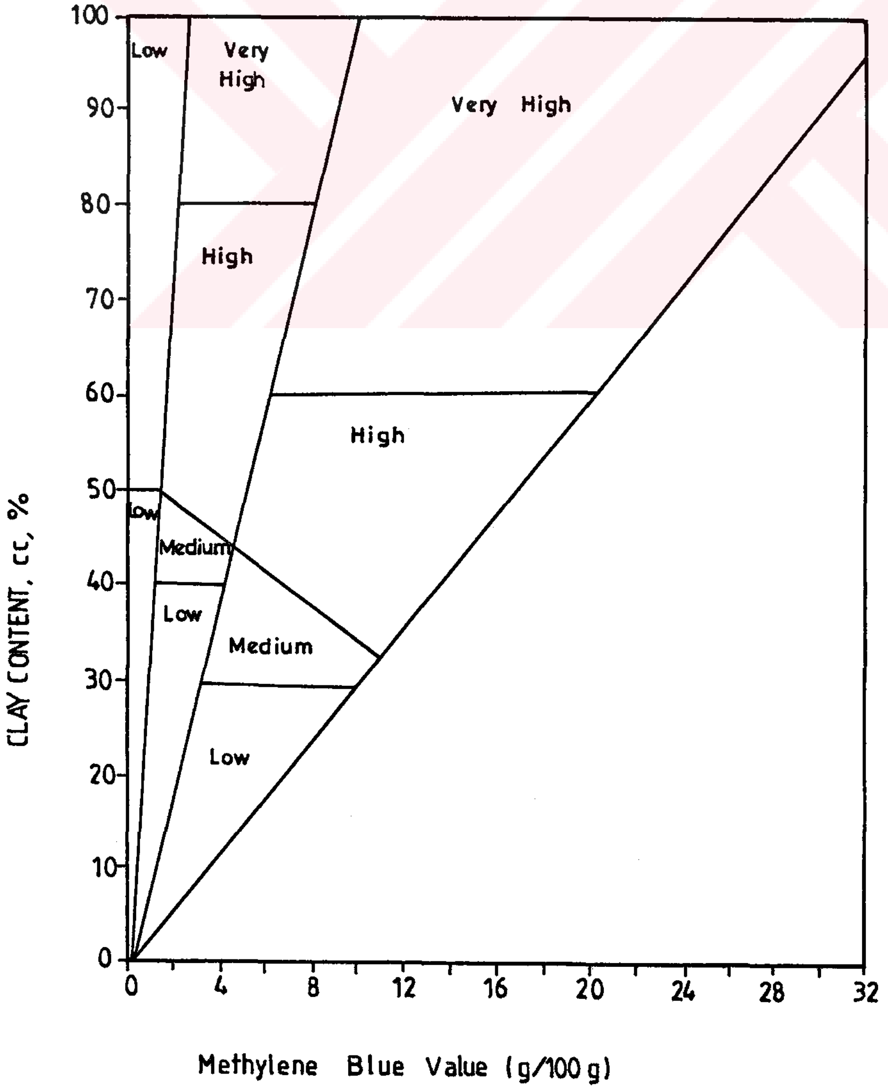


Fig. 8.64. Swelling Potential Classification Chart (Proposed by the Author)

CHAPTER 9

GENERAL DISCUSSIONS AND CONCLUSIONS

The present investigation has resulted in developing a quick and easy method for classification of potentially swelling soils. Data on swelling potential properties of different soil formations in Ankara, namely Pliocene - Pleistocene Fluvial Lacustrine deposits (Terrace Deposits) and Recent Alluvial Deposits were obtained. 22 remolded samples were taken from terrace deposits , 16 remolded samples were taken from alluvial deposits and 2 remolded samples were taken from residual soils. Index, PVC meter, X-ray tests on the one hand and methylene blue (spot test) tests were performed on the other to classify Ankara soils for their swelling potential properties, and to assess the possibility of using the latter for swell potential determination.

Data from previous studies (Atterberg limits, clay content, X-ray test results) on Ankara soils , data from foreign researchers (Atterberg limits, clay content, X-ray and methylene blue test results) in foreign countries and data (index, clay content, swell index, methylene blue, x-ray tests results) obtained from tests which were performed on commercially pure samples (kaolinite, illite, montmorillonite) by the Author were also evaluated for the same purpose.

9.1. General Discussions

Discussions on the General Swell Behaviour of Ankara Soils:

In this study, swelling potential of soil samples were determined by using remolded samples.

The X-ray analysis had shown that the clay fraction of the Ankara clay samples (7 samples) were composed, on the average, of 64 % montmorillonite, 27 % illite, 9 % kaolinite and chlorite, and alluvial soil samples (4 samples) were composed, of 44 % montmorillonite,40 % illite, 12 % kaolinite and chlorite. These results obtained by the Author are in accordance with Kasapoğlu's(1980) and Kiper's (1983) findings on Ankara soils. But these findings are not completely in accordance with the findings of Söylemez (1972), this difference may be due to the limited number of data used in these studies.

From Figs. 8.7. a and b, it is seen that for the upper 2 m deep alluvial soils and terrace deposits are in semi-solid state, below this depth they are in plastic state.

As it is seen from Figs. 8.5.a and 8.5.b., 91 % of the alluvial soil samples (34 % in CH range, 57 % in CL range) and 83 % of the terrace deposits samples (69 % in CH range, 14 % in CL range) fall above A-line.

When the average plasticity index and clay content ranges given by Sürgel (1976) were plotted on Birand's classification chart (Fig.7.8), Sürgel(1976)'s ranges are generally compatible with Birand's ranges, but in this study, some of the terrace deposits samples fell into the alluvial soil range on Birand's classification chart; this may be due to the local alluvial deposits in the terrace deposits regions.

From Fig.7.1, it can be seen that 84 % of the alluvial soils are overconsolidated (or heavily overconsolidated) and from Fig.7.2 97 % of terrace deposits are overconsolidated (or heavily overconsolidated). This finding verifies the previous studies on overconsolidation of Ankara soils. Two different views about the cause of overconsolidation load of Ankara soils are presented with their reasoning.

Birand (1963) states that the Skempton's original definition of activity as A_c =PI/CC is applicable to natural Ankara clays. In this study, this definition of activity was used.

It is found that Seed et.al's (1962) definition of swelling potential is valid for undisturbed Ankara clay and for alluvial soils (Figs. 8.12 and 8.13).

From Figs 8.10 and 8.11 , it is seen that, generally terrace deposits samples show higher swell potential values than Alluvial soil samples. This behaviour can be seen from Figs. 8.63.a and 8.63.b too.

Since the limestone formations cover a larger area in the south of Ankara river with respect to the north of Ankara river, occurrence of calcareous concretions in the terrace deposits are higher in the south of Ankara river than in the north of Ankara river. Ordemir et. al (1977) states that the swelling potential decreases with increasing lime content. Therefore swelling potential of terrace deposits at the south of Ankara river should be less than the swelling potential of terrace deposits at the north of of Ankara river, but no definite conclusion could be reached on this subject.

From Fig. 8.46 it is seen that the mineralogical composition of the clay affects the swelling of the clays. Clays with high cation exchange capacities have higher swelling index values than those with lower cation exchange capacities. Similarly, from Fig.8.47 it can be seen that clays with high specific surface area values have higher swelling index values than those with lower specific surface area values.

Figs. 8.12 and 8.13 show that the swelling potential of Ankara soils increase as the plasticity index increases.

From Figs. 8.63.a and 8.63.b, it is seen that increase in percentage of soil finer than 2 microns increases swelling potential.

Figs. 8.15 and 8.16 show that as the dry densities of the soil samples increase, their natural moisture content decreases and hence swelling potential increases.

Omay's (1970) field swell observations were compared with the percent swell equation proposed by the author; the results seem to be compatible with each other, but since the number of field observations are limited no concrete conclusion could be reached.

Discussions on the Methylene Blue Test:

As stated by Lan (1977) Methylene Blue test permits to qualify the clay fraction without separating clay fraction from the rest of the soil which is difficult in practice.

Lan's (1980) statement " the quantity of methylene blue adsorbed by the mixture of clay minerals is equal to the summation of the methylene blue adsorbed by each mineral " was verified by using commercially pure samples.

The determination of end of test, by using methylene blue (SPOT) test is simpler than the methylene blue test method proposed by Hang and Brindley (1970).

In this study, the water content of the dye (MERCK, $C_{16}H_{12}N_3SCl \cdot 3\text{-}4\ H_2O$) was estimated as stated by Robertson and Ward (1951) and the small amount of chemical impurity which is found in the best grades of methylene blue was neglected.

As stated by Nevins and Weintritt (1967) organic materials in the sample were either not troublesome or could be readily eliminated with hydrogen peroxide. In this study hydrogen peroxide treatment was not used (i.e. methylene blue tests were performed according to the instructions of AFNOR P18-592 standard).

Also, temperature changes cause structural changes in the clay and these cause changes in the methylene blue capacity, therefore all the tests were tried to be performed under the same temperature conditions. Before performing the methylene blue test, soil specimens were dried in the oven for 24 hours (temperature of the oven was around 100 °C) and methylene blue tests were performed under the room temperature (i.e. 20-24 °C).

In this study, the relationships between methylene blue test result, mineralogy and specific surface area were verified by evaluating the test data on methylene blue test given by foreign researchers in section 8.5.2.

Hills and Pettifer (1985) state that the particle size of the test sample affects the methylene blue test results, to get rid of this effect and for uniformity of the test results, all the samples were sieved through No. 40 sieve (400 μm) before performing the methylene blue test.

Beaulieu (1979) showed the effect of time of immersion of the material in distilled water (before performing the methylene blue test) on the specific surface area. In this study, samples were not left in distilled water before performing the methylene blue test to get rid of this effect.

Nevins and Weintritt (1967) stated that simple and rapid methylene blue dye method gave c.e.c. values reasonably close to those determined by time consuming, tedious ammonium acetate method.

Phelps and Harris (1968) state that the specific surface area values determined by N_2 and H_2O adsorption methods give different values for montmorillonitic clays. So, while comparing the specific surface area values determined from the methylene blue test results and from the other methods, such possible differences should be kept in mind.

Brindley and Thomson (1970) stated that the surface area measured by methylene blue is 100 % for Na-montmorillonite, but only 20 to 70 % for Ca-montmorillonite, low specific surface area values of the soil samples in this study may be due to inadequate expansion of montmorillonite sheets.

Taylor (1985) states that with smectites, the methylene blue molecule lies flat on the surface, so that if the lattice is not fully expanded there will be a cover up effect because the molecule has a larger surface area than that associated with the exchange site.

Since the specific surface area of montmorillonite is much greater than kaolinite and illite, even a small amounts of montmorillonite gives larger specific surface area, and this indicates the presence of montmorillonite (Lautrin, 1987) and hence the swelling potential of the soil. So inadequate expansion of montmorillonite sheets is not very important for our study.

Fairbairn and Robertson (1957) stated that for a given site methylene blue can be used as a convenient substitute for liquid limit (LL) provided that the two methods are calibrated. In this study, the correlation coefficients (r) of the methylene blue values versus LL relationship for alluvial soils is 0.8 and for terrace deposits is 0.69, these values are not too high. This may be due to very large areas of sites.

Lan (1977) gave a correlation between plasticity index and methylene blue value (for 32 data).The correlation coefficient of this relationship was not given, but it seems to be not very high. In this study correlation coefficients (r) of methylene blue value - plasticity index relationship for alluvial soils is 0.64 and for terrace deposits is 0.75.

When the 14 data which contain montmorillonite percent in Appendix J2 were plotted on Lautrin's (1987) Hazard Coefficient Chart, it was seen that most of the points did not fall into the regions proposed by Lautrin (1987), but Lautrin (1987) stated that this chart is experimental and open to all readjustments. So , in this study this chart was not used to classify the soils.

In Figs. 8.62.a and 8.62.b, clay contents and methylene blue values of alluvial soils and of terrace deposits were plotted on Magnan and Youssefian's (1989) soil classification chart. As it can be seen from Figs. 8.62.a and 8.62.b, for most of the data, soil classification by using plasticity chart (i.e. Unified

System) and Magnan and Youssefian's (1989) chart are compatible with each other.

The correlation coefficient of the Swelling Index versus methylene blue value relationship is high (r=0.97) for pure minerals, but for alluvial soils and terrace deposits are not high (r=0.79 for alluvial soils, r= 0.77 for terrace deposits).

The correlation coefficients obtained from the relationships of pure samples are higher than the correlation coefficients obtained from the relationships of natural samples. It is quite possible that the pure mineralogy of artificial clays as against the complex mineralogy of natural clays is responsible for the variations.

9.2. Conclusions

The following main conclusions can be drawn on the basis of the present study:

Conclusions on the general swell behaviour of Ankara soils:

1 . The expansive nature of Ankara soils may be attributed to the seasonal swell- shrink phenomenon experienced in semi- arid regions.

2 . Terrace deposits have higher swell parameters than alluvial soils.

3 . Large volume of data collected by other researchers for Ankara soils incluiding Atterberg limits, clay

content and X-ray values have been used to evaluate swelling potential of these soils by different swelling potential classification methods. For the same soil sample these classification methods may give different swelling potential values. Therefore such correlations have to be derived locally.

Conclusions on the methylene blue test results:

4. The study confirmed the influence of the mineralogical composition as a controlling factor governing the swelling potential of expansive clayey soil.

5. Methylene blue test may be used as an indirect method for indication of the mineralogical composition of a clay.

6. Methylene blue test seems to be short, easy and reliable test to determine specific surface area and cation exchange capacities of samples.

7. The grouping of soils according to their potential expansiveness could be better if based on the clay content and methylene blue value of the clayey soil. The proposed relationships eliminate the need for difficult sampling and testing and provide acceptable data for initial procedures. The Swelling Potential Classification Chart (Fig. 8.64) can be used for this purpose.

8. Methylene blue test would be used for the identification of mineralogical composition of soils, but this could not be achieved (because the mineral percentages of only 13 samples could be obtained)

9.3. Recommendations for Future Research:

Following recommendations are given as a guide for future research:

Estimated % heave equation given in Appendix L should be checked by using more field heave measurements.

The relationship between mineral percentage and methylene blue value should be found more precisely.

Affect of lime content on the methylene blue test result should be studied in more detail.

Affect of physicochemical and microstructural characteristics of a soil on methylene blue test result should be studied in more detail.

REFERENCE LIST

Abbasoğlu, C., 1971, " Ion Exchange Process Affecting Swelling and Other Properties of Ankara Clay ", M.S. Thesis, METU, Civil Engineering Department, 78 pages.

Akbay, Ö.Ü., 1972, " The Influence of Saturation on Volume Change Characteristics of Ankara Clay Under Various Surcharge Pressures", M.S. Thesis, METU, Civil Engng. Dept., 53 pages.

Arda, S.,1966, " Preconsolidation of Ankara Clay", M.S. Thesis, METU Civil Engng Dept., 58 pages.

Bandyopadhyay, S.S., 1981, " Prediction of Swelling Potential for Natural Soils", Proc. ASCE J. GE Div., Vol.107, No.5, pp.658-661.

Beaulieu, J., 1979, " Identification Géotechnique de Matériaux Argileux Naturels Par La Measure de Leur Surface au Moyen du Bleu de Methylène", These Pour Obtenir le Titre de Docteur 3ė Cycle, L'Universite de Paris-Sud, Centre d'Orsay, 132 papiers.

Bensted, J., 1985, " Application of the Methylene Blue Test to Cement Raw Materials", J. Chem. Tech. Biotechnol., 35A, pp.181-184.

Birand, A., 1963, " Study of the Characteristics of Ankara Clays Showing Swelling Properties", M.S. Thesis, METU, Civil Engineering Department, 40 pages.

Birand, A., 1965, "Recent Views on the Behaviour of Clay- Water Systems ", METU, Faculty of Engineering, Publication no. 11 , 18 pages.

Birand, A.A., 1976 a, " Presentation of a Case of Damage to an Airfield Pavement", METU Journal of Pure and Applied Sciences, Vol.9, No.1, pp.99-111.

Birand, A.A., 1976 b, " Propensity to Water Intake- A Method for the Prediction of the Expansiveness of Soils", METU Journal of Pure and Applied Sciences, Vol.9, No.3, pp.367-397.

Birand, A.A., 1977, " Ankara Yöresi Zeminlerde Ön Yükleme İsotropisi", 4. Tübitak Teknik Kongresi, Altınyunus, İzmir, pp.277-287.

Birand, A., 1978 a, "Ankara Yöresi Zeminleri ve Jeoteknik Sorunlar", Yerbilimleri Açısından Ankara'nın Sorunları Sempozyumu, Türkiye Jeoloji Kurumu, ss.55-60.

Birand, A.A., 1978 b, " A Contribution to the Double Oedometer Testing of Expansive Soils", A Half Century in Geotechnics Jubilee Papers in Honour of Prof. A. Hamdi Peynircioglu, Edited by E. Toğrol , İstanbul, pp.169-181.

Blight, G.E. and Williams, A.B., 1971, " Cracks and Fissures by Shrinkage and Swelling", Fifth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Luanda, Angola, (Portugusse West Africa), August, pp.1-7.

Brackley, I.J.A., 1983, " An Emprical Equation For the Prediction of Clay Heave", Proc. 7th Int. Asian Reg. Conf. on Soil Mechanics and Foundation Engineering, Vol.1, pp.8-14.

Brindley, G.W. and Thompson, T.D., 1970, " Methylene Blue Adsorption by Montmorillonites. Determination of Surface Areas and Exchange Capacities With Different Initial Cation Saturations (Clay-Organic Studies XIX), Israel Journal of Chemistry, Vol.8, pp. 409-415.

Brooks, C.S., 1964, " Mechanism of Methylene Blue Dye Adsorption on Siliceous Minerals", Kolloid Zeitschrift, Vol.199, No.1, pp.31-36.

Burland, J.B., , " Some Aspects of the Mechanical Behaviour of Partly Saturated Soils", Moisture Equilibrium and Moisture Changes in Soils Beneath Covered Areas, Australia, Butterworths, pp.270-278.

Chen, F.H.,1975. "Foundations on Expansive Soils", Elsevier Scientific Publishing Company, Amsterdam-Oxford- New York ,280 pages

Çalışan, Ö.F., 1987, " A Study on Volume Change Behaviour of Silt Added METU Clay", M.S. Thesis, METU Civil Engng. Dept., 55 pages.

Daksanamurthy, V. and Raman, V., 1973, " A Simple Metho of Identifying an Expansive Soil", Soils and Foundations, Japanese Society of Soil Mechanics and Foundation Engineering, Vol.13, No.1, pp.97-104.

Damla, Ö.R., 1976, " Prediction of Swelling Potential and Swelling Pressure From the Double Oedometer Test", M.S. Thesis, METU, Civil Engng. Dept., 33 pages.

Dawson, R.F., 1959, " Modern Practices Used in the Design of Foundations for Structures on Expansive Soils", Quarterly of the Colorado School of Mines, Vol.54, No.4., Oct., pp.67-87.

De Bruyn, C.M.A., Collins, L.E. and Williams, A.A.B., 1957, " The Specific Surface, Water Affinity and Potential Expansiveness of Clays", Clay Minerals Bulletin, Vol.3, pp.120-128.

Dhowian, A.W., Ruwaih, I.E., Youssef, A.F. and Erol, O.,1984, "Evaluation of Expansive Soils and Foundation Methodology in the Kingdom of Saudi Arabia ", First Progress Report, Saudi Arabian National Center for Science and Technology, Contract No. AT-5-88, 253 Pages.

Doruk, M., 1968, " Swelling Properties of Clays on the METU Campus", M.S. Thesis, METU, Civil Engng. Dept., 46 pages.

Driscoll, R., 1953, " The Influence of Vegetation on the Swelling and Shrinking of Clay Soils in Britain", Geotechnique, Vol.33, No.2, pp.93-105.

El-Sohby, M.A. and Mazen, D., 1983, " Mineralogy and Swelling of Expansive Clayey Soils", Geotechnical Engineering, Vol.14, pp.79-87.

Emodi, B.S., 1946, " The Adsorption of Dyestuffs by Montmorillonite", Clay Minerals Bull., 3, pp.76-79.

Erol, O., 1990, " Gercek Kabarmaların Sişme-Ödometre Metodu ile Karşılaştırılması ", Zemin Mekaniği ve Temel Mühendisliği Üçüncü Ulusal Kongresi, Boğaziçi Üniversitesi, Cilt 1, ss.1-8.

Fairbairn, F.E. and Robertson, R.H.S., 1957 " Liquid Limit and Dye Adsorption", Clay Minerals Bulletin, Vol.17, 3., pp.129-136.

Fourin, L., Millon-Devigne, P. and Lan, T.N., 1989, "Essai au Bleu et Nocivité des Montmorillonites dans les Matériaux Composites", Bulletin de L'Association Internationale de Géologie de l'Ingénieur, No.40, Paris, pp.91-96.

Furtun, U., 1989, " An Investigation on Ankara Soils With Regard to Swelling", M.S. Thesis, METU, Civil Engng. Dept., 151 pages.

Grim, R.E., 1953. "Clay Mineralogy ", Mc Graw- Hill Series in the Geological Sciences

Gromko, G.J., 1974, " Review of Expansive Soils", J. of the Geotechnical Engineering Division, ASCE, GT6, June, pp.667-687.

Gürpınar, A., 1979, " Introduction to Statistical Methods in Engineering", Dept. of Engineering Science, METU, Ankara, Vol.1, 182 pages.

Hang, P.T. and Brindley, G.W., 1970, " Methylene Blue Adsorption by Clay Minerals. Determination of Surface Areas and Cation Exchange Capacities (Clay-Organic Studies XVIII) ", Clays and Clay Minerals, Vol.18, pp.203-21

Hardy, R.M., 1965, " Identification and Performance of Swelling Soil Types", Canadian Geotechnical Journal, Vol.11, No.2, May, pp.141-1

Higgs, N.B., 1988, " Methylene Blue Adsorption as a Rapid and Economical Method of Determining Smectite", Geotechnical Testing Journal, Vol.11, No.1, March, pp.68-71.

Hills, J.F. and Pettifer, G.S., 1985, " The Clay Mineral Content of Various Rock Types Compared With the Methylene Blue Value", J. of Chemical Technology Biotechnol. Chem.-Tech., 35A, pp.168-180.

Holtz, W.G., 1959, " Expansive Clays- Properties and Problems", Quarterly of the Colorado School of Mines, Vol.54, No.4, Oct., pp.89-125.

Jaeger, J.C., 1978, " Elasticity, Fracture and Flow With Engineering and Geological Applications", Chapman and Hall, 268 pages.

Jones, O.F., 1964, " New Fast, Accurate Test Measure", The Oil and Gas Journal, June, pp.76-78.

Jones, D.E. and Holtz, W.G., 1973, " Expansive Soils- The Hidden Disaster", Civil Engineering, Vol.43, No.8, pp.49-51.

Kasapoğlu, K.E., 1980, " Ankara Kenti Zeminlerinin Jeomühendislik Özellikleri", Doçentlik Tezi, Hacettepe University, Geological Engineering Department, Beytepe, Ankara.

Kaynar, A.T., 1972, " Ratio of Swelling Index to Compression Index in Clay Soils" , MS Thesis, METU, Civil Eng. Dept., 76 pages.

Kılıç, R., (1990), " Zemin Bilesimi ile Kayma Dayanımı Arasındaki İlişki; Üst Pliyosen Çökelleri (Ankara)", Jeoloji Mühendisliği, s.36, s.47-54.

Kiper, O.B., 1983, " Etimesgut-Batıkent Yöresindeki Üst Pliosen Çökellerinin Jeomühendislik Özellikleri ve Konsolidasyonu", Ph.d. Thesis, Hacettepe University, Ankara.

Kocabayoğlu, E., 1971, " Contribution of Desiccation to the Preconsolidation of Ankara Clay ", M.S. Thesis, METU Civil Engng. Dept., 18 pages.

Ladd, C.C. and Lambe, T.W., 1961, " The Identification and Behaviour of Compacted Expansive Clays", Proc. 5th Int. Conf. on Soil Mech. and Found. Eng., Paris, pp.201-205.

Lambe, T.W., 1958, " The Structure of Compacted Clay ", J. of the Soil Mechanics and Foundation Division, Proc. of the ASCE, Vol.84, No.SM2, part 1, pp.(1654-1)- (1654-34).

Lambe, T.W. and Whitman, R.V., 1959, " The Role of Effective Stress in the Behaviour of Expansive Soils", Quarterly of the Colorado School of Mines, Vol.54, No.4, pp.33-61.

Lambe, T.W., 1960, " The Character and Identification of Expansive Soils (Soil PVC Meter)", A Report Completed for The Technical Studies Program of The Federal Housing Administration, MIT, 46 Pages.

Lambe,T.W. and Whitman, R.V., 1969, Soil Mechanics, SI Version", John Wiley and Sons, New York.

Lan, T.N., 1977, " Un Nouvel Essai d'Identification des Sols. L'Essai au Bleu de Méthylène, Bull. Liaison Labo. P. et Ch., 88, Mars-Avr., pp.136-137.

Lan, T.N., 1980, " L'Essai au Bleu de Méthylène, Un Progrès dans la Mesure et le Contrôle de la Propreté des Granulats ", Bull. Liaison Labo. P. et Ch., 107, Mai-Juin, pp.130-135.

Lan, T.N., 1981, " Utilisation de L'Essai au Bleu de Méthylène en Terrassement Routier" , Bull. Liaison Labo. P. et Ch., 111, Janv.-Fevr., pp.5-16.

L'Association Francaise De Normalisation (AFNOR), Juillet 1980, "Essai Au Bleu De Méthylène", P18-592, Afnor 80181, Paris La Defence.

Lautrin, D., 1987, " Une Procédure Rapide d'Identification des Argiles", Bull. Liaison Labo. P. et Ch., 152, Nov.-Dec., pp.75-84.

Lautrin, D., 1989, " Utilisation Pratique des Paramèters Dérivés de L'Essai au Bleu de Méthylène dans les Projets de Génie Civil", Bull. Liaison Labo. P. et Ch., 160, Fevr.-Mars., pp.53-65.

Locat, J., Lefebvre, G. and Ballivy, G., 1984, "Mineralogy, Chemistry and Physical Properties Interrelationships of Some Sensitive Clays From Eastern Canada", Can. Geotech., J.21, pp.530-540.

Magnan, J.P. and Youssefian, G., 1989, " Essai au Bleu de Méthylène et Classification Géotechnique des Sols", Bull. Liaison Labo. P. et Ch., 159, Janv.- Fevr., pp.93-103.

McDowell, c., 1959, " The Relation of Laboratory Testing to Design for Pavements and Structures on Expansive Soils", Quarterly of the Colorado School of Mines, Vol. 54, No.4, Oct., pp.127-153.

Means, R.E., 1959, " Buildins on Expansive Clay", Quarterly of the Colorado School of Mines, Vol.54, No.4, Oct., pp.1-31.

Mitchell, J.K., 1976, "Fundamentals of Soil Behaviour", John Wiley and Sons, Inc., New york - London - Sydney-Toronto, 422 pages.

Nevins, M.J. and Weintritt, D.J., 1967, "Determination of Cation Exchange Capacity by Methylene Blue Adsorption", Ceramic Bulletin, Vol.46, No.6, pp.587-592.

Omay, B., 1970, " Swelling of Clays on METU Campus", M.S. Thesis, METU, Civil Engng. Dept., 73 pages.

Ordemir, İ., Alyanak, I. and Birand, A.A., 1965, "Report on Ankara Clay", METU, Publication No.12, Ankara, 30 pages.

Ordemir, I., Soydemir, C., Birand, A., 1977, " Swelling Problems of Ankara Clays", 9th. Intenational Conferen. on Soil Mechanics and Foundation Engineering, Tokyo, Vol.1, pp.243-247.

Öner,M. and Birand, A., 1978, " Effect of an Impervious Surface Cover on the Soil Suction Equilibrium", METU Journal of Pure and Applied Sciences, Vol.10, No.2, pp.207-222.

Özkan, Y., 1987, " Killi Zeminlerde Kuruma Etkisiyle Meydana Gelen Fisür ve Çatlaklar ", Zemin Mekaniği ve Temel Mühendisliği İkinci Ulusal Kongresi, Boğaziçi Üniversitesi, Cilt I, pp.201-218.

Özmelek, A.İ., 1984, " An Investigation of the Concept of Equilibrium Moisture Distribution and the Effect of Climatic Factors on Subgrade Moisture Conditions", M.S. Thesis, METU Civil Engng. Dept. , 197 pages.

Peterson, R. and Peters, N., 1963, " Heave of Spillway Structures on Clay Shales", Canadian Geotechnical Journal, Vol.1, No.1, Sept., pp.5-15.

Phelps, G.W. and Harris, D.L., 1968, " Specific Surface and Dry Strength by Methylene Blue Adsorption", Ceramic Bulletin, Vol.47, No.12, pp.1146-1150.

Robertson, R.H.S. and Ward, R.M., 1951, " The Assay of Pharmaceutical Clays ", Journal of Pharmacy Pharmacology, Vol.3, pp.27-35.

Schreiner, H.D.,1987. "State of the Art Review on Expansive Soils ", Imperial College of Science and Technology, London, 113 pages.

Seed, H.B., Woodward, R.J. and Lundgren, R., 1962, "Prediction of Swelling Potential for Compacted clays", Journal of the Soil Mechanics and Foundations Division, Proc. of the ASCE, pp.53-87.

Shiming, H., 1984, " Identification of Expansive Soils by Specific Surface Area Values ", Fifth Int. Conf. on Expansive Soils, Adelaide, South Australia, May 21-23, pp.1-3.

Skempton, A.W., 1953, " The Colloidal Activity of Clays", Proc. of the 3rd Int. Conf. on Soil Mech. and Found. Engng., Zurich, Vol.1, pp. 57-67.

Snethen, D.R., 1984, "Evaluation of Expedient Methods For Identification and Classification of Potentially Expansive Soils", Fifth International Conference on Expansive Soils, Adelaide, South Australia, pp.22-26.

Söylemez, N., 1972, " Mineralogical Analysis of Ankara Clay by X-Ray Diffraction ", M.S. Thesis, METU Civil Engng. Dept., 89 pages.

Stoffers, P. and Muller, G., 1972, " Clay Mineralogy of Black Sea Sediments", Sedimentology, 18, pp.113-121.

Sürgel, A., 1976, " A Survey of The Geotechnical Properties of Ankara Soils", M.S. Thesis, METU Civil Engineering Department , 96 Pages.

Taylor, R.K., 1985, "Cation Exchange in Clays and Mudrocks by Methlene Blue", J. Chem. Tech. Biotechnol., 35A, pp.195-207.

Tourenq, C. and Lan, T.N., 1989, " Mise en Évidence des Argiles par L'Essai au Bleu de Méthylène", Bull. Liaison Labo. P. et Ch., 159, Janv.-Fevr., pp.79-92.

Vijayvergiya, V.N. and Ghazzaly, O.I., 1973, "Prediction of Swelling Potential For Natural Clays", Proc. 3rd Int. Conf. on Expansive Soils, Haifa, Israel, Vol.1, pp.227-236.

Ward, W.H., 1953, " Soil Movement and Weather", Proc. 3rd Int. Conf. on Soil Mech. and Found. Eng. , Zurich, Vol.1, pp.477-482.

Worrall, W., 1958, " Adsorption of Basic Dyestuffs by Clays ", Trans. Brit. Ceram. Soc., Vol.47, pp.210-17.

Yanıkömeroğlu, K., 1990, " Effect of Lateral Confinement on Swell Behaviour", M.S. Thesis, METU, Civil Engng. Dept., 105 pages.

Yevnin, A. and Zaslovsky, D., 1970, " Some Factors Affecting Compacted Clay Swelling", Canadian Geotechnical Journal, Vol.7, Part 1, pp.79-89.

Yüncü, H., 1972, " An Investigation of Volume Change of Ankara Clay", M.S. Thesis, METU, Civil Engng. Dept., 52 pages.

APPENDICES

APPENDIX A

Two Dimensional Griffith Criterion (Jaeger, 1978; Özkan, 1987)

If σ_1 and σ_3 show principal stresses, T_o shows uniaxial tensile strength and C_o shows unconfined compressive strength then,

$\sigma_1 + 3\sigma_3 > 0 \qquad (\sigma_1 - \sigma_3)^2 = 8T_o(\sigma_1 + \sigma_3)$ (23)

$\sigma_1 + 3\sigma_3 < 0 \qquad \sigma_3 = -T_o$ (24)

$\sigma_3 = 0 \qquad \sigma_1 = C_o$ then $C_o/T_o = 8$ (25)

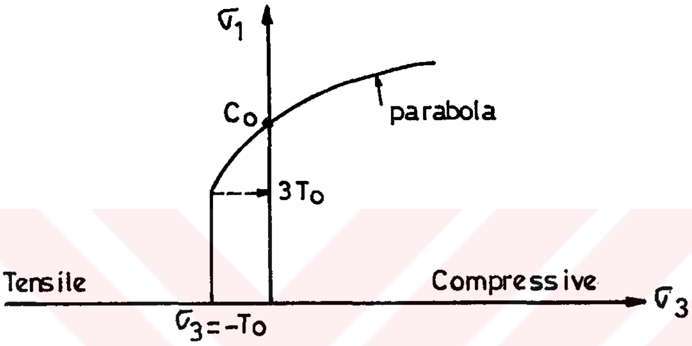


Fig. A.1.Griffith Failure Criterion on Principal Stress Plane.

Griffith failure criterion can be shown on $\tau-\sigma$ plane as in Fig A2.

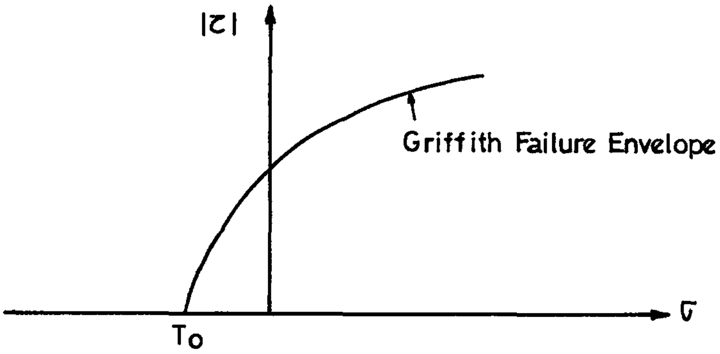


Fig. A.2. Griffith Failure Criterion on $\tau-\sigma$ Plane.

Equation of the above parabola can be written as follows:

$$\tau^2 = 4.T_o(\sigma + T_o) \qquad (26)$$

APPENDIX B

Table B1. Comparison Between the Different Swelling Potential Classification Methods(After Dakshanamurthy and Raman(1973))

S. No.	Location	Natural water content %	Dry density gm/cc	Unified classification	Liquid limit %	Plasticity index PI	Shrinkage limit %	Shrinkage index	Clay %	Activity $= \frac{PI}{C-10}$	Holtz and Gibbs (1956)	Sowers	Seed *et al.* (1963)	Williams (1957)	Ranganatham (1965)	Da Nilov (1961)	Proposed method
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1.	Madras, IIT, Ladies Hostel	20.0	1.65	CH	58	41	5	53	30	2.05	High	High	V. High	V. High	High	Swelling	High
2.	•	16.3	1.64	CH	60	43	5	55	21	3.95	High	High	V. High	High	High	Swelling	High
3.	•	10.4	1.78	CH	61	42	5	56	33	1.50	V. High	High	V. High	V. High	High	Swelling	High
4.	•	10.0	1.85	CH	64	49	5	59	35	1.96	V. High	High	V. High	V. High	High	Swelling	High
5.	•	13.9	1.73	CH	56	40	16	40	30	1.93	V. High	High	V. High	V. High	High	Swelling	High
6.	•	19.2	1.54	CI	48	35	8	40	22	2.92	V. High	High	High	High	High	Ordinary	Medium
7.	•	15.2	1.72	CI	48	33	8	40	21	3.00	V. High	High	High	High	High	Swelling	Medium
8.	IIT, Vibration Laboratory	29.3	1.55	CI	48	21	17	31	19	2.34	Medium	Moderate	High	Medium	High	Ordinary	Medium
9.	Madras-Manali	16.0	1.78	CI	35	22	22	13	15	4.44	V. High	Low	High	Medium	Low	Ordinary	Medium
10.	•	36.0	1.34	CI	42	25	10	32	15	4.90	V. High	Moderate	Medium	Medium	High	Slumping	Medium
11.	•	35.8	1.33	CL	32	16	11	21	23	1.25	Medium	Moderate	High	Medium	Medium	Slumping	Low
12.	•	14.3	1.82	CL	32	19	24	8	14	4.70	V. High	Low	Low	Medium	Low	Ordinary	Low
13.	•	36.0	1.35	CI	36	16	11	25	22	1.32	Medium	Moderate	Medium	Medium	Medium	Slumping	Medium
14.	•	36.6	1.33	CI	35	20	10	25	15	3.26	High	Moderate	Medium	Medium	Medium	Slumping	Medium
15.	•	16.3	1.80	CI	37	19	19	13	11	3.50	High	Moderate	Low	Low	Low	Ordinary	Medium
16.	•	35.8	1.34	CL	33	16	11	22	16	2.68	Medium	Moderate	Low	Medium	Medium	Slumping	Low
17.	•	15.1	1.78	CL	30	11	20	10	15	3.84	Medium	Low	Low	Low	Low	Slumping	Low
18.	Madras-Adyar	26.2	1.54	CH	52	31	5	47	31	1.48	High	High	High	High	High	Ordinary	High
19.	Madras-Porur	8.1	1.63	CH	52	32	10	42	19	3.56	High	High	High	High	High	Swelling	High
20.	Madras-Egmore	—	—	CI	36	23	15	21	35	0.92	Medium	Moderate	High	High	Medium	—	Medium
21.	•	—	—	CH	63	46	11	52	49	1.18	V. High	High	High	High	High	—	High
22.	•	—	—	CH	53	38	12	41	33	1.65	High	High	High	V. High	High	—	High
23.	•	—	—	CH	62	36	14	48	56	0.78	High	High	High	V. High	High	—	High
24.	Madras-Avadi	—	—	CI	35	19	14	21	19	2.10	Low	Moderate	High	Medium	Medium	—	Medium
25.	•	—	—	CI	39	24	16	23	30	1.20	Medium	Low	High	High	Medium	—	Medium
26.	•	—	—	CI	45	28	13	32	41	0.90	Medium	Moderate	High	High	High	—	Medium
27.	•	—	—	CH	96	70	8	88	78	1.03	V. High	High	V. High	V. High	V. High	—	Extra Swelling
28.	Velachery	—	—	CI	45	24	15	30	25	1.60	Medium	Moderate	Medium	High	Medium	—	Medium
29.	Tiruvanmiyur	—	—	CI	47	31	17	30	30	1.55	High	Moderate	High	High	Medium	—	Medium
30.	Nellikuppam	20.3	1.71	CL	34	16	18	16	25	1.00	Medium	Moderate	Medium	Medium	Low	Ordinary	Low
31.	•	20.7	1.60	CL	32	18	14	18	23	1.36	Medium	Moderate	Medium	Medium	Low	Ordinary	Low
32.	•	20.1	1.71	CL	32	16	17	15	28	1.10	Low	Low	Medium	Medium	Low	Ordinary	Low
33.	•	19.9	—	CI	37	20	18	19	26	1.25	Medium	Low	Medium	Medium	Low	—	Medium
34.	•	—	—	CL	34	16	14	20	25	1.07	Low	Moderate	Medium	Medium	Low	—	Low
35.	•	—	—	CL	29	14	15	14	17	2.00	Low	Moderate	Medium	Medium	Low	—	Low
36.	•	—	—	CL	31	15	13	18	27	0.88	Low	Moderate	Medium	Medium	Low	—	Low
37.	•	—	—	CL	30	15	20	10	22	1.25	Low	Low	Medium	Medium	Low	—	Low
38.	•	—	—	CL	29	15	16	13	22	1.25	Low	Low	Medium	Medium	Low	—	Low
39.	•	—	—	CL	30	16	16	14	19	1.77	Low	Low	Medium	Medium	Low	—	Low
40.	Pollachi	—	—	CH	58	31	11	52	50	0.78	High	High	High	High	High	—	High
41.	Madurai	12.30	1.91	CH	58	31	16	42	44	0.92	High	High	High	High	High	Swelling	High
42.	•	11.50	1.78	CH	58	34	20	38	54	0.79	High	Moderate	High	V. High	High	Swelling	High
43.	•	17.60	1.81	CH	58	32	20	38	49	0.81	V. High	Low	High	V. High	High	Swelling	High
44.	Nasik	—	—	CH	61	41	12	49	50	1.03	High	High	High	V. High	High	—	High
45.	Yeldery	—	—	CH	60	41	11	49	50	1.03	High	High	High	V. High	High	—	High
46.	Adilabad	—	—	CH	60	34	13	47	51	0.83	High	High	High	V. High	High	—	High
47.	Akola	—	—	CH	66	42	12	54	49	1.08	High	High	V. High	V. High	High	—	High
48.	•	—	—	CH	64	37	12	52	45	1.06	High	High	High	V. High	High	—	High
49.	•	—	—	CH	57	34	12	45	51	0.83	High	High	High	V. High	High	—	High
50.	Nagpur	—	—	CH	63	32	13	50	52	0.76	High	High	High	V. High	High	—	High

Table B1.(Continue) After Dakshanamurthy and Raman(1973)

S. No.	Location	Natural water content %	Dry density gm/cc	Unified classification	Liquid limit %	Plasticity index PI)	Shrinkage limit %	Shrinkage index	Clay %	Activity $=\frac{PI}{C-10}$	Holtz and Gibbs (1956)	Sowers	Seed *et al.* (1963)	Williams (1957)	Ranganatham (1965)	Da Nilov (1964)	Propose method
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1.	Black Cotton Soil[15]	—	—	MH	79	33	12	67	22	2.80	High	High	High	High	V. High	—	V. High
2.	″	—	—	MH	64	29	10	54	22	2.40	Medium	High	High	High	High	—	High
3.	″	—	—	MH	59	16	10	49	20	1.60	Low	Moderate	Medium	Medium	High	—	High
4.	″	—	—	MH	82	42	8	74	24	3.00	V. High	High	V. High	High	V. High	—	V. High
5.	″	—	—	MH	66	25	12	54	21	2.30	Medium	Moderate	High	High	High	—	High
6.	B. C. Soil[7]	—	—	MH	70	31	12	58	18	3.90	High	Moderate	High	High	High	—	High
7.	″	—	—	MH	74	36	13	61	38	1.30	High	High	High	V. High	V. High	—	V. High
8.	B. C. Soil[17] (Hyderabad)	—	—	MH	53	27	23	35	38	1.00	Medium	Low	High	High	High	—	High
9.	″ (Poona)	—	—	MH	76	33	20	56	57	0.70	High	Low	V. High	V. High	High	—	V. High
10.	″ (Poona)	—	—	MH	95	50	18	77	39	1.70	V. High	Low	V. High	V. High	V. High	—	Extra Hig
11.	″ (Dalta, M. P.)	—	—	MH	65	30	24	41	45	0.86	High	Low	High	V. High	High	—	High
12.	″ (Sholapur)[14]	—	—	MH	69	27	12	57	28	1.50	Medium	Moderate	High	High	High	—	High
13.	″ (Poona)	—	—	MH	67	18	8	59	30	0.90	Low	Moderate	Medium	Medium	High	—	High
14.	″ (Sidheswar)	—	—	MH	70	28	14	56	35	1.12	Medium	Moderate	High	High	High	—	High
15.	″ (Nasik)	—	—	MH	73	25	7	66	45	0.72	Medium	Moderate	High	High	V. High	—	V. High
16.	″ (Nagpur)	—	—	MH	59	16	10	49	45	0.46	Low	Moderate	Medium	Medium	High	—	High
17.	″ (Sholapur)	—	—	MH	66	25	12	54	47	0.68	Medium	Moderate	High	High	High	—	High
18.	″ (Yelderi)	—	—	MH	68	22	14	54	50	0.55	Medium	Moderate	High	Medium	High	—	High
19.	″ (Amaravathi)	—	—	MH	81	34	10	71	49	0.87	High	High	High	V. High	V. High	—	V. Hig
20.	″ (Wadagoan)	—	—	MH	53	21	18	35	54	0.48	Medium	Moderate	High	Medium	High	—	High
21.	″ (Wadagoan)	—	—	MH	73	31	13	60	54	0.71	High	High	High	High	High	—	V. Hig
22.	″ (Poona)	—	—	MH	67	18	8	59	61	0.35	Low	Moderate	Medium	Medium	High	—	High
23.	B. C. Soil[11] (Mysore)	—	—	MH	64	31	13	51	23	2.10	High	Moderate	High	High	High	—	High
24.	″	—	—	MH	76	41	14	62	23	3.20	High	High	High	High	V. High	—	V. Hig
25.	″	—	—	MH	71	36	12	59	28	2.00	High	High	High	V. High	High	—	V. Hig
26.	″	—	—	MH	81	42	14	67	33	1.80	V. High	High	High	V. High	V. High	—	V. Hig
27.	B. C. Soil[12] (Phadegaon)	—	—	MH	79	41	12	67	62	0.79	V. High	High	V. High	V. High	V. High	—	V. Hig
28.	″ (Kopegaon)	—	—	MH	64	30	14	50	55	0.67	High	High	High	High	High	—	High
29.	″ (Batnapur)	—	—	MH	81	41	12	69	57	0.87	High	High	High	V. High	V. High	—	V. Hig
30.	″ (Poona)[13]	—	—	MH	67	18	8	59	39	0.62	Medium	Moderate	High	Medium	High	—	High
31.	″ (Sholapur)	—	—	MH	66	25	12	42	53	0.58	Medium	Moderate	High	High	High	—	High
32.	″ (Nagpur)	—	—	MH	59	16	10	49	51	0.40	Low	Moderate	Medium	Low	High	—	High
33.	″ (Baroda)	—	—	MH	54	21	9	45	56	0.45	Medium	Moderate	High	Low	High	—	High
34.	B. C. Soil[16]	—	—	MH	63	28	12	51	30	1.40	Medium	High	High	High	High	—	High

Table B2. Swelling Potential Classification of Ankara Soils by Using Different Methods

A & T	NO	INITIAL W/C	DEPTH(m)	LOCATION	% CLAY	Gs	LL %	PL %	PI %	CLASSIF.	ACTIVITY PI/%C	SWELL Seed et al,1962	VAN DER MERVE	SNETHEN	DAKSHANA. & RAMAN	PVC RATE	PVC CAT	SW.INDEX KN/M2	DRY U.W KN/M3
A	21	5.36	7.5	DEMET(B)	37	2.751	39	14	25	CL	0.676	MEDIUM	HIGH	LOW	MEDIUM	1.7	NON CRI.	62.22	15.92
A	11	4.68	2	SINCAN2	31	2.745	52	31	21	MH	0.687	LOW	HIGH	MARGINAL	HIGH	6.1	V.CRIT.	230.39	13.26
A	30	6.52	4.5	CEBECI	23.5	2.628	43	24	19	CL	0.775	LOW	MEDIUM	LOW	MEDIUM	2.8	MARGIN.	111.5	14.84
A	12	4.77	2	SINCAN3	43.5	2.772	58	21	37	CH	0.836	HIGH	V.HIGH	MARGINAL	HIGH	7.75	V.CRIT.	299.75	14.88
A	39	7.56	2	ETIMESG	44	2.693	53	25	28	CH	0.631	HIGH	HIGH	MARGINAL	HIGH	3.75	MARGIN.	142.18	13.81
A	34	5.95	2.5	EMEK	45	2.685	50	20	30	CH	0.667	HIGH	HIGH	MARGINAL	MEDIUM	3.5	MARGIN.	128.24	14.91
A	37	5.81	0.5	AOC-KOP.	43	2.586	60	26	34	CH	0.807	HIGH	V.HIGH	MARGINAL	HIGH	3.1	MARGIN.	122.67	13.32
A	33	11.63	0.5	AKDENIZ	42	2.654	60	25	35	CH	0.818	HIGH	V.HIGH	MARGINAL	HIGH	5.1	CRIT.	192.36	14.61
A	36	6.93	1.5	AOC-1	38	2.642	51	20	31	CH	0.796	HIGH	H-V.H.	MARGINAL	HIGH	2.8	MARGIN.	111.51	13.99
A	35	5	2.5	BALGAT	34	2.662	44	21	23	CL	0.668	MEDIUM	HIGH	LOW	MEDIUM	2.4	MARGIN.	94.79	14.62
A	10	5.25	2	SINCAN1	26	2.741	60	35	25	MH	0.974	MEDIUM	HIGH	MARGINAL	HIGH	8.3	V.CRIT.	333.08	13.56
A	15	2.87	3	ODTU(C)	43.5	2.676	57	23	34	CH	0.782	HIGH	V.HIGH	MARGINAL	HIGH	5.6	CRIT.	194.18	15.34
A	31	13.12	1.5	FATIH C.	39	2.632	57	25	32	CH	0.836	HIGH	V.HIGH	MARGINAL	HIGH	4.9	CRIT.	189.57	14.02
A	3	2.47	4.5	EYMIR(Y)	47.5	2.767	50	21	29	CH	0.61	HIGH	HIGH	MARGINAL	MEDIUM	1.3	NON.CRI.	55.5	13.79
A	17	12.56	2.5	BATIKE(A	22	2.575	42	28	14	ML	0.636	LOW	MEDIUM	LOW	MEDIUM	1.7	NON CRI.	67.37	13.53
A	16	2.96	2	ODTU(D)	29	2.68	34	16	18	CL	0.621	LOW	MEDIUM	LOW	LOW	0.5	NON CRI.	25.89	14.38
T	1	9.66	0.5	ODTU(A)	59	2.76	69	26	43	CH	0.73	HIGH	V.HIGH	HIGH	HIGH	6.44	V.CRIT.	239.7	14.27
T	19	10.32	2	BATIKE(C	39	2.668	57	18	39	CH	1	MEDIUM	V.HIGH	MARGINAL	HIGH	3	MARGIN.	108.86	14.64
T	18	6.59	3	BATIKE(B	61.5	2.693	62	24	38	CH	0.618	HIGH	V.VIGH	HIGH	HIGH	2.9	MARGIN.	102.97	14.16
T	2	6.21	0.8	BILK.KAV	56.5	2.768	64	25	39	CH	0.69	HIGH	V.HIGH	HIGH	HIGH	5.4	CRIT.	205.4	14.16
T	32	9.26	2.5	BAHC.BES	35	2.655	49	23	26	CL	0.746	MEDIUM	HIGH	LOW	MEDIUM	5.2	CRIT.	195.14	15.23
T	23	2.82	1.5	ANIT(A)	44	2.7	61	22	39	CH	0.886	HIGH	V.HIGH	HIGH	HIGH	3	MARGIN.	107.49	13.44
T	14	14.03	3	ODTU(B)	61.5	2.787	78	26	52	CH	0.846	V.VIGH	V.HIGH	HIGH	V.HIGH	5.75	CRIT.	199.67	14.05
T	25	7.15	1	ANIT(C)	62	2.733	77	27	50	CH	0.806	V.HIGH	V.HIGH	HIGH	V.HIGH	7.8	V.CRIT.	281.46	15.88
T	13	5.87	2	SICAN4	51.5	2.767	58	21	37	CH	0.726	HIGH	V.HIGH	MARGINAL	HIGH	6.6	V.CRIT.	247.05	14.8
T	27	3.14	3	DIKMEN(B	47.5	2.641	55	20	35	CH	0.737	HIGH	V.HIGH	MARGINAL	HIGH	1.85	NON CRIT	69.14	12.44
T	9	5	2	BESTEPE	31.5	2.667	52	20	32	CH	1.02	HIGH	V.HIGH	MARGINAL	HIGH	1.5	NON.CRIT	66.6	14
T	29	6.43	12	TUSAS	72.5	2.741	146	30	116	CH	1.6	V.HIGH	V.HIGH	HIGH	EXTRA H.	9	V.CRIT.	353.1	14.06
T	7	5.95	1	DIKMEN(D	45	2.753	67	22	47	CH	1.04	HIGH	V.HIGH	HIGH	HIGH	7.05	V.CRIT.	266.5	13.83
T	22	5.18	6	DEMET(C)	52	2.736	59	20	39	CH	0.75	HIGH	V.HIGH	MARGINAL	HIGH	2.4	MARGIN.	88.07	14.14
T	6	7.92	2	UMITKOY	55	2.685	60	20	40	CH	0.727	HIGH	V.HIGH	MARGINAL	HIGH	4.45	CRIT.	166.5	13.84
T	26	4.09	1	DIKMEN(A	44	2.672	59	20	39	CH	0.886	HIGH	V.HIGH	MARGINAL	HIGH	1.85	NON CRIT	69.14	12.9
T	38	13.99	2.5	DEMET CA	46	2.667	83	41	42	MH-OH	0.916	HIGH	V.HIGH	MARGINAL	HIGH	4.4	CRIT.	167.27	10.8
T	20	2.03	4	DEMET(A)	53	2.691	72	31	41	CH	0.774	HIGH	V.HIGH	HIGH	V.HIGH	0.7	NON CRI.	31.11	10.98
T	28	3.94	1.5	DIKMEN(C	66.5	2.753	81	25	56	CH	0.842	V.HIGH	V.HIGH	HIGH	V.HIGH	6.5	V.CRIT.	225.17	12.7
T	24	1.11	1	ANIT(B)	47.5	2.627	60	26	34	CH	0.716	HIGH	V.HIGH	MARGINAL	HIGH	1.9	NON CRI.	71.59	12.38
T	4	6.81	4.5	EYMIR(G)	68.5	2.754	83	26	57	CH	0.832	V.HIGH	V.HIGH	HIGH	V.HIGH	8.4	V.CRIT.	344.2	14.34
T	40	5.08	3.5	UMITK.-K	31	2.602	38	15	23	CL	0.738	MEDIUM	HIGH	LOW	MEDIUM	3.9	MARGIN.	138.18	15.92
R	8	4.18	3.5	TUNALI	31	2.733	39	18	21	CL	0.677	MEDIUM	MEDIUM	LOW	MEDIUM	2.6	MARGIN.	111	14.51
R	5	7.21	3	TARHAN C	62.5	2.743	78	27	51	CH	0.816	HIGH	V.HIGH	HIGH	V.HIGH	4.4	CRIT.	166.5	12.13

APPENDIX C

Classification of Non-Organic Soils

Reference: Essai au Bleu de Méthylène et Classification Géotechnique des sols, J.P. Magnan et G. Youssefian, BLLPC-159,1989

Procedure:

Analyse granulometric curve:

50 % of particles > 0.08 mm (80 μm) → Coarse soils

50 % of particles < 0.08 mm (80 μm) ⇒ Fine soils

Coarse soils:

Fig.C1. → Gravel, Sand

Fig.C2. → Silty sand, clayey sand
silty gravel, clayey gravel

To determine whether the soil is well graded or poorly graded use the classical approach

i.e. $C_u = D_{60} / D_{10}$ = Coefficient of uniformity (27)

$C_c = D_{30}^2 / (D_{60} * D_{10})$ = Coefficient of curvature (28)

Gravels: $C_u > 4$, $1 < C_c < 3$ well graded

Sands : $C_u > 6$, $1 < C_c < 3$ well graded

Determine methylene blue value on particles passing from 80 μm sieve for coarse grained soils

Determine methylene blue value on particles passing from 400 μm sieve for fine grained soils

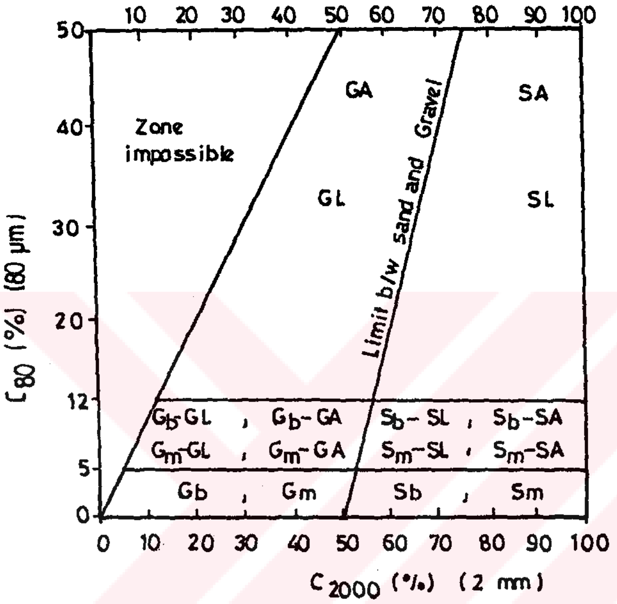


Fig.C1 Separation of Sands and Gravels

GA: Grave argileuse , GC: Clayey gravel

GL: Grave limoneuse , GM: Silty gravel

Gb: Grave propre bien graduée, GW: Well graded gravels

Gm: Grave propre mal graduée, GP: Poorly graded gravels

SA: Sable argileux, SC: Clayey Sands

SL: Sable limoneux, SM: Silty sands

Sb: Sable propre bien graduée, SW: Well graded sands

Sm: Sable propre mal graduée, SP: Poorly graded sands

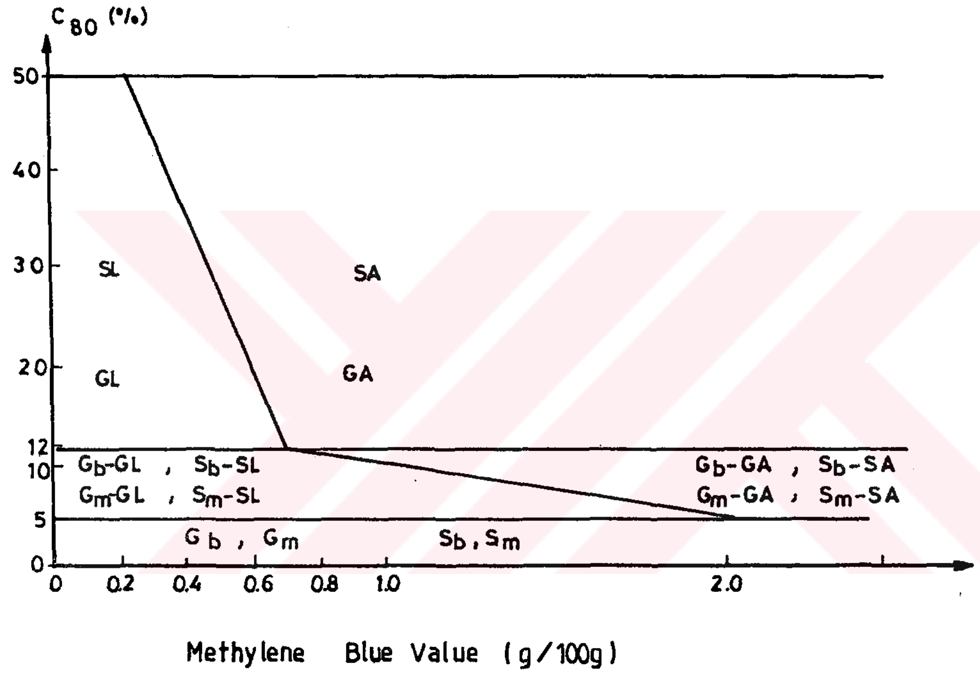


Fig.C2 .Separation of Coarse Grained Soils as Clayey or Silty (C_{80}-MBV)

Fine soils: (determine C_2 %, i.e. % of clay size)

C_2 and methylene blue value (on 400 μm sieve)

Fig.C3. determine CH, CL, MH, ML

Fig.C4. determine Ata, Ama, Apa, Lta, Lma, Lpa

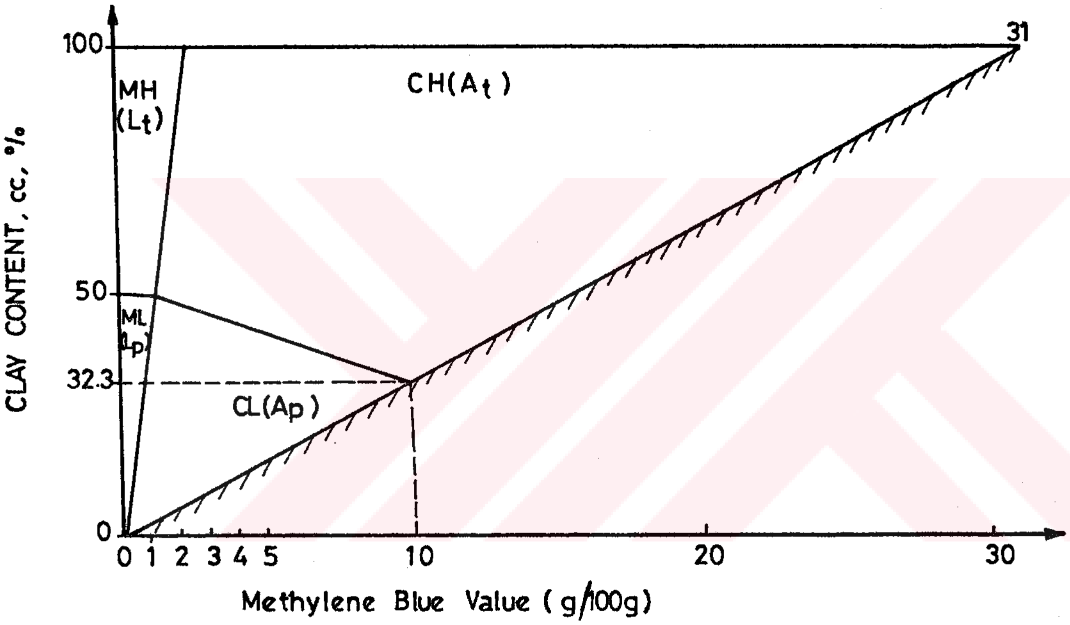


Fig.C3.Classification of Fine Soils (C_{80} >50%)(non-organic)

At: Argile très plastique = Inorganic clays of high plasticity

Ap: Argile peu plastique = Inorganic clays of low plasticity

Lt: Limon très plastique = Inorganic silts of high plasticiy

Lp: Limon peu plastique = Inorganic silts with slight plasticity

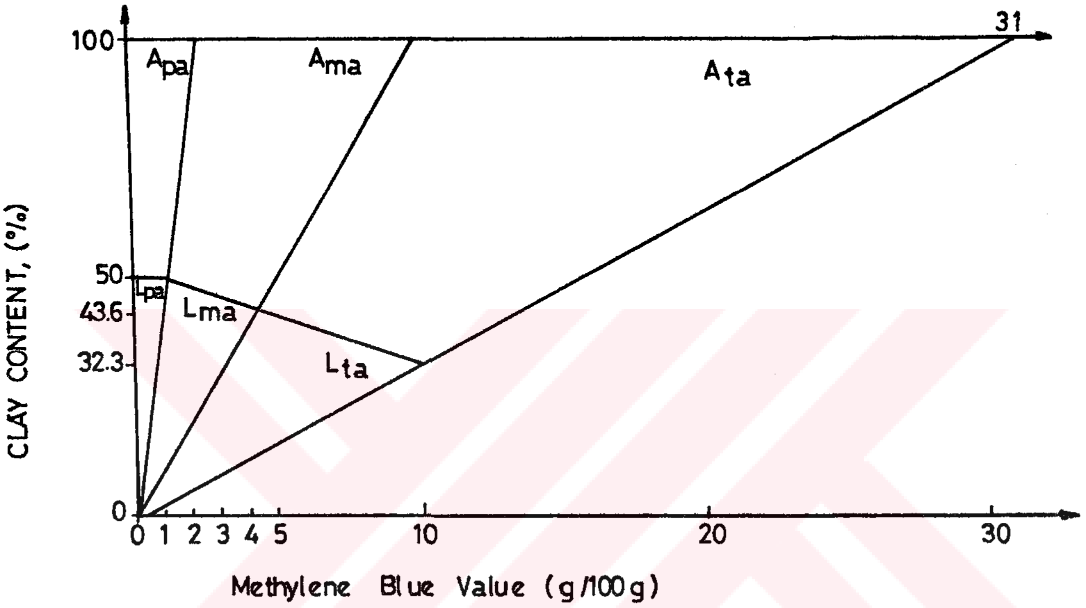


Fig.C4 New Classification Proposed for Fine Soils (clay content - MBV)

Apa: Argile peu active (clay with low activity)

Ama: Argile moyennement active (clay with moderate activity)

Ata: Argile très active (clay with high activity)

Lpa: Limon peu active (silt with low activity)

Lma: Limon moyennement active (silt with moderate activity)

Lta: Limon très active (silt with high activity)

APPENDIX D

Éditée par L'ASSOCIATION FRANÇAISE DE NORMALISATION (AFNOR) — Tour EUROPE CEDEX 7 92080 PARIS LA DEFENSE — Tél (1) 778-13-26

NORME
EXPÉRIMENTALE

GRANULATS

ESSAI AU BLEU DE MÉTHYLENE

P 18-592

Juillet 1980

AVANT-PROPOS

L'AFNOR a procédé à la mise au point de la présente norme et estimé souhaitable de lui donner le statut de norme expérimentale étant donné la nécessité de confirmer, par l'expérience, la validité de l'essai.

Passé un délai maximal de 3 ans, cette norme fera l'objet d'un nouvel examen et d'une modification éventuelle de statut.

1 OBJET

La présente norme a pour objet de décrire la méthode permettant de déterminer la « valeur de bleu » des fines d'un sable (*). Elle décrit également une méthode rapide de contrôle de conformité d'un sable par rapport à une « valeur de bleu » spécifiée.

2 DOMAINE D'APPLICATION

La présente norme s'applique aux sables d'origine naturelle ou artificielle, utilisés dans le domaine du bâtiment et des travaux publics.

3 BUT DE L'ESSAI

Cet essai permet de mesurer la capacité des éléments fins d'un sable à adsorber du bleu de méthylène.

Le bleu de méthylène étant adsorbé préférentiellement par les argiles, les matières organiques et les hydroxydes de fer, cette capacité rend compte globalement de l'activité de surface de ces éléments.

On appelle « valeur de bleu » des fines, la quantité de bleu de méthylène adsorbée par 100 g de fines.

(*) *Voir norme* NF P 18-101 « *Granulats — Terminologie, définitions, classification en préparation.*

Les observations relatives à la présente norme expérimentale doivent être adressées avant le 30 juin 1983 à l'AFNOR Tour Europe CEDEX 7 92080 PARIS LA DÉFENSE

Aggregates — Methylene blue test
Granulate - Methylenblau verfahren

4 PRINCIPE DE L'ESSAI

L'essai consiste à mesurer par dosage la capacité d'adsorption du matériau.

On injecte successivement des doses élémentaires d'une solution de bleu de méthylène dans le bain aqueux contenant la prise d'essai. On contrôle l'adsorption du bleu après chaque ajout en effectuant une tache sur un papier filtre (test de la tache, voir en 7.2.1).

Pour un simple contrôle de conformité, la quantité de bleu spécifiée est injectée en une seule fois.

5 APPAREILLAGE

1 APPAREILLAGE SPÉCIFIQUE

Une burette :

- capacité : 100 ou 50 cm³,
- graduation : 1/10 ou 1/5 cm³,

Papier filtre : quantitatif et sans cendre (< 0,010) ; grammage : 95 g/m² ; épaisseur : 0,20 mm ; vitesse de filtration 75 ; rétention : 8 μm.

Une baguette de verre : longueur 300 mm ; diamètre 8 mm.

Un agitateur à ailettes, tournant entre 400 et 700 tr/min.

Un récipient de 500 ml en verre ou en matière plastique, de diamètre environ 100 mm.

2 APPAREILLAGE D'USAGE COURANT

Une balance dont la portée-limite est compatible avec la masse de la prise d'essai et qui permet de peser à 1 % près,

Un chronomètre ou **un compte-minutes,**

Matériel nécessaire pour effectuer l'échantillonnage du matériau (*).

3 PRODUITS UTILISÉS

- solution de bleu de méthylène de qualité médicinale à 10 g ± 0,1 g/l.
- eau déminéralisée ou distillée.

6 PRÉPARATION DE L'ÉCHANTILLON POUR ESSAI

Connaissant les teneurs en eau ω et en fines f (voir norme **NF P 18-597** (*)), la masse de la prise d'essai à sa teneur en eau en l'état est donnée par la formule :

$$M_h = f' \frac{(\omega + 100)}{f}, \text{ ajustée au gramme près,}$$

représentant la quantité de fines, en grammes, qu'il est souhaitable d'avoir dans la prise d'essai (environ 30 g).

Voir norme **NF P 18-553** « *Préparation d'un échantillon pour essai* ».

) **NF P 18-597** « *Détermination de la propreté des sables : équivalent de sable à 10 % de fines* ».

7 EXÉCUTION DE L'ESSAI

7.1 MISE EN PLACE DE LA PRISE D'ESSAI

La prise d'essai est placée dans un bécher de 500 ml avec 200 cm^3 d'eau déminéralisée ou distillée. L'ensemble est soumis à une agitation d'une minute à 700 tr min puis permanente à 400 tr min pendant toute la durée de l'essai à l'aide de l'agitateur, les ailettes étant situées à 1 cm au-dessus du fond du récipient.

7.2 DÉTERMINATION PAR DOSAGE DE LA QUANTITÉ DE BLEU ADSORBÉE

7.2.1 Définition du test de la tache

Après chaque injection de bleu (voir article 7.2.2), ce test consiste à prélever à l'aide de la baguette de verre une goutte de suspension que l'on dépose sur le papier filtre. La tache ainsi formée se compose d'un dépôt central de matériau, coloré d'un bleu généralement soutenu, entouré d'une zone humide incolore.

La goutte prélevée doit être telle que le diamètre du dépôt soit compris entre 8 et 12 mm.

Le test est dit positif si, dans la zone humide, apparaît autour du dépôt central une auréole bleu-clair ; il est dit négatif si l'auréole est incolore.

7.2.2 Dosage

À l'aide de la burette, on injecte dans le récipient une dose de 5 cm^3 de solution de bleu, cette addition étant suivie du test de la tache sur le papier filtre.

On procède ainsi jusqu'à ce que le test devienne positif. À ce moment, on laisse s'opérer l'adsorption du bleu tout en effectuant des tests de minute en minute, sans rien ajouter.

Si l'auréole bleu-clair disparaît de la tache avant la cinquième minute, on procède à de nouvelles additions élémentaires de bleu qui sont :

- soit de 5 cm^3 comme précédemment si le volume de la solution de bleu déjà introduit est supérieur ou égal à 30 cm^3,
- soit de 2 cm^3 si ce volume est inférieur à 30 cm^3.

Chaque addition est suivie de tests effectués toujours de minute en minute.

Renouveler ces opérations jusqu'à ce que le test demeure positif pendant cinq minutes consécutives ; le dosage est alors considéré comme terminé.

COMMENTAIRE : On procède au nettoyage de l'appareillage dès que l'on a terminé les essais, les dépôts de bleu se détachant facilement quand ils sont récents.

Le matériel se nettoie très bien à l'eau. Si l'on a utilisé des produits détergents, on doit terminer par un rinçage abondant à l'eau.

8 EXPRESSION DES RÉSULTATS

La « valeur de bleu » des fines exprimée en grammes de bleu pour 100 g de fines est donnée par la formule :

$$VB = \frac{V}{P}$$

V étant le volume final de solution injectée, en centimètres cubes.

9 CONTRÔLE DE CONFORMITÉ PAR RAPPORT À UNE SPÉCIFICATION DONNÉE

La spécification est exprimée en « valeur de bleu » pour 100 g de fines, soit s cette valeur.

Le volume de la solution de bleu à injecter en une seule fois est alors :

$$V' = f' . s$$

Le test de la tache est effectué après huit minutes d'agitation. S'il est positif, le sable est conforme à la spécification ; s'il est négatif, on ajoute un volume de solution de bleu égal à :

$$\frac{f' . s}{10}$$

Si le test est toujours négatif après cinq minutes, on effectue le dosage conformément à l'article 7.2 ; si le test est positif, on considère que le sable est conforme à la spécification.

APPENDIX E

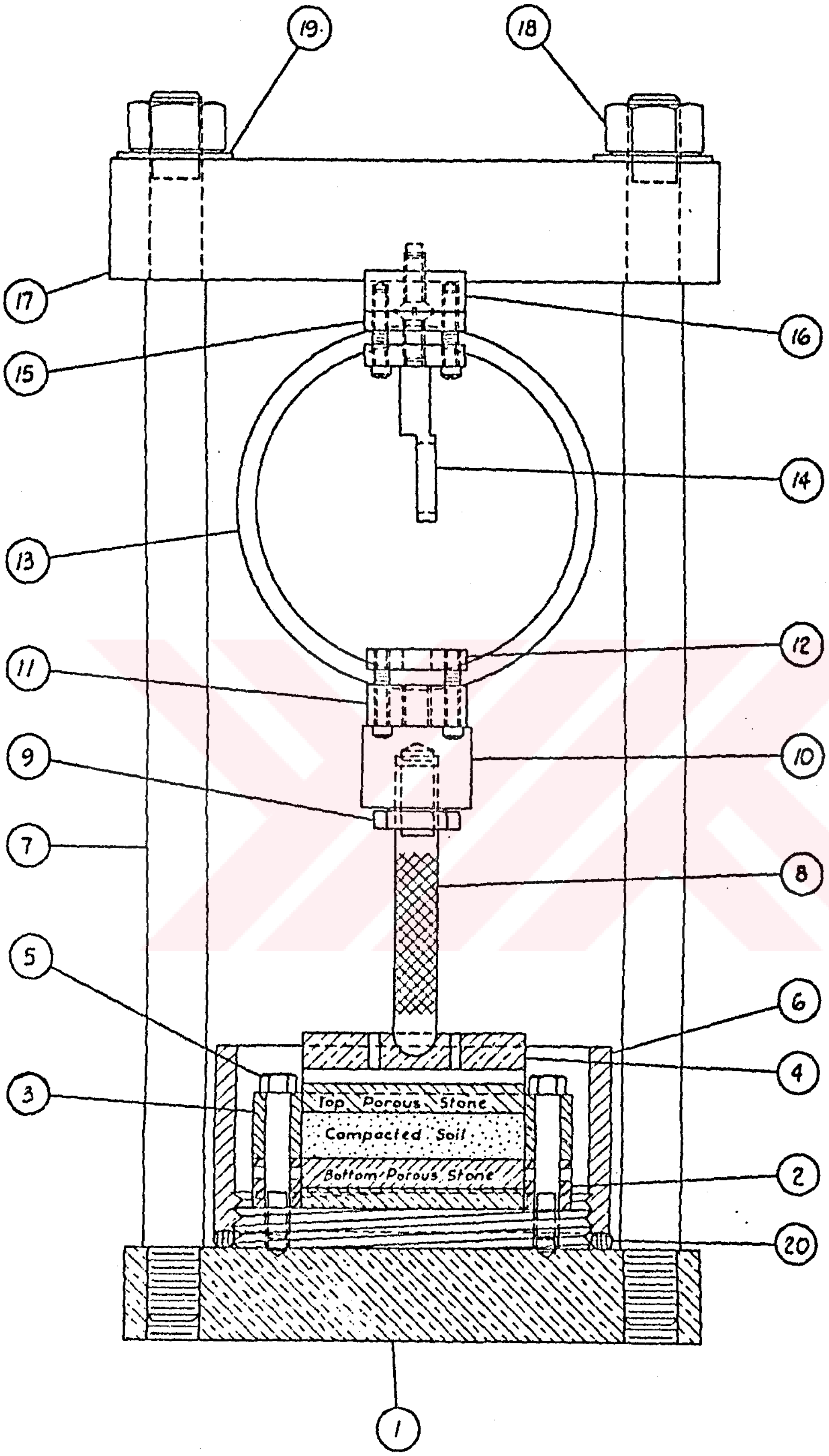


Fig.E1. PVC Meter Apparatus

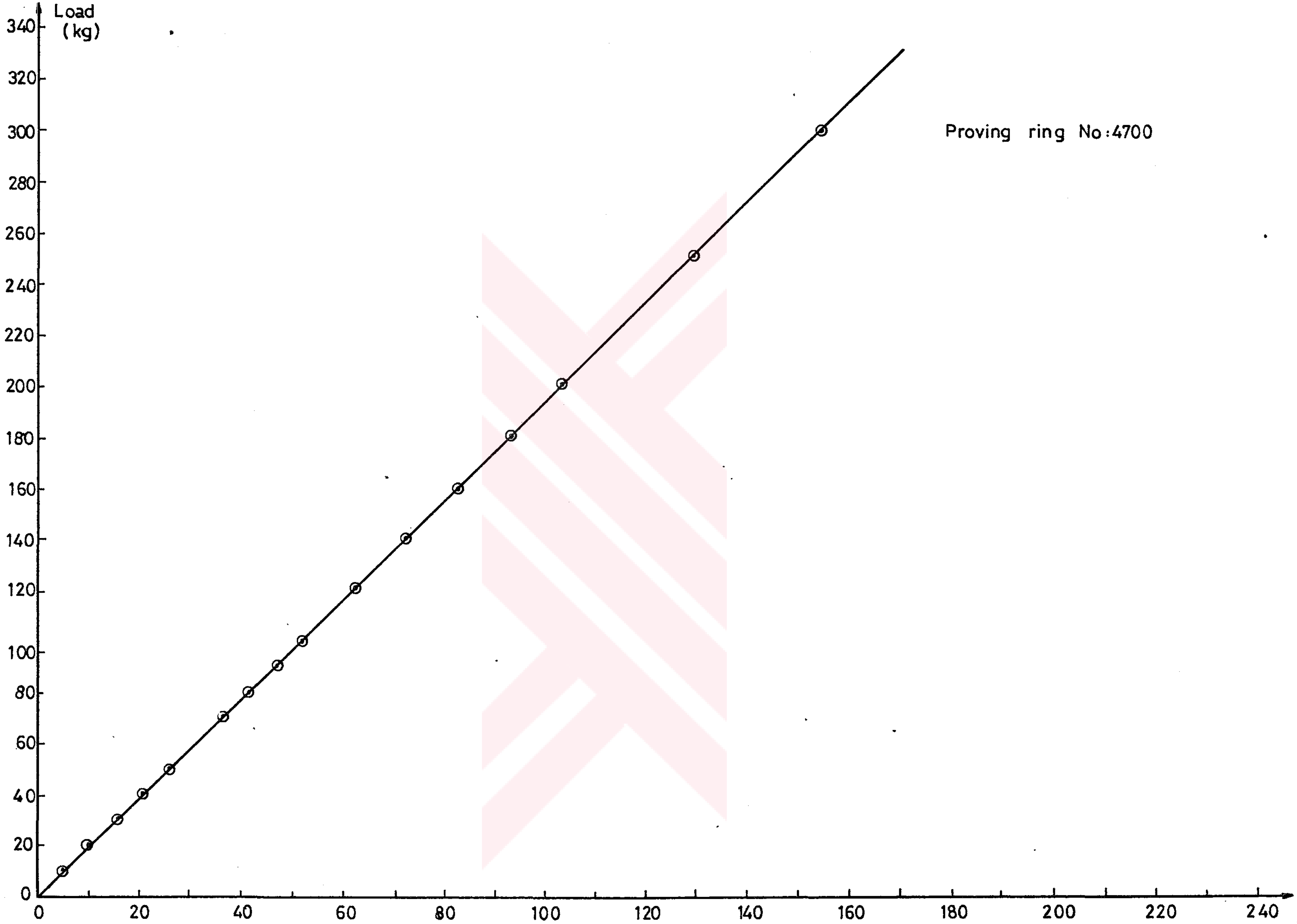


Fig.E2.Load vs Proving Ring Reading

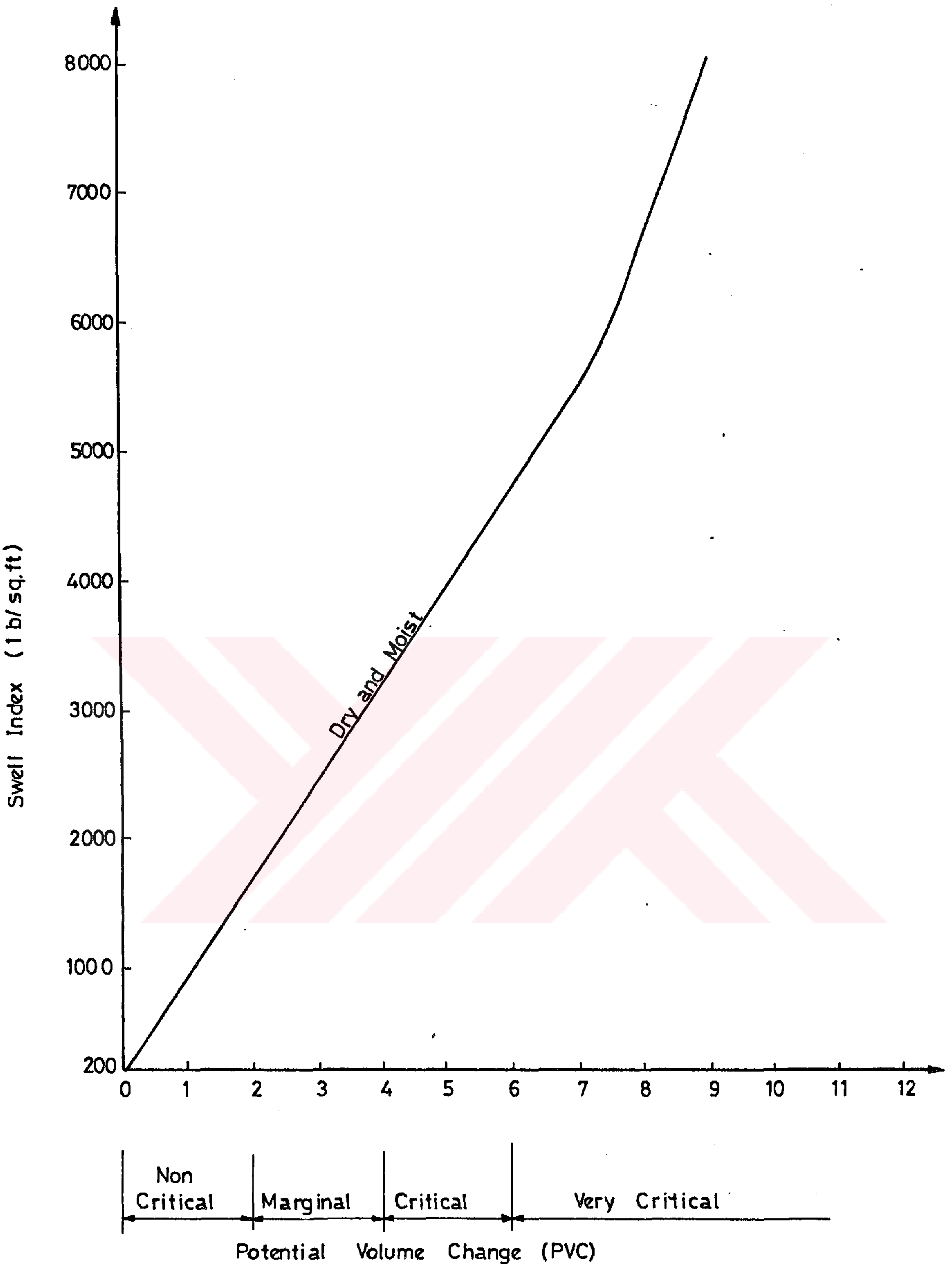


Fig.E3 Swell Index vs Potential Volume Change

APPENDIX F

Era	Age (m.y.)	Period	Epoch	Character	Derivation of name
	2	Quaternary	Pleistocene	Ice age;age of Man	Early name of fourth division ,
Cenozoic	63	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Age of mammals, flowering plants	Early name for third division of time and rocks
Mesozoic	145	Cretaceous		Age of reptiles and ammonites	Extensive chalk in England
	210	Jurassic			From Jura Mountains
	255	Triassic			Has three divisions in Europe
	280	Permian		Age of amphibiana	From Perm, U.S.S.R.
Paleozoic	320	Pennsylvanian	Carboniferous		From Pennsylvania, USA
	306	Mississippian			From Mississipi, USA
	415	Devonian		Age of fishes	From Devonshire, England
	465	Silurian			From name of tribe in Wales
	520	Ordovician			From name of tribe in Wales
	580	Cambrian			From Roman Cambria (Wales)
Precambrian	To oldest rocks 3500			Beginning of life	Before the Cambrian

*Age data adapted from R.F.Flint, The Earth and Its History, Norton, New York, 1973.

Reference: Handbook of Geology in Civil Engineering,
Robert F. Legget and Paul F. Karlrow,
Mc Graw Hill, 1983

APPENDIX G

APPENDIX H

Description of Sample Locations:

Sample No	Location	Formation*	Depth (m)	Description of place
1	ODTU (A)	T	0.5	Behind the new (closed) sport center (10 meters west of it)
2	BILK.KAV	T	1.8	BM Company General Directorate Building Construction , (500 m away from Ankara-Eskişehir highway, at the right of Bilkent overpass)
3	EYMIR (Y)	A	4.5	150 m south of the main entrance of Eymir Lake facilities of METU (TEK football field)
4	EYMIR(G)	T	4.5	100 m east of EYMIR (Y) location
5	TARHAN C	R	3	SOYUT General Directorate Building Construction (Tarhan street)
6	UMITKOY	T	2	ÜMİTKÖY (Türk Konut Gümüşşehir Residential Building Cooperative building construct. site)
7	Dikmen (D)	T	1	Minestry of Justice, Education Centre Construction (Dikmen)
8	TUNALI	R	3.5	Tunalı Hilmi Street (ODEKA Company Construction), near Büklüm Street
9	BESTEPE	T	2	BEŞTEPE,500 m behind the Wireless General Directorate Building
10	SINCAN1	A	2	DÖKÜMCÜLER Construction Cooperative
11	SINCAN2	A	2	at Sincan Osmaniye Village Location
12	SINCAN3	A	2	near the organized indutry location
13	SINCAN4	T	2	second part buildinds construction
14	ODTU(B)	T	3	200 m south of Environmental Engineering building
15	ODTU(C)	A	3	100 m north of dormitories, 500 m east of 100. Yıl road
16	ODTU(D)	A	2	200 m south of private bus station
17	BATIKE(A)	A	2.5	150 m west of Batıkent Recreation Center
18	BATIKE(B)	T	3	Batıkent Mesa Batı Sitesi
19	BATIKE(C)	T	2	Near the ODTÜLÜLER residential building cooperative
20	DEMET(A)	T	4	12 th main street (Demetevler), residential building construction by Erdener Company
21	DEMET(B)	A	7.5	Macunköy Fuel Station construction
22	DEMET(C)	T	6	OSTİM retaining wall construction (at OSTİM intersection)
23	ANIT(A)	T	1.5	Building construction of DMO (State Material Office)
24	ANIT(B)	T	1	Residential building construction of General Commander of Gendarmerie

* A: Alluvial soils
T: Terrace deposits
R: Residual soils

Description of Sample Locations (continue)

25	ANIT(C)	T	1	Anıttepe Savaş street, 150 m away from Gençlik Caddesi
26	DIKMEN(A)	T	1	Dikmen, 100m north of Police House
27	DIKMEN(B)	T	3	50 m west of TRT General Directorate Building
28	DIKMEN(C)	T	1.5	İç Street, building construction of TEV
29	TUSAS	T	12	Macunköy (residential buildings construction of Turkish Airplane Industry factory
30	CEBECI	A	4.5	Demirlibahçe, 200 m east of Bentderesi and Plevne street intersection
31	FATIH C	A	1.5	Fatih street, 500 m west of water treatment plant
32	BAHC.BES	T	2.5	Bahçelievler- Beşevler, on 7 th street
33	AKDENIZ	A	0.5	Akdeniz street, behind the natural gas building
34	EMEK	A	2.5	Emek, 4 th street, 100 m west of Kaya Renault Service station
35	BALGAT	A	2.5	Balgat 2 km south of Yüksel Residential buildings
36	AOC-I	A	1.5	AOÇ, 100 m north of Laboratory Equipment Manufactoring factory
37	AOC-KOP	A	0.5	70 m north-east of AOÇ bridge over the Ankara river
38	DEMETCAM	T	2.5	1 km north-west of AOÇ Bridge
39	ETIMESGUT	A	2	700 m south of old Cancer Hospital building, 25 m south of Ankara river
40	UMITK-KAV	T	3.5	100 m south of Ümitköy entrance

APPENDIX I

Table I. Results of Experiments on Ankara Soils

FORMATION*	NO	INITIAL W/C(%)	DEPTH(m)	LOCATION	% CLAY	G_s	LL %	PL %	PI %	CLASSIF.	ACTIVITY PI/%C	SWELL Seed et al1962	VAN DER MERVE	SNETHEN	DAKSHANA. & RAMAN	PVC RATE	PVC CAT.	SW.INDEX KN/M2	DRY U.W. KN/M3	VAL.D.BL. g/100g	VB (LOG)	Seed et. al,1962 SW.POT.	SI/CC	SPECIFIC SURFACE(m^2/g)
A	21	5.36	7.5	DEMET(B)	37	2.751	39	14	25	CL	0.676	MEDIUM	HIGH	LOW	MEDIUM	1.7	NON CRI.	62.22	15.92	4.92	0.691965	3.435471	1.681621	102.9756
A	11	4.68	2	SINCAN2	31	2.745	52	31	21	MH	0.687	LOW	HIGH	MARGINAL	HIGH	6.1	V.CRIT.	230.39	13.26	7.4	0.869231	1.944290	7.431935	154.882
A	30	6.52	4.5	CEBECI	23.5	2.628	43	24	19	CL	0.775	LOW	MEDIUM	LOW	MEDIUM	2.8	MARGIN.	111.5	14.84	4.26	0.629409	1.006171	4.744680	89.1618
A	12	4.77	2	SINCAN3	43.5	2.772	58	21	37	CH	0.836	HIGH	V.HIGH	MARGINAL	HIGH	7.75	V.CRIT.	299.75	14.38	9.78	0.990338	10.06674	6.890804	204.6954
A	39	7.56	2	ETIMESGUT	44	2.693	53	25	28	CH	0.631	HIGH	HIGH	MARGINAL	HIGH	3.75	MARGIN.	142.18	13.81	5.73	0.758154	5.270494	3.231363	119.9289
A	34	5.95	2.5	EMEK	45	2.685	50	20	30	CH	0.667	HIGH	HIGH	MARGINAL	MEDIUM	3.5	MARGIN.	128.24	14.91	4.94	0.693726	6.519594	2.849777	103.3942
A	37	5.81	0.5	AOC-KOP.	43	2.586	60	26	34	CH	0.807	HIGH	V.HIGH	MARGINAL	HIGH	3.1	MARGIN.	122.67	13.32	7.05	0.848189	8.875757	2.852790	147.5565
A	33	11.63	0.5	AKDENIZ	42	2.654	60	25	35	CH	0.918	HIGH	V.HIGH	MARGINAL	HIGH	5.1	CRIT.	192.36	14.61	6.7	0.826074	8.460540	4.58	140.231
A	36	6.93	1.5	AOC-1	38	2.642	51	20	31	CH	0.796	HIGH	H-V.H.	MARGINAL	HIGH	2.8	MARGIN.	111.51	13.99	6.42	0.807535	5.610298	2.934473	134.3706
A	35	5	2.5	BALGAT	34	2.662	44	21	23	CL	0.668	MEDIUM	HIGH	LOW	MEDIUM	2.4	MARGIN.	94.79	14.62	4.9	0.690196	2.494850	2.787941	102.557
A	10	5.25	2	SINCAN1	26	2.741	60	35	25	MH	0.974	MEDIUM	HIGH	MARGINAL	HIGH	8.3	V.CRIT.	333.08	13.56	7.02	0.846337	2.488253	12.81076	146.9286
A	15	2.87	3	ODTU(C)	43.5	2.676	57	23	34	CH	0.782	HIGH	V.HIGH	MARGINAL	HIGH	5.6	CRIT.	194.18	15.34	6.86	0.836324	8.553227	4.463908	143.5798
A	31	13.12	1.5	FATIH C.	39	2.632	57	25	32	CH	0.836	HIGH	V.HIGH	MARGINAL	HIGH	4.9	CRIT.	189.57	14.02	9.05	0.956648	6.914297	4.860769	189.4165
A	3	2.47	4.5	EYMIR(Y)	47.5	2.767	50	21	29	CH	0.61	HIGH	HIGH	MARGINAL	MEDIUM	1.3	NON.CRI.	55.5	13.79	4.78	0.679427	6.314417	1.168421	100.0454
A	17	12.56	2.5	BATIKE(A)	22	2.575	42	28	14	ML	0.636	LOW	MEDIUM	LOW	MEDIUM	1.7	NON CRI.	67.37	13.53	5.25	0.720159	0.495076	3.062272	109.8825
A	16	2.96	2	ODTU(D)	29	2.68	34	16	18	CL	0.621	LOW	MEDIUM	LOW	LOW	0.5	NON CRI.	25.89	14.38	2.75	0.439332	1.208078	0.892758	57.5575
T	1	9.66	0.5	ODTU(A)	59	2.76	69	26	43	CH	0.73	HIGH	V.HIGH	HIGH	HIGH	6.44	V.CRIT.	239.7	14.27	10.97	1.040206	20.63199	4.062711	229.6021
T	19	10.32	2	BATIKE(C)	39	2.668	57	18	39	CH	1	MEDIUM	V.HIGH	MARGINAL	HIGH	3	MARGIN.	108.86	14.64	7.8	0.892094	10.70445	2.791282	163.254
T	18	6.59	3	BATIKE(B)	61.5	2.693	62	24	38	CH	0.618	HIGH	V.VIGH	HIGH	HIGH	2.9	MARGIN.	102.97	14.16	7.11	0.851369	15.85056	1.674308	148.8123
T	2	6.21	0.8	BILK.KAV.	56.5	2.768	64	25	39	CH	0.69	HIGH	V.HIGH	HIGH	HIGH	5.4	CRIT.	205.4	14.16	6.37	0.804139	15.49319	3.635398	133.3241
T	32	9.26	2.5	BAHC.BES	35	2.655	49	23	26	CL	0.746	MEDIUM	HIGH	LOW	MEDIUM	5.2	CRIT.	195.14	15.23	5.83	0.765668	3.608937	5.575428	122.0219
T	23	2.82	1.5	ANIT(A)	44	2.7	61	22	39	CH	0.886	HIGH	V.HIGH	HIGH	HIGH	3	MARGIN.	107.49	13.44	6.44	0.808885	12.06474	2.442954	134.7892
T	14	14.03	3	ODTU(B)	61.5	2.787	78	26	52	CH	0.846	V.VIGH	V.HIGH	HIGH	V.HIGH	5.75	CRIT.	199.67	14.05	8.36	0.922206	34.10488	3.246666	174.9748
T	25	7.15	1	ANIT(C)	62	2.733	77	27	50	CH	0.806	V.HIGH	V.HIGH	HIGH	V.HIGH	7.8	V.CRIT.	281.46	15.88	8.57	0.932980	31.15928	4.539677	179.3701
T	13	5.87	2	SICAN4	51.5	2.767	58	21	37	CH	0.726	HIGH	V.HIGH	MARGINAL	HIGH	6.6	V.CRIT.	247.05	14.8	9.18	0.962842	12.75277	4.797087	192.1374
T	27	3.14	3	DIKMEN(B)	47.5	2.641	55	20	35	CH	0.737	HIGH	V.HIGH	MARGINAL	HIGH	1.85	NON CRIT.	69.14	12.44	3.44	0.536558	10.01726	1.455578	71.9992
T	9	5	2	BESTEPE	31.5	2.667	52	20	32	CH	1.02	HIGH	V.HIGH	MARGINAL	HIGH	1.5	NON.CRIT.	66.6	14	3.5	0.544068	5.388591	2.114285	73.255
T	29	6.43	12	TUSAS	72.5	2.741	146	30	116	CH	1.6	V.HIGH	V.HIGH	HIGH	EXTRA H.	9	V.CRIT.	353.1	14.06	14.9	1.173186	284.3924	4.870344	311.857
T	7	5.95	1	DIKMEN(D)	45	2.753	67	22	47	CH	1.04	HIGH	V.HIGH	HIGH	HIGH	7.05	V.CRIT.	266.5	13.83	7.77	0.890421	19.27147	5.922222	162.6261
T	22	5.18	6	DEMET(C)	52	2.736	59	20	39	CH	0.75	HIGH	V.HIGH	MARGINAL	HIGH	2.4	MARGIN.	88.07	14.14	9.1	0.959041	14.27261	1.693653	190.463
T	6	7.92	2	UMITKOY	55	2.685	60	20	40	CH	0.727	HIGH	V.HIGH	MARGINAL	HIGH	4.45	CRIT.	166.5	13.84	8.63	0.936010	16.04331	3.027272	180.6259
T	26	4.09	1	DIKMEN(A)	44	2.672	59	20	39	CH	0.886	HIGH	V.HIGH	MARGINAL	HIGH	1.85	NON CRIT.	69.14	12.9	5.55	0.744292	12.06474	1.571363	116.1615
T	38	13.99	2.5	DEMET CAM	46	2.667	83	41	42	MH-CH	0.916	HIGH	V.HIGH	MARGINAL	HIGH	4.4	CRIT.	167.27	10.8	6.07	0.783188	15.24805	3.636304	127.0451
T	20	2.03	4	DEMET(A)	53	2.691	72	31	41	CH	0.774	HIGH	V.HIGH	HIGH	V.HIGH	0.7	NON CRI.	31.11	10.98	2.72	0.434568	16.45657	0.586981	56.9296
T	28	3.94	1.5	DIKMEN(C)	66.5	2.753	81	25	56	CH	0.842	V.HIGH	V.HIGH	HIGH	V.HIGH	6.5	V.CRIT.	225.17	12.7	8.31	0.919601	44.11339	3.386015	173.9283
T	24	1.11	1	ANIT(B)	47.5	2.627	60	26	34	CH	0.716	HIGH	V.HIGH	MARGINAL	HIGH	1.9	NON CRI.	71.59	12.38	4.72	0.673941	9.335042	1.507157	98.7896
T	4	6.81	4.5	EYMIR(G)	68.5	2.754	83	26	57	CH	0.832	V.HIGH	V.HIGH	HIGH	V.HIGH	8.4	V.CRIT.	344.2	14.34	8.55	0.931966	47.44374	5.024817	178.9515
T	40	5.08	3.5	UMITK.-KA	31	2.602	38	15	23	CL	0.738	MEDIUM	HIGH	LOW	MEDIUM	3.9	MARGIN.	138.18	15.92	4.2	0.623249	2.315497		87.906
R	8	4.18	3.5	TUNALI	31	2.733	39	18	21	CL	0.677	MEDIUM	MEDIUM	LOW	MEDIUM	2.6	MARGIN.	111	14.51	3.47	0.540329	1.875957	3.580645	72.6271
R	5	7.21	3	TARHAN C.	62.5	2.743	78	27	51	CH	0.816	HIGH	V.HIGH	HIGH	V.HIGH	4.4	CRIT.	166.5	12.13	6.72	0.827369	33.01062	2.664	

*
A: Alluvial soils
T: Terrace deposits
R: Residual soils

APPENDIX J

TABLE.J 1. X-RAY TEST RESULTS OF SOIL SAMPLES TAKEN FROM DIFFERENT LOCATIONS OF ANKARA BY THE AUTHOR

SAMPLE NO	TESTED BY	SAMPLE LOCATION	MINERALOGY (X-RAY DIFFRACTION RESULTS)*	MBV(g/100g)
1	METU Geol. Eng.Dep.	ODTU(A)	A, C, Ch, Cr, D, I, K, Mic, M	10.97
2	"	BILK.KAV	A, C, Cr, I, K, small amout of M, Q	6.37
3	"	EYMIR(Y)	A, C, Ch, Cr, I, K, M, Q	4.78
4	"	EYMIR(G)	Small amount of A, I, small amount of K and M, Q	8.55
5	"	TARHAN C	A, C, D, I, K, M, Q	6.72
6	"	UMITKOY	A, C, Cr, I, small amout of K and M, Q	8.63
7	"	DIKMEN(D)	C, Ch, I, D, K, M, Q, small amount of A	7.77
8	"	TUNALI	Cr, I, Mic, M, Q	3.47
9	"	BESTEPE	A, C, Ch, Cr, I, M, Q	3.5
10	MTA	SINCAN(1)	very small amount of I, Q, C, and small amount of F	7.02
11	"	SINCAN(2)	very small amount of I, Q, C and small amount of F	7.4
12	"	SINCAN(3)	Ca-M, very small amount of I and K, Q, F, C	9.78
13	"	SINCAN(4)	Ca-M, very small amount of I and K, Q, C, F	9.18
14	CPAT	ODTU(B)	Q, C, A, D, I, Ch, M	8.36
15	"	ODTU(C)	Q, C, A, Ch, M	6.86
16	TPAO	ODTU(D)	S, I, Ch, K	2.75
17	"	BATIKENT(A)	S, I	5.25
18	"	BATIKENT(B)	S, I, Ch, K	7.11
19	CPAT	BATIKENT(C)	Q, C, Cr, A, I, M	7.8
20	"	DEMET(A)	Q, C, A, I	2.72
21	TPAO	DEMET(B)	S, I, K	4.92
22	"	DEMET(C)	S, I, K	9.1
23	CPAT	ANIT(A)	Q, C, Cr, A, D, M	6.44

TABLE J1. (CONTINUE)

SAMPLE NO	TESTED BY	SAMPLE LOCATION	MINERALOGY (X-RAY DIFFRACTION RESULTS)*	MBV (g/ 100 g)
24	CPAT	ANIT(B)	Q, C, Cr, A, Ch, M	4.72
25	"	ANIT(C)	Q, C, Cr, A, M	8.57
26	"	DIKMEN(A)	Q, C, Cr, A, I, Ch, M	5.55
27	"	DIKMEN(B)	Q, C, Cr, A, D, I, M	3.44
28	"	DIKMEN(C)	Q, C, F, D, M	8.31
29	"	TUSAS	Q, C, Cr, A, I, M	14.9
30	"	CEBECI	Q, C, Cr, A, Ch, I, M	4.26
31	"	FATIH.C	Q, C, Cr, A, M	9.05
32	"	BAHCELI	Q, Cr, C, A, M	5.83
33	"	AKDENIZ	Q, C, A, Cr, M	6.7
34	"	EMEK	Q, C, A, I, Ch, M	4.94
35	"	BALGAT	Q, C, A, M	4.9
36	"	AOC-1	Q, C, Cr, A, Ch, M, I	6.42
37	"	AOC-KOP	Q, C, Cr, Mic, Ch, I, M	7.05
38	"	DEMET.CAM	Q, C, A, I, M	6.07
39	"	ETIMESGUT	Q, C, A, Mic, Ch, M	5.73
40	"	UMIT.KAV	Q, C, I, D	4.2

* Q: Quatrz, C: Calcite, Cr: Cristobalite, A: Albite, Ch: Chlorite, I:Illite, M: Montmorillonite, Mic: Microline, D: Dikite, F: Feldspar, S: Smectite

Table J2 . Mineral Percentages of Some Samples

Sample No.	Tested By	Sample Location	MINERAL % Montm. %	Illite %	Kaolin. %	Chlorite %	MBV (g/100 g)
TERRACE DEPOSITS:							
1	METU	ODTU(A)	69	27		3	10.9
2	"	BILK>KAV	63	35	2	-	6.3
4	"	EYMIR(G)	75	23		1.8	8.5
6	"	UMITKOY	82	18	-	-	8.6
7	"	DIKMEN(D)	69	29	0.85	1	7.7
9	"	BESTEPE	91	9	(smectite-illite mixed layers)		3.
18	TPAO	BATIKE(B)	40	40	10	10	7.
22	"	DEMET(C)	50	40	10	-	9.
ALLUVIAL SOILS:							
3	METU	EYMIR(Y)	44	48	3	4	4.
16	TPAO	ODTU(D)	25	25	25	25	2.
17	"	BATIKE(B)	50	50	-	-	5.
21	"	DEMET(B)	55	35	10	-	4.
RESIDUAL SOILS:							
5	METU	TARHAN C.	82	16	2	-	6.
8	"	TUNALI	76	23	-	-	3.

Table J3 . Occurrence of a Mineral in the Samples

OCCURRENCE OF A MINERAL IN THE SAMPLES (%)				
MINERAL	ALLUVIAL (%)	TERRACE (%)	ALLUVIAL+ TERRACE (%)	ALLUVIAL+ TERRACE+ RESIDUAL (%)
ALBITE	63	77	71	70
CALCITE	81	86	84	83
CHLORITE	50	32	40	38
CRISTOBALITE	38	59	50	50
DICKITE	-	32	18	20
FELSPAR	19	9	13	13
ILLITE	69	82	76	78
KAOLINITE	25	36	32	33
MICROLINE	13	9	11	13
MONTMORILL.	88	91	90	90
QUARTZ	81	96	90	90

No. of samples from Alluvial soils= 16

No. of samples from Terrace deposits= 22

No. of samples from Residual soils= 2

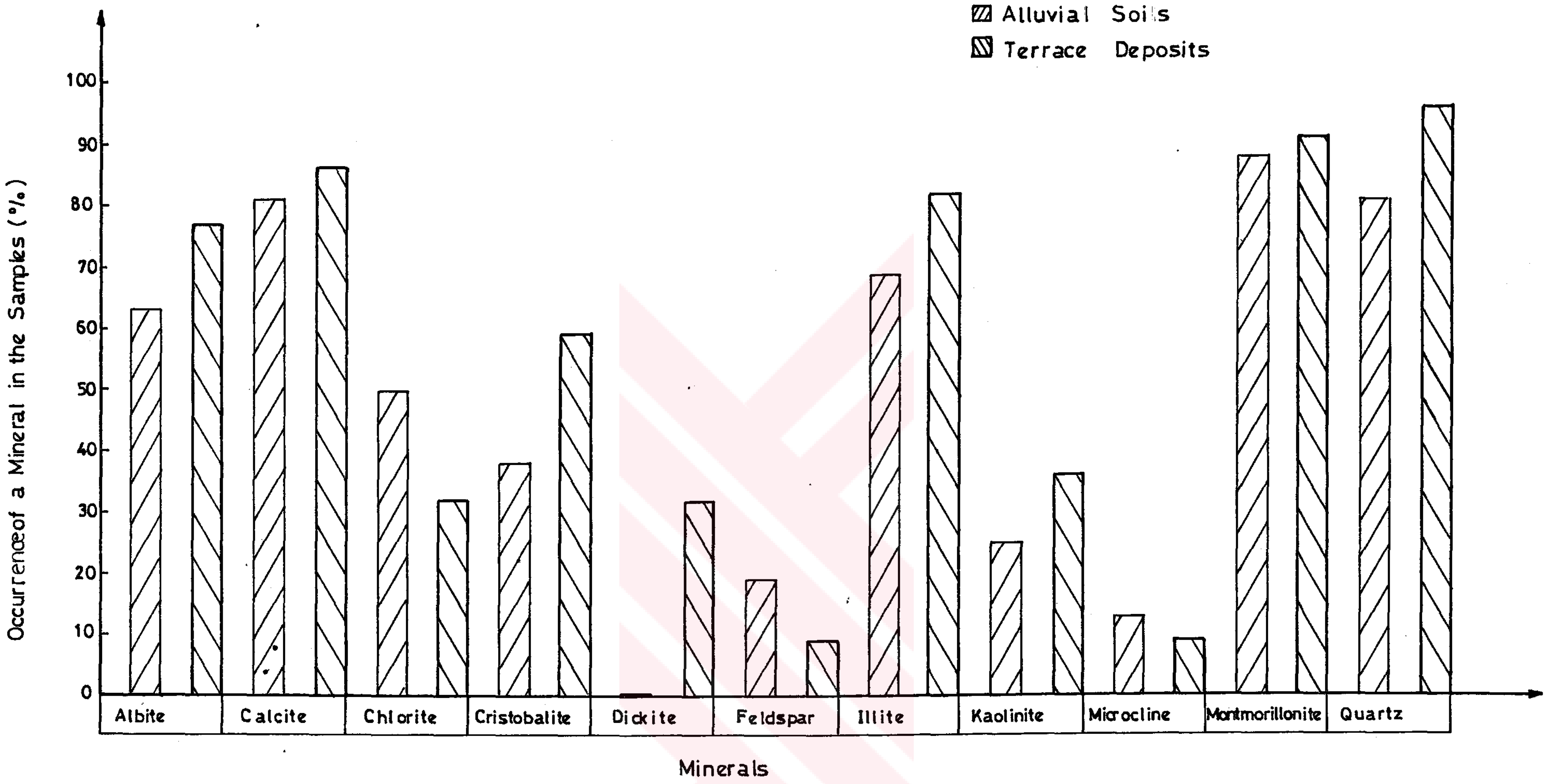


Fig.J .Occurrence of a Mineral in the Samples

APPENDIX K

Table.K. Swelling Potential Classification of Alluvial Soils(A) and Terrace Deposits(w) by Using Different Methods

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ETAL 1962	SEED ET.AL 1962 *	VAN DER MERVE *	SNETHEN *	DAKSANAM. RAMAN *
SÜRGEL	A1	4	2.77	1.426	0.943	78	29		49			48	1.04	CH	24.06210				
	A2	4	2.747	1.26	1.17	60	26		30			35	0.97	CH	6.848880				
	A3	2.7	2.704	1.47	0.84	101	31		70		30.5	44	1.59	CH	50.25608				
	A4	2.5	2.74	1.397	0.962	83	27		56		30.7	39	1.43	CH	25.62032	V	V	H	V
	A5	4	2.74	1.52	0.8	47	22		25		16.6	19	1.34	CL	1.842258	M	H	L	M
	A6	1				51	27	12.8	24	38	16	22	1.09	CH	1.843135	M	H	M	H
	A7	1				32	19	16.5	13	16	15.5	10	1.25	CL	0.170908	L	L	L	L
	A8	0.3				43	28	18.8	15	24	23.3	15	1	OL	0.399996	L	M	L	M
	A9	1.5				48	21	19	27	29	13.3	19	1.45	CL	2.233329	M	H	L-M	M
	A10	0.3				43	27	16	16	27	50.1	32	0.5	OL	0.998861	L	M	L	M
	A11	1				50	27	15	23	35	22.6	24	0.97	CH	1.870476	M	H	M-L	M-H
	A12	2.5				40.	27.	19.4	13	21	21.4	19	0.68	OL	0.351995	L	M	L	M
	A13	2				37	27	22	10	15	15	14	0.71	OL	0.136789	L	L	L	M
	A14	0.4				39	28	12.9	11	16	20	8	1.37	OL	0.099204	L	L	L	M
	A15	0.4				56	25	16.5	31	40	16.4	18	1.75	CH	2.933950	M	M	M	H
	A16	1.5				53	28	15	25	38	22	66	0.38	CH	6.168869	H	L	M	H
	A17	1				43	20	15	23	28	7	79	0.29	CL	5.920942	H	L	L	M
	A18	0.3				40	24	15	16	25	17.9	9.3	1.72	CL	0.290117	L	L	L	M
	A19	0.5	2.48	1.28	0.938	67	35		32		32	15	2.24	OH	2.861947	M	M	H-M	H
	A20	1	2.52	1.4	0.8	66	25		41		22	16	2.55	CL	4.902676	M	M	H	H
	A21	1.5	2.67	1.59	0.68	50	24		26		23	10.	1.97	OH	0.633654	L	L	M	M-H
	A22	0.3				46	26	18.5	20	28	13.2	21	0.97	CL	1.181571	L	M	L	M
	A23	1.5				35	23	20.5	12	15	14.8	20	0.63	CL	0.348527	L	M	L	L-M
	A24	0.7				50	28	17	21	33	34.7	19	1.14	OH	1.241831	L	M	L	M-H
	A25	2	2.65			72	27		45		28.2	22	2.05	CH	8.608271	H	H	H	V
	A26	1.5						NP	NP		6.9			SC					
TOKER	A27	3						NP	NP		6.2			SC					
	A28	4.5				60	18		42		25			CH					
	A29	6.5				64	26		38		26.3			CH					
	A30	2				24	16		8		13.9			CL					
	A31	4	2.65	1.8		24	17		7		16.2			SC					
	A32	4.5				36	18		19		15.7			CL					
	A33	6		1.74		30	16		14		19.4			SC					
	A34	2				32	19		13		11.4			SC					

TABLE K (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	A35	3				23	13		10		7			SC					
	A36	4.5				23	14		9		9.6			SC					
	A37	3	2.7	1.577		51	15		26		24.5			CH					
	A38	4.5				35	18		17		18.6			CL					
	A39	6	2.7	1.658		45	19		26		21			CL					
	A40	3	2.7	1.33		54	28		26		35			CH					
	A41	9	2.7	1.49		44	21		23		30			CL					
	A42	3	2.7	1.541		38	18		20		26.8			CL					
	A43	6	2.68	1.433		48	23		25		31			CL					
	A44	7.5						NP	NP		6.7			SC					
	A45	3.5	2.7	1.532		58	26		32		26.4			CH					
	A46	7.5				49	19		30		32.4			CL					
	A47	3.5				55	22		33		27.6			CH					
	A48	6	2.74	1.392		40	20		20		30.9			CL					
	A49	2				39	22		17		27.4			CL					
	A50	6	2.74	1.369		54	19		35		36.3			CH					
	A52	1.5				28.	20		8.6		28.2			CL					
	A52	3.5				52	17		35		29			CH					
	A53	4.5				30	20		10		30.4			CL					
	A54	6.5	2.71	1.437		45	20		25		29.7			CL					
	A55	1.5				32	21		11		13.8			CL					
	A56	4.7				28	13		15		19.4			SC					
	A57	6	2.75			52	18		34		17.3			CH					
	A58	7.5				59	22		37		31.5			CH					
	A59	1.5				33	18		15		23.8			CL					
	A60	3.5	2.7	1.504		35	19		16		28.3			CL					
	A61	6.5				67	24		43		40.9			CH					
	A62	8				39	16		23		41.4			CL					
	A63	9.5						NP	NP		13.8			SC					
	A64	3.3	2.71	1.416		43.	17.		25.8		32.5			CL					
	A65	4.5				38	20		18		20.9			SC					
	A66	6.5	2.66	1.571	0.848	44	17		27		22.5			SC					
	A67	7.5				40	21		19		23.5			CL					
	A68	10.5				28	15		13		23.8			CL					
TCK	A69	3.6	2.648	1.389		49	28		21		32			CL					
	A70	6.6	2.57	1.176		64	30		34		45.4			CH					
	A71	4.5	2.617	1.406		66	24		42		33.3			CH					

TABLE.K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	A72	6	2.589	1.459		63	22		41		27.2			CH					
	A73	3.5	2.714	1.477		55	23		32		32.5			CH					
	A74	6	2.668	1.476		55	23		32		30.8			CH					
	A75	4.5				43	24		19		31.9			CL					
	A76	6.2				39	24		15		22.3			CL					
	A77	4	2.71	1.65		51	22		29		23			CH					
	A78	3				50	24		26		23.4			CL					
	A79	7				46	20		26		27.8			CL					
	A80	3.5				51	20		31		25.9			CH					
	A81	6				44	21		23		18			SC					
	A82	3				55	25		30		21.4			SC					
	A83	6	2.412	1.38		63	27		36		29.4			CH					
	A84	4.5				67	26		41		27.7			CH					
	A85	3.4	2.732			40	17		25		21.3			SC					
	A86	6				48	20		28		24.3			CL					
	A87	7.8	2.734	1.511		48	21		27		28.1			CL					
	A88	3	2.74	1.49		57	21		36		30.6			CH					
	A89	5				70	24		46		33			CH					
	A90	6				52	20		32		28.2			CH					
	A91	8				74	33		41		38.6			CH					
	A92	2	2.7	1.61		31	15		16		23.4								
	A93	3	2.7	1.47		43	17		26		31.1								
	A94	3.6	2.7	1.51		35	18		17		27.4								
	A95	4.65	2.54	1.47		34	22		12		29								
	A96	4.65	2.61	1.368		62	20		42		35								
	A97	2.3	2.7	1.52		32	17		15		25								
	A98	2.8	2.59	1.503		35	19		16		28								
	A99	2.7	2.58	1.51		36	18		18		28								
	A100	2	2.6	1.47		40	18		22		29								
	A101	1.2		1.37		68	24		44		31.2			CH					
	A102	1.5		1.54		59	26		33		23.5			CH					
	A103	1.5		1.55		71	25		46		20.3			CH					
	A104	1.2		1.46		50	20		30		19.5			CL					
	A105	4	2.7	1.62		51	24		27		24.7			CL					
	A106	7	2.7	1.31		61	24		37		39.6			CH					
	A107	4	2.7	1.59		52	22		30		25.7			CH					
	A108	6	2.7			46	19		27		26.6			CL					

TABLE.K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	A109	1.5				50	26		24		13.7			CL					
	A110	4	2.65	1.61		60	23		37		25.6			CH					
	A111	7	2.65	1.53		50	19		31		29.2			CL					
	A112	2	2.75	1.75		42	19		23		15.1			CL					
	A113	3.5	2.75	1.72		40	17		23		19.7			CL					
	A114	1.5	2.75	1.68		64	23		41		19.8			CH					
	A115	3	2.7	1.45		61	25		36		28.6			CH					
	A116	4	2.72	1.74		45	20		25		19.7			CL					
	A117	2.5	2.72	1.61		41	15		26		24.4			CL					
	A118	5		1.37		59	22		37		36			CH					
	A119	8.5		1.45		45	20		25		31.2			CL					
	A120	2.6		1.47		59	22		37		30.7			CH					
	A121	4		1.48		57	26		31		29.8			CH					
	A122	3				42	22		20		29.8			CL					
	A123	2.4		1.28		65	25		40		41.3			CL					
	A124	5.4		1.53		45	20		25		28.6			CL					
	A125	4.5	2.59	1.44		65	23		42		35.1								
	A126	5		1.44		67	23		44		35.3								
	A127	5	2.6	1.58		42	18		24		29.2								
	A128	5		1.89		28	20		8		11.4								
	A129	4.5		1.82		32	30		12		24								
	A130	5		1.52		67	24		43		33.5								
	A131	4.5	2.6	1.43		63	27		36		35.4								
	A132	4.5	2.6	1.35		46	27		19		40								
	A133	4.5	2.6	1.41		33	24		9		35.9								
	A134	5	2.7	1.46		41	20		21		30								
	A135	9		1.33		36	20		16		39.5								
	A136	5	2.56	1.39		50	20		30		37.4								
	A137	5		1.38		56	18		38		39.3								
	A138	9		1.56		47	19		28		30								
	A139	6	2.566	1.68		41	18		23		26.7			CL					
	A140	6	2.562	1.41		43	17		26		29.5			CL					
	A141	4	2.64	1.4		27	20		7		31.4			ML					
	A142	4.5	2.53	1.4		42	19		23		32.3			CL					
	A143	5	2.68	1.36		46	17		29		35.7			CL					
TOKER	A144	2	2.71	1.34		43	22		21		29.8	23		CL			M	L	M
	A145	4.5	2.7	1.29		58	24		34		37.8			CH					

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	A146	7.5		1.46		54	20		34		28.7			CH					
	A147	3	2.743	1.27		58	28		30		35.1	42		CH			H	M	H
	A148	6	2.701	1.39		39	24		15		29.4	12		CL			M	L	M
	A149	9	2.701	1.47		37	22		15		26.9	15		CL			M	L	M
	A150	12	2.75	1.59		52	20		32		23.5	17		CH			M	M	H
	A151	2	2.75	1.55		55	24		31		25.5			CH					
	A152	5	2.76	1.43		52	20		32		31			CH					
	A153	7.5	2.71	1.63		41	19		22		18.6	16		CL			M	L	M
KASAPOĞLU	A154	1	2.58			61	40	12	21	49	35	35	0.6	MH	2.121219	M	M	H-L	H
	A155	3.5	2.55			62	28	13	34	49	25	30	1.03	CH	4.665760	M	V	H-M	H
	A156	0.5	2.5			45	25	18	20	37	24	27	0.72	SC	1.355455	L	M	L	M
	A157	0.4	2.61			56	25	21	31	35	22	31	0.98	CH	4.625709	M	H	M	H
	A158	3	2.53			56	28	11	28	45	25	43	0.65	CH	5.235312	H	H	M	H
	A159	1.5	2.6			26	19	19	7	7	17	14	0.5	SM	0.058139	L	L	L	L
	A160	5	2.6			62	43	17	19	45	38	25	0.78	MH	1.264523	L	M	H-L	H
	A161	0.3	2.5			62	38	15	24	47	33	43	0.55	MH	3.482723	M	H	H-L	H
	A162	1.5	2.5			56	29	22	28	34	26	13	2.12	SM	1.529421	M	M	M	H
	A163	1	2.56			58	28	14	30	44	25	50	0.6	CH	7.235163	H	H	M	H
	A164	2.5	2.63			23	19	19	4	4	16	11	0.36	SM	0.011378	L	L	L	L
	A165	0.3	2.67			57	27	18	30	39	28	38	0.79	CH	5.507673	H	H	M	H
	A166	3.5	2.62			36	23	16	13	20	20	30	0.42	CL	0.522790	L	M	L	M
	A167	2	2.64			55	24	11	31	44	21	36	0.86	CH	5.625476	H	H	M	H
	A168	0.3	2.57			37	28	19	9	18	25	16	0.56	SM	0.121353	L	L	L	M
	A169	1.5				30	24		6		15.2			SC					
	A170	3				31	17		14		15.5			SC					
	A171	6				40	20		20		19.2			SC					
	A172	3	2.69			39	19		20		18.5			SC					
	A173	4.5				39	22		17		19.9			SC					
	A174	8				48	23		25		28.9			CL					
	A175	3.25		1.65		35	16		19		14.1			SC					
	A176	6.4	2.7	1.662		43	17		26		19.2	32	0.81	CL	3.241319	M	H	L-M	M
	A177	9.25	2.73	1.429		56	25		30		25	36	0.83	CH	5.158621	H	H	M	H
	A178	6.3	2.7	1.429		47	22		33		34.3			CH					
	A179	9.25	2.7	1.421	0.908	27	18		29		32.3	42	0.69	CL	5.585625	H	H	L-M	L
	A180	3.2	2.71	1.636	0.624	26	14		12		18.6			SC					
	A181	6.3	2.685	1.712	0.565	38	16		22		17.8	28	0.79	SC	1.926354	M	H	L	M
	A182	12.3	2.72	1.617	0.695	36	19		17		23.3			CL					

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	A183	6.1	2.7	1.645	0.64	46	19		27		19.2			CL					
	A184	3.4	2.7	1.4	0.92	37	18		19		32.9	42	0.45	CL	1.968423	M	L	L	M
	A185	3.4	2.671	1.602		42	18		24		25.4	33	0.73	CL	2.795749	M	H	L	M
	A186	3.4	2.77	1.455	0.873	37	17		20		29.7	33	0.61	CL	1.803828	M	L	L	M
	A187	3.2	2.7			28	14		14		29.6			CL					
	A188	6.3	2.7	1.492	0.801	48	17		31		30.2	36	0.86	CL	5.625476	H	H	L-M	M
KİPER	A189		2.7			53	28	8.5	25	45	25	37	0.74	CH	4.283924	M	H	M	H
	A190		2.68	1.79	0.49	40	23	16	17	24	16.5	28	0.63	CL	1.108963	L	M	L	M-H
	A191		2.65	1.63	0.62	42	21	9	21	33	22.5	43	0.51	CL	2.896711	M	L	L	M
	A192		2.74	1.45	0.88	42	27	17	15	25	27.5	27	0.57	ML	0.766528		M	L	M
	A193		2.74	1.34	1.04	39	25	17.5	14	22	27.5	18	0.78	CL	0.408461		M	L	M
	A194		2.67	1.75	0.51	38	21	16.5	17	22	17.5	17	1.03	CL	0.661255		M	L	M
	A195		2.6	1.86	0.39	30	19	15.5	12	15	14.5	22	0.55	CL	0.347313		M	L	L
	A196		2.76			63	32	10	31	53	22	43	0.71	MH	6.493881	H	H	H-M	H
	A197		2.7			40	21	13	19	27		22	0.95	CL	1.317898	L	M	L	M
SÜRGEL	W1	4.5				89	32		57			65	0.88	CH	45.42157				
	W2	1.5				92	31		61			77	0.79	CH	62.52312				
	W3	3.3	2.67	1.381	0.933	72	32		40		27	38	1.05		11.02706				
	W4	8	2.72	1.583	0.718	51	28		23		23.1			CH					
	W5	0.3	2.7	1.444	0.87	63	26		37			40	0.92	CH	9.655498	H	V	H	H
	W6	0.75	2.71	1.278	1.12	65	25		40			38	1.05	CH	11.02706	H	V	H	H
	W7	1.3	2.7	1.304	1.07	57	25		32			32	1.01	CH	5.553446	H	V	H-M	H
	W8	1.75	2.73	1.398	0.95	74	34		40			54	0.74	CH	15.72759	H	V	H	V
	W9	2.35	2.725	1.397	0.95	77	35		42		31	48	0.88	CH	16.00700	H	V	H	V
	W10	0.3	2.77	1.276	1.17	54	25		29		38	33	1.26	CH	10.58996	H	H	M	H
	W11	1	2.74	1.292	1.12	59	29		30		26	30	1	CH	4.341098	M	H	M	H
	W12	1.7	2.71	1.355	1	55	24		31		29.5	32	1.97	CH	28.34758	V	H	M	H
	W13	2.4	2.71	1.415	0.93	59	26		33		27.2	19	1.74	CH	3.484617	M	H	M	H
	W14	1.6	2.74	1.435	0.91	68	29		39		26	46	0.67	CH	7.109056	H	V	H	H
	W15	2.3	2.72	1.63	0.9	79	34		43		31	43	1.11	CH	19.32066	H	V	H	V
	W16	3.25	2.72	1.445	0.88	56	24		32		26	48	0.97	CH	20.29996	H	V	M	H
	W17	1.2	2.66	1.333	0.995	79	39	16	40	63	35	23	1.74	OH	6.723360	H	H	H	V
	W18	1.5	2.69	1.341	1.005	67	31	10	35	57	23	36	0.97	CH	7.545814	H	V	H	H
	W19	1.3	2.7	1.421	0.9	62	31	13	31	49	33	19	1.63	CH	2.971342	M	H	M-H	H
	W20	1.4	2.71	1.43	0.895	47	40	18	7	29	21	13	0.54	ML	0.054363	L	L	L	M
	W21	2.5	2.78	1.31	1.12	94	35		61		37.9	40	1.49	CH	30.90034	V	V	H	E
	W22	12.5	2.7	1.41	0.915	51	25		26		30			CH					

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W23	2.5	2.7	1.42	0.907	83	28		55		34.2	39	1.4	CH	24.32860	H	V	H	V
	W24	5	2.65	1.46	0.817	52	22		30		18.2	17	1.79	CH	2.546878	M	M	M	H
	W25	0.4				42	20	12.6	22	30	25.3	15	1.46	CL	1.007111	L	M	L	M
	W26	1				62	27	16.7	35	45	23.8	19.	1.28	OH	1.738649	M	H	H	H
	W27	6.2				55	20		35		29			CH					
	W28	4.2				63	22		41		23.5			CH					
	W29	10.2				61	20		41		18.9			CH					
	W30	6.2				41	19		22		28			CH					
	W31	14.2		1.22		79	28		50		36.2			CH					
	W32	2.2		1.26		64	28		36		31.1			CH					
	W33	4.2		1.39		70	27		43		30.6			CH					
	W34	6.2		1.29		67	25		41		31			CH					
	W35	8.2		1.42		53	29		24		31.4			CH					
	W36	11.2		1.51		63	26		37		29.7			CH					
	W37	2.2		1.42		59	25		34		28.6			CH					
	W38	4.2		1.38		62	27		35		29.9			CH					
	W39	13.2		1.38		77	27		50		33.7			CH					
	W40	4.15		1.24		79	28		51		39.3			CH					
	W41	7.5		1.4		64	30		34		31.8			CH					
	W42	10.2		1.43		66	28		38		30.1			CH					
	W43	11.7		1.41		70	29		41		32.4			CH					
	W44	13.2		1.44		77	27		50		31			CH					
	W45	8.2	2.55	1.5	0.7	47	22		25		28.7			CL					
	W46	11.2	2.55	1.45	0.76	45	23		22		30.7			CL					
	W47	14.2	2.6	1.57	0.66	61	20		41		24.6			CH					
	W48	3.2		1.66		51	12		39		20.9			CH					
	W49	7.6		1.5		64	25		39		29.7			CH					
	W50	11.7	2.56	1.53	0.67	60	20		40		26.2			CH					
	W51	13.8	2.66	1.8	0.47	35	13		22		17.6			CL					
	W52	8.2	2.72	1.5	0.82	60	25		35		28.9			CH					
	W53	4.1	2.51	1.63	0.54	40	16		24		20.9			CL					
	W54	10.3	2.72	1.43	0.9	63	26		37		29.3			CH					
	W55	4.3	2.76	1.79	0.54	40	18		22		18.1			CL					
	W56	6.3	2.75	1.66	0.66	48	18		30		23.5			CL					
	W57	2	2.7	1.53	0.76	59	24		35		24.5			CH					
	W58	5	2.7	1.53	0.76	62	25		37		21.8			CH					
	W59	14		1.54		62	26		36		23.1			CH					

TABLE K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
TCK	W60	2				63	21		42		21								
	W61	2				61	20		41		26								
	W62	2.5				48	19		29		23								
	W63	1.5	2.635			60	22		38		30.6								
	W64	3.5				50	19		31		26								
	W65	6.5				88	33		55		42								
	W66	1.8	2.659	1.378		70	27		43		32.8								
	W67	2.5	2.635	1.41		62	24		38		32.4								
	W68	6.5				73	29		44		40.2								
	W69	6.5	2.75	1.236		84	31		53		42.8								
	W70	2.5	2.765	1.56		52	19		33		27.2								
	W71	7.5				81	32		49		38.2								
	W72	5.5		1.41		59	22		37		32.6			CH					
	W73	5.6		1.51		44	18		26		26.1			CL					
	W74	5.6		1.48		47	17		30		27.7			CL					
	W75	5.6		1.52		53	21		32		25.5			CH					
	W76	2.5	2.65	1.42		67	28		39		33.4								
	W77	6	2.69	1.5		62	21		41		29.4								
	W78	3	2.65	1.42		70	26		44		32.2								
	W79	5.5	2.7	1.471		69	19		50		30.2								
	W80	3	2.49	1.461		79	27		52		28.5	46					V	H	V
	W81	6	2.61	1.697		41	18		23		14.3								
	W82	6	2.53			81	29		52		26.5	66					V	H	V
	W83	9	2.79	1.832		41	16		25		15.1	13					M	L	M
	W84	9.25	2.58	1.628		53	19		34		20.2	20					H	M	H
	W85	9	2.5			76	22		54		23.9	59					V	H	V
	W86	10.5	2.612			85	26		59		38.5	63					V	H	V
	W87	6	2.57			53	24		29		18	4					L	M	H
	W88	66	2.46			81	27		54		31.1	78					V	H	V
	W89	9	2.67	1.525		70	22		48		25.9	62					V	H	H-V
	W90	4.5	2.58	1.504		80	29		51		25.5	59					V	H	V
	W91	6	2.68			41	15		26		15.1	17					M	L-M	M
	W92	7.5	2.67	1.86		36	16		20		13.9	21					M	L	M
	W93	4.8	2.7	1.31		88	28		60		37.9	47					V	H	V
	W94	7.5	2.68			28	15		13		15.5	4					L	L	L
	W95	5	2.721	1.508		68	24		44		28.5								
KASAPOĞLU	W96																		

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W97	7	2.57			82	42	9	40	73	39	56	0.72	MH	16.67095	H	V	H	V
	W98																		
	W99																		
	W100	1.5	2.51			62	30	18	32	44	27	53	0.6	CH	8.840982	H	V	H-M	H
	W101																		
	W102																		
	W103																		
	W104	4.9	2.59			70	38	21	31	49	35	56	0.56	MH	9.029175	H	H	H-M	H-V
	W105																		
	W106																		
	W107	9.5	2.69			73	34	17	40	56	31	47	0.84	CH	13.29108	H	V	H	V
	W108	2	2.52			46	25	16	20	30	22	36	0.58	CL	2.151530	M	M	L	M
	W109	4	2.58			78	43	15	35	63	40	65	0.54	MH	13.79638	H	V	H	V
	W110	4	2.63			63	25	15	38	48	22	38	1.01	CH	10.03002	H	V	H	H
	W111	3	2.65			74	33	19	41	55		60		CH			V	H	V
	W112	7.5	2.54			63	38	18	25	45		36		MH			H	H-M	H
	W113	3	2.6			52	21	17	31	35		36		CH			H	M	H
SÜRGEL	W114	0.4				61	31	16.5	30	45	41.4	31	0.98	OH	4.625709	M	H	H-M	H
	W115	0.3				52.	26.	14.5	25.8	38	30	30	0.86	CH	3.004525	M	H	M	H
	W116	8	2.72	1.448	0.879	50	22		27		22	22	1.25	CL	2.574524	M	H	M	H
	W117	10.5	2.619	1.33	0.969	59	24		35		24	28.	1.55	CH	10.60176	H	H	M	H
	W118	8	2.62	1.43	0.83	59	24		35		31.1	22.	1.56	CH	4.775670	M	H	M	H
	W119	4.5	2.67	1.39	0.92	73	29		44		35	36	1.21	CH	13.12478	H	V	H	V
	W120	12	2.55	1.54	0.654	59	24		35		27.9	22	1.56	CH	4.420389	M	H	M	H
TOKER	W127	3	2.74	1.386		62	30		32		34.6	30	1.07	CH	5.120307	H	V	H-M	H
	W128	9				43	23		20		22.4			CL					
	W129	16				64	28		36		25.7			CH					
	W130	3.5	2.695	1.309		54	27		27		30.8	22	1.23	CH	2.475169	M	H	M	H
	W131	6.4	2.66	1.33	1.047	47	24		23		31.2			CL					
	W132	7.5				58	23		25		32.2			CH					
	W133	10.5				51	23		28		28.6			CH					
	W134	3.3	2.68	1.434		51	31		20		25.5	12	1.67	MH	0.648804	L	M	L	H
	W135	6				60	30		30		27.1			CH					
	W136	9.3	2.68	1.483		86	33		53		26.5			CH					
	W137	1.74				47	33		14		29			ML					
	W138	3.3	2.7	1.481		50	20		30		24.7			CL					
	W139	6.3	2.7	1.378	1.316	45	31		14		31.6	13	1.08	ML	0.294999	L	M	L	M

TABLE.K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W140	3.3				80	28		52		32.5			CH					
	W141	6.3				44	34		10		40			ML					
	W142	9.3	2.74	1.219	1.213	67	21		36		38.1	20	1.8	CH	4.515549	M	H	H	H
	W143	3.45	2.71	1.325		76	27		49		33.5	16	3.1	CH	7.895829	H	M	H	V
	W144	6.4	2.72	1.28	1.119	76	31		45		35.1			CH					
	W145	3.4				48	33		15		32.3			ML					
	W146	6.3	2.725	1.148	1.391	60	31		29		40.5	11	2.6	CH	1.416538	M	L	M	H
	W147	6.4	2.75	1.321		70	32		38		37.5	16	2.4	CH	4.228542	M	M	H	H-V
	W148	9.4	2.73	1.204	1.307	76.	31.		44.9		38.5			CH					
	W149	3.5				65.	32		33.8		28.1			CH					
	W154	3.3	2.75	1.245		80	33		47		42.2			CH					
	W155	9.2	2.75	1.447		75	23		52		28.6			CH					
	W156	3.4	2.77	1.71		47	19		28		19			CL					
	W157	9.2	2.77	1.325	1.15	75	33		42		38.6	45	0.93	CH	14.67073	H	V	H	V
	W158	12.2	2.74	1.47		63	30		33		25.8			CH					
	W159	18.3	2.74	1.297	1.128	60	26		34		35.2			CH					
	W160	3.45	2.7	1.298		80	35		45		40.3	12	3.75	CH	4.670058	M	M	H	V
	W161	6.15	2.7	1.445		60	23		37		32.2			CH					
	W162	9.3	2.7	1.51		57	29		29		27.1	34	0.85	CH	4.491300	M	H	M	H
	W163	6.2	2.74			79	39		40		35.3	52	0.77	MH	15.21918	H	V	H	V
	W164	13.8	2.77			66	27		39		33.6	40	0.98	CH	11.11681	H	V	H	H
	W165	3.25	2.57			75	26		49		35.1			CH					
	W166	6.2	2.74	1.314		78	39		39		35.3	52	0.75	MH	14.27261	H	V	H	V
	W167	13.8	2.77	1.426		66	27		39		33.6	40	0.98	CH	11.11681	H	V	H	H
	W168	3.25		1.387		75	26		49		35.1			CH					
	W169	6.25	2.73	1.34		87	32		54		38	26	2.08	CH	15.84474	H	H	H	V
	W173	1.5	2.7	1.17		66	31		35		44			CH					
TCK	W174	4.5	2.7			72	38		34		57			MH					
	W175	7.5	2.7	1.114		75	37		38		50			MH					
	W176	1.5	2.79	1.566		56	19		37		18.4			CH					
	W177	2.5	2.63	1.621		57	21		36		22.4			CH					
	W178	2	2.69	1.722		52	15		37		18			CH					
	W179	1.8	2.71	1.689		55	20		35		19.4			CH					
	W180	2	2.71	1.584		65	19		46		23.9			CH					
	W181	1.5	2.48	1.362		101	26		75		36.2			CH					
	W182	1.6	2.67	1.33		111	27		84		34.7			CH					
	W183	1.6	2.6	1.387		119	28		91		32.5			CH					

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W184	2.2	2.7	1.388		80	27		53		26.5			CH					
	W185	1.5	2.69	1.319		67	29		38		30.7			CH					
	W196		2.68	1.448		56	25		31		15.5			CH					
	W187	1.3	2.74	1.41		65	29		36		28.5			CH					
	W188	1.5		1.42		74	31		43		31.1			CH					
	W189	3.6	2.56	1.4		69	28		41		32.7			CH					
	W190	5		1.43		63	23		40		30.4			CH					
	W191	0.3	2.46			40	35		5		30	16	0.34	ML	0.035915	L	L	L	M
KASAPOĞLU	W192	5	2.61			67	31	19	36	48	30	60	0.59	SM	13.00234	H	V	H	H
	W193	4	2.47			52	29	18	23	34	24	25	0.92	MH	1.891726	M	H	M-L	H
	W194	1	2.59			43	35	26	8	17	28	0		SM			L	L	M
	W195	1.5	2.5			47	26	27	22	20	20	8	2.69	SM	0.514668	L	L	L	M
	W196	2	2.63			32	21	28	11	4	15	8	1.38	SM	0.100980	L	L	L	L
	W197	3	2.55			61	41	11	20	40	35	10	2	MH	0.538041	L	L	H	H
	W198	6	2.55			74	40	22	34	63	39	42	0.81	MH	8.260065	H	V	H	V
	W199	0.6	2.66			68	33	16	34	46	27	32	1.08	SC	6.539919	H	V	H-M	H
	W200	5	2.6			48	33	16	15	32	26	15	1	SM	0.399996	L	M	L	M
	W201	1.7	2.5			56	37	25	19	40	33	37	0.51	MH	1.727379	M	M	M-L	H
	W202	3.5	2.5			53	30	15	23	28	26	11	2.09	SM	0.831477	L	L	M-L	H
	W203	3.5	2.63			59	32	18	27	44	25	24	1.13	SC	2.714817	M	H	M	H
	W204	1	2.55			77	51	15	26	59	30	32	0.81	MH	3.241319	M	H	H-M	V
	W205	5	2.67			69	40	23	29	46	35	35	0.83	MH	4.682169	M	H	H-M	H
	W206	2	2.53			59	38	17	20	42	30	21	0.98	MH	1.211514	L	M	M-L	H
	W207	3	2.6			75	56	25	19	50	40	15	1.27	SM	0.716700	L	M	H-L	V
	W208	1.5	2.61			46	26	20	20	26	21	15	1.37	SM	0.862292	L	M	L	M
	W209	1	2.51			55	33	17	22	38	26	41	0.55	MH	2.956405	M	M	M-L	H
	W210	4.5	2.51			59	30	21	29	38	20	19	1.55	SM	2.627993	M	H	M	H
	W211	4	2.6			58	37	19	21	39	32	23	0.91	MH	1.382634	L	M	M-L	H
	W212	10	2.61			60	31	10	29	50	30	41	0.7	MH	5.324982	H	H	M	H
	W213	3	2.58			70	34	16	36	54	31	41	0.88	MH	9.307149	H	V	H	H-V
TCK	W214	3.5				64	29		35		50			CH					
	W215	3.5				60	32		28		44			CH					
	W216	1.5				66	31		35		44			CH					
	W217	1.5				75	37		38		50			CH					
TOKER	W220	3.15	2.71	1.775	0.581	55	17		38		15.8			CH					
	W221	6.4	2.76	1.765	0.562	57	18		39		19.3	52		CH			V	M-H	H
	W222	9.37	2.74	1.754	0.55	48	17		31		14.9			CL					

TABLE.K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W223	3.25	2.74	1.329		66	29		37		39			CH					
	W224	6.37	2.69	1.778	0.5	46	20		26		19.3	35		CL			H	L-M	M
	W225	9.8	2.7	1.49	0.57	55	24.		30.5		20.7			CH					
	W226	3.2	2.68	1.3		72.	27		45.5		28.6			CH					
	W227	6.2	2.68	1.715	1.078	65	31		34		27.4	15		CH			M	H-M	H
	W228	3.3	2.69	1.78		50.	24.		26.3		21.1			CH					
	W229	6.4	2.69	1.75	0.492	46.	22.		24		19.6			CL					
	W230	9.2	2.74	1.71		58	23		35		21.8	62		CH			V	M	H
	W231	9.35	2.67	1.654	0.592	48	15		33		23.3			CL					
	W232	3.3	2.67	1.343		85	32		53		36.5	65		CH			V	H	V
	W233	6.3	2.7	1.335	1.02	73	32		41		34.5			CH					
	W234	9.3	2.665	1.692	0.566	42	16		26		17.6	24		CL			H	L-M	M
	W239	3.4	2.735	1.438		34	24		40		32.1	46		CH			V	L-H	L
	W242	6.2	2.68	1.402		74	26		48		33.8	46		CH			V	H	V
	W243	3.4	2.68	1.55		54	23		31		26.4			CH					
	W244																		
	W245					71	29		42										
	W246					72	28		44		25.3								
	W247					69	28		41										
	W248	6.3	2.75	1.377	1	62	23		39		32.8	50		CH			V	H	H
TCK	W249	2.5	2.68	1.63		46	15		31		22.5								
	W250	2.8	2.69	1.57		45	16		29		23.4								
	W251	6		1.56		63	23		40		25.9								
	W252	9	2.805	1.72		40	19		21		18.4								
	W253	3	2.796	1.659		54	22		32		22.3								
	W254	6		1.48		47	22		25		29.9								
	W255	3	2.786			51	20		31		22.2								
	W256	4.5				47	20		27										
	W257	3	2.83	1.592		59	28		31		24.9								
	W258	4.5				69	28		41										
	W259	3	1.55	1.55		68	25		43		24								
	W260	6				42	19		23		18								
	W261	6				68	21		47		24								
	W262	9		1.59		45	26		19		21								
	W263	12		1.607		54	23		31		20								
	W264	3		1.79		49	23		26		18								
	W265	6	2.79	1.83		52	20		32		16								

TABLE.K. (CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEEDET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W266	3		1.61		66	24		42		25								
	W267	6.5	2.535	1.06		68	25		43		24								
	W268	3.5		1.66		54	20		34		22								
	W269	6	2.626	1.73		45	19		26		20								
KİPER	W270		2.68	1.4	0.91	82	37	9	45	73	27	56	0.81	MH	22.22146	H	V	H	V
	W277		2.76	1.66	0.67	60	25	9.5	35	50	24	47	0.74	CH	9.755387	H	V	M	H
	W278		2.73	1.47	0.85	66	28	20	38	46	22	46	0.88	CH	13.82697	H	V	H	H
	W280		2.7			101	50	19	51	82	40	28	1.84	MH	15.15938	H	H	H	E
	W281		2.72			82	42	10	40	72	32	69	0.58	MH	20.17008	H	V	H	V
	W282		2.75			73	33	13	40	60	23	52	0.74	CH	13.81272	H	V	H	V
	W283		2.71			54	28	13	26	41	25	37	0.7	CH	3.740723	M	H	M	H
	W285		2.69			58	31	12	27	46	27	66	0.4	MH	6.991333	H	L	M	H
	W286		2.65			77	28	71	49	70	25	46	1.05	CH	21.27606	H	V	H	V
	W287		2.73			49	22	7.5	27	42	20	41	0.66	CL	4.612816	M	H	L-M	M
	W290		2.67			61	32	12	29	49	25	47	0.62	MH	6.335120	H	H	H-M	H
	W291		2.76			63	32	9.5	31	53	22	43	0.71	MH	6.493881	H	H	H-M	H
	W292		2.68			64	27	7.5	36	57.	24	53	0.68	CH	11.99867	H	V	H	H
	W293		2.77			65	28	11.5	36	53	25	58	0.63	CH	13.57956	H	V	H	H
	W294		2.68			58	25	8	32.5	50	22	51	0.64	CH	9.066152	H	V	M	H
	W295		2.77			50	26	8.5	25	42	22	25	1	CL	2.318548	M	H	M	M-H
SÜRGEL	W296	2.5	2.64	1.38	0.913	70.	25	20	45.5	50	32			CH					
	W297	2.5	2.65	1.38	0.921	76	31	16	45	60	32.4	55	0.82	CH	21.52067	H	V	H	V
	W298		2.76			74	24		50			57	0.88	CH	28.91010	V	V	H	V
	W299	3.5				86	31		55			64	0.84	CH	38.44174	V	V	H	V
	W300	3				76	29		47			68	0.69	CH	29.30386	V	V	H	V
	W301	5.7	2.64			79	32	10	47	69	31.6	55	0.86	CH	24.17276	H	V	H	V
	W302	2.85	2.71			83.	31.		52.2			48	1.09	CH	26.98317	V	V	H	V
	W303		2.71	1.45	0.864	73	30		43		30.7	35	1.23	CH	12.22545	H	V	H	V
	W304	3.5	2.7	1.47	0.838	78	27		51		30.6	39	1.3	CH	20.30423	H	V	H	V
	W305	4	2.7	1.49	0.812	78	27		51		27	39	1.3	CH	20.30423	H	V	H	V
	W306	4	2.72	1.36	1	79	36		43		33	22	1.95	CH-OH	7.619403	H	H	H	V
	W307	4.5	2.72	1.51	0.803	79	36		43		33	22	1.95	CH-OH	7.619403	H	H	H	V
	W308	4	2.7	1.51	0.79	78	27		51		27.5	38	1.34	CH	19.99372	H	V	H	V
	W309	2.5	2.7	1.49	0.82	71	26		45		28	36	1.25	CH	14.01017	H	V	H	V
	W310	3.3	2.7	1.41	0.92	76.	24.		51.7		32.2	37	1.4	CH	20.29872	H	V	H	V
	W311	1.25	2.76	1.49	0.85	53	24		29		26.6	52.	0.55	CH	7.011581	H	H	M	H
	W312	1.25	2.72	1.51	0.8	60	38	13	22	47	26	46	0.48	MH	3.150779	M	H	M-L	H

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W313	1.25	2.71	1.53	0.77	56	35	12	21	44	20.8	40	0.53	MH	2.480972	M	H	M-L	H
	W314	1.5	2.52	1.4	0.8	111	35.		75.5		39.2	48	1.52	CH	60.73942	V	V	H	E
	W315	0.5	2.77	1.43	0.94	88	32.		53.5		44.6	39	1.37	CH	23.07612	H	V	H	V
	W316	2.5	2.67	1.59	0.659	128	38		89.7		30	64	1.4	CH	133.6946	V	V	H	E
	W317	2	2.72	1.49	0.826	85	31		54		32.8	18	3.04	CH	11.28889	H	M	H	V
	W318	4	2.72	1.48	0.838	74	31		46		27	14	3.28	CH	5.724204	H	M	H	V
	W319	6	2.7	1.5	0.8	74	35		38		34	11	3.45	OH	2.824697	M	L	H	V
	W320	0.5		1.24		64.	29.	20.4	34.9	44	26	47	0.74	CH	9.755387	H	V	H	H
	W321	1		1.34		52	25	24	27	28		33	0.82	CH	3.712754	M	H	M	H
	W322	2		1.45		63	27.	22	34.7	41	27	37	0.94	CH	7.679773	H	V	H	H
	W323	0.5		1.29		79	30.	18	39.6	61	43	50	0.79	OH	14.15694	H	V	H	V
	W324	1		1.42		84	32.		52.1		30	40	1.3	CH	22.15188	H	V	H	V
	W325	2		1.42		81.	33		48			54	0.89	CH	24.67451	H	V	H	V
	W326	0.5	2.77	1.41	0.96	70	30	14	40	56	28	45	0.89	CH	13.17847	H	V	H	H-V
	W327	1.1	2.76	1.39	0.981	74	32	10	42	64	30.1	37	1.14	CH	12.29601	H	V	H	V
	W328	1.6	2.74	1.37	1	84	34	12	50	72	32.1	47	0.85	OH	13.68047	H	V	H	V
	W329	2.1	2.71	1.4	0.939	71	30	13	41	58	29	44	0.93	CH	13.57932	H	V	H	V
	W330	3.9	2.77	1.41	0.975	73	35	12	38	61	29	54	0.7	OH	13.73334	H	V	H	V
	W331	4.3	2.44	1.35	0.808	79	33	12	44	67	32	54	0.82	CH	20.20425	H	V	H	V
	W332	4	2.72			75	34	13	41	62		40	1.03	CH	12.55196	H	V	H	V
	W333	1	2.72	1.4	0.95	79.	28.		51		26	19	2.7	CH	10.17987	H	H	H	V
	W334	4	2.72	1.47	0.85	81	28		53		28.6	27	1.96	CH	15.60625	H	H	H	V
	W335	5	2.72	1.56	0.745	77.	27.		50.2		34	15	3.5	CH	8.503201	H	M	H	V
	W336	1			0.995	84	28		55		25			CH					
	W337	2			0.846	80	30		50		29			CH					
	W338	3			0.936	78	30		48		24			CH					
	W339	4			0.905	83	30		53		27			CH					
	W340	6.5	2.67	1.5	0.782	75	28		47		31			CH					
	W341	0.5			0.994	78	27		51		24.5			CH					
	W342	1	2.7	1.45	0.869	77	32		45		29.2			CH					
	W343	2.5			1.05	76	31.		44.5		30.5			CH					
	W344	0.5	2.69	1.37	0.958	82.	29.		53		26.5			CH					
	W345	1			0.932	75.	29		46.5		27.5			CH					
	W346	2	2.65	1.415	0.872	73.	31.		42		32			CH					
	W347	1	2.75	1.39	0.978	76.	30		46.3		28.5			CH					
	W348	2	2.7	1.403	0.925	77.	30.		46.7		29			CH					
	W349	3	2.65	1.352	0.96	77.	31.		45.7		30			CH					

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W350	4			0.94	81	30.		50.5		30.2			CH					
	W351	3	2.66	1.45	0.834	76.	24.		51.7		28.9	37	1.39	CH	20.19275	H	V	H	V
	W352	2.5	2.74			75	44		31		30.4			OH					
	W353	5.8	2.74			86	27		59		33			CH					
	W354	4				73	33		40		30			CH					
	W355	1.5				71.	23.		47.6		29.3			CH					
	W356	4.25		1.57		69	24		45		27.5			CH					
	W357	6.25		1.55		70	26		44		27.1			CH					
	W358	9.2				78	25		53		32.1			CH					
	W359	11.2				72	26		45		26.2			CH					
	W360	13.2				71	21		49		24.1			CH					
	W361	15.2				71	25		46		27.1			CH					
ÇETİNKAYA	W362	1.4	2.697	1.493		72	26		45		29.2	41	1.1		16.04268	H	V	H	V
	W363	3.4	2.682	1.606		71	25		44		24	43	1.03		16.09744	H	V	H	V
	W364	4.94	2.722	1.487		69	27		41		28.8	45	0.92		14.28880	H	V	H	H
	W365	6.98	2.704	1.531		65	20		45		28.1	46	0.8		10.95794	H	V	H	H
ÜNER	W366	1	2.74	1.501		60	21		39		29	38	1.04		10.77257	H	V	H	H
	W367	2	2.73	1.596		57	19		39		26	29	1.5		10.38996	H	V	M-H	H
	W368	3				68	16		31		33	25	1.28		4.234561	M	H	H-M	H
	W369	1	2.77	1.595		72	23		48		24	48	0.6		6.287259	H	V	H	V
	W370	2	2.75	1.483		77	26		51		30	43	0.95		13.21537	H	V	H	V
	W371	3				70	22		48		25	44	1.08		19.55841	H	V	H	H-V
DURUKAN	W375	0.5				64	29		35			47					V	H	H
	W376	1				52	25		27			43					H	M	H
	W377	1				85	33		52			40					V	H	V
	W378	2				81	33		48			54					V	H	V
	W379	1.25				53	24		29		26	53					H	M	H
	W380	1.25				60	38		22		27	46					H	M-L	H
	W381	1.25				56	35		21		23	40					M	M-L	H
ÖZKAN	W382	6.5	2.83	1.48		70	24		46		31.4								
	W383	9.3	2.76	1.55		49	19		30		26.9								
	W384	7.2	2.79	1.47		64	20		44		27.1								
	W385	3.25	2.81	1.4		75	25		50		32.7								
	W386	7.5	2.81	1.48		68	20		48		33.5								
	W387	4.5	2.8	1.39		77	27		50		32.4								
	W388	3	2.79	1.44		75	30		45		32.1								
	W389	6	2.79	1.52		58	22		36		28								

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W390	5	2.82	1.35		91	30		61		31.5								
	W391	6	2.81	1.336		82	27		55		39.2								
	W392	6	2.8	1.53		56	18		38		21.5								
TCK	W393	1		1.437		63	23		40		32								
	W394	3	2.787	1.537		67	22		45		27	40					V	H	H
	W395	5.5	2.756	1.426		69	29		40		32	46					V	H	H
	W396	3	2.793	1.52		67	24		43		28.4								
	W397	3	2.628	1.569		60	21		39		22.6	40					V	M-H	H
	W398	1.5	2.67	1.435		68	26		42		29.8	33					V	H	H
	W399	3	2.64	1.414		74	26		48		30.8	51					V	H	V
	W400	9.5	2.61	1.51		60	20		40		25.4	39		CH			V	M-H	H
	W401	2	2.55	1.292		77	26		51		30.6	41		CH			V	H	V
TOKER	W402	1.5	2.761	1.443		69	27		42		30.6	15		CH			M	H	H
	W403	2.5	2.745	1.6		65	26		39		19.5	12		CH			M	H	H
	W404	4.4	2.75	1.4		74	26		48		33.1	18		CH			M	H	V
	W405	6.5	2.695	1.452		70	26		44		28.7	18		CH			M	H-M	H-V
	W406	4.5	2.738	1.469		62	28		34		29.3	20		CH			H	H	H
	W407	3.5	2.74	1.39		70	25		45		30.8			CH					
TCK	W408	1.5	2.7	1.596		64	26		38		24.8			CH					
	W409	1.5	2.7	1.408		74	22		52		32.8			CH					
	E410	4	2.656	1.4		83	20		63		35			CH					
	W411	9	2.633	1.537		68	20		48		21			CH					
	W412	6.5	2.508	1.38		77	22		55		34			CH					
	W413	4.5	2.702	1.57		56	20		36		30			CH					
	W414	1.5	2.585	1.58		58	18		30		26			CH					
	W415	2.5	2.596	1.52		65	20		45		24			CH					
KASAPOĞLU	W416	2	2.56			48	30	21	18	27	27	35		ML			M	L	M
	W417	4	2.55			72	35	14	37	58	32	50	0.74	MH	12.06937	H	V	H	V
	W418	4.5	2.68			70	33	15	37	55	30	48	0.77	CH	11.55605	H	V	H	H-V
	W419	3	2.66			51	31	15	20	36	28	38	0.53	MH	2.079654	M	M	L	H
	W420	6	2.65			89	52	13	37	76	49	73	0.51	MH	17.88975	H	V	H	V
	W421	1.5	2.56			84	35	15	49	69	32	55	0.8	CH	20.26234	H	V	H	V
	W422	2.5	2.53			55	25	14	30	41	23	43	0.7	CH	6.272969	H	H	M	H
	W425	4	2.5			86	44	21	41	65	41	61	0.68	MH	19.46071	H	V	H	V
	W426	7	2.53			58	32	15	26	43	29	45	0.58	MH	4.635727	M	H	M	H
	W427	3	2.72			83	46	16	37	67	43	62	0.6	MH	15.16418	H	V	H	V
	W428	2.5	2.58			62	29	18	32	44	26	41	0.79	CH	7.153013	H	V	H-M	H

TABLE.K.(CONT'D)

REFERENCE	MAP NO	DEPTH (m)	G_s	P_d Mg/m3	VOID RATIO	LL %	PL %	SL %	PI %	I_s %	W_n %	CC %	ACT.	SOIL CLS	SW.POT. SEED ET.AL 1962	SEED ET.AL 1962	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
	W430	4.5	2.52			67	41	14	26	53	38	51	0.5	MH	4.963987	M	H	H-M	H
	W431	4	2.58			55	36	14	19	41	33	38	0.5	MH	1.804034	M	M	M-L	H
	W432	8	2.65			89	52	13	37	76		78		MH			L	H	V
	W433	4.5	2.5			84	52	15	32	69		64		MH			V	H-M	V
	W434	6	2.58			85	35	15	50	70		58		CH			V	H	V
	W435	2	2.68			70	40	14	30	56		60		MH			H	H-M	H-V
ORDEMİR &	W436	3.5				80	17	24	63	56	43	36	1.75		31.84167	V	V	H	V
ERDEMGİL	W437	6.9				82	44	26	38	56	46	38	1		9.789445	H	V	H	V
	W438	2.9				74	32		42		45								
	W439	5.8				64	33		31		50								
	W440	2.2				71	39	31	32	40	57	41	0.78		6.934095	H	V	H-M	V
	W441	6.8				75	39	26	36	49	48	58	0.62		13.05961	H	V	H	V
	W442	3.6				70	23	20	47	50	47	38	1.24		16.54653	H	V	H	H-V
	W443	7				62	26	20	36	42	40	38	0.98		9.318579	H	V	M-H	H
	W444	3.6				46	16		30		18								
	W445	9.8				56	20		36		20								
	W446	3.6				80	25		55		31	33	1.67		21.05807	H	V	H	V
	W447	8.5				97	42		55		47								
	W448	2.8				78	27		51		42								
	W449	5.8				50	25		25		30								
	W450	3.7				48	24		24		16								
	W451	7				55	27		28		23								
	W452	2.8				65	27	23	38	42	52	82	0.46		20.74680	H	L	H	H
	W453	4.3				87	35		52		38								
	W454	5.8				74	31	21	43	53	40	45	0.96		15.85241	H	V	H	V
	W455	2.8				66	35		31		35								
	W456	0.5	2.48	1.28		66.	34.		32.4		30.1	14.					M	H-M	H
	W457	1	2.52	1.4		66.	25.		40.8		29	16					M	H	H
	W458	1.5	2.67	1.59		50	24.		20.9		25.6	10.					M	L	M-H
	W459	0.5	2.64	1.38		51	29.		27.1		13.5	0.7					L	M-L	H
	W460	1	2.74	1.4		54.	31.		22.9		25.4	0.3					L	M-L	H
	W461	1.5	2.61	1.3		73	37.		35.1		36.2	4.7					L	H	V

*

ABBREVIATIONS USED IN THE SWELL POTENTIAL CLASSIFICATIONS

SEED ET AL. 1962

L: LOW SWELL POTENTIAL
M: MEDIUM SWELL POTENTIAL
H: HIGH SWELL POTENTIAL
V: VERY HIGH SWELL POTENTIAL

VAN DER MERVE

L: LOW SWELL POTENTIAL
M: MEDIUM SWELL POTENTIAL
H: HIGH SWELL POTENTIAL
V: VERY HIGH SWELL POTENTIAL

SNETHEN

L: LOW SWELL POTENTIAL
M: MARGINAL SWELL POTENTIAL
H: HIGH SWELL POTENTIAL

DAKSANAMURTHY & RAMAN

N: NON-SWELLING
L: LOW SWELLING
M: MEDIUM SWELLING
H: HIGH SWELLING
V: VERY HIGH SWELLING
E: EXTRA HIGH SWELLING

APPENDIX L

DERIVATION OF LINEAR STRAIN (i.e.ESTIMATED % HEAVE) EQUATION

Terrace Deposits:

$W_n=79.5-34.66\ \rho_d$ (Emprical Equation) [29]

$\rho_d=G_s*\ \rho_w/(1+e)$ [30]

$W_n=79.5-34.66\{G_s*\ \rho_w/(1+e)\}$ [31]

$G_{s_{\substack{\text{ave}\\ \text{Terrace}}}}=2.656$

$W_n=79.5-(34.66*2.656/(1+e))=79.5-(92.057/(1+e))$ [32]

$e=[92.057/(79.5-w)]-1$ [33]

If e_o and e_1 are the initial and final void ratios before and after swelling (w_o = initial water content, w_1 = final water content)

$e_o=[92.057/(79.5-w_o)]-1$ [34]

$e_1=[92.057/(79.5-w_1)]-1$ [35]

$$\text{Volumetric Strain}=\frac{[(92.057/(79.5-w_1))-(92.057/(79.5-w_0))]}{(92.057/(79.5-w_0))} \quad [36]$$

To convert volumetric strain to linear strain:

V_o= initial volume=1

v_1= final volume= $(1+\varepsilon_1)(1+\varepsilon_2)(1+\varepsilon_3)$ [37]

$\varepsilon_1,\varepsilon_2,\varepsilon_3$ = strains in x, y, z directions respectively

if $\varepsilon_1=\varepsilon_2=\varepsilon_3=\varepsilon$ (assumption)

$V=(1+\varepsilon)^3$ [38]

$V=V_1-V_o=(1+\varepsilon)^3-1$ [39]

$$\text{Volumetric strain}=\frac{\Delta V}{V_o}=\frac{V_1-V_o}{V_o}=(1+\varepsilon)^3-1 \quad [40]$$

$$\varepsilon=\sqrt[3]{(1+\text{volumetric strain})}-1 \quad [41]$$

$$\text{Linear Strain}=\left[\sqrt[3]{(1+\text{volumetric strain})}-1\right]*100. \quad [42]$$
(estimated % heave)

CALCULATIONS OF ESTIMATED % HEAVE VALUES FOR STATIONS A AND B BY USING ESTIMATED % HEAVE EQUATION (i.e Eqn.42) (See Figs.L1 & L2)

STATION A

Between 50 cm-100 cm:

$W_{n\,\text{initial average}}$ =21 % (July)

$W_{n\,\text{final average}}$ = 29.5 % (december)

From eqn.42

Volumetric strain=0.163

Estimated % Heave = 5.16 %

Between 100 cm - 200 cm :

$W_{n\,\text{initial average}}$ = 25 % (july)

$W_{n\,\text{final average}}$ = 29.55 % (december)

From Eqn .42

Volumetric Strain=0.091

Estimated % Heave = 2.95 %

STATION B:

Between 50 cm - 100 cm :

$W_{n\ \text{initial average}}$ = 25.6 % (july)

$W_{n\ \text{final average}}$ = 31.5 % (december)

From Eqn.42

Volumetric Strain = 0.123

Estimated % Heave = 3.94 %

Between 100 cm- 200 cm :

$W_{n\ \text{initial average}}$ = 29.3 % (july)

$W_{n\ \text{final average}}$ = 33 % (december)

From Eqn.42

Volumetric Strain = 0.079

Estimated % Heave = 2.58 %

MEASURED % HEAVE VALUES FOR STATIONS A AND B

(OMAY, 1970) (See Figs. L1 and L2)

	STATION A					
TIME	50cm		100 cm		200 cm	
	Elevation (mm)	w/c (%)	Elevation (mm)	w/c (%)	Elevation (mm)	w/c (%)
JULY	6130	19	6170	23	6085	27
DECEM.	6156	29.8	6210	28.6	6110	30.5

STATION A :

Change in thickness of layers between july- december:

Between 50 cm-100 cm:

dH_{50} = 6156-6130= 26 mm

dH_{100} = 6210-6170= 40 mm

change in thickness of layer= dh_{50-100} = 40-26=14 mm
=1.4 cm
=2.8 %

Between 100 cm-200 cm:

dH_{100} = 6210-6170= 40 mm

dH_{200} = 6110-6085= 25 mm

change in thickness of layer= $dh_{100-200}$ = 40-25=15 mm
= 1.5 cm
= 1.5 %

	STATION B					
TIME	50 cm		100 cm		200 cm	
	Elevation (mm)	w/c (%)	Elevation (mm)	w/c (%)	Elevation (mm)	w/c (%)
JULY	3270	22	3400	29.2	3450	29.5
DECEM.	3280	29	3431	34	3458	32

STATION B:

Change in thickness of layers b/w july-december:

Between 50 cm-100 cm:

dH_{50} = 3280-3270 =10 mm

dH_{100} = 3431-3400 = 31 mm

change in thickness of layer dH_{50-100} = 31-10 = 21 mm

=2.1 cm

=4.2 %

Between 100 cm-200 cm:

dH_{100} = 3431-3400= 31 mm

dH_{200} = 3458-3450= 8 mm

change in thickness of layer $dH_{100-200}$ = 31-8= 23 mm

=2.3 cm

=2.3 %

FIELD MEASUREMENTS (Omay,1970)

Type of gauging at stations is shown in Fig. L1 and Description of sampling is shown in Fig. L2.

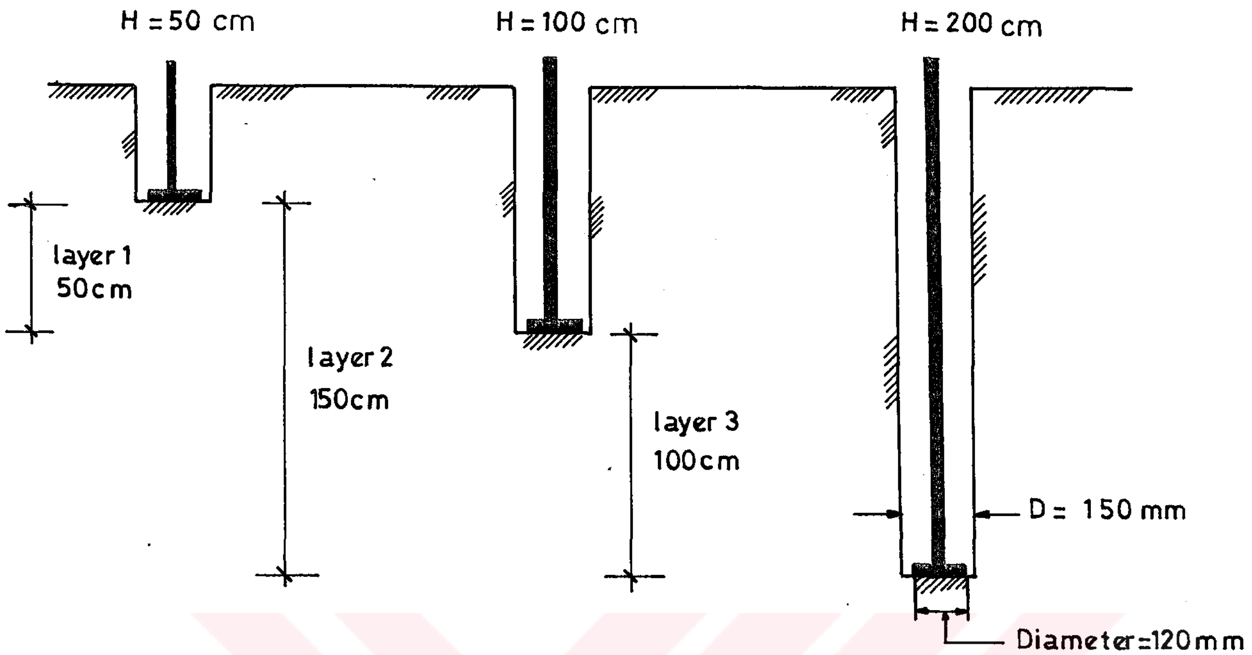


Fig. L1. Type of gauging at stations

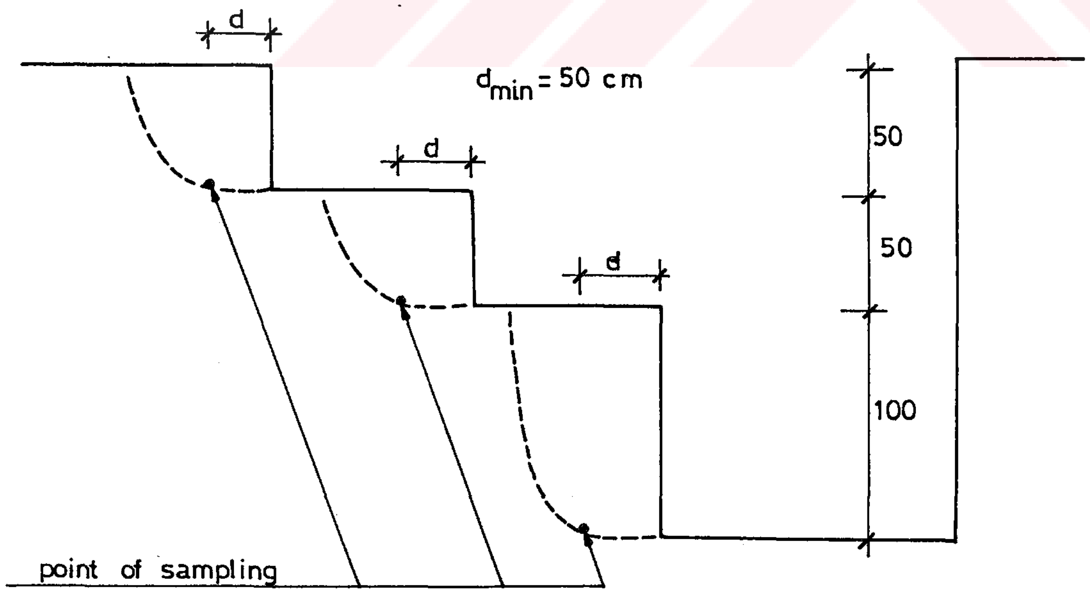


Fig. L2. Description of sampling

APPENDIX M

Table,M.Swelling Potential Classification of the Soils Given by Lautrin (1987) and Magnan and Youssefian (1989)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100g	SWELL POT Seed et al 1962	HazardC	SEED* ET.AL	VAN DER* MERVE	SNETHEN*	DAKSANAM* RAMAN
LAUTRIN1	72	105	43	62	0.86	11	61.05236	15.27777	V	V	H	E
2	32	42	21	21	0.66	2.8	1.966552	8.75	M	M	L	M
3	65	96	40	56	0.85	10.6	41.73559	16.30769	V	V	H	E
4	40	48	31	17	0.43	3.2	1.489539	8	L	L	L	M
5	38	54	23	31	0.79	5.4	5.507673	14.21052	H	H	M	H
6	30	43	22	21	0.7	2.4	1.818188	8	M	M	L	M
7	79	122	64	58	0.73	15.4	56.31803	19.49367	V	V	H	E
8	93	59	28	31	0.33	3.2	14.22518	3.440860	H	L	M	H
9	94	72	34	38	0.4	5.2	23.59873	5.531914	H	L	H	V
10	93	74	34	40	0.43	5	27.13606	5.376344	V	L	H	V
11	86	77	37	40	0.47	8	25.75703	9.302325	V	L	H	V
12	85	54	29	25	0.29	3.2	7.616487	3.764705	H	L	M	H
13	91	60	29	31	0.34	3.6	14.19755	3.956043	H	L	M	H
14	44	46	25	21	0.47	2.4	2.568611	5.454545	M	L	L	M
15	63	59	29	30	0.47	3.2	8.829838	5.079365	H	L	M	H
16	66	90	43	47	0.71	10.8	28.35332	16.36363	V	V	H	V
17	77	80	37	43	0.56	6.4	27.00283	8.311688	V	V	H	V
18	41	54	28	26	0.63	4.4	4.117844	10.73170	M	H	M	H
19	32	35	18	17	0.53	3.2	1.151467	10	L	L	L	L
20	37	34	18	16	0.43	2	1.139146	5.405405	L	L	L	L
21	24	34	17	17	0.7	1.6	0.843856	6.666666	L	M	L	L
22	88	99	43	56	0.63	10	56.97887	11.36363	V	V	H	E
23	79	114	47	67	0.84	12.4	79.31971	15.69620	V	V	H	E
24	91	103	47	56	0.61	11.6	59.10302	12.74725	V	V	H	E
25	80	108	45	63	0.78	10.8	69.12623	13.5	V	V	H	E
26	40	57	29.5	27.5	0.68	1.4	4.557331	3.5	M	H	M	H
27	59	64	31	33	0.55	1.6	10.33994	2.711864	H	V	H	H
28	29	32.5	20	12.5	0.43	0.5	0.492736	1.724137	L	L	L	L
29	28	32.5	20	12.5	0.44	0.6	0.461902	2.142857	L	L	L	L
30	34	34.5	23	11.5	0.33	0.6	0.446440	1.764705	L	L	L	L
31	32	29	18	11	0.34	1.4	0.389786	4.375	L	L	L	L
32	72	85.5	35	50.5	0.7	10.4	36.94583	14.44444	V	V	H	V
33	44	59.5	28	31.5	0.71	1.8	7.028296	4.090909	H	V	M	H
34	80	86.5	39	47.5	0.59	6.8	34.97928	8.5	V	V	H	V

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100g	SWELL POT. Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
35	61	61	28.5	32.5	0.53	2.2	10.59425	3.606557	H	V	H	H
36	40	50.5	24.5	26	0.65	3	4.082229	7.5	M	H	M	H
37	32	40	22	18	0.56	2.8	1.317034	8.75	L	M	L	M
38	38	50	30	20	0.52	1.8	1.985208	4.736842	M	M	M	M
39	40	51	28	23	0.57	1.7	2.962944	4.25	M	H	M	H
40	43	67	27	40	0.93	1.8	12.54678	4.186046	H	V	H	H
41	45	64	27	37	0.82	3.1	10.79094	6.888888	H	V	H	H
42	46	58	28	30	0.65	2.2	6.602342	4.782608	H	H	M	H
43	45	56	29	27	0.6	2.1	5.035499	4.666666	H	H	M	H
44	51	69	30	39	0.76	3.1	13.78888	6.078431	H	V	H	H
45	53	70	31	39	0.74	6	14.74812	11.32075	H	V	H	H
46	60	60	22	38	0.63	6.2	15.25926	10.33333	H	V	M	H
47	61	66	27	39	0.64	7.4	16.78480	12.13114	H	V	H	H
48	75	85	35	50	0.67	7.8	38.20636	10.4	V	V	H	V
49	79	86	38	48	0.61	7.2	36.33661	9.113924	V	V	H	V
50	60	63	34	29	0.48	5.4	7.859074	9	H	H	H	H
51	45	57	28	29	0.64	3.6	5.894306	8	H	H	M	H
52	43	65.5	30	35.5	0.82	3.2	9.228684	7.441860	H	V	H	H
53	47	74	32.5	41.5	0.88	5.6	14.88870	11.91489	H	V	H	V
54	67	86.5	38.5	48	0.71	11	29.85865	16.41791	V	V	H	V
55	82	114.	42.5	72	0.88	3	101.0089	3.658536	V	V	H	E
56	69	81	41	40	0.57	2	19.33205	2.898550	H	V	H	V
57	65	98	48	50	0.76	2.2	31.76212	3.384615	V	V	H	E
58	85	91.5	47.5	44	0.51	3.2	30.19776	3.764705	V	V	H	E
59	68	92.5	42	50.5	0.74	1.2	34.75830	1.764705	V	V	H	E
60	68	98	46	52	0.76	2.2	37.09525	3.235294	V	V	H	E
61	68	93	39	54	0.79	2	40.77023	2.941176	V	V	H	E
62	68	97.5	43	54.5	0.8	1.8	42.04097	2.647058	V	V	H	E
63	61	54	32.5	21.5	0.35	6	3.849135	9.836065	M	L	M	H
64	59	72.5	30	42.5	0.72	4.2	19.94916	7.118644	H	V	H	V
65	80	150	74.5	75.5	0.94	7.8	108.9843	9.75	V	V	H	E
66	75	71.5	32	39.5	0.52	7.4	20.58549	9.866666	H	V	H	V
67	69	75	35	40	0.57	7	19.33205	10.14492	H	V	H	V
68	94	95.5	38	57.5	0.61	11	66.07955	11.70212	V	V	H	E
69	33	36	21	15	0.45	2.4	0.858675	7.272727	L	L	L	M
70	32	36	22	14	0.44	2.3	0.731211	7.1875	L	L	L	M
71	31	40	22	17	0.55	1.8	1.129982	5.806451	L	M	L	M

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100g	SWELL POT Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
72	30	42	24	18	0.6	2.2	1.248212	7.333333	L	M	L	M
73	52	67	31	36	0.69	3.8	11.64516	7.307692	H	V	H	H
74	26	36.5	22	14.5	0.55	1.4	0.617015	5.384615	L	M	L	M
75	51	63	28.5	34.5	0.67	3	10.13833	5.882352	H	V	H	H
76	87	88	43.5	44.5	0.51	6.2	32.71296	7.126436	V	V	H	V
77	45	50	23.5	26.5	0.58	2.8	4.635727	6.222222	M	H	M	M
78	23	31	19	12	0.52	1.5	0.352934	6.521739	L	L	L	L
79	59	49	29	20	0.33	6.8	2.973085	11.52542	M	L	L	M
MAGNAN80	28	25		10	0.357142	2.3	0.277626	8.214285	L	L	L	L
81	42	34		18	0.428571	2.7	1.747498	6.428571	M	L	L	L
82	40	28		8	0.2	1.7	0.230092	4.25	L	L	L	L
83	35	26		10	0.285714	1.75	0.347032	5	L	L	L	L
84	38	35		17	0.447368	2.45	1.375249	6.447368	L	L	L	L
85	27	24		7	0.259259	1.52	0.112125	5.629629	L	L	L	L
86	21	34		16	0.761904	3.7	0.655502	17.61904	L	M	L	L
87	33	53		28	0.848484	10.3	4.035357	31.21212	M	H	M	H
88	33	47		29	0.878787	9.7	4.396099	29.39393	M	H	M	L
89	45	48		27	0.6	5.65	5.035499	12.55555	H	H	L	M
90	38	42		20	0.526315	4.41	2.044557	11.60526	M	M	L	M
91	47	55		33	0.702127	5.8	8.581720	12.34042	H	V	M	H
92	24	40		17	0.708333	5.1	0.868578	21.25	L	M	L	M
93	33	50		27	0.818181	6.4	3.692699	19.39393	M	H	M	M
94	21	32		10	0.476190	2.7	0.208219	12.85714	L	L	L	L
95	26	35		15	0.576923	3.8	0.693327	14.61538	L	M	L	L
96	46	49		22	0.478260	6	3.122997	13.04347	M	L	L	M
97	41	34		12	0.292682	1	0.634291	2.439024	L	L	L	L
98	35	36		6	0.171428	0.76	0.099783	2.171428	L	L	L	M
99	27	38		17	0.629629	1.5	0.977150	5.555555	L	M	L	M
100	65	70		40	0.615384	3.8	18.97764	5.846153	H	V	H	H
101	48	44		20	0.416666	1.5	2.582598	3.125	M	L	L	M
102	35	44		18	0.514285	1.06	1.456248	3.028571	L	L	L	M
103	46	38		13	0.282608	2.85	0.865131	6.195652	L	L	L	M
104	36	40		16	0.444444	1	1.123719	2.777777	L	L	L	M
105	38	41		23	0.605263	4.75	2.875424	12.5	M	H	L	M
106	45	27		13	0.288888	3	0.846324	6.666666	L	L	L	L
107	23	50		24	1.043478	3.17	1.930837	13.78260	M	H	M	M
108	54	45		18	0.333333	2.1	2.246783	3.888888	M	L	L	M

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100 g	SWELL POT Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
109	42	41		17	0.404761	2.3	1.520012	5.476190	M	L	L	M
110	30	26		10	0.333333	1.1	0.297456	3.666666	L	L	L	L
111	35	45		18	0.514285	1.3	1.456248	3.714285	L	L	L	M
112	39	45		21	0.538461	2.2	2.363644	5.641025	M	M	L	M
113	39	46		20	0.512820	1.6	2.098361	4.102564	M	M	L	M
114	38	30		13	0.342105	1.6	0.714673	4.210526	L	L	L	L
115	35	41		17	0.485714	1.55	1.266677	4.428571	L	L	L	M
116	35	47		13	0.371428	0.8	0.658252	2.285714	L	L	L	M
117	72	105		62	0.861111	11	61.24501	15.27777	V	V	H	E
118	32	42		21	0.65625	2.8	1.939400	8.75	M	M	L	M
119	65	96		56	0.861538	10.6	43.13150	16.30769	V	V	H	E
120	40	48		17	0.425	3.2	1.447630	8	L	L	L	M
121	38	54		31	0.815789	5.4	5.956739	14.21052	H	H	M	H
122	30	43		21	0.7	2.4	1.818188	8	M	M	L	M
123	79	122		58	0.734177	15.4	57.10759	19.49367	V	V	H	E
124	93	59		31	0.333333	3.2	14.57833	3.440860	H	L	M	H
125	94	72		38	0.404255	5.2	24.21599	5.531914	H	L	H	V
126	93	74		40	0.430107	5	27.15262	5.376344	V	L	H	V
127	86	77		40	0.465116	8	25.10887	9.302325	V	L	H	V
128	85	54		25	0.294117	3.2	7.883063	3.764705	H	L	M	H
129	91	60		31	0.340659	3.6	14.26482	3.956043	H	L	M	H
130	44	46		21	0.477272	2.4	2.666676	5.454545	H	M	L	M
131	63	59		30	0.476190	3.2	9.116306	5.079365	H	L	M	H
132	66	90		47	0.712121	10.8	28.56046	16.36363	V	V	H	V
133	77	80		43	0.558441	6.4	26.81984	8.311688	V	V	H	V
134	41	54		26	0.634146	4.4	4.184285	10.73170	M	H	M	H
135	32	35		17	0.53125	3.2	1.158104	10	L	L	L	L
136	37	34		16	0.432432	2	1.154933	5.405405	L	L	L	L
137	24	34		17	0.708333	1.6	0.868578	6.666666	L	M	L	L
138	88	99		56	0.636363	10	58.39342	11.36363	V	V	H	E
139	79	114		67	0.848101	12.4	81.19926	15.69620	V	V	H	E
140	91	103		56	0.615384	11.6	60.38411	12.74725	V	V	H	E
141	80	108		63	0.7875	10.8	70.75928	13.5	V	V	H	E
142	40	57		27.5	0.6875	1.4	4.680952	3.5	M	H	M	H
143	59	64		33	0.559322	1.6	10.77279	2.711864	H	V	H	H
144	29	32.5		12.5	0.431034	0.5	0.495633	1.724137	L	L	L	L
145	28	32.5		12.5	0.446428	0.6	0.478542	2.142857	L	L	L	L

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100 g	SWELL POT Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
146	34	34.5		11.5	0.338235	0.6	0.474115	1.764705	L	L	L	L
147	32	29		11	0.34375	1.4	0.400359	4.375	L	L	L	L
148	72	85.5		50.5	0.701388	10.4	37.12495	14.44444	V	V	H	V
149	44	59.5		31.5	0.715909	1.8	7.171878	4.090909	H	V	M	H
150	80	86.5		47.5	0.59375	6.8	35.52424	8.5	V	V	H	V
151	61	61		32.5	0.532786	2.2	10.73069	3.606557	H	V	H	H
152	40	50.5		26	0.65	3	4.082229	7.5	M	H	M	H
153	32	40		18	0.5625	2.8	1.331427	8.75	L	M	L	M
154	38	50		20	0.526315	1.8	2.044557	4.736842	M	M	M	M
155	40	51		23	0.575	1.7	3.026762	4.25	M	H	M	H
156	43	67		40	0.930232	1.8	12.55443	4.186046	H	V	H	H
157	45	64		37	0.822222	3.1	10.86243	6.888888	H	V	H	H
158	46	58		30	0.652173	2.2	6.656350	4.782608	H	H	M	H
159	45	56		27	0.6	2.1	5.035499	4.666666	H	H	M	H
160	51	69		39	0.764705	3.1	13.99813	6.078431	H	H	H	H
161	53	70		39	0.735849	6	14.54708	11.32075	H	V	H	H
162	60	60		38	0.633333	6.2	15.45701	10.33333	H	V	M	H
163	61	66		39	0.639344	7.4	16.74287	12.13114	H	V	H	H
164	75	85		50	0.666666	7.8	37.74423	10.4	V	V	H	V
165	79	86		48	0.607594	7.2	35.98804	9.113924	V	V	H	V
166	60	63		29	0.483333	5.4	7.992908	9	H	H	H	H
167	45	57		29	0.644444	3.6	5.994681	8	H	H	M	H
168	43	65.5		35.5	0.825581	3.2	9.382706	7.441860	H	V	H	H
169	47	74		41.5	0.882978	5.6	15.01197	11.91489	H	V	H	V
170	67	86.5		48	0.716417	11	30.52150	16.41791	V	V	H	V
171	82	114.		72	0.878048	3	100.4633	3.658536	V	V	H	E
172	69	81		40	0.579710	2	20.14549	2.898550	H	V	H	V
173	65	98		50	0.769230	2.2	32.71166	3.384615	V	V	H	E
174	85	91.5		44	0.517647	3.2	31.31453	3.764705	V	V	H	E
175	68	92.5		50.5	0.742647	1.2	35.06245	1.764705	V	V	H	E
176	68	98		52	0.764705	2.2	37.65820	3.235294	V	V	H	E
177	68	93		54	0.794117	2	41.29069	2.941176	V	V	H	E
178	68	97.5		54.5	0.801470	1.8	42.22978	2.647058	V	V	H	E
179	61	54		21.5	0.352459	6	3.915454	9.836065	M	L	M	H
180	59	72.5		42.5	0.720338	4.2	19.97208	7.118644	H	V	H	V
181	80	150		75.5	0.94375	7.875	110.0482	9.84375	V	V	H	E
182	75	71.5		39.5	0.526666	7.4	21.23541	9.866666	H	V	H	V

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100g	SWELL POT. Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
183	69	75.5		40	0.579710	7	20.14549	10.14492	H	V	H	V
184	94	95.5		57.5	0.611702	11	66.53036	11.70212	V	V	H	E
185	33	36		15	0.454545	2.4	0.879992	7.272727	L	L	L	M
186	32	36		14	0.4375	2.3	0.721115	7.1875	L	L	L	M
187	31	40		17	0.548387	1.8	1.121913	5.806451	L	M	L	M
188	30	42		18	0.6	2.2	1.248212	7.333333	L	M	L	M
189	52	67		36	0.692307	2.8	11.74042	5.384615	H	V	H	H
190	26	36.5		14.5	0.557692	1.4	0.638283	5.384615	L	M	L	M
191	51	63		34.5	0.676470	3	10.37889	5.882352	H	V	H	H
192	87	88		44.5	0.511494	6.2	32.94732	7.126436	V	V	H	V
193	45	50		26.5	0.588888	2.8	4.810995	6.222222	M	H	M	M
194	23	31		12	0.521739	1.5	0.355821	6.521739	L	M	L	L
195	59	49		20	0.338983	6.8	3.174444	11.52542	M	L	L	M
196	74	36		12	0.162162	1.24	1.144818	1.675675	L	L	L	M
197	66	35.8		12.8	0.193939	1.29	1.195194	1.954545	L	L	L	M
198	70	36.9		11.9	0.17	1.15	1.061048	1.642857	L	L	L	M
199	94	73.4		47.4	0.504255	4.06	41.52689	4.319148	V	V	H	V
200	82	66.7		38.7	0.471951	2.29	22.08671	2.792682	H	L	H	H
201	88	67.6		39.8	0.452272	2.63	25.38048	2.988636	V	L	H	H
202	85	64		36	0.423529	3.2	19.19108	3.764705	H	L	H	H
203	85	61.8		36	0.423529	2.77	19.19108	3.258823	H	L	H	H
204	74	61		37.5	0.506756	2.67	18.45739	3.608108	H	V	H	H
205	43	36		15	0.348837	2.2	1.146657	5.116279	L	L	L	M
206	50	43		23	0.46	1.91	3.783453	3.82	M	L	L	M
207	36	34		16	0.444444	1.39	1.123719	3.861111	L	L	L	L
208	55	28		10	0.181818	1.19	0.545337	2.163636	L	L	L	L
209	50	34		12.5	0.25	1.43	0.854541	2.86	L	L	L	L
210	47	25		8	0.170212	1.1	0.270358	2.340425	L	L	L	L
211	58	77		41	0.706896	7.5	17.98552	12.93103	H	V	H	V
212	62	76		48	0.774193	4.8	28.24377	7.741935	V	V	H	V
213	42	53		30	0.714285	4.6	6.077537	10.95238	H	H	M	H
214	62	68		40	0.645161	5.8	18.10175	9.354838	H	V	H	H
215	56	188		119	2.125	7.5	233.7895	13.39285	V	V	H	E
216	54	77		44	0.814814	1.5	19.89393	2.777777	H	V	H	V
217	27	48		24	0.888888	0.7	2.266635	2.592592	M	H	L	M
218	8.2	40		18	2.195121	0.2	0.341178	2.439024	L	L	L	M
219	17	48		23	1.352941	0.4	1.286374	2.352941	L	M	L	M

TABLE M (continue)

REF. NO.	CC %	LL %	PL %	PI %	ACT. PI/CC	MBV g/100 g	SWELL POT. Seed et.al 1962	HazardC.	SEED ET.AL	VAN DER MERVE	SNETHEN	DAKSANAM. RAMAN
220	25	33		13	0.52	0.7	0.470180	2.8	L	M	L	L
221	61	62		32	0.524590	4.3	10.33233	7.049180	H	V	H	H
222	72	82		51	0.708333	13.2	38.02824	18.33333	V	V	H	V
223	85	184		97	1.141176	11.9	215.4986	14	V	V	H	E
224	65	120		64	0.984615	8.1	59.74409	12.46153	V	V	H	E
225	60	111		63	1.05	6.4	53.06946	10.66666	V	V	H	E
226	58	115		65	1.120689	6.9	55.36548	11.89655	V	V	H	E
227	67	117		61	0.910447	8.2	54.77496	12.23880	V	V	H	E
228	75	145		85	1.133333	7.7	137.7672	10.26666	V	V	H	E
229	55	117		67	1.218181	4.6	56.53113	8.363636	V	V	H	E
230	80	163		103	1.2875	9	234.8093	11.25	V	V	H	E
231	20	68		38	1.9	0.5	5.152339	2.5	H	H	H	H
232	27	73		46	1.703703	2.8	11.08652	10.37037	V	H	H	V
233	51	135		81	1.588235	5.6	83.28678	10.98039	V	V	H	E
234	48	109		65	1.354166	2.5	45.81970	5.208333	V	V	H	E
235	60	110		65	1.083333	10.1	57.27463	16.83333	V	V	H	E
236	54	96		53	0.981481	4.6	31.32776	8.518518	V	V	H	E
237	52	110		75	1.442307	6.1	70.38098	11.73076	V	V	H	E
238	59	128		75	1.271186	9	79.85534	15.25423	V	V	H	E
239	65	116		68	1.046153	7.2	69.26879	11.07692	V	V	H	E
240	53	80		40	0.754716	6	15.47407	11.32075	H	V	H	V

* ABBREVIATIONS USED IN THE SWELL POTENTIAL CLASSIFICATIONS

SEED ET AL. 1962

L: LOW SWELL POTENTIAL
M: MEDIUM SWELL POTENTIAL
H: HIGH SWELL POTENTIAL
V: VERY HIGH SWELL POTENTIAL

VAN DER MERVE

L: LOW SWELL POTENTIAL
M: MEDIUM SWELL POTENTIAL
H: HIGH SWELL POTENTIAL
V: VERY HIGH SWELL POTENTIAL

SNETHEN

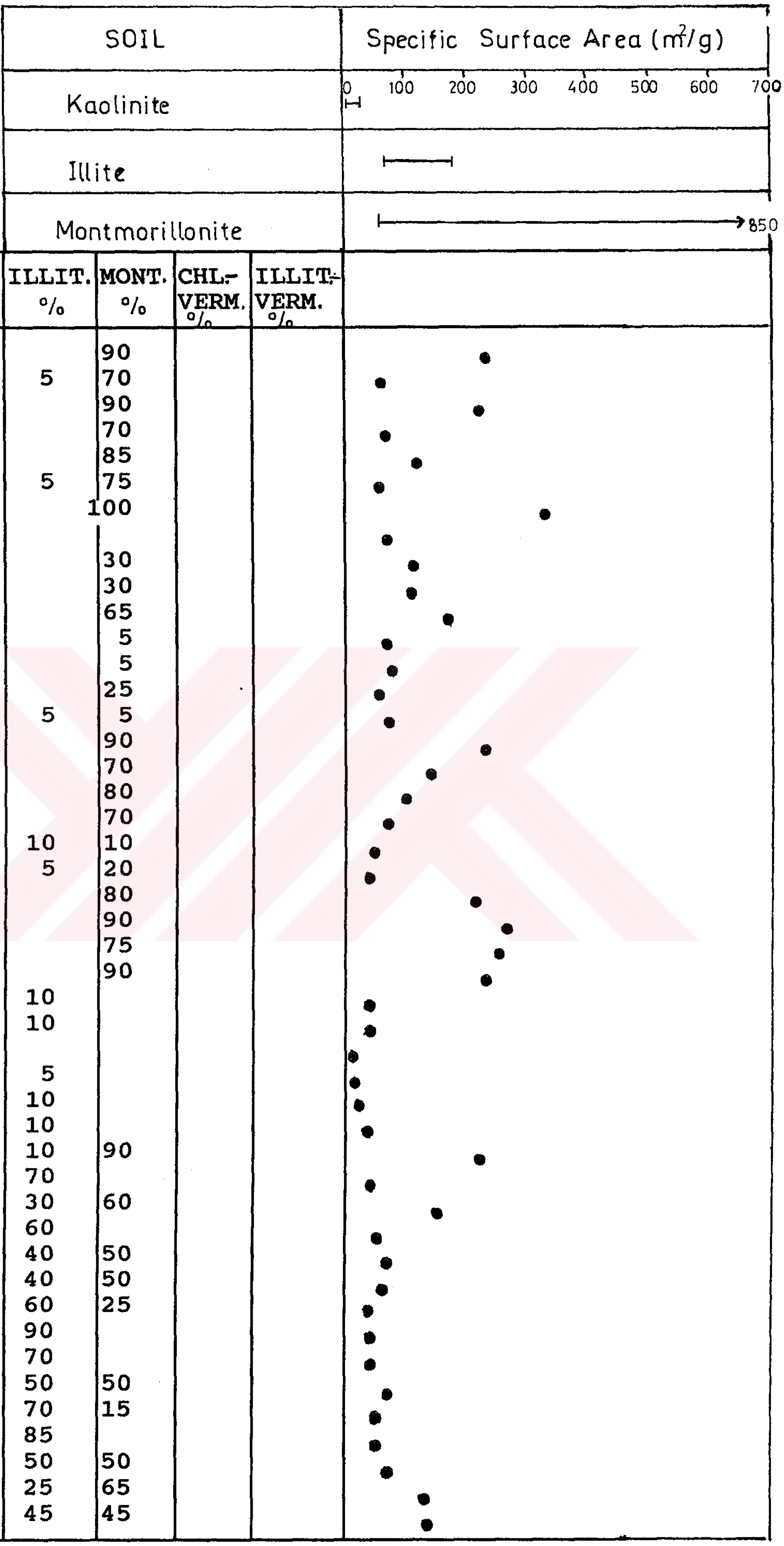
L: LOW SWELL POTENTIAL
M: MARGINAL SWELL POTENTIAL
H: HIGH SWELL POTENTIAL

DAKSANAMURTHY & RAMAN

N: NON-SWELLING
L: LOW SWELLING
M: MEDIUM SWELLING
H: HIGH SWELLING
V: VERY HIGH SWELLING
E: EXTRA HIGH SWELLING

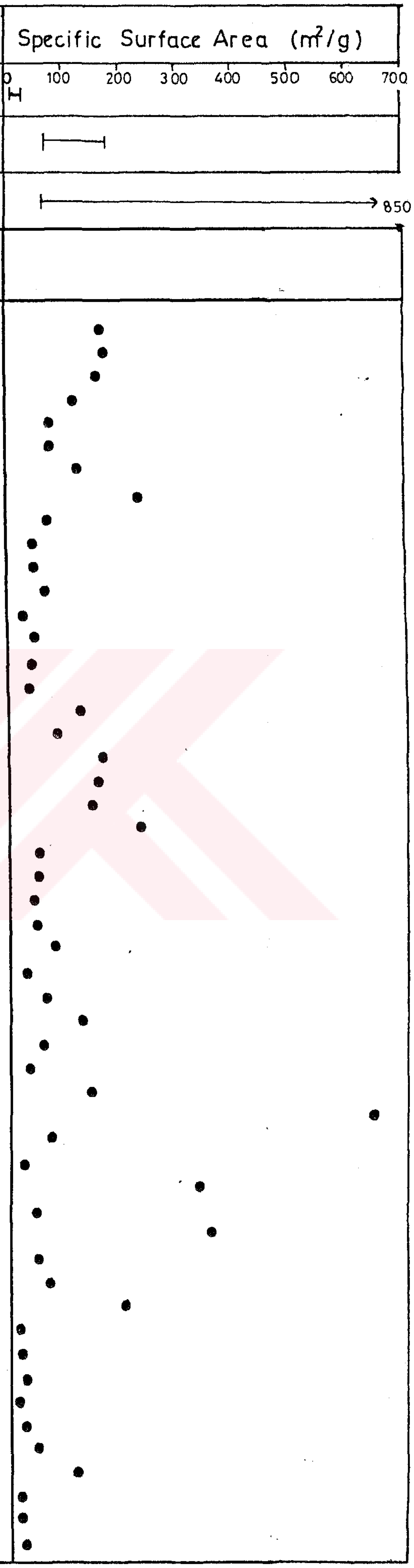
APPENDIX N

Table.N. Specific Surface Area Values for Lautrin (1987)' Data



MBV g/100g	SSA m²/g	KAOL. %	ILLIT. %	MONT. %	CHL.-VERM. %	ILLIT.-VERM. %
11	230.23	10		90		
2.8	58.604	25	5	70		
10.6	221.858	10		90		
3.2	66.976	30		70		
5.4	113.022	15		85		
2.4	50.232	20	5	75		
15.4	322.322			100		
3.2	66.976	100				
5.2	108.836	70		30		
5	104.65	70		30		
8	167.44	35		65		
3.2	66.976	95		5		
3.6	75.348	95		5		
2.4	50.232	75		25		
3.2	66.976	90	5	5		
10.8	226.044	10		90		
6.4	133.952	30		70		
4.4	92.092	20		80		
3.2	66.976	30		70		
2	41.86	80	10	10		
1.6	33.488	75	5	20		
10	209.3	20		80		
12.4	259.532	10		90		
11.6	242.788	25		75		
10.8	226.044	10		90		
1.4	29.302	90	10			
1.6	33.488	90	10			
0.5	10.465	100				
0.6	12.558	95	5			
0.6	12.558	90	10			
1.4	29.302	90	10			
10.4	217.672		10	90		
1.8	37.674	30	70			
6.8	142.324	10	30	60		
2.2	46.046	40	60			
3	62.79	10	40	50		
2.8	58.604	10	40	50		
1.8	37.674	15	60	25		
1.7	35.581	10	90			
1.8	37.674	30	70			
3.1	64.883		50	50		
2.2	46.046	15	70	15		
2.1	43.953	15	85			
3.1	64.883		50	50		
6	125.58	10	25	65		
6.2	129.766	10	45	45		

Table,IV,(cont'd)



MBV g/100g	SSA m²/g	KAOL. %	ILLIT. %	MONT. %	CHL.-VERM. %	ILLIT. VERM. %
7.4	154.882	10	50	40		
7.8	163.254	15	40	45		
7.2	150.696	10	50	40		
5.4	113.022	10	50	40		
3.6	75.348	25	30	45		
3.2	66.976	15	40	45		
5.6	117.208	5	5	90		
11	230.23		10	90		
3	62.79	50	45	5		
2	41.86	50	50			
2.2	46.046	48	47		5	
3.2	66.976	47	43			10
1.2	25.116	55	45			
2.2	46.046	53	47			
2	41.86	51	49			
1.8	37.674	58	42			
6	125.58	25	35	40		
4.2	87.906	30	40	30		
7.8	163.254		100			
7.4	154.882	25	35	40		
7	146.51	10	25	65		
11	230.23	10	30	60		
2.4	50.232	15	35	45	5	
2.3	48.139	15	40	40	5	
1.8	37.674	10	65	20	5	
2.2	46.046	20	40	40		
3.8	79.534	5	30	60	5	
1.4	29.302	45	35		20	
3	62.79	75	25			
6.2	129.766	45	10	35		10
2.8	58.604	60	30		10	
1.5	31.395	50	35		15	
6.8	142.324	15	25	60		
31	648.83			100		
3.4	71.162		100			
1.1	23.023	100				
16	334.88	50		50		
2.2	46.046	50	50			
17	355.81		50	50		
2.37	49.6041			100		
3.33	69.6969			100		
9.83	205.741			100		
0.67	14.0231	100				
0.9	18.837	100				
1.27	26.5811	100				
0.6	12.558	10	90			
1.27	26.5811	10	90			
2.33	48.7669	10	90			
5.67	118.673	10	90			
0.83	17.3719	100				
0.93	19.4649	100				
1.14	23.8602	100				

APPENDIX O

DERIVATION OF C.E.C. EQUATION:

$$\text{Equivalent weight} = \frac{\text{gram formula weight (gfw)}}{e^{-}\ \text{shared} \ (\equiv \text{eq})} \qquad (43)$$

1 charge = 1 Equivalent (unit) (≡eq)

1000 meq = 1 Equivalent

$$\text{No. of equivalent} = \frac{\text{weight of substance}}{\text{Equivalent weight}} \qquad (44)$$

$$= \frac{\text{weight of substance}}{\left(\dfrac{\text{gfw}}{1\ \text{eq}}\right)} \qquad (45)$$

$$= \frac{\text{weight of substance}}{\left(\dfrac{\text{gfw}}{1000\ \text{meq}}\right)} \qquad (46)$$

$$\text{Normality} = \frac{\text{No. of equivalent}}{\text{lt}} \qquad (47)$$

$$= \frac{\text{weight of substance}}{\text{gfw}} * \left[\frac{1000\ \text{meq}}{1000\ \text{ml}}\right] \qquad (48)$$

$$\text{Normality (meq/ml)} = \frac{\text{Wgt. of substance}}{\text{gfw}} * \left[\frac{100-X}{100}\right] \qquad (49)$$

$$\text{c.e.c.} \left(\frac{\#\ \text{of meq}}{100\ \text{gr clay}}\right) = \frac{100}{\begin{array}{c}\text{weight of}\\ \text{clay sample}\\ \text{(gr)}\end{array}} * \begin{array}{c}\text{volume}\\ \text{titrant}\\ \text{(ml)}\end{array} * \begin{array}{c}\text{Normality}\\ \left(\dfrac{\#\ \text{of meq}}{\text{ml}}\right)\end{array} \qquad (50)$$

NORMALITY OF METHYLENE BLUE SUBSTANCE:

$$N_{MB} = \frac{\text{weight of MB in g}}{320} * \frac{100- X}{100} \qquad (51)$$

sample (moist) of MB = 0.9996 g

sample (dry) of MB = 0.7776 g

$$X = \text{moisture content of MB} = \frac{0.9996 - 0.7776}{0.7776} = 28.55\ \%$$

$$\text{Normality}_{MB} = \frac{10\ g}{320} \times \frac{100- 28.55}{100} = 0.0223\ \text{meq/ml}$$

VITA

The Author was born in Adapazarı, Turkey on July, 1961. He graduated from Civil Engineering Department of Middle East Technical University in 1984. He studied the Consolidation Behaviour of Clays in his master thesis and obtained his M.Sc. degree in 1986. He took part as a reseach assistant in the department from 1985 to 1988. Since 1989, he has been on the teaching staff as an instructor. He has been teaching Soil Mechanics I and Soil Mechanics II courses in Civil Engineering Department. He is interested in Soil Mechanics.