UTILIZATION OF BORAX SLUDGE IN SOFT SUBGRADE SOIL STABILIZATION

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ABSTRACT

UTILIZATION OF BORAX SLUDGE IN SOFT SUBGRADE SOIL STABILIZATION

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As a result of its unfavorable natural behavior (e.g., high shrinkage or swelling capacity, weakness, excessive plasticity, poor grading) soft sub-grade soils are not generally preferred in road constructions. Chemical stabilization is used as a solution to improve engineering properties of the weak soil. This study aimed at investigation of stabilization of a soft sub-grade soil by using Borax Sludge (from ETİ Maden İşletmeleri). The index properties (e.g. Atterberg limits, specific gravity and sieve analysis) of soft sub-grade soil and borax sludge samples are determined with these series of experiments. Also, compaction characteristics, unconfined compressive strength and California Bearing Ratio of the samples are observed. By mixing different percentages of borax sludge (e.g. 0% 3%, 6%, 10%, 15%) specimens representing soft subgrade soil are prepared to test for a number of engineering properties. The test specimens compacted to the maximum dry densities are subjected to unconfined compressive strength (UCS) and California bearing ratio (CBR) tests after 0, 7, and 28 days of curing in damp room. The results show that borax sludge addition increases liquid limit, compressive strength, bearing ratio, optimum moisture content and decreases dry density, plasticity and swell. Nevertheless improvement level is not sufficient for stabilization purposes except for swell which is satisfactory.

Keywords: California Bearing Ratio, unconfined compressive strength, chemical stabilization, Soft Sub-Grade Soil, Borax Sludge, Swell.

ÖZ

BORAKS ŞLAMININ YUMUŞAK ALT TEMEL TABAKASI STABİLİZASYONUNDA KULLANILMASI

Ceylan, Can
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Doğal davranışlarının sonucunda yüksek şişme ve büzülme kapasitesi, zayıflık, yüksek plastisitesi ve zayıf gradasyon özellikleri nedeniyle karayolu inşaası çalışmalarında zayıf zeminlerin alt temel olarak kullanılması tercih edilmeyen bir durumdur. Bu istenmeyen koşulların aşılmasında bazı katkı maddelerinin kullanılması bu tür zeminlerin iyileştirilmesine yardımcı olabilir. Bu çalışmada, ETİ Maden İşletmelerinden temin edilen borax çamuru katkısında zayıf zemin olarak kullanılan Ankara Kili nin stabilizasyon açısından davranışı araştırılmıştır. Bir dizi deneysel çalışma sonucunda zayıf alt temel malzemesinin ve borax çamurunun indeks özellikleri (Atterberg limitleri, özgül ağırlık, elek analizi) belirlenmiştir. Bununla birlikte Standart Sıkışma Deneyi(UCS) ve Kaliforniya Taşıma Kapasitesi(CBR) deneyleri yapılmıştır. Değişik oranlarda (0%, 3%, 6%, 10%, 15%) boraks çamuru karıştırılarak yumuşak zemini temsil eden numuneler hazırlanmış ve mühendislik özellikleri test edilmiştir. Maksimum kuru yoğunluklarına gore sıkıştırılan bu numuneler UCS ve CBR için 0, 7 ve 28 günlük periyotlarla kür odasında bekletilmiştir. Sonuçlar boraks çamurunun likit limiti, basınç dayanımını, optimum su muhtevasını artırdığını, kuru birim ağırlığını, plastisiteyi ve şişmeyi düşürdüğünü göstermiştir. Ancak yumuşak zeminin mühendislik

özelliklerindeki gelişme, şişmedeki tatmin edici azaltma haricinde yetersiz kalmıştır

Anahtar Kelimeler: Kaliforniya Taşıma Oranı, Serbest Basınç Dayanımı, Kimyasal Stabilizasyon, Zayıf Zemin, Boraks Çamuru, Şişme,

To My Family

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The last but not the least, I am thankful to my wife for her endless patience and encouragement during my studies.

This research study consists of personal opinions of the researcher.

Bu çalışma öğrencinin kişisel görüşlerini içermektedir.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BS	Borax Sludge
CBR	California Bearing Ratio
CH	Fat Clay
GI	Group Index
G_S	Specific Gravity
Lab.	Laboratory
LL	Liquid Limit
MDD	Maximum Dry Density
METU	Middle East Technical University
Mr	Resillient Modulus
OMC	Optimum Moisture Content
PC	Portland Cement
PI	Plasticity Index
PL	Plastic Limit
SS	Soft Soil
TRB	Transportation Research Board
TS	Türk Standartları
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
XRD	X-Ray Diffraction
XRF	X-RayFluorescence

CHAPTER 1

INTRODUCTION

1.1 Background

Subgrade is the underlying ground which forms the bottom layer of pavement structure and plays a very important role on the structural design of highways. Soft subgrade soils such as silt and clay are composed of fine materials with low strength, high swelling and frost susceptible characteristics which cause a significant problem in highway construction. They can cause roughness and deterioration of pavement with different forms of cracking or rutting, both of which degrades the serviceability level and lowers the expected service life of highways by requiring earlier maintenance and rehabilitation activities. In order to overcome this problem, the solution could be either removing soft soil or replacing it with a quality material (e.g. crushed rock), or applying several stabilization methods to achieve a stronger foundation for the pavement structure. Due to high cost of replacement of poor soils, in many cases soil stabilization methods are preferred to reduce plasticity and swelling to improve subgrade stability and create a solid working platform for the pavement structure.

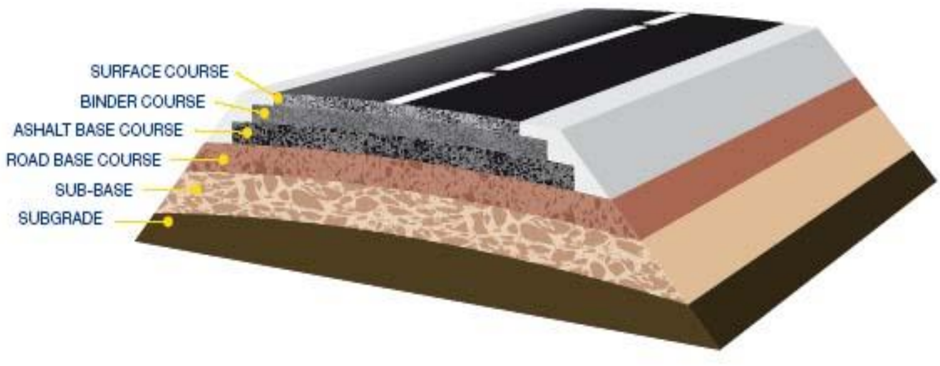

Figure 1.1 Asphalt Pavement Structure and Subgrade

Since soil is heterogeneous and variant in structure, a proper stabilization technique must be identified by taking into account of the engineering properties of the subgrade. The stabilization methods can be separated in two broad categories as mechanical and chemical stabilization. While mechanical stabilization is used to achieve desired soil properties by altering the physical nature of soil, the latter relies on chemical reactions between soil and stabilizer additive. Chemical stabilization is most commonly used for fine grained granular materials which have large surface areas such as clays. Cement, lime and fly ash are known as the most commonly used stabilizing agents. There has been an increase in researches on the utilization of by-products in road construction in order to minimize disposal costs and improve properties of subgrade soil. In this research boron waste material borax sludge is chosen as a candidate stabilization agent to improve the weak soil properties.

Figure 1.2 Mechanical Stabilization Using Geosynthetics

Figure 1.3 Chemical Stabilization Using Lime

Boron is a valuable industrial material which can be found in nature more than 230 different types of minerals. These minerals are concentrated by physical procedures and then refined and turned into various boron chemicals. These chemicals are used in many different industrial sectors such as aviation and space, nuclear, military, electronics, agriculture, glass, chemical, detergent, ceramics and polymeric materials, nanotechnology, metallurgy and construction. Turkey is the leading country in terms of boron reserves (%72.8), production (%47) and market share (%47) in the world. Boron production is increasing every year and as in 2013, 1.8 million tons of boron products were produced in Turkey. (Maden, 2013).

After mining the boron minerals are concentrated in a concentration plant, and then reacted with sulfuric acid to produce boric acid. The concentrator waste is removed to ponds as sludge and contains about 6 to 20% boron trioxide (B_2O_3) respectively. Previous researchers stated that 600.000 tones waste is produced as a result of borax production (Güyagüler, 2001). 900.000 tons of boron waste is accumulated every year in Turkey. (Maden, 2010). Although boron is a known micro nutrient, higher concentrations are reported to be deleterious for plants and therefore high boron concentration can be considered as pollutant (Kaya et al., 2006). Open field disposal of boron waste raises substantial environmental concerns in fear of leaching and groundwater pollution. In order to solve this environmental problem as well as an economical one, there has been researches on recycling and utilization of borax sludge on other sectors.

As mentioned above, the amount of boron waste material in Turkey is significant and its utilization is essential. In this research boron waste material borax sludge is used as an additive to improve soft clay soil's bearing capacity and swelling characteristics. It is expected that utilization of waste material for subgrade stabilization can reduce the road construction cost, reduce the amount of disposed sludge in the mining area and hence reduce its detrimental effects on environment. The research will give guidance on borax sludge usability as a stabilizer for soft clay subgrade soils.

1.2. The Research Hypotheses

The main goal of this study is to demonstrate that the borax sludge produced in Balıkesir Bigadiç region can be used in subgrade soil stabilization. To achieve this, a series of experimental program were designed to investigate the effect of borax sludge addition on strength and swelling potential of subgrade soil samples. The study program was, therefore, furnished to prove the following research hypotheses;

- Borax sludge addition can improve the bearing capacity of soft subgrade soils,
- Borax sludge addition can reduce the swelling of high plastic soils,
- Borax sludge addition improves plasticity characteristics of soft soils.

1.3 Scope of The Study

The scope of this study includes laboratory tests for soft subgrade soil, CBR (California Bearing Ratio) tests, UCS (Unconfined Compressive Strength) tests for measuring bearing capacity and tests for evaluating the mineralogical properties of borax sludge. Soft sub-grade soil samples were obtained from Limak Batı Çimento in Ankara, Turkey. Stabilizing material called Borax Sludge was obtained from ETİ Maden İşletmeleri, Bigadiç, Turkey. A literature review of the previous studies on boron waste and soil stabilization is made in the first place. Engineering properties of soft soil and Borax Sludge are investigated by applying standard ASTM laboratory tests. X-Ray Diffraction and X-Ray Fluorescense Tests are conducted in order to identify minerals and study the crystal structure in METU Central Laboratory. Atterberg limits, specific gravity, sieve analysis tests were also carried out to determine the index properties of the test samples. Borax sludge stabilized samples were prepared at different borax sludge contents. Optimum moisture contents and maximum dry densities of the borax sludge-soil mixtures are determined as a result of Standard Proctor compaction tests. The samples were compacted to the maximum dry densities at the optimum moisture contents and then cured for three different curing periods. After each curing period and 4 days of soaking, samples were subjected to CBR test. Using the same the moisture contents, same dry density values and the curing periods without soaking, Unconfined Compression Tests were performed. Throughout this research study, soil tests were performed at the Middle East Technical University, Transport Laboratory and Soil Mechanics Laboratory of Civil Engineering Department.

1.4 Outline of Thesis

The research report is divided into five chapters:

- Chapter 1 gives a brief introduction about the background of the subject, the research hypothesis, the research objectives, scope and the outline of the thesis.
- Chapter 2 discusses soil stabilization, borax sludge and related studies.
- Chapter 3 includes a description of the materials used, detailed test procedures and the analysis performed in the study.
- Chapter 4 discusses the results obtained from the laboratory experiments, their statistical analyses and proposed models.
- Finally, Chapter 5 includes conclusions and recommendations for further research.
- Data sheets of the experiments can be found at appendix section.

CHAPTER 2

LITERATURE REVIEW

2.1. Stabilization of Soft Soils

Soft soils such as silt and clay are composed of fine materials with low strength and high compressibility. Especially cohesive clay soils are frost susceptible and have a very high potential for swelling. Due to varying climatic conditions, normally physical and engineering properties (namely void ratio, compressibility, grain size distribution, water content, permeability and strength) show a consequential variation. Stiffness of soils for road construction is expressed in various ways such as resilient modulus (Mr), California Bearing Ratio, unconfined compressive strength, R-value and k value. CBR and Mr values are the most common used tests and values for pavement design today. CBR is still the most common used strength property for base, subbase and subgrade in Turkey. Technical Specification Book of Turkish Directorate of Highways suggests embankment as 15%, subbase 20%, base layer 50% and subgrade 10%. Inappropriate soft soil is considered as soils with a liquid limit higher than 60%, plasticity index higher than 35%, maximum dry density equal or lower than 1.45 t/m^3 and a swelling ratio of more than 3%. (Technical Specification for Highways, 2013)

Soil stabilization and modification are similar terms for improvement of engineering properties such as strength, compressibility, volume stability, permeability and durability of existing soil. They both aim at increasing soil strength and water resistance by bonding soil particles together. While modification can be described as short term improvement (within hours or 7 days), stabilization is a longer term improvement method providing improved soil properties. In order to define an improvement as stabilization, a strength increase of 350 kPa or higher should be expected (Little & Nair, 2009). Since soil has a heterogeneous structure and variation in structure, a proper stabilization technique should be selected. The soil stabilization methods can be separated in two general categories as mechanical stabilization and chemical stabilization.

Mechanical stabilization is used to obtain desired soil properties by physically altering the nature of soil and includes compaction, gravel or lightweight fill, blending and geosynthetics applications. Very weak silts and clays can be improved by mechanical stabilization methods. FHWA suggests the usage of geosynthetics for stabilization (separation, filtration and some reinforcement) of soils with a CBR of lower than 3% (Holtz et al., 2008). Table-1 demonstrates the applications and associated functions of geosynthetics with different soil strength parameters.

Chemical stabilization however relies on facilitating the chemical reactions between soil and stabilizer additive. It is most commonly used for fine grained soils as clays. For instance, cement, lime and fly ash are the most commonly used stabilizing agents. Cement is used for a wide range of soils, decreasing plasticity, compressibility and increasing the strength of the stabilized soil. Its advantage comes from the fact that its pozzolanic reaction is initiated by water, hence stabilization becomes independent of soil type. Cement is quite successful in decreasing plasticity, volume expansion, compressibility and increasing strength (Makusa, 2012) (Little & Nair, 2009). Another stabilization agent that is commonly used in field applications is the lime stabilization, which provides a cheaper way of improving soil properties. In this method, the desired strength increase is achieved by cation exchange mechanism with soil minerals. That's why it can give different results with different soil types. The reactivity of the soil can be improved with pozzolan additives (source of silica and alumina). The results are dependent on the soil type or other pozzolan additives to improve the effect. Quicklime (CaO) or hydrated lime ($CaOH_2$) can be used with the former having more advantages over the latter. It is widely used for slope stabilization, highway capping and foundation improvement (NLA, 2004).

Table 2.1 Application and Functions of Geosynthetics (FHWA, 2008)

Application	Function(s)	Subgrade Strength	Qualifier
Separator	Separation Secondary: filtration*	2000 psf $\leq c_u \leq$ 5000 psf (90 kPa $\leq c_u \leq$ 240 kPa) 3 $\leq$ CBR $\leq$ 8 4500 psi $\leq M_R \geq$ 11,600 psi (30 MPa $\leq M_R \geq$ 80 MPa)	Soils containing high fines (SC, CL, CH, ML, MH, SM, SC, GM,GC)
Stabilization	Separation, filtration and some reinforcement (especially CBR <1) Secondary: Transmission	c_u < 2000 psf (90 kPa) CBR < 3 M_R < 4500 psi (30 MPa)	Wet, saturated fine grained soils (i.e., silt, clay and organic soils)
Base Reinforcement	Reinforcement Secondary: separation	600 psf $\leq c_u \leq$ 5000 psf (30 kPa $\leq c_u \leq$ 240 kPa) 3 $\leq$ CBR $\leq$ 8 1500 psi $\leq M_R \geq$ 11,600 psi (10 MPa $\leq M_R \geq$ 80 MPa)	All subgrade conditions. Reinforcement located within 6 to 12 in. (150 to 300 mm) of pavement
Drainage	Transmission and filtration Secondary: separation	not applicable	Poorly draining subgrade

Fly ashes and blast furnace slags are other pozzolanic agents which provide cheap, yet environmentally friendly solutions. Fly ash is a byproduct retrieved from coal power plants. Whilst Class C fly ashes with high free lime content can be sufficient for stabilization, class F fly ash with less than 20% lime content needs extra lime or cement addition. Blast furnace slags are the by-product in pig iron production which are not cementitious by themselves. Due to its latent hydraulic properties it can improve the hydraulic properties of soil with addition of lime (Makusa, 2012). Technical Specification Book of Turkish Directorate of Highways suggests that according to AASHTO A5, A6, A7, A-2-6 and A-2-7 or according to USCS CH,CL,MH,ML,GC,SC class soils with CBR below 10% and plasticity index higher than 10% be considered as weak soil and may be improved with lime. In addition, CBR swell measurement higher than 3% is appropriate for lime stabilization. The minimum values after stabilization shall be CBR over 15%, swelling less than 2% and Plasticity index less than 20% (Technical Specification for Highways, 2013).

2.2 Borax sludge

2.2.1 General

Boron is a valuable industrial material which can be found in nature more than 230 different types of minerals (Figure 2.1). These minerals are concentrated by physical procedures and then refined and transformed into various boron chemicals (Bor Sector Report, 2003). Commercially the most important minerals are tincalconite ($Na_2B_4O_7\_10H_2O$), colemanite ($Ca_2B_6O_{11}\_5H_2O$) and Ulexite ($NaCaB_5O_9\_8H_2O$) (Helvacı C, 2005). Boron is used in many different industrial sectors such as aviation and space technology, nuclear, military, electronics, agriculture, glass, chemical, detergent, ceramics and polymeric materials, nanotechnology, metallurgy and construction. Around 85% of boron products are used in glass, ceramic-frit, agriculture and detergent sectors. Boron production is increasing every year and in 2013 1.8 million tons of boron products were produced (Bor Sector Report, 2013). Some statistical data are listed on the following page in order to demonstrate the extent of boron industry and production in Turkey (Figure 2.2, 2.3, Table 2.2, 2.3). It is apparent that boron production is significant for Turkey and waste utilization of this material needs serious consideration.

Figure 2.1 Boron Ore

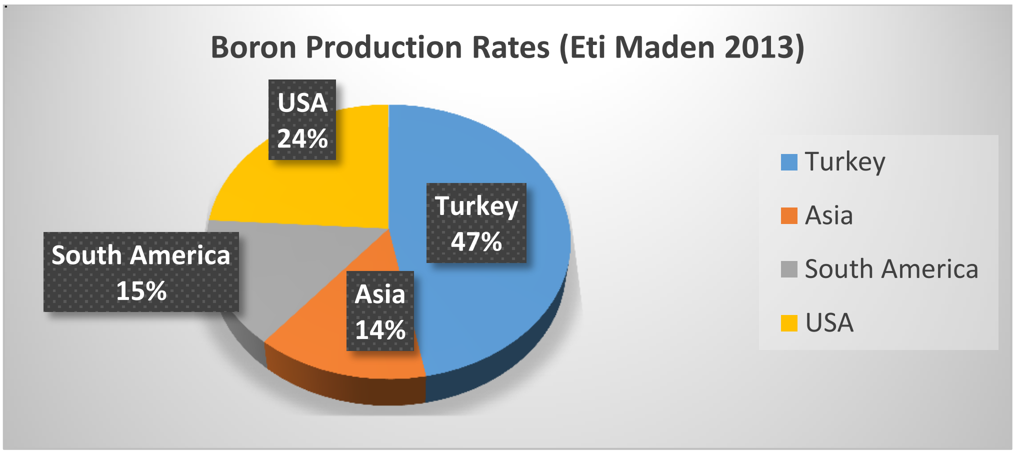

Figure 2.2 Boron Production Rates (Bor Sector Report, 2013)

Table 2.2 World Boron Production Capacities

Countries	Capacity (1000 tons of B_2O_3)
USA	1.092
South America	652
Asia	350
World Total	324

Table 2.3 World Boron Reserves

Countries	Total Reserves (1000 tons of B_2O_3)	World Share (%)
Turkey	955.300	72.8
USA	80.000	6.1
Russia	100.000	7.6
China	47.000	3.6
Argentina	9.000	0.7
Bolivia	19.000	1.4
Chile	41.000	3.2
Peru	22.000	1.7
Kazakhstan	15.000	1.2
Serbia	24.000	1.7
TOTAL	1.312.300	100

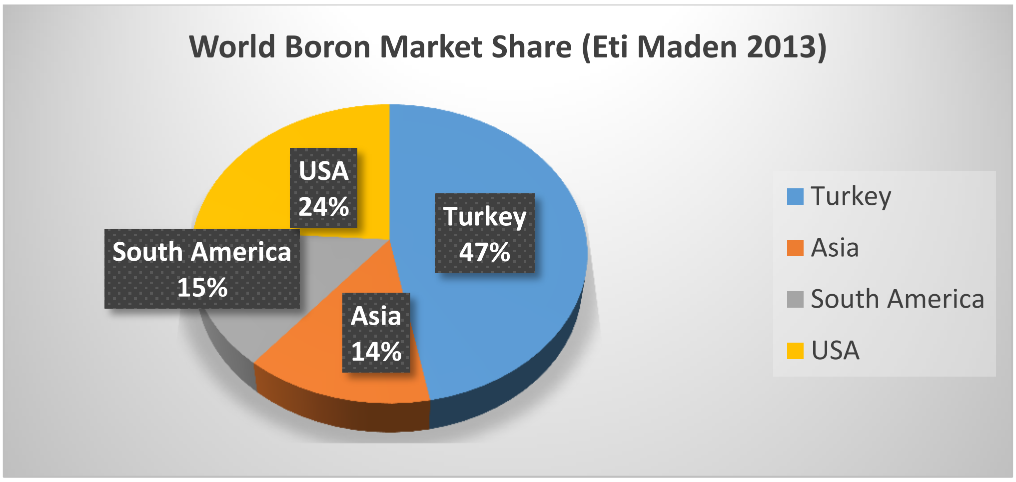

Figure 2.3 World Boron Market Share (Bor Sector Report, 2013)

Table 2.3 and Figure 2.3 apparently demonstrates that Turkey is the leading country in terms of boron reserves and market share in the world. Boron is a valuable resource for Turkey and needs to be utilized properly. Commercial boron ores are in the form of colemanite, tincal and ulexite. After colemanite is mined, it is concentrated in a concentration plant, and then reacted with sulfuric acid to produce boric acid. Waste from the concentration plant is called colemanite concentrator waste (CW) and that of boric acid plant is borogypsum. The waste material contains about 6 to 20% boron trioxide (B_2O_3). Previous researchers stated that 600.000 tpy waste is produced as a result of borax production and 900.000 tons of boron waste is accumulated every year in Turkey (Güyagüler, 2001), (Bor Sector Report, 2010).

Although boron is known as micro nutrient, higher concentrations are reported to be deleterious for plants and, therefore, high boron concentration can be considered as pollutant (Kaya et al., 2006). The production route of boron products results in significant amounts of different types of boron wastes. Their open field disposal raises substantial environmental concerns in fear of leaching and groundwater pollution. Due to increasing environmental awareness and regulations in the world, manufacturing companies have started seeking ways of waste management. In order to solve this environmental problem, first alternative is to recover boron minerals from tailings and then utilize the remainder of mainly clay minerals in suitable sectors. Recycling or utilization on other sectors of these waste materials have been studied by various authors.

In recent years, waste materials collected in ponds were recycled by producing various borax products (Sönmez & Aytekin, 1992) (Mordoğan et al., 1995), (Griffin & Downing, 1998).

Due to high clay content, research on utilization of these wastes on different sectors are mostly focused on ceramics, brick and cement production. Studies have been mostly aimed in improving physical or mechanical characteristics of materials such as brick, cement and ceramics which were produced using traditional methods.

2.2.2 Boron Waste in Brick Production

Experimental studies show that boron waste addition improves physical properties of bricks and that's why many researchers studied boron waste in brick production. Demir and Orhan (2002) used pumice sand and borax waste in different mixtures to build light and porous building blocks and found out that at 900C porous blocks with low gravity can be made with 50% borax waste addition.

Kavas and Önce (2002) mixed two different types of borax wastes as flux material in different proportions to improve the physical properties of structural bricks. They suggested that 10% borax sludge increased the compressive strength and reduced the firing temperature. He also studied the usability of clay and fine wastes of boron from the concentrator plant in Kırka (Turkey) as a fluxing agent in production of red mud brick. He suggested that the samples obtained by adding 15%wt clay waste and fine waste to red mud showed the best mechanical characteristics. In addition, in this study using clay waste and fine waste, energy consumption in sintering is reduced because of the fact that boron is a flux material (Kavas T. , 2006).

Uslu and Arol (2004) suggested that addition of concentrator waste clay up to 30% was successful in increasing the compressive strength, water absorption and density. Abalı et al. (2007) stated that boron concentrator waste addition was not useful in producing structural bricks because the specimens ended up crashing whilst firing.

2.2.3 Boron Waste in Cement Production

There has been various studies on boron waste on cement production. Borax sludge were mixed with Portland cement and the effects were investigated by various authors. Erdoğan et al. (1998) suggested that up to 5% colemanite wastes can be used as cement additives. Kula et al. (2001) suggested that using colemanite waste, pond ash and fly ash compressive strength of portland cement can be increased. On another study, Kula et. al (2002) suggested that adding the same material above can be used as cement additive.

Boncukçuoğlu et al. (2002) investigated using borogypsum as an alternative to natural gypsum and found out that concrete with borogypsum has higher compressive strength and setting time of cement is higher than the natural one. They suggested that borogypsum can be used as set retarder up to 10%. Özdemir and Öztürk (2003) investigated the use of two types of boron clay waste as cement additive and stated that B_2O_3 and clay waste amount decreased the compressive and tensile strength of Portland cement. Targan et al. (2003) suggested that different proportions of colemanite waste could be utilized in cement production and provide energy savings in clinker production. Erdoğmuş et al. (2004) investigated mechanical properties of Portland cement with concentrator waste in different proportion. They found out that setting times have changed in a positive way and compressive strength of the PC increased slightly with 28 days of curing. However 2 days of curing reduced the compressive strength. They state that while fly ash increases the strength, concentrator waste reduces it.

Zeybek et al. (2004) suggested that in order to increase early compressive strength and reduce setting time, some chemicals such as formaldehite sulfonate (NFS), melanine formaldehite (MFR), potassium sulfate (PS) and sodium sulfate (SS) could be used. Borax clay was added in cement and mechanical properties were compared with traditional cement and suggested that borax clay acts as retarder and can be used as an alternative to gypsum. Borax waste has the same elements as clay and therefore has a slight puzzolanic character. It was stated that B_2O_3 content gave positive results, more than 7% gave either neutral or negative results (Topçu et al., 2006). Erdoğmuş et al. (2004) tried to add a combination of concentrator waste, fly ash, blast furnace slag on portland cement durability. Although compressive strength of the mixed specimens were lower than that of traditional PC, given enough curing time, the values were above the minimum.

2.2.3 Boron Waste in Wall Tiling-Ceramics

Genç et al. (1998) suggested that boron wastes can be used to produce glaze for wall tilings. Karasu and Gerede (2002) suggested that borax waste can be used as additive in floor tiling production. Borax waste obtained from the crystallization unit of Etibor Kırka Borax Company, was investigated in terracotta production in an attempt to improve final product properties. It was found out that increased presence of TSW as a co-fluxing material accelerated the vitrification process. (Kurama et al., 2006)

Christegorou et al. (2009) suggested that usage of boron waste in small percentages in heavy clay production is feasible whereas higher additions may necessitate the optimization of the sintering profile of pre calcination step. Kavas et.al (2011) investigated four different types of boron containing wastes and mixtures of them with other materials to produce lightweight aggregates. They suggested that 20% clay mixture, 35% sieve boron waste, 35% dewatering boron waste and 10% quartz sand gave the best results.

Through literature research boron wastes have been studied mainly on ceramics, cement and brick production due to its clay content. There has been very few studies on its usage for geotechnical purposes. Ulutaş et al. (2014) studied geotechnical aspects of waste clay from Kırka factory. According to their study the properties of waste boron material is shown at Table 4. They suggested that the waste material could be used in solid waste landfill sites as impermeable liner.

Table 2.4 Geotechnical Properties of Waste Clay from Kırka Factor (Ulutaş et al., 2014)

Specific Gravity	2.77 g/cm^3
Liquid Limit	58 %
Plastic Limit	30 %
Plasticity Index	28 %
Optimum Water Content	33 %
Unconfined Compressive Strength	2.16 kg/cm2
Swell	10.4 %
Soil Classification	CH

CHAPTER 3

EXPERIMENTAL STUDY AND RESULTS

3.1 Introduction

In order to prove the research hypotheses highlighted in the introduction section, the main objective of this study is to determine the effect of borax sludge on strength, plasticity and swell characteristics of soft clay soil. Whilst strength parameters are tested by CBR and UCS, swell characteristics are measured by CBR test. Therefore the main test objectives are California Bearing Ratio and Unconfined Compressive Strength tests. These tests require determining index properties such as Atterberg limits, specific gravity, sieve analysis and standard proctor compaction.

In the first phase, borax sludge and test soil were obtained from the related plants. Meanwhile statistical experimental design and research plan was developed. Tools and materials in the laboratory were prepared and calibrated, required maintenance and repairs were performed. Additional materials and tools such as swell apparatus and CBR molds were procured. Tests were conducted in the METU Transportation and Geotechnical Laboratory by the researcher himself in accordance with the relevant ASTM standards. Three basic experimental design principles as randomization, replication and blocking were used during the experiments. XRF and XRD tests were performed in METU Central Laboratory by the Lab staff. In due course statistical analysis was performed and finally conclusions were made.

This chapter gives information about the physical and chemical properties of borax sludge, soft soil and their engineering properties, explains the experimental design and exemplifies tests procedures, standards and results in detail subsequently.

3.2 Materials

3.2.1 Borax Sludge

The borax sludge material was obtained from Borax plant in Bigadiç Turkey, working under Eti Maden İşletmeleri. The plant produces 200,000 tons of borax decahydrate ($Na_2B_4O_7.10H_2O$) and 120,000 tons borax pentahydrate ($Na_2B_4O_7.5H_2O$) per year. Borax sludge is a byproduct obtained during production of borax from tincal ore at borax concentrator plant (Figure 3.1) (Bor Sector Report, 2013). During borax production process, tincal concentrate is supplied to a solving reactor. The reactor contains water at 95-100 ◦C where the clay content of tincal becomes colloidal and moves to the thickener. Borax waste is formed during the precipitation process and discharged into the waste dams near the plant area. It is stated that the waste material used for this research is produced roughly 25000 tons/year (Elbeyli et al, 2004).

Figure 3.1 Bigadiç Factory Site and Tailing Pond

The material was brought in sacks and contained in METU Transportation Laboratory (Figure 3.2). The material was in solid form resembling to granular materials due to containment and desiccation (Figure 3.3).

Figure 3.2 Sacks Containing Borax Sludge Used For The Research

Figure 3.3 Borax Sludge

In order to use the waste borax sludge in the experiments it was first broken to smaller sizes by using a jaw crusher (Figure 3.4) and then grinded using a ball mill in the METU Materials Laboratory (Figure 3.5). The material was contained in room temperature in METU Transportation Laboratory throughout research. Material properties are explained in detail on tests section.

Figure 3.4 Borax Sludge After Crusher

Figure 3.5 Borax Sludge After Ball Mill

3.2.2 Soft Soil

Soft subgrade soil samples were obtained from Limak Batı Çimento factory in Ankara, Turkey. The soil wasobtained from the plant, dried and used throughout the research study.

Summary of the soil properties and test results is demonstrated in Table 3.1. It can be seen that all the parameters are below the minimum subgrade values specified by the Turkish Directorate Highway Technical Criteria as discussed in the previous chapter. The soil sample falls into fat clay with sand in unified soil classification system and A-7 (very poor) in AASHTO classification. It is a highly plastic clay type that is unacceptable for road subgrade and therefore needs to be improved. The detailed test procedure and the results are explained in the following sections.

Figure 3.6 Soft Soil in Sack

Figure 3.7 Soft Soil Used For The Research

Table 3.1 Properties of Soft Soil Used For the Research

PROPERTIES OF SOFT SOIL		
Specific Gravity (g/cm^3)	2.72	
Clay (%)	45	
Silt (%)	25.5	
Sand (%)	23.2	
Gravel (%)	6.3	
USCS Soil Class	CH	Fat clay with sand
AASHTO Soil Class	A-7-6 (29.45)	Very poor
Liquid Limit	71	
Plastic Limit	28	
Plasticity Index	43	
Optimum Water Content (%)	26	Standard Proctor Test
Maximum Dry Density (g/cm^3)	1.45	
Swell (%)	6.25	
Average CBR soaked	2	ASTM D1883
Average UCS (kPa)	165.3	ASTM D2166, remolded, compacted.

3.3 Experimental Design and Performed Tests

Statistical design of experiments is essential in answering the research hypotheses and evaluate the effect of borax sludge experiments. A factorial design with two main effects, i.e., Borax sludge and curing time, is satisfactory to perform the experiments and analyze the result data. In order to analyze the effect of borax sludge content, five different levels of sludge content (0, 3%, 6%, 10% and 15% dry weight) were found to be appropriate as a shorter range might have caused more time, effort, material and results which could be difficult to interpret. In addition, a wider range would have caused questionable results to observe the stabilizing effect. For curing time, on the other hand, three levels were selected (0, 7 and 28 days) in a traditional manner. Mixture combinations, their related designations and tests which were performed for each mixture is in Table 3.2.

Table 3.2 Mixture Designations and Performed Tests for the Research

Mixture Designations (% dry weight) SS = Soft soil BS = Borax Sludge	XRF	XRD	G_s	Sieve Analysis	Atterberg Limits	Standard Proctor	CBR Curing Time (days)			UCS Curing Time (days)		
							0	7	28	0	7	28
SS (% 100 SS)		+	+	+	+	+	+			+		
3%BS (97% SS + 3 % BS)			+		+	+	+	+	+	+	+	+
%6 BS (94% SS + 6 % BS)			+		+	+	+	+	+	+	+	+
10%BS (90% SS+ 10 % BS)			+		+	+	+	+	+	+	+	+
15%BS (85%SS + 15 % BS)			+		+	+	+	+	+	+	+	+
BS (%100 BS)	+	+	+	+	+							

The model representation of a two-factor design of experiment can be written as,

$Y_{ijk} = \beta_0 + \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$

where

Y_{ijk} = The observed response when factor A (borax sludge) is at ith level, B (curing time) is at jth level for the kth replicate. Response refers to CBR or UCS test result which are analyzed separately.

μ = overall mean effect,

i = 1,2,3,4,5 (5 levels of Borax Sludge content, %0, %3, %6, %10, %15),

j = 1,2,3 (3 levels of curing time 0, 7 and 28 days),

k = 1,2,3 (for UCS and CBR 3 replications of each combination is performed),

τ_i = effect of the ith level of borax sludge factor,

β_i = effect of the ith level of curing time factor,

ε_{ijk} = random error component,

$(\tau\beta)_{ij}$ = the effect of interaction between borax sludge and curing time factors.

For ANOVA, testing hypotheses were built on the assumption that the factors were fixed and of equal interest. The first hypotheses is that all borax sludge content has the same effect on response, namely CBR and UCS results,

$H_0 : \tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = 0$

H_1 : at least one $\tau_i \neq 0$

The equality on curing time effect on response,

$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$

H_1 : at least one $\beta_i \neq 0$

In factorial design it is necessary to control any interaction between the factors. Therefore the hypotheses for the interaction effects,

$H_0 : (\tau\beta)_{ij}$ for all i,j

H_1 : at least one $(\tau\beta)_{ij} \neq 0$

The hypotheses and test results are discussed in Chapter 5. In the following sections, a detailed description of the procedure used is given.

3.3.1 XRF Analysis

XRF Analysis of borax sludge was performed at the METU Central Laboratory and additional test results made by Eti Maden Laboratory was used for the research study. Results of both tests and averages are shown in Table 3.3. It is important to note that the material has an average of 7% B2O3 (boron), and 18.2% CaO (lime). Class C Fly,another by product that can be used for stabilization purpose, improves soft soils by the lime content which is generally more than 20%. Lime content of borax sludge may have an effect on stabilization, however using without any additive may not be sufficient to achieve the intended strength improvements. On the other hand, siliceous and aluminous pozzolan materials can react chemically with calcium hydroxide and therefore should be taken into consideration. In the samples tested, SiO_2 was found around 15% and Al_2O_3 content was less than 1%. These values are less than that of common fly ash content but closer to that of fly ash. Bituminous fly ashes have less self-cementing properties (Benson & Bradshaw, 2011).

Table 3.3 XRF Test Results

Component	1st Test	2nd Test	Average
CO2 (%)	NA	33.4	NA
CaO (%)	16.7	19.7	18.2
MgO (%)	15	18.3	16.7
SiO2 (%)	16.6	14.3	15.5
B2O3 (%)	6.8	7.2	7
Na2O (%)	3.5	3.1	3.3
SrO (%)	.9	1.2	1.1
F (%)	.5	.8	.7
Al2O3 (%)	.6	.8	.7
K2O (%)	.1	.5	.3
Fe2O3 (%)	.3	.16	.17
Cl (%)	NA	.04	
Rb2O (%)	.01	.01	.01

3.3.2 X-RAY Diffraction Test

X-Ray Diffraction test is useful for analysis of crystal structures. The test is basically initiated with crystalline atoms to result diffracted x-rays to many specific directions. Diffracted atoms constitute a sample in compliance with Bragg's law (formulation shown below) and their distances can be measured. The d-spacings and their intensities are unique for all minerals and are used as fingerprints. By this fingerprint, identification of crystallites in the range of 2-100 nm can be made (Mitchell & Kenichi, 2005).

Bragg's Law is defined as, $n\lambda=2d\sin\theta$.
Where n= order of the diffracted beam, λ=wavelength of X-Ray beam, d=d spacing (space between two beams), and θ= beam angle

In order to identify minerals and therefore understand engineering behavior of the materials, x-ray diffraction tests were done in the METU Central Laboratory. The peak lists of the tests and mineral structure are demonstrated at Appendix C. Rikagu database was used to identify the phase pattern. For the borax sludge test, the most dominant phases observed are dolomite and calcium bis (borate). Dolomite is a carbonate mineral which consist of calcium magnesium carbonate. Calcium borate is a result of calcium reacting with boric acid. The graphical demonstration of Borax sludges mineral structure is shown at Appendix C. For the soft soil, the Rikagu database identifies the nonclay minerals as quartz and calcite. Most possible candidates for 4 unknown minerals (minerals with asterisk) were found as feldspar, smectite, and illite (Mitchell & Kenichi, 2005). Quartz, feldspar and calcite are very common non clay minerals. Smectite is a group of minerals including montmorillonite and bentonite with high swelling properties. Illite is another group of minerals commonly found with less cation exchange capacity than smectite.

3.3.3 Specific Gravity Test

Specific gravity tests of all BS mixtures were performed in compliance with ASTM D5550-06 Standard Test Method for Specific Gravity of Soil Solids by Gas Pycnometer. Specific gravity is ratio of density of a substance to that of distilled water at 4°C. It is a fundamental parameter which is necessary to calculate soil properties like degree of saturation and void ratio. Standard commercially used gas pycnometer with two chambers was used for the test. In order to execute the test, specimens were dried in oven at 105 °C and a constant mass was obtained. The specimen was removed from the oven and placed into a desiccator. The mass of the specimen was recorded when the temperature of the specimen was back at room temperature. The soil was transferred to the test chamber where the volume of the specimen was recorded. Subsequently, the mass of the specimen was obtained again and specific gravity of the soil was calculated using the equation,

$Gs = (M_s / V_s) / P_w$ (distilled water density)

The results show that specific gravity of BS is below 2.6 g/cm^3, which is seen usually for organic soils. Gs of the soft soil falls in the inorganic clay category (2.7-2.8) (FM5-472, 2001).

Table 3.4 Specific Gravity Results

Material	Specific Gravity - g/cm^3
Borax Sludge	2.523
SS+0%BS	2.718
SS+3%BS	2.712
SS+6%BS	2.706
SS+10%BS	2.699
SS+15%BS	2.689

3.3.4 Sieve Analysis

Sieve Analysis of soft soil was performed in accordance with ASTM C136/14 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates and ASTM C117-13 Standard Test Method for Materials Finer than 75μm (No.200) sieve in Mineral Aggregates by Washing (ASTM C117, 2013) (ASTM C136, 2014). 1800 grams of dry weight samples were used with no curing applied in the METU Geotechnical Laboratory. The results show that the soil which is used is very fine (70.5%) and uniformly graded.

In order to determine fine particle size distribution and clay fraction hydrometer test was performed to in accordance with ASTM D 422-63 (Standard Test Method for Particle-Size Analysis of Soils). First, 50 gr. of sample soil retained on No.10 sieve was added into control cylinder full with 125 ml. of 4% $NaPO_3$ solution. After waiting for 12 hours, the mixture was transferred to a dispersion cup and mixed using a mixer. The mixture was added back to a 1000 ml. cylinder and mixed by turning the cylinder upside down repeatedly. Subsequently, a stopwatch was started and at specific intervals such as 0.5 min., 1 min. etc. The hydrometer was inserted into the cylinder and upper level of meniscus was read. (ASTM D 422-63(2007)e2, 2007). Calculation was started with hydrometer reading correction for meniscus and temperature. Then percent of fines were calculated using readings and specific gravity. For the last step, the percentages were combined and calculated with the sieve analysis values tested previously. As a result, percent of fines were determined and shown in Appendix C.

As a result of both tests, the sieve gradation curve is demonstrated in Figure 3.8. From the gradation charts and curves, it is determined that the soil to be used on research consists of 6.3% gravel, 23.2%sand, 25.5% silt and 45% clay. In order to determine the soil classification, plasticity characteristics were necessary and therefore Atterberg limits tests were performed. Sieve analysis of borax sludge was conducted by Etibor Company and the results are given in Table 3.5.

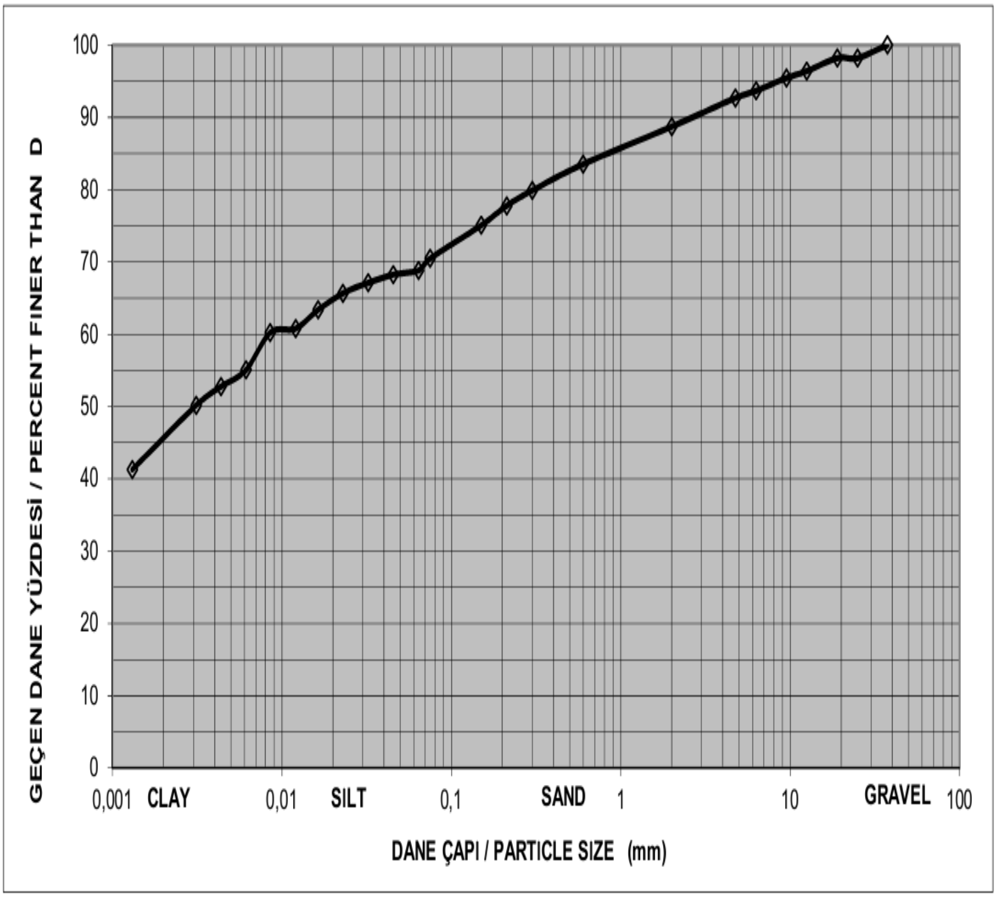

Figure 3.8 Soft Soil Gradation Curve

Table 3.5 Borax Sludge Sieve Analysis

Sieve Analysis	
Sieve Size	Passing %
+0,315 mm	0,12
+0,250 mm	0,35
+0,106 mm	1,01
+0,063 mm	3,40
-0,063 mm	96,60

3.3.5 Atterberg Limits

Atterberg limits, namely plastic and liquid limits of soil are the water contents at which defined consistency levels are obtained. While the water content at which soil passes from plastic to liquid state is liquid limit, from a plastic state to brittle state is the plastic limit. These limits are an indication of plasticity of clay and can be used to estimate various engineering properties.

The Atterberg limit tests were carried out on uncured (0 day cured) samples according to ASTM D 4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils". Tests were performed in the Soil Mechanics and Transportation Laboratories in the METU Civil Engineering Department with the tools available. The purpose of the test was to determine the plastic and liquid limits of fine grained soil. Liquid limit was conducted with a Cassagrande device, which consists of a hard base and a sliding carriage assembled to a brass cup 100 mm. in diameter (Figure 3.9). The cup can be elevated up to 10 mm. height with the carriage and then dropped to the rubber base. The sample soil was sieved through No.40 sieve, air dried and then mixed with a small amount of water to a uniform mass of stiff consistency. Then the soil was placed in the cup of Cassagrande device to a depth of 10 mm. properly. The soil was divided with a firm stroke of the grooving tool along the diameter through centerline (Figure 3.10). The crank was turned to raise and drop and the number of blows were recorded. The used soil was put in a cup and dried to obtain moisture content. For each combination test was repeated 4 times and moisture contents were recorded. In the end, a linear regression analysis was done and the moisture content for 25 blows was accepted as the liquid limit for the tested soil sample. In order to determine the plastic limit of the soil, 8 to 12 gr. of wet soil sample was formed into a uniform ellipsoidal shape. The ball was rolled by hand on the rolling surface until 3 mm. thickness till it starts crumbling. These portions were gathered and placed in a tare to dry and determine the moisture content (ASTM D4318, 2010).

Figure 3.9 Atterberg Limits Test Tools and Materials

Figure 3.10 Execution of Liquid Limit Test

The results obtained from Atterberg limit tests of soft soil is shown in Table 3.6. It can be seen that the soil is highly plastic (PI over 30%) with a PI of 43%. The detailed data sheets can be found in Appendix D. Atterberg limits of the borax sludge was also tested in the same way and the results showed that the material is very plastic with a liquid limit over 100%. The same test was conducted with all soft soil – borax sludge mixtures and it was observed that all the measured consistency parameters increase with addition of borax sludge. Whilst liquid limit increased slightly, plastic limit increased little higher causing a slight decrease in plasticity index. Decrease in plasticity index is an indication of improvement in geotechnical properties and it is common with stabilizing agents such as lime and fly ash.

Table 3.6 Atterberg Test Results of BS Combinations

Borax sludge Content %	Plastic limit (PL-%)	Liquid Limit (LL-%)	Plasticity Index (PI-%)
0 (Soft Soil)	27.9	70.6	42.6
3	31.0	71.2	40.1
6	32.5	71.7	39.2
10	33.9	72.9	39.1
15	35.1	74.1	39.0
100	31.9	107.3	75.5

3.3.6 Soil Classification

Using Atterberg limits and sieve analysis test results, the group symbol (e.g. soil type) of the samples are determined according to Unified and AASHTO Classification systems respectively. Procedures werre performed in accordance with ASTM D 2487 “Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)” and ASTM D3282 “Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes”.

Unified soil class system is based on three major soil divisions which are coarse grained soils (more than 50% retained on No.200 sieve), fine-grained soils (more than 50% passing No.200 sieve), and highly organic soils. These classes are further divided resulting in 15 basic soil groups. The procedure is using a simple flow chart beginning with percentage of specimen passing or retaining no.200 sieve. The soft soil is fine grained (≥ 50% passes #200), Liquid limit is over 50, over 70% passes 200, sand content (23.2%) is over than gravel (6.3%) . Using the Flow chart (Figure 3.11) first, the group symbol was determined as fat clay with sand. The second step is the Plasticity chart (Figure 3.12) which is divided into empirically determined boundaries where plasticity levels of the soil indicate engineering properties. The A line separates inorganic clays (over the line) with inorganic silts and organic soils (below the line). The U line is a control level for erroneous data because it defines upper limit for natural soils. Using plasticity levels required from Atterberg tests, the index properties fall above A line and below U line indication inorganic fat clay. As a result, the soil is classified as fat clay with sand (CH) according to USCS (ASTM D 2487-11, 2011).

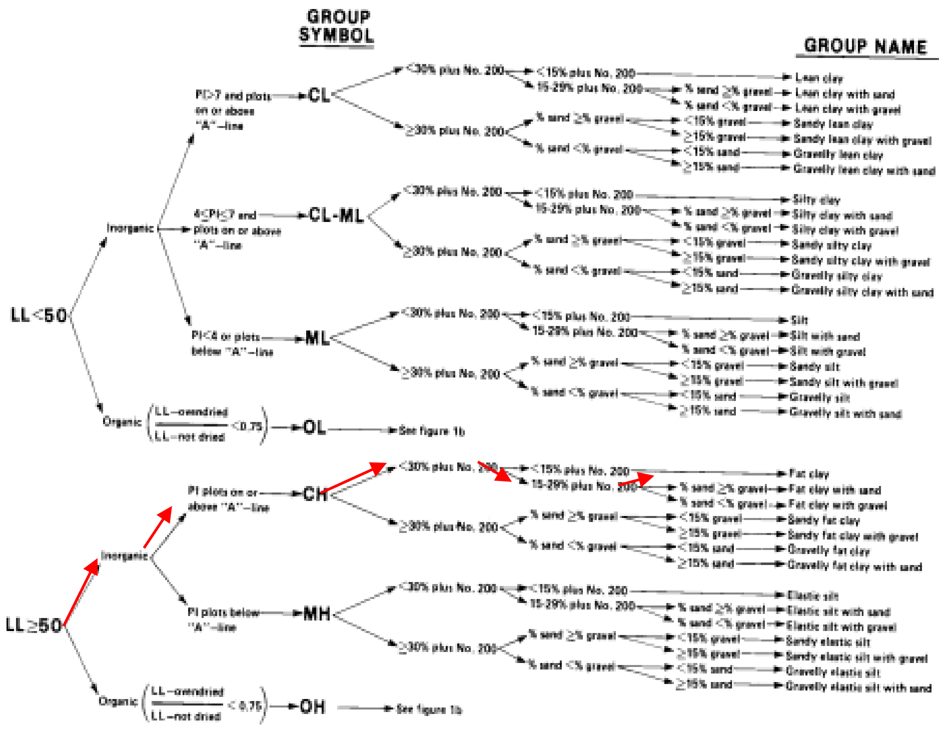

FIG. 1 Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

Figure 3.11 USCS Group Symbol Flow Chart (ASTM D 2487-11)

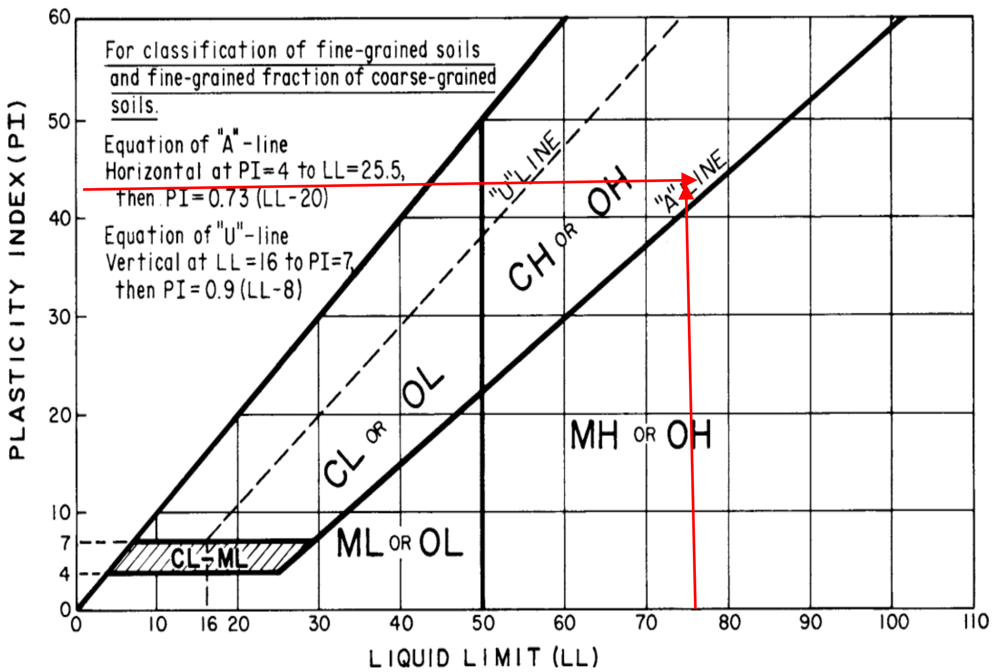

Figure 3.12 Plasticity Chart (ASTM D 2487-11)

AASHTO Soil Classification system is used for subgrade rating in road construction. It consists of 8 groups, from A1 to A8 with several subgroups and a group index number. AASHTO soil classes range between A-1 (best) to A-7 (worst) with subcategories according to its plastic properties.A-1 and A-3 are granular materials which indicate 35% retained on no.200 sieve and A-4 to A-7 silt-clay materials. Group index ranges from 0 (good soils) to 20 or more (very poor soils) (ASTM D3282, 2009). In order to determine the soil class, Table 3.7 is used. More than 36% passes #200 sieve, the liquid limit is over 40, the plastic limit of the soil is over 11 and finally plasticity index (43) is more than LL (71) - 30 = 41. The table suggests that the soil sample used falls in A-7 category. In order to identify the subgroup of the soil, AASHTO Plasticity Index (Figure 3.13) was used. AASHTO Classification of the soft soil was found as A-7-6, which means a poor soil. Additionally group index was calculated by the suggested formula;

$GI = (F_{200} – 35) ((0.2+0.005(LL-40))+0.01(F_{200}-15)(PI-10) = 29.81.$

Therefore the AASHTO Soil Classification is A-7-6 (29.81) which indicates a very poor clay soil.

Table 3.7 AASHTO Soil Classification (ASTM D3282, 2009)

General Classification	Granular Materials (35 % or less passing No. 200 (75 μm))			Silt-Clay Materials (More than 35 % passing No. 200 (75 μm))			
Group Classification	A-1	A-3[A]	A-2	A-4	A-5	A-6	A-7
Sieve analysis, % passing:							
No. 10 (2.00 mm)	...	...	...	...	...	...	...
No. 40 (425 μm)	50 max	51 min	...	...	...	...	...
No. 200 (75 μm)	25 max	10 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40 (425 μm):							
Liquid limit Plasticity index	... 6 max	... N.P.		40 max 10 max	41 min 10 max	40 max 11 min	41 min 11 min
General rating as subgrade	Excellent to Good			Fair to Poor			

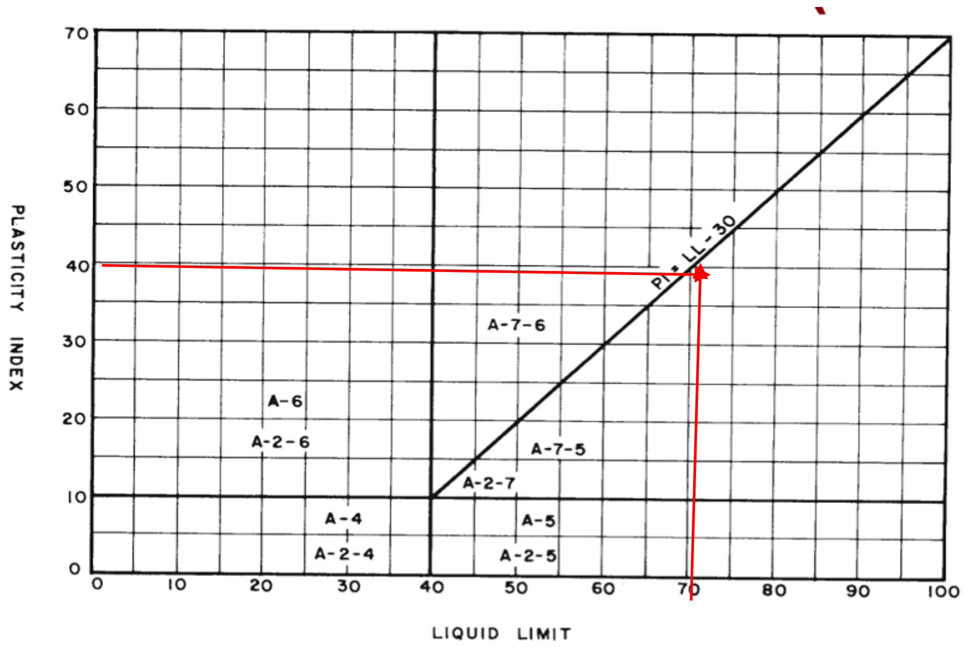

Figure 3.13 Plasticity Index for AASHTO Soil Classification (ASTM D3282, 2009)

3.3.7 Standard Proctor Test

Compaction is the mechanical effort to remove air voids and improve geotechnical properties of soils such as density, strength, stiffness and permeability. Various researchers have mentioned that compaction is crucial in dense graded pavement performance. Compaction effort aims to achieve a more solid material in the same volume using mechanical equipment. Water content of the compacted soil plays an important role during compaction. While too much water results in a dispersed soil structure, too less water results in a flocculated one, both of which are less than highest dry density value achievable by the optimum water content. Compaction tests aim in determining maximum dry density and optimum water content of subgrade soils. Standard laboratory test for compaction of soils is routinely performed using two different ways namely Standard Proctor and Modified Proctor tests. Both tests are based on compaction effort which is provided by a hammer which falls on to a molded soil. The distinction of the tests are the weight of the hammer, the number of layers compacted and number of drops. Each test has 3 different methods to be applied for different type of soils or purposes.

The Standard Proctor compaction tests were carried out on uncured samples in accordance with ASTM D 698-12 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (56,000 ft-lbf/ft^3(2,700 kN-m/m^3))". The results of Standard Proctor compaction tests were to be used in sample preparation for the California Bearing Ratio tests. Therefore, the Method C, which requires using 6 inch mold was chosen (ASTM D-1883). Proctor Machine in the METU Transportation Laboratory was used to conduct the tests.

Large amount of soil sample was air dried, sieved through ¾ inch sieve and existing water content was measured. The plasticity results obtained from Atterberg tests were used to estimate the optimum water content and determine the starting water content for the tests. For every combination at least 6 different water content was selected and the amount of water, soil and borax sludge to add was determined. For each test 6 kg of dry sample was taken, and then calculated amount of water was added before mixing. The necessary measurements such as weight and volume of the mold, weight of the moisture cans were made. The soil sample was placed into the mold carefully, then compacted with 3 layers and 56 blows per layer using the mechanical proctor machine available in the METU Transportation Laboratory (Figure 3.14). The soil in the mold was trimmed and the mass of the mold was measured. Samples were taken from the mold for measuring the water content and added into moisture cans, dried in oven at 105^{o}C for 24 hours and water content was determined. For each combination at least 6 different water contents were tried and the same procedure applied (ASTM D698-12, 2012). For BS combinations the optimum water content, maximum dry densities, air void percentages were calculated and finally the compaction curves were plotted. The Proctor test results are given on the next chapter and the detailed data sheets and calculations can be found in Appendix E.

Figure 3.14 Proctor Machine Used For the Research

3.3.8 California Bearing Ratio (CBR) Test

California Bearing Ratio Test is a penetration test which was developed during 1930s in order to measure bearing capacity of subgrade, subbase or base materials. CBR of a soil is calculated by measuring load and penetration when a 76.2 mm. diameter piston penetrates the soil at a standard rate (1.27 mm./min.). Although slowly replaced by Resilient Modulus parameter, CBR is still used by many agencies around the world including Turkey. On this research, CBR tests were conducted in accordance with ASTM D 1883 “Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils”. (ASTM D1883, 2007) The following sections briefly explains the testing process and results.

3.3.8.1 Sample Preparation

For compaction and bearing capacity tests, disturbed samples of soft soil were air-dried and then passed through ¾ inch sieve (Figure 3.15). The amount of soil which was retained on the sieve was replaced by the material passing ¾ inch but retained on No.4 sieve. 6 kg weight samples were prepared by mixing the calculated amount of stabilizing agent with SS (Figure 3.16). The predetermined amounts of soil and stabilizing agent, namely borax sludge, are mixed manually and also by using a dry and clean trowel. For the soaked CBR tests on cured samples, the samples which were prepared according to the above procedure were compacted according to the Standard Compaction Effort Method C (ASTM D 698) in 6 inch CBR molds and then taken to damp room to prevent the loss of moisture. The samples were set to cure in the damp room for 7 and 28 days. The curing temperature and relative humidity in the humidity room were approximately 20°C and 99%, respectively. After 7 and 28 days, the cured samples were taken out of the humidity room and soaked in water for 4 days in order to perform soaked CBR tests. During 4 days of soaking swell measurements were made and swell rate calculated.


Figure 3.15 Soil Soft After Sieving


Figure 3.16 Soft Soil and Borax Sludge Mixture

3.3.8.2 Test Apparatus

CBR tests were performed in the Transportation Laboratory in METU Civil Engineering Department. The machine to be used was a modified ELE Multiplex 50 device (Figure 3.17). The dial gages of the original machine were removed and instead a digital scale and load cell was implanted on the mainframe to obtain more precise results. The scale and load cell were connected to pc with connectors and labview software was set up to read and record data. As a result the modified machine was capable of measuring load and deformation in each second, thus showing more detailed and dependable data. Loading piston was 3 inch (49.63 mm.) in diameter and the moving plate speed was adjusted to 1.27 mm./min. The mold to contain tested soil was a rigid metal cylinder with an inside diameter of 152.4 mm, a height of 177.8 mm and a volume of 2,124 cm^3 with a metal extension collar and a metal base plate. Metal base plate had at least twenty eight 1.59 mm diameter holes uniformly spaced over the plate within the inside circumference of the mold.

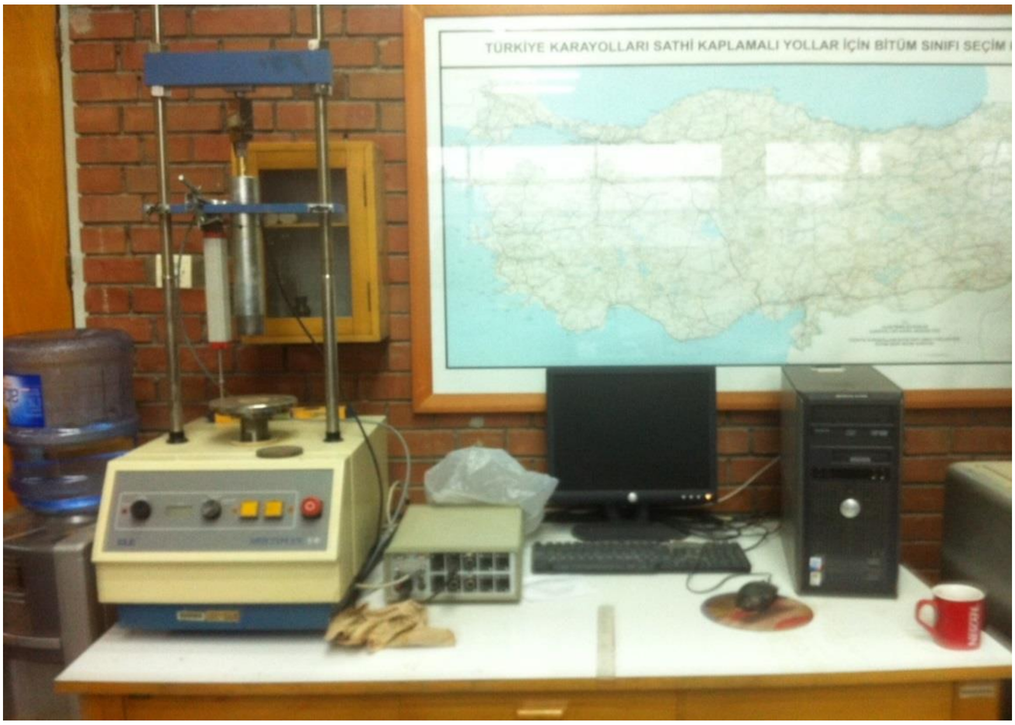

Figure 3.17 California Bearing Ratio Test Device and Data Processing Equipment

3.3.8.3 Test Procedure

As mentioned before, the specimens were compacted to its predetermined optimum moisture content (±0.5%) and the maximum dry density using the proctor device, cured in damp room and soaked for 4 days in water. After the final swell measurements were done, free water was removed and the specimen was allowed to drain downward for 15 minutes. After weight measurement, the mold was placed on the moving plate of CBR machine. Surcharge weights of 4.54 kg were placed onto the test sample and the penetration piston was lowered as close as possible without disturbing the specimen. The device adjustments were checked and the load rate was set to 1.27 mm/min. The labview program was turned on and the connection between PC, scale and load cell was assured. As moving plate moved upward and provides piston penetration into the specimen, data transfer on PC and visual control of device was maintained. The moving motion namely penetration was maintained until at least 0.5 inch of penetration was achieved. The test specimen was removed from the mold and the water content was determined.

3.3.8.4 CBR Calculation

The load readings were recorded to a txt file including time, deformation and load readings. Using excel worksheet loads were converted to the stresses by dividing them into the cross-sectional area of the penetration piston. To illustrate, part of a sample worksheet is shown in Appendix F. In order to make the calculations easier universal units were converted to psi and inches. Stress at 0.1 and 0.2 inches were recorded and CBR was calculated. The stresses at 0.1 and 0.2 inch penetrations were divided to 1000 and 1500 psi respectively and then multiplied with 100. The California Bearing Ratio value was calculated as the one at 2.54 mm (0.1 inch) penetration. However if the value at 5.08 mm (0.2 inch) penetration was higher than the one at 2.54 mm (0.1 inch) then the CBR at 5.08 mm penetration was accepted. In order to visualize the stress penetration relation, stress - penetration curve is plotted on Figure 3.18.

In some instances, due to surface irregularities or initial contact of piston and sample, the curve was concave upward shape. The CBR value was then corrected using Excel trendline function (Figure 3.19). The equation for the initial slope was calculated and deformations at 0.1 and 0.2 inches were adjusted.

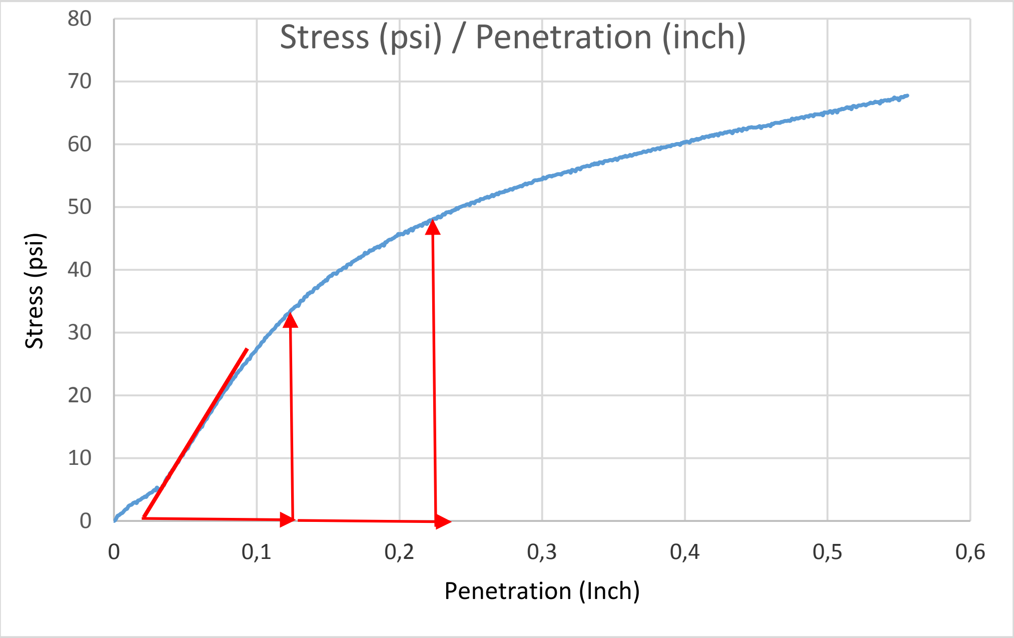

Figure 3.18 Stress/Penetration Curve

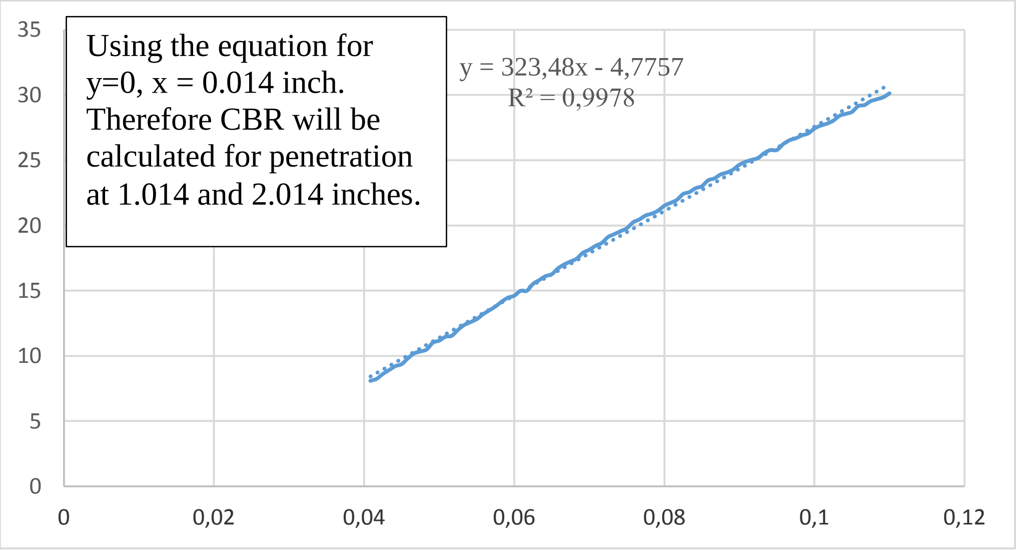

Figure 3.19 California Bearing Ratio Correction Using Trendline

3.3.8.5 Swell Measurements

Swell measurements were performed during soaking step of CBR tests in the METU Transportation Laboratory. The procedure was applied in accordance with ASTM D 1883 “Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils” (ASTM D1883, 2007). The compacted soil in 6 inch molds were soaked under water with 4.54 kg. surcharge weights. Standard CBR molds provided water access through openings and filter paper at top and bottom of the soil. This additional free water caused the soil in the mold to swell and swell readings were measured with dial gages capable of reading 0.001 in. mounted on metal tripod attached to the top of the mold. The readings were recorded every 24 hours until the end of soaking period. The final swell measurement was calculated as percentage over the initial specimen height. The results and discussion are on the next chapter and swell readings of each specimen are recorded on CBR data sheets.

Figure 3.20 Swell Measurement Tools

3.3.9 Unconfined Compressive Strength (UCS) Test

Unconfined Compressive Strength Test is an undrained and unconsolidated test without lateral confinement to determine an approximate value of strength of cohesive soils. It is a quick test to determine shear strength parameters of cohesive soils. Its standards are designated by ASTM D 2166 (Standard Test Method for Unconfined Compressive Strength of Cohesive Soil) (ASTM D2166, 2013). Whereas CBR is a penetration test, UCS is a compression one. Unconfined specimen was compressed until failure and stress with strain was calculated. If failure occured before 15% strain the highest stress, otherwise stress at 15% strain gave Unconfined Compressive Strength (q_u). Shear strength (s_u) was calculated as half of the unconfined compressive strength. Because CBR tests were done at soaked conditions, UCS tests were preferred to perform at unsoaked condition for this research. Therefore the soil had a stiff condition and UCS results were expected higher than normal conditions.

3.3.9.1 Sample Preparation

Generally it is preferred to use undisturbed specimens for UCS test. However for this research, remolded method was used due to the availability of disturbed soil. ASTM suggests sample height to diameter ratio to be between 2-2.5 with a minimum diameter of 30 mm. For convenience and mold availability, 100 mm (height) 50 mm. (diameter) molds were preferred for the research. ASTM suggests that the largest particle diameter can not be larger than 1/10 of the diameter. For that reason, soil was sieved through No.4 sieve (4.76 mm.) (Figure 3.21). The amount of dry soil and water mass were calculated according to the dry densities and optimum moisture contents which were previously determined by standard proctor tests. The soil was compacted in the mold using laboratory tools and later removed by an extruder. The specimens prepared for curing were kept in molds, wrapped in plastic bags and placed in a damp room for curing. Samples were prepared in the METU Geotechnics Laboratory.

Figure 3.21 Sieved Soil Samples for Unconfined Compressive Strength Test

3.3.9.2 Test Procedure and Calculation

The same loading device used for CBR tests in METU Transport Laboratory was used to perform the UCS tests. The sample was located on the moving plate without wrap and upper plate is lowered until it contacted the specimen. The load was applied at a strain rate of 1.27 mm/min which was the same for CBR. Load and deformation were recorded by loadcell and electronic scale respectively. Labview program was set to save the data to a .txt file and drew a stress/strain graph. The load was applied until the load values decrease. New dimensions of the specimen was measured by scale and a photo of the specimen was taken showing the breaking form. Subsequently, the water content was determined using the entire specimen and recorded on the data sheet. An excel worksheet was prepared to calculate stress, strain and corrected area. As load was applied, the length of the sample decreased and its cross sectional area increased. The stress was calculated according to the new cross sectional area. A sample of excel worksheet and related calculations are shown at Appendix G. Following section will describe discussion of test results.

CHAPTER 4

DISCUSSION OF TEST RESULTS

The objective, scope and procedure of experimental program aimed to investigate the effect of borax sludge addition on soft soils were previously presented. Additionally, results and discussion of the index tests such as XRF, XRD, Gs etc. were introduced in the previous chapter. In this chapter the questions which was initially presented for research hypotheses and related test results (Table 4.1) are discussed, their statistical analysis and model are represented. The research hypotheses suggest that plasticity, swell, bearing capacity parameters are to be improved and curing time effect to have a meaningful effect. CBR, UCS, plasticity, compaction tests and a proposed statistical model is suggested in the following sections.

Table 4.1 Mixture Designations and Performed Tests for the Research

Mixture Designations (% dry weight) SS = Soft soil BS = Borax Sludge	Atterberg Limits	Standard Proctor	CBR			UCS		
			Curing Time (days)					
			0	7	28	0	7	28
SS (% 100 SS)	+	+	+			+		
3%BS (97% SS + 3 % BS)	+	+	+	+	+	+	+	+
%6 BS (94% SS + 6 % BS)	+	+	+	+	+	+	+	+
10%BS (90% SS +10 % BS)	+	+	+	+	+	+	+	+
15%BS (85% SS +15 % BS)	+	+	+	+	+	+	+	+
BS (%100 BS)	+							

4.1 Plasticity Characteristics

Atterberg limit tests were conducted with all soft soil – borax sludge mixtures and it is apparent from the results (Table 4.2, Figure 4.1) that all parameters increase with BS content. While the liquid limit increases slightly, plastic limit increases little higher causing a slight decrease in plasticity index. Decrease in the plasticity index is an improvement of geotechnical properties soft soil and commonly seen during stabilization with agents such as lime and fly ash. As discussed şn the first chapter, Turkish General Directorate of Highways recommends PI to be less than 20% for subgrades. Considering the plasticity indexes obtained, the values are still too high to meet the criteria. Therefore, it can be concluded that the improvement in plasticity of the soil is not sufficient.

Table 4.2 Atterberg Limits Test Results

Borax sludge Content %	Plastic limit (PL-%)	Liquid Limit (LL-%)	Plasticity Index (PI-%)
0	28	70.6	42.6
3	31	71.2	40.2
6	32.5	71.7	39.2
10	33.9	72.9	39.1
15	35.1	74.1	39
100	31.9	107.3	75.5

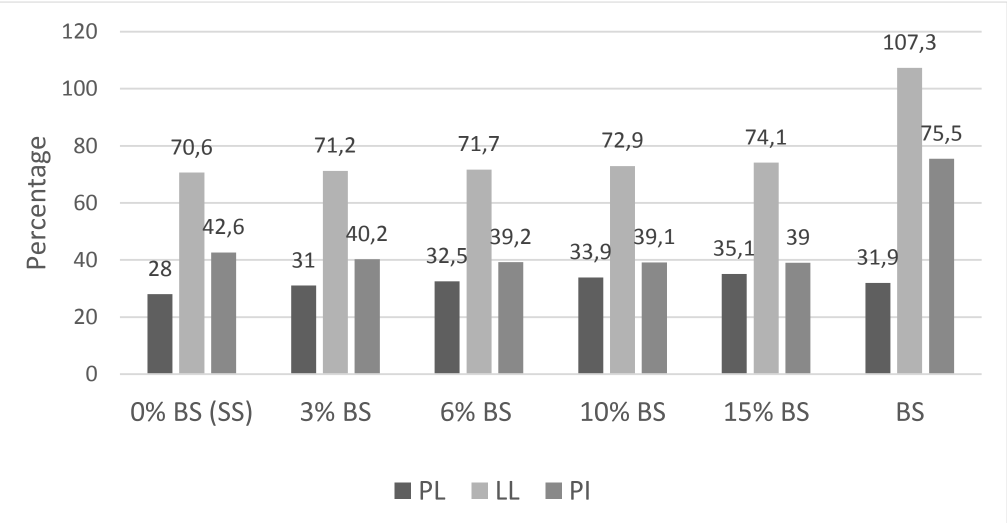

Figure 4.1 Plasticity Characteristics

4.2 Swelling Characteristics

Swell results after 4 days of soaking are presented in Table 4.3 and the histogram of average swell rates are demonstrated in Figure 4.2. BS content and curing time both reduce swelling significantly. As curing time increases the amount of swelling decreases from 6.25% up to 1.4%. Borax Sludge has an improving effect on swelling. The improvement can be monitored highest at 6% BS content. 10% and 15% BS have similar values. Decrease in sweling complies with the Turkish General Directorate of Highways criteria which requires swelling less than 2%. Therefore, swelling improvement obtained by borax sludge addition is satisfactory.

Expansive clay soils swell due to cation exchange of clay minerals when exposed to water. Swelling of soil depends on soil characteristics, environmental factors and the state of stress. The main factors of swelling related to soil characteristics are clay content, mineralogy, chemical structure, dry density and fine grained fraction (Yazıcı, 2004). As mentioned previously, XRD results demonstrated that the soil has smectite and illite minerals which cause high swell. Additionally it is fine grained with a low dry density. Stabilization of swelling can be achieved through modification of cation exchange capacity, flocculation and pozzolanic reactions. Stabilization process starts with a very quick cation exchange and continues with flocculation and agglomeration. A secondary process of pozzolanic reaction occurs between calcium and silica or alumina ions. The lime (CaO) content of BS which is 18.2% is expected to cause reduction of swelling in this research.

Table 4.3 Swelling Results

CuringTime/BS Content	SS (%)	%3BS	%6BS	%10BS	%15 BS
0 Days	6.20 6.15 6.41	4.77 4.47 4.63	4.14 3.98 4.02	4.42 4.16 4.20	3.99 3.90 4.05
7 Days	NA	3.24 3.46 3.11	1.95 1.84 2.13	2.97 2.30 2.16	2.67 2.01 2.50
28 Days	NA	NA 2.45 2.21	1.27 1.38 1.53	1.62 1.33 1.37	1.82 1.49 2.01

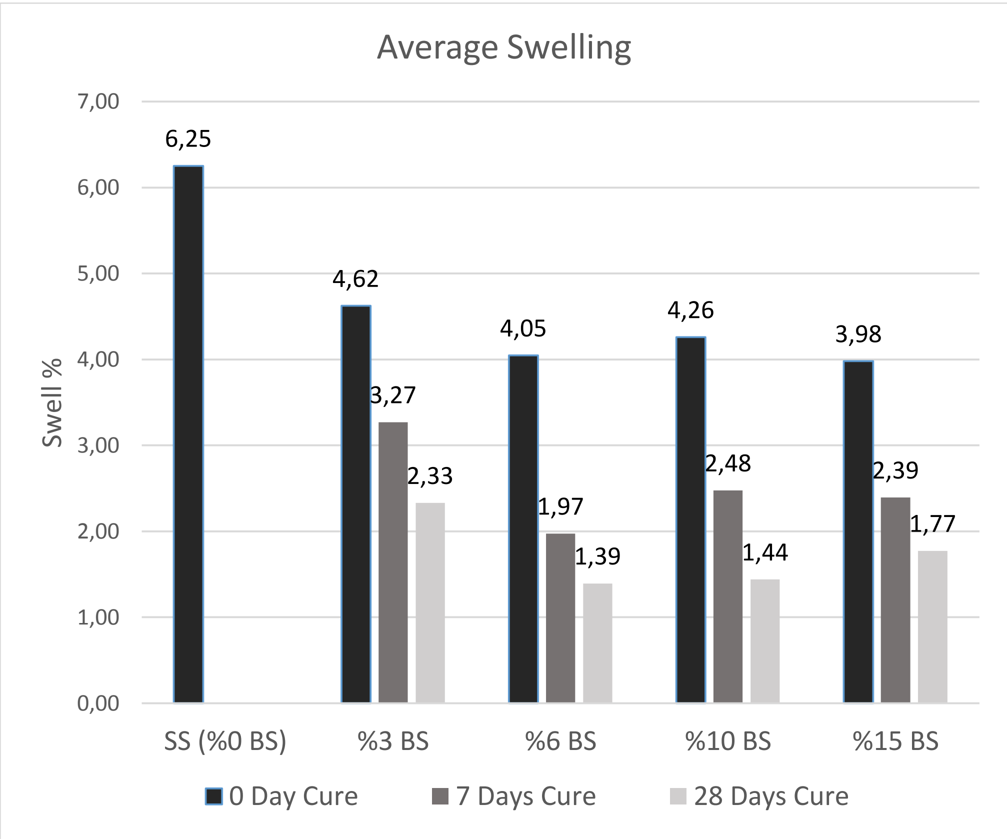

Figure 4.2 Average Swelling

4.3 Compaction Characteristics

A summary of compaction principles and test methodology used in this research were explained in previous chapter. Compaction tests are required to determine the optimum water content and maximum dry density to assess the compaction characteristics of the soil and use the related values for further CBR and UCS tests. Standard Proctor Compaction Test (Method C) results are demonstrated on Table 4.4 and related moisture curves are shown on Figure 4.3. The dry density of the soft soil is quite low, indicating poor geotechnical properties including the compressive strength. BS addition increases the optimum moisture content while reducing the dry density. The reduction in the dry density can be explained due to the low specific gravity of BS. It can also be seen that the curves get closer to zero air void line indicating better compaction and less air voids.

Table 4.4 Proctor Test Results

Material	Optimum Moisture Content (%)	Max. Dry Density (g/cm^3)
SS+0%BS	26	1.449
SS+3%BS	29.3	1.430
SS+6%BS	31.04	1.411
SS+10%BS	32.34	1.398
SS+15%BS	33.1	1.387

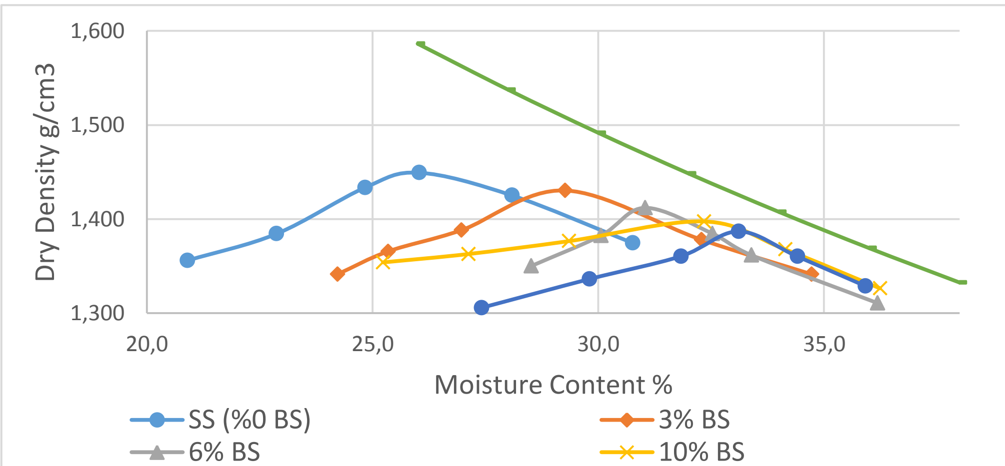

Figure 4.3 Proctor Moisture Curves

Some correlations between plasticity characteristics can be used to check the validity of the results. Figure 4.4 shows typical moisture curves based on many standard proctor tests compiled by the Ohio Dept. to be used as a simple reference tool. To illustrate, for the soft soil with no borax sludge addition, the wet density is 1.827 g/cm3 (114 pounds/cu ft.). dry density is 1.449 g/cm3 (90.5 pounds per cu ft.) and OMC is 26%. These values comply with the chart values represented on the figure. On the other hand, ASTM suggests that generally OMC is slightly lower than PI (ASTM D 698-12 , 2012). All samples have a slightly lower OMC than their respective plasticity indices indicating the proctor test results are similar to that of literature.

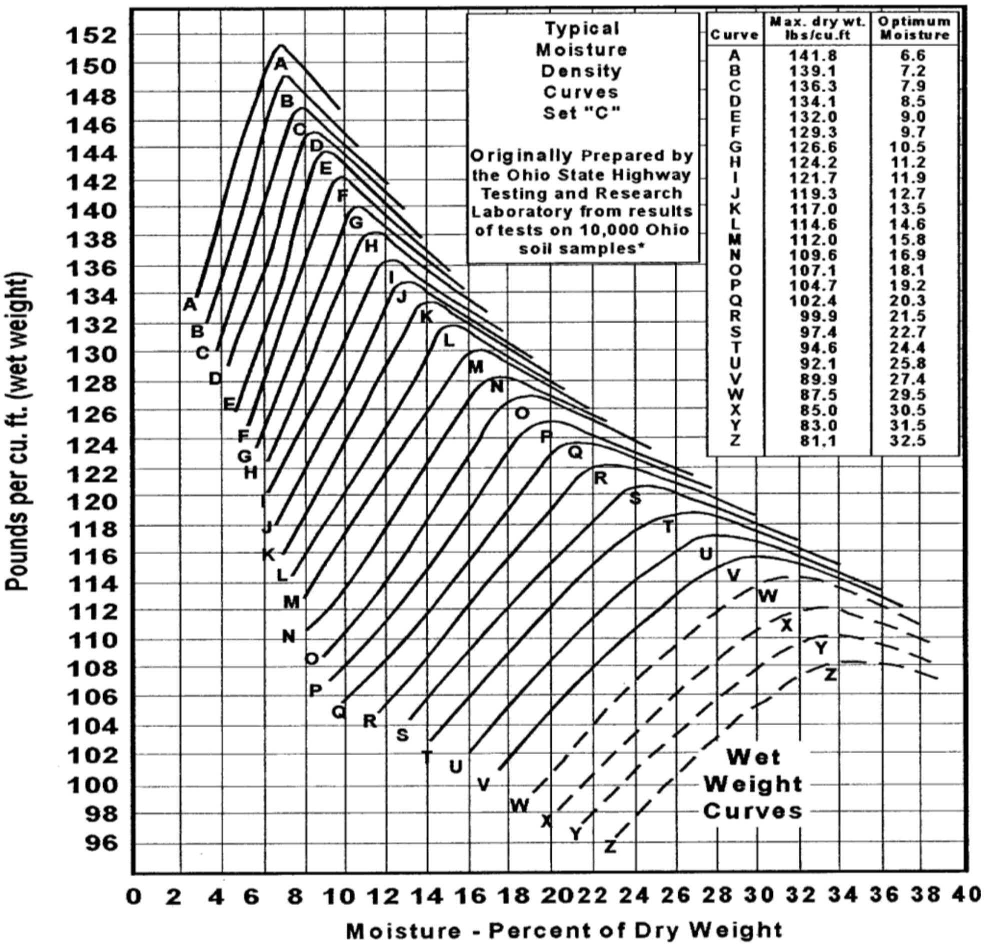

Figure 4.4 Family of expected wet density compaction curves, based on 18,000 compaction tests compiled by the Ohio DOT

4.4 California Bearing Ratio

The CBR Test Results are tabulated in Table 4.5. The soft soil has an average CBR value of 2% which is considered as weak soil and either needs to be improved or removed. As a matter of fact this CBR value is predictable when plasticity, compaction properties and soil classification is considered. Yoder and Witczak (1975) suggest that fat clays (CH) might have field CBR values between 1 and 5 Additionaly, it is suggested that presumptive CBR values of CH can be between 2 and 3 (IRC-SP72, 2007). The value is not acceptable for subgrade minimum requirements suggested by Turkish Directorate of Highways and necessitates strength improvement.

Table 4.5 California Bearing Ratio Test Results

CuringTime/BS	SS	%3BS	%6BS	%10BS	%15 BS
0 Days	1.918 2.083 2.008	2.57 2.508 2.713	3.17 3.087 2.99	2.982 3.078 3.005	2.518 2.57 2.563
7 Days		2.89 2.997 3.065	3.747 3.634 3.852	3.649 3.762 3.492	2.848 2.93 2.878
28 Days		3.297 3.372 3.23	4.099 4.166 4.03	4.135 4.017 3.964	3.372 3.364 3.237

To begin with, a simple comparison between results easily demonstrate that there is an increase in CBR values of BS added specimens. When vertically analyzed a CBR increase with curing time is also visible. The highest CBR improvement has been 4.166% with 6% BS addition and 28 days of curing. Although there is a 100% strength increase, this value is not sufficient for stabilization alone as discussed at previous chapters. Borax sludge content and curing effect can be observed more easily using a scatterplot. A bell curve shape of borax sludge content indicates that CBR increases in all cases but it is highest when BS content is between 6 and 10% and lower at 3 and 15%. It can also be seen that curing effect for 7 days is higher than that of 28 days, however 28 day results are highest. Therefore it can be suggested that CBR increase with BS content and curing.

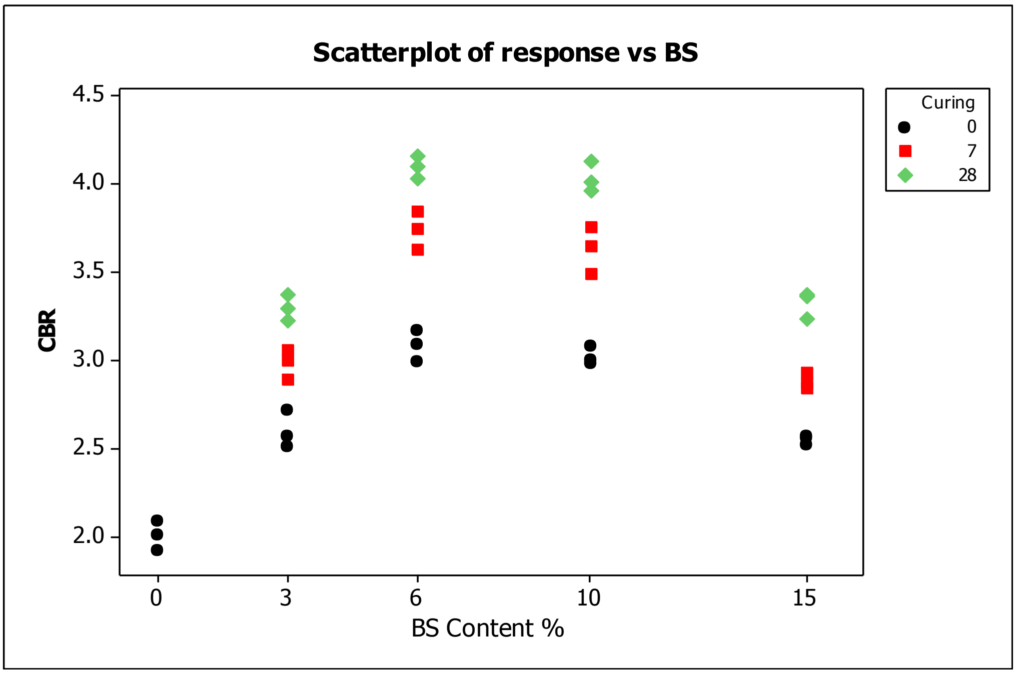

Figure 4.5 California Bearing Ratio Test Results

The experimental design and statistical testing hypotheses for ANOVA were previously presented. While Borax sludge has α= 5 levels (0,3,6,10,15 %) and n=3 replicates, curing time has α= 3 levels (0,7,28 days) and n=3 replicates. Because soft soil without borax addition was not cured and tested, an unbalanced experimental design is tested using general linear model option of Minitab software. ANOVA results retrieved from Minitab 16 statistical software are demonstrated in Table 4.6. For 5% confidence interval P values are approximately zero at ANOVA table which represents that both borax sludge addition and curing times have a significant effect on CBR value. F values suggest that curing time has a more significant effect than BS content. The model suggests that there are no interaction between factors. Two observations seem as outliers and labeled as unusual response (%3BS 0Day Sample 1 and %6BS 0 Day Sample 3).

Table 4.6 ANOVA output of California Bearing Ratio Test Results

Results for: cbr minitab.txt

General Linear Model: response versus BS, Curing

```
Factor  Type   Levels  Values
BS      fixed       5  0, 3, 6, 10, 15
Curing  fixed       3  0, 7, 28


Analysis of Variance for response, using Adjusted SS for Tests

Source  DF   Seq SS  Adj SS  Adj MS       F      P
BS       4   8.4492  5.5659  1.3915  126.49  0.000
Curing   2   4.6484  4.6484  2.3242  211.28  0.000
Error   32   0.3520  0.3520  0.0110
Total   38  13.4497


S = 0.104885   R-Sq = 97.38%   R-Sq(adj) = 96.89%


Unusual Observations for response

Obs  response      Fit   SE Fit  Residual  St Resid
  6   2.71300  2.50136  0.04282   0.21164      2.21 R
 15   2.99000  3.18281  0.04282  -0.19281     -2.01 R
```

Residual plots are useful in analyzing the data and checking model adequacy. Boxplot of residuals (Figure 4.6) indicate that the variances are generally symmetrical and equal. However 15%BS with 0 day and 28 day results seem skewed indication outliers. In Figure 4.7, residual plots for the experimental data are presented. Residual vs. Fitted Values graph helps us to detect non linearity, outliers and unequal error variances. It is apparent that the residuals do not bounce very randomly around the 0 line which indicates a non-linearity. Results around 2.5 is inclined to be over and around 3 lower than the residual line. Variances of error terms seem to be equal and there are no outliers. Residual histogram can be used to check if residual variance is normally distributed. The histogram suggests that residual deviation is normally distributed. Residuals vs. order plot can be used to question if error terms, namely serial correlation are independent. On the plot the residuals are on the y axis and the order data is collected on the x axis. Although residuals between 7 and 15 are mostly below the zero line, generally error terms show no obvious trend. That means error terms are independent. Normal probability plot is useful in showing deviations from normality. The plot for CBR results suggests that residuals comply with normal distribution. All the additional charts show that the experimental results are statistically acceptable and no data transformation is necessary.

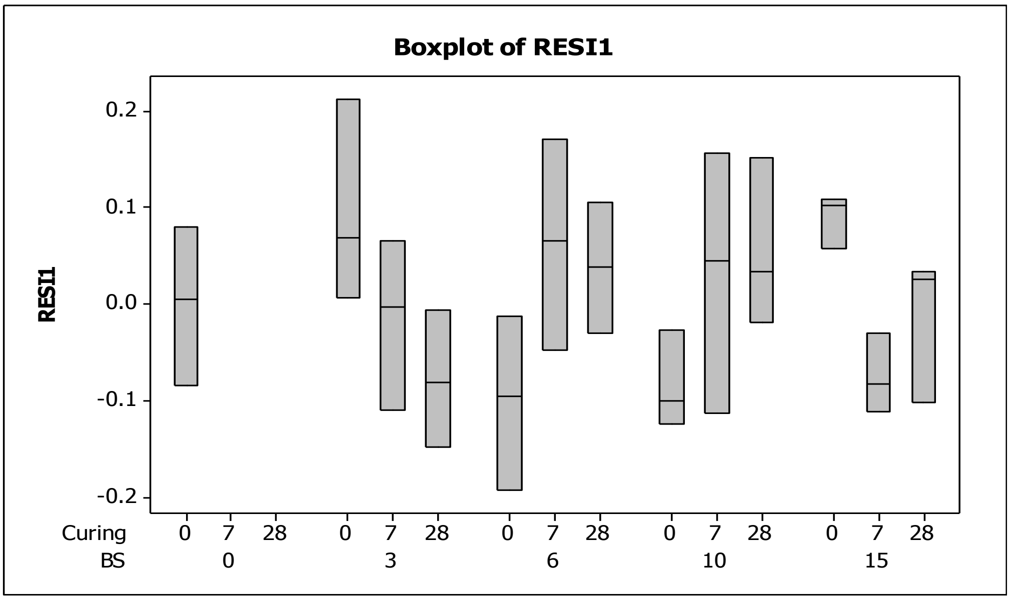

Figure 4.6 Boxplot of Residuals for California Bearing Ratio Test Results

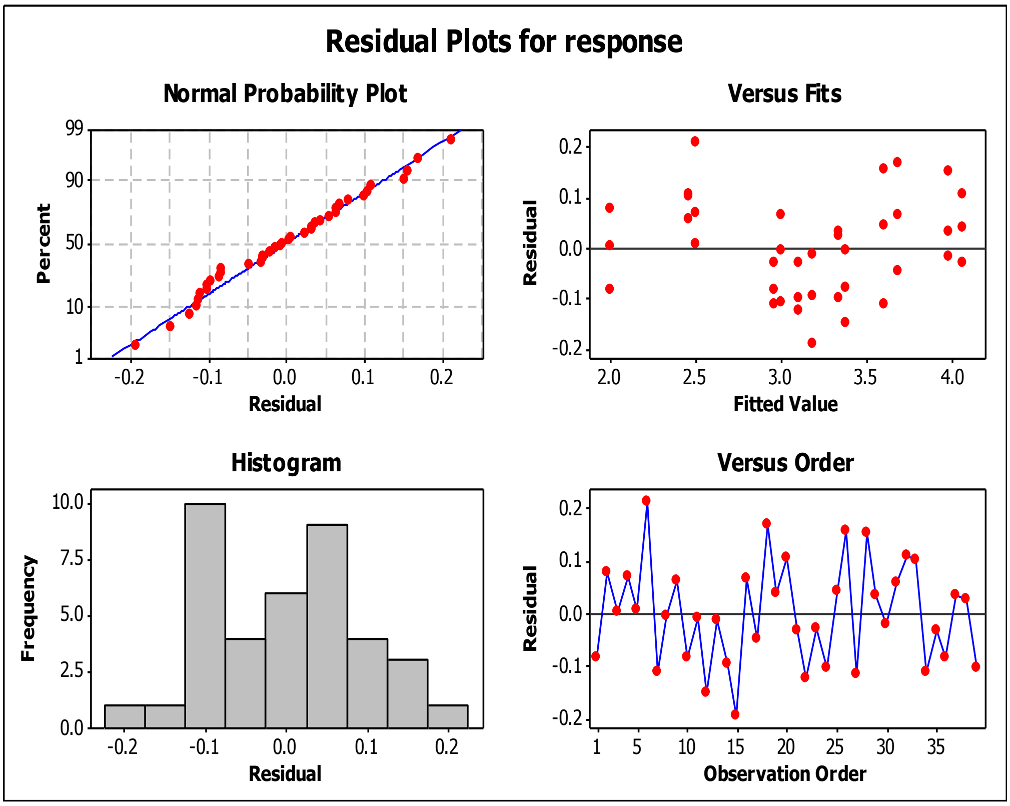

Figure 4.7Residual Plots for California Bearing Ratio Test Results

Plot of the main effects (Figure 4.8) can be useful to visualize the effects of factors on the response variables. It can be seen that around 6% BS content the values are highest and shows a bell shape curve indicating a quadratic function. On the other hand, curing effect has a linear shape indicating the more curing time the better CBR performance is achieved.

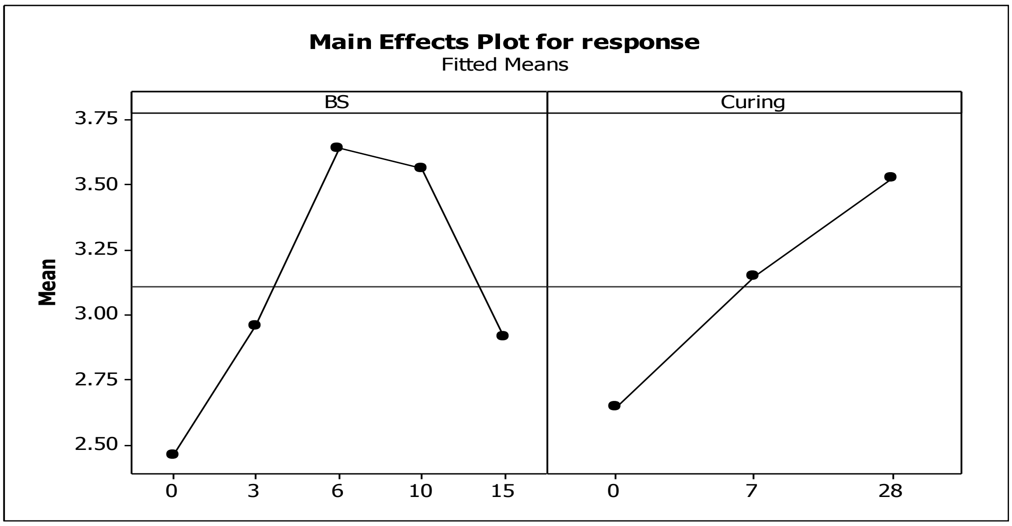

Figure 4.8 Factorial Fitted Means Graph of California Bearing Ratio Test Results

CBR results with 28 days of curing are highest and more curing time was not tested. Therefore a model including curing time is only applicable within 28 days. It is possible to determine a simple model for borax sludge addition if curing time is assumed as 28 days. Therefore BS is chosen as independent variable and curing effect has been fixed for 28 days. In order to model the 28 day curing effect of borax sludge only 28 day cured sample results are evaluated. Using Excel software and trendline function a 4^{th} level polynomial model with a satisfactory R-Sq .9931 is determined (Figure 4.9).

CBR at 28D Curing = $0.0002x^4-0.0056x^3+0.0081x^2+0.4518x+2.003$

When the derivative is applied to find the peak point of the equation, borax sludge content is found 7.7% BS resulting 4.2 CBR. Therefore we can suggest that according to our experimental results, the maximum CBR gain is achieved with 7.7% BS addition in 28 days as approximately 4.2 CBR. However, the calculated value is still below the criteria suggested by many agencies including Turkish Directorate of Highways. CBR improvement is not sufficient.

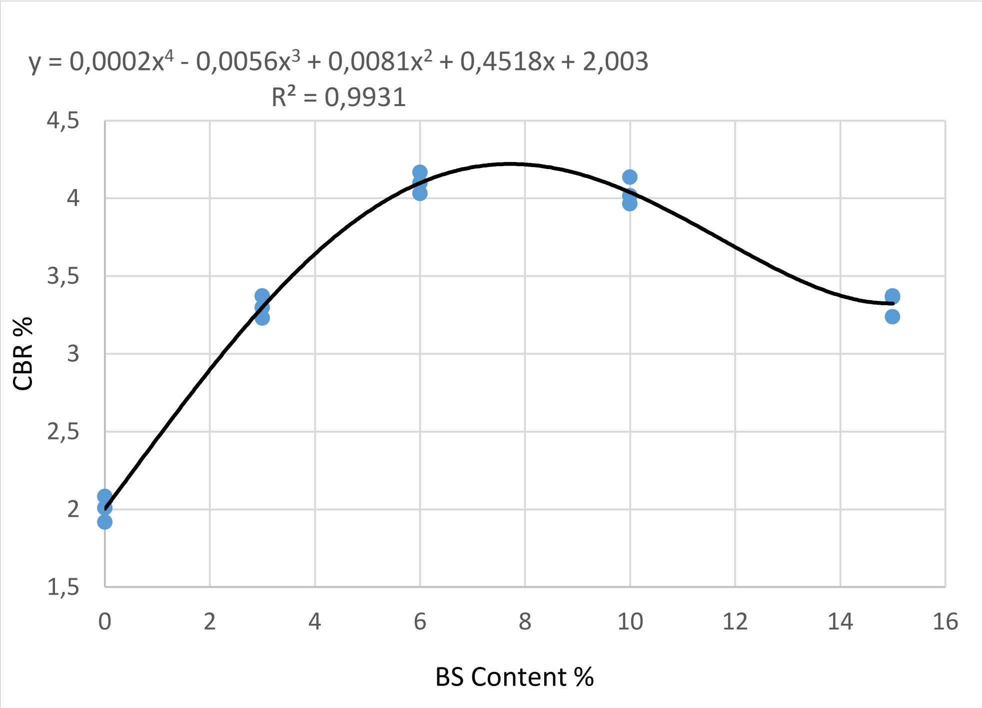

Figure 4.9 California Bearing Ratio Polynomial Model for 28 Days Curing

4.5 Unconfined Compressive Strength

Unconfined Compressive Strength Test Results are demonstrated on Table 4.7. The average UCS value for the SS is 165 kPa. Black (1961) suggests a correlation formula between CBR and UCS.

$$CBR = q_u\ (kPa) / 70$$

Using formula, the expected value is slightly lower than the results which was determined in this research. This can result from the disturbed and remoulded specimens. The values prove that the soil and mixtures were in stiff condition. Borax sludge content and curing effect can easily be observed using a scatterplot (Figure 4.10). The bell curve shape of borax sludge content similar to CBR can easily be seen. However, the shape bends on 10% and higher on 3% than CBR results. Also, the strength difference between 7 and 28 day cured samples is lower. The peak at 6% is more evident.

Table 4.7 Unconfined Compressive Strength Test Results

Curing Time /BS Content		SS (kPa)	%3BS (kPa)	%6BS (kPa)	%10BS (kPa)	%15 BS (kPa)
0 Days	Test 1	162.5	207.4	231.8	201.2	181.7
	Test 2	173.9	190.9	217.9	191.9	181.2
	Test 3	159.5	195.5	229.5	199.6	191.2
7 Days	Test 1		256.9	288.0	242.9	233.5
	Test 2		245.7	282.3	246.4	229.4
	Test 3		250.5	278.9	234.0	235.6
28 Days	Test 1		295.2	318.6	285.4	248.2
	Test 2		282.8	312.0	266.9	258.1
	Test 3		295.5	316.0	289.3	246.6

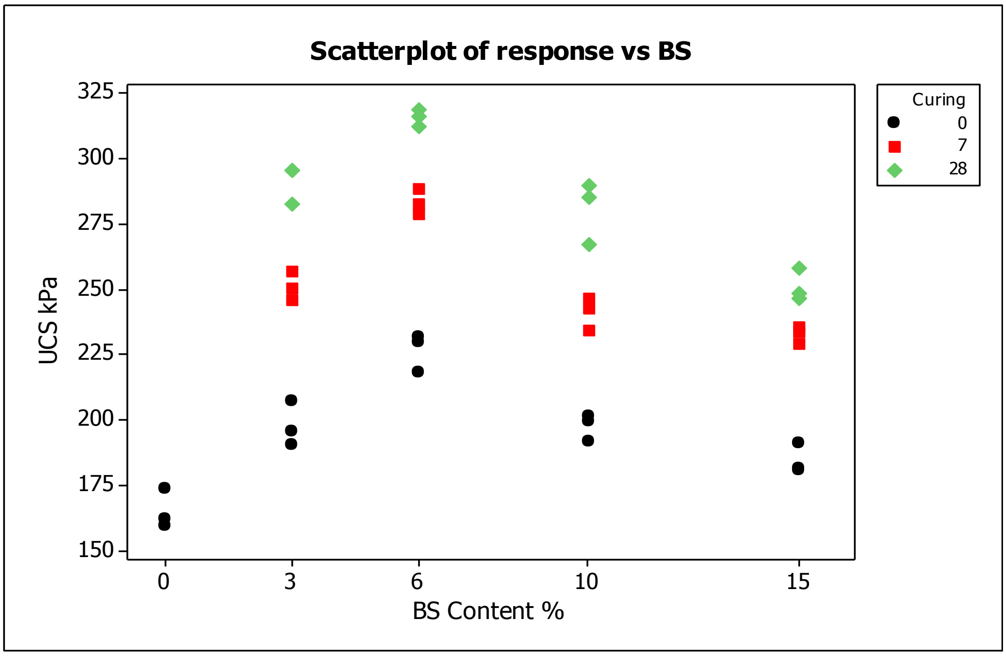

Figure 4.10 Scatterplot of Unconfined Compressive Test Results

In order to analyze the UCS test results, the same ANOVA procedure and Minitab software was used. While Borax sludge has α= 5 levels (0,3,6,10,15) and n=3 replicates, curing time has α= 3 levels (0,7,28) and n=3 replicates. ANOVA output is demonstrated in Table 4.8. Checking P values at ANOVA table, we can clearly state that both borax sludge addition and curing times have a significant effect on UCS value. F values suggest that curing time has a higher effect than BS content. The model suggests that there is no interaction between factors and R-Sq value is similar to that of CBR. One observation seem as an outlier and labeled as unusual response in the table (15% BS 28Day Sample 3).

Table 4.8 ANOVA Output of Unconfined Compressive Strength Test Results

General Linear Model: response versus BS, Curing

```
Factor  Type   Levels  Values
BS      fixed       5  0, 3, 6, 10, 15
Curing  fixed       3  0, 7, 28


Analysis of Variance for response, using Adjusted SS for Tests

Source  DF  Seq SS  Adj SS  Adj MS       F      P
BS       4   30826   15933    3983   63.37  0.000
Curing   2   41879   41879   20939  333.11  0.000
Error   32    2012    2012      63
Total   38   74717


S = 7.92844   R-Sq = 97.31%   R-Sq(adj) = 96.80%

Unusual Observations for response

Obs  response      Fit  SE Fit  Residual  St Resid
 39   246.620  261.313   3.237   -14.693     -2.03 R

R denotes an observation with a large standardized residual.
```

Residual plots are evaluated for the UCS test results (Figure 4.11 & 4.12). Box-plot of residuals shows that variance is generally close to equal, however results of 28 days cured 3%BS and uncured 15%BS test results are skewed. A transformation is not necessary. Residual histogram shows normal distribution although weight can be seen on the positive side. Residuals vs. order plot looks normal and that error terms are independent. Sample 3 remains very below zero line. This was considered as an outlier and presented at ANOVA output in Table 19. Normal probability plot shows that residuals comply with normal distribution. No significant outlier is detected and there is no need for a data transformation. Residual vs. Fitted Values graph suggests that variances of error terms are equal and randomly placed.

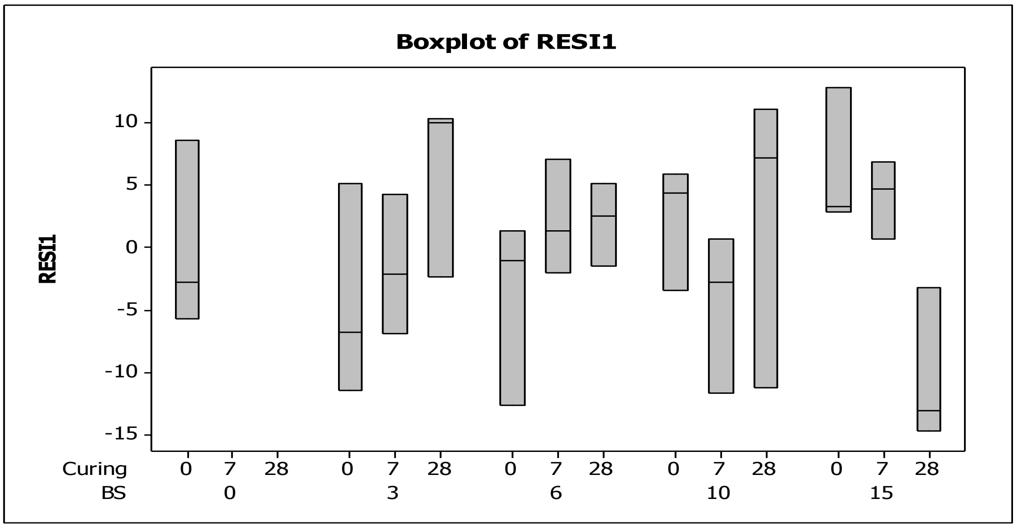

Figure 4.11 Boxplot of Residuals of Unconfined Compressive Strength Test Results

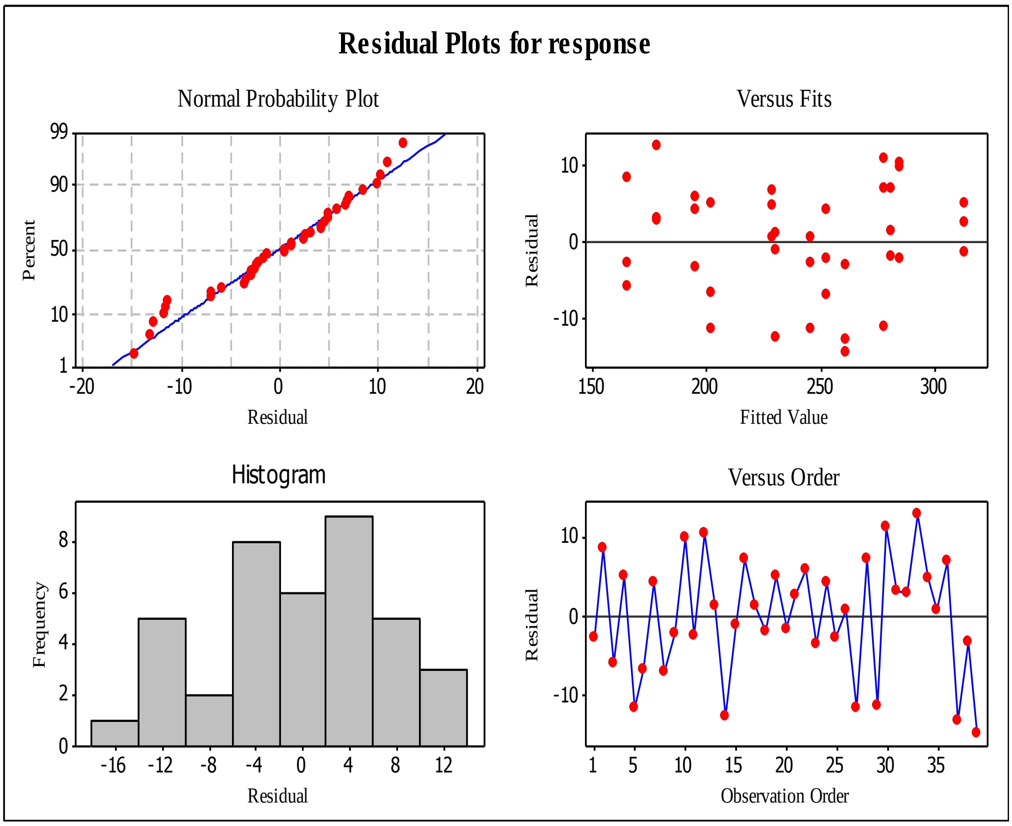

Figure 4.12 Residual Plots for Unconfined Compressive Strength Test Results

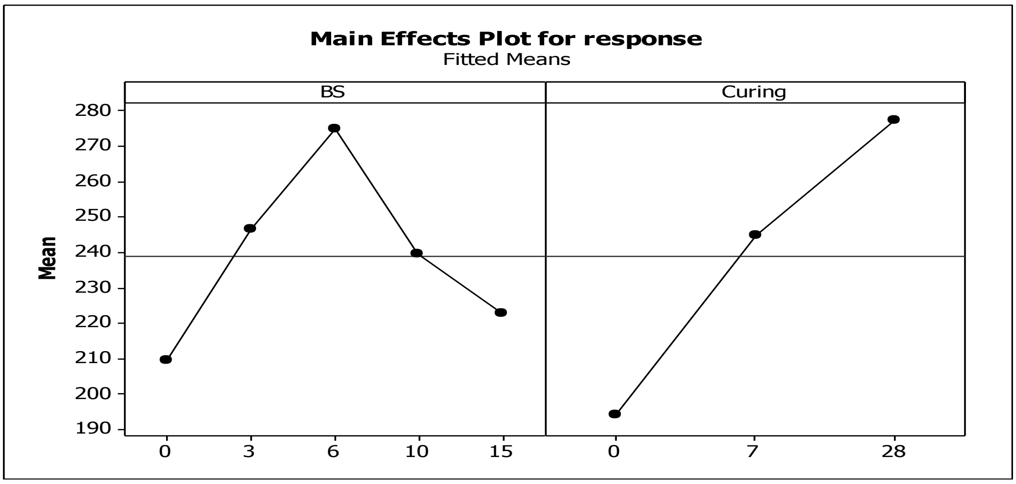

Figure 4.13 Main Effects Plot for Unconfined Compressive Strength Test

Main effects plot (Figure 4.13) shows that around 6% BS content the values are highest and an inclined bell shape curve indicating a polynomial function. On the other hand, curing effect has a linear shape so similar to that of CBR. In a similar manner to fit the data to a simple model, curing time is fixed as 28 days and BS content is selected as independent variable. Using Excel software and trendline function a 4th order polynomial model is determined (figure 4.14). More orders changes the R-Sq value only 1 in 10^{-15} therefore 4th order is accepted as sufficient.

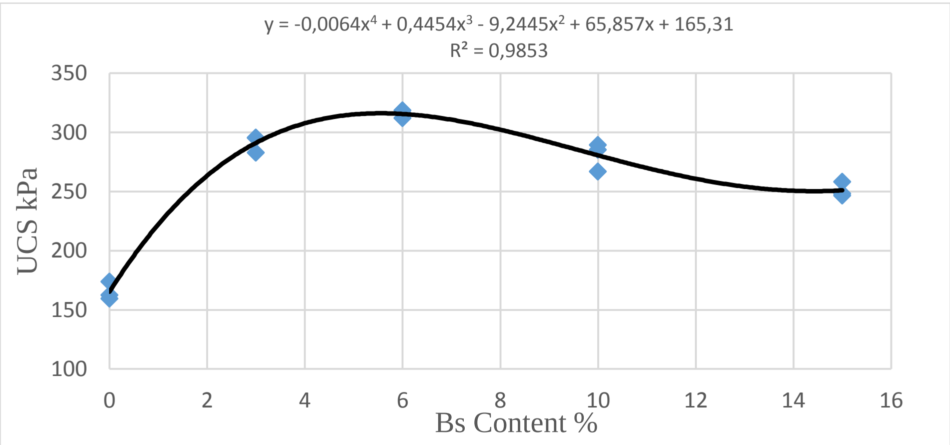

Figure 4.14 Polynomial Model for Unconfined Compressive Strength Test Results

Suggested Model, R-Sq = 0.9853:

UCS at 28D Curing = $-0.0064x^4+0.4454x^3-9.2445x^2+65.857x+165.31$pol

When the derivative is applied in order to find the peak point, the root is found at 5.5%. Subsequently when the model is applied for 5.5 % BS addition, UCS is found as 316.1 kPa. Therefore we can suggest that according to our experimental results, the maximum UCS gain is achieved with %5.5 BS addition. In the next chapter, a summary of the conclusions and further recommendations are presented.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The conclusions made from this research and recommendations for future studies are included in this chapter. More studies will be useful in the utilization of boron waste materials for construction of transport structures and geotechnical applications. In this research, the effect of borax sludge obtained from concentrator plant on compressive strength and other geotechnical properties of soft soil was investigated. BS was mixed 0, 3, 6, 10 and 15% by dry weight with soft soil and cured for 0, 7 and 28 days and changes in geotechnical properties were studied with standard laboratory tests. Mainly, Unconfined Compressive Strength and California Bearing Ratios were tested and analyzed. The soil which was used for this research was a fat clay (CH) with high plasticity and very low strength properties. It is a type of subgrade which needs to be removed or stabilized by different means. Borax Sludge was retrieved from concentrator plant from Bigadiç, Turkey. It is highly plastic soil and consists of very fine particles.

5.1 Conclusions

Based on the results of analyses on laboratory outcomes, the following conclusions can be drawn from the study.

- XRD Analysis shows that the main minerals of borax sludge include dolomite and borates, and soft soil quartz, feldspar, smectite and illite. Smectite and illite explain the high swelling and plastic character of the soil.

- XRF Analysis demonstrates that borax ludge has an average of 7% B2O3 (boron), and 18.2% CaO (lime). Lime content may have an effect on stabilization, however this amount alone may not be sufficient to achieve the intended strength improvements. On the other hand pozzolanic content consists only around 15% of silica, which may not be sufficient to create a reaction with calcium in the case of fly ash.

- Borax Sludge content increases liquid limit slightly and plastic limit significantly. This results in a decrease in the plasticity index, which is a preferred effect. However, this improvement is not satisfactory in terms of field applications.

- Optimum moisture content increases while the maximum dry density decreases with the increasing borax sludge content. This may result from the difference between the specific gravity of the soft soil (2.718) and the borax sludge (2.523). It was found that borax sludge addition decreases air void ratio which is a sign of higher compactibility.

- CBR of soft soil increases in all borax sludge combination, however the highest increase can be gained between 6%BS and 10%BS. 28 day cured model suggests a BS content of 7.7% for the highest CBR result.

- Curing has also significant effect on CBR results. An average of 25% strength gain is achieved at 7 days of curing and additional 17% more gain is achieved after 28 days of curing.

- While the highest CBR value was 4.1, according to the model, 4.2 CBR could be achieved with 7.7% BS. Although this value is twice as much as the CBR of the soft soil, the strength gain is still not sufficient for stabilization purposes.

- Satisfactory reduction in swelling was achieved by the addition of borax sludge in that the swelling was decreased from 6.3% to 1.4% after 28 days of curing. This improvement complies with the criteria stated by the Turkish General Directorate of Highways.

- Unconfined compressive strength results were similar to those of CBR, however, samples with 10%BS content did not perform well. The highest increase was observed with 6%BS samples. The estimated model demonstrates that an optimum BS content as of 5.6 % can increase the strength from 165.3 kPa to 316.1 kPa. However, the improvement is not as high as 350kPa to be named as stabilization.

- Curing for UCS tests had a similar effect to that of CBR. 7 days of curing had an average of 27% strength increase while the additional 15% average strength gain was achieved after 28 days of curing.

- To sum up, Borax Sludge addition increases liquid limit, compressive strength, bearing ratio, optimum moisture content and decreases dry density, plasticity and swell rate. Nevertheless the improvement level is not sufficient for stabilization purposes except for swelling which was found to be satisfactory.

- Finally, it can be stated that BS can be used for soft soil modification and improvement of swelling characteristics. Even though sufficient bearing ratio was not obtained, borax sludge can be used on low volume road construction as a waste utilization resort.

5.2 Recommendations for Future Studies

After the literature review and experimental studies conducted for this research, the following recommendations for future studies can be made as follows,

- Borax sludge can be used to modify soft soils and be utilized as a waste management solution. However, research on varying combination with different stabilizing agents such as lime, fly ash and cement are recommended. Such a combination may result with a better strength improvement.

- Borax sludge was also studied on cement production. Further research on its usage for Portland cement and asphalt concrete may provide more utilization areas.

- This research was done using only soft subgrade soil. Further research using granular materials for base or subbase layers of pavement should be evaluated.

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APPENDIX A

BORAX SLUDGE XRF ANALYSIS REPORT

ETİ MADEN İŞLETMELERİ GENEL MÜDÜRLÜĞÜ
BANDIRMA BOR VE ASİT FABRİKALARI
İŞLETME MÜDÜRLÜĞÜ LABORATUVARLARI

ANALİZ RAPORU

Numune : BORAKS ŞLAMI Tarih : 22/03/2012

150 KG BORAKS ŞLAMI NUMUNESİ ANALİZ SONUÇLARI.

B2O3	**%**	**6,77**
SO4	%	0,54
CaO	**%**	**16,70**
Na2O	%	3,50
SiO2	%	16,60
MgO	%	15,00
SrO	%	0,91
Al2O3	%	0,61
Fe2O3	%	0,16
As2O3	%	0,0029
Elek Analizi		
+0,315 mm	%	0,12
+0,250 mm	%	0,35
+0,106 mm	%	1,01
+0,063 mm	%	3,40
-0,063 mm	%	96,60

APPENDIX B

XRD TEST RESULTS

General information

Analysis date	7/1/2014 2:09:12 PM		
Sample name	TEST SAMPLE	Measurement date	6/30/2014
File name	01_BorAtigi.raw	Operator	metu-xrd
Comment			

Measurement profile

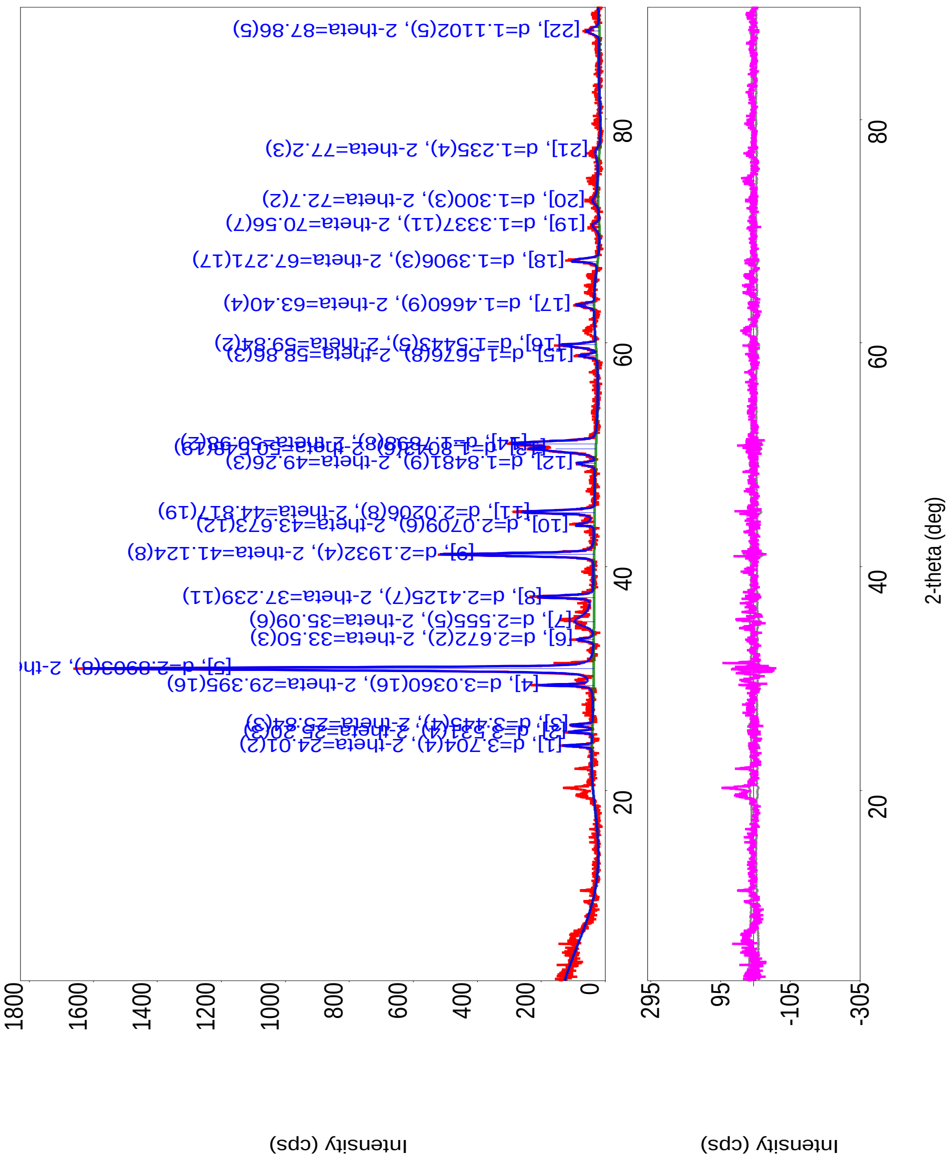

Figure B.1 XRD Test Results

Peak list

2-theta(deg)	d (A)	Height(cps)	Int. I(cps deg)	FWHM(deg)	Size	Phase name
24.01(2)	3.704(4)	64(10)	13.1(13)	0.192(18)	442(42)	Dolomite, (0,1,2)
25.20(3)	3.531(4)	54(9)	11.4(9)	0.200(19)	425(39)	Unknown,
25.84(3)	3.445(4)	48(9)	12.3(9)	0.24(2)	354(31)	calcium bis(borate), (1,1,1)
29.395(16)	3.0360(16)	142(15)	26.5(18)	0.11(3)	769(209)	Unknown,
30.913(9)	2.8903(8)	1103(43)	388(5)	0.281(7)	306(8)	Dolomite, (1,0,4), 01-078-1277@calcium bis(borate), (0,3,1)
33.50(3)	2.672(2)	38(8)	11.3(13)	0.24(3)	360(52)	Dolomite, (0,0,6)
35.09(6)	2.555(5)	40(8)	65(3)	1.13(8)	77(5)	Dolomite, (0,1,5), 01-078-1277@calcium bis(borate), (1,3,1)
37.239(11)	2.4125(7)	134(15)	36.1(17)	0.212(15)	413(29)	Dolomite, (1,1,0)
41.124(8)	2.1932(4)	346(24)	112(2)	0.250(11)	354(15)	Dolomite, (1,1,3), 01-078-1277@calcium bis(borate), (0,0,2)
43.673(12)	2.0709(6)	54(9)	15.4(13)	0.16(6)	545(193)	Dolomite, (0,2,1), 01-078-1277@calcium bis(borate), (1,0,2)
44.817(19)	2.0206(8)	174(17)	58(2)	0.274(19)	328(23)	Dolomite, (2,0,2)
49.26(3)	1.8481(9)	42(8)	13.1(10)	0.27(3)	335(36)	Dolomite, (0,2,4), 01-078-1277@calcium bis(borate), (2,5,0)
50.548(19)	1.8042(6)	127(15)	60(5)	0.42(2)	219(11)	Dolomite, (0,1,8), 01-078-1277@calcium bis(borate), (2,0,2)
50.98(2)	1.7898(8)	186(18)	96(5)	0.45(3)	206(14)	Dolomite, (1,1,-6), 01-078-1277@calcium bis(borate), (3,2,1)
58.86(3)	1.5676(8)	44(9)	12.2(9)	0.25(3)	374(42)	Dolomite, (1,2,-1), 01-078-1277@calcium bis(borate), (4,0,0)
59.84(2)	1.5443(5)	79(11)	29.8(12)	0.35(2)	273(17)	Dolomite, (2,1,-2), 01-078-1277@calcium bis(borate), (0,7,1)
63.40(4)	1.4660(9)	45(9)	13.6(12)	0.29(4)	341(45)	Dolomite, (1,2,-4), 01-078-1277@calcium bis(borate), (4,1,1)
67.271(17)	1.3906(3)	76(11)	23.0(14)	0.23(2)	432(43)	Dolomite, (3,0,0)
70.56(7)	1.3337(11)	15(5)	10.6(11)	0.65(8)	156(18)	Dolomite, (0,0,12), 01-078-1277@calcium bis(borate), (3,4,2)
72.7(2)	1.300(3)	13(5)	12(2)	0.7(2)	152(51)	Dolomite, (1,2,-7), 01-078-1277@calcium bis(borate), (2,8,0)
77.2(3)	1.235(4)	8(4)	10.5(12)	1.1(2)	94(19)	Dolomite, (2,1,-8), 01-078-1277@calcium bis(borate), (4,5,1)
87.86(5)	1.1102(5)	33(7)	18.8(16)	0.41(7)	284(46)	Dolomite, (3,1,-4), 01-078-1277@calcium bis(borate), (3,7,2)

Figure B.1 (Continued)

Quantitative Analysis Results (RIR)

General information

Analysis date	12/30/2014 4:50:50 PM		
Sample name	TEST SAMPLE	Measurement date	6/30/2014
File name	01_BorAtigi.raw	Operator	metu-xrd
Comment			

Qualitative analysis

Phase name	Formula	Figure of merit	Phase reg. detail
Dolomite	Ca Mg (C O3)2	0.4309137259854437	10732324 (ICDD)
calcium bis(borate)	Ca (B O2)2	1.097427952851041	10781277 (ICDD)

Weight ratio

Phase name	Content(%)
Dolomite	89(6)
calcium bis(borate)	10.7(12)

QAGraphs.emf

Measurement profile

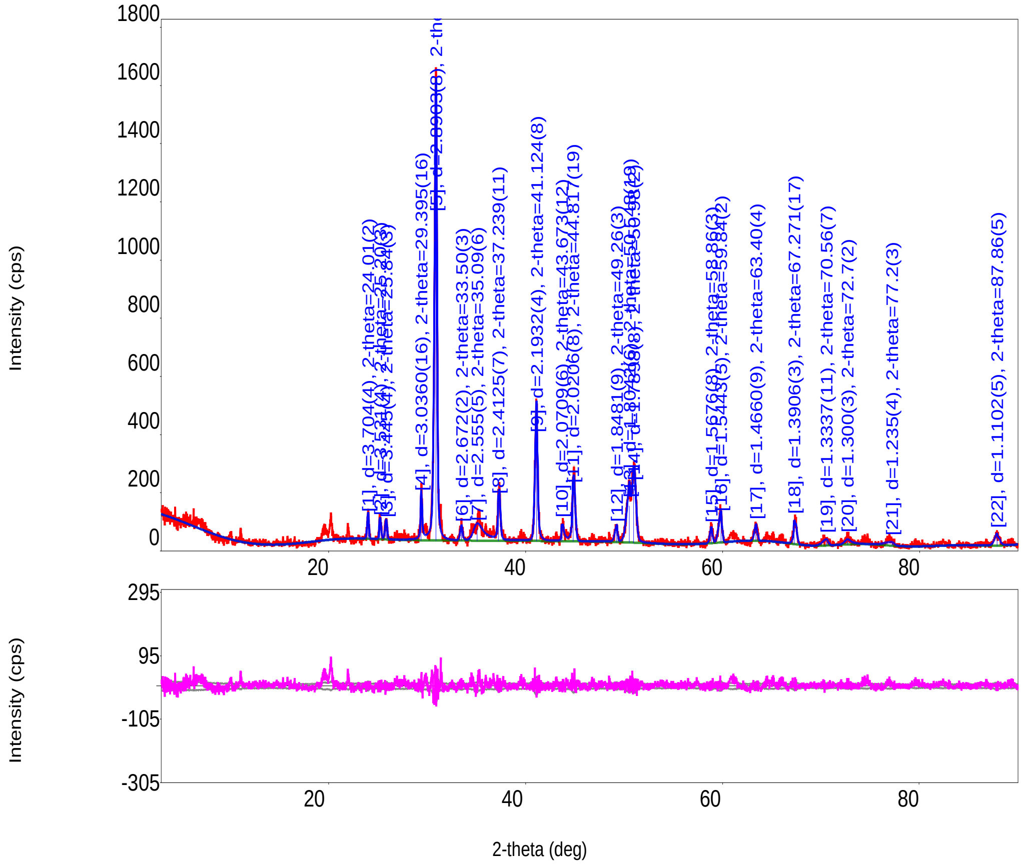

Figure B.1 (Continued)

General information

Analysis date	7/1/2014 2:11:10 PM		
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File name	03_AnkaraKili.raw	Operator	metu-xrd
Comment			

Measurement profile

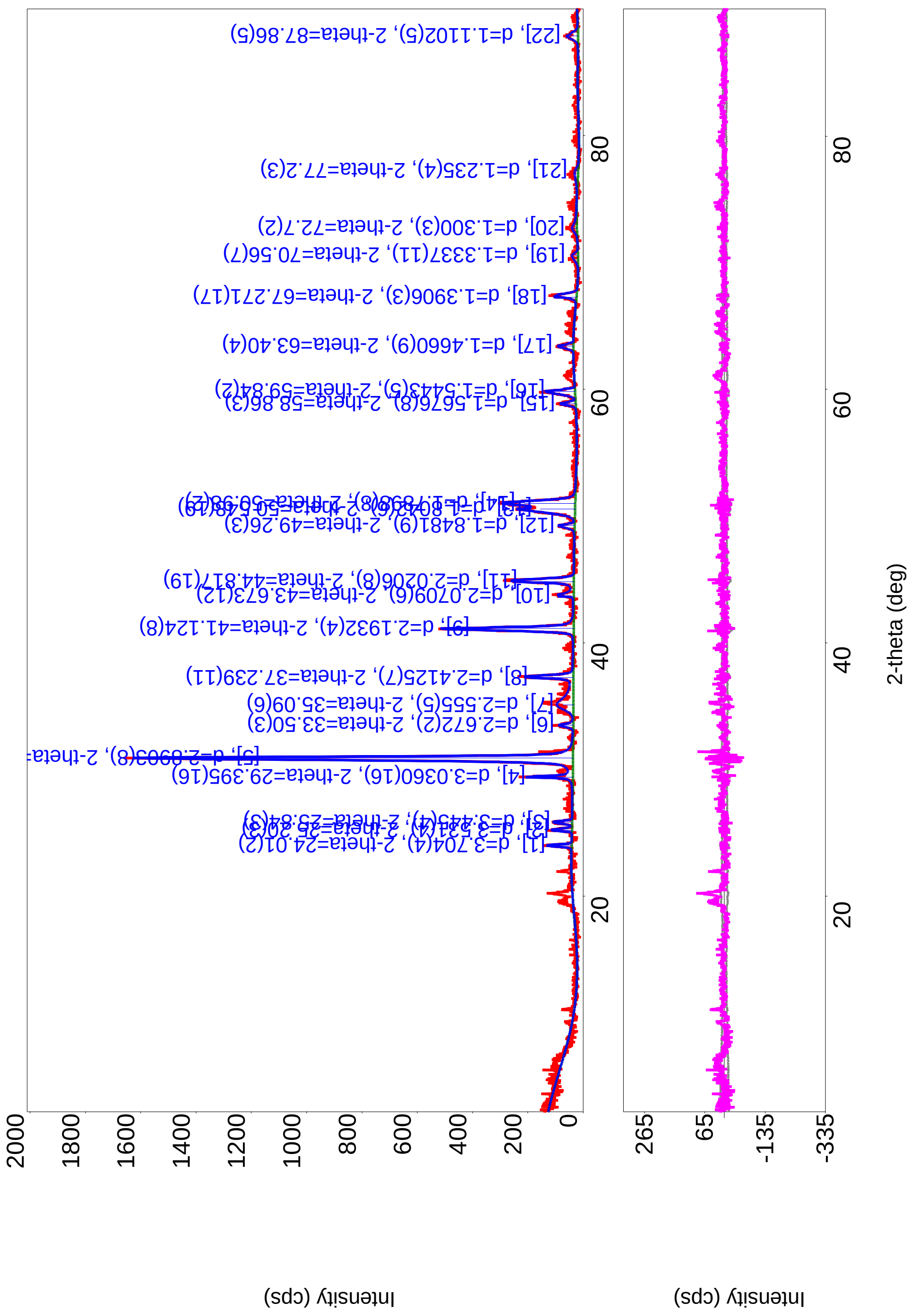

Figure B.1 (Continued)

Peak list

2-theta(deg)	d (A)	Height(cps)	Int. I(cps deg)	FWHM(deg)	Size	Phase name
19.77(3)	4.488(6)	84(12)	80(3)	0.61(4)	139(10)	Unknown,
20.849(5)	4.2570(11)	154(16)	22.5(13)	0.121(8)	699(47)	Quartz, (1,0,0)
21.95(3)	4.045(6)	51(9)	12.5(13)	0.18(3)	466(86)	Unknown,
23.04(2)	3.856(4)	87(12)	12.0(14)	0.09(3)	943(303)	Calcite, syn, (0,1,2)
26.612(4)	3.3469(5)	836(37)	124(2)	0.105(6)	810(46)	Quartz, (0,1,1)
27.96(2)	3.188(3)	59(10)	31.5(18)	0.45(3)	188(12)	Unknown,
29.415(10)	3.0340(10)	396(26)	82.1(19)	0.162(8)	529(27)	Calcite, syn, (1,0,4)
34.70(2)	2.5833(15)	49(9)	91(5)	1.04(8)	83(6)	Unknown,
39.465(15)	2.2815(8)	164(17)	24.4(17)	0.117(16)	751(100)	Quartz, (1,0,2), 00-005-0586@Calcite, syn, (1,1,3)
42.44(2)	2.1283(11)	50(9)	8.9(9)	0.12(3)	734(180)	Quartz, (2,0,0)
43.23(2)	2.0912(10)	60(10)	13.5(13)	0.20(2)	446(51)	Calcite, syn, (2,0,2)
47.579(18)	1.9096(7)	60(10)	21.7(12)	0.21(3)	423(55)	Calcite, syn, (0,1,8)
48.52(2)	1.8746(9)	80(12)	15.3(10)	0.180(18)	506(52)	Calcite, syn, (1,1,6)
50.121(13)	1.8185(4)	111(14)	16.3(11)	0.104(14)	878(115)	Quartz, (1,1,2)
54.4(2)	1.685(6)	9(4)	23(2)	2.3(2)	41(4)	Quartz, (0,2,2), 00-005-0586@Calcite, syn, (2,1,1)
59.949(14)	1.5417(3)	74(11)	9.0(9)	0.115(12)	834(87)	Quartz, (1,2,1)
61.79(10)	1.500(2)	23(6)	30.2(19)	1.26(10)	77(6)	Calcite, syn, (2,1,4)
67.763(13)	1.3817(2)	44(9)	7.3(8)	0.129(19)	774(114)	Quartz, (1,2,2)
68.113(15)	1.3755(3)	67(11)	16.0(12)	0.14(2)	721(120)	Quartz, (2,0,3)
79.89(4)	1.1997(4)	10(4)	4.7(6)	0.40(12)	270(84)	Quartz, (2,1,3)
81.44(5)	1.1807(6)	18(6)	8.3(10)	0.32(6)	337(66)	Quartz, (3,1,0), 00-005-0586@Calcite, syn, (2,1,10)

Figure B.1 (Continued)

APPENDIX C

SIEVE ANALYSIS TEST RESULTS

Kuru örneğin toplam ağırlığı (g)= **1800,00** Deney tipi: WET/ YAŞ
Total mass of dry sample: Test type:

TEST SIEVES ELEK SERİSİ Sieve no: Elek no:	mm	Mass retained Kalan ağırlık g	Cumulative mass retained Kalan toplam ağırlık. g	Cumulative percentage retained Kalan toplam yüzde %	Cumulative percentage passing Geçen toplam yüzde %
2 in	50	0	0	0	100
1 1/2 inc	37,5	0	0	0	100
1 İnc	25	32,32	32,32	1,8	98,2
3/4 inc	19	0,00	32,32	1,8	98,2
1/2 inc	12,5	32,63	64,95	3,6	96,4
3/8 inc	9,5	16,98	81,93	4,6	95,4
1/4 inc	6,3	31,81	113,74	6,3	93,7
4	4,75	18,03	131,77	7,3	92,7
10	2	71,10	202,87	11,3	88,7
30	0,6	93,58	296,45	16,5	83,5
50	0,300	65,63	362,08	20,1	79,9
70	0,212	37,96	400,04	22,2	77,8
100	0,150	48,70	448,74	24,9	75,1
200	0,075	82,35	531,09	29,5	70,5

Hidrometre türü / Hydrometer type: **H 151** Özgül ağ. / Specific gravity G_s = 2,718
Kuru örn. ağırlığı / Dry mass of sample Mb= 50,0 Menüsküs düzelt./Meniscus Correc. Cm: 0,5

Geçen süre Elapsed time Dk./ Min.	Sıcaklık Temp. ^0C	Hidrometre okuması Hydrometer reading R'_h	Düz. hid.oku. Cor.hydr.rdg. R_h	Dane çapı Part.diameter D (mm)	Sıc.düzelt. Temp. cor. M_t	R_h+M_t-X	Geçen dane yüzdesi Percent finer than D %
0,50	22	27,10	27,60	0,0641	0,39	23,99	68,83
1	22	26,90	27,40	0,0454	0,39	23,79	68,26
2	22	26,50	27,00	0,0323	0,39	23,39	67,11
4	22	26,00	26,50	0,0229	0,39	22,89	65,68
8	22	25,20	25,70	0,0163	0,39	22,09	63,38
15	22	24,30	24,80	0,0120	0,39	21,19	60,80
30	22	24,10	24,60	0,0085	0,39	20,99	60,23
60	22	22,30	22,80	0,0061	0,39	19,19	55,06
120	22	21,50	22,00	0,0044	0,39	18,39	52,77
240	22	20,60	21,10	0,0031	0,39	17,49	50,18
1440	22	17,50	18,00	0,0013	0,39	14,39	41,29

Figure C.1 Sieve Analysis Test Results of Soft Soil

APPENDIX D

ATTERBERG LIMITS TEST FORMS

Numune	SS (%0BS)				23.01.2014	
	LL	LL	LL	LL	PL	PL
No.Of Drops	36	27	21	18	0	0
Mass of Container + wet soil	29.00	24.30	24.90	29.40	37.61	38.02
Mass of Container + dry soil	23.40	20.14	19.90	22.54	35.89	36.58
Mass of Container	14.10	14.00	13.30	13.60	29.8	31.37
Mass of Moisture	5.60	4.16	5.00	6.86	1.72	1.44
Mass of Dry Soil	9.30	6.14	6.60	8.94	6.09	5.21
Moisture Content	60.22	67.75	75.76	76.73	28.243	27.639
LL	70.599	y = -0.9657x + 94.741			R² = 0.9835	
PL	27.941					
PI	42.657					

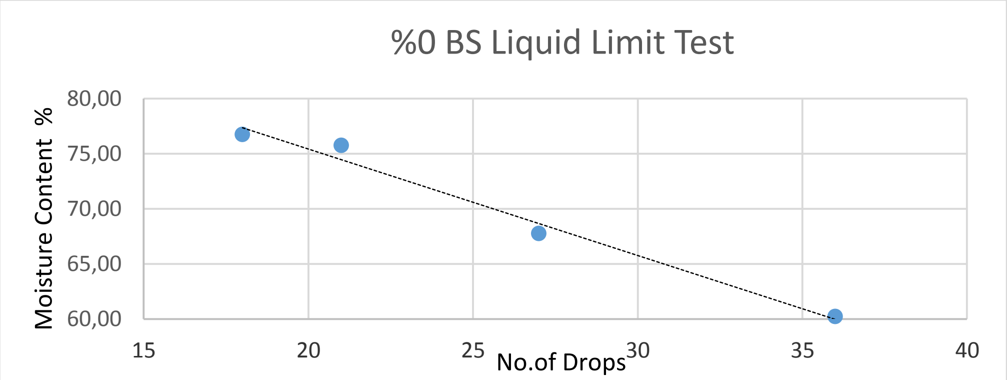

Figure D.1 Atterberg Limits Test Data Sheets

Numune	3% BS				23.01.2014	
	LL	LL	LL	LL	PL	PL
No.Of Drops	13	22	33	47	0	0
Mass of Container + wet soil	42.27	38.83	37.98	38.45	29.1	32.39
Mass of Container + dry soil	34.59	32.61	31.05	31.11	28.08	30.78
Mass of Container	24.03	23.9	21.16	20.46	24.77	25.63
Mass of Moisture	7.68	6.22	6.93	7.34	1.02	1.61
Mass of Dry Soil	10.56	8.71	9.89	10.65	3.31	5.15
Moisture Content	72.727	71.412	70.071	68.92	30.816	31.262
LL	71.201	y = -0.1115x + 73.988			R² = 0.9832	
PL	31.039					
PI	40.162					

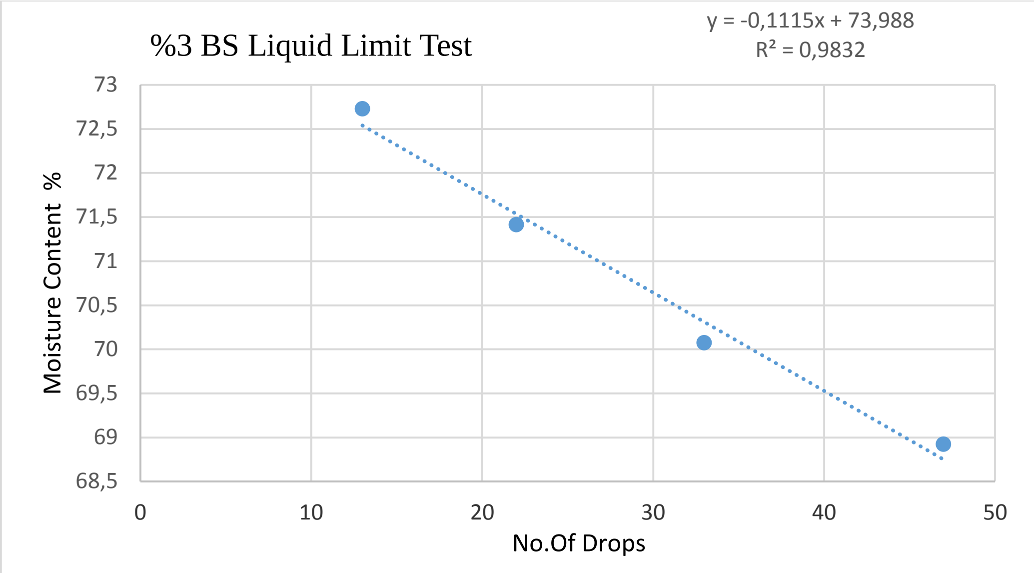

Figure D.1 (Continued)

Numune	%6BS	5%			23.01.2014	
	LL	LL	LL		PL	PL
No.Of Drops	46	35	23	13	0	0
Mass of Container + wet soil	47.57	46.7	45.31	48.56	31.16	28.87
Mass of Container + dry soil	38.01	37.35	34.94	38.11	30.07	27.89
Mass of Container	23.9	24	20.46	24.1	26.76	24.83
Mass of Moisture	9.56	9.35	10.37	10.45	1.09	0.98
Mass of Dry Soil	14.11	13.35	14.48	14.01	3.31	3.06
Moisture Content	67.753	70.037	71.616	74.59	32.931	32.026
LL	71.84	y=-.0198x+76.79			R^2 = 0.9773	
PL	32.478					
PI	39.362					

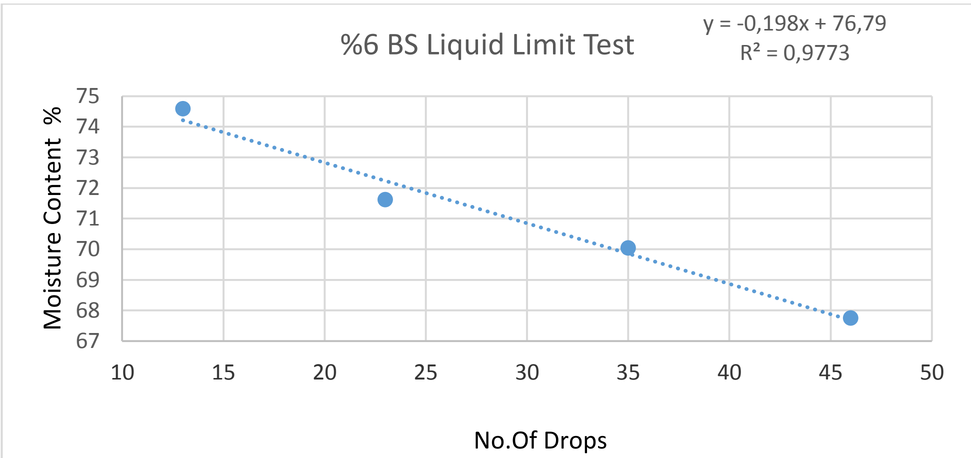

Figure D.1 (Continued)

Numune	%10 BS			24.01.2014	
	LL	LL	LL	LL	PL	PL
No.Of Drops	41	32	22	15	0	0
Mass of Container + wet soil	44.46	42.6	47.06	43.02	27.69	34.27
Mass of Container + dry soil	36.09	35.29	37.4	33.5	26.43	32.55
Mass of Container	23.97	25.1	24.18	20.88	22.67	27.52
Mass of Moisture	8.37	7.31	9.66	9.52	1.26	1.72
Mass of Dry Soil	12.12	10.19	13.22	12.62	3.76	5.03
Moisture Content	69.059	71.737	73.071	75.436	33.511	34.195
LL	72.904	y=-0.24386179558011x+78.816056685				
PL	33.853				$R^2 = 0.9741$	
PI	39.051					

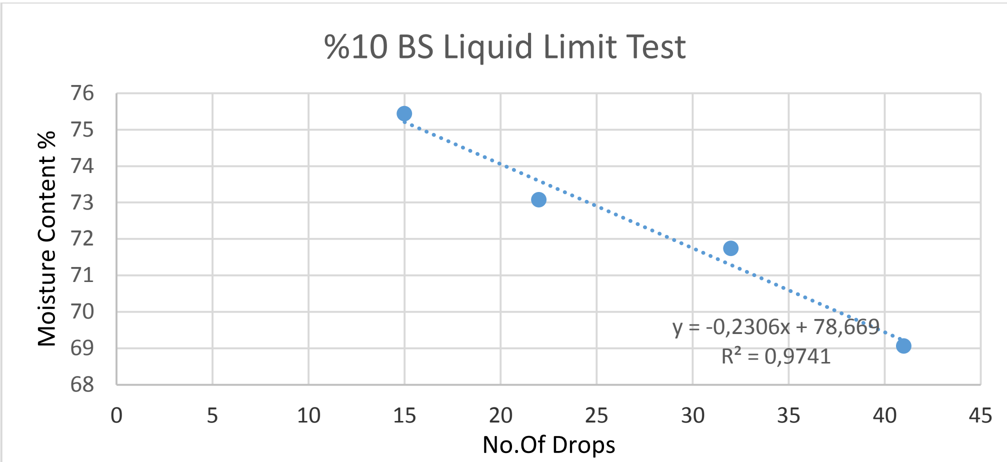

Figure D.1 (Continued)

Numune	%15 BS			24.01.2014	
	LL	LL	LL	LL	PL	PL
No.Of Drops	41	32	22	15	0	0
Mass of Container + wet soil	42.6	42.6	38.8	51.8	28.12	34.25
Mass of Container + dry soil	35.33	35.25	31.04	40.35	26.48	32.1
Mass of Container	25.1	25.1	20.6	25.4	21.8	26
Mass of Moisture	7.27	7.35	7.76	11.45	1.64	2.15
Mass of Dry Soil	10.23	10.15	10.44	14.95	4.68	6.1
Moisture Content	71.065	72.414	74.33	76.589	35.043	35.246
LL	74.12	y=-0.25651553571429x+83.61632982143				
PL	35.144				$R^2 = 0.9734$	
PI	38.976					

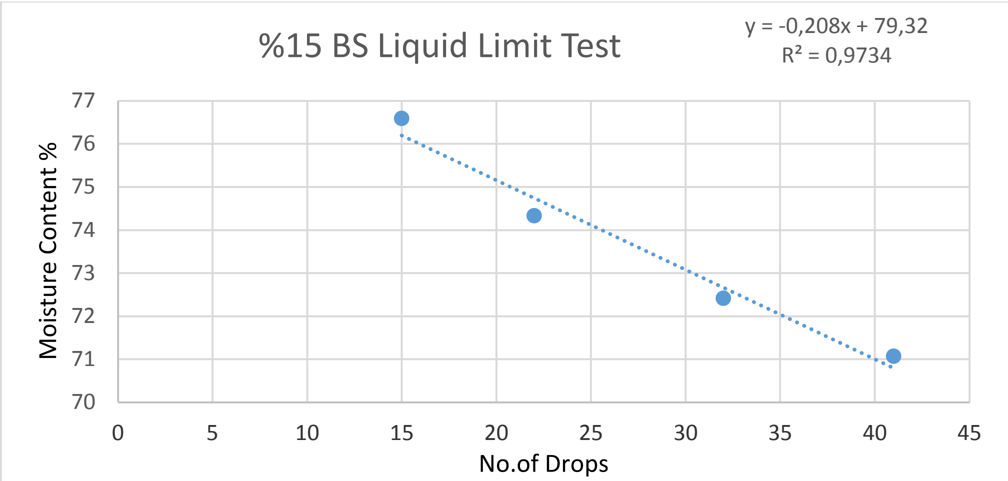

Figure D.1 (Continued)

Numune	BS				24.01.2014	
	LL	LL	LL	LL	PL	PL
No.Of Drops	31	28	23	19		
Mass of Container + wet soil	25.5	25.3	25	24	24.76	25.93
Mass of Container + dry soil	19.7	19.5	18.9	18.5	22.21	23.02
Mass of Container	14	14	13.3	13.6	14.10	14.00
Mass of Moisture	5.8	5.8	6.1	5.5	2.55	2.91
Mass of Dry Soil	5.7	5.5	5.6	4.9	8.11	9.02
Moisture Content	101.75	105.45	108.93	112.24	31.44	32.26
LL	107.31	y=128.41-.844x			$R^2 = 0.9882$	
PL	31.852					
PI	75.458					

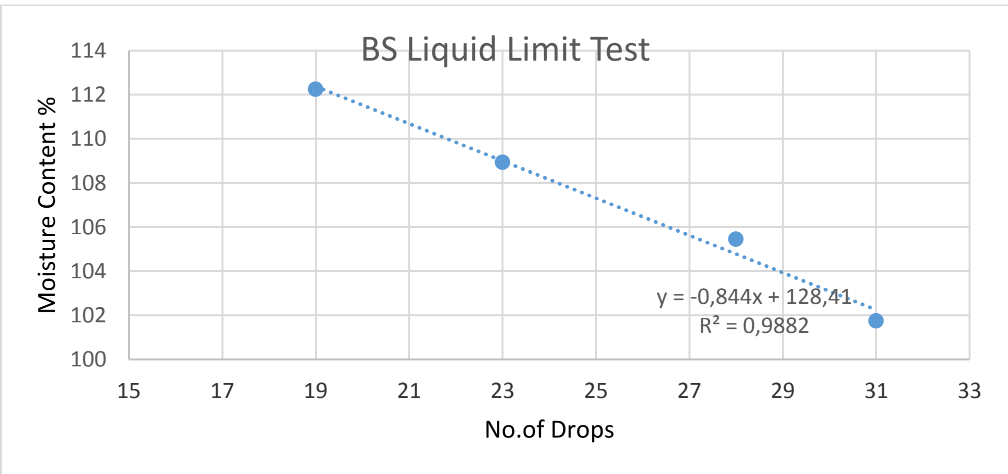

Figure D.1 (Continued)

APPENDIX E

PROCTOR DATA SHEETS

Middle East Technical University
Transport Laboratory
Standard Proctor Test Data Sheet

Sample No	SS		Tested by	Can CEYLAN	
Standard Method C	ASTM	D 698	Date	03.02.2014	
6 inch mold 56 blows				METU Transport Laboratory	
Volume of mould	2124	cm^3	Gs	2.718	g/cm^3

Test Number	1	2	3	4	5	6
Mass of mould+base+ specimen	8588.1	8719.1	8907.5	8985.7	8983.1	8923.6
Mass of mould+base	5106	5106	5106.6	5106	5105.7	5105.6
Mass of specimen	3482.1	3613.1	3800.9	3879.7	3877.4	3818
Bulk density	1.639	1.701	1.790	1.827	1.826	1.798
Moisture Content	209	0.229	0.248	0.260	0.281	0.308
Dry Density	1.356	1.384	1.434	1.449	1.425	1.375
Dry Density kN	13.298	13.576	14.058	14.213	13.976	13.481
Dry Density lb/ft3	84.652	86.426	89.492	90.477	88.971	85.819
MOISTURE CONTENT						
Container+Wet Sample	4741.3	4406.7	2993.71	5052.8	4662	4987.8
Container+Dry Sample	4143.2	3739	2560.5	4259.8	3819.5	4099.7
Mass of container	1281.5	820	816	1213.7	820.2	1212.6
Mass of moisture	598.1	667.7	433.21	793	842.5	888.1
Dry mass	2861.7	2919	1744.5	3046.1	2999.3	2887.1
Moisture content	0.209	0.229	0.248	0.260	0.281	0.308
AIR VOID CURVES						
100%	1.733	1.676	1.623	1.592	1.541	1.480
95%	1.647	1.592	1.542	1.512	1.464	1.406
90%	1.560	1.508	1.460	1.433	1.387	1.332

Max.Dry Dens. **1.45** **O.M.C.** **26.00%**

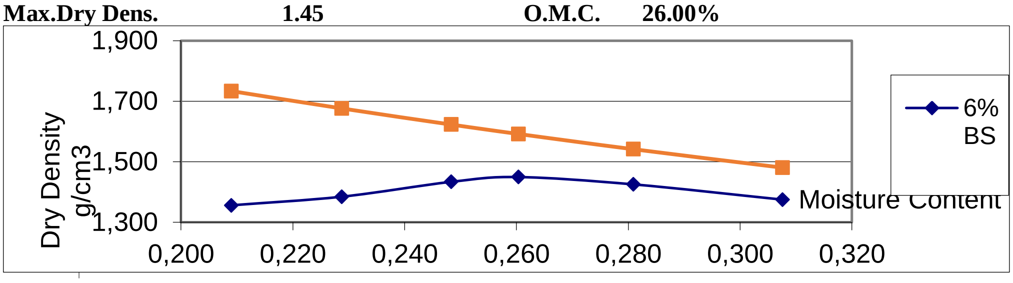

Figure E.1 Standard Proctor Test Data Sheets

Middle East Technical University
Transport Laboratory
Standard Proctor Test Data Sheet

Sample No	% 3 BS Standard Method C		Tested by	Can CEYLAN		
Method			Date	05.02.2014		
ASTM D 698			Location	METU Transport Lab.		
6 inch mold 56 blows			Device	Yüksel Makina		
Volume of mould	2124	cm^3	Gs	2.712	g/cm^3	
Test Number	1	2	3	4	5	6
Mass of mould+base+ specimen	8691.5	8703.4	8812.8	8996.4	9025.3	6109.1
Mass of mould+base	5152.2	5067.5	5068.9	5068.9	5153.1	2270.5
Mass of specimen	3539.3	3635.9	3743.9	3927.5	3872.2	3838.6
Bulk density	1.666	1.712	1.763	1.849	1.823	1.807
Moisture Content	0.242	0.253	0.270	0.293	0.323	0.347
Dry Density	1.341	1.366	1.388	1.430	1.378	1.341
Dry Density kN	13.155	13.393	13.614	14.028	13.515	13.155
Dry Density lb/ft3	83.742	85.258	86.667	89.301	86.034	83.745
MOISTURE CONTENT						
Container+Wet Sample	4035.1	4748.2	4894.7	4971.6	5039.6	4349.6
Container+Dry Sample	3380	4060.6	4131.8	4140.3	4138.5	3444.7
Mass of container	675.5	1347.5	1302.9	1299.8	1347.5	838.6
Mass of moisture	655.1	687.6	762.9	831.3	901.1	904.9
Dry mass	2704.5	2713.1	2828.9	2840.5	2791	2606.1
Moisture content	0.242	0.253	0.270	0.293	0.323	0.347
AIR VOID CURVES						
100%	1.637	1.607	1.566	1.512	1.446	1.397
95%	1.555	1.527	1.488	1.436	1.374	1.327
90%	1.473	1.447	1.410	1.361	1.301	1.257

Max.Dry Dens. **1.430** **O.M.C.** **29.27%**

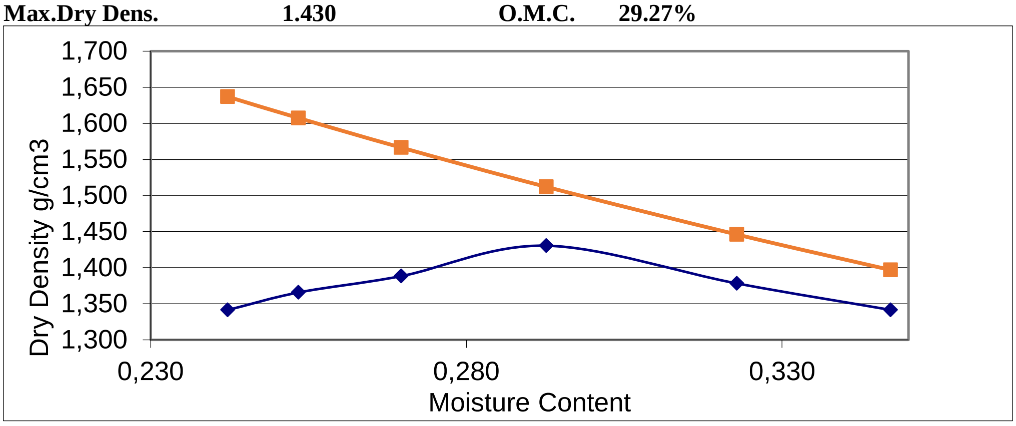

Figure E.1 (Continued)

Middle East Technical University
Transport Laboratory
Standard Proctor Test Data Sheet

Sample No	% 6 BS		Tested by	Can CEYLAN	
Method	Standard Method C		Date	07.02.2014	
ASTM D 698			Location	METU Transport Lab.	
6 inch mold 56 blows			Device	Yüksel Makina	
Volume of mould	2124	cm^3	Gs	2.706	g/cm^3

Test Number	1	2	3	4	5	6
Mass of mould+base+ specimen	5956.4	6089.9	6201	6168.8	6129.1	6062.6
Mass of mould+base	2271	2271	2271	2271	2271	2271
Mass of specimen	3685.4	3818.9	3930	3897.8	3858.1	3791.6
Bulk density	1.735	1.798	1.850	1.835	1.816	1.785
Moisture Content	0.285	0.301	0.310	0.325	0.334	0.362
Dry Density	1.350	1.382	1.412	1.385	1.362	1.311
Dry Density kN	13.240	13.557	13.847	13.579	13.354	12.855
Dry Density lb/ft3	84.287	86.304	88.149	86.445	85.012	81.832
MOISTURE CONTENT						
Container+Wet Sample	5048.4	5106.6	5068.8	5090.8	4598.3	5223
Container+Dry Sample	4198	4205.3	4186.8	4156.6	3657.2	4181.5
Mass of container	1215.5	1206.6	1345.2	1284.5	838.6	1303.1
Mass of moisture	850.4	901.3	882	934.2	941.1	1041.5
Dry mass	2982.5	2998.7	2841.6	2872.1	2818.6	2878.4
Moisture content	0.285	0.301	0.310	0.325	0.334	0.362
AIR VOID CURVES						
100%	1.527	1.492	1.471	1.439	1.422	1.367
95%	1.451	1.418	1.397	1.367	1.351	1.299
90%	1.375	1.343	1.324	1.295	1.279	1.231

Max.Dry Dens. **1.412** **O.M.C.** **31.04%**

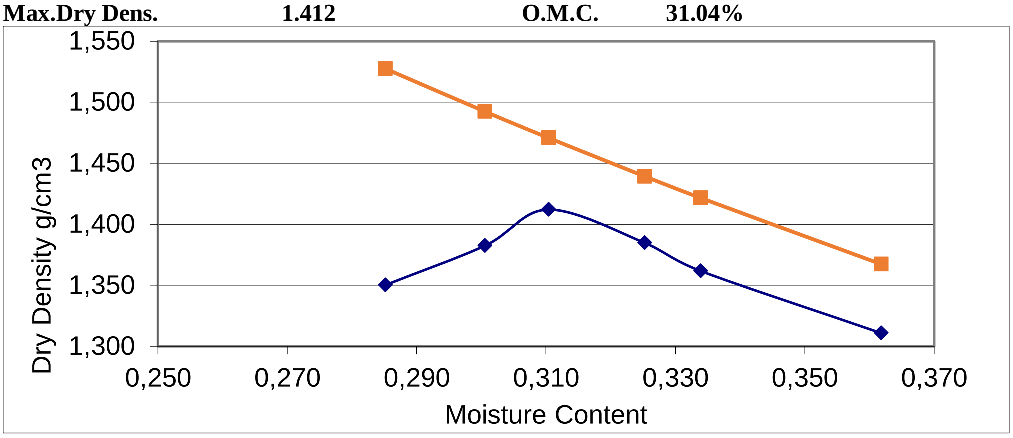

Figure E.1 (Continued)

Middle East Technical University
Transport Laboratory
Standard Proctor Test Data Sheet

Sample No	%10 BS		Tested by	Can CEYLAN	
Method	Standard Method C		Date	10.02.2014	
ASTM D 698			Location	METU Transport Lab.	
6 inch mold 56 blows			Device	Yüksel Makina	
Volume of mould	2124	cm^3	Gs	2.699	g/cm^3

Test Number	1	2	3	4	5	6
Mass of mould+base+ specimen	8708.7	8785.3	8888.6	9035.4	9002.1	8943.8
Mass of mould+base	5107	5105.2	5106.4	5106.9	5105.1	5105.3
Mass of specimen	3601.7	3680.1	3782.2	3928.5	3897	3838.5
Bulk density	1.696	1.733	1.781	1.850	1.835	1.807
Moisture Content	0.252	0.271	0.294	0.323	0.341	0.362
Dry Density	1.354	1.363	1.377	1.398	1.368	1.326
Dry Density kN	13.279	13.366	13.500	13.705	13.413	13.008
Dry Density lb/ft3	84.531	85.085	85.941	87.247	85.388	82.810
MOISTURE CONTENT						
Container+Wet Sample	4364.1	4561.3	5009.4	4553.4	4948.6	4469.9
Container+Dry Sample	3648.1	3763.1	4167.8	3640.1	4015.3	3457.4
Mass of container	810.5	820.4	1300.4	816.3	1281.5	663.5
Mass of moisture	716	798.2	841.6	913.3	933.3	1012.5
Dry mass	2837.6	2942.7	2867.4	2823.8	2733.8	2793.9
Moisture content	0.252	0.271	0.294	0.323	0.341	0.362
AIR VOID CURVES						
100%	1.606	1.558	1.506	1.441	1.405	1.364
95%	1.525	1.480	1.431	1.369	1.334	1.296
90%	1.445	1.402	1.355	1.297	1.264	1.228

Max.Dry Dens. **1.398** **O.M.C.** **32.34%**

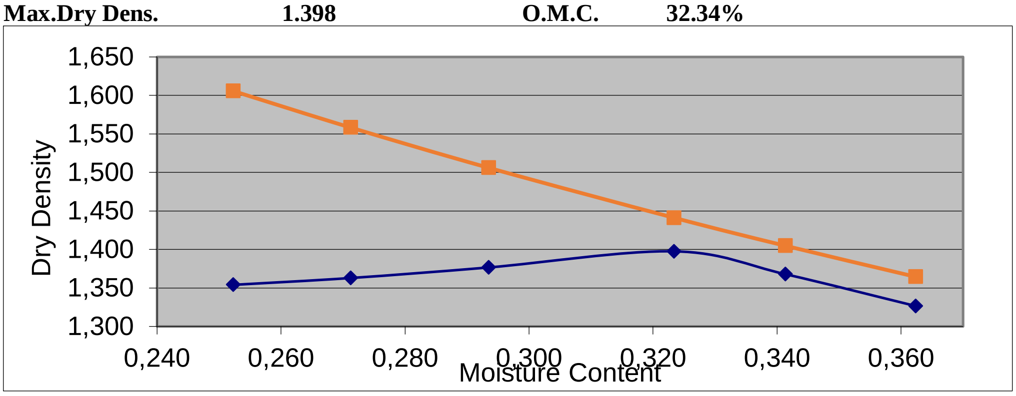

Figure D.1 (Continued)

Middle East Technical University
Transport Laboratory
Standard Proctor Test Data Sheet

Sample No	%15 BS		Tested by	Can CEYLAN	
Method	Standard Method C		Date	12.02.2014	
ASTM D 698			Location	METU Transport Lab.	
6 inch mold 56 blows			Device	Yüksel Makina	
Volume of mould	2124	cm^3	Gs	2.689	g/cm^3

Test Number	1	2	3	4	5	6
Mass of mould+base + specimen	8601.4	8837.5	8962.8	8679.1	9036.3	8989.6
Mass of mould+base	5067.5	5153.2	5153.2	4757.9	5152.8	5153.2
Mass of specimen	3533.9	3684.3	3809.6	3921.2	3883.5	3836.4
Bulk density	1.664	1.735	1.794	1.846	1.828	1.806
Moisture Content	0.274	0.298	0.318	0.331	0.344	0.359
Dry Density	1.306	1.336	1.361	1.387	1.360	1.329
Dry Density kN	12.806	13.105	13.342	13.601	13.340	13.032
Dry Density lb/ft3	81.520	83.425	84.937	86.584	84.920	82.963
MOISTURE CONTENT						
Container+WetSample	4758.3	5019.6	5051.9	5059.7	5030	4965.7
Container+DrySample	4011	4176.6	4140.7	4125.8	4076.8	3995.8
Mass of container	1285	1348	1277.8	1305.1	1306.8	1295.2
Mass of moisture	747.3	843	911.2	933.9	953.2	969.9
Dry mass	2726	2828.6	2862.9	2820.7	2770	2700.6
Moisture content	0.274	0.298	0.318	0.331	0.344	0.359
AIR VOID CURVES						
100%	1.548	1.493	1.449	1.423	1.397	1.368
95%	1.471	1.418	1.376	1.351	1.327	1.299
90%	1.393	1.343	1.304	1.280	1.257	1.231

Max.Dry Dens. **1.387** **O.M.C.** **33.11%**

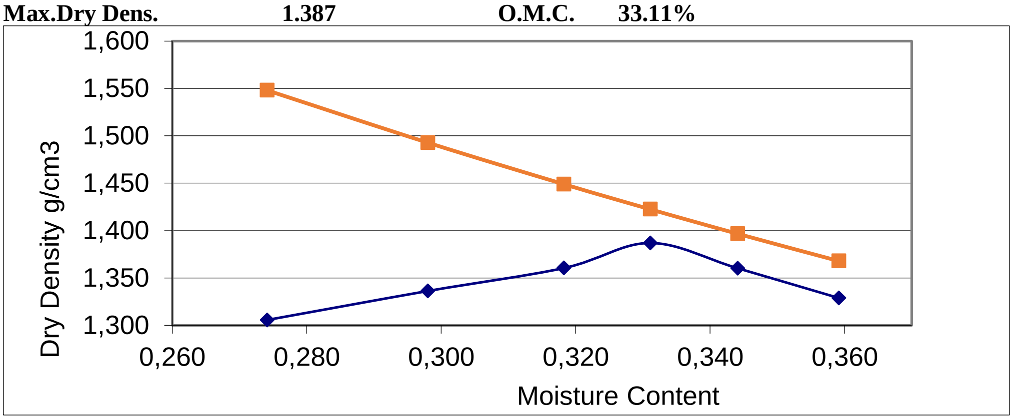

Figure E.1 (Continued)

APPENDIX F

TEST SAMPLE CALCULATIONS FOR UCS AND CBR TESTS

13 May 2014 Sal,17:52						
Time (sec.	Deformation (mm)	Load	Unit Load N/mm2	Stress psi	Def. (Inch)	Stress Psi
0	71.023	0	-0.020170023	-2.922516259	0	0
1	70.946	0.003	-0.018618483	-2.697707316	0.00083333	0.224808943
2	70.948	0.008	-0.016032583	-2.323025744	0.00166667	0.599490515
3	70.903	0.011	-0.014481042	-2.098216801	0.0025	0.824299458
4	70.909	0.012	-0.013963862	-2.023280487	0.00333333	0.899235772
5	70.911	0.013	-0.013446682	-1.948344173	0.00416667	0.974172086
6	70.88	0.018	-0.010860782	-1.573662601	0.005	1.348853658
7	70.911	0.02	-0.009826422	-1.423789972	0.00583333	1.498726287
8	70.819	0.022	-0.008792061	-1.273917344	0.00666667	1.648598915
9	70.768	0.021	-0.009309242	-1.348853658	0.0075	1.573662601
10	70.861	0.027	-0.006206161	-0.899235772	0.00833333	2.023280487
11	70.697	0.031	-0.004137441	-0.599490515	0.00916667	2.323025744
12	70.827	0.03	-0.004654621	-0.674426829	0.01	2.24808943
13	70.753	0.035	-0.00206872	-0.299745257	0.01083333	2.622771002
14	70.665	0.038	-0.00051718	-0.074936314	0.01166667	2.847579945
15	70.599	0.041	0.00103436	0.149872629	0.0125	3.072388888
16	70.729	0.044	0.0025859	0.374681572	0.01333333	3.297197831
17	70.649	0.044	0.0025859	0.374681572	0.01416667	3.297197831
18	70.617	0.05	0.005688981	0.824299458	0.015	3.746815717
19	70.52	0.05	0.005688981	0.824299458	0.01583333	3.746815717
20	70.602	0.052	0.006723341	0.974172086	0.01666667	3.896688345
21	70.53	0.05	0.005688981	0.824299458	0.0175	3.746815717
22	70.541	0.056	0.008792061	1.273917344	0.01833333	4.196433603
23	70.485	0.057	0.009309242	1.348853658	0.01916667	4.271369917
24	70.437	0.059	0.010343602	1.498726287	0.02	4.421242546
25	70.406	0.061	0.011377962	1.648598915	0.02083333	4.571115174
26	70.284	0.063	0.012412322	1.798471544	0.02166667	4.720987803
27	70.313	0.065	0.013446682	1.948344173	0.0225	4.870860432
28	69.775	0.065	0.013446682	1.948344173	0.02333333	4.870860432
29	69.73	0.068	0.014998222	2.173153116	0.02416667	5.095669375
30	69.667	0.072	0.017066943	2.472898373	0.025	5.395414632

Figure F.1 Sample of CBR Calculation Sheet

03 Eki 2014 Cum,17:54				
Time (sec.)	Deformation d = mm.	Load P=kN	Cor.Area (mm2) A^o=A*d/L	Stress (kPa) σ=P/ A^o
0	0	0	1963.5	0
1	0.020833333	0.001	1963.909148	0.509188524
2	0.041666667	0.002	1964.318466	1.018164842
3	0.0625	0.004	1964.727955	2.035905271
4	0.083333333	0.005	1965.137615	2.544351074
5	0.104166667	0.008	1965.547445	4.070112894
6	0.125	0.008	1965.957447	4.069264069
7	0.145833333	0.009	1966.367619	4.57696715
8	0.166666667	0.01	1966.777963	5.084458026
9	0.1875	0.011	1967.188478	5.591736695
10	0.208333333	0.013	1967.599165	6.607036754
11	0.229166667	0.014	1968.010023	7.113784908
12	0.25	0.017	1968.421053	8.636363636
13	0.270833333	0.02	1968.832254	10.15830575
14	0.291666667	0.022	1969.243627	11.17180205
15	0.3125	0.022	1969.655172	11.16946779
16	0.333333333	0.027	1970.06689	13.70511841
17	0.354166667	0.032	1970.478779	16.239708
18	0.375	0.035	1970.890841	17.75846702

Figure F.2 Sample UCS Calculation Sheet

APPENDIX G

CALIFORNIA BEARING RATIO TEST DATA SHEETS

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information					
Project Name		%0 BS	Start Date		04.05.2014
Curing Period		0 days	End Date		08.05.2014
Sample Number		1			
Standard		ASTM D 1883-07, D 698-12			
Method Of Compaction		Standard Effort, Method C			
Tested By		Can CEYLAN	Condition of Sample		Soaked
Soil Classification		CH	Surcharge		4.54 kg.
Maximum Dry Density g/cm3		1.45	SwellReading (mm.)		7.19
Optimum Moisture Content (%)		26	Swell Rate (%)		6.20
Area of Penetration (mm2)		1.935	Device		ELE Multip 50
Dry Density Determination			Before Soaking		After Soaking
Mass of Mould + Base + Soil (g)			11155.71		11417.1
Mass of Mould + Base (g)			7293.5		7293.5
Mass of Compacted Specimen			3862.21		4123.6
Bulk Density (g/cm3)			1.818		1.941
Dry Density (g/cm3)			1.440		1.396
Moisture Content Determination			Before Soaking		After Soaking
Mass of Container + Wet Soil			851.2		653.1
Mass of Container + Dry Soil			755.9		505.7
Mass of Container			393.2		128.3
Mass of Moisture			95.3		147.4
Moisture Content			26.275		39.057
California Bearing Ratio Determination					
Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	125.547	18.209	19.384	1.821	**1.918**
0.2 Inch	168.391	24.423	24.729	1.628	

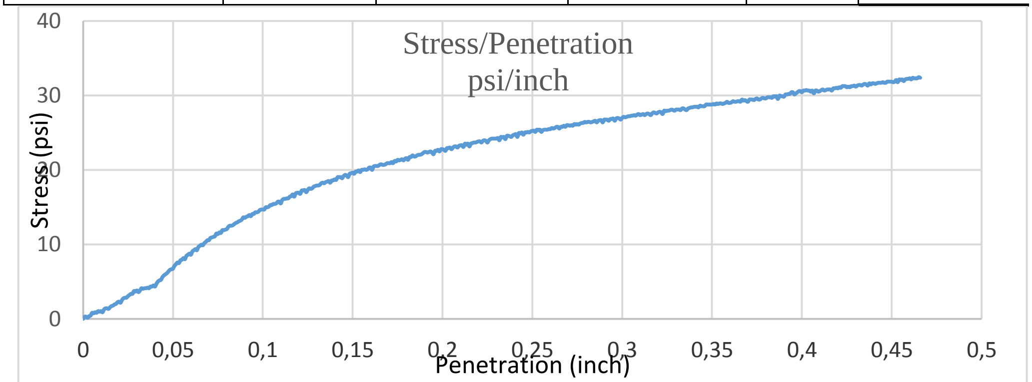

Figure G.1 California Bearing Ratio Test Data Sheets

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%0 BS	Start Date	04.05.2014
Curing Period	0 days	End Date	08.05.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.45	Swell Dial Reading (mm.)	7.14
Optimum Moisture Content (%)	26	Swell Rate (%)	6.155
Area of Penetration (mm2)	1.935	Device	ELE Multip 50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8233.9	8446
Mass of Mould + Base	(g)	4362.2	4362.2
Mass of Compacted Specimen	(g)	3871.7	4083.8
Bulk Density	(g/cm3)	1.823	1.923
Dry Density	(g/cm3)	1.445	1.370
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	488.1	538.4
Mass of Container + Dry Soil	(g)	414.4	421.8
Massof Container	(g)	132.9	132.9
Mass of Moisture	(g)	73.7	116.6
Moisture Content	%	26.181	40.35998615

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	143.632	20.832	20.832	2.083	**2.083**
0.2 Inch	159.650	23.155	31.248	2.083	

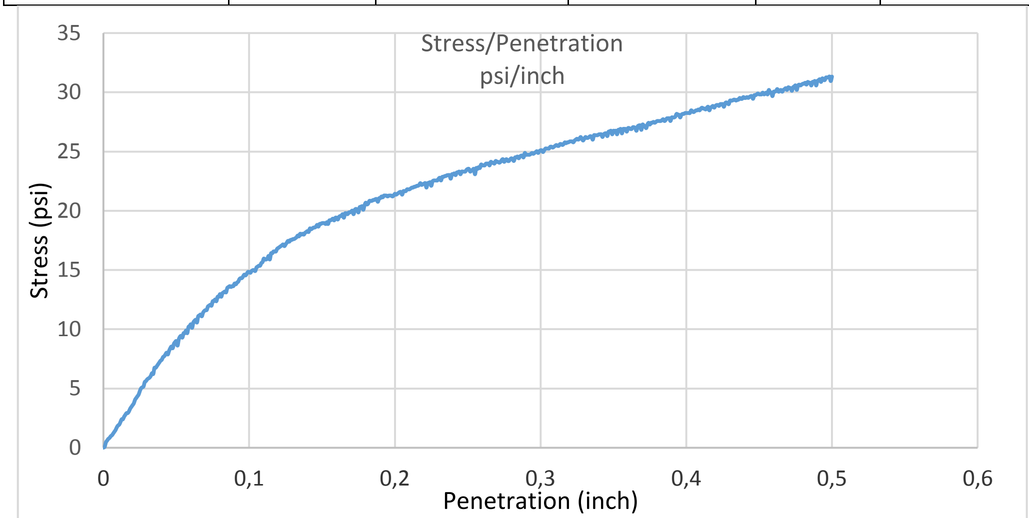

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%0 BS	Start Date	04.05.2014
Curing Period	0 days	End Date	08.05.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.45	Swell Dial Reading (mm.)	7.43
Optimum Moisture Content (%)	26	Swell Rate (%)	6.405
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8508.5	8835
Mass of Mould + Base	(g)	4662.8	4662.8
Mass of Compacted Specimen	(g)	3845.7	4172.2
Bulk Density	(g/cm3)	1.811	1.964
Dry Density	(g/cm3)	1.441	1.385
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	432.1	535.1
Mass of Container + Dry Soil	(g)	370	401.7
Mass of Container	(g)	128.2	70.5
Mass of Moisture	(g)	62.1	133.4
Moisture Content	%	25.682	40.278

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	138.467	20.083	20.083	2.008	**2.008**
0.2 Inch	187.034	27.127	27.127	1.808	

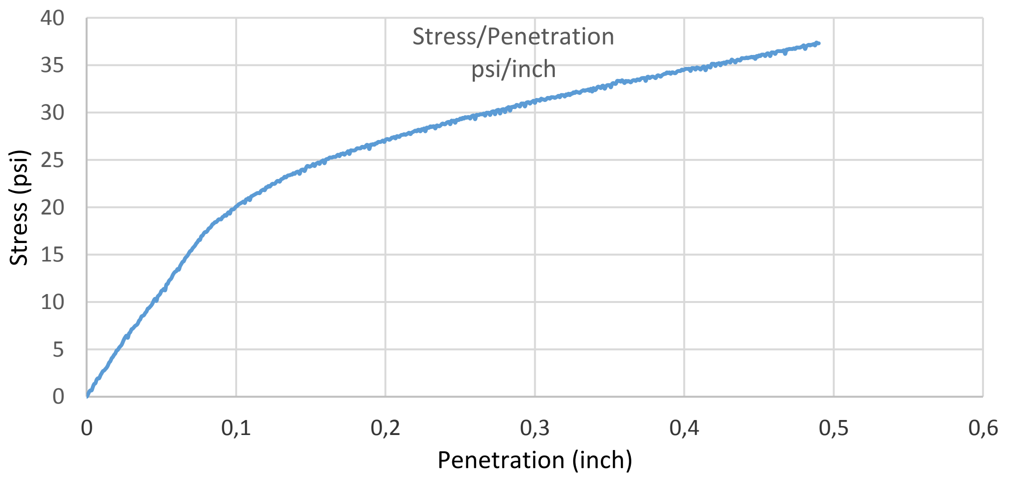

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 BS	Start Date	10.05.2014
Curing Period	0 days	End Date	14.05.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	7.19
Optimum Moisture Content (%)	29.3	Swell Rate (%)	6.198
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8074.9	8268.8
Mass of Mould + Base	(g)	4166.6	4166.6
Mass of Compacted Specimen	(g)	3908.3	4102.2
Bulk Density	(g/cm3)	1.840	1.931
Dry Density	(g/cm3)	1.426	1.377
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	549.2	538.4
Mass of Container + Dry Soil	(g)	454.4	421.8
Massof Container	(g)	128.2	132.9
Mass of Moisture	(g)	94.8	116.6
Moisture Content	%	29.062	41.360

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	177.217	25.703	25.703	2.570	**2.570**
0.2 Inch	257.817	37.393	37.393	2.493	

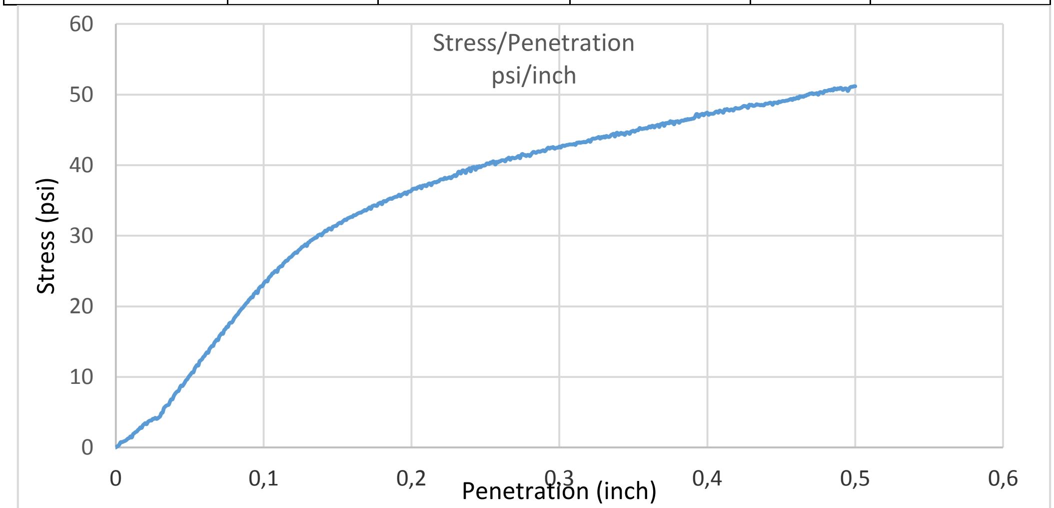

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 BS	Start Date	10.05.2014
Curing Period	0 days	End Date	14.05.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	7.13
Optimum Moisture Content (%)	29.5	Swell Rate (%)	6.147
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8104.3	8288.5
Mass of Mould + Base	(g)	4166.6	4166.6
Mass of Compacted Specimen	(g)	3937.7	4121.9
Bulk Density	(g/cm3)	1.854	1.941
Dry Density	(g/cm3)	1.429	1.374

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	479.5	480.4
Mass of Container + Dry Soil	(g)	400.1	377.6
Mass of container	(g)	133	128.4
Mass of Moisture	(g)	79.4	102.8
Moisture Content	%	29.727	41.252

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	171.534	24.879	24.879	2.488	**2.508**
0.2 Inch	259.367	37.618	37.618	2.508	

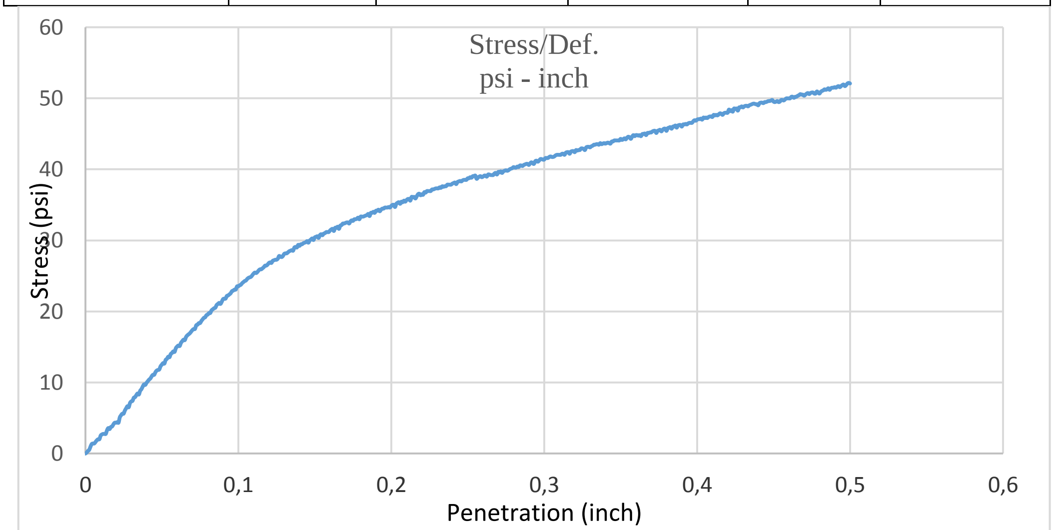

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 BS	Start Date	10.05.2014
Curing Period	0 days	End Date	14.05.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	7.43
Optimum Moisture Content (%)	29.5	Swell Rate (%)	*
Area of Penetration (mm2)	1.935	Device	ELE Multip 50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8103.5	8254.5
Mass of Mould + Base	(g)	4166.7	4166.7
Mass of Compacted Specimen	(g)	3936.8	4087.8
Bulk Density	(g/cm3)	1.853	1.925
Dry Density	(g/cm3)	1.433	1.372

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	457.4	480.8
Mass of Container + Dry Soil	(g)	382.8	377.3
Mass of Container	(g)	128.4	128.6
Mass of Moisture	(g)	74.6	103.5
Moisture Content	%	29.324	41.616

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	187.034	27.127	27.127	2.713	**2.713**
0.2 Inch	266.084	38.592	38.592	2.573	

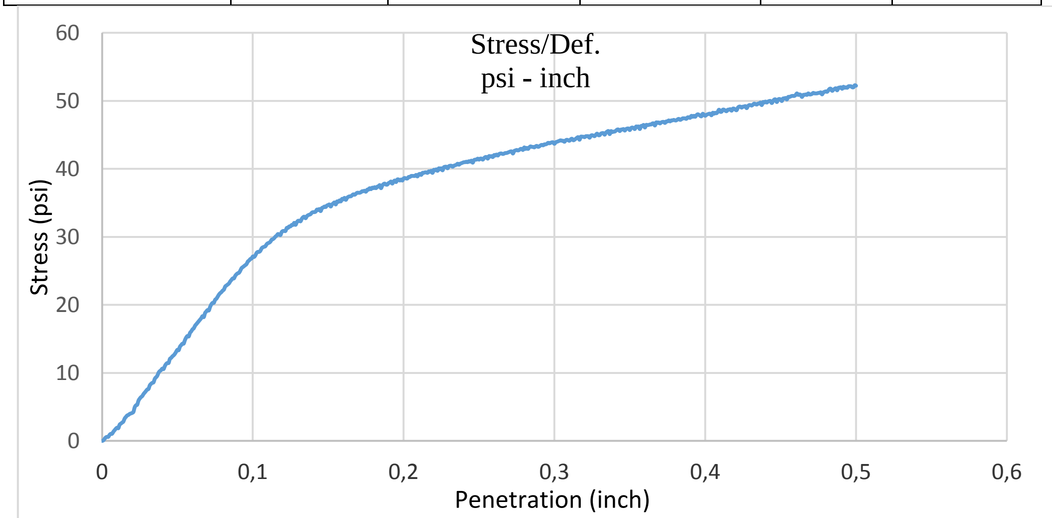

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 BS	Start Date	16.05.2014
Curing Period	0 days	End Date	20.05.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	5.53
Optimum Moisture Content (%)	31.1	Swell Rate (%)	4.767
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8096.3	8190.7
Mass of Mould + Base	(g)	4144.3	4144.3
Mass of Compacted Specimen	(g)	3952	4046.4
Bulk Density	(g/cm3)	1.861	1.905
Dry Density	(g/cm3)	1.419	1.367
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	462.6	482.5
Mass of Container + Dry Soil	(g)	389.5	375.9
Mass of container	(g)	154.4	128.4
Mass of Moisture	(g)	73.1	105.6
Moisture Content	%	31.093	43.071

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	183.417	26.602	31.698	3.170	**3.170**
0.2 Inch	259.367	37.618	44.437	2.962	

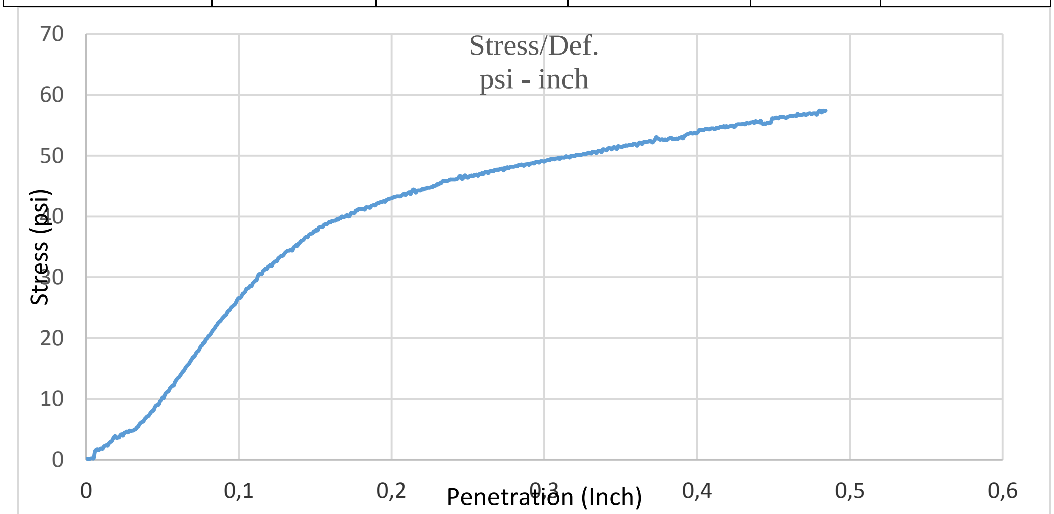

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 BS	Start Date	16.05.2014
Curing Period	0 days	End Date	20.05.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	5.19
Optimum Moisture Content (%)	31.1	Swell Rate (%)	4.474
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8100.7	8258.4
Mass of Mould + Base	(g)	4170.4	4170.4
Mass of Compacted Specimen	(g)	3930.3	4088
Bulk Density	(g/cm3)	1.850	1.925
Dry Density	(g/cm3)	1.411	1.361
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	581.7	494.3
Mass of Container + Dry Soil	(g)	488.4	384.3
Mass of Container	(g)	188.8	128.6
Mass of Moisture	(g)	93.3	110
Moisture Content	%	31.142	43.019

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	212.867	30.874	30.874	3.087	**3.087**
0.2 Inch	301.734	43.763	43.763	2.918	

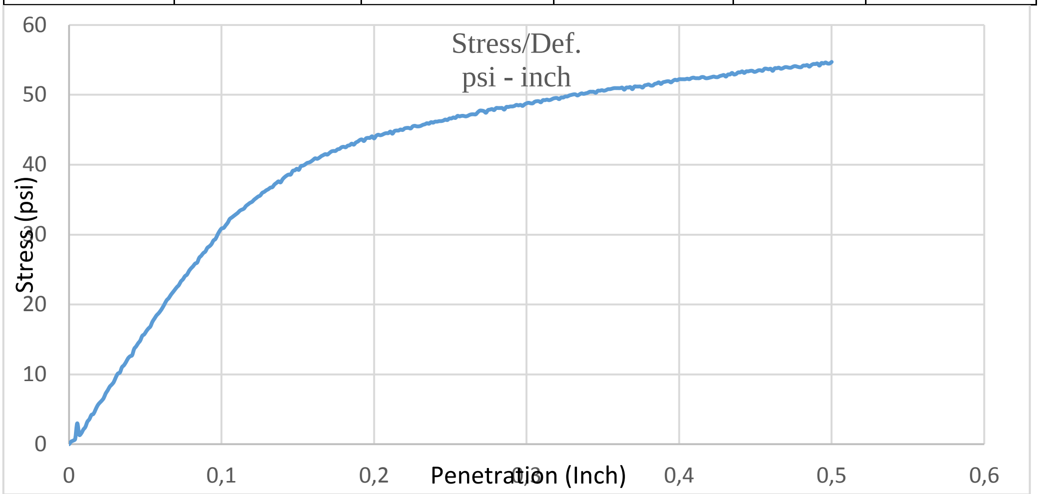

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 BS	Start Date	16.05.2014
Curing Period	0 days	End Date	20.05.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	5.37
Optimum Moisture Content (%)	31.1	Swell Rate (%)	4.629
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8072.3	8190.7
Mass of Mould + Base	(g)	4144.3	4144.3
Mass of Compacted Specimen	(g)	3928	4046.4
Bulk Density	(g/cm3)	1.849	1.905
Dry Density	(g/cm3)	1.413	1.370
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	591.3	566.3
Mass of Container + Dry Soil	(g)	483.6	432.3
Mass of Container	(g)	134.6	128.4
Mass of Moisture	(g)	107.7	134
Moisture Content	%	30.860	44.094

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	204.600	29.675	29.900	2.990	**2.990**
0.2 Inch	284.684	41.290	41.365	2.758	

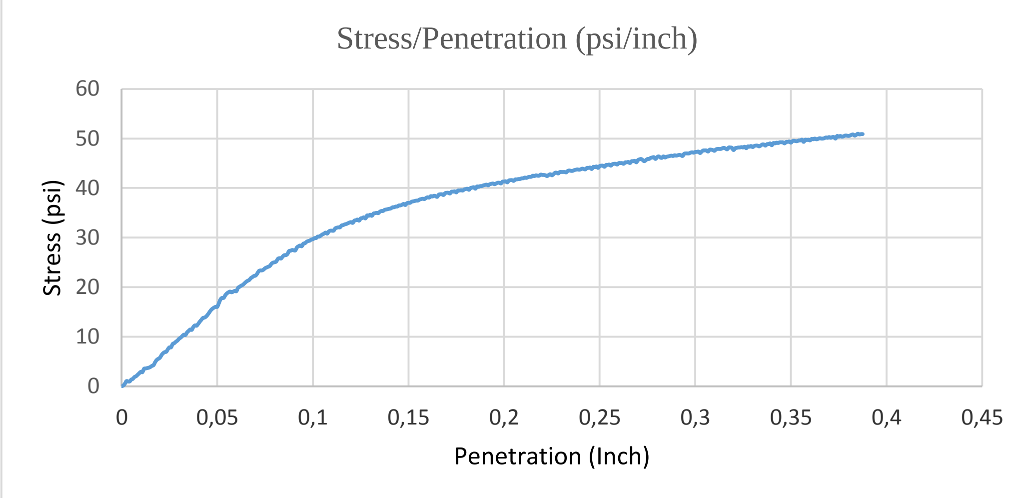

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 BS	Start Date	27.05.2014
Curing Period	0 days	End Date	31.05.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	4,8
Optimum Moisture Content (%)	32,4	Swell Rate (%)	4,138
Area of Penetration (mm2)	1,935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8235,4	8341,9
Mass of Mould + Base	(g)	4349,3	4349,3
Mass of Compacted Specimen	(g)	3886,1	3992,6
Bulk Density	(g/cm3)	1,830	1,880
Dry Density	(g/cm3)	1,377	1,344

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	477,8	652,6
Mass of Container + Dry Soil	(g)	391,4	489,3
Mass of Container	(g)	128,3	128,6
Mass of Moisture	(g)	86,4	163,3
Moisture Content	%	32,839	45,273

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	201,692	29,253	29,253	2,925	**2,925**
0.2 Inch	302,767	43,913	43,913	2,928	

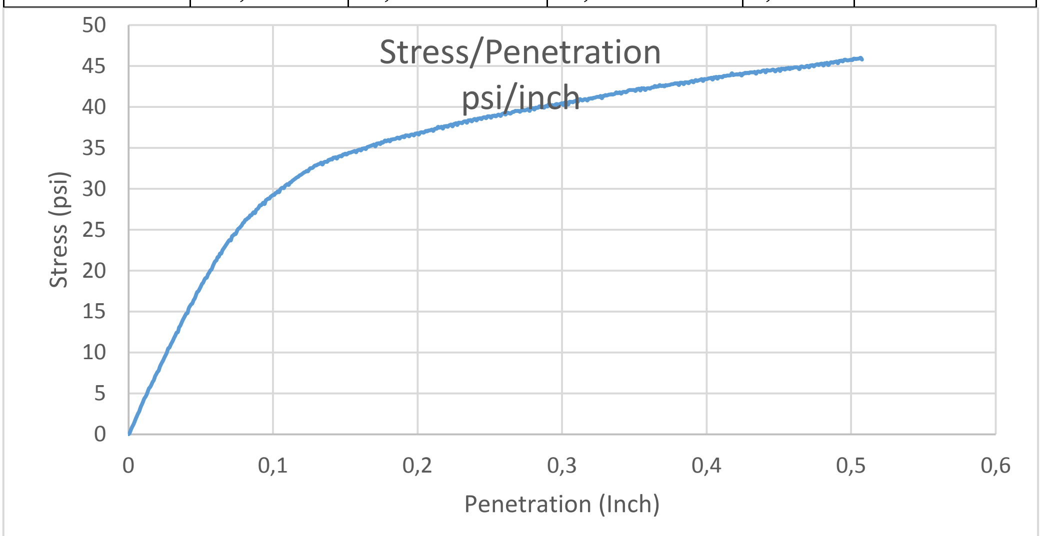

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 BS	Start Date	27.05.2014
Curing Period	0 days	End Date	31.05.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1,39	Swell Dial Reading (mm.)	4,6168
Optimum Moisture Content (%)	32,4	Swell Rate (%)	3,980
Area of Penetration (mm2)	1,935	Device	ELE Multip50

Dry Density Determination	Before Soaking	After Soaking
Mass of Mould + Base + Soil (g)	10932,6	11083,4
Mass of Mould + Base (g)	7026,9	7026,9
Mass of Compacted Specimen	3905,7	4056,5
Bulk Density (g/cm3)	1,839	1,910
Dry Density (g/cm3)	1,388	1,362
Moisture Content Determination	**Before Soaking**	**After Soaking**
Mass of Container + Wet Soil	344,1	545,7
Mass of Container + Dry Soil	277,7	400,3
Mass of Container	73,2	70,7
Mass of Moisture	66,4	145,4
Moisture Content	32,469	44,114

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	193,750	28,101	29,975	2,997	**3,077**
0.2 Inch	312,067	45,262	46,161	3,077	

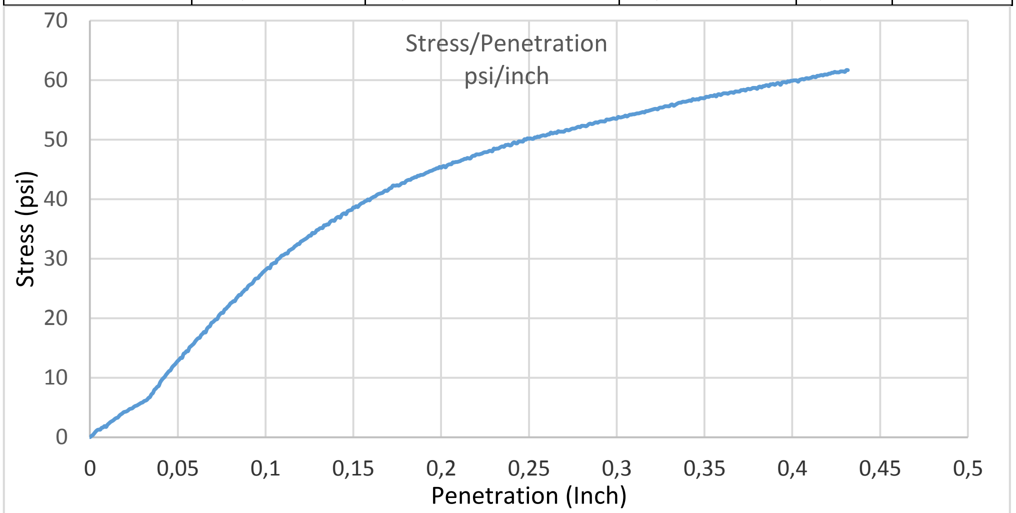

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 BS	Start Date	27.05.2014
Curing Period	0 days	End Date	31.05.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1,39	Swell Dial Reading (mm.)	4,66
Optimum Moisture Content (%)	32,4	Swell Rate (%)	4,017
Area of Penetration (mm2)	1,935	Device	ELE Multip50

Dry Density Determination	Before Soaking	Soaking
Mass of Mould + Base + Soil (g)	10838,7	10950,8
Mass of Mould + Base (g)	6978,1	6978,4
Mass of Compacted Specimen	3860,6	3972,4
Bulk Density (g/cm3)	1,818	1,870
Dry Density (g/cm3)	1,377	1,328
Moisture Content Determination	**Before Soaking**	**After Soaking**
Mass of Container + Wet Soil	421,4	425,5
Mass of Container + Dry Soil	350,4	317,9
Mass of Container	128,7	128
Mass of Moisture	71	107,6
Moisture Content	32,025	44,777

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	205,117	29,750	30,049	3,005	**3,005**
0.2 Inch	274,351	39,791	39,866	2,658	

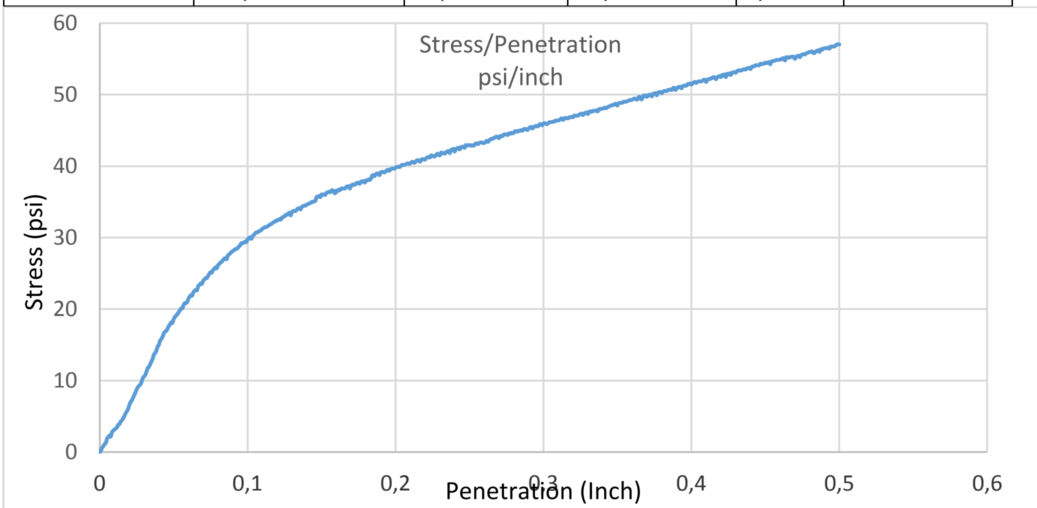

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 BS	Start Date	09.05.2014
Curing Period	0 days	End Date	13.05.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	4.63
Optimum Moisture Content (%)	33,1	Swell Rate (%)	3.991
Area of Penetration (mm2)	1,935	Device	ELE Multip50

Dry Density Determination	Before Soaking	After Soaking
Mass of Mould + Base + Soil (g)	7980.6	8192.2
Mass of Mould + Base (g)	4133.9	4133.9
Mass of Compacted Specimen	3846.7	4058.3
Bulk Density (g/cm3)	1.811	1.911
Dry Density (g/cm3)	1.364	1.348

Moisture Content Determination	Before Soaking	After Soaking
Mass of Container + Wet Soil	467.2	529.4
Mass of Container + Dry Soil	381	405.6
Mass of Container	118.2	128
Mass of Moisture	86.2	123.8
Moisture Content	32.801	44.597

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	166.884	24.204	25.179	2.518	**2.518**
0.2 Inch	245.934	35.670	36.419	2.428	

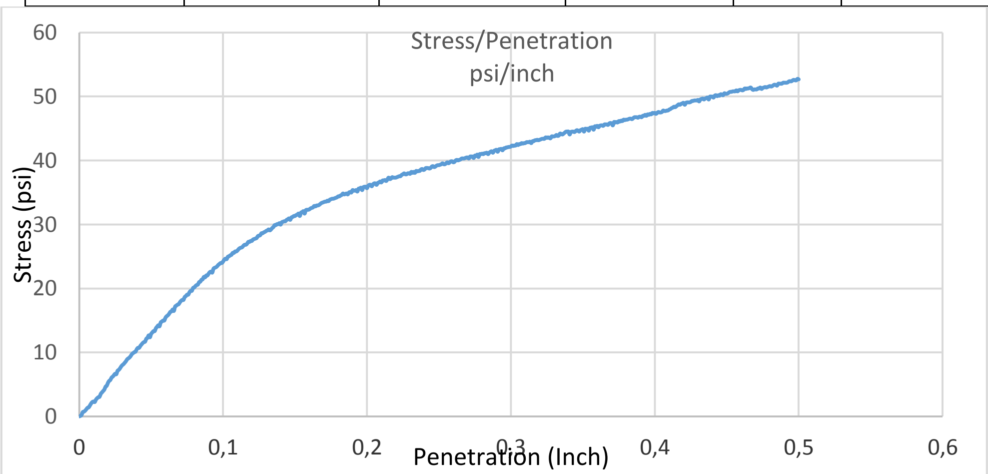

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	09.05.2014
Curing Period	0 days	End Date	13.05.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	4.53
Optimum Moisture Content (%)	33.1	Swell Rate (%)	3.905
Area of Penetration (mm2)	1.935	Device	ELE Multipl50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8035	8164.1
Mass of Mould + Base	(g)	4166.3	4166.3
Mass of Compacted Specimen	(g)	3868.7	3997.8
Bulk Density	(g/cm3)	1.821	1.882
Dry Density	(g/cm3)	1.369	1.325

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	794.9	571.9
Mass of Container + Dry Soil	(g)	644.4	437.6
Mass of Container	(g)	188.7	135.4
Mass of Moisture	(g)	150.5	134.3
Moisture Content	%	33.026	44.441

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	162.234	23.530	25.703	2.570	**2.570**
0.2 Inch	222.684	32.298	33.197	2.213	

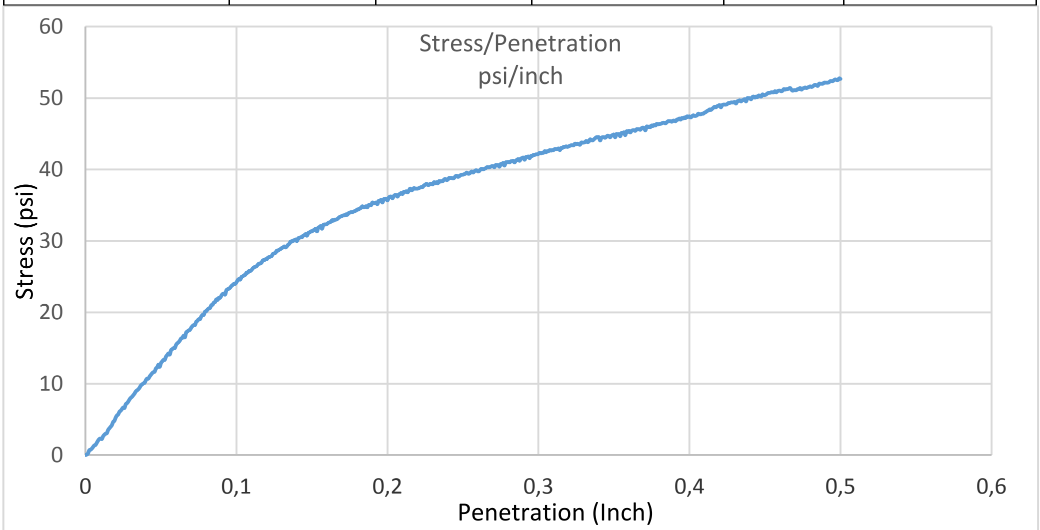

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	09.05.2014
Curing Period	0 days	End Date	13.05.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	4.7
Optimum Moisture Content (%)	33.1	Swell Rate (%)	4.052
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8011.2	8170
Mass of Mould + Base	(g)	4145.1	4145.1
Mass of Compacted Specimen	(g)	3866.1	4024.9
Bulk Density	(g/cm3)	1.820	1.895
Dry Density	(g/cm3)	1.367	1.337
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	571.6	526.7
Mass of Container + Dry Soil	(g)	446.8	407.5
Mass of Container	(g)	70.5	153.4
Mass of Moisture	(g)	124.8	119.2
Moisture Content	%	33.165	46.911

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	165.850	24.055	25.179	2.518	**2.563**
0.2 Inch	264.534	38.367	38.442	2.563	

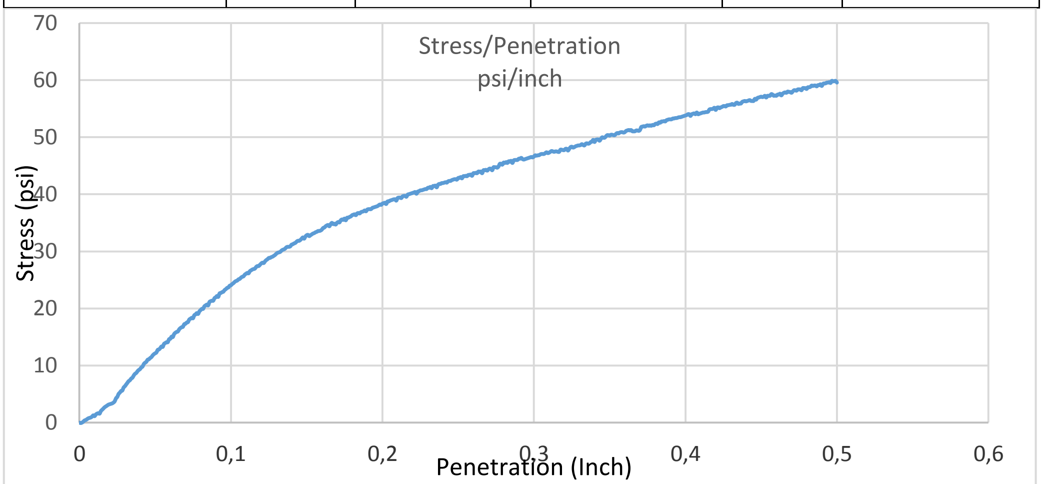

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	3.76
Optimum Moisture Content (%)	29.3	Swell Rate (%)	3.241
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8074.9	8268.8
Mass of Mould + Base	(g)	4166.6	4166.6
Mass of Compacted Specimen	(g)	3908.3	4102.2
Bulk Density	(g/cm3)	1.840	1.931
Dry Density	(g/cm3)	1.426	1.377
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	549.2	538.3
Mass of Container + Dry Soil	(g)	454.4	401.6
Mass of Container	(g)	128.2	70.5
Mass of Moisture	(g)	94.8	136.7
Moisture Content	%	29.062	41.287

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	199.373	28.917	28.917	2.892	**2.892**
0.2 Inch	246.785	35.793	35.793	2.386	

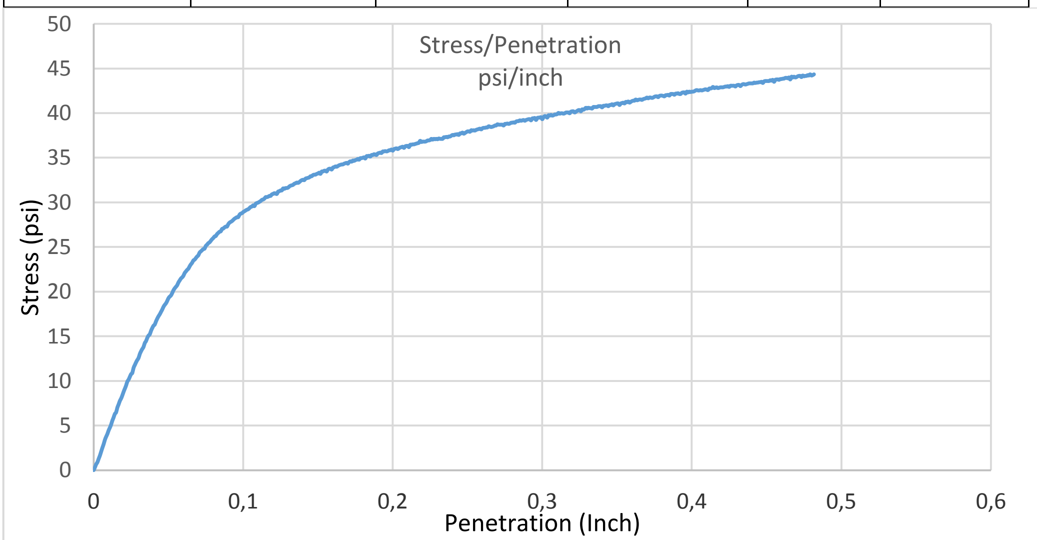

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	4.01
Optimum Moisture Content (%)	29.5	Swell Rate (%)	3.457
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8056.1	8288.5
Mass of Mould + Base	(g)	4165.7	4166.6
Mass of Compacted Specimen	(g)	3890.4	4121.9
Bulk Density	(g/cm3)	1.832	1.941
Dry Density	(g/cm3)	1.418	1.374
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	543.9	480.4
Mass of Container + Dry Soil	(g)	453.4	377.6
Mass of Container	(g)	143	128.4
Mass of Moisture	(g)	90.5	102.8
Moisture Content	%	29.156	41.252

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	206.667	29.975	29.975	2.997	**2.997**
0.2 Inch	266.084	38.592	38.592	2.573	

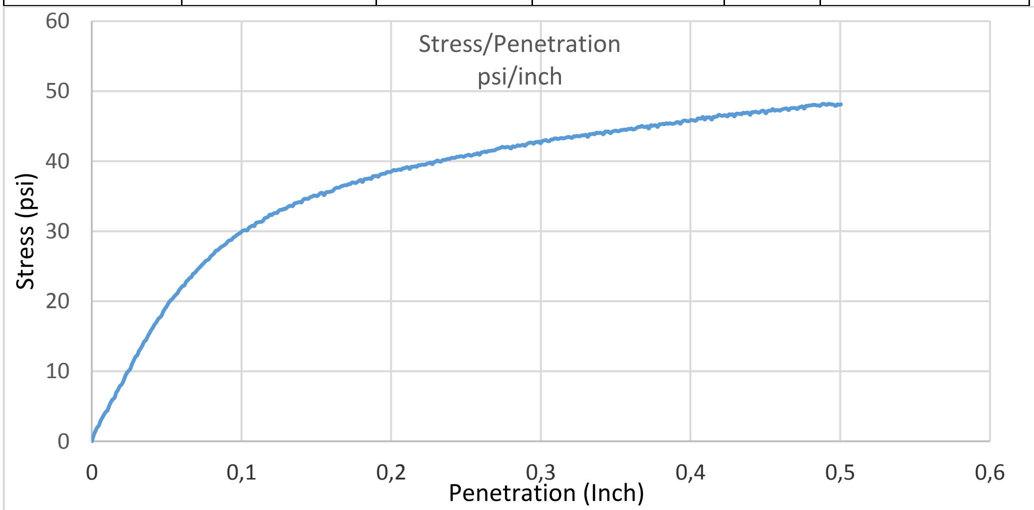

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	3.61
Optimum Moisture Content (%)	29.5	Swell Rate (%)	3.112
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8103.5	8254.5
Mass of Mould + Base	(g)	4166.7	4166.7
Mass of Compacted Specimen	(g)	3936.8	4087.8
Bulk Density	(g/cm3)	1.853	1.925
Dry Density	(g/cm3)	1.433	1.372
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	457.4	514.7
Mass of Container + Dry Soil	(g)	382.8	384.5
Mass of Container	(g)	128.4	70.5
Mass of Moisture	(g)	74.6	130.2
Moisture Content	%	29.324	41.465

California Bearing Ratio Determination					
Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	197.046	28.579	30.646	3.065	**3.065**
0.2 Inch	275.081	39.897	40.569	2.705	

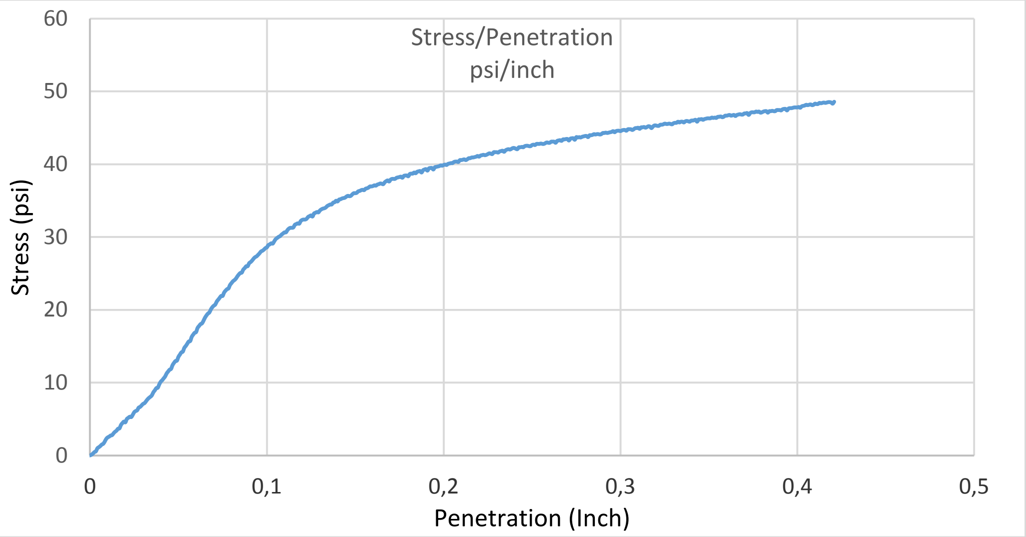

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.08.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	2.26
Optimum Moisture Content (%)	31.1	Swell Rate (%)	1.948
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8019.1	8190.7
Mass of Mould + Base	(g)	4133.5	4133.5
Mass of Compacted Specimen	(g)	3885.6	4057.2
Bulk Density	(g/cm3)	1.829	1.910
Dry Density	(g/cm3)	1.399	1.461
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	407.9	585.3
Mass of Container + Dry Soil	(g)	347.9	467.5
Mass of Container	(g)	153.1	188.5
Mass of Moisture	(g)	60	117.8
Moisture Content	%	30.801	42.222

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	245.934	35.670	37.468	3.747	**3.747**
0.2 Inch	328.601	47.659	47.959	3.197	

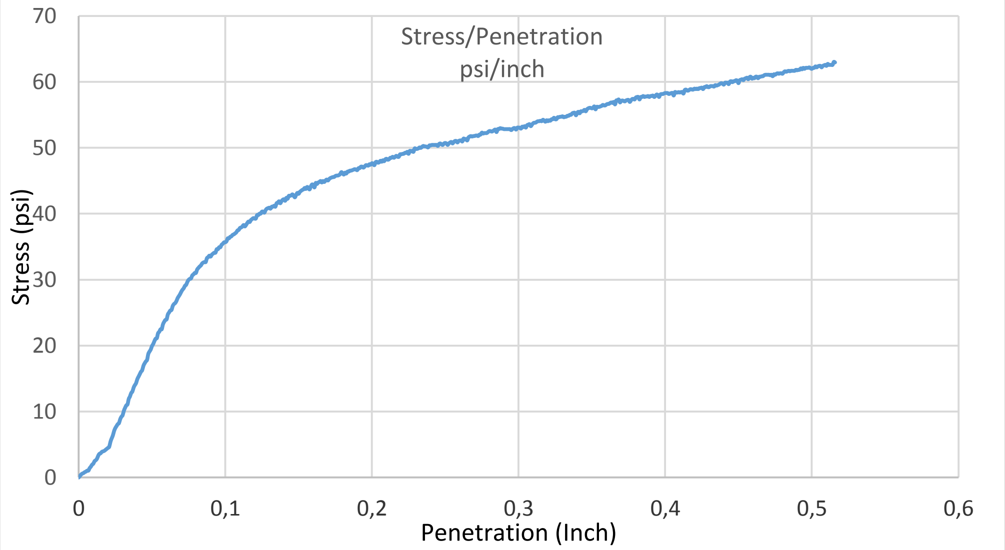

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.08.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	2.14
Optimum Moisture Content (%)	31.1	Swell Rate (%)	1.845
Area of Penetration (mm2)	1.935	Device	ELE Multip 50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8039.7	8258.4
Mass of Mould + Base	(g)	4159.5	4159.5
Mass of Compacted Specimen	(g)	3880.2	4098.9
Bulk Density	(g/cm3)	1.827	1.930
Dry Density	(g/cm3)	1.390	1.464

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	415.1	550.2
Mass of Container + Dry Soil	(g)	342	427.1
Mass of Container	(g)	109.3	135.2
Mass of Moisture	(g)	73.1	123.1
Moisture Content	%	31.414	42.172

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	241.801	35.070	36.344	3.634	**3.634**
0.2 Inch	323.434	46.910	48.334	3.222	

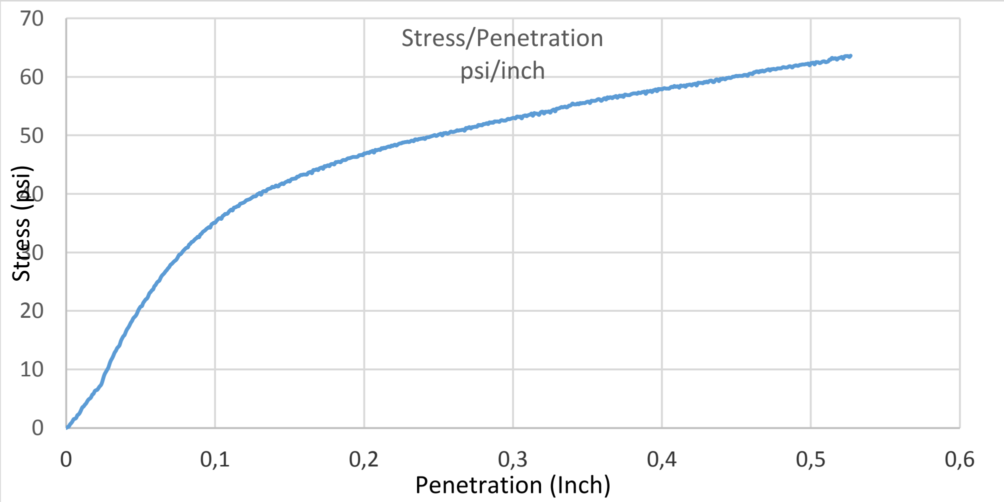

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.08.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	2.47
Optimum Moisture Content (%)	31.1	Swell Rate (%)	2.129
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8315.4	8190.7
Mass of Mould + Base	(g)	4332.5	4332.5
Mass of Compacted Specimen	(g)	3928	3858.2
Bulk Density	(g/cm3)	1.849	NA
Dry Density	(g/cm3)	1.413	NA
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	435.7	413.4
Mass of Container + Dry Soil	(g)	366.5	432.3
Mass of Container	(g)	142.8	142
Mass of Moisture	(g)	69.2	NA
Moisture Content	%	30.934	NA

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	251.617	36.494	38.517	3.852	**3.852**
0.2 Inch	371.484	53.879	54.554	3.637	

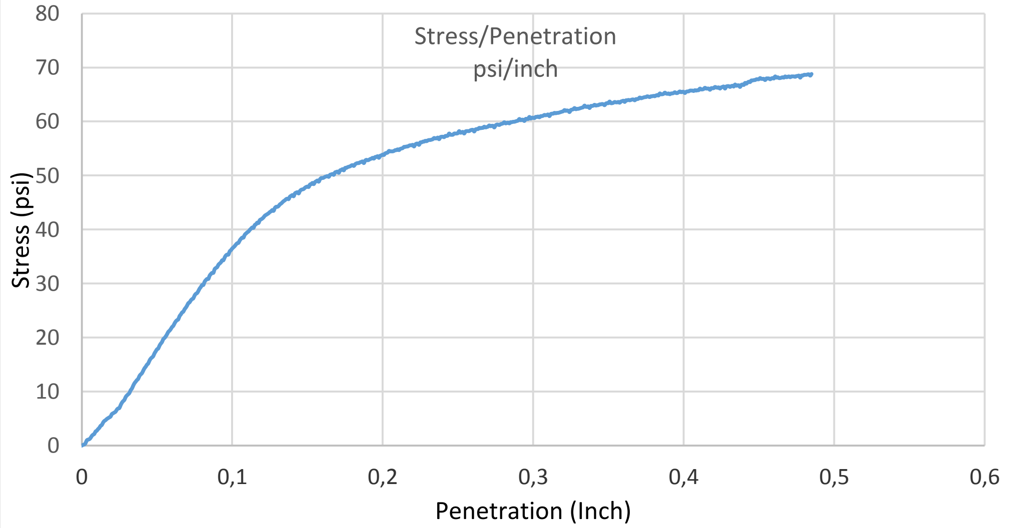

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	3.45
Optimum Moisture Content (%)	32.4	Swell Rate (%)	2.974
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8032.7	8341.9
Mass of Mould + Base	(g)	4155.2	4155.2
Mass of Compacted Specimen	(g)	3877.5	4186.7
Bulk Density	(g/cm3)	1.826	1.971
Dry Density	(g/cm3)	1.383	1.484
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	675.1	391.8
Mass of Container + Dry Soil	(g)	543.7	309.7
Mass of Container	(g)	132.8	119.7
Mass of Moisture	(g)	131.4	82.1
Moisture Content	%	31.979	43.211

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	251.617	36.494	36.494	3.649	**3.649**
0.2 Inch	334.801	48.559	48.559	3.237	

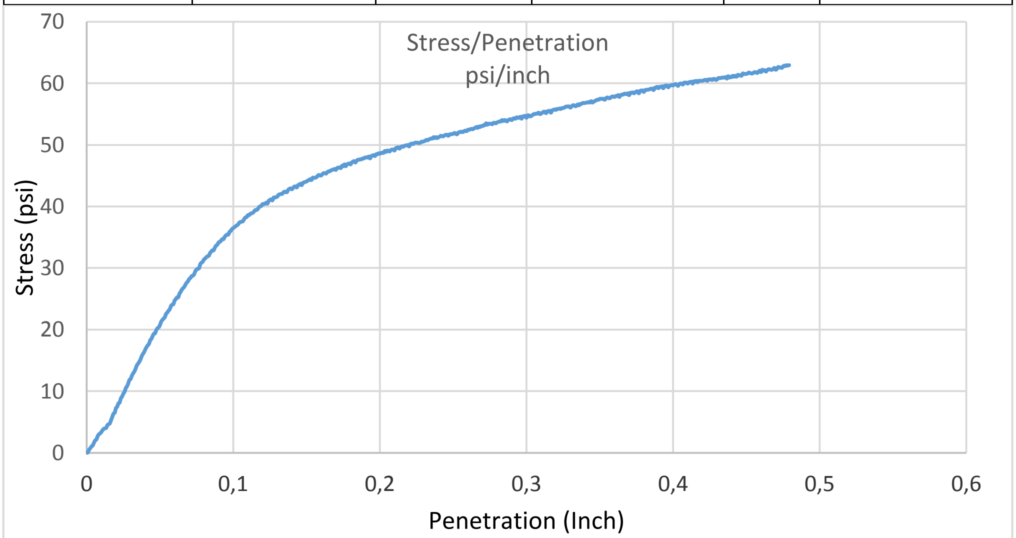

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.08.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	4.826
Optimum Moisture Content (%)	32.4	Swell Rate (%)	4.160
Area of Penetration (mm2)	1.935	Device	ELE Multip 50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8064.7	8283.1
Mass of Mould + Base	(g)	4154.2	4154.2
Mass of Compacted Specimen	(g)	3910.5	4128.9
Bulk Density	(g/cm3)	1.841	1.944
Dry Density	(g/cm3)	1.389	1.354
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	535.5	559.8
Mass of Container + Dry Soil	(g)	439.1	430.1
Mass of Container	(g)	142.8	132.7
Mass of Moisture	(g)	96.4	129.7
Moisture Content	%	32.535	43.611

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	259.367	37.618	37.618	3.762	**3.762**
0.2 Inch	382.334	55.453	55.453	3.697	

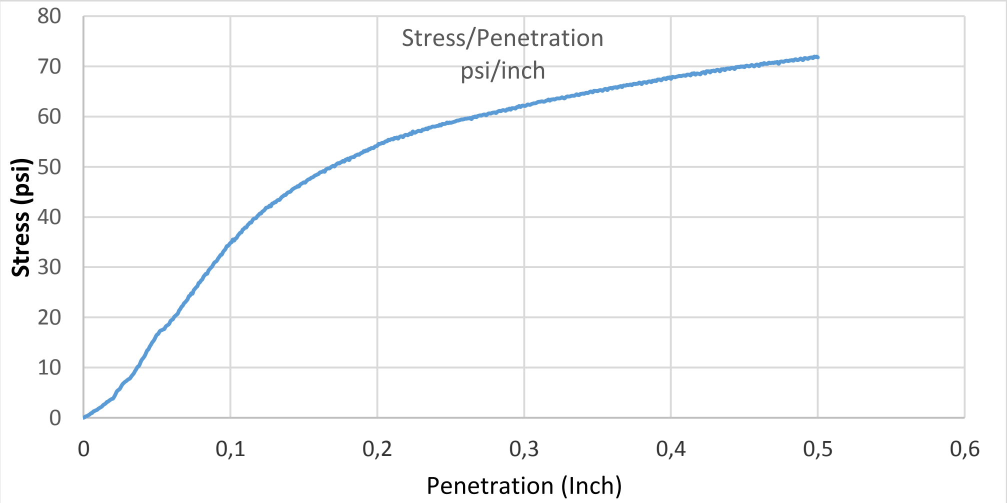

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.07.2014
Curing Period	7 days	End Date	10.08.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	2.51
Optimum Moisture Content (%)	32.4	Swell Rate (%)	2.164
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8197.5	8401.3
Mass of Mould + Base	(g)	4346.1	4346.1
Mass of Compacted Specimen	(g)	3851.4	4055.2
Bulk Density	(g/cm3)	1.813	1.909
Dry Density	(g/cm3)	1.365	1.327
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	506.9	469.5
Mass of Container + Dry Soil	(g)	418.4	374.7
Mass of Container	(g)	149.3	158.4
Mass of Moisture	(g)	88.5	94.8
Moisture Content	%	32.887	43.828

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	228.884	33.197	34.920	3.492	**3.492**
0.2 Inch	323.951	46.985	47.510	3.167	

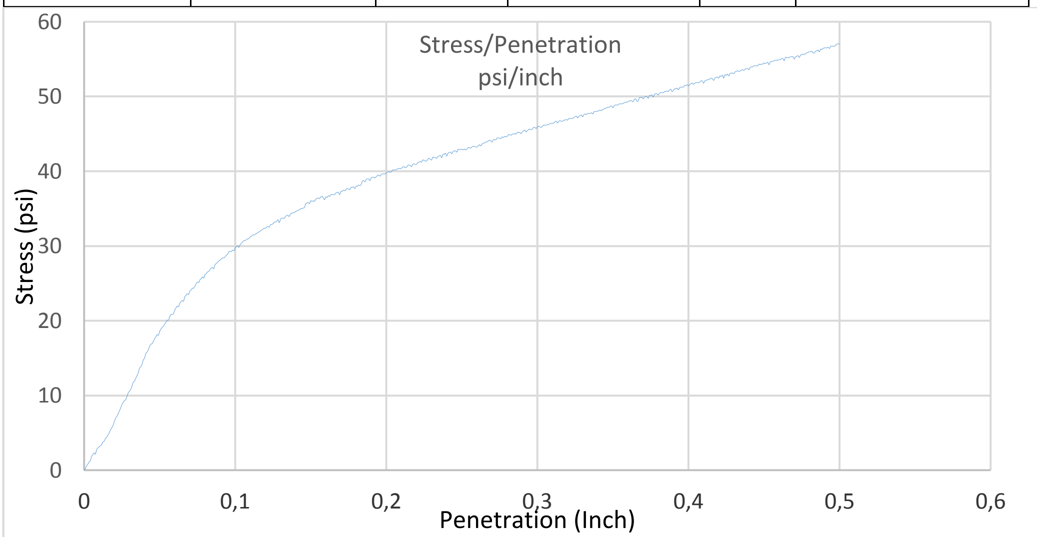

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	3.09
Optimum Moisture Content (%)	33.1	Swell Rate (%)	2.664
Area of Penetration (mm2)	1.935	Device	ELE Multip 50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8011.3	8192.2
Mass of Mould + Base	(g)	4135.1	4135.1
Mass of Compacted Specimen	(g)	3876.2	4057.1
Bulk Density	(g/cm3)	1.825	1.910
Dry Density	(g/cm3)	1.368	1.312
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	459.3	521.4
Mass of Container + Dry Soil	(g)	377.9	402.6
Mass of Container	(g)	134.3	142.1
Mass of Moisture	(g)	81.4	118.8
Moisture Content	%	33.415	45.605

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	191.684	27.801	28.476	2.848	**2.848**
0.2 Inch	275.901	40.016	40.391	2.693	

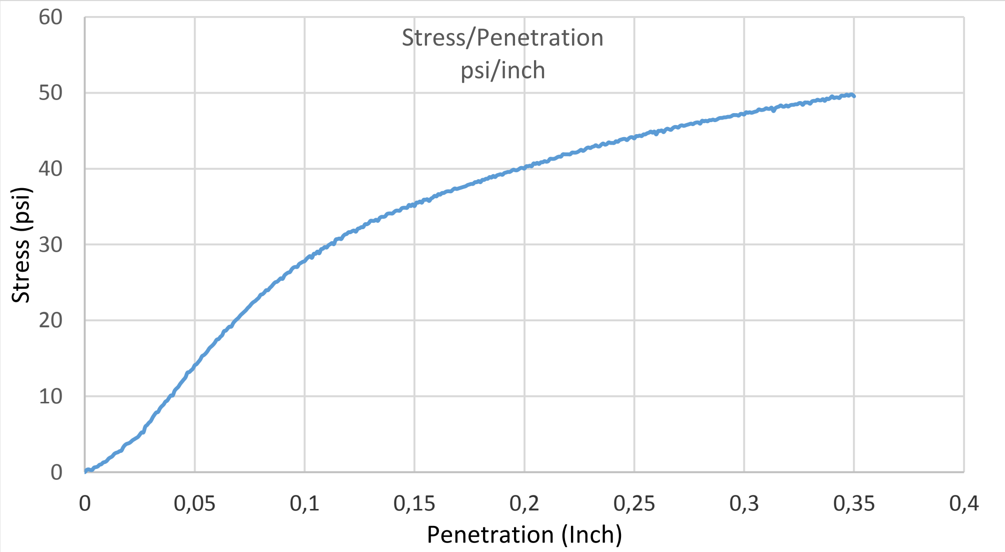

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	2.33
Optimum Moisture Content (%)	33.1	Swell Rate (%)	2.009
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8038.1	8164.1
Mass of Mould + Base	(g)	4154.3	4154.3
Mass of Compacted Specimen	(g)	3883.8	4009.8
Bulk Density	(g/cm3)	1.829	1.888
Dry Density	(g/cm3)	1.373	1.298
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	587.7	551.4
Mass of Container + Dry Soil	(g)	473.9	425.7
Mass of Container	(g)	130.8	149.2
Mass of Moisture	(g)	113.8	125.7
Moisture Content	%	33.168	45.461

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	201.970	29.293	29.293	2.929	**2.929**
0.2 Inch	255.281	37.025	37.025	2.468	

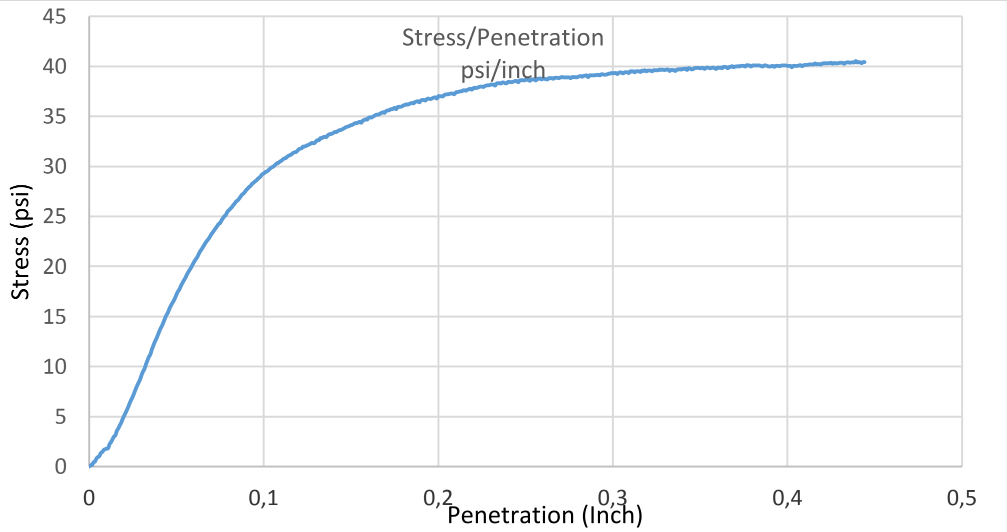

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	01.07.2014
Curing Period	7 days	End Date	12.07.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	2.9
Optimum Moisture Content (%)	33.1	Swell Rate (%)	2.500
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8207.7	8170
Mass of Mould + Base	(g)	4346.1	4346.1
Mass of Compacted Specimen	(g)	3861.6	3823.9
Bulk Density	(g/cm3)	1.818	1.800
Dry Density	(g/cm3)	1.368	1.222

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	455.2	553.5
Mass of Container + Dry Soil	(g)	376.1	418.9
Mass of Container	(g)	135.4	134.3
Mass of Moisture	(g)	79.1	134.6
Moisture Content	%	32.862	47.294

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	165.850	24.055	25.179	2.518	**2.563**
0.2 Inch	264.534	38.367	38.442	2.563	

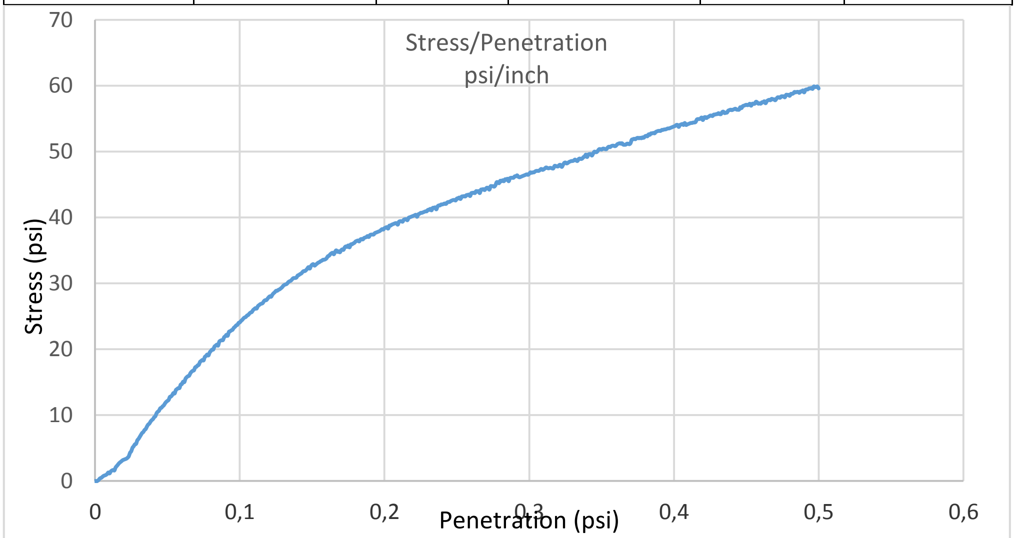

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	29.06.2014
Curing Period	28 days	End Date	31.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	NA
Optimum Moisture Content (%)	29.3	Swell Rate (%)	NA
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8100.5	8233.4
Mass of Mould + Base	(g)	4166.6	4166.6
Mass of Compacted Specimen	(g)	3933.9	4066.8
Bulk Density	(g/cm3)	1.852	1.915
Dry Density	(g/cm3)	1.429	1.357
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	442.6	512.8
Mass of Container + Dry Soil	(g)	370.8	400.3
Mass of Container	(g)	128.2	126.8
Mass of Moisture	(g)	71.8	112.5
Moisture Content	%	29.596	41.133

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	189.100	27.427	32.972	3.297	**3.297**
0.2 Inch	324.467	47.060	49.008	3.267	

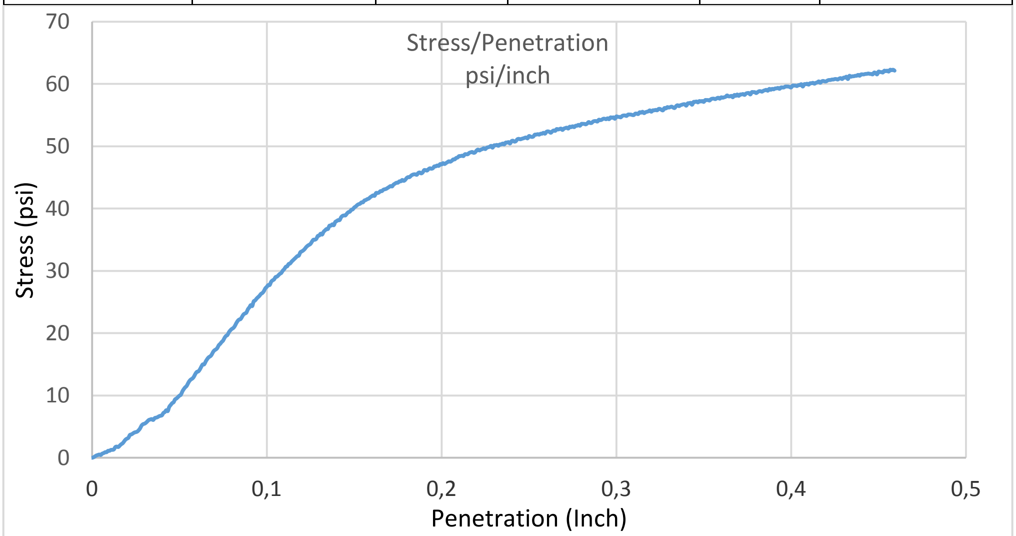

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	29.06.2014
Curing Period	28 days	End Date	31.07.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	2.84
Optimum Moisture Content (%)	29.5	Swell Rate (%)	2.448
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8062.9	8248.7
Mass of Mould + Base	(g)	4155.2	4155.2
Mass of Compacted Specimen	(g)	3907.7	4093.5
Bulk Density	(g/cm3)	1.840	1.927
Dry Density	(g/cm3)	1.423	1.363
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	405.7	564.7
Mass of Container + Dry Soil	(g)	348.8	439
Mass of Container	(g)	154.4	135.4
Mass of Moisture	(g)	56.9	125.7
Moisture Content	%	29.270	41.403

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	209.250	30.349	33.721	3.372	**3.372**
0.2 Inch	302.767	43.913	44.812	2.987	

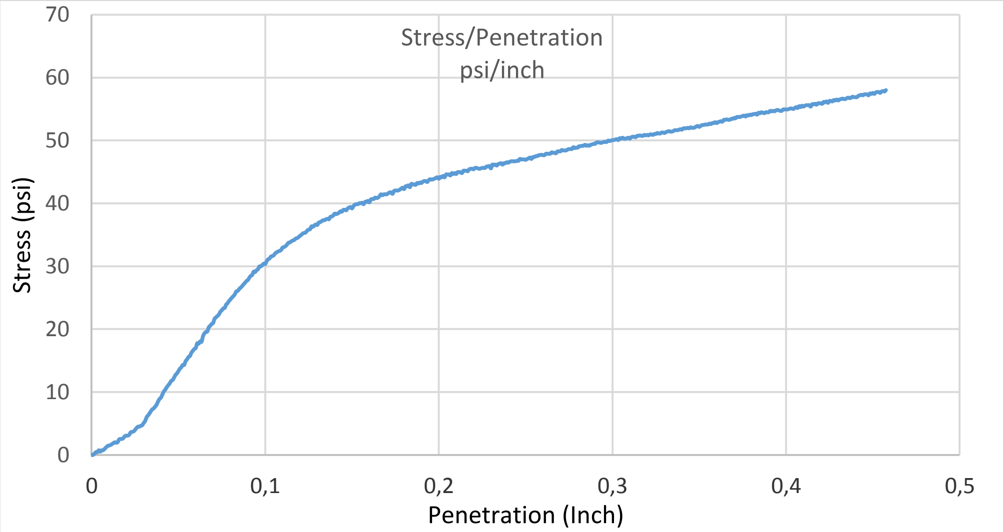

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%3 B	Start Date	29.06.2014
Curing Period	28 days	End Date	31.07.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.43	Swell Dial Reading (mm.)	2.56
Optimum Moisture Content (%)	29.5	Swell Rate (%)	2.207
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8701.4	8864.5
Mass of Mould + Base	(g)	4751	4751
Mass of Compacted Specimen	(g)	3950.4	4113.5
Bulk Density	(g/cm3)	1.860	1.937
Dry Density	(g/cm3)	1.431	1.366
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	539.5	544.4
Mass of Container + Dry Soil	(g)	446.2	423.2
Mass of Container	(g)	134.7	133
Mass of Moisture	(g)	93.3	121.2
Moisture Content	%	29.952	41.764

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	205.117	29.750	32.298	3.230	**3.230**
0.2 Inch	322.401	46.760	47.734	3.182	

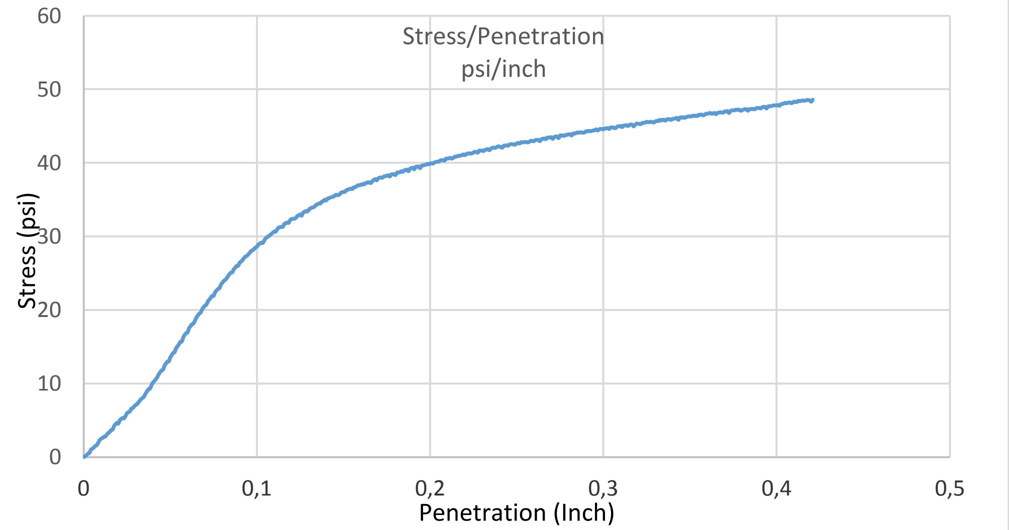

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	28.06.2014
Curing Period	28 days	End Date	30.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	1.48
Optimum Moisture Content (%)	31.1	Swell Rate (%)	1.276
Area of Penetration (mm2)	1.935	Device	ELE Multiplex 50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8095.4	8240.7
Mass of Mould + Base	(g)	4144.8	4133.5
Mass of Compacted Specimen	(g)	3950.6	4107.2
Bulk Density	(g/cm3)	1.860	1.934
Dry Density	(g/cm3)	1.418	1.358
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	542.8	524.9
Mass of Container + Dry Soil	(g)	445.8	409.1
Mass of Container	(g)	134.7	135.7
Mass of Moisture	(g)	97	115.8
Moisture Content	%	31.180	42.355

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	259.884	37.693	40.990	4.099	**4.099**
0.2 Inch	385.434	55.902	56.802	3.787	

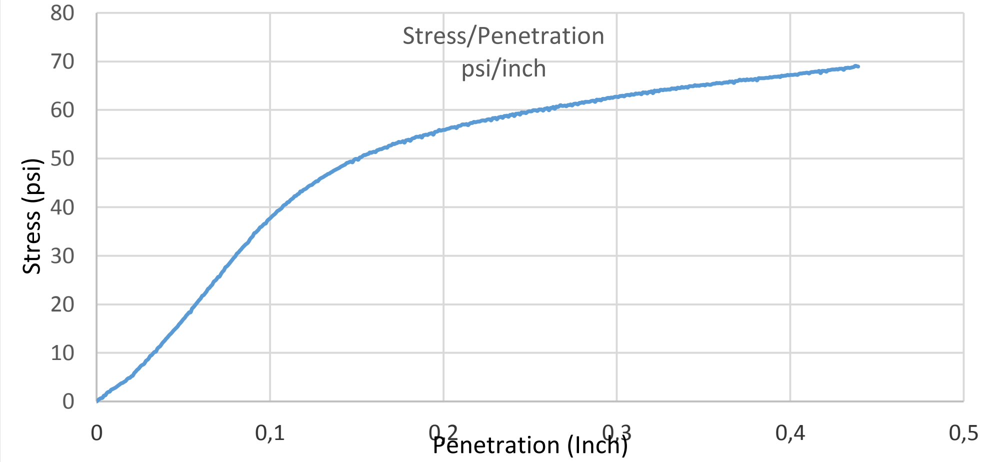

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	28.06.2014
Curing Period	28 days	End Date	30.07.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	1.6
Optimum Moisture Content (%)	31.1	Swell Rate (%)	1.379
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8102.9	8200.4
Mass of Mould + Base	(g)	4172	4159.5
Mass of Compacted Specimen	(g)	3930.9	4040.9
Bulk Density	(g/cm3)	1.851	1.902
Dry Density	(g/cm3)	1.407	1.355
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	447.2	598.9
Mass of Container + Dry Soil	(g)	368.7	476.4
Mass of Container	(g)	119.9	188.4
Mass of Moisture	(g)	78.5	122.5
Moisture Content	%	31.551	42.535

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	243.867	35.370	39.641	3.964	**3.964**
0.2 Inch	365.284	52.980	54.029	3.602	

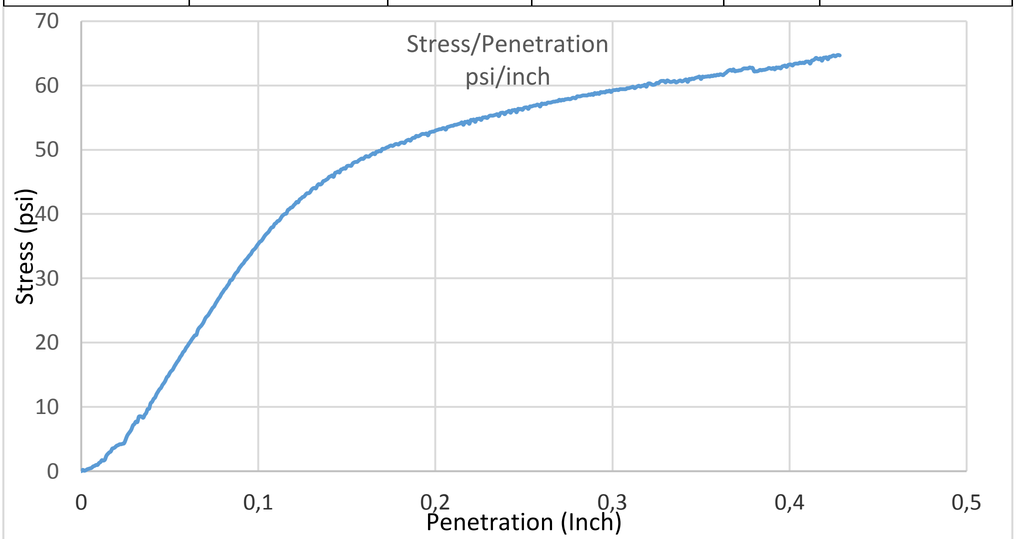

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%6 B	Start Date	28.06.2014
Curing Period	28 days	End Date	30.07.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.42	Swell Dial Reading (mm.)	1.78
Optimum Moisture Content (%)	31.1	Swell Rate (%)	1.534
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8170	8210.7
Mass of Mould + Base (g)	(g)	4131	4131
Mass of Compacted Specimen	(g)	4039	4079.7
Bulk Density (g/cm3)	(g/cm3)	1.849	1.921
Dry Density (g/cm3)	(g/cm3)	1.414	1.379
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	406	469.4
Mass of Container + Dry Soil	(g)	342.1	371.5
Mass of Container	(g)	134.4	142.8
Mass of Moisture	(g)	63.9	97.9
Moisture Content	%	30.766	42.807

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	253.167	36.719	40.316	4.032	**4.032**
0.2 Inch	389.568	56.502	57.551	3.837	

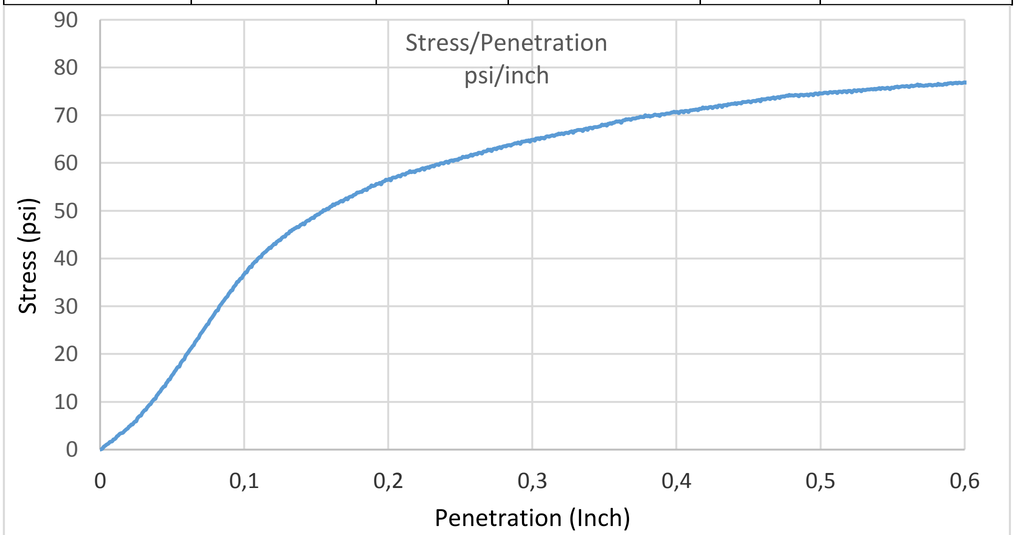

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.07.2014
Curing Period	28 days	End Date	10.07.2014
Sample Number	1		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	1.88
Optimum Moisture Content (%)	32.4	Swell Rate (%)	1.621
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8061.6	8142.4
Mass of Mould + Base	(g)	4165.6	4165.6
Mass of Compacted Specimen	(g)	3896	3976.8
Bulk Density	(g/cm3)	1.834	1.872
Dry Density	(g/cm3)	1.384	1.296
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	711.6	417.7
Mass of Container + Dry Soil	(g)	583.4	330.8
Mass of Container	(g)	188.9	135.2
Mass of Moisture	(g)	128.2	86.9
Moisture Content	%	32.497	44.427

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	276.934	40.166	41.365	4.136	**4.136**
0.2 Inch	334.801	48.559	54.104	3.607	

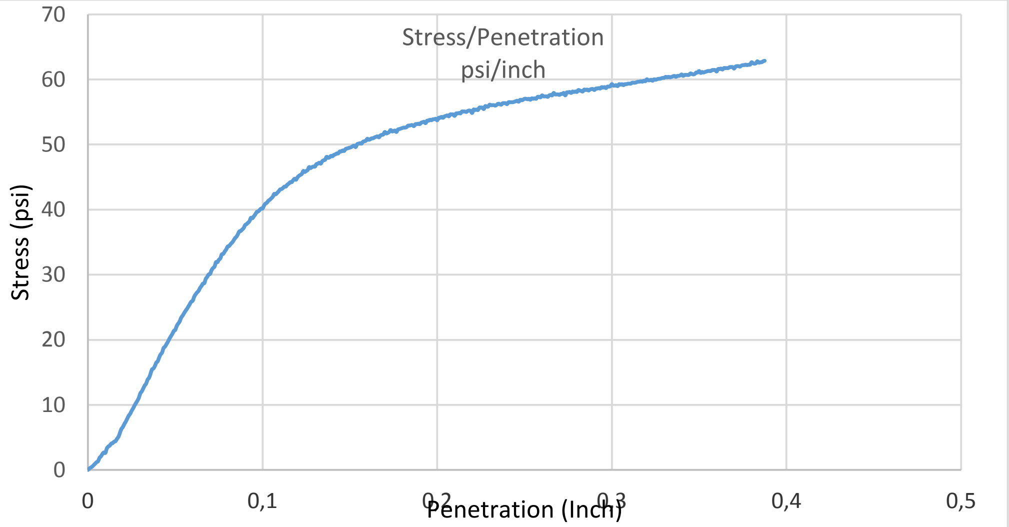

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.06.2014
Curing Period	28 days	End Date	10.08.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	1.54
Optimum Moisture Content (%)	32.4	Swell Rate (%)	1.328
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8059.5	8216.4
Mass of Mould + Base	(g)	4165.3	4165.3
Mass of Compacted Specimen	(g)	3894.2	4051.1
Bulk Density	(g/cm3)	1.833	1.907
Dry Density	(g/cm3)	1.381	1.350

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	699.2	411.2
Mass of Container + Dry Soil	(g)	558.4	322
Mass of Container	(g)	128.8	119.6
Mass of Moisture	(g)	140.8	83.2
Moisture Content	%	32.775	44.0711

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	276.934	40.166	40.166	4.017	**4.017**
0.2 Inch	367.867	53.355	53.355	3.557	

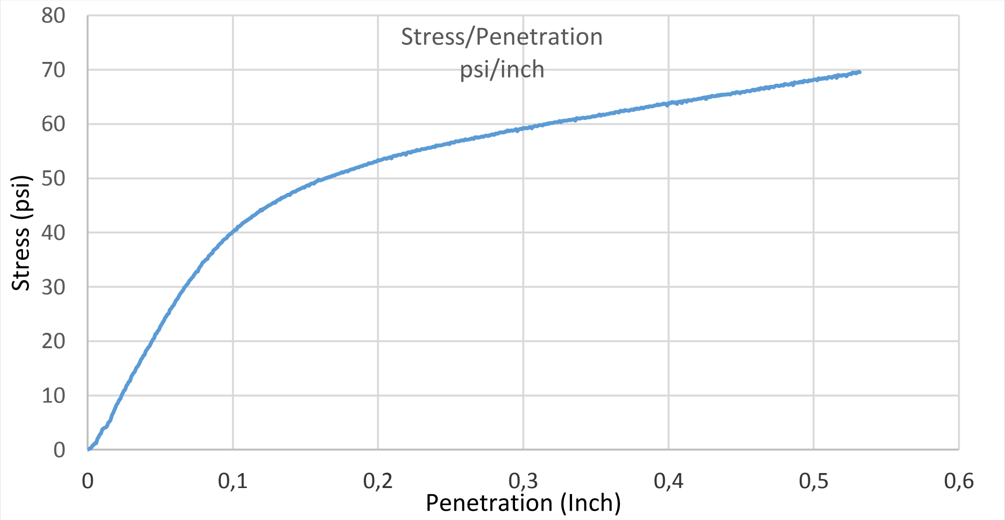

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%10 B	Start Date	29.07.2014
Curing Period	28 days	End Date	10.08.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.39	Swell Dial Reading (mm.)	1.59
Optimum Moisture Content (%)	32.4	Swell Rate (%)	1.371
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8052.9	8180.4
Mass of Mould + Base	(g)	4157.2	4157.1
Mass of Compacted Specimen	(g)	3895.7	4023.3
Bulk Density	(g/cm3)	1.834	1.894
Dry Density	(g/cm3)	1.386	1.316

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	465.3	497.3
Mass of Container + Dry Soil	(g)	386.3	392
Mass of Container	(g)	142.1	149.3
Mass of Moisture	(g)	79	106.3
Moisture Content	%	32.351	43.98

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	287.267	41.665	41.665	4.166	**4.166**
0.2 Inch	412.301	59.799	59.799	3.987	

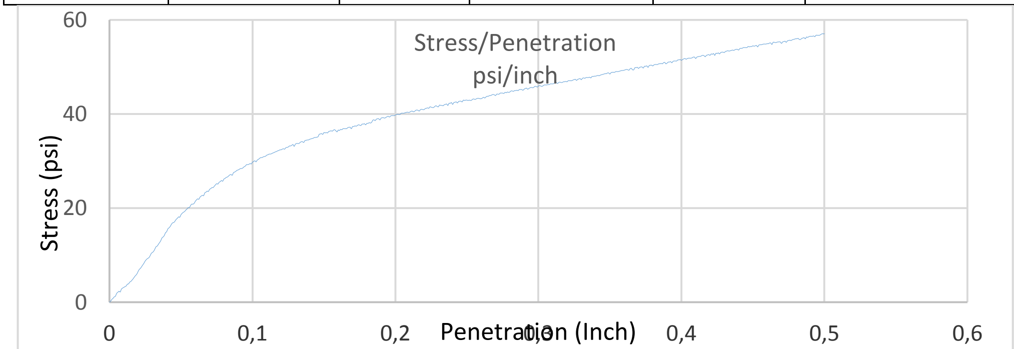

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information				
Project Name	%15 B	Start Date		28.06.2014
Curing Period	28 days	End Date		12.07.2014
Sample Number	1			
Standard	ASTM D 1883-07, D 698-12			
Method Of Compaction	Standard Effort, Method C			
Tested By	Can CEYLAN	Condition of Sample		Soaked
Soil Classification	CH	Surcharge		4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)		2.11
Optimum Moisture Content (%)	33.1	Swell Rate (%)		1.819
Area of Penetration (mm2)	1.935	Device		ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8219.4	8314.5
Mass of Mould + Base	(g)	4361.4	4361.4
Mass of Compacted Specimen	(g)	3858	3953.1
Bulk Density	(g/cm3)	1.816	1.861
Dry Density	(g/cm3)	1.366	1.275
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	597.8	489.3
Mass of Container + Dry Soil	(g)	489	380.1
Mass of Container	(g)	158.8	142.8
Mass of Moisture	(g)	108.8	109.2
Moisture Content	%	32.950	46.018

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	214.417	31.099	33.721	3.372	**3.372**
0.2 Inch	321.367	46.610	47.510	3.167	

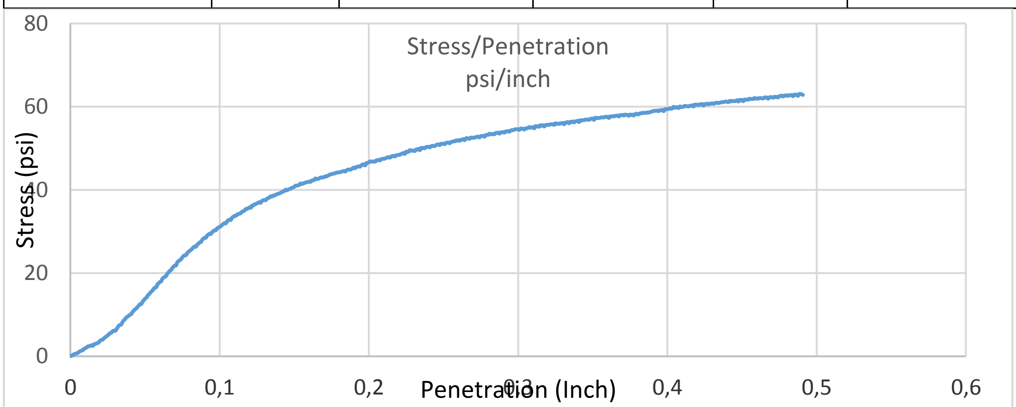

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	28.06.2014
Curing Period	28 days	End Date	12.07.2014
Sample Number	2		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	1.73
Optimum Moisture Content (%)	33.1	Swell Rate (%)	1.491
Area of Penetration (mm2)	1.935	Device	ELE Multip50
Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8515.7	8673.7
Mass of Mould + Base	(g)	4642.5	4642.5
Mass of Compacted Specimen	(g)	3873.2	4031.2
Bulk Density	(g/cm3)	1.824	1.898
Dry Density	(g/cm3)	1.371	1.299
Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	466.7	432.8
Mass of Container + Dry Soil	(g)	389.2	333.4
Mass of Container	(g)	154.5	118
Mass of Moisture	(g)	77.5	99.4
Moisture Content	%	33.021	46.147

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	231.984	33.646	33.646	3.365	**3.365**
0.2 Inch	296.051	42.939	42.939	2.863	

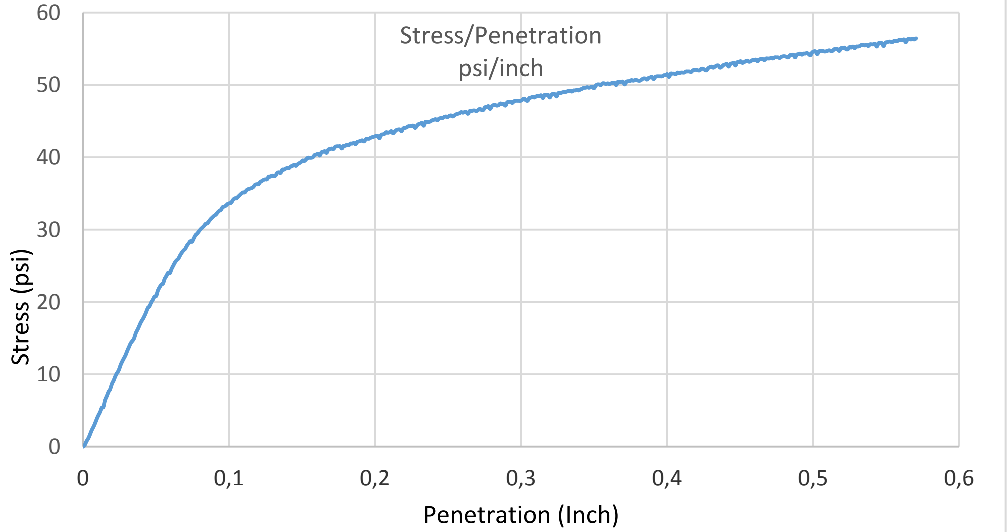

Figure G1(Continued)

Middle East Technical University
Transport Laboratory
California Bearing Ratio Test Data Sheet

Project Information			
Project Name	%15 B	Start Date	01.07.2014
Curing Period	28 days	End Date	12.07.2014
Sample Number	3		
Standard	ASTM D 1883-07, D 698-12		
Method Of Compaction	Standard Effort, Method C		
Tested By	Can CEYLAN	Condition of Sample	Soaked
Soil Classification	CH	Surcharge	4.54 kg.
Maximum Dry Density g/cm3	1.37	Swell Dial Reading (mm.)	2.33
Optimum Moisture Content (%)	33.1	Swell Rate (%)	2.009
Area of Penetration (mm2)	1.935	Device	ELE Multip50

Dry Density Determination		Before Soaking	After Soaking
Mass of Mould + Base + Soil	(g)	8012.4	8270
Mass of Mould + Base	(g)	4154	4346.1
Mass of Compacted Specimen	(g)	3858.4	3923.9
Bulk Density	(g/cm3)	1.817	1.847
Dry Density	(g/cm3)	1.362	1.325

Moisture Content Determination		Before Soaking	After Soaking
Mass of Container + Wet Soil	(g)	435.7	524.9
Mass of Container + Dry Soil	(g)	366.4	401.4
Mass of Container	(g)	158.5	135.2
Mass of Moisture	(g)	69.3	123.5
Moisture Content	%	33.333	46.394

California Bearing Ratio Determination

Deformation	Pressure kPa	Pressure psi	Corrected Pressure (psi)	CBR	**Final CBR**
0.1 Inch	221.651	32.148	32.372	3.237	**3.237**
0.2 Inch	310.001	44.962	44.737	2.982	

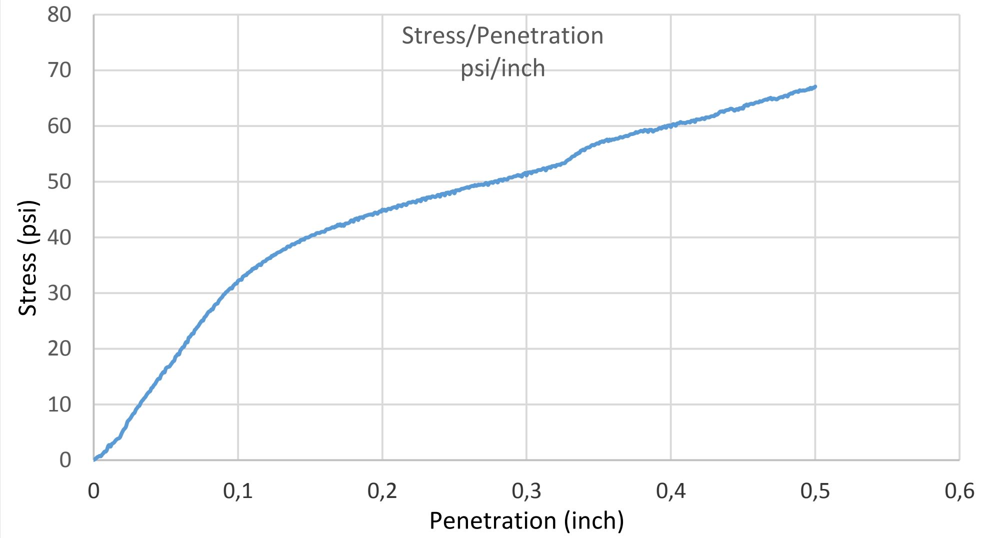

Figure G1(Continued)

APPENDIX H

UNCONFINED COMPRESSIVE STRENGTH TEST DATA SHEETS

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	0 BS	Prep. Date	
Curing Period	0 days	Test Date	
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH/A-7-6		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		
Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	471.000	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	395.800	L/D	2.020
Mass of Container (gr.)	109.260	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	361.740	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	286.540	Strain at failure (mm.)	5.950
Mass of Moisture (gr.)	75.200	Axial Strain %	5.891
Moisture Content %	26.2	Corrected Area (mm2)	2086.412
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.445	**UCS Strength (kPa)**	**162.489**
Bulk Density (g/cm3)	1.824	**Shear Strength (kPa)**	81.245

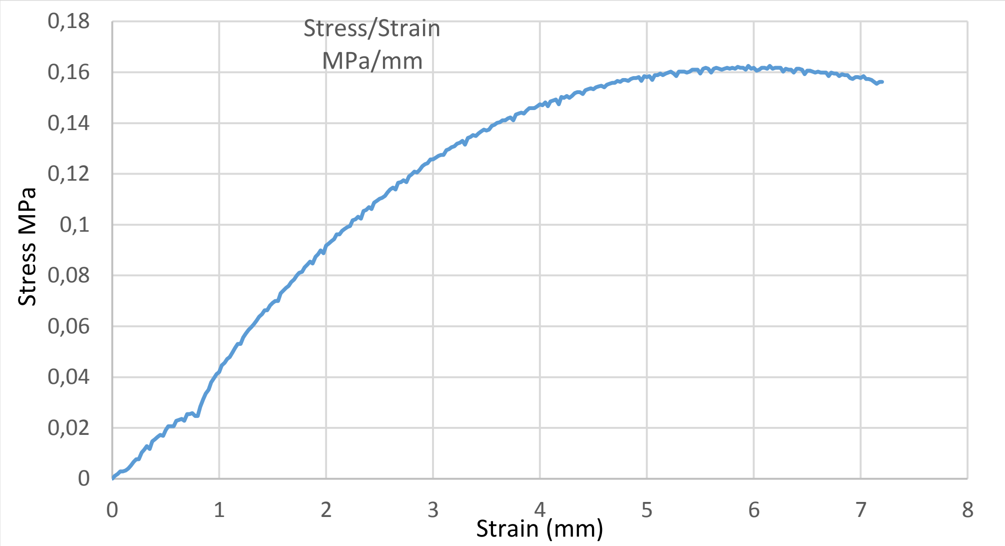

Figure H.1 Unconfined Compressive Strength Test Data Sheets

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	0 BS	Prep. Date	
Curing Period	0 days	Test Date	
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH/A-7-6		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		
Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	197.332	Initial Length (mm.)	100.500
Mass of Cont. + Wet Soil (gr.)	479.430	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	405.700	L/D	2.010
Mass of Container (gr.)	119.800	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	359.630	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	285.900	Strain at failure (mm.)	6.060
Mass of Moisture (gr.)	73.730	Axial Strain %	6.030
Moisture Content %	25.8	Corrected Area (mm2)	2089.493
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.449	**UCS Strength (kPa)**	**173.759**
Bulk Density (g/cm3)	1.822	**Shear Strength (kPa)**	86.880

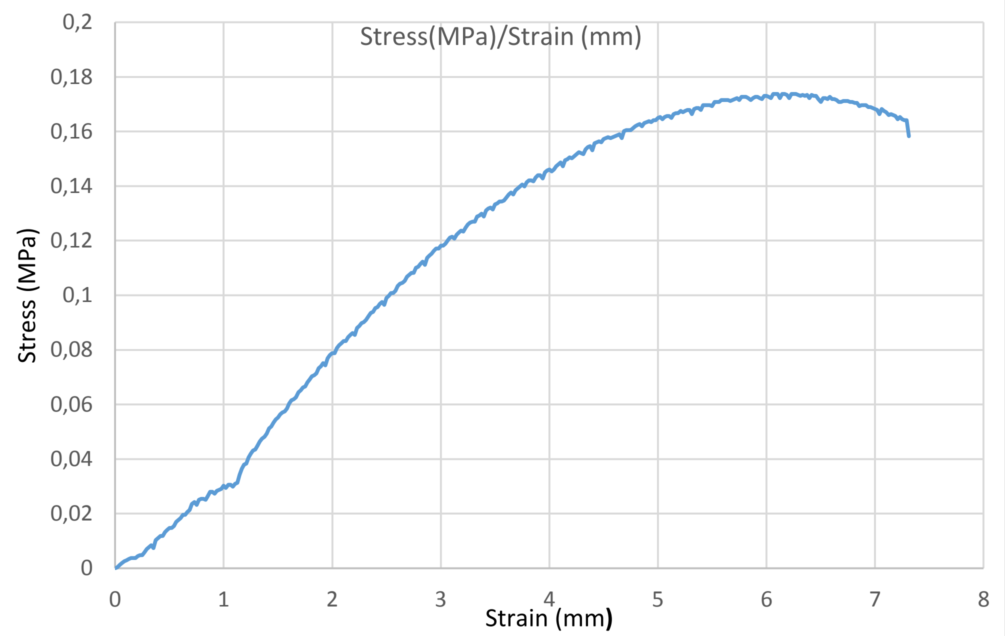

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	0 BS	Prep. Date	
Curing Period	0 days	Test Date	
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip 50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	197.921	Initial Length (mm.)	100.800
Mass of Cont. + Wet Soil (gr.)	509.120	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	435.700	L/D	2.016
Mass of Container (gr.)	149.800	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	359.320	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	285.900	Strain at failure (mm.)	5.787
Mass of Moisture (gr.)	73.420	Axial Strain %	5.741
Moisture Content %	25.7	Corrected Area (mm2)	2083.092
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.445	**UCS Strength (kPa)**	**159.527**
Bulk Density (g/cm3)	1.815	**Shear Strength (kPa)**	79.764

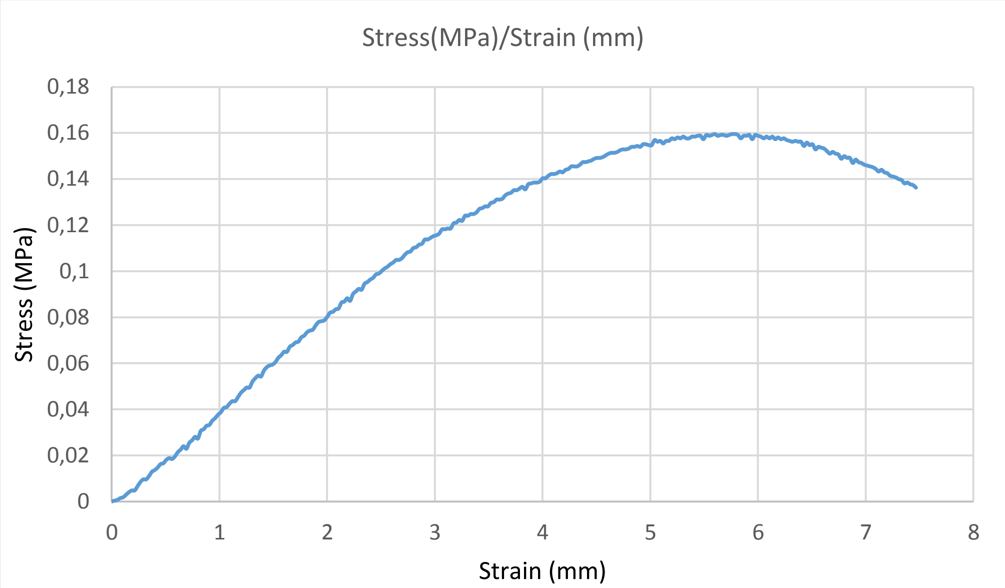

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	487.230	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	403.100	L/D	2.020
Mass of Container (gr.)	118.060	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	369.170	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	285.040	Strain at failure (mm.)	5.640
Mass of Moisture (gr.)	84.130	Final Length	96.542
Moisture Content %	0.295	Corrected Area	2054.175
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.437	**UCS Strength**	**207.385**
Bulk Density (g/cm3)	1.862	**Shear Strength**	103.692

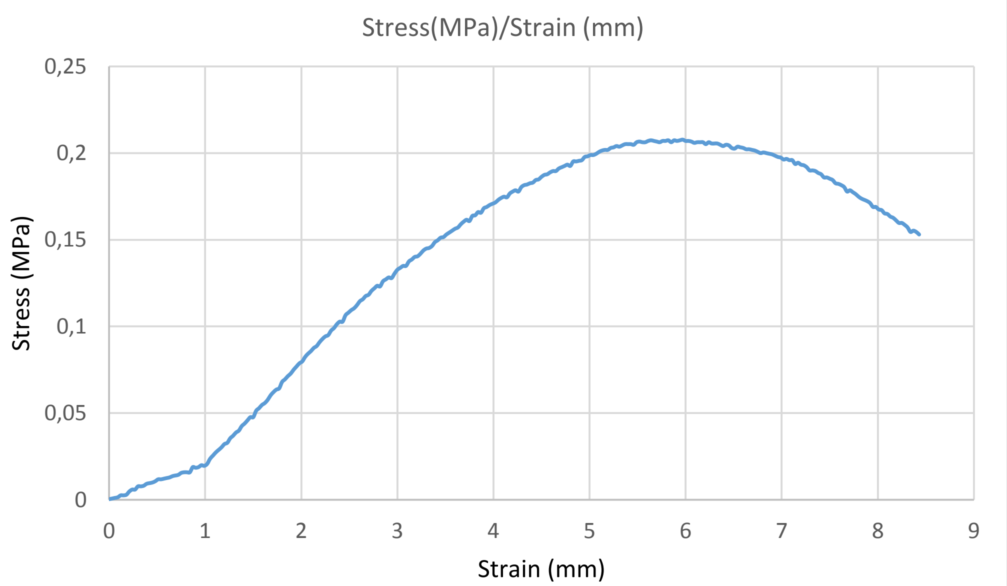

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	518.230	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	434.800	L/D	2.000
Mass of Container (gr.)	153.260	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	364.970	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	281.540	Strain at failure (mm.)	3.883
Mass of Moisture (gr.)	83.430	Axial Strain %	6.043
Moisture Content %	0.296	Corrected Area (mm2)	2089.786
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.434	**UCS Strength (kPa)**	**192.188**
Bulk Density (g/cm3)	1.859	**Shear Strength (kPa)**	96.094

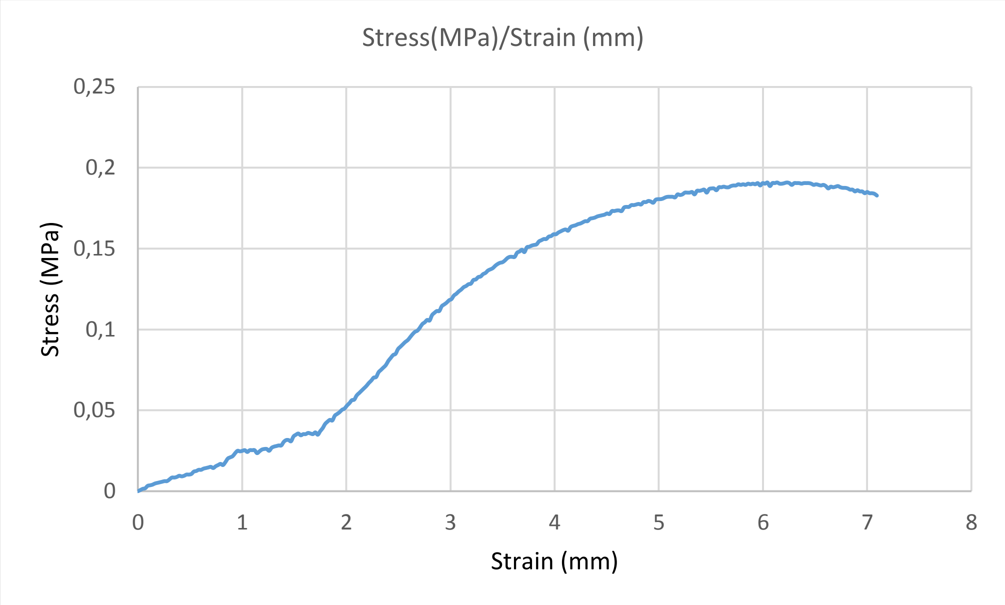

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	556.880	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	470.500	L/D	2.020
Mass of Container (gr.)	188.400	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	368.480	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	282.100	Strain at failure (mm.)	6.188
Mass of Moisture (gr.)	86.380	Axial Strain %	6.127
Moisture Content %	0.306	Corrected Area (mm2)	2091.650
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.422	**UCS Strength (kPa)**	**195.523**
Bulk Density (g/cm3)	1.858	**Shear Strength (kPa)**	97.762

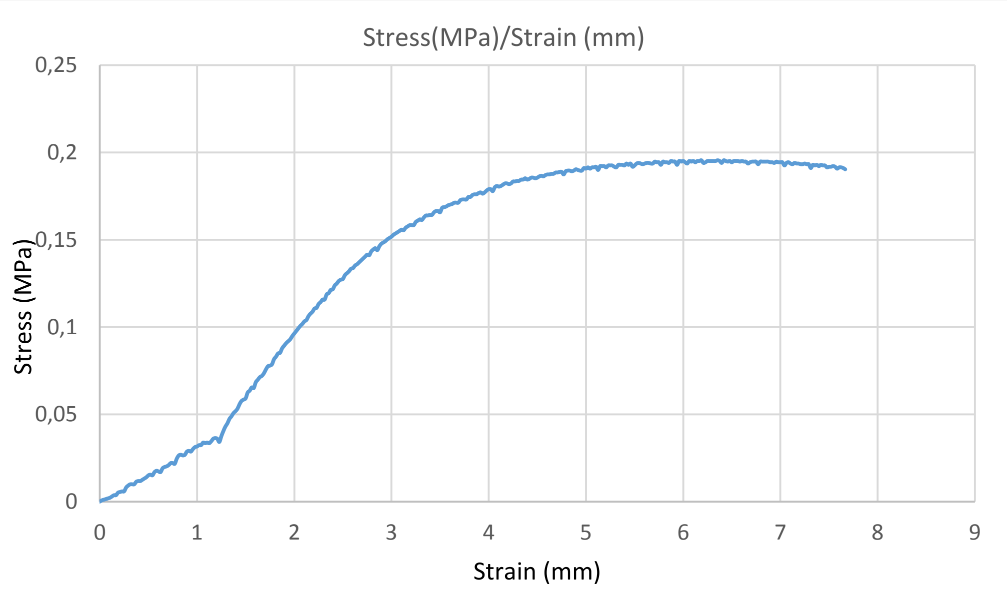

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		
Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	491.310	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	405.100	L/D	2.000
Mass of Container (gr.)	124.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	367.110	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	280.900	Strain at failure (mm.)	5.033
Mass of Moisture (gr.)	86.210	Axial Strain %	5.033
Moisture Content %	30.691	Corrected Area (mm2)	2067.560
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.431	**UCS Strength (kPa)**	**231.848**
Bulk Density (g/cm3)	1.870	**Shear Strength (kPa)**	115.924

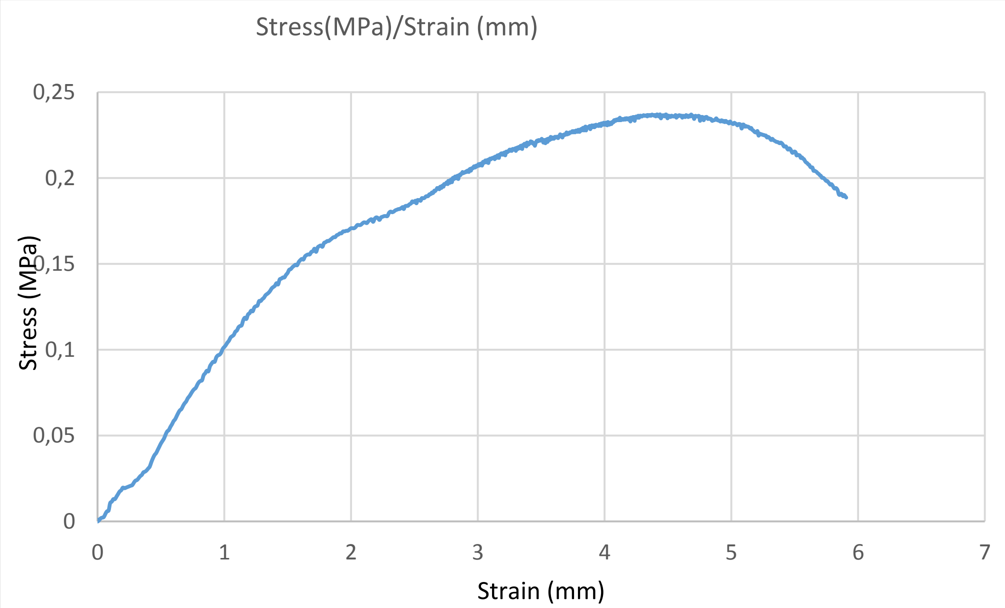

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	517.900	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	429.700	L/D	2.000
Mass of Container (gr.)	149.400	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	368.500	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	280.300	Strain at failure (mm.)	5.013
Mass of Moisture (gr.)	88.200	Axial Strain %	5.013
Moisture Content %	31.466	Corrected Area (mm2)	2067.125
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.428	**UCS Strength (kPa)**	**216.204**
Bulk Density (g/cm3)	1.877	**Shear Strength (kPa)**	108.102

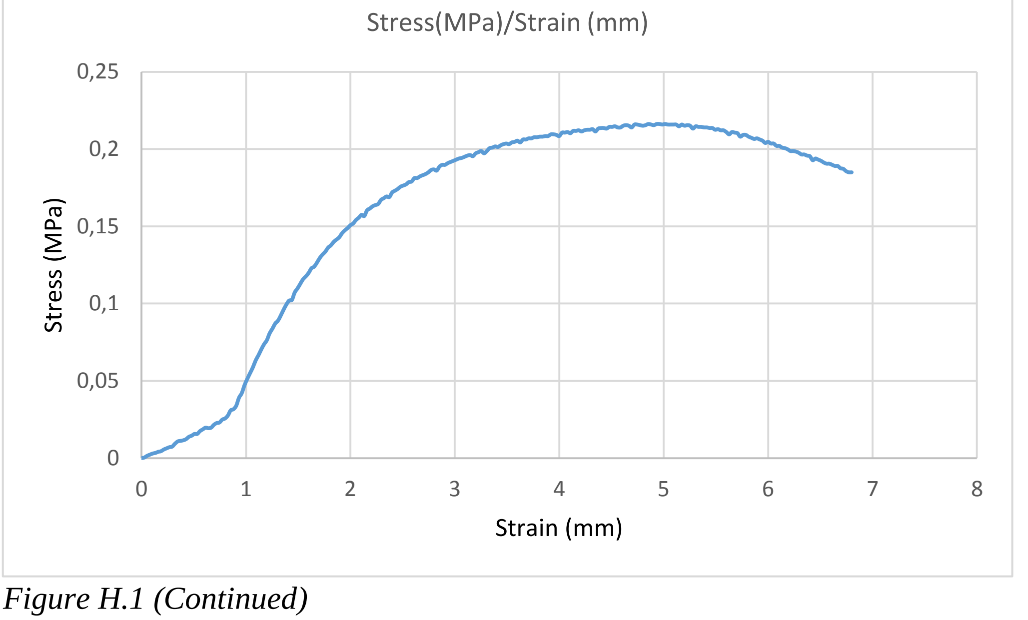

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	200.201	Initial Length (mm.)	100.800
Mass of Cont. + Wet Soil (gr.)	502.800	Initial Diameter (mm.)	50.300
Mass of Cont. + Dry Soil (gr.)	414.100	L/D	2.004
Mass of Container (gr.)	126.600	Initial Area (mm2)	1986.121
Mass of Sample (gr.)	376.200	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	287.500	Strain at failure (mm.)	6.090
Mass of Moisture (gr.)	88.700	Axial Strain %	6.042
Moisture Content %	30.852	Corrected Area (mm2)	2113.831
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.436	**UCS Strength (kPa)**	**229.506**
Bulk Density (g/cm3)	1.879	**Shear Strength (kPa)**	114.753

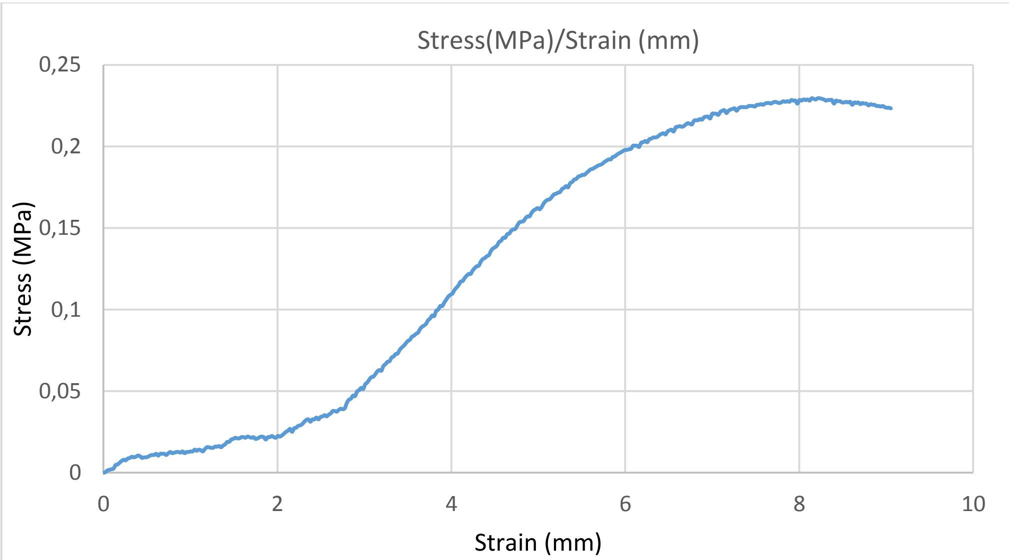

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	482.430	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	394.600	L/D	2.000
Mass of Container (gr.)	118.000	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	364.430	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	276.600	Strain at failure (mm.)	5.940
Mass of Moisture (gr.)	87.830	Axial Strain %	5.940
Moisture Content %	31.753	Corrected Area (mm2)	2086.434
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.409	**UCS Strength (kPa)**	**201.198**
Bulk Density (g/cm3)	1.857	**Shear Strength (kPa)**	100.599

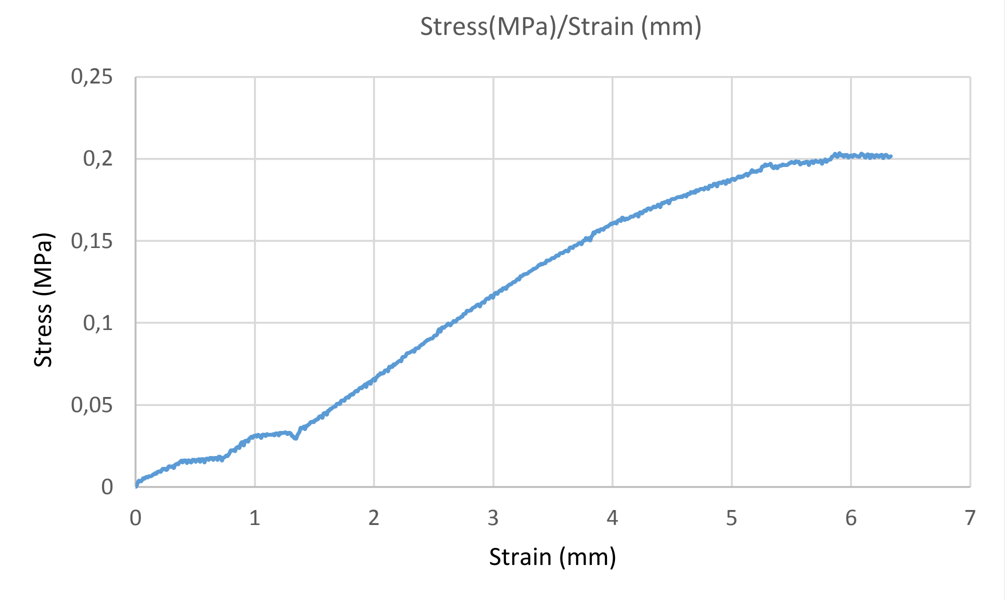

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	496.540	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	408.400	L/D	2.000
Mass of Container (gr.)	130.800	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	365.740	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	277.600	Strain at failure (mm.)	5.623
Mass of Moisture (gr.)	88.140	Axial Strain %	5.623
Moisture Content %	31.751	Corrected Area (mm2)	2079.426
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.415	**UCS Strength (kPa)**	**191.878**
Bulk Density (g/cm3)	1.864	**Shear Strength (kPa)**	95.939

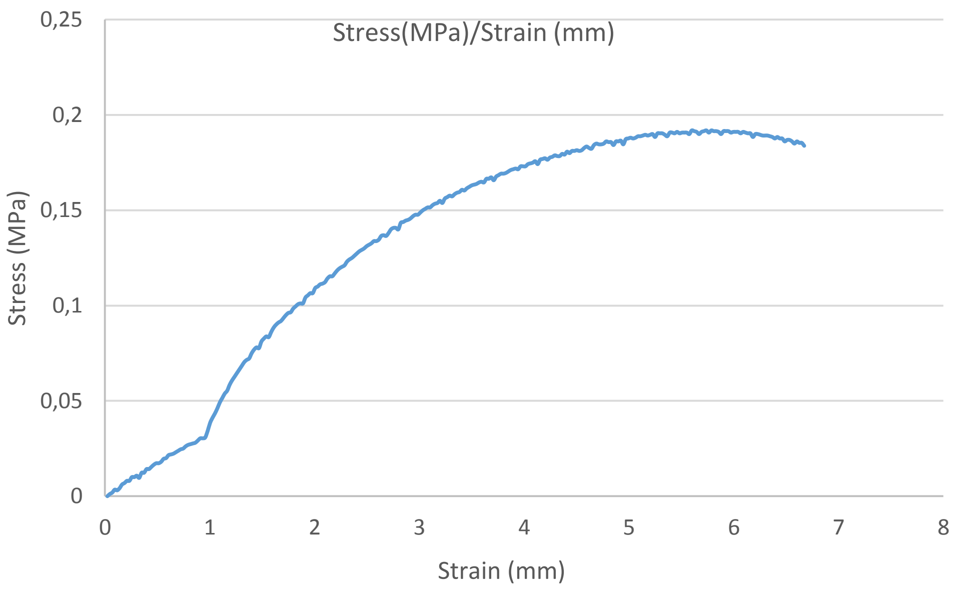

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	498.400	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	408.200	L/D	2.000
Mass of Container (gr.)	131.000	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	367.400	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	277.200	Strain at failure (mm.)	5.400
Mass of Moisture (gr.)	90.200	Axial Strain %	5.400
Moisture Content %	32.540	Corrected Area (mm2)	2074.524
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.412	**UCS Strength (kPa)**	**199.649**
Bulk Density (g/cm3)	1.872	**Shear Strength (kPa)**	99.825

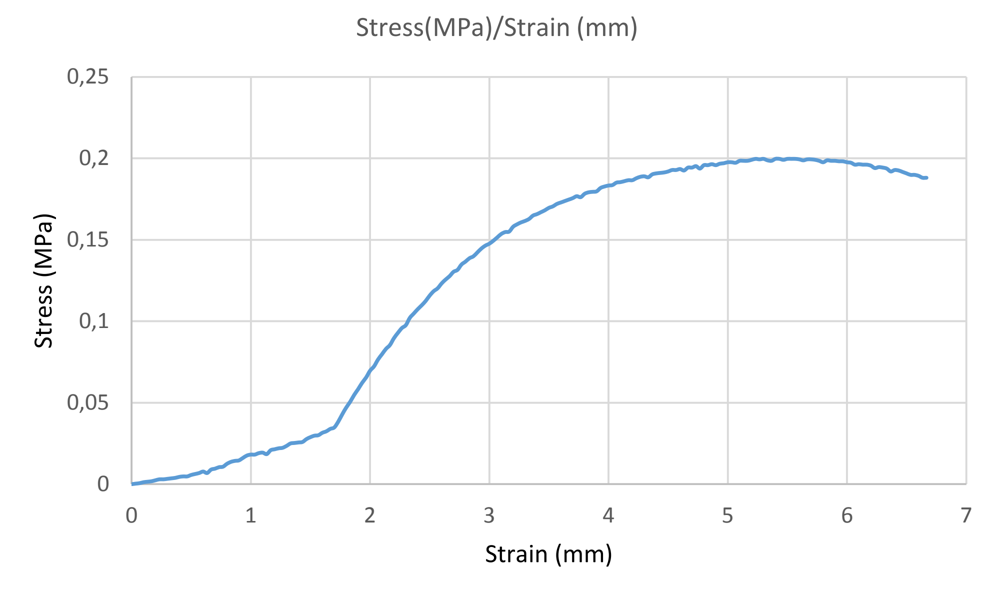

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	515.900	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	425.900	L/D	2.000
Mass of Container (gr.)	153.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	362.700	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	272.700	Strain at failure (mm.)	5.883
Mass of Moisture (gr.)	90.000	Axial Strain %	5.883
Moisture Content %	33.003	Corrected Area (mm2)	2086.233
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.389	**UCS Strength (kPa)**	**180.531**
Bulk Density (g/cm3)	1.847	**Shear Strength (kPa)**	90.266

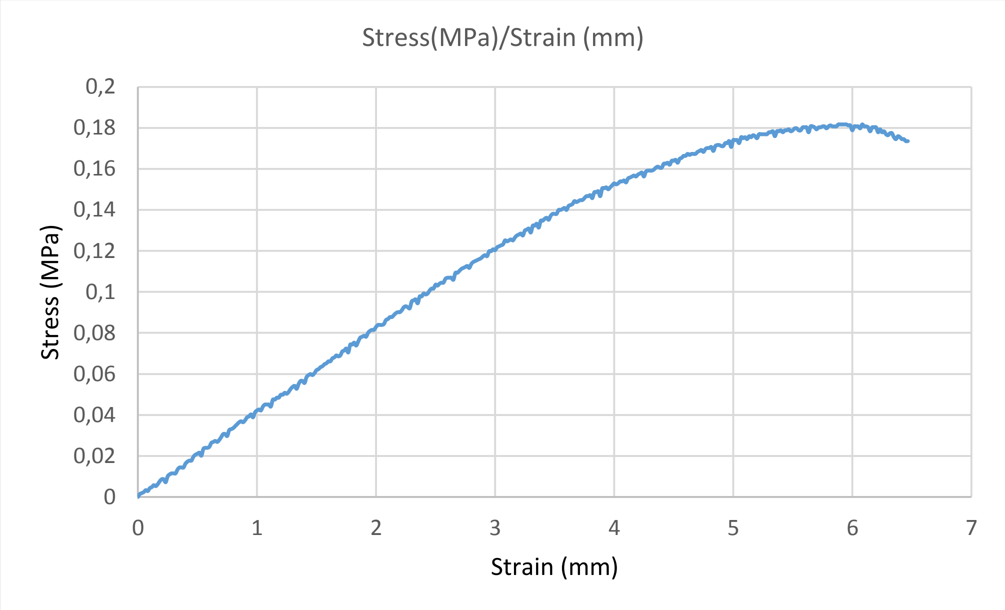

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	513.820	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	420.100	L/D	2.020
Mass of Container (gr.)	142.800	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	371.020	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	277.300	Strain at failure (mm.)	5.990
Mass of Moisture (gr.)	93.720	Axial Strain %	5.931
Moisture Content %	33.797	Corrected Area (mm2)	2087.291
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.398	**UCS Strength (kPa)**	**181.203**
Bulk Density (g/cm3)	1.871	**Shear Strength (kPa)**	90.602

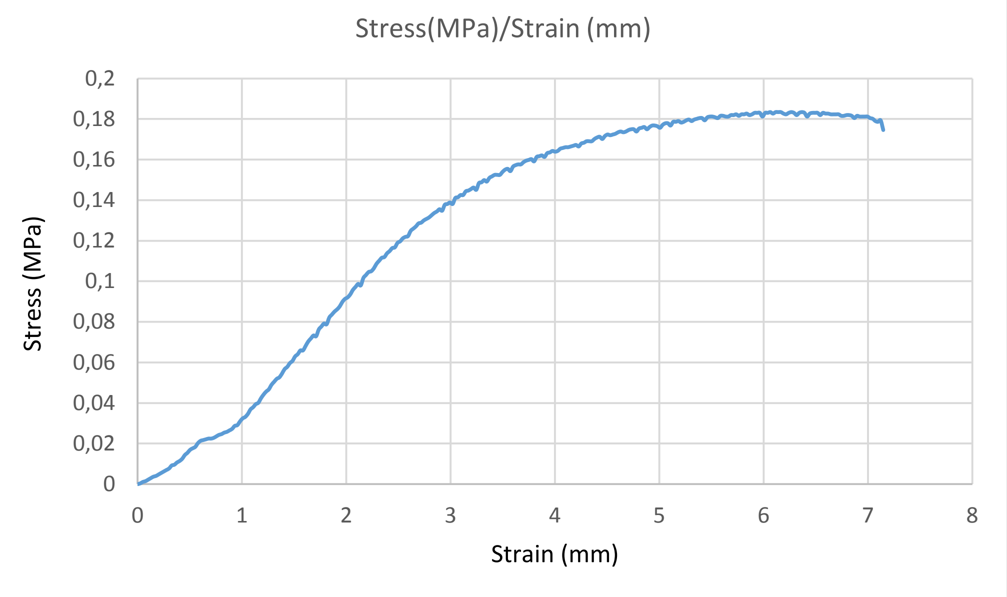

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	0 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	559.880	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	467.300	L/D	2.000
Mass of Container (gr.)	192.400	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	367.480	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	274.900	Strain at failure (mm.)	5.985
Mass of Moisture (gr.)	92.580	Axial Strain %	5.985
Moisture Content %	33.678	Corrected Area (mm2)	2088.497
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.400	**UCS Strength (kPa)**	**191.167**
Bulk Density (g/cm3)	1.872	**Shear Strength (kPa)**	95.584

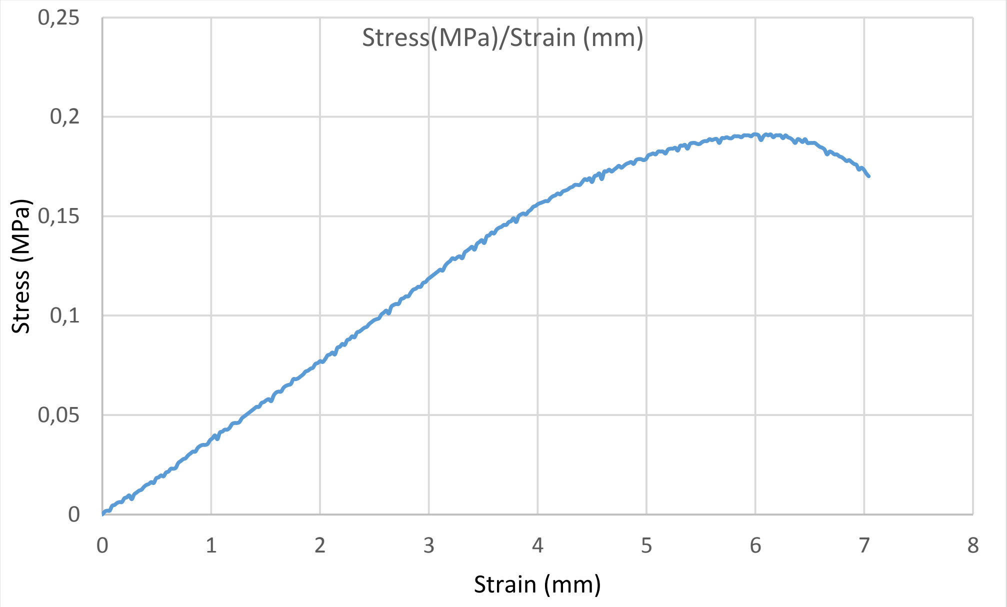

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	197.921	Initial Length (mm.)	100.800
Mass of Cont. + Wet Soil (gr.)	502.800	Initial Diameter (mm.)	50.400
Mass of Cont. + Dry Soil (gr.)	420.200	L/D	2.000
Mass of Container (gr.)	134.500	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	368.300	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	285.700	Strain at failure (mm.)	5.529
Mass of Moisture (gr.)	82.600	Axial Strain %	5.485
Moisture Content %	0.289	Corrected Area (mm2)	2077.451
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.444	**UCS Strength (kPa)**	**256.918**
Bulk Density (g/cm3)	1.861	**Shear Strength (kPa)**	128.459

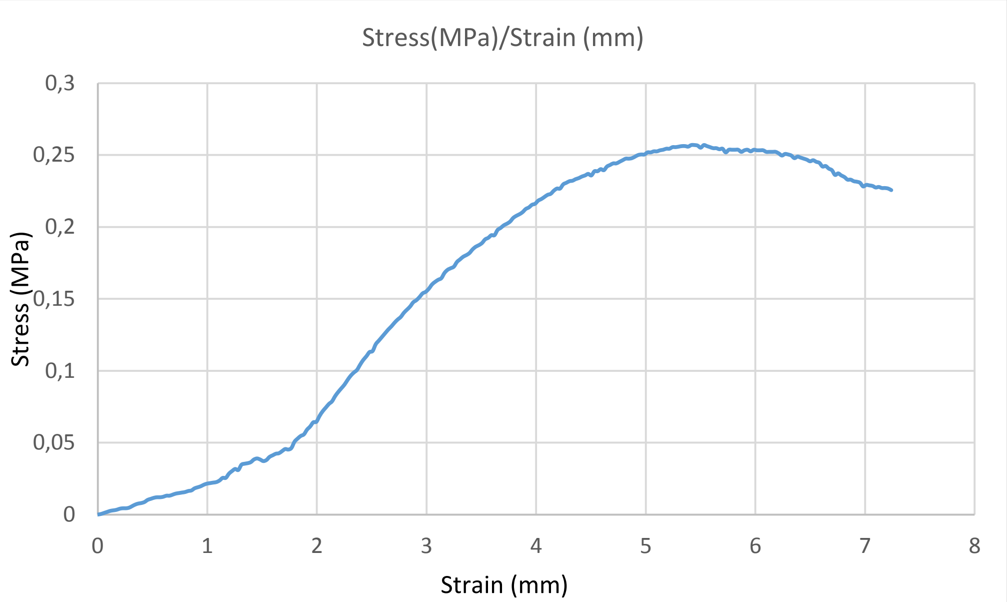

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	198.314	Initial Length (mm.)	100.200
Mass of Cont. + Wet Soil (gr.)	481.000	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	397.600	L/D	2.004
Mass of Container (gr.)	114.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	366.800	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	283.400	Strain at failure (mm.)	5.333
Mass of Moisture (gr.)	83.400	Final Length	96.542
Moisture Content %	0.294	Corrected Area	2054.175
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.429	**UCS Strength**	**245.730**
Bulk Density (g/cm3)	1.850	**Shear Strength**	122.865

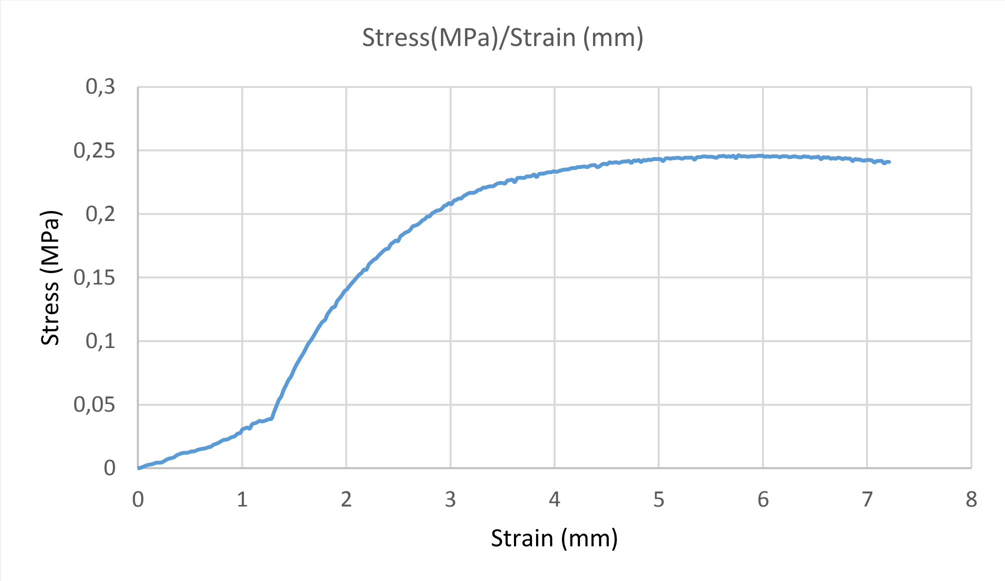

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.939	Initial Length (mm.)	100.300
Mass of Cont. + Wet Soil (gr.)	500.500	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	416.200	L/D	2.006
Mass of Container (gr.)	134.700	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	365.800	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	281.500	Strain at failure (mm.)	6.251
Mass of Moisture (gr.)	84.300	Axial Strain %	6.232
Moisture Content %	0.299	Corrected Area (mm2)	2094.005
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.429	**UCS Strength (kPa)**	**250.482**
Bulk Density (g/cm3)	1.857	**Shear Strength (kPa)**	125.241

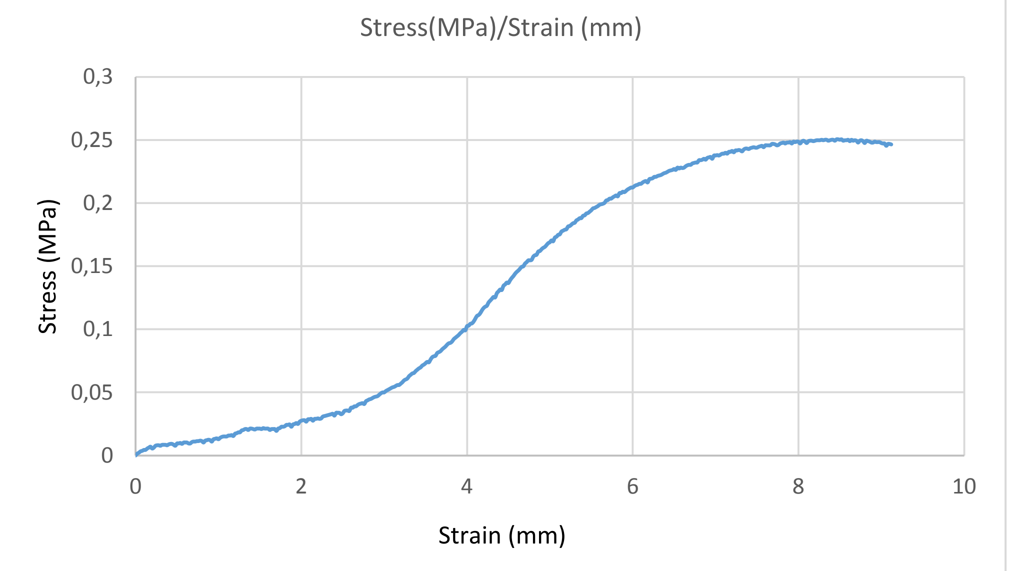

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	500.300	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	413.100	L/D	2.000
Mass of Container (gr.)	130.900	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	369.400	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	282.200	Strain at failure (mm.)	5.383
Mass of Moisture (gr.)	87.200	Axial Strain %	5.383
Moisture Content %	30.900	Corrected Area (mm2)	2075.208
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.437	**UCS Strength (kPa)**	**288.015**
Bulk Density (g/cm3)	1.881	**Shear Strength (kPa)**	144.008

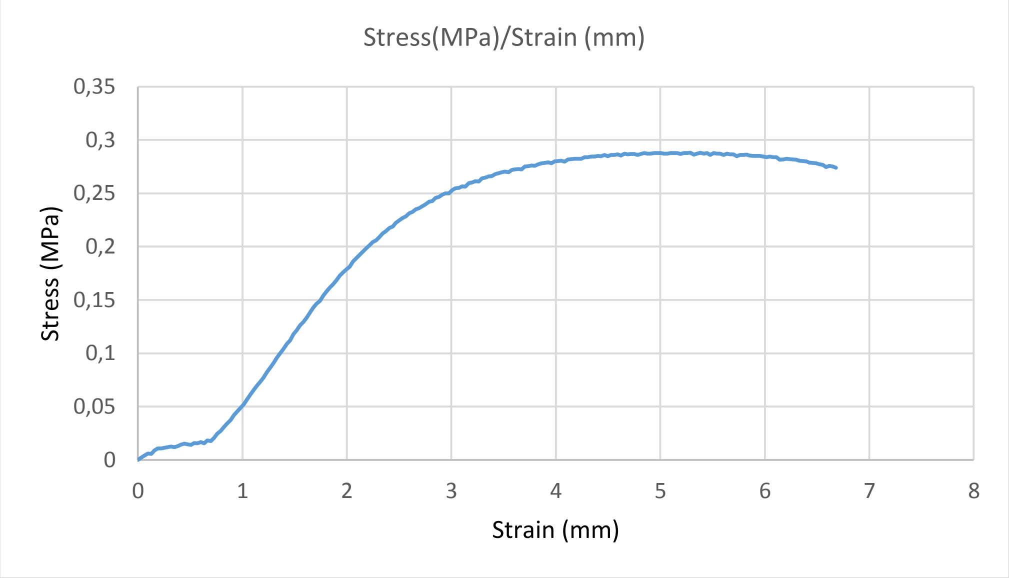

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	534.900	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	447.800	L/D	2.000
Mass of Container (gr.)	165.600	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	369.300	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	282.200	Strain at failure (mm.)	4.063
Mass of Moisture (gr.)	87.100	Axial Strain %	4.063
Moisture Content %	30.865	Corrected Area (mm2)	2046.656
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.437	**UCS Strength (kPa)**	**282.263**
Bulk Density (g/cm3)	1.881	**Shear Strength (kPa)**	141.132

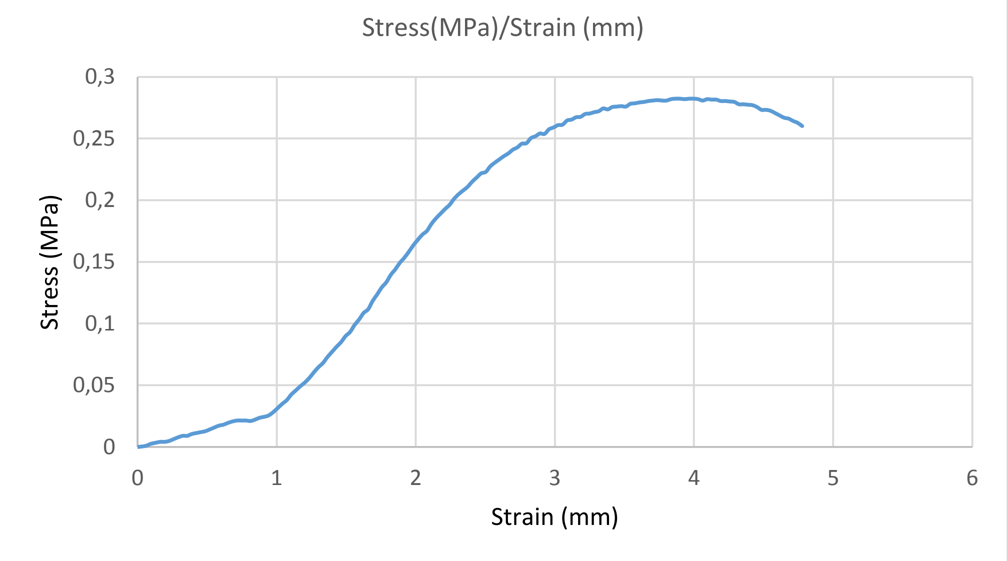

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 B	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	197.231	Initial Length (mm.)	100.500
Mass of Cont. + Wet Soil (gr.)	488.700	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	400.300	L/D	2.010
Mass of Container (gr.)	118.400	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	370.300	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	281.900	Strain at failure (mm.)	5.600
Mass of Moisture (gr.)	88.400	Axial Strain %	5.572
Moisture Content %	31.359	Corrected Area (mm2)	2078.306
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.429	**UCS Strength (kPa)**	**278.931**
Bulk Density (g/cm3)	1.877	**Shear Strength (kPa)**	139.466

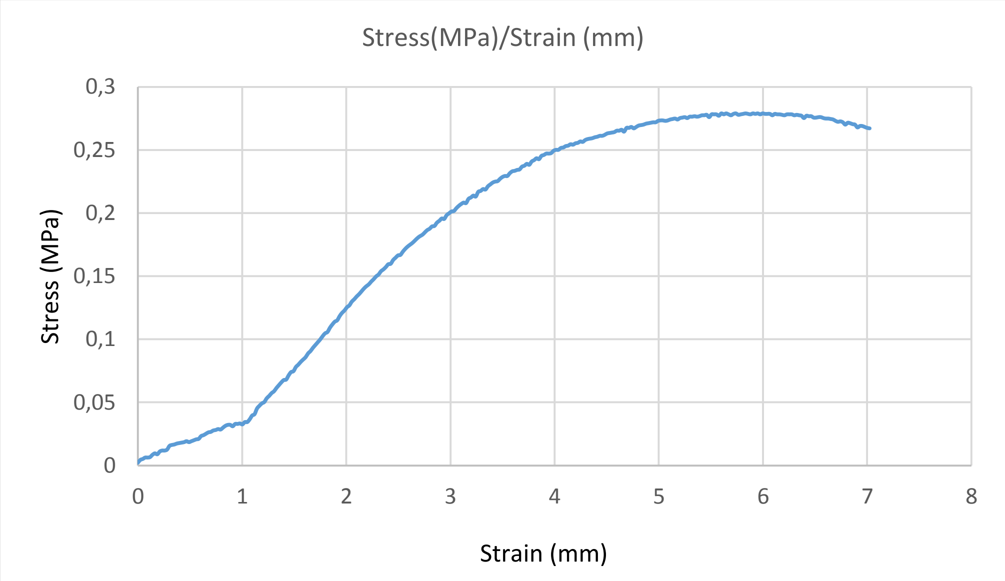

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 B	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	460.400	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	369.300	L/D	2.000
Mass of Container (gr.)	89.700	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	370.700	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	279.600	Strain at failure (mm.)	5.750
Mass of Moisture (gr.)	91.100	Axial Strain %	5.750
Moisture Content %	32.582	Corrected Area (mm2)	2082.228
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.425	**UCS Strength (kPa)**	**242.902**
Bulk Density (g/cm3)	1.889	**Shear Strength (kPa)**	121.451

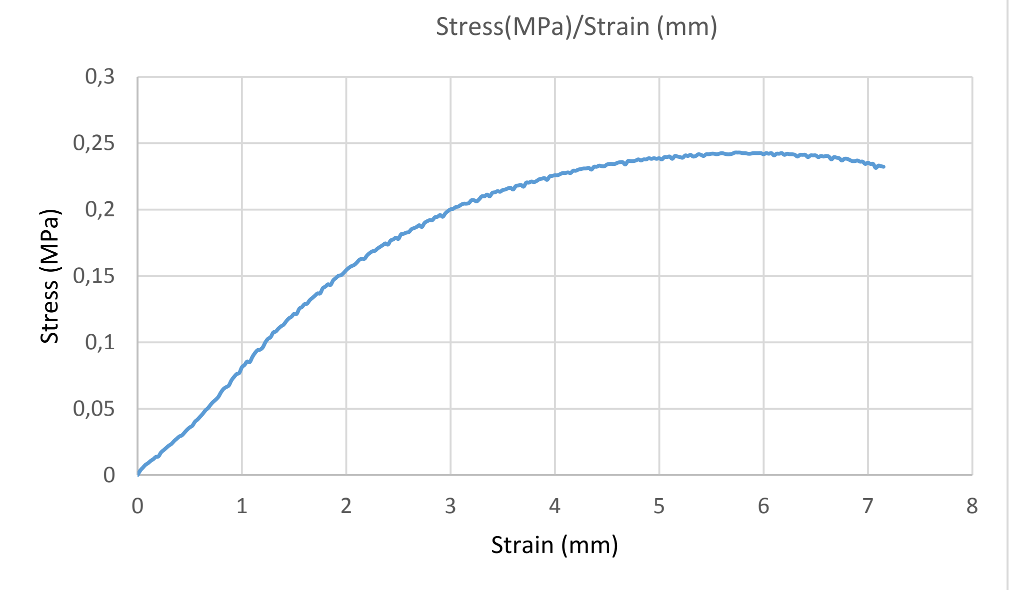

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	499.540	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	408.400	L/D	2.000
Mass of Container (gr.)	129.900	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	369.640	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	278.500	Strain at failure (mm.)	5.440
Mass of Moisture (gr.)	91.140	Axial Strain %	5.440
Moisture Content %	32.725	Corrected Area (mm2)	2075.402
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.419	**UCS Strength (kPa)**	**246.351**
Bulk Density (g/cm3)	1.884	**Shear Strength (kPa)**	123.176

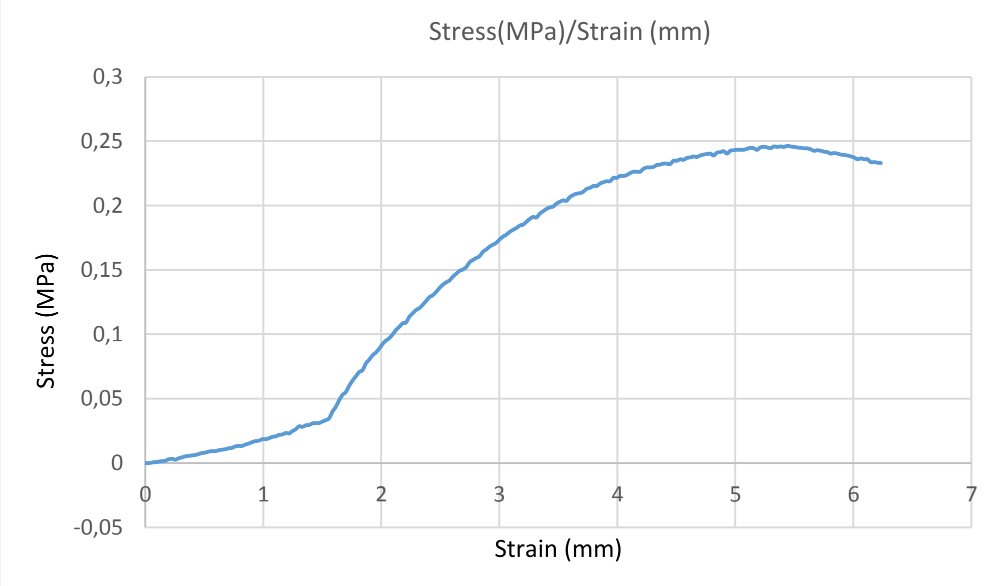

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	514.000	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	423.100	L/D	2.000
Mass of Container (gr.)	146.700	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	367.300	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	276.400	Strain at failure (mm.)	5.025
Mass of Moisture (gr.)	90.900	Axial Strain %	5.025
Moisture Content %	32.887	Corrected Area (mm2)	2066.333
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.408	**UCS Strength (kPa)**	**234.038**
Bulk Density (g/cm3)	1.872	**Shear Strength (kPa)**	117.019

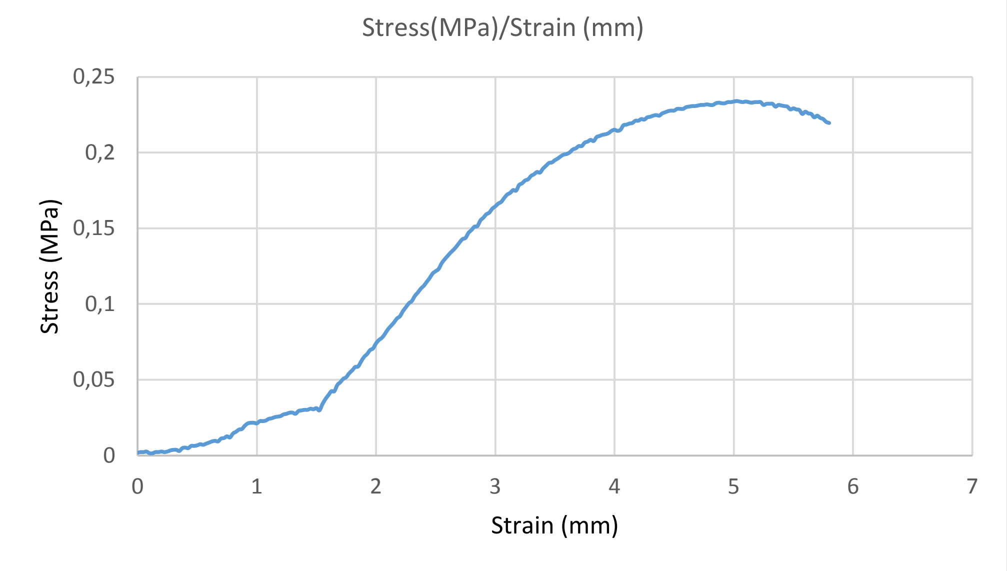

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	491.600	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	400.300	L/D	2.020
Mass of Container (gr.)	124.400	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	367.200	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	275.900	Strain at failure (mm.)	6.220
Mass of Moisture (gr.)	91.300	Axial Strain %	6.158
Moisture Content %	33.092	Corrected Area (mm2)	2092.356
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.391	**UCS Strength (kPa)**	**233.451**
Bulk Density (g/cm3)	1.852	**Shear Strength (kPa)**	116.726

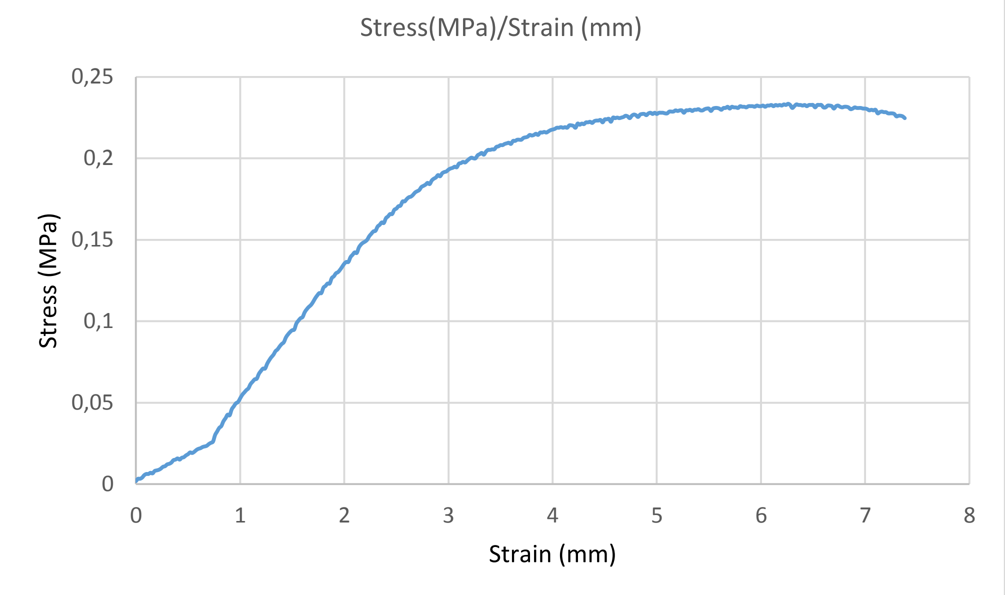

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	463.100	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	370.900	L/D	2.000
Mass of Container (gr.)	97.500	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	365.600	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	273.400	Strain at failure (mm.)	6.362
Mass of Moisture (gr.)	92.200	Axial Strain %	6.362
Moisture Content %	33.723	Corrected Area (mm2)	2096.905
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.392	**UCS Strength (kPa)**	**229.415**
Bulk Density (g/cm3)	1.862	**Shear Strength (kPa)**	114.708

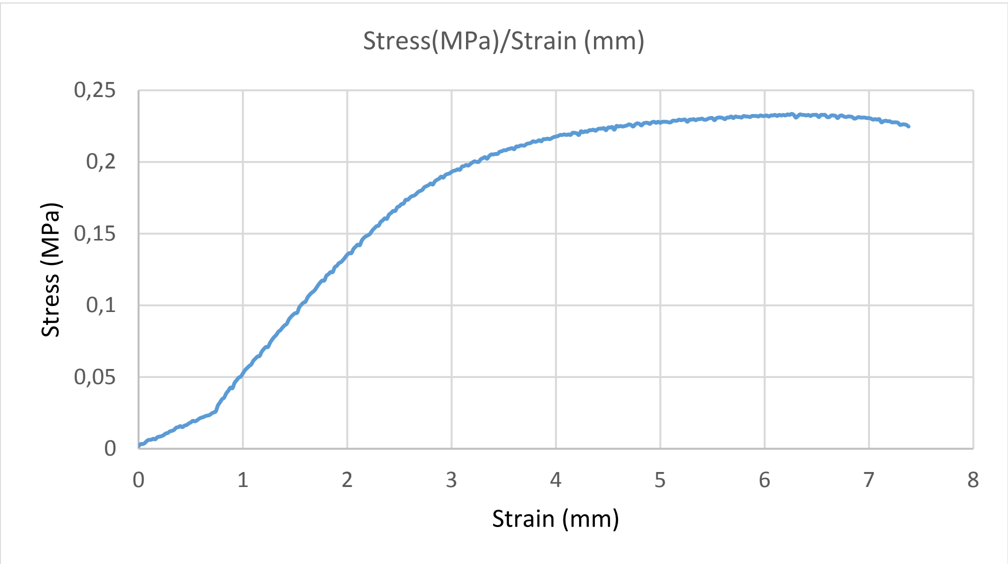

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	509.800	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	418.600	L/D	2.000
Mass of Container (gr.)	143.000	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	366.800	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	275.600	Strain at failure (mm.)	5.750
Mass of Moisture (gr.)	91.200	Axial Strain %	5.750
Moisture Content %	33.091	Corrected Area (mm2)	2083.289
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.404	**UCS Strength (kPa)**	**235.574**
Bulk Density (g/cm3)	1.868	**Shear Strength (kPa)**	117.787

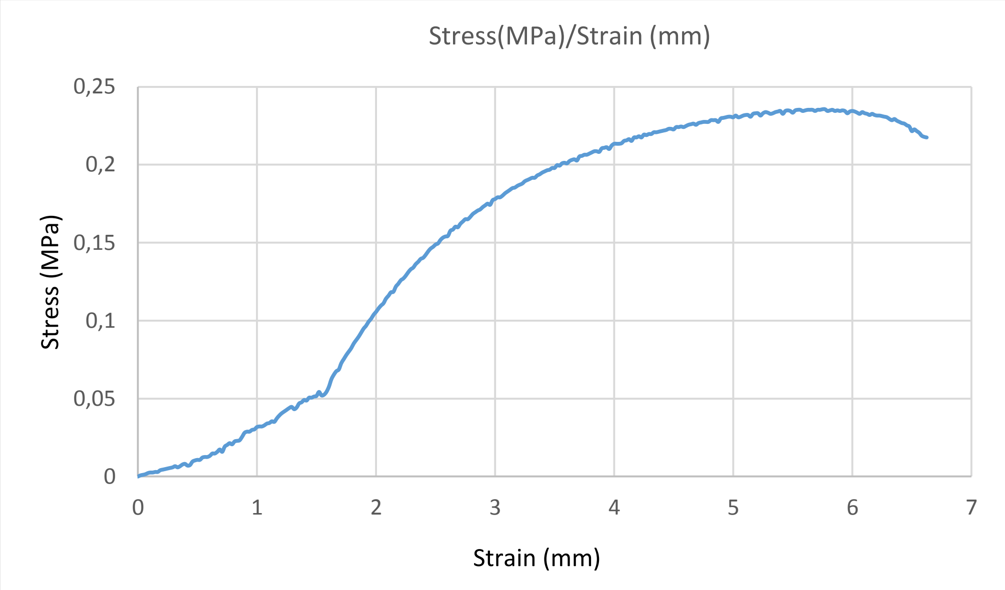

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 B	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	502.570	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	418.200	L/D	2.000
Mass of Container (gr.)	134.500	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	368.070	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	283.700	Strain at failure (mm.)	5.700
Mass of Moisture (gr.)	84.370	Axial Strain %	5.700
Moisture Content %	0.297	Corrected Area (mm2)	2082.185
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.445	**UCS Strength (kPa)**	**295.178**
Bulk Density (g/cm3)	1.875	**Shear Strength (kPa)**	147.589

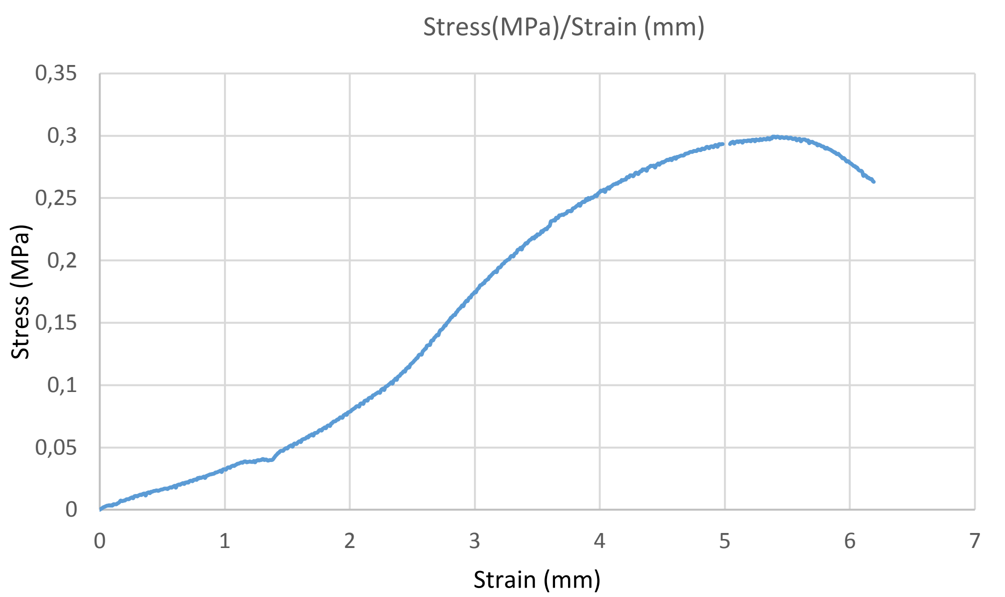

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (mm3)	198.314	Initial Length (mm.)	101.000
Mass of Cont. + Wet Soil (gr.)	477.500	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	394.000	L/D	2.020
Mass of Container (gr.)	109.300	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	368.200	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	284.700	Strain at failure (mm.)	5.933
Mass of Moisture (gr.)	83.500	Axial Strain %	5.874
Moisture Content %	0.293	Corrected Area (mm2)	2086.039
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.436	**UCS Strength**	**282.832**
Bulk Density (g/cm3)	1.857	**Shear Strength**	141.416

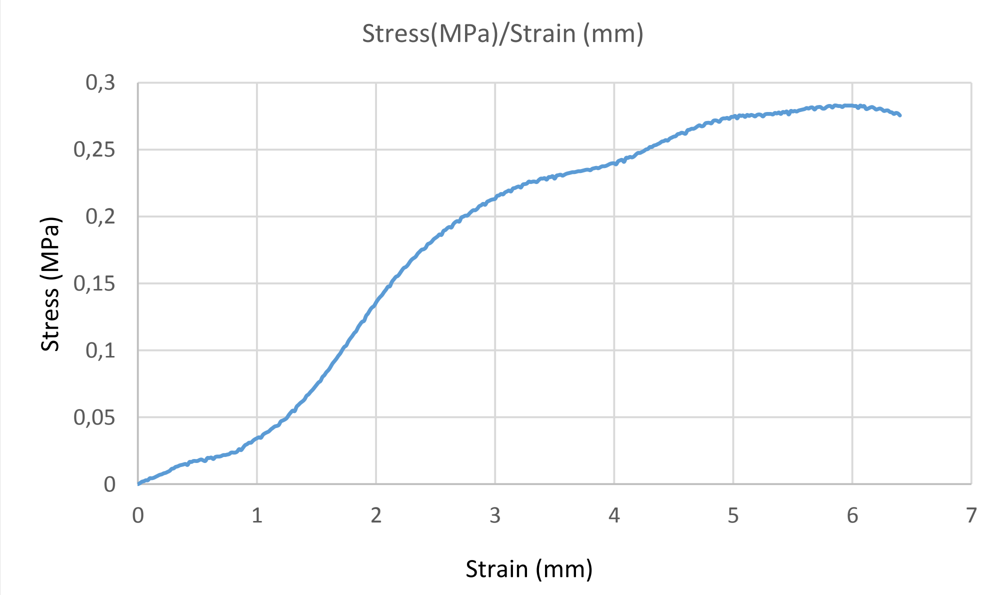

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	3 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	514.700	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	429.800	L/D	2.000
Mass of Container (gr.)	145.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	369.500	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	284.600	Strain at failure (mm.)	5.583
Mass of Moisture (gr.)	84.900	Axial Strain %	5.583
Moisture Content %	0.298	Corrected Area (mm2)	2079.604
Specific Gravity (g/cm3)	2.712		
Dry Density (g/cm3)	1.449	**UCS Strength (kPa)**	**295.543**
Bulk Density (g/cm3)	1.882	**Shear Strength (kPa)**	147.772

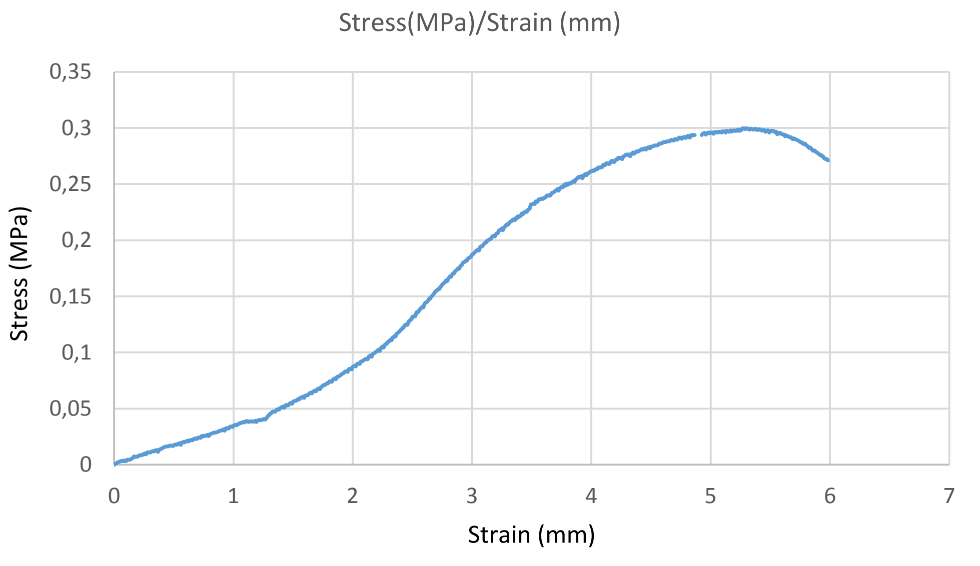

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	503.100	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	414.800	L/D	2.000
Mass of Container (gr.)	132.900	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	370.200	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	281.900	Strain at failure (mm.)	5.733
Mass of Moisture (gr.)	88.300	Axial Strain %	5.733
Moisture Content %	31.323	Corrected Area (mm2)	2082.913
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.436	**UCS Strength (kPa)**	**318.560**
Bulk Density (g/cm3)	1.885	**Shear Strength (kPa)**	159.280

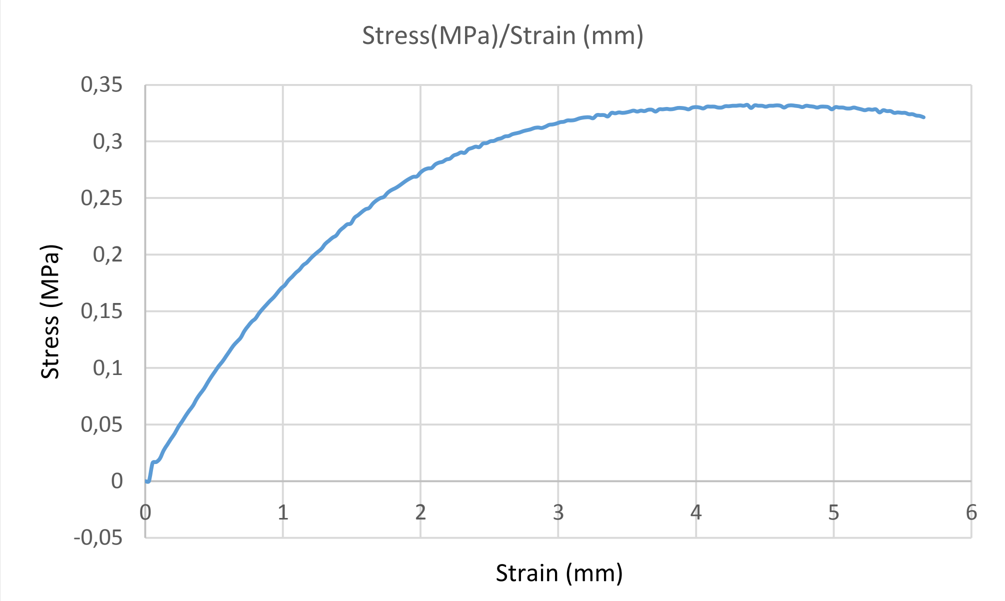

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	502.500	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	415.800	L/D	2.000
Mass of Container (gr.)	134.700	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	367.800	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	281.100	Strain at failure (mm.)	4.333
Mass of Moisture (gr.)	86.700	Axial Strain %	4.333
Moisture Content %	30.843	Corrected Area (mm2)	2052.432
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.432	**UCS Strength (kPa)**	**311.996**
Bulk Density (g/cm3)	1.873	**Shear Strength (kPa)**	155.998

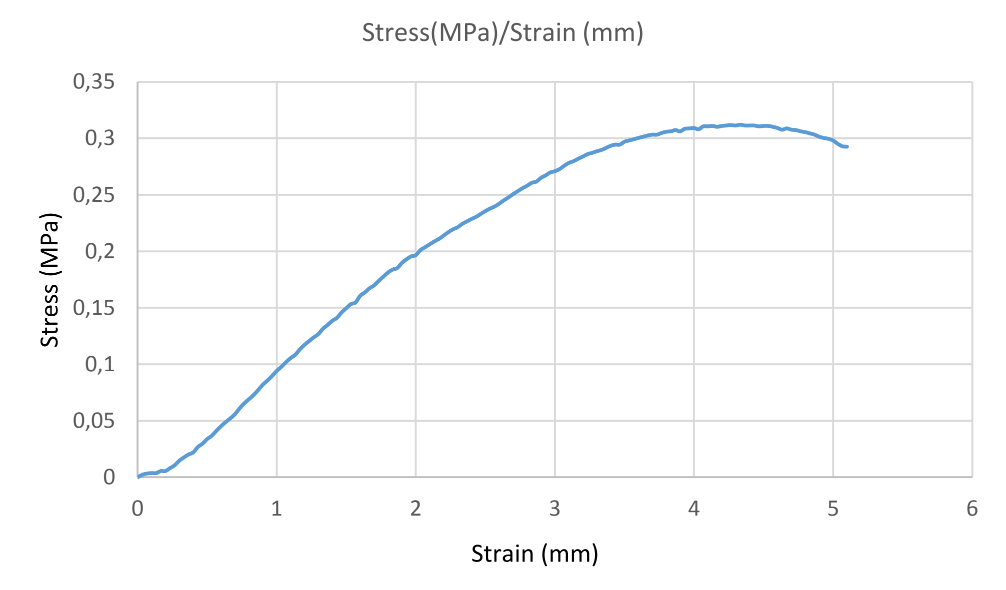

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	6 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	533.000	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	445.700	L/D	2.000
Mass of Container (gr.)	163.100	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	369.900	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	282.600	Strain at failure (mm.)	5.100
Mass of Moisture (gr.)	87.300	Axial Strain %	5.100
Moisture Content %	30.892	Corrected Area (mm2)	2067.966
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.440	**UCS Strength (kPa)**	**316.017**
Bulk Density (g/cm3)	1.885	**Shear Strength (kPa)**	158.009

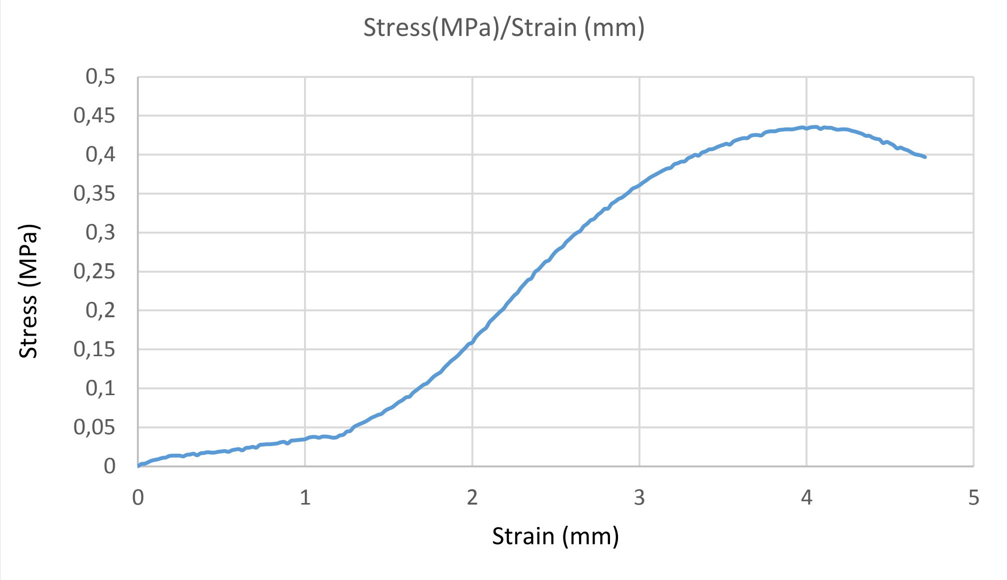

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	28days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		
Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	197.231	Initial Length (mm.)	100.500
Mass of Cont. + Wet Soil (gr.)	516.600	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	425.500	L/D	2.010
Mass of Container (gr.)	144.700	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	371.900	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	280.800	Strain at failure (mm.)	5.180
Mass of Moisture (gr.)	91.100	Axial Strain %	5.154
Moisture Content %	32.443	Corrected Area (mm2)	2069.149
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.424	**UCS Strength (kPa)**	**285.368**
Bulk Density (g/cm3)	1.886	**Shear Strength (kPa)**	142.684

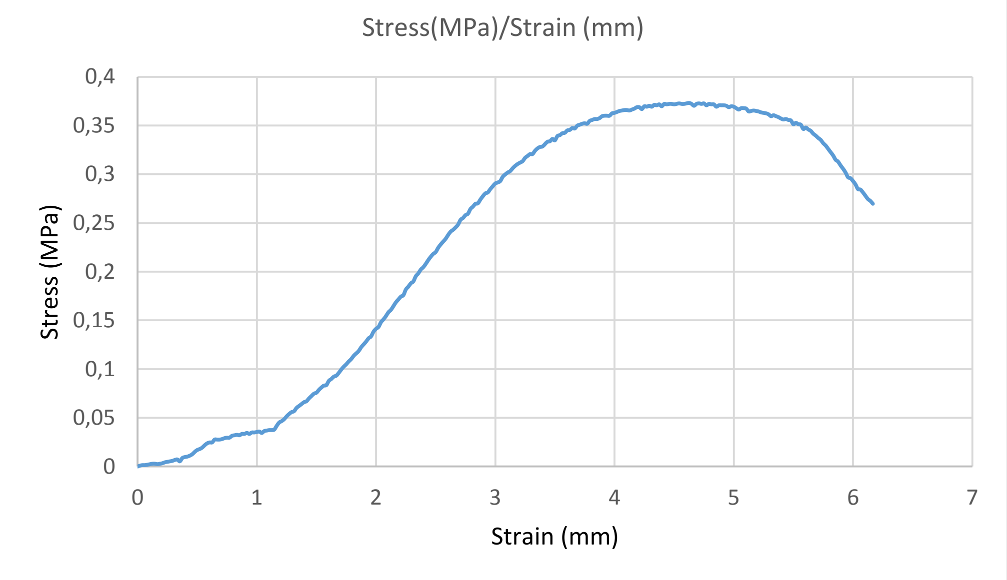

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	516.090	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	424.800	L/D	2.000
Mass of Container (gr.)	147.000	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	369.090	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	277.800	Strain at failure (mm.)	5.750
Mass of Moisture (gr.)	91.290	Axial Strain %	5.750
Moisture Content %	32.862	Corrected Area (mm2)	2082.228
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.416	**UCS Strength (kPa)**	**266.960**
Bulk Density (g/cm3)	1.881	**Shear Strength (kPa)**	133.480

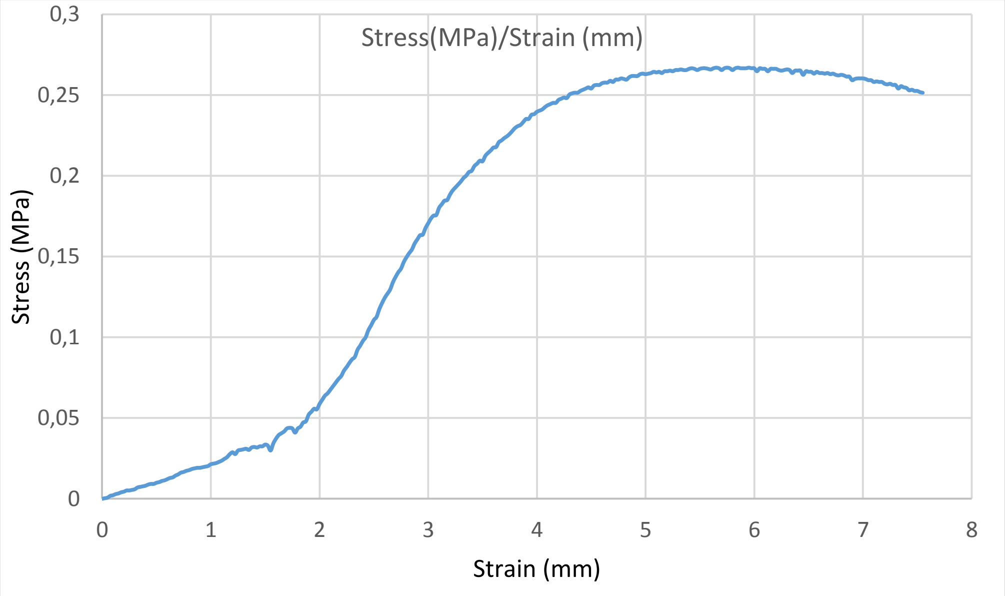

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	10 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.250	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	496.600	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	406.800	L/D	2.000
Mass of Container (gr.)	126.400	Initial Area (mm2)	1962.500
Mass of Sample (gr.)	370.200	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	280.400	Strain at failure (mm.)	5.317
Mass of Moisture (gr.)	89.800	Axial Strain %	5.317
Moisture Content %	32.026	Corrected Area (mm2)	2072.706
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.429	**UCS Strength (kPa)**	**289.330**
Bulk Density (g/cm3)	1.886	**Shear Strength (kPa)**	144.665

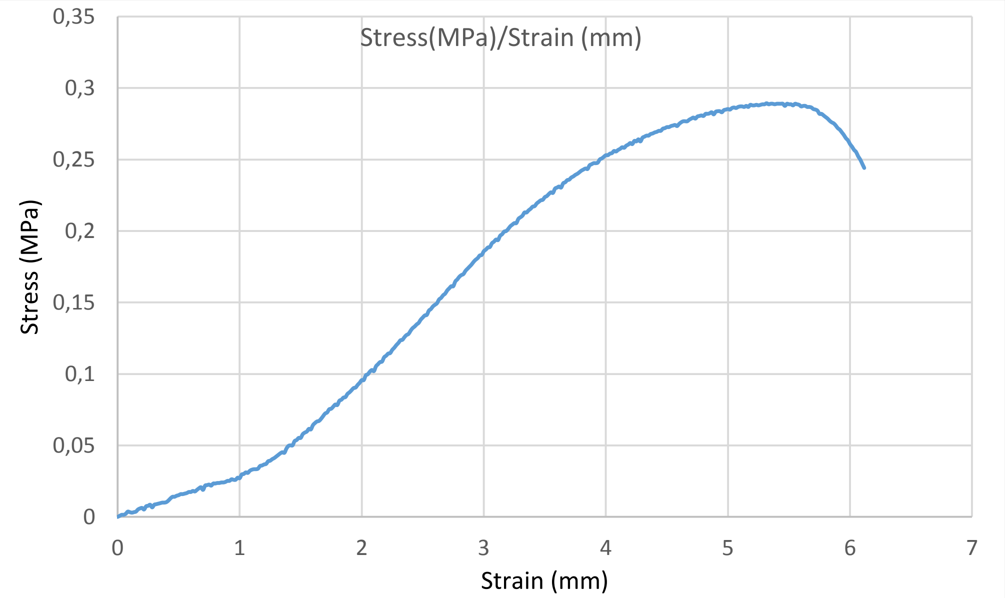

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	1	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	197.332	Initial Length (mm.)	100.500
Mass of Cont. + Wet Soil (gr.)	535.100	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	442.700	L/D	2.010
Mass of Container (gr.)	165.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	369.900	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	277.500	Strain at failure (mm.)	5.739
Mass of Moisture (gr.)	92.400	Axial Strain %	5.710
Moisture Content %	33.297	Corrected Area (mm2)	2082.415
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.406	**UCS Strength (kPa)**	**248.232**
Bulk Density (g/cm3)	1.875	**Shear Strength (kPa)**	124.116

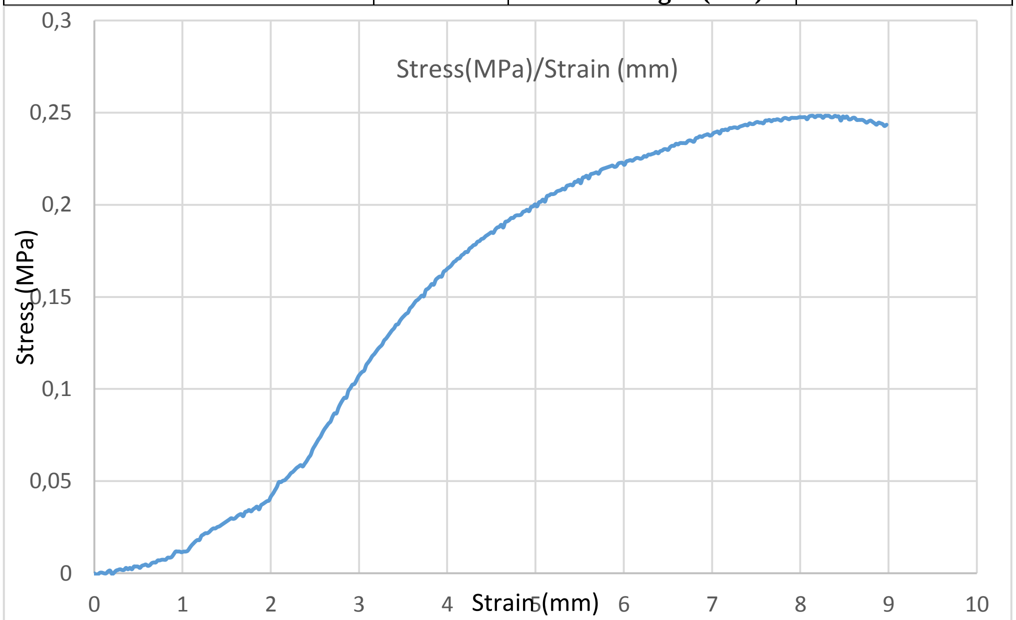

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	7 days	Test Date	05.10.14
Sample Number	2	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	494.210	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	402.700	L/D	2.000
Mass of Container (gr.)	127.200	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	367.010	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	275.500	Strain at failure (mm.)	5.518
Mass of Moisture (gr.)	91.510	Axial Strain %	5.518
Moisture Content %	33.216	Corrected Area (mm2)	2078.174
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.403	**UCS Strength (kPa)**	**258.093**
Bulk Density (g/cm3)	1.869	**Shear Strength (kPa)**	129.047

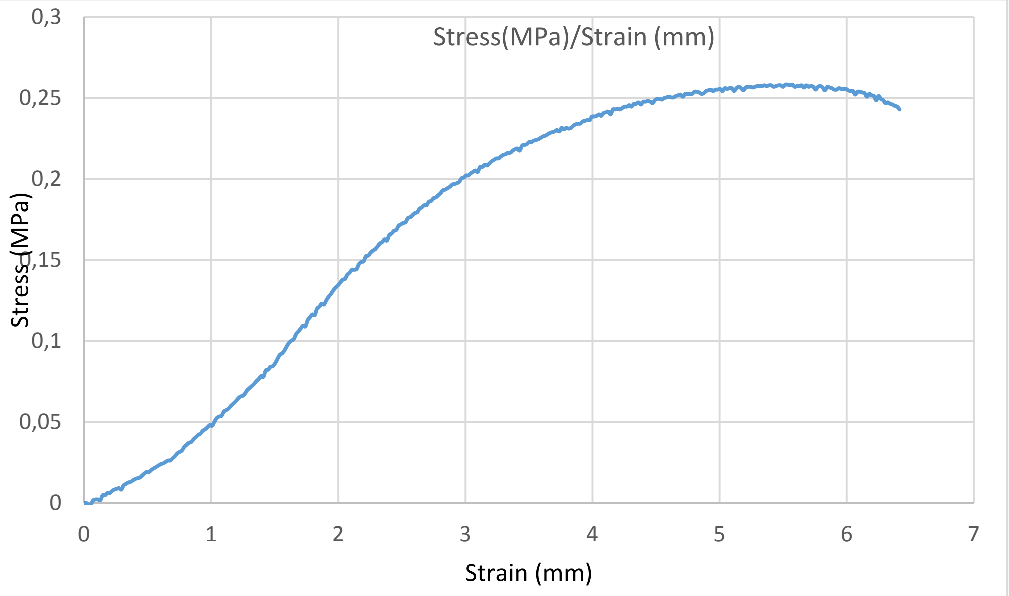

Figure H.1 (Continued)

Middle East Technical University
Transport Laboratory
Unconfined Compressive Strength Test Data Sheet

Project Information			
Project Name	15 BS	Prep. Date	05.10.14
Curing Period	28 days	Test Date	05.10.14
Sample Number	3	Tested By	Can CEYLAN
Standard	ASTM D 2166	Device	ELE Multip50
Soil Classification	CH		
Location	METU Transport Lab.		
Condition of Sample	Disturbed-Remolded-Unsoaked		

Specimen Properties and Unconfined Compressive Strength			
Initial Volume (cm3)	196.350	Initial Length (mm.)	100.000
Mass of Cont. + Wet Soil (gr.)	509.000	Initial Diameter (mm.)	50.000
Mass of Cont. + Dry Soil (gr.)	417.200	L/D	2.000
Mass of Container (gr.)	143.000	Initial Area (mm2)	1963.500
Mass of Sample (gr.)	366.000	Strain Rate (mm./min.)	1.250
Mass of Dry Sample (gr.)	274.200	Strain at failure (mm.)	5.973
Mass of Moisture (gr.)	91.800	Axial Strain %	5.973
Moisture Content %	33.479	Corrected Area (mm2)	2088.230
Specific Gravity (g/cm3)	2.706		
Dry Density (g/cm3)	1.396	**UCS Strength (kPa)**	**246.620**
Bulk Density (g/cm3)	1.864	**Shear Strength (kPa)**	123.310

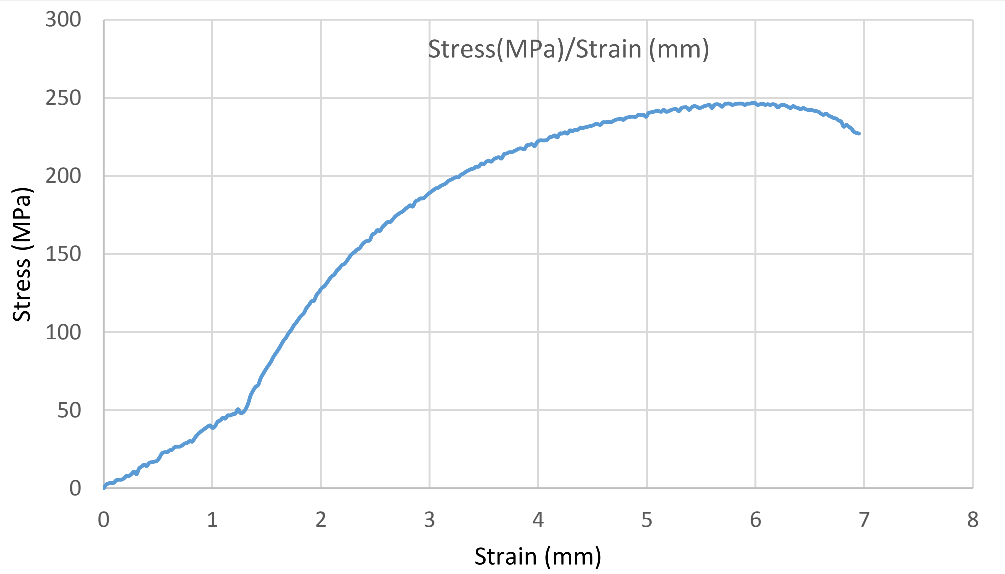

Figure H.1 (Continued)