Effect of Date Seed-Ash Stabilization on the Behavior of Expansive Soil

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ABSTRACT

One of the challenges that has been faced by civil engineers is the damage to structures due to expansive soils. When such soils get wetted, their volume increase and due to drying, they shrink and the volume decreases. Consequently, this causes serious damages especially to lightly loaded buildings and pavements. In this study, an attempt has been made to solve the expansive soil problem in Gazimagusa, North Cyprus by using the waste product, date seed ash, DSA as a soil stabilizer. In Libya, the dates are cheap and available in huge amounts. The seeds of dates are the waste generated by some factories producing dates' jam. In the study, laboratory tests have been performed to study the effect of DSA as a soil stabilizer on the expansion and compressibility of the expansive soil. The effect of wetting-drying cycles on the volume change characteristics of the soil was also investigated. The soil was mixed with three percentages of DSA: 4%, 6%, and 8 % and laboratory tests were performed on both natural and treated soils. These tests include the hydrometer, compaction, Atterberg limits, unconfined compression, one-dimensional consolidation-swelling, cyclic wetting-drying and California Bearing Ratio (CBR) test. Test results show that addition of DSA into the soil resulted in a decrease in the plasticity and the swelling potential of the treated soils. However, DSA treatment caused a reduction in the unconfined compressive strength due to reduction in dry density of the treated soils. DSA treatment did not contribute to the improvement of the CBR value of the treated soils. From the obtained results, it can be concluded that DSA could be a good soil stabilizer for improving the plasticity and the swelling properties of the expansive soil but no improvement in the unconfined compressive strength and the CBR number was obtained.

Keywords: Compressibility, date seed ash, expansive soil, plasticity, soil stabilization, swelling soil, wetting-drying cycles.

ÖZ

İnşaat mühendislerinin karşılaştıkları sorunlardan bir tanesi de şişen zeminlerden dolayı yapıların zarar görmesidir. Zemin ıslandığı zaman, hacimleri artmakta kurumaya maruz kaldıklarında ise, büzülmektedirler. Bunun neticesinde, özellikle hafif yüklü bina ve kaldırımlarda ciddi hasarların meydana gelmesine neden olmaktadır. Bu çalışma kapsamında, Gazimağusa, Kuzey Kıbrıs'da şişen zemin problemini çözebilmek için zemin stabilizasyon malzemesi olarak atık ürün olan hurma çekirdeği külü, HÇK kullanılmıştır. Libya'da hurma çok ucuz ve oldukça bol miktarda bulunmaktadır. Hurma çekirdeği, hurma reçeli üreten bazı fabrikalardan atık malzemesi olarak ortaya çıkmaktadır. Bu çalışmada, zemin stabilizasyon malzemesi olarak HÇK'nin doğal şişen zeminde kabarma ve sıkışabilme karakterine etkisini çalışabilmek için laboratuvar deneyleri gerçekleştirilmiştir. Tekrarlı ıslatma-kurutmanın şişme ve büzülme karakterine etkisi de incelenmiştir. Doğal şişen zemin üç farklı HÇK yüzdesi: 4%, 6% ve 8% ile karıştırılmış ve doğal ve stabilize edilmiş zemin üzerinde laboratuvar deneyleri yapılmıştır. Yapılan bu deneyler hidrometre, kompaksiyon, Atterberg limitler, serbest basınç, tek yönlü konsolidasyon ve şişme, tekrarlı ıslatıp-kurutma şişme deneyi ve California Taşıma Oranı (CBR) deneyi içermektedir. Labaratuvar deney neticeleri göstermektedir ki HÇK'nü zemine karıştırmak plastisite endeksi ve şişme potansiyelinde düşmeye neden olmuştur. Ancak, HÇK stabilizasyonu, stabilize edilmiş zeminin düşük kuru yoğunluğundan dolayı zeminin serbest basınç mukavemet değerinin düşmesine neden olmuştur. HÇK stabilizasyonu, stabilite edilmiş zeminin CBR değerini iyileştirmede herhangi bir katkı sağlamamıştır. Bu çalışma içerisinde elde edilen neticelerden, HÇK stabilizasyonunun şişen zeminin plastisite ve şişme özelliklerini iyileştirmede iyi bir iyileştirme

malzemesi olduğu ancak serbest basınç mukavemeti ve CBR sayısını iyileştirme için uygun olmadığı neticesi ortaya çıkarmaktadır.

Anahtar Kelimeler: Sıkıştırma, hurma çekirdeği külü, şişen zemin, plastisite, zemin stabilizasyonu, şişen zemin, ıslatma-kurutma döngüsü.

I dedicate this thesis to my parents Mr. Abdelkader Sahad and, Mrs. Sabah Alazouzi who never failed to guide me to be successful in my study and my life.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
$^{\circ}C$	Celsius
C_c	Compression Index
CH	Clay with high plasticity
C_r	Rebound index
c_u	Undrained cohesion values
C_v	Consolidation coefficient
DSA	Date seed ash
g/cm^3	grams per cubic centimeter
Gs	Specific Gravity
kPa	Kilopascal
LL	Liquid limit
LS	Linear shrinkage
mm	Millimeter
No.	number
PI	Plasticity index
PL	Plastic limit
q_u	Unconfined Compressive Strength
RHA	Rice husk ash
TSF	Ton (U.S.) Per Square Foot
US	The United States

USCS	Unified Soil Classification System
w_{opt}	Optimum water content
μm	Micrometer

Chapter 1

INTRODUCTION

1.1 Research Significance

Expansive soils is one of the most common problems that challenge geotechnical engineers. Because of its ability to increase in volume when absorb water, expansive soils can cause a considerable damage to existing infrastructures and buildings. Consequently, expansive soils result in great financial losses, and it is considered to be a cause of risk to population (Seco & García, 2011).

As a result of the highly cost repair methods of the damage associated with expansive of soil, such soils have been the focus of many researchers during the last years. However, because of the variety of mineral composition, expansive soils are very likely to behave differently under the same conditions. For this reason, engineers find it very difficult to develop effective-unified stabilization procedures, therefore, the development of new procedure is still undergoing in the research. The primary goal of this study is to provide literature review of some of main previous studies conducted on the topic of soil stabilization. As for the practical side, since expansive soils are highly affected by the seasonal fluctuation of water table, the current study addresses the efficiency of a new technique for improving expansive soils. The proposed technique involves the usage of recycled waste material, date seeds, to improve the properties of expansive soils. The swelling pressure is the main driving force behind the foundation-damage associated with expansion of clays (Chen, 1988). As the moisture content of the soil increases, the swelling pressure increases. At that instant, the soils start increase in volume and generate an upward pressure on foundations. Consequently, additional tension stresses are produced in the sub-structural elements (ground beams, columns and foundations). In many practical cases, these stresses are not considered in the structural design stage, likely because of the lack of the estimation procedures. As a result, cracks may initiate in the structural elements which can cause reduction in strength and ductility (Basma et al., 1995).

The tendency of clay soils to increase in volume as they absorb water is measured by the so called "swell potential". The higher is the swell potential of clay, the more water it can absorb. The swell potential of a soil is determined by its mineral composition. Interestingly, it has been found that clays with more complex mineral compositions have higher swelling potentials, and therefore can experience higher volumes changes. The increase in volume in expansive clays can be as high as 10% of its original volume (Chen 1988; Nelson and Miller, 1992).

Expansive soils are mostly clay soils. They usually form as a result of weathering of parent rocks (Peck et al., 1974). At microscopic level, expansive soils are characterized by the activity of the montmorillonite group in the crystal structure. It is also noted that expansive clays are defined by their higher plasticity index. Visually, expansive clays are described by colors. They range from black to dark gray. In addition, during rainy seasons, expansive clays become much stickier and quite difficult to walk through (Peck et al., 1974).

Plastic clays and clay shales that often contain colloidal clay minerals, such as the montmorillonites, are the component of expansive soils. They consist of clayey siltstone, marls and saprolites, and sandstone. Some of these soils, particulary dry residual clayeysoil, may swell under low applied pressure but fail under greater pressure. (Murthy, 2002).

Generally, soils that undergo a large volume change upon saturation is called collapsible soils or metastable soils. The volume change may or may not occur due to an additional load, however, it is always associated with great loss of strength (Peck et al., 1974). Meta stable soils are not necessarily clays, saturated loose sand, for example, can exhibit large change in volume which is lead to liquefaction (Murthy, 2002).

Typical types of structural damages associated with soil swelling may include cracks in foundations, floors, and basement walls. In most severe cases, relative movement between stories of building were recorded as a result of soil expansion (Jones& Jefferson, 2012). Therefore, for consideration of foundation design, it is very important to estimate the swell potential for these soils. Expansive potential degrees identification may specified as follows (Bowless, 1978).

Table 2.1: Degrees of Expansive Potential

Liquid Limit, %.	**Plasticity Index, %.**	**Natural Soil Suction (TSF).**	**Degree of**
> 60	> 35	> 4	High
50-60	25-35	1.5-4	Marginal
< 50	< 25	< 1.5	Low

1.2 Outlines of Thesis

The presented work is framed in five chapters. The first chapter contains the aim of the study: problem statement, study objectives and research methodology. The second chapter presents the literature review. Then in the third chapter, the methods and standards which have been used in the laboratory for this study are illustrated. The laboratory work results are presented and discussed in the fourth chapter. In the final chapter, the results of the study are summarised, and conclusions and recommendations are drawn.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Any soil or rock material exhibits swelling or shrinkage upon the change in water content is called expansive soil. Their main problem is the unexpected deformation and uneven pattern of movement that leads to a considerable damage to the structures and pavements (Nelson & Miller, 1992).

High expansion and shrink behavior of expansive soils are considered to be very important subject when related to successful civil engineering activities. Expansive soils suffer from shrinkage and result in settlement beneath building during drying period. When they get wetted, they heave causing building or other structures lifting upward. Expansion of the soil also create uplift pressure on the foundations, retaining walls and basement and as a result, lateral movements occur. Expansive soils have serious effects on roads. Underground pipelines, and ground anchors. About 8 % of the world's land is covered by expansive soils. Many methods have been suggested to improve expansive soil characteristics. However an efficient and cost effective technique with less time is more preferable.

They also create pressure on the foundations vertical face, retaining walls and basements and as a result, there will be lateral movements. They affect foundations and building constructions and they have serious effects on roads, underground pipelines, and ground anchors. 20% of India's land is almost covered by expansive soils. About 8% of the world's land is covered by expansive soils. Therefore, they should be considered for activities of the pavement and the construction in order to they have problematic nature. Many methods have been suggested to improve expansive soil characteristics. However an efficient and cost effective technique with less time is more preferable. Lime stabilization is one of the effective methods of expansive soil stabilization (Arumairaj & Sivajothi, 2011).

In this study, the literature survey has been done to know some of the problems and their solutions related to expansive soils. The behavior of expansive soils under wetting-drying cycles is also a very important issue.

2.2 Some Techniques to Solve the Expansive Soil Problems

The following are some suggestions to solve the swelling problem of expansive soils.

2.2.1 Choosing the Suitable Design of Structure for Expansive Soil

Some of the previous studies have suggested choosing the suitable design of structure for expansive soil. Like Spain traverse tunnel which has been excavated in volcanic origin rock formations in the Canary Islands. The suggestion was choosing a circular or similar cross-sections in order to come over the swelling problem of expansive soil. (Pérez-Romero et al., 2007)

2.2.2 Replacement of Expansive Soil

If the expansive soil exists at shallow depth, this problematic soil can be removed and replaced by less expansive soils (Das, 2015).

2.2.3 Changing the Nature of Expansive Soil

2.2.3.1 Compaction

When the expansive soil is compacted to a lower unit weight on the high side of the optimum moisture content, the heave of expansive soils drops considerably.

2.2.3.2 Pre-Wetting

This procedure is used to increase soil water content before construction. The soil is pooled so the soil will reach the maximum of the expansion before loading.

2.2.3.3 Moisture Barriers Installation

Differential heave which has a long term effect can be decreased by the influence of the moisture variation of the soil.

2.2.3.4 Soil Stabilization

It has been proved that it is very effective to apply chemical stabilization by adding lime or cement in to an expansive soil. A soil-lime mixture containing about 5% lime is sufficient in most cases. Pressure injection of lime slurry or lime-fly ash slurry into the soil is another method of expansive soil stabilization, commonly to a depth of 4 to 5 m or in some cases to a greater depth in order to cover the active zone. Lime is applied by adding lime slurry using a pumping system from a tank (Das, 2015).

2.2.4 Stabilization Using Lime Cement and Sarooj

Some other studies have been done using lime, cement, lime and cement combinations. It has been observed that the swell percentage decreased to zero, with the addition of 6% lime into an expansive soil. (Al-Rawas et al., 2005).

2.2.5 Stabilization Using Rice Husk Ash RHA

Rice husk ash together with lime and calcium chloride as a stabilizer material for remolded expansive soil specimens, presented good results. Lime which has been used in the investigation is hydrated lime; Rice-Husk Ash (RHA) which is well-burnt with 425 μm size of particles was used in the investigation for convenient mixing with clay and compaction (Sharma et al., 2008).

2.2.6 Stabilization Using Pyroclastic Rock Dust

To investigate the impact of pyroclastic rock dust in terms of engineering properties of expansive soil experiments has been carried out, and it can be said that pyroclastic rock dust, is very effective as a stabilizer material (Ene & Okagbue 2009).

2.2.7 Stabilization Using Class C Fly Ash

Class C fly ash has a self-cementing property. Because of cation exchange; it was found to be effective in terms of the swelling reduction for expansive soil (Nalbantoğlu, 2004).

2.2.8 Geofibers- Reinforced Expansive Soil

Geofibers have been used to restrain the swelling capacity of expansive soil with a random distribution, and it was useful (Viswanadham et al., 2009).

2.2.9 Effect of Keratin Structure on Expansive Soil Remediation

Avian keratin and a fibrillar protein are the main component of chicken feathers, and they have a complex structure, with essential properties such as being chemically inert, hydrophobicity, durability, and their reliant on the specific purpose can change their internal structures, and morphological. The benefit of these features has been achieved. Swell-consolidation, one-dimensional tests were performed on specimens, using methylene blue. Random distribution and interaction between soil and keratin structures were conducted. The outcomes indicate that when the distribution of fibers is random, it becomes effective in limiting the expansive soils expansion affinity (Montes et al., 2015).

2.2.10 Effect of Cyclic Wetting Drying on Expansive Soil

Figure 2.1 shows the roller– coaster road surface due to expansive soil (Wang et al., 2013). Soils expansive behavior is controlled or affected by many factors: the existence of the amount of clay particles and moisture of the soil comes first. The surcharge pressure and the state of the soil in terms of dry density and the water content, soil type, and non- expansive material amount determine the expansive soil behavior. Generally, the expansion potential rises as the dry density increases and the moisture content declines. Expansive soils behavior which is associated with wetting and drying cycles has been of great interest for many recent studies. Many researchers have tried to subject remolded clay samples to maximum expansion. At that time, the researchers dried up to the first water content. This method was repeated, after each cycle. After wetting drying cycles, the soil exhibited an irreversible wetting and drying deformation. Almost no volume change in remolded clay was recorded after a minimum 3 or 4 drying and wetting cycles (Dif and Blumel, 1991). The wetting and drying behavior in terms of changing moisture content, void ratio has been studied by Tripathy et al. (2002). The behavior of expansive soils under chemical influence has been investigated by several studies (Estabragh et al., 2015).


Figure 2.1: Typical "roller– coaster road (Wang et al., 2013)

2.2.11 Effect of Seawater on Expansive Soil Properties

Seawater effects on different expansive soils properties were studied and compared with the results when using tap water. Reduction in free swell index and swell pressure of clay mineral was caused by sea water addition. Due to treatment with sea water, the compressibility of the clay soil reduced. And an increase in the California bearing ratio value was obtained (Arumairaj & Sivajothi, 2011).

Eshaher, 2011 used date seed ash as a brick material in manufacturing of bricks. The results showed an incense in water absorption, and decrease in density and compressive strength (Eshaher, 2011).

However, none of the previous studies tried to solve the problem of expansive soils using date seed ash or study the effect of wetting-drying cycles for date seed ash stabilized expansive soil. The aim of this study is to use the date seed ash as a chemical soil stabilizer for expansive soil.

Chapter 3

MATERIALS AND METHODS

3.1 Introduction

This chapter focus on the methods and test procedures which have been presented and explained already. Tests have been carried out on natural and date seed ash, DSA treated soils were stated and the effect of DSA on expansive soil was analysed.

A detailed experimental work was performed to identify and compare the behavior of the natural expansive soil, and date seed ash stabilized expansive soil. The physical and engineering properties, such as one-dimensional swelling and compressibility, unconfined compressive strength and California Bearing Ratio (CBR) were determined. Most laboratory tests were conducted according to American standards ASTM, excluding the linear shrinkage test; which was performed according to British standard 1377.

3.2 Materials

The test materials used in this study were naturally existing expansive soil tested and date seed ash.

3.2.1 Expansive Soil

The soil which has been used in this study was an expansive soil. Different laboratory experiments have been conducted on an expansive clayey soil that has been collected from the Eastern Mediterranean University campus, Famagusta, North Cyprus.

The soil was taken from the field which was put in plastic packets and carried to Soil Mechanics Laboratory, Eastern Mediterranean University (EMU). The soil was placed in trays at 50◦C oven before conducting any tests. In this investigation, hydrometer analysis was performed to determine the particle sizes of the fine grained soils. The compaction characteristics: the optimum moisture content, w_{opt} and the maximum dry density, $\rho_{d\,(max)}$ of the natural soil have been determined by using the standard proctor compaction test. For preparing test samples for swell, consolidation, unconfined compression, CBR, and cyclic wetting-drying tests, the specimens were prepared and compacted at optimum water content.

Table 3.1: Physical Properties of the Natural Soil.

Soil property	**Values**
Fraction of clay size (< 2µm) [a] (%)	60.00
Fraction of silt size (2µm-74 µm) [a] (%)	38.00
Fraction of sand size (≥74 µm) [a] (%)	02.20
Maximum dry density [b], ρd (max) (g/cm^3)	01.58
Optimum moisture content, wop (%)	22.50
Specific gravity [c], (Gs)	02.65
Liquid limit [d], LL (%)	58.30
Plastic limit [d], PL (%)	30.50
Plasticity index [d], PI (%)	27.80
Linear shrinkage [e], LS (%)	16.70
Activity [d]	00.46
Soil classification [f], USCS	CH

a According to ASTM D 422-98
b According to ASTM D 698-07
c According to ASTM D 854-06
d According to ASTM D 4318
e According to BS 1377
f According to ASTM D 2487-00 (Unified Soil Classification System, USCS)

The location of expansive soil which has been used in this study is shown in the Figure 3.1, it is behind the stadium of EMU. The location is approximately at latitude 35.14, and longitude 33.90.

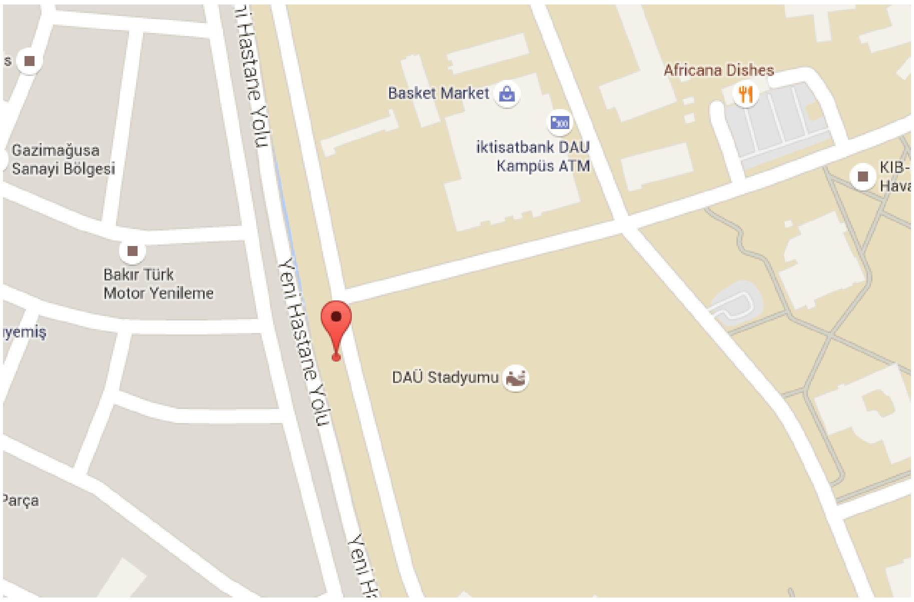

Figure 3.1: Approximate Location of Expansive Soil Used in This Study

3.2.2 Date Seed Ash

Libya is considered as one of the top 10 date producing countries. The number of palm trees in Libya is approximately 2100,000 tree for the area of 28000 ha (El-Juhany, 2010).

The date seeds, have been grinded and used as a coffee in some countries. In the past, the women of the city of "Ghadames" were using the dye of these seeds as a painter material to draw on the walls as a kind of activity in free time.

Date seed was used in this research as a soil stabilizer material has been burnt in an oven at 250 ˚C temperature. Then it has pulverized in the grind machine. Date seed ash was the stabilizer material (pozzolanic) used in this research. Date seeds have been collected from Eastern Mediterranean University date trees, and also from some trees which are available in streets of " Famagusta" city. The collected date seeds have been burnt in a furnace at 250˚C about one hour. The burning of the seed was performed at the Mechanical Engineering Department laboratory of EMU. Figure: 3.2 shows the particle size distribution of the date seed ash used in this study.

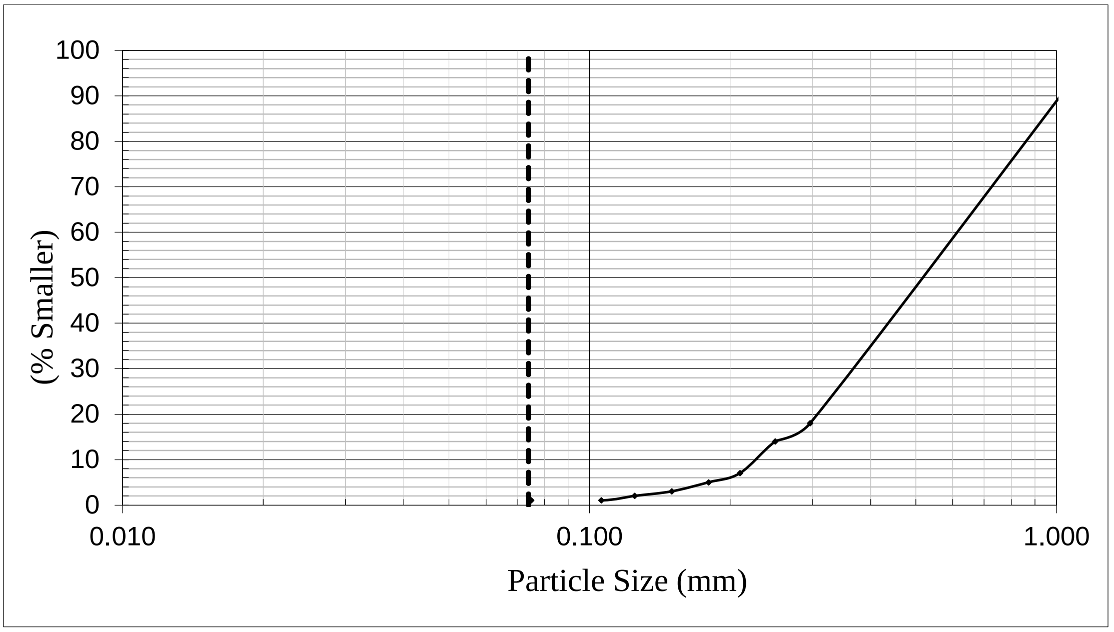

Figure 3.2: Particle Size Distribution Curve of the DSA

3.3 Methods

The following laboratory tests: linear shrinkage, liquid limit, plastic limit, standard Proctor compaction test, unconfined compression, one-dimensional swelling and consolidation, and California Bearing Capacity Ratio, CBR tests were performed on the natural expansive soil and the date seed ash treated soils in order to investigate the effect of date seed ash on the engineering properties of the expansive soil. For this purpose, 3 different percentage of date seed ash were added into the soil: 4, 6 and 8% and all the laboratory tests were performed on both natural and treated soils. Each test was repeated at least three times until reliable results were obtained. As aforementioned, almost all these laboratory tests were conducted according to American standards ASTM excluding the linear shrinkage test.

Figure 3.3: Date Seed Ash Specimens' Preparation

3.3.1 Cyclic Wetting-Drying Tests

Cyclic wetting-drying test specimens were prepared in the same test producer that has been used in consolidation and swelling tests. The specimens were compacted at the optimum water content, and extracted from the standard Proctor compaction mold for testing. Then the specimen was subjected to wetting stage under a surcharge pressure of 7 kPa. The specimen was allowed to swell up to the maximum point until the swelling of the specimen became stable. Then, the drying stage was started and the specimen was dried at 40°C until the specimen returned back to its initial water content. In the beginning, the period of drying was not known, so it has been obtained by trial and error method and the drying duration was calibrated to be around 5 days for natural soil and 1.5 days for the treated soils. The cyclic wetting drying tests were continued until reaching the equilibrium stage. Figures 3.3 and 3.4 show the test set up used for wetting drying tests.

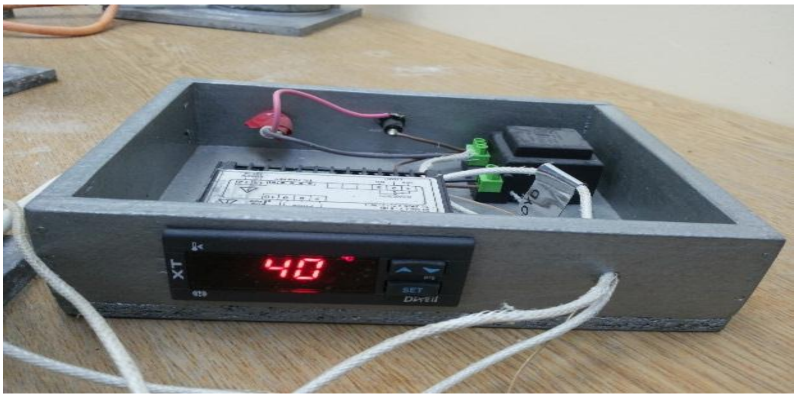

Figure 3.4: The Temperature Controller Used for Drying Stage

During drying, the specimens were surrounded by a flexible heater and the specimens were dried at 40ºC. Figure 3.5 shows the flexible heater and the test set up controller during the drying process.

Figure 3.5: The Flexible Heater and the Test Set up Used for Drying Stage

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

In Chapter 4 of this thesis, the explanation of all the laboratory tests performed in this study has been presented. And in this chapter, discussion and analyzing of all the results have been reported in detail. These results can be divided into two parts: include the analysis of the results of natural expansive soil, plasticity index, swelling characteristics, compressibility, and effect of wetting drying cycles on expansion behavior of this soil whereas, in the second part, all these analysis have been conducted for the date seed ash stabilized expansive soil.

4.2 Natural Soils Properties

The natural clay soil with high plasticity index was subjected to series of tests which have been mentioned in Chapter 3, and the following are the results of these tests.

4.2.1 Hydrometer Test

Figure 4.1 shows the particle size distribution curve of the natural expansive soil. As it can be seen from the figure, percentage of clay particles found in the soil was around 60%.

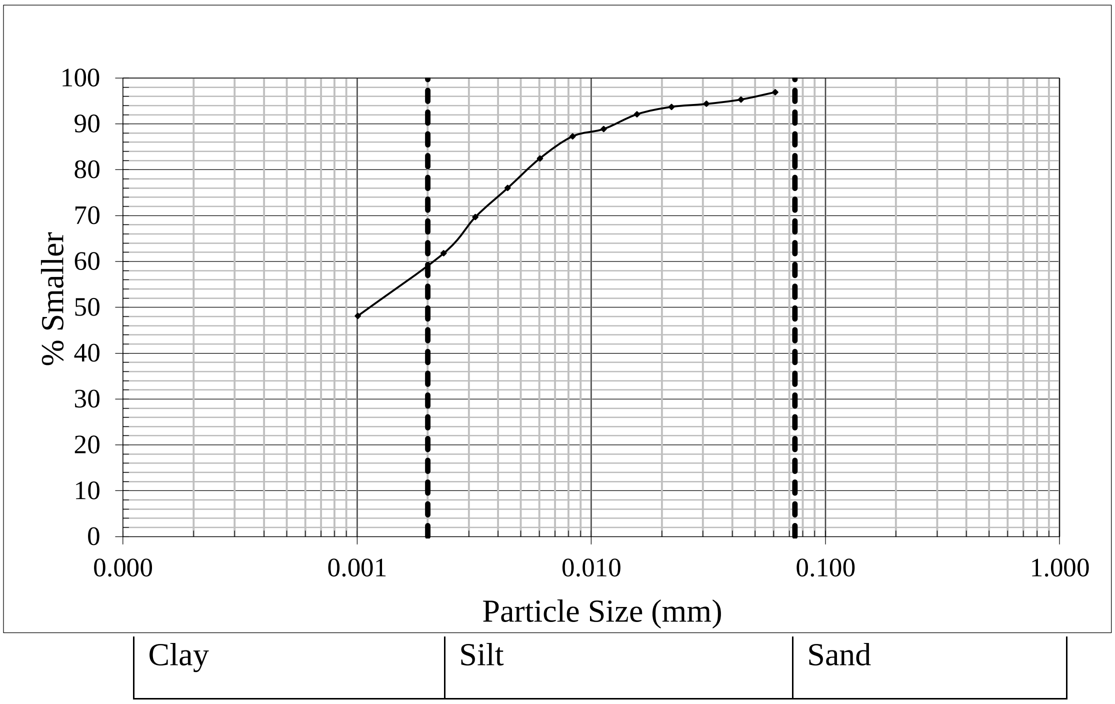

Figure 4.1: Particle Size Distribution of Natural Expansive Soil

4.2.2 Atterberg Limits Test

Atterberg limits are represented by the liquid limit and plastic limit values. These tests were performed according to ASTM D 4318. The results of liquid limit, plastic limit, and the plasticity index values for natural expansive soil were 58, 31, and 28% respectively. According to the Unified Soil Classification System and by using the results of liquid limit and plasticity index values, the soil was classified as CH, clay with high plasticity. Liquid limit, plastic limit, and the plasticity index values for 4% date seed ash treated expansive soil were 55.9, 30.9, and 25.0% respectively. For 6% date seed ash stabilized expansive soil were, 54.8, 30.2, and 24.6% respectively. And for 8% date seed ash treated soil, liquid limit, plastic limit, and the plasticity index values were found to be 51.7, 29.0, and 22.6% respectively. Figure 4.2 shows the comparison between PI for 0, 4, 6, and 8% treated soils.

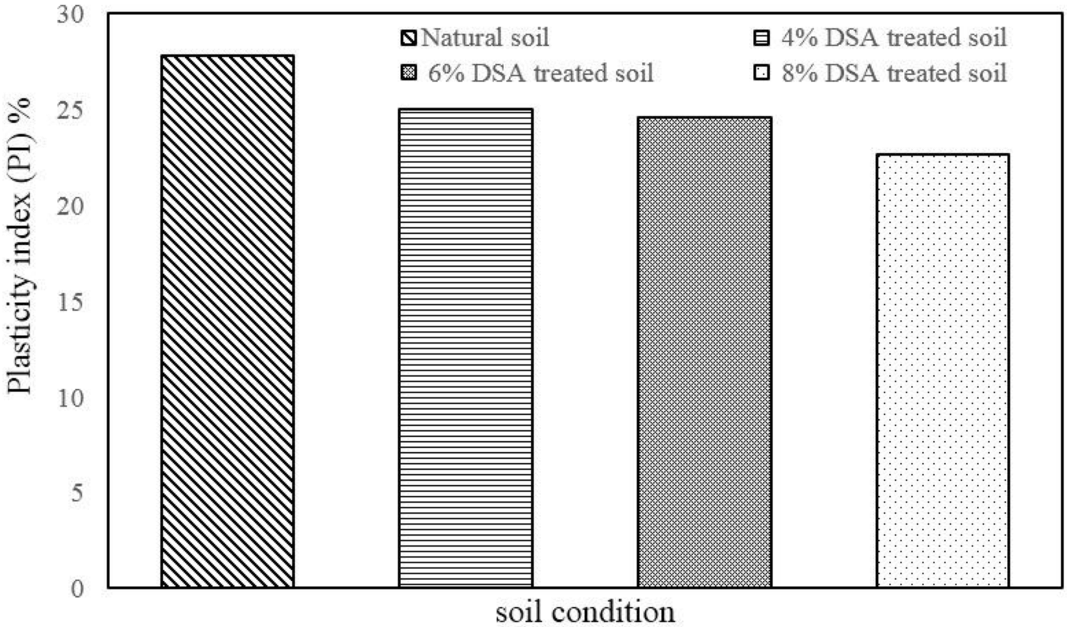

Figure 4.2: Plasticity Index for Natural, 4, 6, and 8% DSA Treated Soils

4.2.3 Linear Shrinkage Test

According to British standard, BS 1377, the linear shrinkage test was conducted on natural and date seed ash treated soils. Result of the linear shrinkage for the 0, 4, 6, and 8% date seed ash treated soil were obtained as 16.7, 14.7, 13.8%, and 12.4% respectively.

4.2.4 Standard Proctor Compaction Test

The dry density versus water content curve obtained from the standard Proctor compaction test for natural soil is given in Figure 4.3. From the figure, the maximum dry density and the optimum water content of the soil were found to be 1.58 g/cm^3 and 22.50%, respectively.

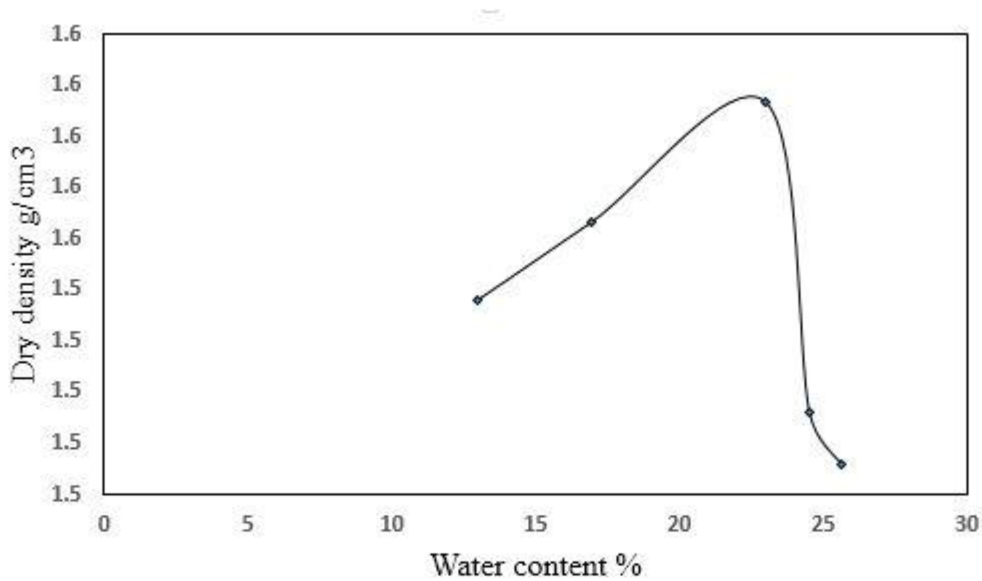

Figure 4.3: The Compaction Curve of Natural Soil

The standard proctor compaction test was also performed on 8% date seed ash treated soil and the results were compared with the results obtained for the natural soil. Figure 4.4 shows the maximum dry density obtained for natural and 8% DSA treated soil. The figure indicates that there is a decrease in the maximum dry density of the treated soil due to the light weight date seed ash particles.

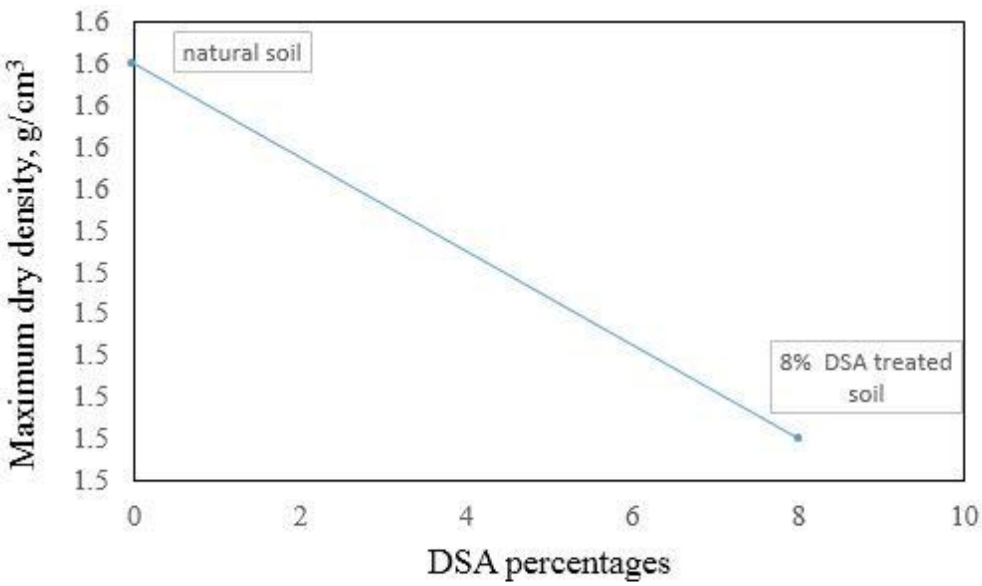

Figure 4.4: Variation of Maximum Dry Density with DSA%

4.2.5 One Dimensional Consolidation and Swelling Test

The standard one dimensional oedometer device has been used and the tests were performed under a surcharge pressure of 7 kPa. The swelling of the natural soil under this surcharge pressure took almost two weeks to stabilize. The percentage of swelling was calculated as the ratio of change in the height of the specimen to the initial height. The results obtained from the swell tests for the natural and date seed ash treated soils were shown in Figure 4.5 and Figure 4.6.

The one dimensional consolidation test was conducted according to ASTM D2435-04 standard. The curves of void ratio-pressure values obtained from the one dimensional consolidation test were shown in Figure 4.5. The compression index (C_c), rebound index (C_r) and consolidation coefficient (C_v) are calculated from the results obtained from the consolidation curve, Figure 4.6 presents the consolidation curves for 8% date seed ash treated soil, and the compressibility characteristics are presented in Table: 4.1.

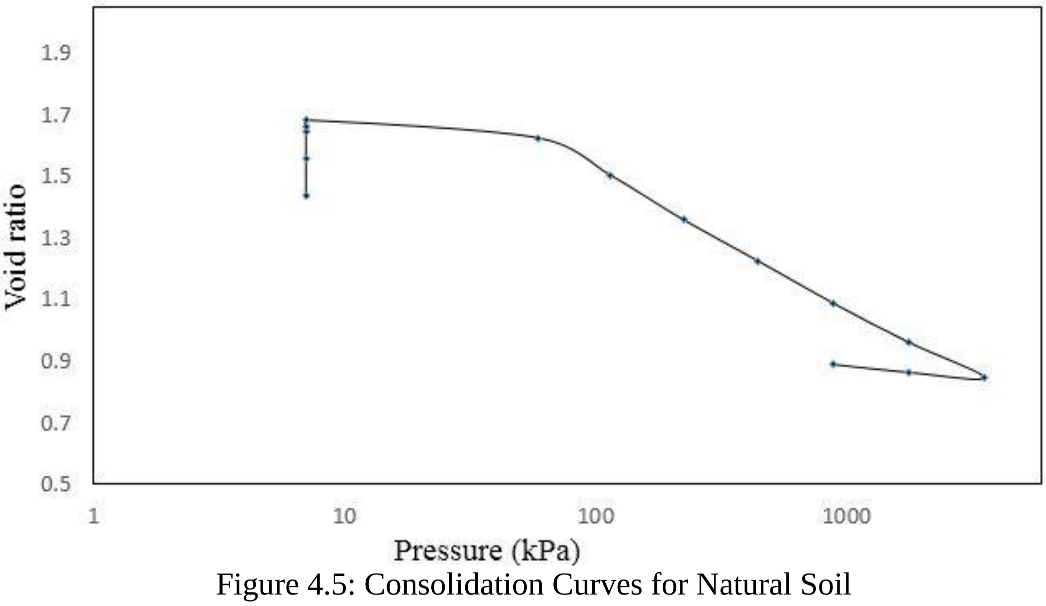

Figure 4.5: Consolidation Curves for Natural Soil

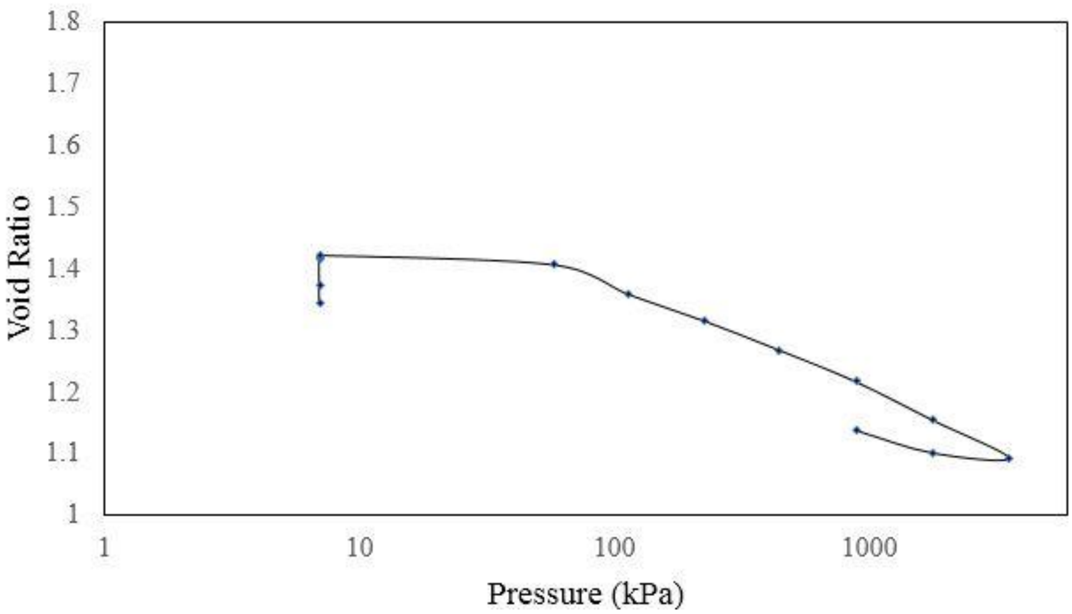

Figure 4.6: Consolidation Curves for 8% DSA Treated Soil

Table 4.1: Compressibility Characters of Natural and 8% DSA Treated Soils

Compressibility characteristics	**Natural soil**	**8% DSA treated soil**
Compression index Cc	0.446	0.161
Rebound index Cr	0.085	0.122
Consolidation coefficient (Cv) m2/min	2.07E-05	4.4911E-06
Swell pressure, (kPa)	180	125

Referring to the obtained results above, due to the lesser values of C_c of the treated soil, it could be concluded that the treated soil has lower ability to be compressed than the natural soil. That can be explained due to the fact that date seed ash particles coat the soil particles and fill the void space in between the particles. So reduction in the void space consequently reduces the compressibility of the treated soils. The curves for the maximum percentage of primary swelling obtained for the natural and date seed ash treated soils are shown in Figure 4.7 and 4.8. Figure 4.7 indicates that the maximum swelling obtained for the natural soil was about 9 % and for 4, 6, and 8%

date seed ash treated soils, the swelling was 1, 0.8, and 0.5 %, respectively. Test results indicate swelling pressure for treated soil was less than that for natural soil. That is in good harmony with the swelling percentage of the natural and treated soils in Figure 4.7 and Figure 4.8. Reduction in the swelling pressure of the treated soil means that swelling of prevented under lower stress values.

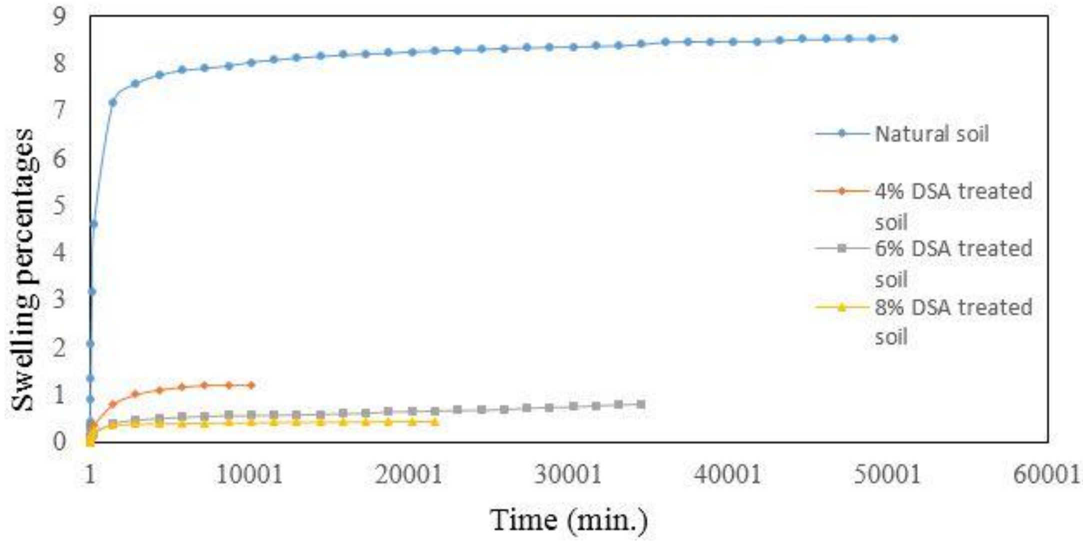

Figure 4.7: Swell-Time Curves for 0%, 4%, 6%, and 8% DSA Treated Soils

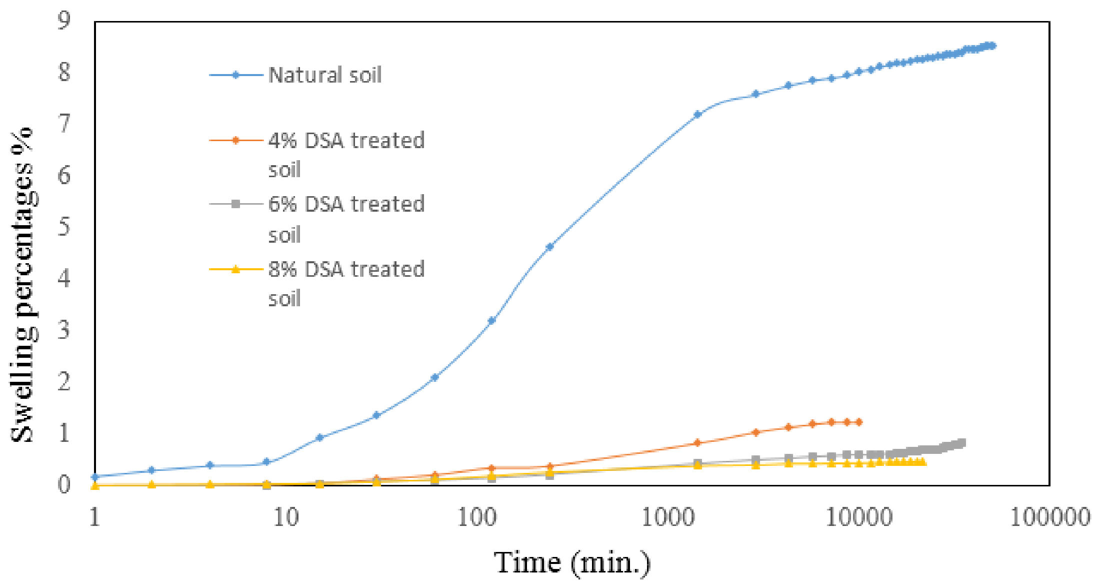

Figure 4.8: Swell-Log Time Curves for Natural, 4, 6, and 8% DSA Treated Soils

4.2.6 Unconfined Compression Test

The unconfined compression tests on natural and date seed ash treated soils were performed to measure and compare the unconfined compressive strength of the natural and treated soils. The curves for unconfined compression were represented in Figure 4.9. In the unconfined compression tests, all the specimens were compacted at the optimum moisture content of the natural soil and the unconfined compression tests were performed. From the figure, it can be seen that the unconfined compressive strength, q_u obtained for the natural soil was 364 kPa. The Figure indicates that treatment of the natural expansive with date seed ash did not improve the unconfined compressive strength of the treated soil. No increment in the unconfined compressive strength of the treated soils was obtained. That can be explained due the reduction in the density of the treated soils causing a reduction in the unconfined compressive strength. Treatment of the expansive soil with light weight date seed ash reduced the dry density and resulted in decrease in the unconfined compressive strength.

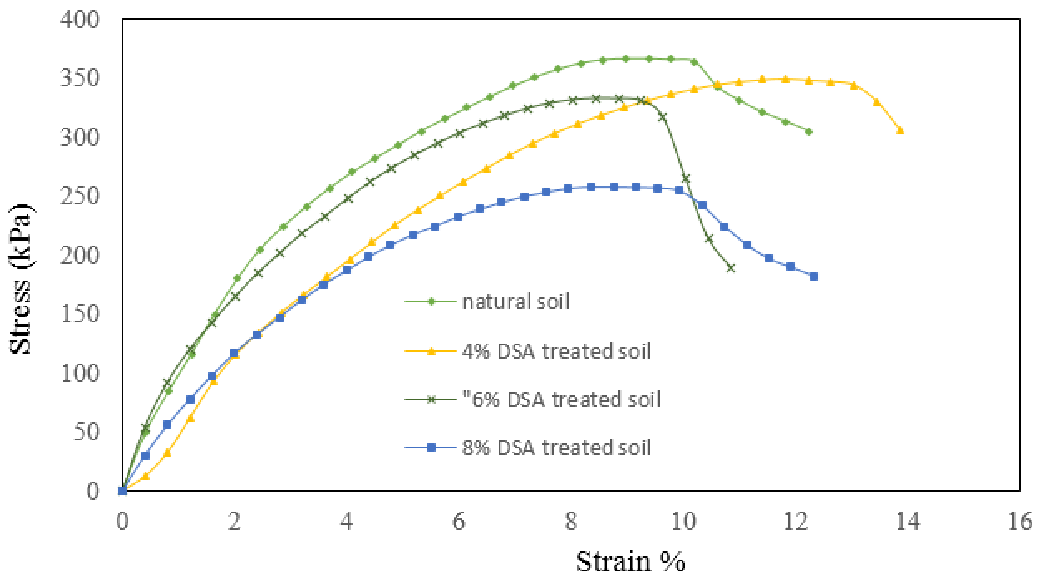

Figure 4.9: Unconfined Compression Curves for Natural and DSA Treated Soils

The undrained cohesion values, c_u for the natural and treated soils were calculated by using the unconfined compressive strength, q_u obtained in unconfined compression test. cu is equal to the half of the unconfined compressive strength, $q_{u.}$ The undrained cohesion values, c_u obtained for the natural and date seed ash treated soils are given in Table 4.2.

Table 2.2: The Undrained Cohesion Values, cu for the Natural and Treated Soils

Percentage DSA (%)	**cu(kPa)**
0	182
4	175
6	167
8	129

From the results in Table 4.2, it can be seen that the date seed ash treatment of the expansive soil caused a reduction of the undrained cohesion values, c_u of the treated soils. It is known that soils with high plasticity have usually higher cohesion. These results obtained in Table 4.2 were in good harmony with the reduction obtained in the plasticity of the treated soils.

4.2.7 California Bearing Ratio, CBR Test

California Bearing Ratio, CBR is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material (Bowles, 1978).

This test is used for calculating the bearing capacity of subgrade pavements. The CBR tests were performed on the natural and date seed ash treated soils and the results were compared in order to see the effect of date seed ash on the CBR value for the subgrade soil. Figure 4.10 shows the un-soaked CBR values obtained for the natural and treated soils.

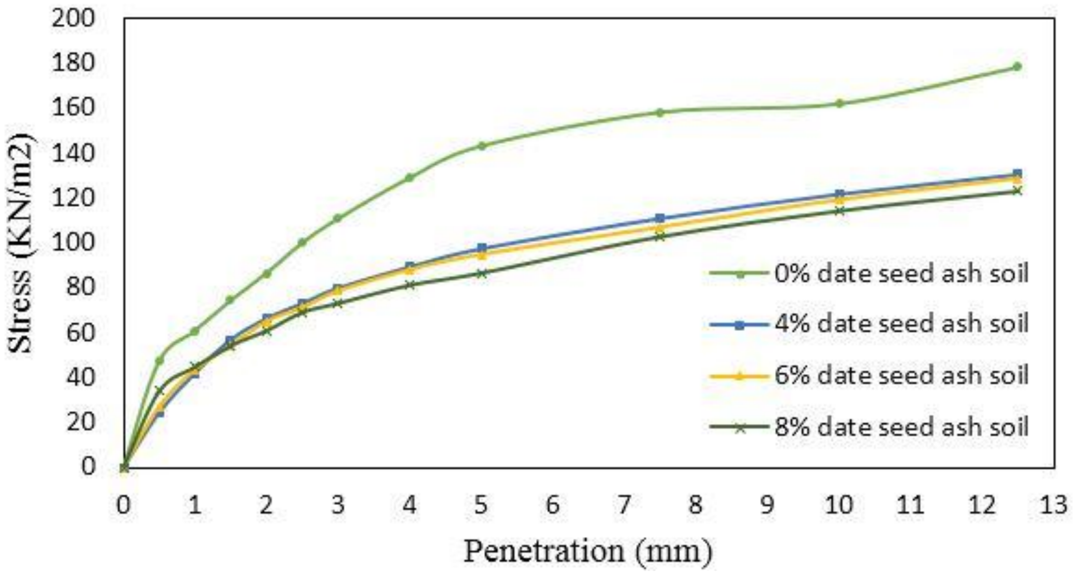

Figure 4.10: The Un-Soaked CBR Curves for Different Percentages of DSA Soil

Table 4.3: Variations of CBR Number with Different Percentages of Date Seed Ash

% of DSA	CBR number for 2.54mm	CBR number for 5.08mm
0	1.45	1.44
4	1.06	0.97
6	1.02	0.92
8	0.99	0.88

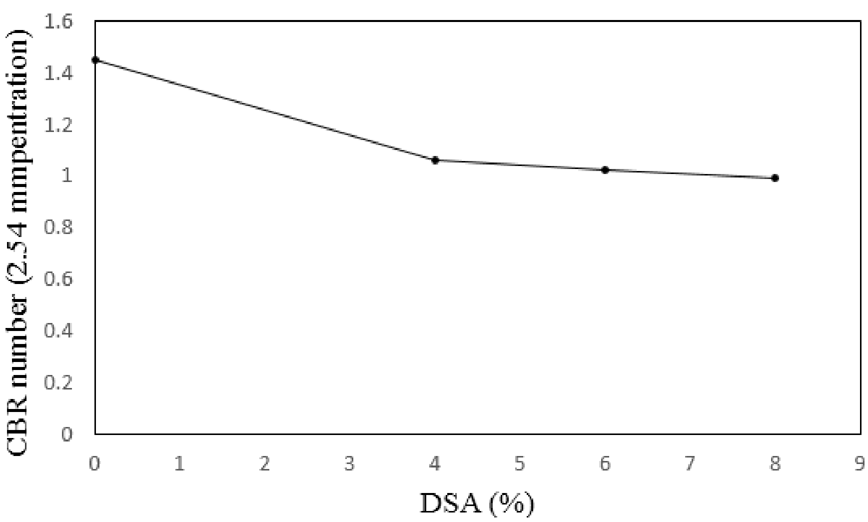

Figure 4.11: CBR Number for DSA Treated Soils for 2.54mm Penetration

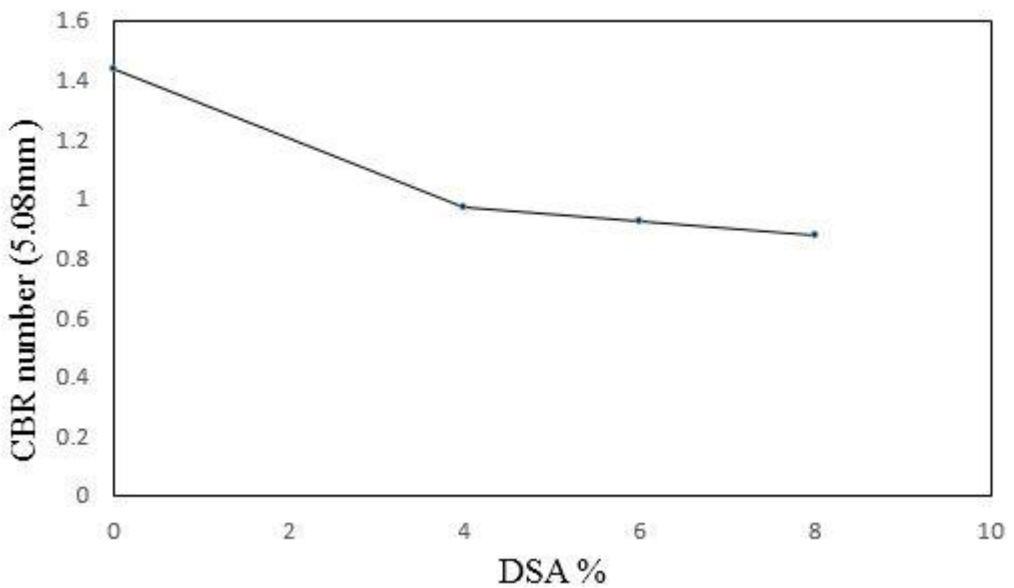

Figure 4.12: CBR Number for DSA Treated Soils for 5.08mm Penetration

According to Table 4.3, Figure 4.11, and Figure 4.12, it can be seen that with increasing percentage of date seed ash, the CBR numbers decreases. The reduction in CBR value is explained due to the reduction in the dry density of treated soils. Because of the low CBR value of both natural and DSA treated soils, the soil is not recommended to be used as bases beneath pavements.

4.3 Effect of Wetting Drying Cycles on the Swelling Behaviour of Expansive Soil

Figures 4.13, and 4.14 show the swelling curves for the natural and 8% DSA treated soils obtained after each wetting drying cycles.

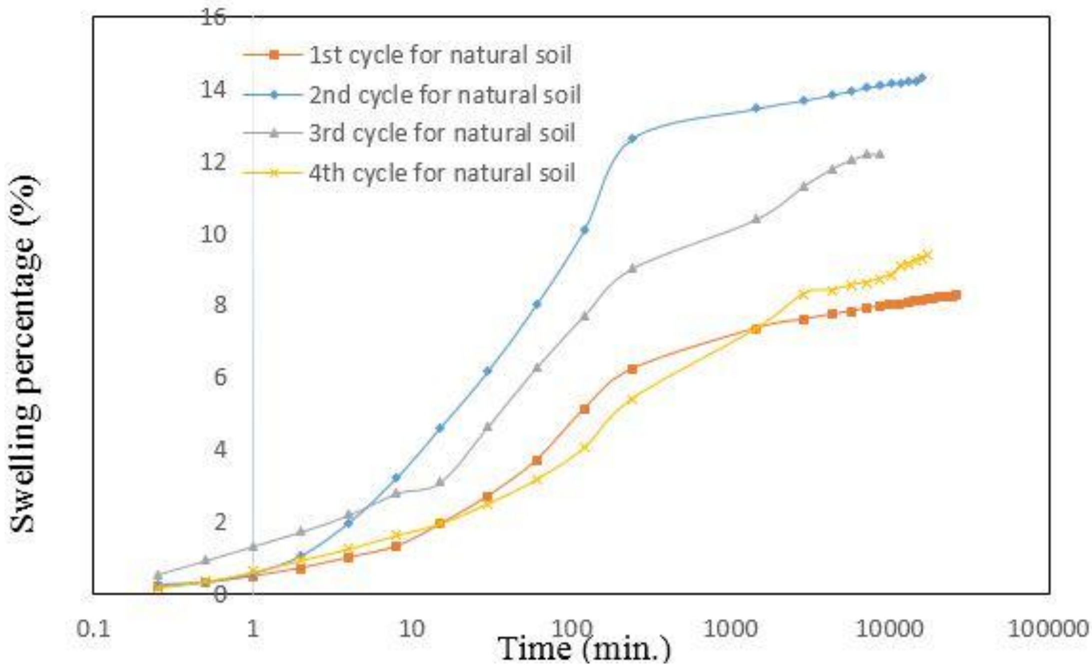

Figure 4.13 Swelling-Log Time Curve for Natural Soil

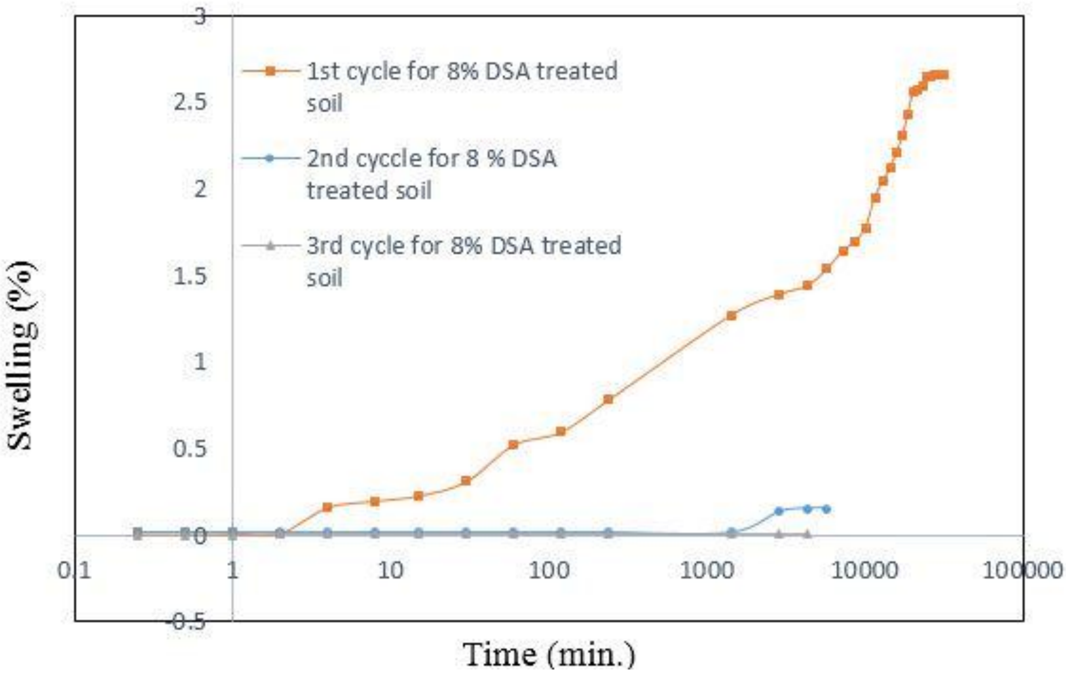

Figure 4.14: Swelling-Log Time Curve for 8%DSA Treated Soil

From the wetting-drying cycles shown in Figures 4.13 and 4.14, it could be said that, the cyclic wetting drying affected the swelling of the natural soil in positive direction.

Figure 4.13 indicated that the swelling of the soil decreased as the number of wetting-drying cycles increased. Although there is an increase just after the second cycle, the swelling started to decrease after that cycle. For the DSA treated soil reduction in the swelling of the soil was obtained even after the first cycle. Figure 4.15 shows that there is a great amount of reduction in the swelling of the treated soils after wetting-drying cycles.

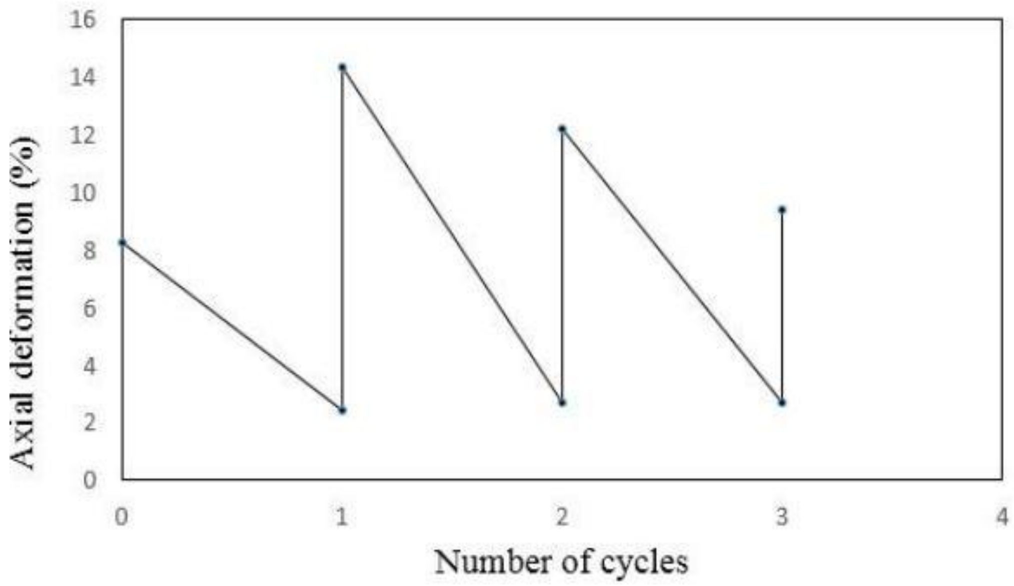

Figure 4.15: Wetting -Drying Cycles for Natural Soil

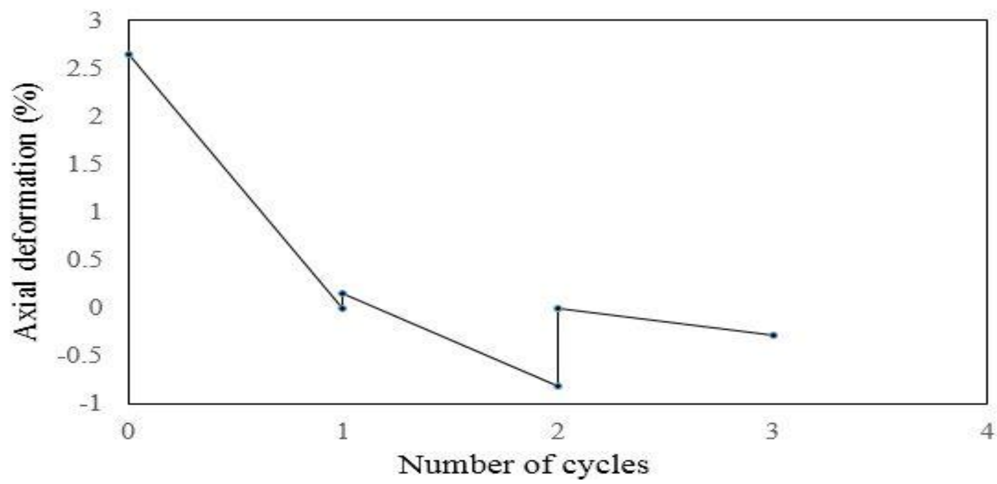

Figure 4.16: Wetting-Drying Cycle for 8% DSA Treated Soil

Figure 4.15 shows the comparison of the swelling percentages obtained after each cycle for natural, 4%and 8% DSA treated soils.

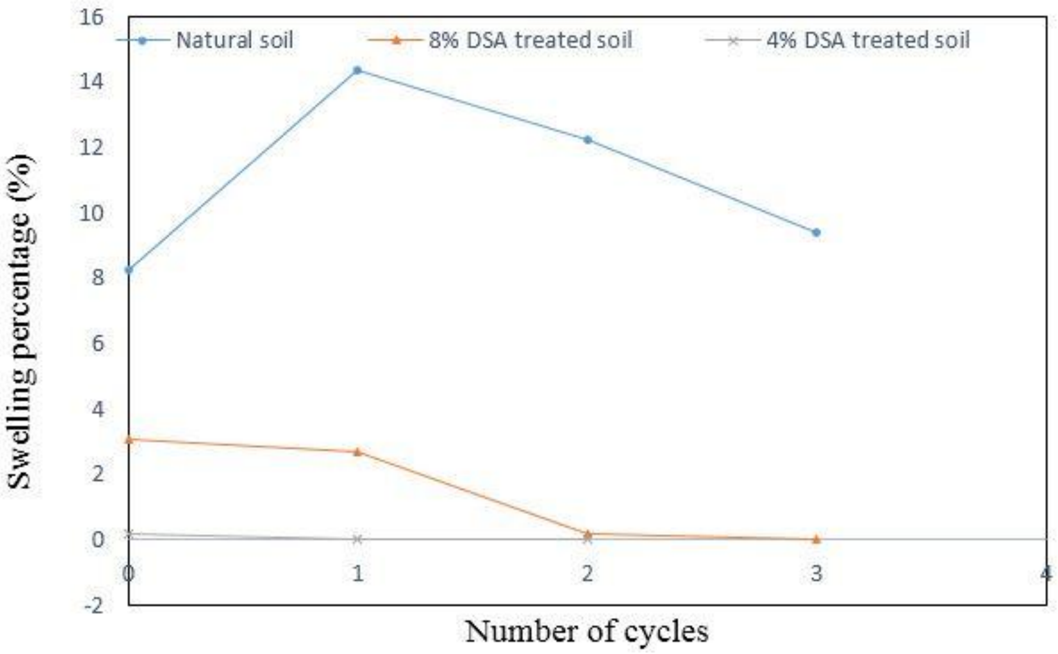

Figure 4.17: The Variation of Swelling Percentage with Number of Cycles for Natural, 4%, and 8% DSA Treated Soil

Figures 4.18 shows the natural and 8% DSA treated soils after the drying process. As it can be seen from the figure, the shrinkage cracks are more in the natural soil after drying, whereas in 8% DSA treated soils, no shrinkage cracks were observed.

Figure (a)

Figure (b)

Figure 4.18: Specimens after Drying (a) Natural Soil, (b) 8% Date Seed Ash Treated Soil

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

- The natural expansive soil which used in this research, is clay with high plasticity, and classified as CH. Maximum dry density was 1.58 g/cm^3 and optimum water content was 22.5 %. The treatment of this soil with date seed ash has been encouraging due to the decrease in the plasticity of the treated soils. The expansive soil used in this research has a high swelling percentage of 8.5 %. Along with the swelling test results obtained in this study, date seed ash treatment improved the swelling properties of the natural expansive soil and the swelling of the soil decreased from 8.5 % to 1.0, 0.8, 0.5 % with 4 ,6 ,8 % of date ash treatment, respectively.

- Test results indicated a decrease in the unconfined compressive strength of the date seed ash treated soils. Treatment of the expansive soil with light weight date seed ash reduced the dry density and resulted in a decrease in the unconfined compressive strength. Consequently, decrease in the undrained cohesion of the treated soils was obtained.

- With increasing percentage of date seed ash, the CBR numbers decreased. The reduction in CBR value was explained by the reduction in the dry density of treated soils. Because of the low CBR value of both natural and DSA treated soils, the soil could not be recommended to be used as bases beneath pavements.

- The date seed ash treated soils have less compressibility than the natural soil. That can be explained due to the reduction in the plasticity of the treated soils. Addition of date seed ash into the high plastic soil decreased the workability and caused a reduction in the compressibility of the treated soils.

- The cyclic wetting drying affected the swelling of the natural soil in positive direction. The swelling of the soil decreased as the number of wetting-drying cycles increased. For the DSA treated soils, reduction in the swelling of the soil was obtained after the first cycle.

5.2 Recommendations for Future Studies

Since the research work needs financial support, effort and time, it is recommended that researchers should carefully choose the suitable stabilizer material for their soils. The availability and the ease of getting such materials should be carefully considered. The curing effect was not considered in the present study. The effect of curing on the engineering properties of the soil should also be considered and the tests should be repeated at different curing periods.

REFERENCES

Al-Rawas, A. A., Hago, A. W., & Al-Sarmi, H. (2005). Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. *Building and Environment*, *40* (5), 681-687.

Basma, A. A., Al-Homoud, A. S., & Husein, A. (1995). Laboratory assessment of swelling pressure of expansive soils. *Applied Clay Science*, *9* (5), 355-368.

Bowless, J. E. (1978). Engineering Properties Of Soil And Their Measurement. *Mc Graw4 international Student Edition 2nd*.

Das, B. (2015). *Principles of foundation engineering*. Cengage learning. Book.

El-Juhany, L. I. (2010). Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. *Aust J Basic Appl Sci*, *4*(8), 3998-4010.

Ene, E., & Okagbue, C. (2009). Some basic geotechnical properties of expansive soil modified using pyroclastic dust. *Engineering Geology*, *107*(1), 61-65. Gillott, J. E. (2012). *Clay in engineering geology* (Vol. 41). Elsevier.

Estabragh, A. R., Parsaei, B., & Javadi, A. A. (2015). Laboratory investigation of the effect of cyclic wetting and drying on the behavior of an expansive soil. *Soils and Foundations*, *55*(2), 304-314.

Flesher, D. L., Samson, W. D., & Previts, G. J. (2003). The origins of value-for-money auditing: the Baltimore and Ohio Railroad: 1827-1830. *Managerial Auditing Journal*, *18*(5), 374-386.

Jones, L. D., & Jefferson, I. (2012). *Expansive soils* (pp. 413-441). ICE Publishing.

Kleiner, F. (2015). *Gardner's Art through the Ages: Backpack Edition, Book F: Non-Western Art Since 1300*. Cengage Learning.

Kumor, M. (2008). Selected geotechnical problems of expansive clays in the area of Poland. *Architecture Civil Engineering Environment*, *1*(4), 75-92.

Pérez-Romero, J., Oteo, C. S., & De la Fuente, P. (2007). Design and optimization of the lining of a tunnel in the presence of expansive clay levels. *Tunneling and underground space technology*, *22*(1), 10-22.

Seco, A., Ramírez, F., Miqueleiz, L., & García, B. (2011). Stabilization of expansive soils for use in construction. *Applied Clay Science*, *51*(3), 348-352.

Sharma, R. S., Phanikumar, B. R., & Rao, B. V. (2008). Engineering behavior of a remolded expansive clay blended with lime, calcium chloride, and rice-husk ash. *Journal of materials in civil engineering*, *20*(8), 509-515.

Thyagaraj, T., Rao, S. M., Sai Suresh, P., & Salini, U. (2012). Laboratory studies on stabilization of an expansive soil by lime precipitation technique. *Journal of Materials in Civil Engineering*, *24*(8), 1067-1075.

Viswanadham, B. V. S., Phanikumar, B. R., & Mukherjee, R. V. (2009). Swelling behavior of a geofiber-reinforced expansive soil. *Geotextiles and Geomembranes*, *27*(1), 73-76.

Wang, M. W., Li, J., Ge, S., & Li, S. T. (2013). Moisture migration tests on unsaturated expansive clays in Hefei, China. *Applied Clay Science*, *79*, 30-35.

APPENDIX

Appendix A: Graphs of Some Tests that have been Repeated

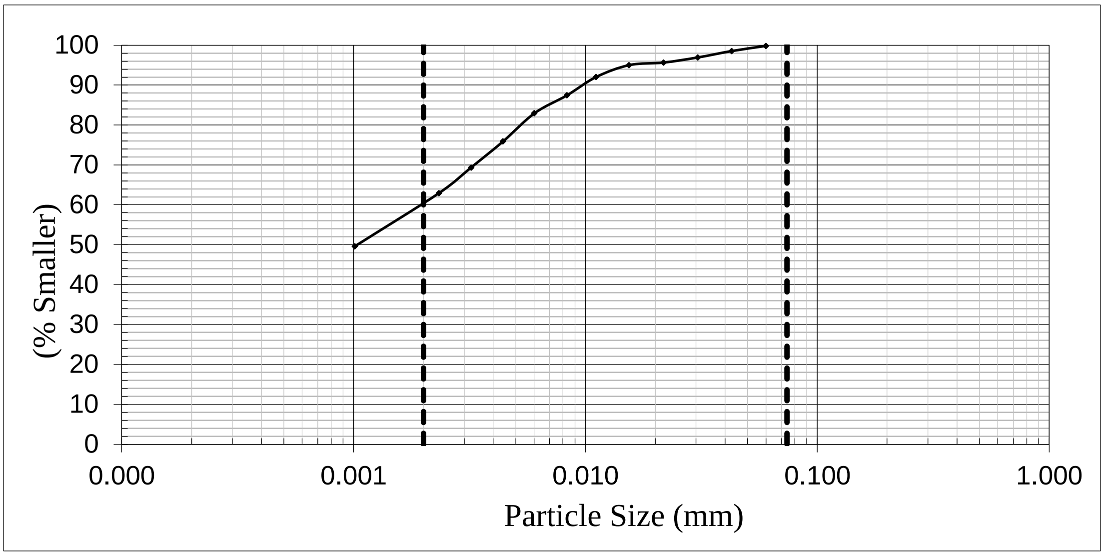

Figure A1: Hydrometer Test Curve for the 2nd Sample

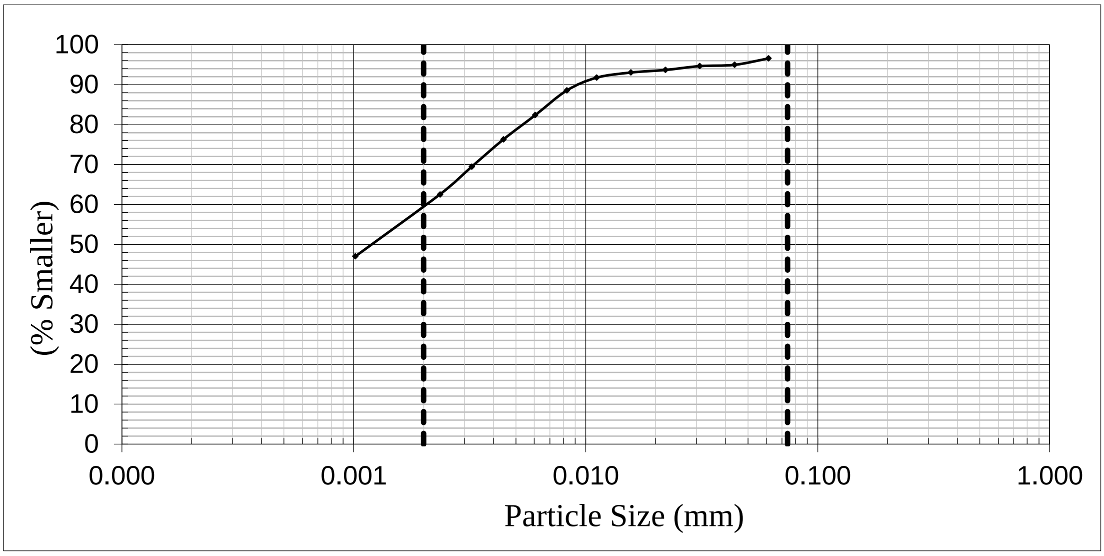

Figure A2: Hydrometer Test Curve for the 3rd Sample

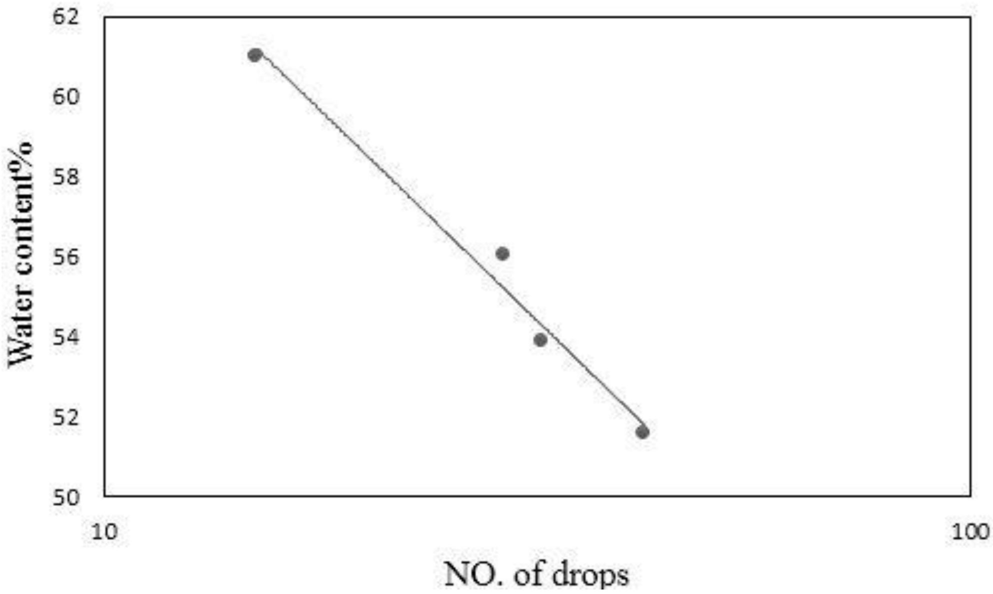

Figure A3: Liquid Limit Test for 1st Natural Soil

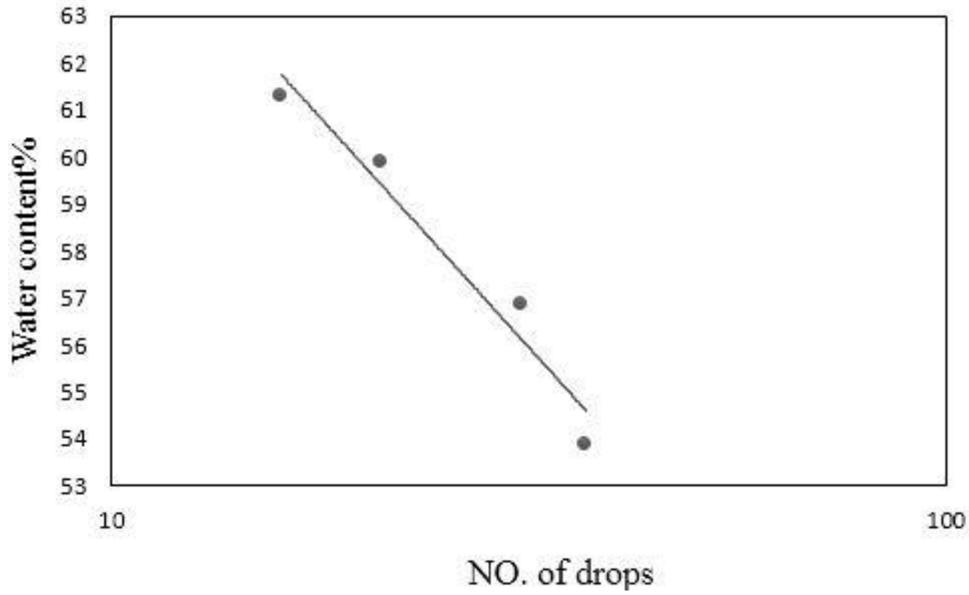

Figure A4: Liquid Limit Test for 2nd Natural Soil

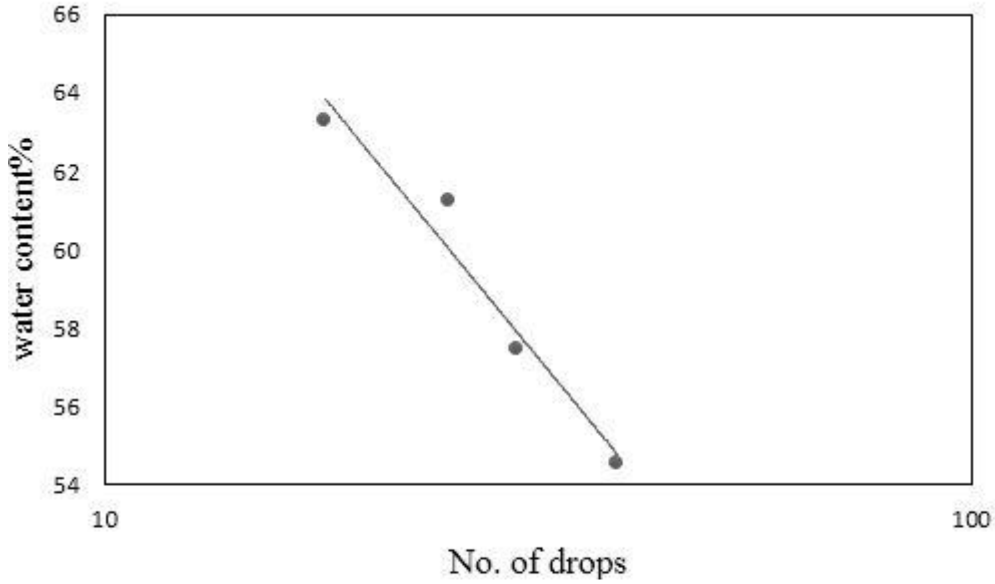

Figure A5: Liquid Limit Test for 3_{rd} Natural Soil

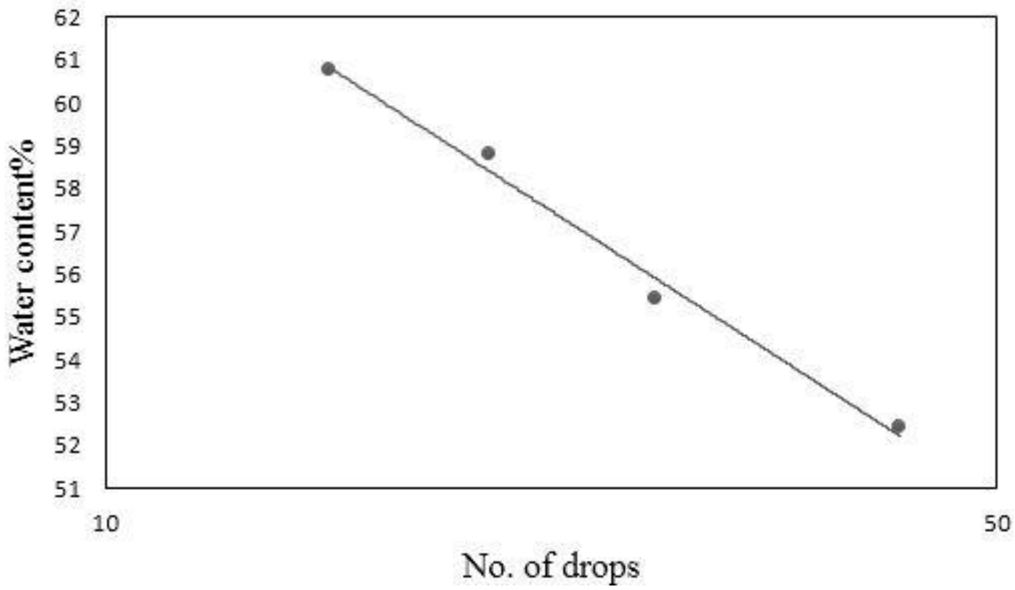

Figure A6: Liquid Limit Test for 1_{st} 4% DSA Treated Soil

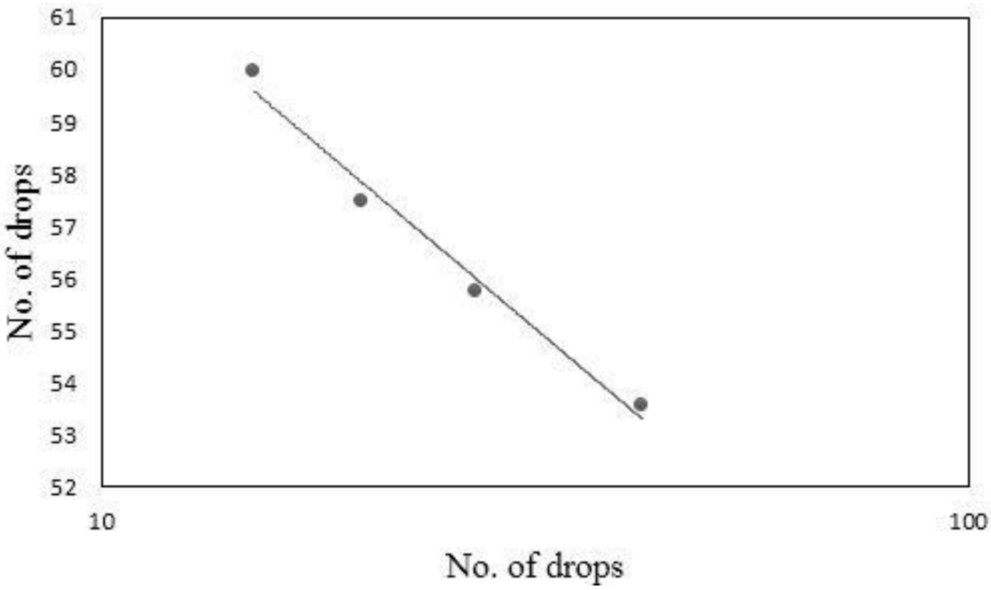

Figure A7: Liquid Limit Test for 2nd 4% DSA Treated Soil

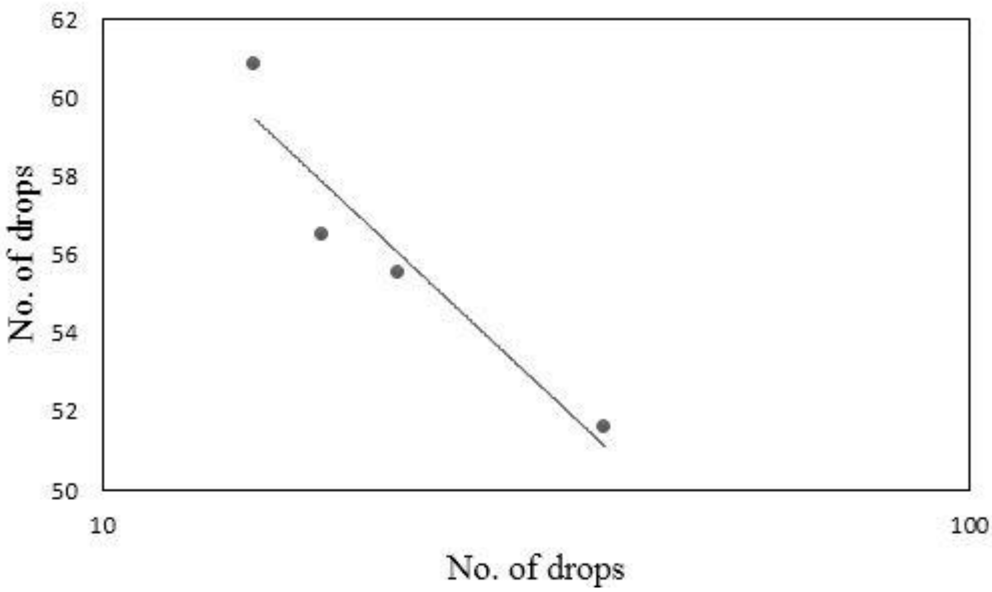

Figure A8: Liquid Limit Test for 3rd 4% DSA Treated Soil

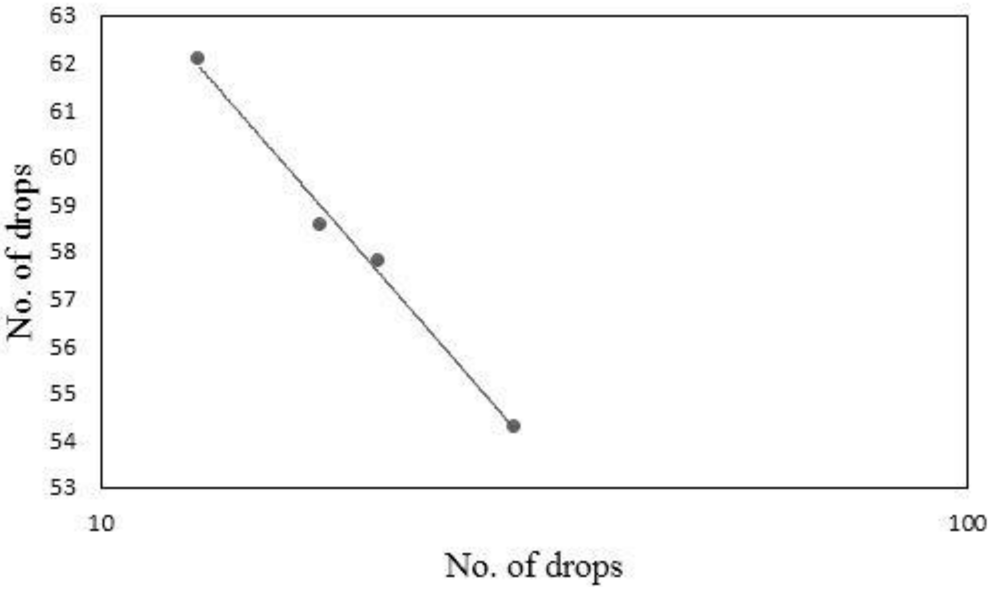

Figure A9: Liquid Limit Test for 1_{st} 6% DSA Treated Soil

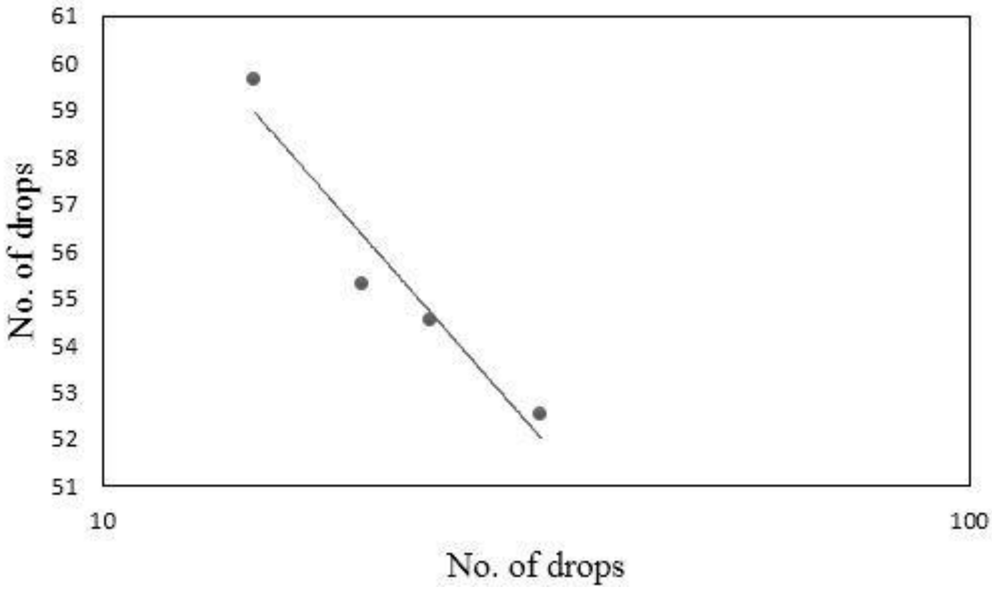

Figure A10: Liquid Limit Test for 2_{nd} 6% DSA Treated Soil

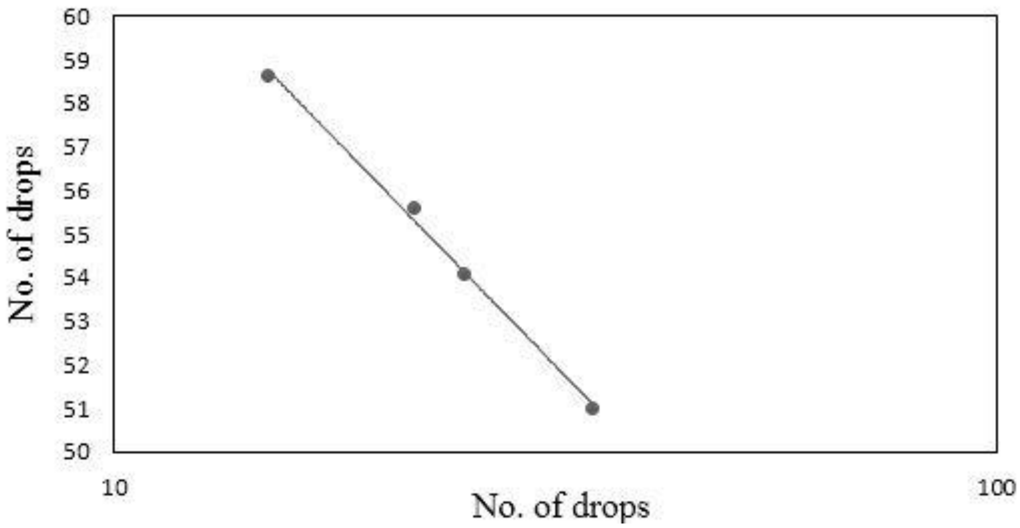

Figure A11: Liquid Limit Test for 3_{rd} 6% DSA Treated Soil

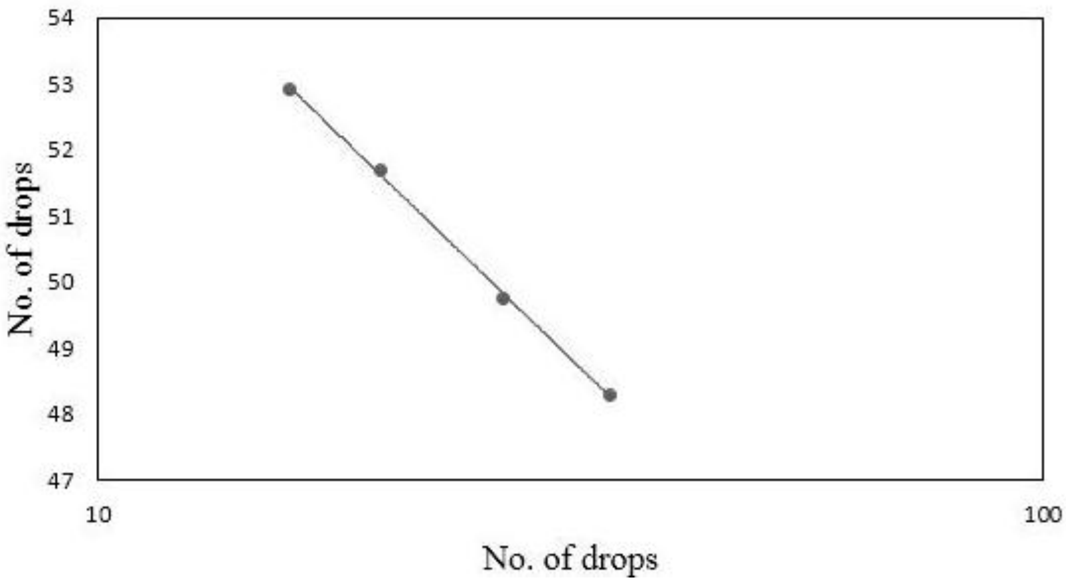

Figure A12: Liquid Limit Test for 1_{st} 8% DSA Treated Soil

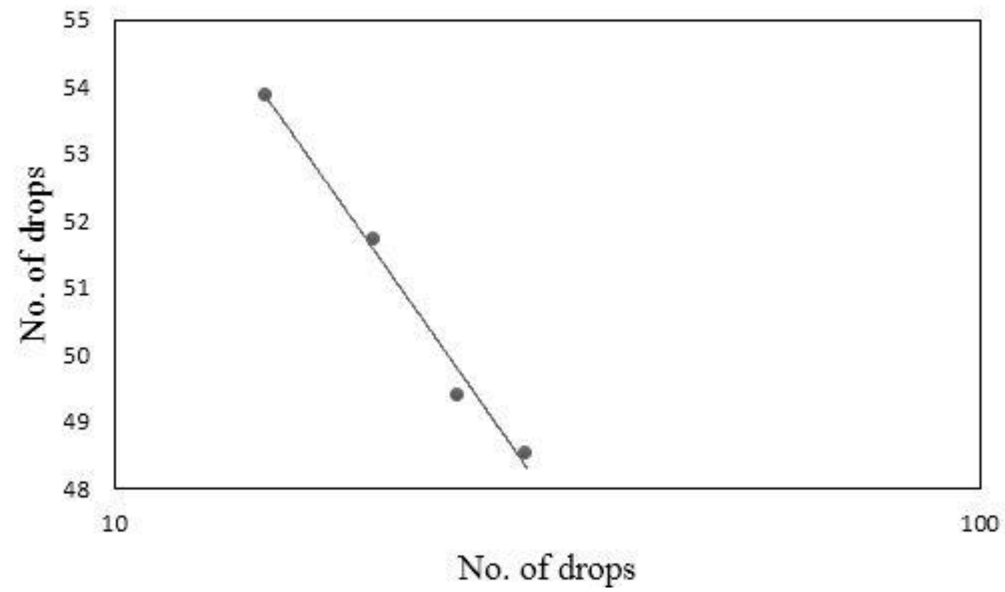

Figure A13: Liquid Limit Test for 2nd 8% DSA Treated Soil

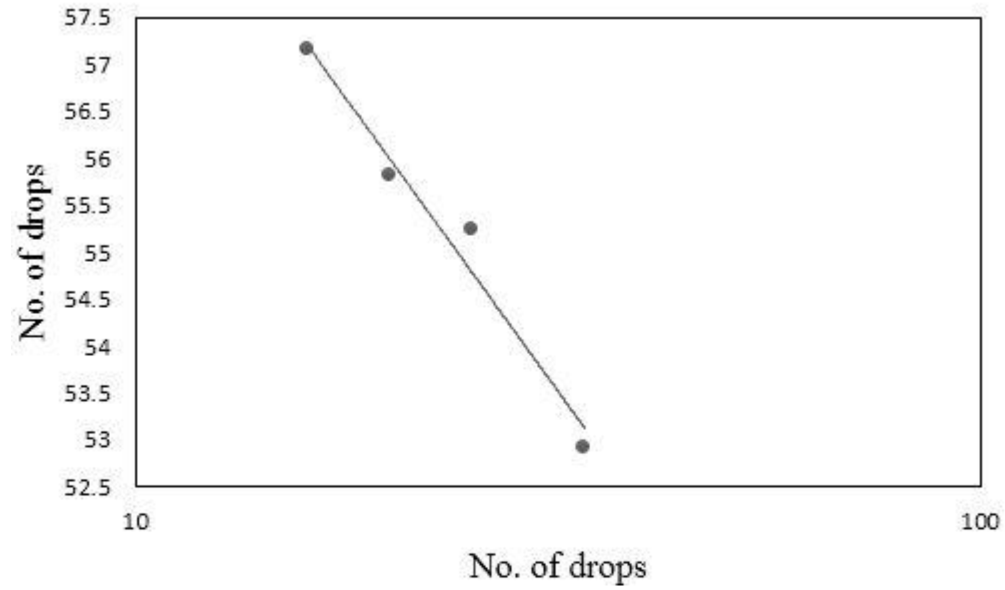

Figure A14: Liquid Limit Test for 3rd 8% DSA Treated Soil

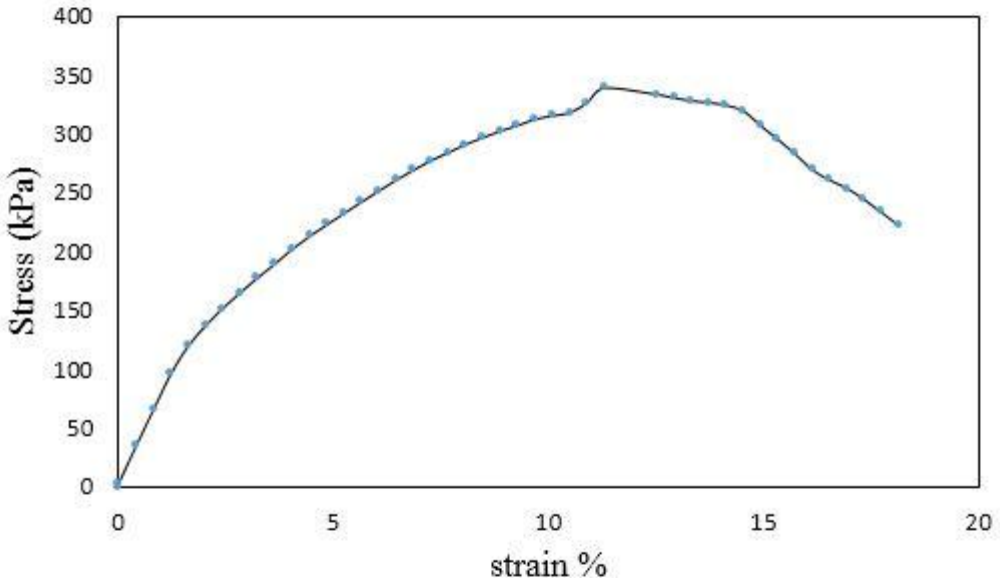

Figure A15: Unconfined Compression Curve for 2_{nd} 4 % DSA Treated Soil

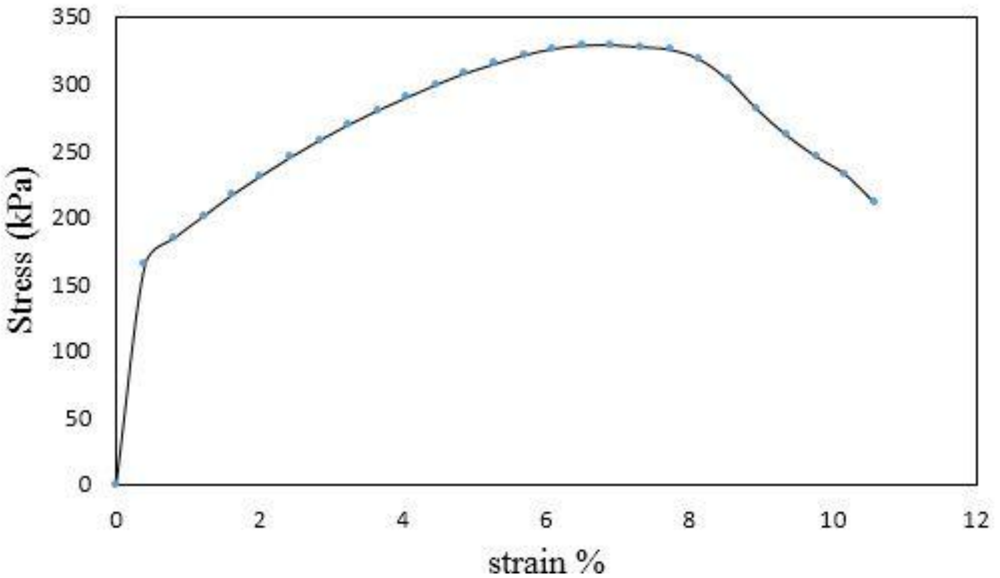

Figure A16: Unconfined Compression Curve for 3_{rd} 4 % DSA Treated Soil

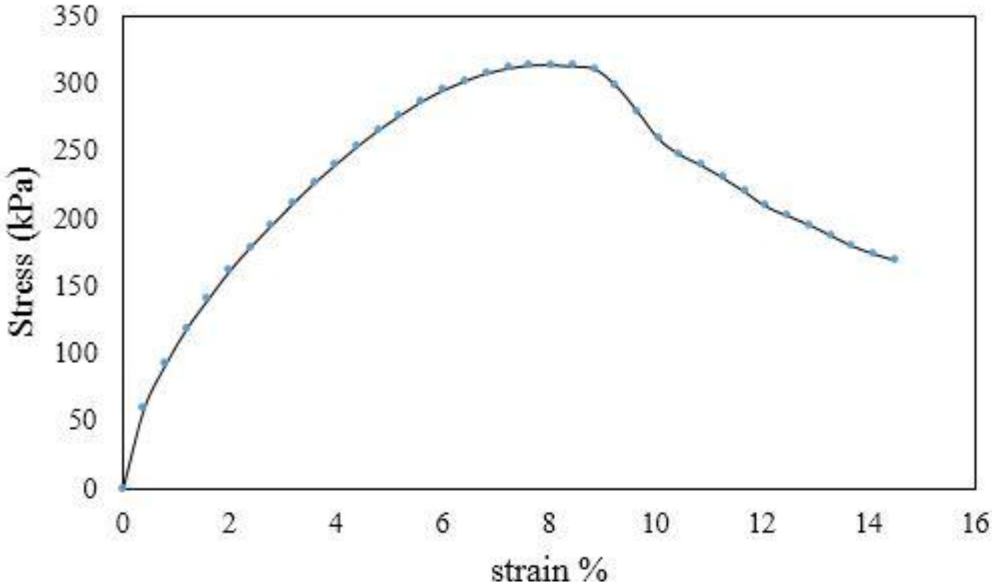

Figure A17: Unconfined Compression Curve for 2_{nd} 6 % DSA Treated Soil

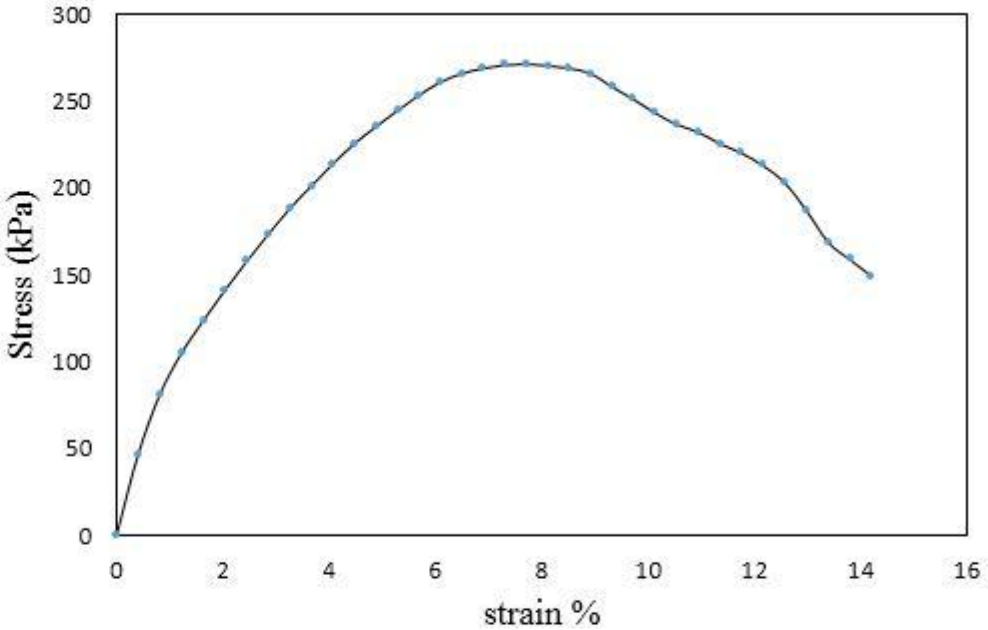

Figure A18: Unconfined Compression Curve for 3_{rd} 6 % DSA Treated Soil