STABILIZATION OF EXPANSIVE SOIL USING SODIUM HYDROXIDE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY

By
SADDAM HUSSAIN

In Partial Fulfilment of the Requirements for the Degree of Masters in Science
in
Civil Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results to this work.

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Signature:

Date:

Dedicated to my parents and siblings…

ACKNOWLEDGEMENTS

My immense gratitude goes to my hard-working supervisor and vice chairman Asst. prof.Dr. Anoosheh Iravanian for assisting and guiding me from the beginning until the ending of this research work. Her dedication, motivation and encouragement towards the success of this work were an interesting experience.

My sincere thanks and full respect go to the Dean of Civil and Environmental Engineering Faculty Prof. Dr. Hüseyin Gökçekuş for granting me full support and feedback which helped in increasing my research knowledge.

I would also like to express my appreciation to chairman of Chamber of Civil Engineers Mr.GūrkanYağcioğlufor giving me the approval to perform some of the experimental works in their laboratory. My gratitude also goes to Mr.Mustafa Turk and EnverTokerfor their support in carrying out the experiments in the Laboratory.

I would also use this opportunity to deeply appreciate my parents for their financial support and prayers throughout my educational career.

ABSTRACT

Construction on expansive clay is the most critical problem faced by the civil engineers due to the volume change either in the presence or in the absence of moisture. In the same way, soils which have high clay content tend to swell when their moisture content is allowed to increase. The major objective of this thesis is to investigate the influence of sodium hydroxide (NaOH) as a stabilizer in clay soil of Cyprus and compared it to Permian red clay of Pakistan.

For this purpose, the experimental laboratory work soils with different percentage of NaOH were used for standard Proctor compaction and unconfined compressive strength (UCS) test. In Cyprus, the clay is highly expansive with plasticity indexes greater than 30 and it has to be stabilized. In this study, performance of the NaOH as stabilizer with different percentages, namely 0, 5, 10, 15 and 20% on plasticity index, maximum dry density (MDD) and unconfined compression strength of a sample of Cyprus clay was studied. The results obtained indicated that the use of 15% NaOH would result in optimum experimental outcome. The other basic properties of soil were found by specific gravity test and grain size analysis. It can be seen from the results obtained that when the percentage of NaOH is increased the MDD and UCS will be increased. These is achieved at the range of 0-15% of NaOH, but by further increment of NaOH to 20% the MDD and UCS were eventually decreased. The comparison also demonstrated that as the plasticity index of Permian red clay and clay soil of Cyprus are both very close to each other, 33 and 36% respectively, the optimum amount of NaOH found to be used as stabilizer on these soils are also compatible.

Keywords: Soil stabilization; Sodium Hydroxide; Unconfined compression strength; Maximum dry density, Plasticity index

ÖZET

İnşaat mühendisleri tarafından karşılaşılan en büyük problemlerden biri şişen zeminler üzerinde yapılan inşaatların zeminin su içeriğine bağlı olarak gösterdiği hacimsel değişimdir. Fazla kil içeriğine sahip olan zeminler su içeriğini artıracak ortamlarla karşılaştığında hacimsel olarak kabarırlar. Bu tezin amacı, bir stabilizatör (iyileştirici) olarak NaOH'ın Kıbrıs kili üzerindeki performansını ölçmek ve Pakistan'ın Permiyen kırmızı kiliyle karşılaştırmaktır.

Bu amaçla, standart Proctor kompaksiyon ve serbest basınç dayanımı (UCS) testleri için farklı oranlarda NaOH içeren deney örnekleri kullanılarak laboratuvarda test edilmiştir. Kıbrıs kilinin %30 dan fazla plastisite indisi bulunduğundan iyileştirilmesi gerekmektedir. Bu amaçla Kıbrıs kilinin farklı oranlarda NaOH, % 0, 5, 10, 15 ve 20 içeren örnekleri üzerinde plastisite indisi, maksimum kuru yoğunluk ve serbest basınç dayanımı araştırıldı. Toprağın diğer temel özellikleri özgül ağırlık testi ve dane boyut dağılım analizi ile bulunmuştur. Elde edilen sonuçlar, % 15'lik NaOH içeriğinin deneysel sonuçlarda optimum davranış gösterdiği gözlemlenmiştir. Bu davranış iyileşmesi % 0-15 NaOH aralığında gerçekleşmiştir, ancak NaOH'ın % 20'ye çıkarılmasıyla MDD ve UCS sonuçları azalmıştır. Ayrıca Kıbrıs kili Permiyen kırmızı kili ile karşılaştırıldığında plastisite indisinin birbirine çok yakın olduğu durumlarda,% 36 ve 33, bu tür zeminlerde stabilizatör olarak kullanılabileceği ve optimum sonuçların alınabileceği sonucu elde edilmiştir.

Anahtar Kelimeler: Toprak stabilizasyonu (iyileştirme); Sodyum hidroksit; serbest basınç dayanımı; maksimum kuru yoğunluk; plastisite endeksi

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ASTM:	American Society for Testing and Materials
USCS:	Unified Soil Classification System
PI:	Plasticity Index
P:	Swelling Pressure
N:	Number of Blows
LL:	Liquid Limits
PL:	Plastic Limit
G_s:	Specific Gravity
A_c:	Activity
C_c:	Clay Content
FS:	Free Swell
CEC:	Cation Exchange Capacity
Hi:	Initial Height of the Sample
SEM:	Scanning Electron Microscope
SSA:	Specific Surface Area
R^2:	Determination coefficient
CH:	Clay with High Plasticity
MDD:	Maximum Dry Density
OMC:	Optimum Moisture Content
CC:	Cubic centimeter
NaOH:	Sodium hydroxide
SL:	Shrinkage Limit
RMSC:	Root mean square error
c :	Cohesion
R:	Correlation Analysis
UCS:	Unconfined Compressive Strength

CHAPTER 1

INTRODUCTION

1.1 Background

In civil engineering works most problems occur when the sub-structure is found to be expansive clay. The low strength is the most critical situation of construction on expansive soil and this may also lead to poor construction of buildings over those soils, the tendency to enhance their volume when they come in contact with moisture and to shrink if moisture is eradicated from them. Those soils which possess more clay particles have the behavior of swelling when their moisture content is allowed to increase(Neeladharan et al., 2018). Volume change behaviors in swelling type of soils presence or absence of moisture are the origin of a lot of troubles in structures such as bridges, roads, building etc.; which are being constructed over those soils (Patel et al., 2015). Clay has the property of low strength and high compressibility. Many of the clayey soils are very sensitive, in the sense that their strength is reduced by mechanical disturbance. The problematic expansive clay material used for road and building construction needs its properties to be improved (stabilized) to avoid failure. The idea of soil replacement with good engineering properties by cut and fill is highly expensive and time consuming (Thomas et al 2016).

1.2 Problem statement

Expansive clayey material is an undesirable foundation for road construction, engineer may choose to remove the undesirable material and replace it with a more desirable one in terms of strength, and durability (Fattah, 2013). These undesirable properties are; the clay soil has the capability to enhance its volume during the presence of hydro conditions and to reduce its volume if moisture contents are being remove from them (Anwar, 2011). The volume change behavior inexpensive soils are the cause of a lot of problems in structures that come into their contact or constructed out of them which result in decreasing the strength and causing settlement of the pavement. Figure 1.1 shows when water gets in contact with the foundation in an expansive soil, the foundation is pushed upwards but the roof will resist the movement thereby pushing it inwards. These movements generate forces which causes cracks to appear (Brooks, 2009).

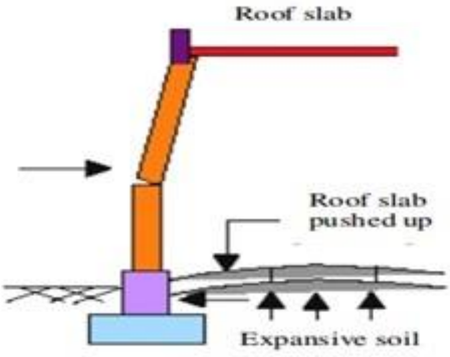


Figure 1.1: Horizontal pressure of Expansive soil (Sitar, 2012)

Even though in the past many researches had proved that different additives can be used as methods of ground improvement of these type of soils, but the significant increase of soil strength is still less due to lowering of compacted dry unit weight of clay. The studies indicate that by using an additive, the strength of clay soils will increase much better compared to the used of sawdust ash alone. Soils exhibiting high clay particles are the capability to enhance their volume when their moisture content is allowed to increase. Expansive clay soil has low compressive strength and bearing capacity so when shrinkage or swelling occur cracks propagates which results to failure in buildings as shown in Figure 1.2 (Mir, 2017)

Figure 1.2: Expansive soils in building deterioration (Sitar, 2012)

Expansive clay is also major problem in light structure and highway construction work shows that over the years, our engineers have relied greatly on the conventional stabilizing agents that are cement, lime, and bitumen for upgrading the properties of problematic soil. However, the highway cost of these additives has prevented their wide-spread application in general road construction(Thomas et al 2016). In order to reduce the cost of stabilization of materials for road construction, one reasonable alternative is to mix the soil-cement with the requisite amount of admixture. Expansive soils also results to cracks on roads when there is shrinkage and swelling activities as shown in Figure 1.3(Thomas et al., 2016).

Figure 1.3: Expansive soil in road Colorado, USA (Nelson, 1997)

The general or overall target of this thesis is directed to improve those attributes of soil which are being related to its geotechnical and engineering properties of clayey sub-grade material by the addition of sodium hydroxide (NaOH) chemical at different levels as additives.

We intend to carry out these objectives in the laboratory by carrying out the following tests; compaction test, grain size distribution test (hydrometer), Atterberg limit test which describes the liquid limit test, plastic limit test, and plasticity index, compaction test and unconfined compressive strength.

1.3 Aim and Objective of research

The aim of this research is stabilization of expansive soil using NaOH.. However, other specific objectives in line with research are given as follows:

- To determine the additive sodium hydroxide effect on plasticity of expansive soil.
- To assess the effect of NaOH compaction and unconfined compression strength of soil properties in north Cyprus.
- To determine the percentage of strength increment for expansive soil obtained on mixture at different percentage of Sodium Hydroxide additive addition.
- To determine the correlation between plastic index, maximum dry density and unconfined compression strength.

1.4Summary of Study and Possible Usage

The problematic soil material use for road, building construction needs its properties to improve by stabilization to avoid excessive and uneconomical cost. The idea of soil replacement with good engineering properties by cut and fill is highly expensive and time consuming.

This study will help us understand the relative advantages and properties of Sodium Hydroxide as soil stabilizers in terms of strength and durability. This will reduce the over-dependence of stabilization using cement, lime and bitumen and encourages the use of less expensive materials such as NaOH. However, the major reason we are using Pakistan clay is that there is high relationship between the Pakistan and Cyprus clay in term of plasticity index (PI) of a soil which is approximately greater than 30% PI.In Pakistan, the salts deposit exists in large quantity and used as a material in Civil Engineering works to solve the problem of soil. While sodium hydroxide has a very high cation and absorption capacity on the stabilized soil and clay soil increases the expansive capacity of the soil.

As sodium chloride is abundant in nature, the possible combination of sodium hydroxide as additive will revolutionize the geotechnical and engineering world in Pakistan. This project can contribute a lot after knowing how these stabilizing agents can be cheaply sourced and can be used as a substitute to other materials which can perform better i.e. in stabilization and strength.

1.5 Presentation of Thesis

In this research five chapters could be found as given below;

Chapter 1.Introduction

Chapter 2. Literature Review is focused on the history and outlook of relatively existing research, subjects or projects.

Chapter3.Focuses on methodology strategies, (Specific gravity, Grain size analysis, Atterberg limit test Compaction test and Unconfined Compressive Strength test).

Chapter 4. Result Analysis focuses on the test output needed to be carried out and achieves our objectives discussion on them.

Chapter 5.Conclusion and Recommendation. Based on our result and analysis we come to conclusion and give needed recommendations.

CHAPTER 2

LITERATURE REVIEWS SOIL STABILIZATION

2.1 General Introduction

Stabilization is a technique to improve phys-chemical and geotechnical properties of soil so as obtain desired characteristics of soil for any structural work. This involves methods for treating the expensive soils to make them fit for construction.

The problem of soil expansion is an important issue which continually the civil engineers and soil stabilization is also an important technique in civil engineering department which deals with procedures and techniques by which unsuitable soils may be improved by for desirable engineering purposes. Broadly speaking soil stabilization encompasses every physical, physio-chemical and chemical method developed and used to make a soil perform better its desired engineering purpose.

Soil stabilization in its specific meaning as commonly understood in highway and airfield engineering, soil stabilization actually is the treatment by those methods of construction in which unsuited soils are treated to provide sub-base and base courses which can carry the applied traffic loads under all normal conditions of moisture and traffic for an economic service period. Soil stabilization is an important technique introduced many years ago in order to develop the desirable properties of soil and make it suitable for specific civil or construction engineering projects. There are many of additives which are required for soil modification and improvement likewise cement, lime, and some other mineral additives being widely used for soil stabilization such as Sodium Hydroxide, fly ash, silica fume, rice husk ash, and some other mulching materials have been used underarm in the past.

2.2 Previous Experimental Studies

According to Sahu and Rajesh Jain (2016) they usedNaOHin their research to stabilize black cotton soil which was taken from Jabalpur region. Their aim was to find the effects of NaOH on mixing with black cotton soil which serves as a stabilizing agent. The percentage NaOH used was 0-16% with soil and having properties such as shrinkage limit, swelling percentage and consistency limit were seen as the concentration of NaOH is increased. Finally, it is concluded that some of the properties of the soil improved while some deteriorated.

Also, according to R.Y Raja sundariet al.(2017). This kind of soils swells when they are exposed to water and shrink when the water is removed. Soil stabilization has been the major method for ground improvement which involves the use of chemical admixture. Their study involves the use of NaOH as the chemical admixture and sand act as filler in order to stabilize the soil. The main target of their research is to stabilize Kaolinite soil using NaOH by varying the concentration of the soil and keeping the NaOH constant. The unconfined compressive strength of the soil was studied after adding NaOH and soil under different conditions; dry, wet, cyclic and soaked condition.

Neeladharanel et. al. (2017), the engineering and geo technical properties of some soils could be enhanced by treating those soils with tile waste as well as sodium as a binder. Generally, weak soils swell mostly when they are in contact with moisture and shrinks when it dries out and this kind of soil possesses low bearing capacity. Therefore it’s very important to stabilize weak soil, which improves the load bearing capacity of the sub grade in order to support pavement and foundation. Weak soil was collected and mixed with different percentage of tile waste and the sodium hydroxide as binder. Different test were conducted on the soil in order to determine the improvement achieved in the properties of problematic soils. Such as plastic liquid test, liquid limit test, direct shear test, standard proctor test, another test named as falling head permeability test and California bearing ratio test were also being used in this research project for the improvement of geotechnical and structural properties of soil.

It was also reported by Greenland (1982), Abramson et al. (2001), that improvement of unstable soil is referred to soil stabilization. Wheat husk is among the agricultural waste material which can be utilized in soil stabilization process. This is a lignocelluloses waste product which serves as cattle feed. It is treated with potassium permanganate ($KMnO_4$) and sodium Hydroxide (NaOH) at different percentage. In this research, it wasobserved that this combination can be used to improve soil properties as well as reduce environmental risk and also economically feasible.

It has also been reported by Edil et al. (2006) that in order to achieve the correlation of California Bearing Ratio (CBR) and Resilient Modulus (MR) of sub grade, soil stabilizes using chemical stabilization which is Fly Ash (FA). The research was conducted at various content of FA obtained from electric generator system Kapar and soil samples were taken from TanjungHarapan, Klang. In order to determine the optimum moisture content (OMC) present during soil after the process of stabilization and maximum dry density (MDD) of problematic soil, compaction test was also conducted using Standard Proctor Test as a determination. The stabilized soil samples were prepared by mixing the 4% of FA, 10% of FA and 20% of FA by weight of soil of each sample. The strength of the samples was tested using Unconfined Compressive Strength (UCS). Four (4) samples from different percentage of FA at OMC were tested for CBR value and MR value curing in 7 days and 28 days. The result shows increase in the CBR and MR value by addition of FA where the presence of FA in different percentage affected by different curing time period increased the value of CBR and MR differently. By using Pearson Correlation, the correlation between CBR and MR for 7 days is 0.625, 28 days is 0.648 and for overall data consists of both 7- and 28-days curing period is 0.553.

Furthermore, Das&Parhi,(2013)that soft soil with less in situ bearing ability requires adequate stabilization prior to any construction on such soil. It has been proven by many researchers that cement binders are the most effective method for stabilization. The strength of cement as a binder depends on so many attributes of soil such as the geo technical and structural properties of soil, the percentage of cement in the mixture and the water cement ratio. In the research they try to develop a model to predict and find out the maximum dry density (MDD), multi vitiate regression splines (MARS) and unconfined compressive strength (UCS) with the aid of artificial intelligence (AI) techniques and functional networks (FN). Previous research data was utilized to build up the prediction models. Depending on statistical methods, different output criteria were selected using functional networks and MARS techniques in the prediction of UCS and MDD and compared to the AI method. Professionals and engineer can use the predication model because it's comprehensive and complicated

According to Coban, (2017) and Yilmaz et al. (2018). low strength of soil affects the service life of the foundation and life of the structure significantly, and construction of thick layers on the top is required. Poor soil can be treated with the chemical stabilizers. Fly ash and Portland cement can be usefor stabilization of the soil. Fly ash may cause the temporary shortage in concrete industries and Portland cement is more expansive when compared to other stabilizer. Their research investigates the alternative stabilizer lime sludge, it is a waste material available and maybe in future may be preferred instead of fly ash and cement. For this purpose, lime sludge is use with stabilizer and the compressive strength,freeze-thaw and wet-dry tests and swelling test under F-T was investigated. The unconfined compressive strength of soil was increasedafter the sample was cured for 90days.The F-T test shows that the cement uses the LS to decrease the effect because the cement has low pH value. When used with fly ash and cement, it decreases the effect of W-D test and F-T test and increase the durability of soil. It was observed that 12% of LS has moreeffect and gave better results in F-T, and W-D decreases the swelling.

Soil is one of the most readily available materials for civil engineering construction purposes. Its area of application in civil engineering field is vast in structures such as building, bridges, highway, tunnel, wall, tower, canal and dam, which are founded on soil. Due to weathering of rocks soil came into exist by the accumulation of any un-cemented or weakly cemented or some time cemented mineral particles (Petry, 2002). In the structural composition of soil there is the presence of void space between the particles of soil containing the water and air. The product of the weathering remains at their original position and ultimately, they will constitute a residual soil. The process of soil stabilization must has to be assumed as remedy in soft soils (expansive soil, clayey peat, silt) with the purpose of acquire engineering as well as geotechnical properties (Sridharan and Prakash, (2000). According to Phanikumar (1993) a famous soil chemist, fine grain granular material is the easiest to stabilize by the process of stabilizations a result when the surface area is larger and diameter. Due to the large surface area of expansive soil and particles shape, the process is extensive (Phanikumar and Singla, (2016); Phanikumar et al., 2004) .Alternatively when we consider silt material or silt particles, those can be sensitive to small changes in moisture or dryness and as a result may not be easy to improve during stabilization(Liu et al., 2008). On the other hand peat soils and those of expansive soils absorbs water content up to about 2000%,as compared to others its absorption is higher, these soils may also possess high expansive matter and porosity. This constancy of peat soil can differ based on its type, from fibrous to muddy type of soil and its deposit is mostly shallow, except in worse cases where it can expand to some meters below the surface of soil(Burroughs, 2001). Expansive soil have much high ion exchange capacity, it can hinder the hydration process by acquiring the calcium ions released during the hydration of calc0ium silicate and calcium acuminate in the cement in order to stabilize the ion swap over capacity. In these soils, the success of the process of stabilization has to depend upon suitable selection of sticky and quantity of sticky materials put in during the process(Ling et al., 2014).

The process of expansive clay stabilization concerns the method in which clay, cement substance, or other chemical substance (stabilizing materials) are being put in to a natural expansive clay to get better results one or more of its geotechnical as well as structural properties. It is also proved that stabilization process of soil can also be achieved mechanically by mixing the expansive soil and stabilizing agent together so as to acquire an all the same mixture or by simple addition of stabilizing material to an expansive soil put and obtain relations by allowing it to permeate during soil particle’s void(Boukdir et al., 2017). In these processes, the expansive clay and stabilizer are mixed together and the positionprocesses of soil particles typically include compaction of soil and it will tell about the success of process of soil stabilization. Expansive clay stabilizer additives are used to increase the structural and geotechnical properties of soils. It is already explained that a prominent not easy problem in civil engineering going to be faced when the sub-structure is found to be expansive soil. When these stabilizing agents are being used then these can develop and sustain soil moisture content, these stabilizers will improve soil particle cohesion force and serve as cementing and impermeability increase stabilizer in soils(Keesstra et al., 2016; Parras-Alcántara et al., 2016).

In the past there was a lot of research work son expansive soil stabilization using different stabilizer additives, some of the common methods of expansive soil stabilization in foundation construction is the use of lime and cement stabilization process. As per this process of stabilization, high strengths of particles are obtained which may not always be required and may not as successful as that of other methods, however, necessity and justification of looking for and adoption of lower price and easily available stabilizer which may be used to stabilize the soil properties either related to structural or geotechnical properties of soil (Brandan et al. 2019).

This research was designed to improve in the design of substructure for durability and reliability through the improvement of the foundation and road pavement to evolve suitable stabilization of expansive clay using sodium hydroxide as admixtures. Recent research has shown that utilization of salt has resulted in considerable savings in construction cost as well as improvement in soil properties.

2.3 Graphical representation of Variation in Compressive Strength and Density With respect To Soil Properties

Quantity of stabilizer Sodium hydroxide is influence on the properties of the unconfined compressive strength and density of natural soils. To examine the sodium hydroxide scatter graph assessing influences on soil properties. Some previous study chapter 2 explains about those research and properties of the soil.

2.3.1 Variation in Compressive Strength with respect to soil

Scatter graph plotted is interesting one between stabilizer sodium hydroxide quantity and unconfined compressive strength (UCS) Figure 2.1 is showing that the value of NaOH is less than 16%, compressive strength is between 200 to 400 UCS. For the black cotton soil is not suitable for NaOH because increase the percentage of NaOH UCS is decrease gradually.

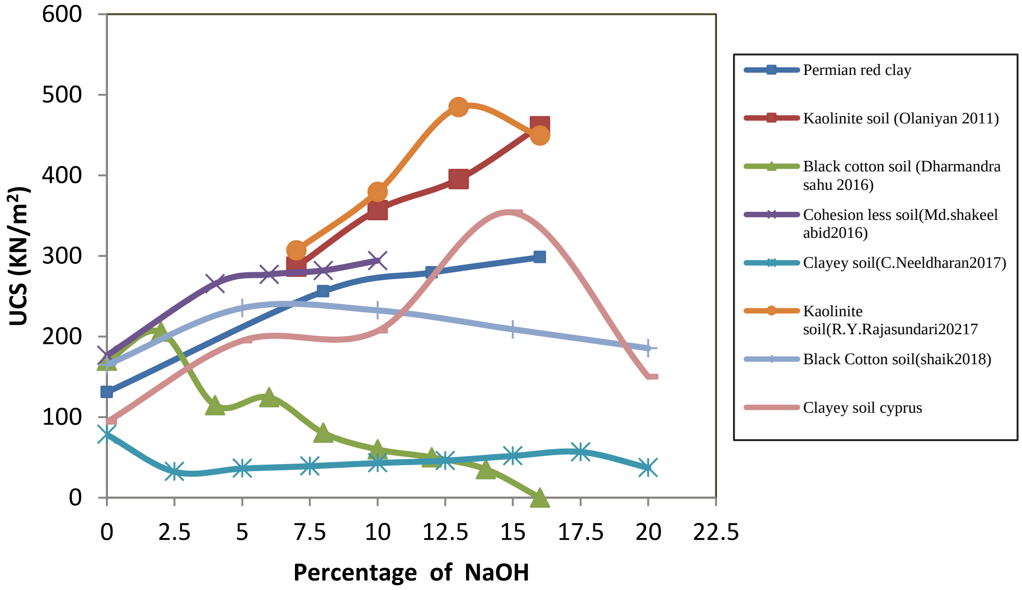


Figure 2.1: Unconfined compression strengthof different soil with respect to NaOH

In figure 2.1 show that the results of different soil stabilize with sodium hydroxide Permian red clay with use the different percentage of NaOH 5, 10, 15 and 20 percent results show that compression strength is increased as compared to control sample. But 20% is decrease strength as compared to 15% and clay of Cyprus is montmorillonite is lattice show the expansion 20 times. Kaolnite soil is also hydrous silicate crystals but is formed by a stacking of alternate layers of silicate and gibbsite sheet bonded together by a hydrogen bond. Sodium hydroxide as a additive giving high strength with Kaolnite soil and we can observe that in two soil are stabilized with NaOH. Black cotton soil results show that the soil is strength is decreased when increase the percentage of NaOH is increase at the 16% NaOH black cotton soil is almost zero. NaOH is also organic compound soil is also organic and due to the reaction of same charge, those charge are repel to each other due to this repel strength is loosed.

2.3.2 Variation in Density with Respect to Soil

Generally, compressive strength is similar to the density of the soil properties. In figure 4.16 scatter line graph showing us the increasing the percentage 0-14% of sodium hydroxide the Maximum dry density is increasing 1.5 to 2g/cc. after the 14% the peak value of 16% is density is 2.2g/cc above the value of sodium hydroxide is to threshold.

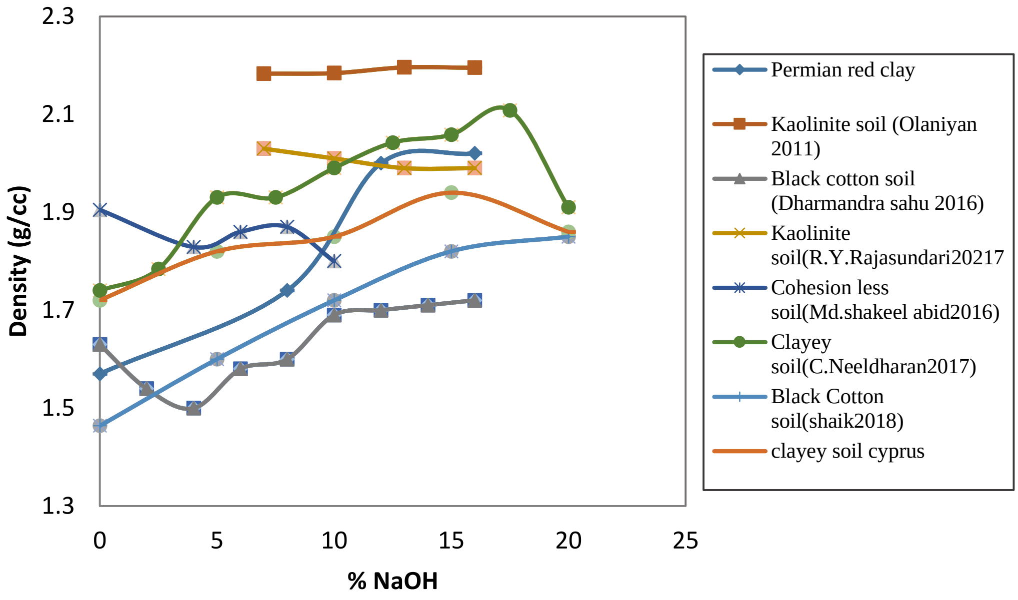


Figure 2.2: Maximum dry density of different soil with respect to NaOH

In the density figure 2.2 Kaolnite soil is not gain mach density because of Kaolinite has a hydrogen bond between the sheets. Hydrogen bond is stronger because of between surface of the silica and gibbsite layer is quite strong the lattice. In the black cotton soil is show that in the density is increased with percentage of NaOH.

2.4 Methods of Stabilizing Soils

Soil stabilization can be divided into two classes given as follows:

- Physical Stabilization
- Chemical Stabilization

2.4.1 Physical Soil Stabilization

This is the process by which the physical properties of soil may be improved or altered by either mechanical treatment or with the addition of chemical the process by which the strength and the durability characteristics of soil and soil aggregate mixtures are increased by the utilization of the proper combination of soil with coarse and fine aggregate, is mechanical stabilization.

2.4.2 Chemical Soil Stabilization

Chemical stabilization involves adding to a soil an optimum percentage of a material of opposite ion polarity to produce by exchange phenomena, a mixture of greater strength or a mixture in which the clay mineral particles or aggregates are surrounded by shield resistant to moisture penetration, this problem is essentially one of a surface chemical type. Not only can the usual soil properties be altered, but also entirely new soil properties such as tensile strength and flexibility can be produced in soil by the proper chemical treatment, this is called Chemical Soil Stabilization.

2.5 Advantages of Stabilization of Soil

The technique of stabilization of soil are generally used,

- For soil strength improvement.
- For decreasing the compressibility and permeability and to improve shear strength of clay.
- To improve the soil bearing capacity.
- To improve the natural soil for construction purposes.

2.6 Structure of Clay Minerals

According to scientists, it is stated that clay is the basic expression used to denote both particle size and representation of a family of minerals. (Te, 1995). Clay is an important terminology when representing particle size of soil, it specifies the soil particles those have their size less than 0.002 mm and also describes those particles having size more then 0.002.

Usually clay minerals are characterized by the following characteristics given below:

a) Small particle size or the large particle size of different soil particles

b) A net negative electrical charge on surface area of soil particles and

c) Plasticity of soil specially when mixed with water.

According to different scientists different concepts exist with respect to structure of clay minerals, some of them are given as follows:

Clay minerals in general are principally hydrous aluminum silicates, having generally platy shape, tubular or needle shaped structures (Miura et al., 2001).

Minerals of clay like kaolin, smectites and palygorskitesepiolite are some of the world's principal and helpful engineering minerals. Lightly loaded structures and pavement founded on these soils are more susceptible for damages due to degree of variation caused by the expansive soil. They play an important role in various geological studies for example, strati-graphic correlations, environment of deposition and study of temperature at the time of generation of hydrocarbons(Klein and Murray, 2007); (Jemal et al., 2007). Soils generally include a range of non-clay, crystalline clay and minerals, no crystalline matter and precipitated salts (Mitchell andSoga2005).

Most of the soils are comprised of crystalline minerals, which are basically non–clay. Therefore, the percentage of crystalline clay minerals in a given soil is comparatively low. However, these clay minerals have more influence on the properties of the soil than their presence in volume. Size, shape, physical and chemical properties are influenced by the mineralogy of soil.

Working or handling expansive clays as foundation soils is difficult proposition due to innate property of alternate swell-shrink behavior. Studies over years proved that expansive soils are global geological hazard (Jones and Holtz, 1973). The above researcher stated that the root cause for the damages to the structures on expansive soils is excess irrigation or poor drainage, unless they are properly addressed.

In 1923 Hauser stated that, different scientists study the structure of clay minerals by using X-Ray diffraction, and then the investigators were able to prove by the use of X-Ray diffraction studies that structure of clays was crystalline in structure. Since then the knowledge of the structure of clays has greatly increased and it has been discovered that the common clay minerals are all composed of hydrous aluminum silicates, which pave very weak basal cleavage planes that allow them to be broken into extremely thin sheets. These hydrous aluminum silicate minerals, as discussed by Means and Paroher are composed generally of two fundamental building blocks, which are given as following:

- Tetrahedral Silica Unit and
- Octahedral Hydrous Aluminum Oxide Unit

2.6.1 Tetrahedral silica

The tetrahedral silica unit is actually tetrahedral arrangement of four oxygen ions with a silicon ion enclosed within the oxygen ion arrangement. The distances between the silicon and oxygen ions are such that they permit the four oxygen atoms to touch leaving a space just large enough to include the silicon ion. These tetrahedral silica units become bonded together with each of silica units by sharing of each of the oxygen ions in the ease with another tetrahedral silica unit. The strong horizontal forces that are developed between these units developed by exchange or sharing of electrons are by ionic or covalent bonds. Due to the strong bond provided by the sharing of the oxygen ions with two molecules, a sheet structure of silicon ions between two layers of oxygen ions is formed. As shown in figure 2.3 arrangement the oxygen bases of the tetrahedral are in a common plane with all the apexes which are oriented in a same direction. So a tetrahedral structure is formed which is given as following:

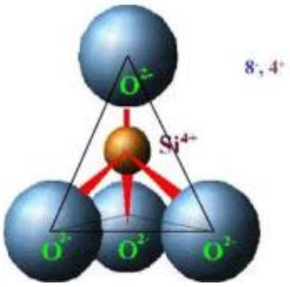


Figure 2.3: Tetrahedral Structure (Hauser 1923)

After the formation of tetrahedral structure the net charge of the unit becomes a negative one, this negative one ion is because of the negative five charge are produced by the shared oxygen ions and only a single positive four charges are produced from the silicon ions so a single minus charge will remained after all cancelling of positive and negative charges.

2.6.2 Octahedral Hydrous Aluminum Silicate structure

When discuss about the second arrangement style of molecules in soil structure development that is the octahedral hydrous aluminum oxide subunit. In figure 2.4octahedral hydrous aluminum oxide unit (gibbsite) is an octahedral arrangement of hexa (six) of hydroxyl ions accomplishing an aluminum ion; these octahedral units are tightly bound together in a sheet structure with each of hydroxyl ion common to three other octahedral units and then make a crystalline structure. Because aluminum has a positive three charge and the sharing of hydroxyl ions contributes only a negative two charge, the resulting net charge of the octahedral unit is positive one.

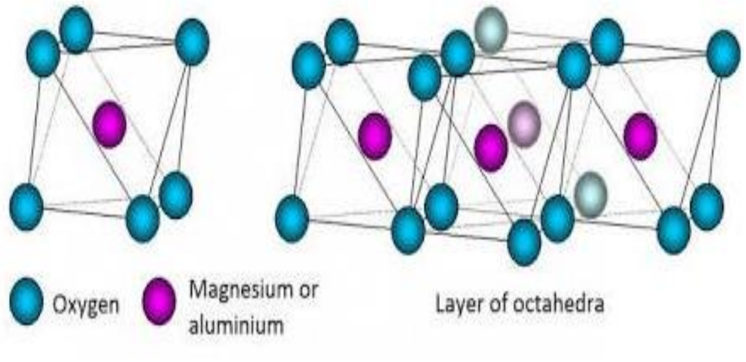


Figure 2.4: Octahedral Hydrous Aluminum Silicate structure (Hauser1923)

Under some special conditions without changing of crystalline structure the aluminum ion may be substituted for an iron or magnesium ion. According to Hauser, it is induced into the structure of these units with substituted ions, crystalline structures which are produced by the replacement of magnesium ion being larger than that of the structures produced by the aluminum ion. The structure or the strain which is developed by the magnesium ion has the ability to stretch the aluminum cavity to be able to fit itself into the cavity. The substitution of one element for another in the crystal formation but without changing the crystalline form of that crystal is known as isomorphism substitution.

The different clay minerals that exist in nature are formed by bonding together with the help of different combinations and arrangements of the molecular sheets of silica and gibbsite. When the apex's of the silica units enter into the hydroxyl ions of the gibbsite units, a two layer elemental sheet is formed with a strong ionic bond because of the opposite charges of the two units. If in the formation of' the two layer silica gibbsite sheet, there are more silica units present than that of aluminum hydroxyl units, then a silica-gibbsite sheet with an excess of negative charges is formed. In two layers combined sheet has the shared oxygen ions of the silica sheet will be shown on one side and the shared hydroxyl ions of the gibbsite sheet exposed on the other side of two layer silica-gibbsite sheet.

During the formation of minerals, in the above discussed two layer sheet there was excess of oxygen ions when compared with silica ions and sometimes it is commonly observed that they become an excess of silica ions which may lead to the formation of another elemental sheet to come into existence by the addition of another silica sheet being bonded to the other side of the gibbsite sheet. This newly formed silica-gibbsite and silica sheet structure becomes even more negative if magnesium ion substitutes all of the aluminum ions by the phenomenon of isomorphic substitution. Then these negatively charged surfaces may attract, and will be held apart by, dipolar water molecules when their positive ends are oriented toward the negative surfaces of the elemental sheets.

It is observed that the negative surface of these elemental sheets may also be held together with cations of potassium, calcium, sodium and some more of the other commonly existing elements. When we talk about the distance between these elemental sheets, that distance is controlled by the amount of dipolar water-available for reaction with the negative surfaces.

2.7 Principal Clay Minerals

There are also some principal and basic subunits of clays which prominently constitute the sheets or clay structure. Out of them three clay minerals play a vital role in the formation of clay sheets are given as following:

- Montmorillonite
- Illite and
- kaolinite

The above three minerals are the principal minerals of clay and are responsible for many of the clay's characteristic properties.

2.6.1 Montmorillonite

Montmorillonite is a hydrous aluminum silicate crystal formed by layers of silica-gibbsite silica sheets separated by attracted water layers between the negatively charged silica sheets. In figure 2.5 very important characteristic of the montmorillonite clay is that it has an expanding lattice. This expanding lattice is caused by the varying amounts ofwater that is available and can be attracted between then negatively charged silica sheets expanding lattices developed by the power of the silica- gibbsite-silicasheet being able to attract a water thickness up to twentytimes the thickness of the elemental sheet.

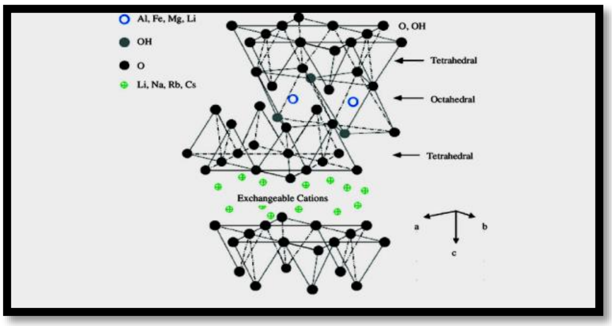


Figure 2.5: Structure of Montmorillonite (Gacanja, 2016)

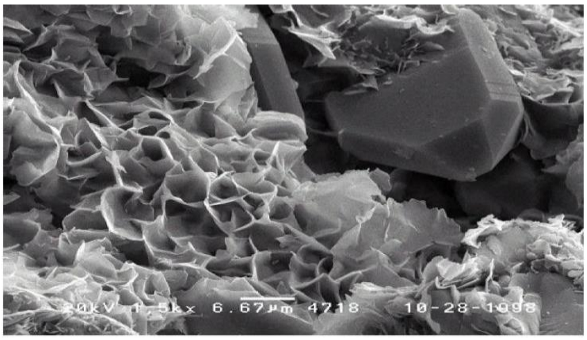


Figure 2.6: Scanning electron microscopy of montmorillonite (Al-Ani&Sarapää, 2008).

In central octahedral sheet, aluminum is partially substituted by magnesium. Apart from potassium, the water molecules and cation that can be exchanged fill up the gap between stacked sheets. Weak bonds are usually produced in between joined sheets due to existing ions (Craig, 2004). In figure 2.4The weak bond present in montmorillonite is normally open to destruction as polar cationic substance enters in between sheets, this is why it expands when it mixes with water. The swelling of the layers can help to detect the entrance of water especially if particles having small sizes with a big SSA are endured (Baban and Flannagan, 1998, Al-Ani&Sarapää, 2008).

A soil with huge amount of montmorillonite possesses a great swelling potentials and this leads to shrinking if dried, it is considered as a unique mineral when compared to others asa result of its high potential of swelling, activity in clay and liquid limit. Montmorillonite can be divided into two main categories namely; calcium montmorillonite possessing low capacity of swelling and sodium montmorillonite possessing high capacity of swelling. There is another type which is named bentonite, it consists of both sodium and calcium bentonite.

2.7.2 Illite

The second principal component of cay minerals is Illite. It is a hydrous aluminum silicate crystal that is very similar to Figure 2.7montmorillonite except that the adjacent silica layers are bonded together with potassium ions instead of water, because the cation bond of the illite is stronger than the water bond of the montmorillonite the tendency of the illite lattice to expand is not as great as that of the montmorillonite.

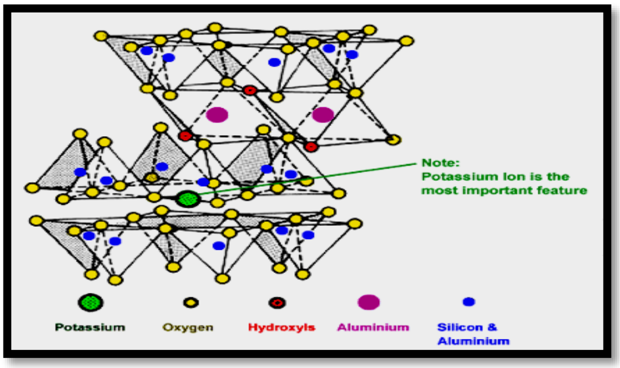


Figure 2.7: Structure of Illite

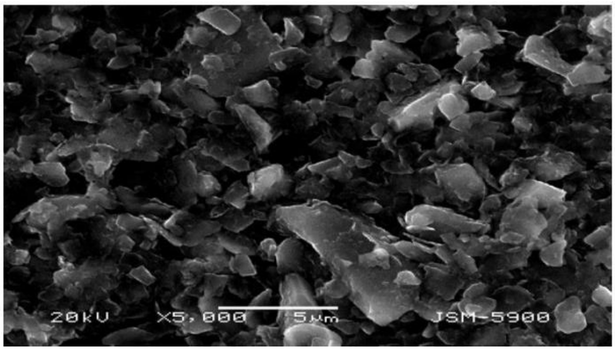


Figure 2.8: Scanning electron microscopy of Illite (Al-Ani&Sarapää, 2008).

When alumina substitutes a number of silica atoms, the potassium ions situated in between layers leads to lack of balance in charge. The potassium ion that bonds with illite which cannot be exchanged is the cause of the lower swelling potential of illite. Potassium bonds show stronger bonding when compared to hydrogen bonds (Al-Ani&Sarapää, 2008).

2.7.3 Kaolinite

In figure 2.11 Kaolinite is also a hydrous allowing silicate crystal but is formed by a stacking of alternate layers of silicate and gibbsite sheets bonded together by a hydrogen bond; because this hydrogen bond between the base surface of the silica layer and the gibbsite layer is quite strong the lattice is stable and does not expand readily.

Also because of this relatively strong hydrogen bond the particles of kaolinite do not break down into single silica-gibbsite sheets but clusters of sheets with highly negative charges which can attract very thick layers of water.

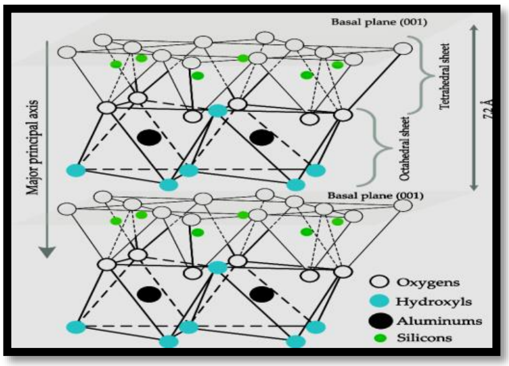


Figure 2.9: Structure of Kaolnite (Rana, H. T. (2003).

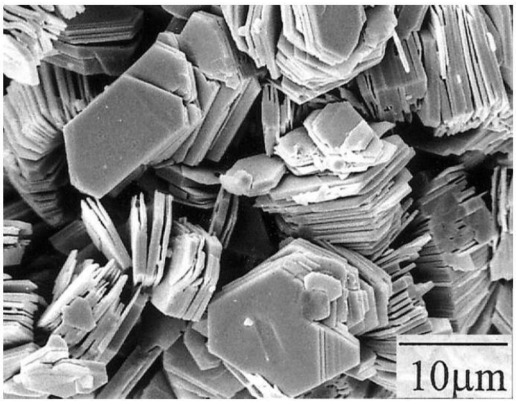


Figure 2.10: Scanning electron microscopy of Kaolinite(AMR 2018, Al-Ani&Sarapää, 2008).

Because kaolinite sheets are stacked on eachother, the hydroxyls of octahedral sheets are given access to be pulled to oxygen of silica tetrahedron sheet through bonds of oxygen. Cleavage occurs if ionic and covalent bond becomes weak when compared to primary bonds. 70 to 100 thick layers of crystals are formed because of the developing structural sheets occurring in two directions (Oweis, 1998).

2.8 The Geochemistry of Clay Minerals

Discuss the ion exchange and equilibrium absorption and surface charge as below,

2.8.1 Ion Exchange and Equilibrium Adsorption

Minerals clay having particle size less than 2μm results to having large surface area. The large surface area helps to make the exchange of ions and molecules with the surrounding solution possible. Adsorption and desorption processes whom are usual fast takes place as exchange of ions is done. Adsorption is the process of ions getting attracted to a surface. The bond strengths varies from moderate absorption (electrostatic adsorption) to weak Van der Waals (physical adsorption) and to strong chemical bonds (chemisorption). These process involve organic molecules, neutral species, H_4SiO_4, H_2O, ions (Al-Ani&Sarapää, 2008). An example illustrating attraction of positively charged ions by a 2:1 smectite structure to tetrahedral oxygen surface (light green).

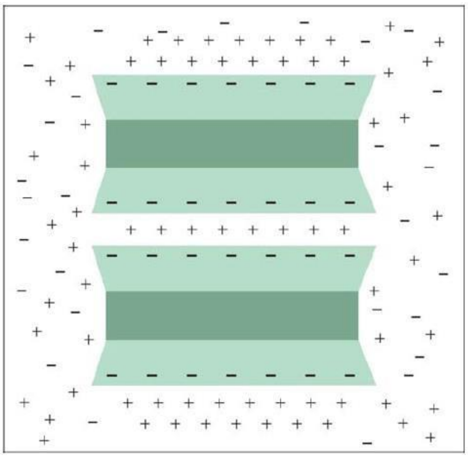


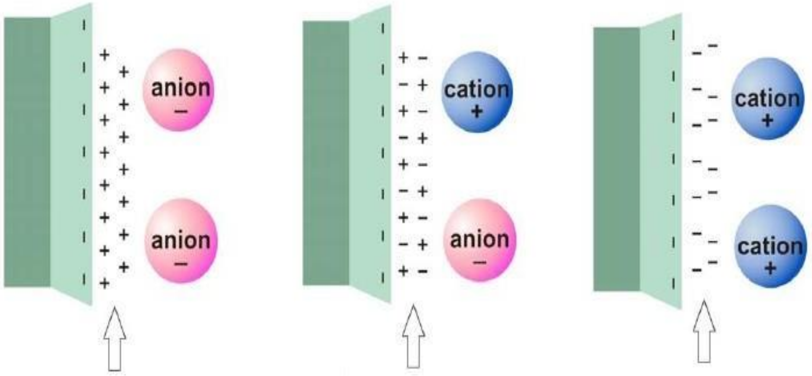
Figure 2.11: Attraction of ions to a 2:1 smectite structure

2.8.2 Surface charge properties

This carries the responsibilities of determining the charge which depends on the pH of sediments and soil. Protons adsorption by them produces positive charge. At higher pH value, they act as neutral and negative charge will be formed finally. Another way of forming surface charge is the adsorption of anions, when the surface of clay serves as the electrode.

Action of ions as they react with the surface of minerals defines the surface potential in the aqueous method of clay. When total charge from both anions and cation on a surface equals to zero, it is termed as ZPC (zero point of charge), this idea is adopted when there is occurrence of concurrent adsorption of protons and hydroxyls together with other potentials that determines the cation and anions.

The amount of cation against anions doesn't generally say they are equal at a zero charge instance. H^+, OH^- and complex ion produced as results of OH- and H+ bonds are the potentials that determine the ions present in clays. The level of pH determines the surface charge as shown in Figure 2.12.



(a) pH below ZPC (b) pH at the ZPC (c) pH above ZPC

Figure 2.12: Different pH level versus surface charge (Al-Ani&Sarapää, 2008, Bergaya, F., &Lagaly, G.2013)

In Figure 2.12, more protons are formed on the tetrahedral sheet's surface at lower pH level. This occurs when contact happens in between oxygen and solution surface, it can be seen in Figure 2.12 a, the exchange ability of anions will be portrayed on the surface.

When pH is same as ZPC, the proton and hydroxyls on the tetrahedral sheet's surface balances as the solution come in contact with the surface of oxygen, it is shown in Figure 2.12 b, there is absence of exchange ability exhibition on the surface.

When pH increases, more hydroxyls are formed on the tetrahedral sheet's surface because ofinteraction between surface of solution and oxygen, it can be seen in Figure 2.12 c, the exchange ability of cation will be portrayed on the surface.

2.8.3 Reaction of NaOH with clay minerals

As solution of NaOH is added to clay soil, the clay minerals which include montmorillonite, illite and kaolin are attacked. But the kaolin is more strongly reaction the other minerals and this leads to complete or partial removal of AlO_3, Fe_2O_3 and SiO_2 which are the main constituents of the clay minerals(Carroll & Starkey, 1971).

2.9Expansive Clay ofCyprus

The changes in the sedimentary cycles of pelagic sediments and Trodosophiolite give rise to the formation of the Cyprus soils which is mainly expansive. The type of expansive soils in Cyprus includes clay of Mamonia complex, Bentonitic clay, alluvium clay, Kythera group clay and Nicosia formation clay.

Bentonitic clay and Mamonia complex have a liquid limit that varies between 55 – 210% and 33 – 167% possessing very high swelling potential, alluvium clay have a liquid limit approximate to 48% possessing average swelling potential. Kythera group clay have a liquid limit that varies between 47 and 73% possessing high swelling potential, Nicosia formation clay possesses extremely high swelling potential. But the bentonitic clay sample obtained from western part of North Cyprus was also found to have a liquid limit of 119% (Bilsel &Iravanian, 2017).

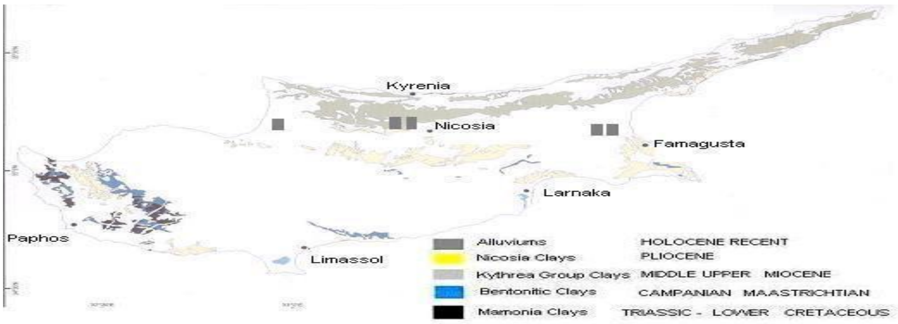
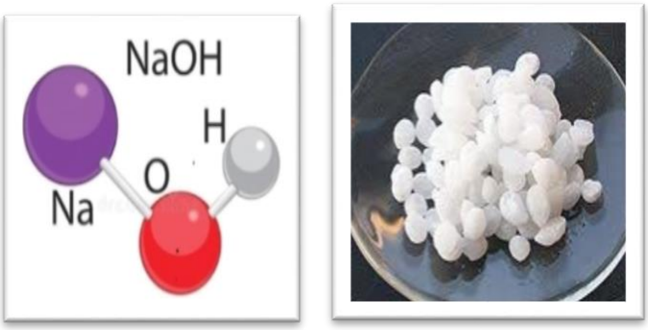


Figure 2.13: Expansive clay of North Cyprus(Revised from GSD, 1995).

Haspolat and yigitler village is very high liquid limit is 50 - 150% and plastic index 80-43% and this is high problematic soil. Stabilizationiseffect of quarry dust enhancement on the volume change characteristics of expansive clay. Different percentage of quarry dust is 10%, 20% and 30% stabilized soil swell (AMR and Salah Al-dubai 2018).

2.10Sodium Hydroxide

Sodium hydroxide is an important laboratory chemical; mainly present in a mixture of odorless, white, non-volatile solution. It doesn’t explode but is highly reactive. It acts heatedly with water and many generally come acrossapparatus, it develops sufficient heat to inflame close to flammable equipment. This consumes moisture from the air from informant NaOH at room temperature is a, deliquescent solid, white crystalline and odorless.



(a) (b)

Figure 2.14: Sodium Hydroxide molecular structure (NaOH) (a) and NaOH is at room temperature (b)

Table 2.1: Physical and Chemical Properties of Caustic Soda

Sr. No.	Properties	Values
1	Density	1.52gm/cm^3
2	Color	White

2.10.1 Characteristics of NaOH

Sodium hydroxide contains most aspects of the strong alkalis. Despite there is no risk of its explosion and ignite, it acts with different acids, for example hydrochloric acid, and it neutralizes as well as generate significant enthalpy of neutralization by exothermic.

Caustic Soda rust metals, such as tin, zinc and aluminum. According to this process, it creates hydrogen(H), which has the possibility to act as exploding gases. It is highly hygroscopic; humidity absorbs the air from, CO_2, and SiO_2. It’s also highly wet and absorbs humidity to form solution water. The same time if liquid NaOH is diluted, it creates a significant quantity of heat of intensity and the resultant mixture may spray if water is irresponsibly pouring into it.

2.10.2 Method Used for Dissolving of NaOH

When solid form of sodium hydroxide is being liquefied, it creates a high amount of heat. It is also risky if a huge amount of solid form is mixed because it will heat up and the liquid may carry up if it is in a restricted space. Since flake NaOH mixed quickly in warm water, same time when this is dissolve in water and without inspiring this outcome in sprinkle, so should be mixed gently as constantly the solution inspiring. Easy methods of mixing solid NaOH is explained as follows,

A barrier plate on which drums are arranged is fixed with the upper side of a container of and lump solid NaOH from which steel sheet has been taken and placed on the barrier plate. NaOH is submerging in the water to their breadth, the mixing starts. The upper side returns to the bottom side layer and dissolving proceeds.

CHAPTER 3

MATERIALS AND METHODOLOGY OF SOIL STABILIZATION

3.1 Research Methodology

This chapter provides the detailed information of the material used. The experimental tests carried out are stated as well as the procedures. The tests were carried out in civil engineering department laboratory of Near East University. The primary objective is to assess the performance of NaOH used as stabilizer in expansive soils.

3.2 Materials

Soil stabilization is an important technique which is done physically or mechanically but can also be done through chemical means, for this purpose various chemicals were used in the past using different concentrations. Some of them include Gypsum, Sodium Hydroxide, Aluminum oxide, Phosphorus Pent oxide and many other trace chemicals are used in chemical stabilization. And all have prime importance and play a vital role in soil stabilization. Our main focus is upon sodium hydroxide to achieve our objectives.

3.2.1 Sodium Hydroxide

Sodium hydroxide is an important laboratory chemical; mainly present in a mixture of non-volatile odorless, white, solution. It is not explosive but it’s highly reactive. It acts furiously with water and many other materials; it develops sufficient heat to inflame close to flammable equipment. NaOH consumes moisture from the air at room temperature;it’s also a deliquescent solid, white crystalline and odorless.

Figure 3.1: Sodium Hydroxide (NaOH)

3.2.2 Clayey soil

This is collected from Haspolat village behind Cyprus International University north side of pit. Soil is gray in color and comes from organic mud stone. A soil of about 30kg was taken in plastic bags.

Figure 3.2: Expansive Clayey soilHaspolat village Cyprus

3.3 Equipment

The equipment used for the respective experimental test as stated as follows,

3.3.1 Pyncnometer

Pyncnometer is used to describe the specific gravity. It is mostly filled with 100-300gm of soil and distilled water. After that sample will be combined with glass rod and covered.

Figure 3.3: Pyncnometer

3.3.2 Vacuum pump

Vacuum pump was used to remove air from the sample in pyncnometer.

Figure 3.4: vacuum pump

3.3.3 Hydrometer

Hydrometer is used in investigating the particle size distribution of soil. The particle size distribution of soils having particles smaller than 75µm can be determined using sedimentation technique with hydrometer test method but for particles bigger than 75µm, it can be determined by the use of sieves.

Figure 3.5: hydrometer

3.3.4 Cassagrande Apparatus

The cassagrande apparatus is manufactured by ELE International, it also comes with a grooving tool used for dividing the soil placed in the cup.

Figure 3.6: Cassagrande apparatus

3.3.5 Compaction apparatus

The compaction test apparatus consists of the compaction mould and the rammer. They are manufactured by ELE International. The compaction mould has a height of 11cm and diameter of 10cm, and the rammer has a weight of 2.5kg.

Figure 3.7: Compaction mould and rammer

3.3.4 Unconfined compression test apparatus

This unconfined compression test apparatus (model code: 25-3605) used was manufactured by ELE International. It has a load capacity of 6.6kN. Strain controlled tri- axial test apparatus. Strain controlled mechanism consisting of strain setting lever and turret lever for inducing axial strains in the sample at rates varying from 0.02 mm/minute to 1.00 mm/minute. Formeasurementofcompressivestrengthtakenbythesample, 250kgcapacity of proving ring with proving constant of 0.150kg/division. Load gauge installed in proving ring with a least count of0.002mm. For measurement of vertical deformation in the sample, deformation dial gauge with a least count of 0.01mm.

3.4Methodology

To find out the properties of the soil according to the American society for testing and materials (ASTM) as shown in figure this method in not use only the properties of soil it is also study about the NaOH as a using stabilizer and the effect of properties

Table 3.1: Test and ASTM code

Test Name	Code Used
Specific Gravity	ASTM D854
Hydrometer	ASTM D422
Atterberg limits	ASTM D4318
Proctor compaction test	ASTM D698
Unconfined Compressive strength	ASTM D2166

3.4.1 Soil Collection from Site

The red soil and grey clayey soil collected was pulverized into fine powder using wooden hammer and then air dried. Then it was poured in a sieve of 2.35mm, the sieved soil was then mixed accurately. The well blended soil was stored in a polythene bag. During every test, the needed quantity of soil was taken from the polythene bag and dried up in an oven at temperature 60˚C±5˚ C for 24 hours. Then soil was left to cool at room temperature.

Figure 3.8: soil collection fromhaspolat village site

3.4.2 Specific gravity

Specific gravity (G_{S}) of soil generally defines the specific gravity of the solid particles in the soil sample. The specific gravity of solids is usually simply appropriate to the soils that pass out through the No. 4 of sieve.

The weight of the pycnometer was first measured and recorded as w1, 100g of soil is then poured in to the pycnometer and recorded as w2. Sufficient water is added to the soil in pyncnometer to a marked point and mixed, vacuum pump was used to remove air from the sample in pyncnometer, it was then measured and recorded as w3. The mixture is poured away and the pyncnometer is dried. Water was poured to the pyncnometer to the marked point, it was then measured and recorded as w4. The specific gravity was then determined using equation 3.

$$\mathbf{G_s = \alpha \frac{(w2-w1)}{(w4-w1)-(w3-w2)}} \qquad (3.1)$$

Where,

w1= weight of empty pyncnometer

w2= weight of soil and pyncnometer

w3=weight of soil+ water + pyncnometer

w4=weight of water + pyncnometer

Table 3.2: Recommended mass according to pyncnometer volume (ASTM)

Soil type	**Specimen mass by using 250 ml pyncnometer**	**Specimen mass by using 500ml pyncnometer**
SP, SP-SM	60 ± 10	100 ± 10
SP-SC, SM, SC	45 ± 10	75 ± 10
SILT OR CLAY	35 ± 5	50 ± 10

3.4.3 Hydrometer test

Hydrometer test is used in determining the particle size distribution of soil. Sieves are usually used in determining the soil distribution for particles bigger than 75µm but hydrometer test which uses process of sedimentation is used for particles smaller than 75µm(American society for testing and materials, 2007).

The water should have the room temperature. Dematerialized water or sodium hexametaphosphate should be added to distilled water in order to avoid effects of impurities and salt content. The amount of the sodium hexametaphosphate to be used should be 40g/L of the solution.

50g of soil sample that passed through #200 sieve was taken and oven dried in the oven at 60°C for 24hrs in order to remove retained moisture content. The sodium hexametaphosphate was added to the water based on 40g/L. Slurry was made after mixing the oven dried soil and water uniformly. It was then added into the 1000ml cylindrical tube and filled with the distilled water until the 1000ml mark. The solution was covered and shaken for 1 min. hydrometer (H151) was then inserted in the cylindrical tube and the readings were taken. The hydrometer is then inserted in another tube filled with distilled water only. The hydrometer test results will be presented in Chapter 4.

Figure 3.9: Hydrometer test

3.4.4 Liquid limit

The liquid limit was examined in the laboratory with the help of cassagrande apparatus. Soil sample of about 120gms is dried in air and soil that passed through 425µ IS sieve was take a dish and dissolved thoroughly with noted quantity of water and poured in a cup having a maximum depth of 12mm. The sample was grooved and leveled to a maximum depth of 12mm. The sample was grooved and handle rotate at 2 spins per second(s^{-1}). Sum of blows compulsory to close the groove with the base of soil sample were computed. The moisture percentage of soil in the cup was changed and the experiment was repeated by fixing the moisture percentage in this way the sum of blows needed to close the groove fell in the number of range of 10-40 blows. A plot of moisture percentage was made against the log of blows. The moisture content related to 25 blows was known as liquid limit.

Figure 3.10: Cassagrande's apparatus

3.4.5 Plastic limit

The soil which is dried in air was sieved by 425µ IS sieve and about 30gms was taken for performing test. It is properly mixed with nearly about 10% quantity of water completely in an evaporate plate. It was combined thoroughly with help of fingers. It was approximately 10gms of plastic soil mass prepared a ball was developed. In figure 3.11(a) The ball was coiled with the help of fingers to make thread of soil until 3mm diameter without crumbling on a glass plate. Figure 3.11(b) the process of combining and coiling were repeated the soil till showed the collapsing when the diameter is 3mm the moisture content of the crumbled portion of the thread was determined.

(a) **(b)**

Figure 3.11: Plastic limit samples thread (a) and after dry the thread (b)

Plastic index is (PI) is a measure of the plasticity of a soil. In another words, it is the size of the range of water contents were the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit as in equation 3.2. PI is used to relate how expansive clays were. A PI index lower than 20-24 was generally a safe area, but higher than that and would then have to respond to swelling clay conditions.

$$PI = LL - PL \tag{3.2}$$

3.4.6 Standard Proctor Test

Standard Proctor test was performed to calculate the Maximal Dry Density (MDD) and Optimum Moisture Content (OMC) of soil and for stabilized with the varying (NaOH) percentage with soil. Specimens of soil treated with permian red clay 0%, 8%,12%,16% and clayey soil Cyprus 0%, 5%, 10%, 15%, 20% of sodium hydroxidewere processed at MDD and OMC as per ASTM.

Clayey soil was dried by Oven combined with different percentages of chemicals. Adequate amount of distilled water was then mixed to bring the water content to the preferred level. The mixture was mixed again properly with the help of spatula.

The apparatus which is available for light compaction consists of a cylindrical mould with an inside diameter of 100mm and height(H) of mould is about 127.5mm and volume(V) of mould is1000 ml. A removable collar of 60mm height fits on the top of the mould with portable base. The rammer apply in the test weigh(w) 2.6 kg with a drop of 310 mm and having face diameter of 50 mm. About 3.0 kg soil sample was taken which is dried in oven. It was mixed properly about 10% potable water by weight. Sample (mixture of soil and water) was place in an air tight vessel for about 10 hours. The mould was cleaned, dried, greased lightly. The empty mould after attaching the collar was filled with matured soil to such an extent that after compaction by hammer with 25 even distributed. Blows it is about one third of its height. The top of the first layer was scraped with a knife before putting and compact the second layer. After the removing of the collar of mould and excessive soil trim off the straight knife. The sample with mould and base plate was weighed. A representative sample from the centre of the compacted specimen was taken for its moisture content determination. Method was redone 4-5 times, after adding 5%

increase in moisture content than the proceedings one till there was either a reduce or no vary in the mass of soil in the mould of compacted. Water content and dry density (DD) was calculate for reach set and then for the calculation of maximum dry density (MDD) and optimum moisture content(OMC) graph was drawn. The method was redone for finding the optimum moisture content (OMC) and maximal dry density (MDD) of soil with chemical mixture. By the equations with calculate the dry density

Wet density of soil $\gamma t=(W-Wm)/Vm$

Moisture content of soil $(w\ \%) = (W2-W3)100/(W3-W1)$

Dry density of soil , $\gamma d = \gamma t / (1+ w/100)$

Whereas, mould weight = Wm,

Mouldweight + soil compacted = W

Moisture container of Weight = W1

Container Weight + soil wet = W2

Weight of container + soil dry = W3

Figure 3.12: Compaction moulds

3.4.7 Unconfined Compressive Strength Test

The Unconfined Compressive test is a unique form of tri-axial test, in which the imprison pressure is zero. The test can be done only on clayey soil which can withstand load without confinement. The test is generally conducted on intact saturated clay specimens.

Cylindrical samples were condensing by still compaction in the 3.6cm diameter and 7.5cm high mould. The within of surface the mould was blur with mobile oil of low viscosity which does not affect the property of samples texture depth sample from mould with minimum disturbance. The wet homogeneous mixture was placed inside the specimen mould in seven layers using spoon, leveled and gently tap – compacted by 1cm diameter ram. Pressure padding is insert into the mould and the complete assembly of statically condense in load frame to the desired density. The case was placed under static load for not < 10 minutes in arrange to version for any following raise in height of sample due to expansion. The sample was then drain out from the mould with sample extruder.

A set of unconfined compressive strength test werecarry out to calculate to unconfined compression strength features invariable soil. Soil treated 0%, 5%, 10%, 12%, 15%, 16% and 20% of sodium hydroxide to evaluate the effect of chemicals on shear strength of soil. These specifications have been established by developing the relationship among resulting axial stress. Applied strain in strain controlled tests. Unconfined compressive strength has been determined as peak strength value and respective failure strain has been calculated from the observations which were taken during test.

The molded sample was kept on the pedestal of the tri-axial cell with impervious discs at the top and bottom. A loading plate was kept at the top which was connected through loading pi ton to a proving ring. The axial strain rate was chosen as 1.0 mm/minute by suitable setting of turret lever and strain setting levels. At failure, peak compressive stress wad noted as unconfined compressive strength and failures strain was recorded. The results have been reported in next chapter.

Soil passing through sieve 600μ sieve was used to prepare the sample in the mould. The weight of soil is equal to the result of MDD and volume of the mould, was properly mixed with quantity of water equal to O.M.C. the sample were made by compacting the soil mixes in the mould. The sample were extracted from the moulds and tested in unconfined compression testing machine.

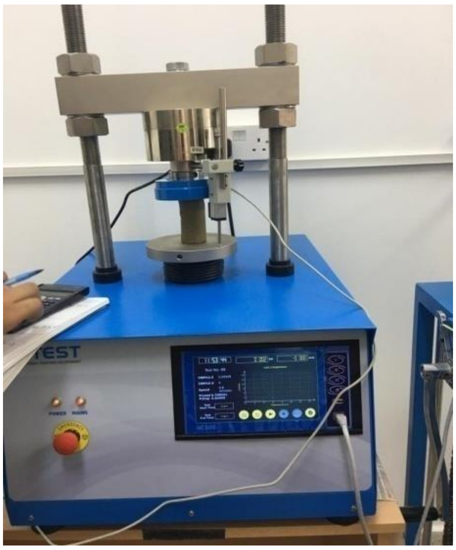


Figure 3.13: Unconfined compression test apparatus

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Explained in the last chapters, this is experimental research evaluating the appropriateness of sodium hydroxide to be implemented as soil modifying agent for stability of expansive soils. In order to give emphasis, the result of NaOH on the performance of expansive soil gathers from NEU, CYPRUS, carried out a sequence of tests. The investigational result are offered and interpret in this section discuss both positive and negative special effects of different percentages of NaOH on the individuality of expansive soil. The investigational program of these lessons consists of resolve of physical properties of soil and UCS action parameters, potential volume change (compressibility), strength behavior (unconfined compressive strength).

4.2 Analysis Grain Size Particles

All the soil passed through sieve No.200 and sedimentation test is carried out. A hydrometer test was used to categorize the particle which are lesser than 0.002 mm (sieve No.200 ASTMD422–63). In figure 4.1 results demonstrated signify that the extensive soil consists of clay 67% and 33% silt of clayey soil Cyprus.

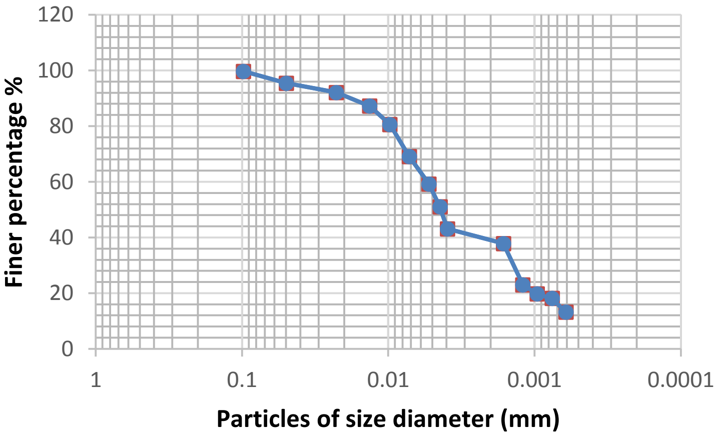


Figure 4.1: Particles size distribution of size of clay

4.3 Specific Gravity

Specific gravity of the normal expansive soil finds according to the ASTM D854–14 standards is 2.69. However, we are used for the determination of the gravity by pyrometer test. Therefore, for finding the specific gravity of the mixtures, standard test method is functional which mention in the methodology chapter 3. It can be considered by using each component's dry mass and the values of specific gravity value according to Eq 4.1, and clayey soil Cyprus is 2.55. NaOH specific gravity was assumed as 2.12, (Carroroetal, 2011) was used 2.12 as the NaOH specific gravity.

$$G_{S}= \frac{\text{Density of object}}{\text{Density of water}} \qquad (4.1)$$

Table 4.1: specific gravity of materials

Materials	Specific Gravity
Clayey soil Cyprus	2.55
NaOH	2.12

4.4 Atterberg Limits Theory

The obtained samples were subjected to a soil consistency test in order to obtain their liquid limit, plastic limit and plasticity index. The results obtained are shown in figure 4.2 Clayey soil of Cyprus has LL, PL and PI of 68%, 32% and 36%respectively. For the percentage NaOH of 5%, 10%, 15% and 20% the Atterberg limits results were obtained. And 5%NaOH had LL, PL and PI of 56%, 27% and 29%respectively. At the 10% NaOH, 47%, 25% and 23 were obtained. At 15% NaOH, 35%, 20% and 15%, and at 20% NaOH 30%, 17% and 5% respectively. According to table 4.3, the soil was a clayey soil and was highly expansive because the liquid limit was 50-70%, but using additive stabilizer the plasticity of soil decreasesat 15% of NaOH and the plasticity was 15%.

Table 4.2: Atterberg limits result with different percentage of NaOH

% NaOH	LL	PL	PI
0%	68	32	36
5%	56	27	29
10%	47	25	23
15%	35	20	15
20%	30	17	5

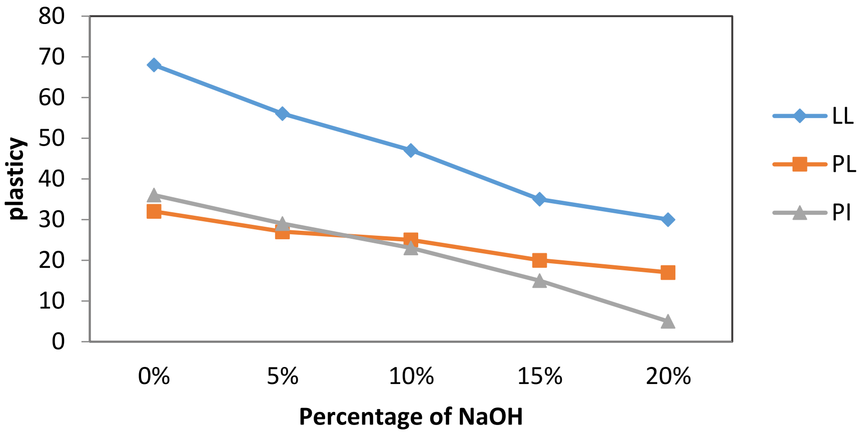


Figure 4.2: Atterberg limit graph clayey soil Cyprus

An Atterberg limit of Permian red clay is comparatively close to Cyprus clay. Both soils have plasticity index greater than 30%, therefore the expansive properties of these two clay samples is expected to be quite alike. According to the Holtz and Kovacs, (1981) and considering the result demo stated in Table 4.2 the range of LL is between 30 to 68percent which is clearly indicating that the volume change of soil is expected to be medium to high. The results also showed that 0-5% of NaOH fall under the high-volume change while 10%, 15% and 20%of NaOH falls under medium volume change values. The followingare the main effect of high-volume change: Large volume changes will occur in a climate with alternate wet and dry seasons, while smaller changes will result from alternating precipitation and drying periods. If the volume change is uniform it is not easily observed, and considerable vertical soil movements may occur without being recognized.A large amount of shrinkage occurs when water-deposited clays are first dried. The amount of re-swelling in the presence of free water depends primarily upon the clay minerals present in the soil(Degirmenci, N 2007).

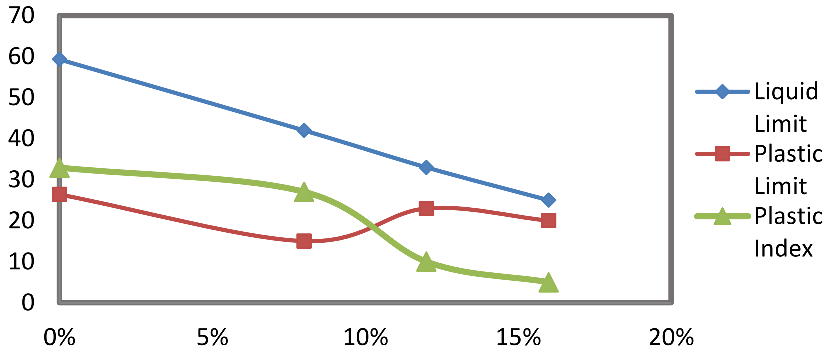


Figure 4.3: Atterberg limit graph Permian red clay

The characterization of Atterberg limits as indicated by their swell potential dependent on a plan done by (Holtz and Kovacs, 1981) which notices the connection between volume change with fluid breaking points and plastic cutoff points are appeared Table 4.2 and the plan can be found in Table 4.3. The adjustment of swell potential was observed to be from high to extremely high.

Table 4.3: A scheme of volume change related to plasticity index and liquid limit (Holtz & Kovacs, 1981).

Liquid Limit (%)	20-35	35-50	50-70	>70
Plasticity Index (%)	<18	15-28	25-41	>35
Volume change	Low	Medium	High	Very High

4.5 Compaction Test of Expansive Soil with different Percentages of NaOH

This test presents the results of the test conducted on locally available Cyprusstabilized with sodium hydroxide in geotechnical laboratory of civil engineering department laboratory of Near East University Cyprus. The standard protector test is experimentally method determining the OMC and MDD.

4.5.1 Clayey soil

Sodium hydroxide used in experiments taken in different percentage of 0%, 5%, 10%, 15% and 20%. Below is the test results related to treatment of clayey soil Cyprus with NaOH. In table 4.4, it can be seen that the increase in the percentage of NaOH gradually increases the Maximum dry density. It can also be seen that MDD is maximum with the 15% NaOH but when increasedto 20% NaOH, the MDD reduces as compared to 15% NaOH.

Table: 4.4: Characteristics of Different Percentages of NaOH with Clayey soil Cyprus

Sample of soil with Percentages of Sodium Hydroxide	Optimum Moisture content (%)	Maximum Dry Density (g/cc)
Soil+0%NaOH	20	1.72
Soil + 5% NaOH	17.6	1.82
Soil + 10 % NaOH	16.3	1.85
Soil + 15% NaOH	15.54	1.94
Soil + 20% NaOH	16.08	1.86

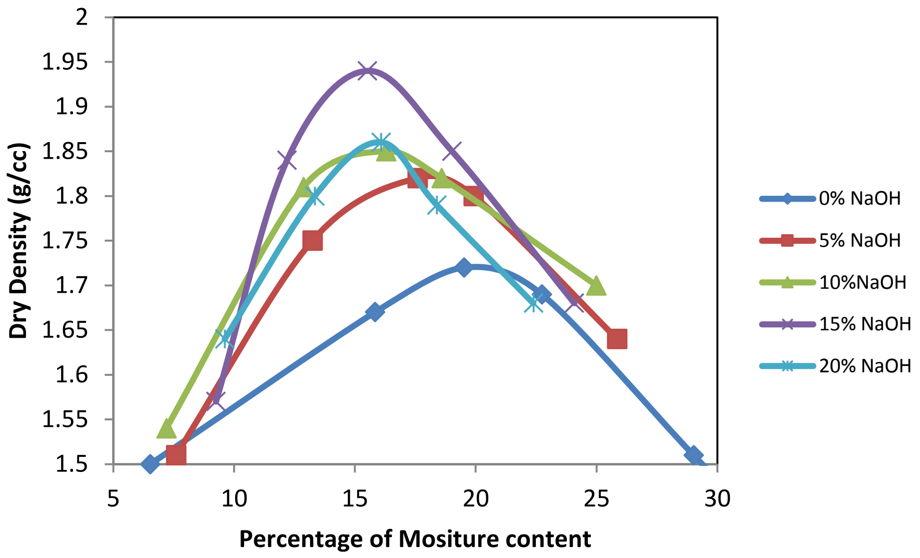


Figure 4.4: Compaction test clayey soil Cyprus

In table 4.5, the result of the optimum water content and maximum dry density for control samples is given which is 1.82(g/cc). But when the percentage was increasedto 8% NaOH, the density becomes 2.01 and increasing the percentageto 12% and 16%, the densityalso increases to 2.05 and 2.15. The maximum density increases up tothe 16% but us not sure that about the percentage of NaOH increase or decreasing. The MDD increases as the NaOH percentage increases up to16% which was the maximum percentage used for the Permian red clay, therefore we are not certain if the MDD will increase or decrease with increase of NaOH percentage over 16%.

Table: 4.5: Characteristics of Different Percentages of Caustic Soda with Permian Red clay

Sample of soil with Percentages of Sodium Hydroxide	Optimum Moisture content (%)	Maximum Dry Density (g/cc)
Soil+0%NaOH	19.48	1.82

Soil + 8% NaOH	20.80	2.01
Soil + 12 % NaOH	19.3	2.05
Soil + 16% NaOH	20.1	2.15

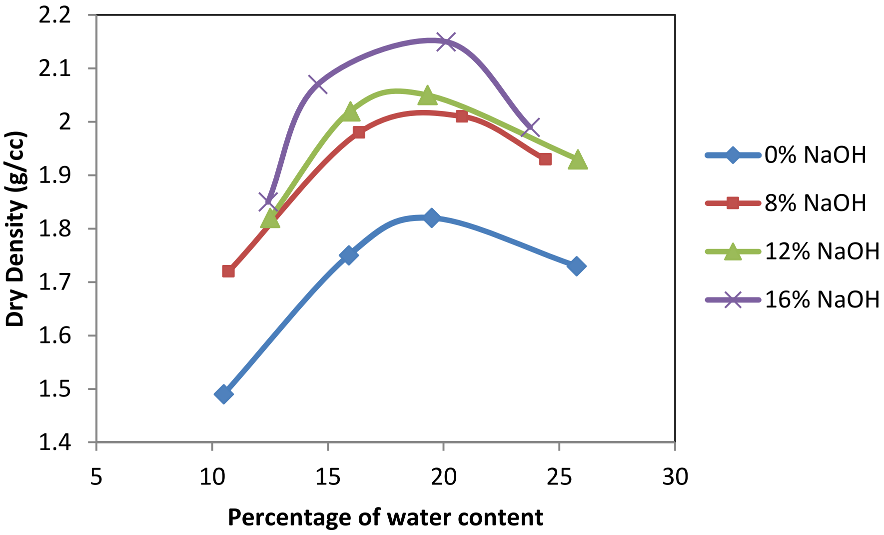


Figure 4.5: Compaction test Permian red clay

There are variations of water absorption as percentage of NaOH changes. The water absorption more or less increases with increases in the percentage of NaOH. There is no significant difference in water absorption/open porosity with the increase in NaOH content. Though, a slight increase was observed by increasing the NaOH content to 16.

4.5.2 Comparison of Permian Red Clay and Clayey Soil Compaction Test

Thedata below was obtained from Pakistan used for the comparison of different percentages of NaOH, and analysis of the data was done to further explanation. Permian red clay used was 0%, 8%, 12% and 16% NaOH. In the figure 4.4 the comparison of Permian red clay and clayey soil Cyprus shows that increasing the percentage of NaOH increases the density.The control sample which is Permian red clay has a MDD of 1.6 g/cc and clayey soil Cyprus has 1.74 g/cc. Maximum density achieved for the Permian red clay and clayey soil Cyprus is 16% and 15% NaOH with values of 2.15g/cc and 1.94g/cc respectively, and it can be seen that increasing the percentage of NaOH above 16% lead to loss in the density.

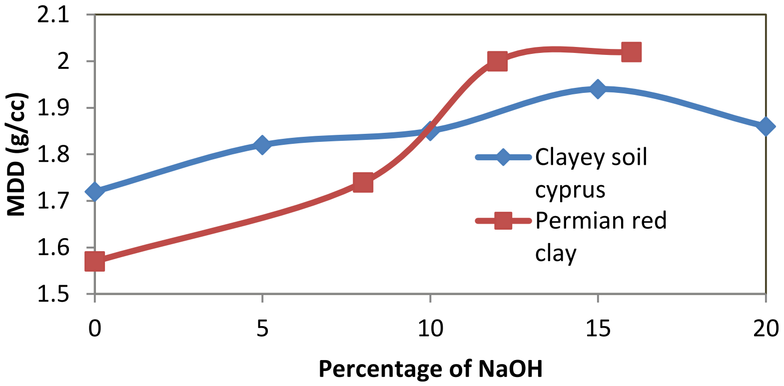


Figure 4.6: Comparison maximum dry density ofPermian red clay and clayey soil

Relationship between MDD and OMC of soil in Fig. 4.5can be obtained from soil compaction curve obtained from Standard Compaction Test. This relationship helps in determining the optimum water content at which maximum dry density of soil can be attained through compaction. From the above Fig. 4.6, the major reason why compaction was carried out is; to increase load-bearing capacity, prevent soil settlement and frost damage, provide stability, reduce water seepage, swelling and contraction, and reduce settling of soil. MDD achieved for Permian red clay and clayey soil Cyprus was 16% and 15% as mentioned above. Greater than 15%, the MDD decreases for the Cyprus clay. Therefore, it can conclude that 15% of NaOH is negotiable as the optimum.

The bonding created by alkaline solution and the subsequent isomorphous substitution of Aluminium (Al) has indeed increased the packing between the grains. The densities of the samples under all NaOH content have increased.. The maximum density after moulding was 2.15g/cc at 16%NaOH, while the minimum was 1.82g/cc under 0% NaOH. A careful investigation of the plot of density against NaOH content shows an increase in density after 15%. If the NaOH content increased more than 16%, the best packing between the grains may have being obtained.

4.6 Unconfined Compression Test

In this test clayey soil was used to identify unconfined compression test with respect to the percentage of NaOH as a stabilizer.

4.6.1 Clayey Soil

Sodium hydroxide used in experiments was taken in different percentages; 0%, 5%, 10%, 15% and 20%. The graph below shows the effect of UCS on different percentage ofsodium hydroxide. The value of UCS with 0%,5% 10%, 15%, and 20% obtained was 94, 195, 207, 354 and 150 KN/m^{2}respectively..

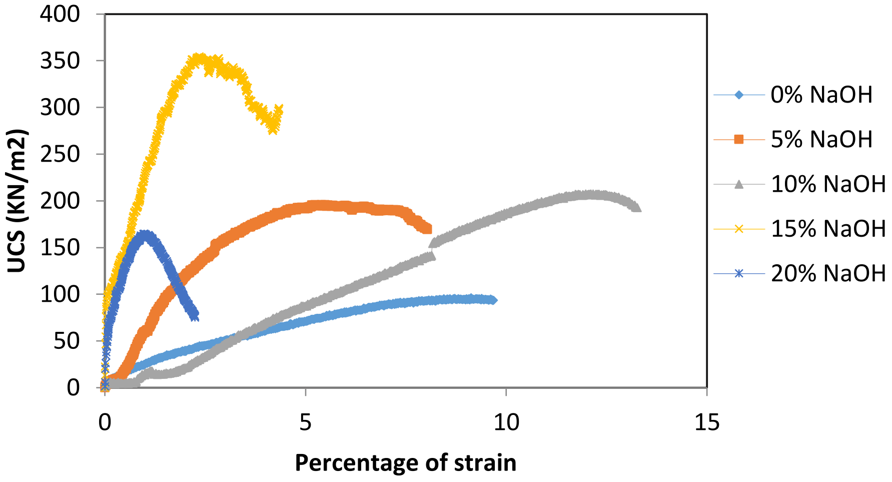


Figure 4.7: Clayey soil Cyprus unconfined compression strength with strain

Figure 4.7 shows the results of different percentages of NaOH. At 0%, the results showed there was no high strength but there was high shrinkage because the sample was not stiff and deformation is increases subsequently. As compared to other samples, itcan beseen theincrease in percentage of NaOH strength lead to increase in strength but maximum at

15% because the soil particles and NaOH bonds very well. And at 20% NaOH,the strength was not increasing as compared to the 15%. Additionally figure 4.8 shows that at 20% there was loss in the strength as in the case of the control samples.

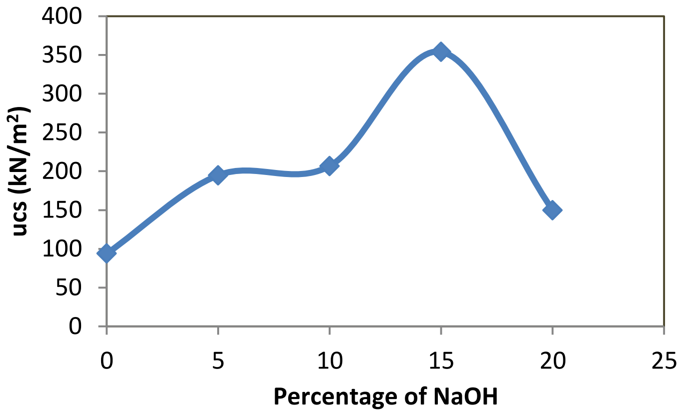


Figure 4.8: Clayey soil unconfined compression strength at different percentage of NaOH

Table 4.6: Unconfined compressive strength and consistency relationship (Das and Sobhan, 2014)

UCS (kN/m^2)	Consistency	Indication on field
24.8	Very Soft Soil	When squeezed, slips out of fingers.
24.8-48.3	Soft Soil	Easy to mold in fingers.
48.3-96.5	Firm soil	Strong finger pressure is needed for molding
96.5-193.1	Stiff soil	Can’t be molded by fingers
193.1-386	Very stiff soil	Very tough
>386	Hard Soil	Difficult to indent by thumb nail

According to Das and Sobhan, (2014), the soil without stabilizer (0% NaOH) was regarded as a firm soil and has lowest consistency as shown in table 4.6. And the highest consistency of soil was experienced in 15% NaOH as the soil becomes very stiff. Three of percentages; 5%, 10% and 20% made the soil stiff

Table 4.7: Summery of UCS with NaOH

Samples With NaOH	Unconfined compressive strength (kN/m^2)	Undrained Shear Strength (kN/m^2)	Soil Consistency	Field Identification
0%	94.03	43.76	firm soil	Can't be molded by fingers
5%	195	97.5	stiff soil	Can't be molded by fingers
10%	205	102.5	Stiff soil	Can't be molded by fingers
15%	354	177	Very stiff soil	Very tough
20%	150	75	Stiff soil	Can't be molded by fingers

According to Table 4.6, Das and Sobhan, (2014) classified the different UCS categories of soils interms of consistency from very soft soil to hard soil with the respective field indication. From our obtained result in Table 4.7, it can be observed that the categories are classified as follows: 0% (with UCS=94) was a firm soil with field indicator of strong finger pressure needed for molding, 5% (with UCS=195) was a stiff soil with field indicator that it can't be molded by fingers, 10% and 15% (with UCS=207 and 345) were both falling in very stiff soil category and 20% (with UCS=150) was acategorized as a stiff soil. Due to the increase the percentage NaOH is increase the strength is increase because alkaline attack and give the strong bonding between soil and NaOH particles. However, increase the percentage of 20% NaOH soil is lose the strength as compared to 15% NaOH. According to (Olaniyan 2011) in Na is positive charge and soil have a negative charge due to the charge equalities on 15% NaOH is giving good strength but percentage of NaOH is increase 20 strength is loosed because soil have no negative charge to bond with NaOH.

4.6.2 Permian Red Clay Pakistan

Sodium hydroxide used in experiments was taken in different percentage as 0%, 8%, 12% and 16%. The graph shows the effect of UCS on different percentage with sodium hydroxide. It shows that the value of UCS increases from the parent soil. The value of UCS with 8% was 256.05UCS, with 12% was 279.58UCS and with 16% was 298.41UCS.

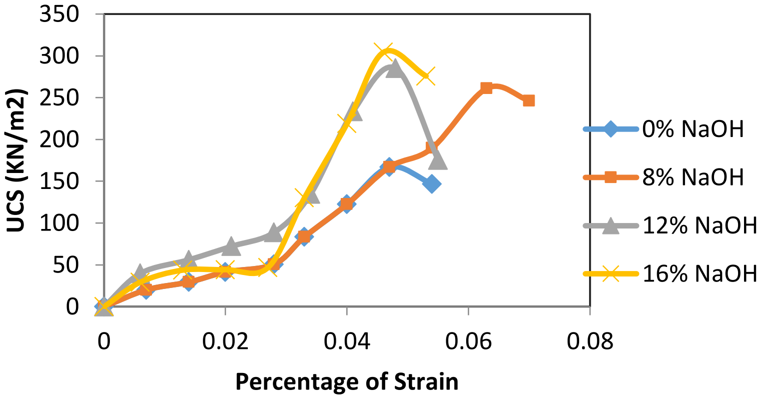


Figure 4.9: Permian red clay unconfined compression strength at differ percentage of NaOH

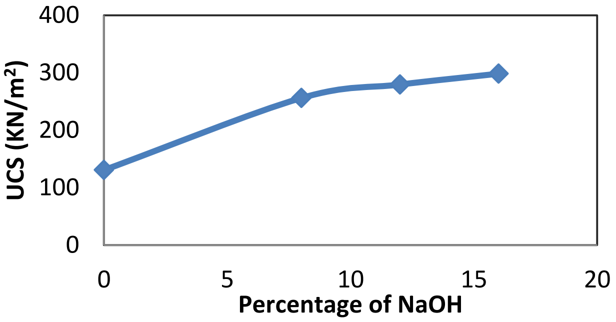


Figure 4.10: Unconfined compression test at different percentage of NaOH of Permian red clay

The primary purpose of the Unconfined Compression strength of fine grained soils that possess sufficient cohesion to permit testing in the unconfined state.In figure 4.10,it can be seen that as the percentage of NaOH was increasing from 8, 12 and 16% the strength increases but we can't say for the strength over 16%whether it will increase or decrease. With percentage of NaOH in Permian red clay,compressive strength ranges between 250-300 kN/m^2(Das and Sobhan, 2014).

4.6.3 Comparison of clayey soil and Permian red clay

Similarly, increase in the percentage of NaOH to Permian and clayey soil lead to increase in the unconfined compression strength, and the maximum strength of soil was achieved at 14-16% NaOH. After 16% we observed the clayey soil strength decreases.

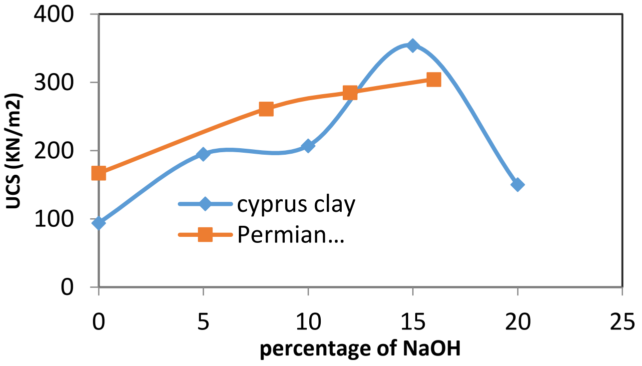


Figure 4.11: Comparison of unconfined compression test of Permian red clay and clayey soil

The Fig 4.11 also proved the aforementioned results by comparing the UCS test versus the corresponding NaOH percentage in two different regions. The graph also justifies the maximum UCS between the ranges of 15-16%. With drastic decrease of optimum UCS after 15% in Cyprus clay soil.

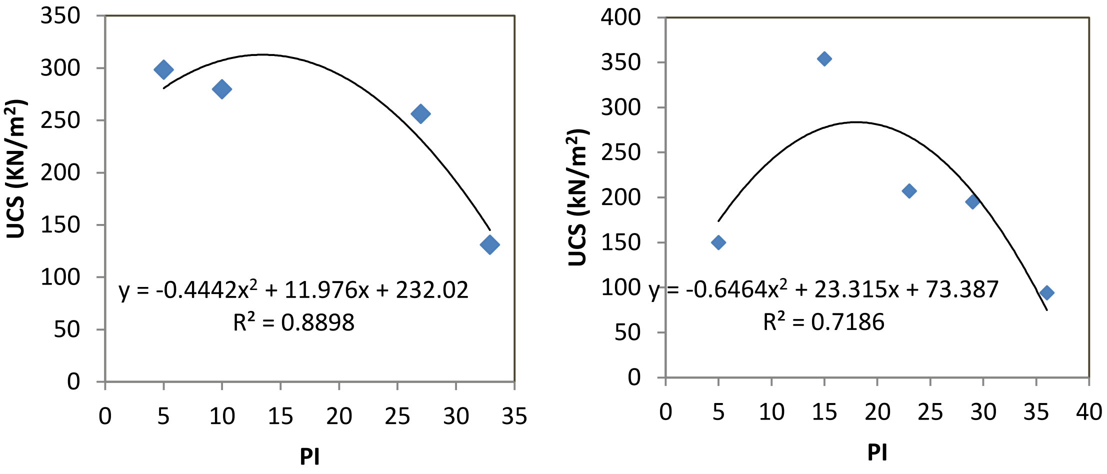
According to Olaniyan et al., (2011) the activity of expansive minerals in the soil with NaOH gives more amounts of hard geopolymeric products (feldspatoid and hydroxysodalite) which increase the strength., NaOH content of 20 % was not enough to increase the strength by compensating the decrease in cohesion. This means that such a stabilized soil is less resistant to compressive loads under wet conditions.

4.7 Correlation of Clayey Soil Cyprus and Permian Red Clay

Mutual relationship between UCS, PI, MDD and NaOH was also studied.

4.7.1 Correlation between UCS and PI

Here we try to correlates the UCS test and plastic indices to determine their relationship. The correlation was given in figure 4.12(a)(b) The lowest R^2 value was found to be 0.889 for Permian red clay and clayey soil Cyprus R^2 is 0. 718.Therefore, we conclude that there is a linear relationship between the strength results and plasticity indices. Larger strength values in the sample showed lower plasticity indices and vice versa. An increase to the stabilizer content or the use of stabilizers having higher NaOH contents lead to more significant decrease in PI and hence increases the strength of the soil. In figure 4.12 (b), the curvewas not linear because the 20% results decreased and 15% of NaOH gave the high compressive strength at 15% plasticity index. It showed that if itwas linear curve, increasing the percentage of NaOH causes plasticity index to decrease and compressive strength increases subsequently.

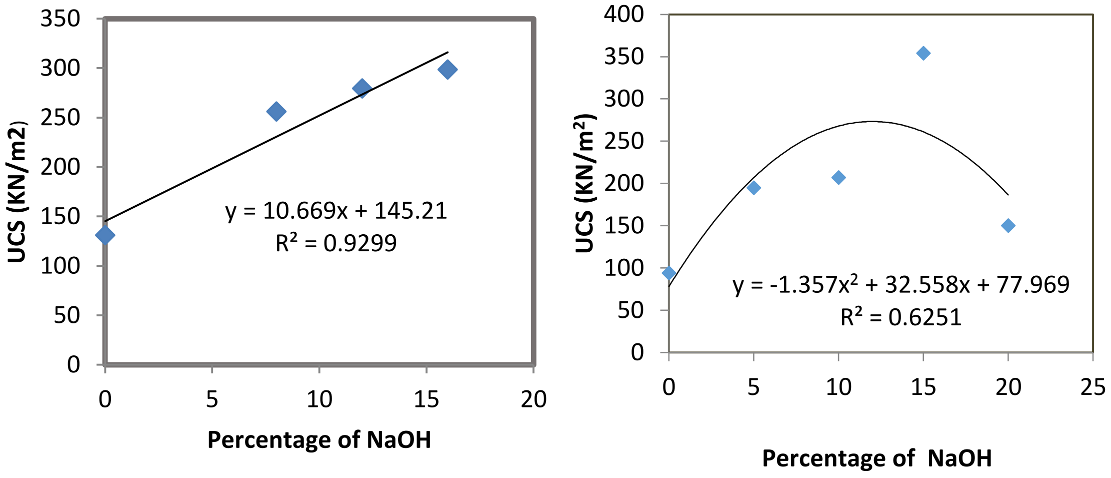


(a) (b)

Figure 4.12: Correlations between of UCS and PI Permian red clay (a) and clayey soil Cyprus (b)

7.4.2 Correlation between UCS and NaOH percentage

Here we try to correlates the UCS test and the percentage NaOH to determine their linear relationship. The correlation was shown in figure 4.13(a, b)and thePermian red clay R^2 value was found to be 0.929 and the clayey soil Cyprus value is 0.625. Therefore, we conclude that there is a linear relationship between the unconfined compression strength and the percentage NaOH, hence increase in the strength of the soil.At the 15-16% NaOH,the optimum value and the determination coefficient showing the results of good relationship between unconfined compression strength and NaOH. Larger strength values in the sample showed lower unconfined compression strength and vice versa. An increase to the stabilizer content or the use of stabilizers having higher NaOH contents lead to more significant increase in strength but decrease at the 20% of NaOH and hence increases the strength of the soil.

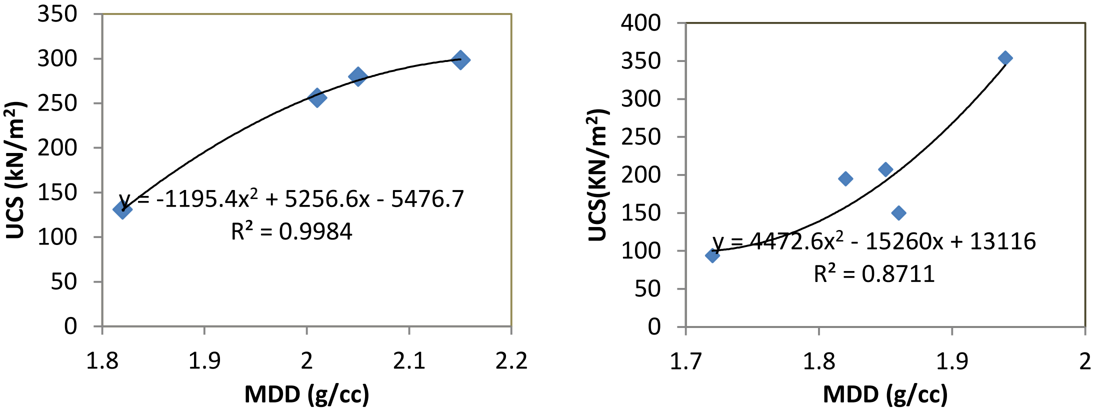


(a) **(b)**

Figure 4.13: Correlations between of UCS and NaOH Permian red clay (a) and clayey soil (b)

4.7.3 Correlation between UCS and Maximum dry density (MDD)

Here we try to correlates the UCS test and the maximum dry density (MDD) to determine their linear relationship. The correlation was shown in figure 4.14(a, b). And the $R^2$of Permian red clay value was found to be 0.948 and the clayey soil Cyprus 0.871. Therefore, we conclude that there is a linear relationship between the unconfined compression strength and the maximum dry density (MDD). And lager maximum dry density values lead to significant unconfined compression strength. Hence increase the strength of the soil.



(a) (b)

Figure 4.14: Correlations between of UCS and MDD Permianclay (a) and clayey soil(b)

In the relationship of Permian red clay is R^2 =0.99 is more linear because density and Unconfined compression strength is increase with percentage of NaOH no decrement after 16%. In figure 4.14 (b) is increasing the MDD and UCS but 20% is lost density and compressive strength.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Outcome of the study

This thesis focuses on the two major important approaches, including experimental based on laboratory analysis of sodium hydroxide (NaOH). To find theunconfined compressive strength (UCS) maximum at optimum value of sodium Hydroxide. The following collusion for experimental analysis was derived from the study.

- By the addition of NaOH in the soil the plasticity of expansive soil is decreasing this is to say when NaOH percentage is added the liquid limit and plastic limit is drastically reducing.
- At some percentage interval (0-16%) addition of NaOH increases the maximum dry density (MDD), however when 20% of NaOH is added the MDD is decreasing in both the case study (Cyprus and Pakistan).
- At some percentage interval (0-15%) addition of NaOH increases the unconfined compressive strength (UCS), however when 20% of NaOH is added the UCS is decreasing in both the case study (Cyprus and Pakistan).
- From both the case study the 14-16% is the maximum percentage of NaOH to obtain the maximum strength and therefore is more economical. This conclusion is going hand in hand with some previous research where they got almost around 15% percentage of NaOH in order to obtained the maximum strength

5.2Recommendations for Future Research

The following listed items are recommendations for future research that may be considered for further investigations of the effectiveness of sodium hydroxide on the improvement of problematic soils:

- It is recommended that the controlled, field testing should be performed arid investigated to determine the relationship with the laboratory investigati0ons.
- Economic studies should be carried out upon the practicality of sodium hydroxide mixtures as clay soil chemical stabilizers.
- It is also recommended that further refinements of the compaction test should also be investigated to be able to reproduce more consistent test results for the improvement of problematic soils.
- Erosion effects of using the different chemicals upon the laboratory and field equipment.
- Storage and handling problems associated with the use of chemicals in soil stabilization should be investigated.

The recommendation also suggested that other new approaches of experimental analysis should be explored and also different materials should be compared with different case study. As for the data driven models there are several methods of linear and nonlinear models, hence it is suggested also to introduce different algorithms and compare to identify with method is going to be more suitable and acceptable in the case study

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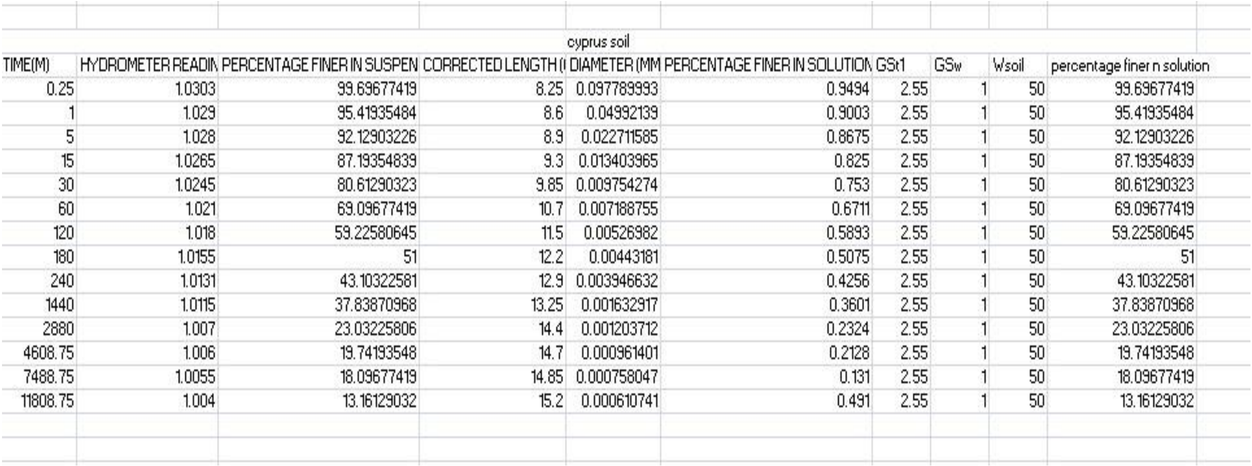
APPENDICES

APPENDIX 1

Hydrometer test grain size analysis



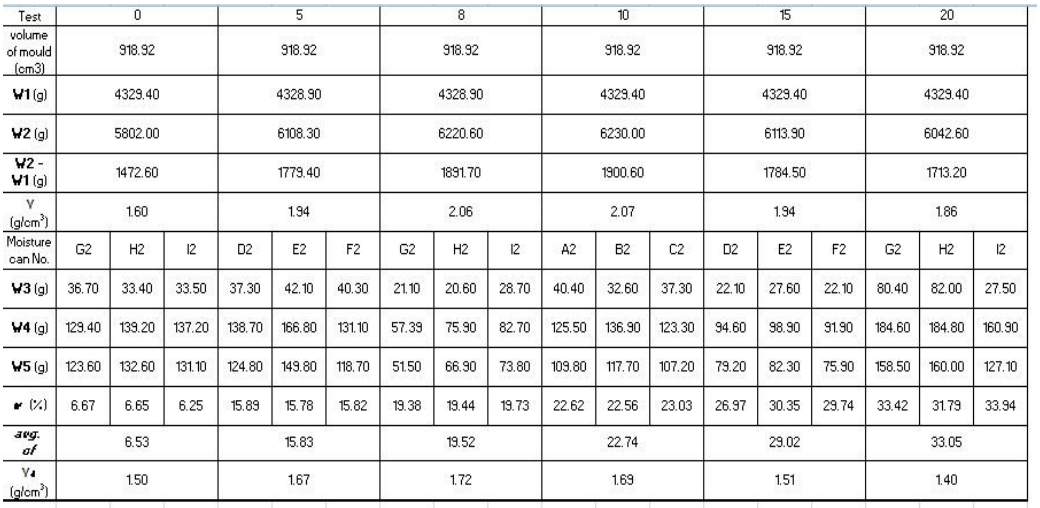
cyprus soil

TIME(M)	HYDROMETER READIN	PERCENTAGE FINER IN SUSPEN	CORRECTED LENGTH (	DIAMETER (MM	PERCENTAGE FINER IN SOLUTION	GSt1	GSw	Wsoil	percentage finer n solution
0.25	1.0303	99.69677419	8.25	0.097789993	0.9494	2.55	1	50	99.69677419
1	1.029	95.41935484	8.6	0.04992139	0.9003	2.55	1	50	95.41935484
5	1.028	92.12903226	8.9	0.022711585	0.8675	2.55	1	50	92.12903226
15	1.0265	87.19354839	9.3	0.013403965	0.825	2.55	1	50	87.19354839
30	1.0245	80.61290323	9.85	0.009754274	0.753	2.55	1	50	80.61290323
60	1.021	69.09677419	10.7	0.007188755	0.6711	2.55	1	50	69.09677419
120	1.018	59.22580645	11.5	0.00526982	0.5893	2.55	1	50	59.22580645
180	1.0155	51	12.2	0.00443181	0.5075	2.55	1	50	51
240	1.0131	43.10322581	12.9	0.003946632	0.4256	2.55	1	50	43.10322581
1440	1.0115	37.83870968	13.25	0.001632917	0.3601	2.55	1	50	37.83870968
2880	1.007	23.03225806	14.4	0.001203712	0.2324	2.55	1	50	23.03225806
4608.75	1.006	19.74193548	14.7	0.000961401	0.2128	2.55	1	50	19.74193548
7488.75	1.0055	18.09677419	14.85	0.000758047	0.131	2.55	1	50	18.09677419
11808.75	1.004	13.16129032	15.2	0.000610741	0.491	2.55	1	50	13.16129032

APPENDIX 2

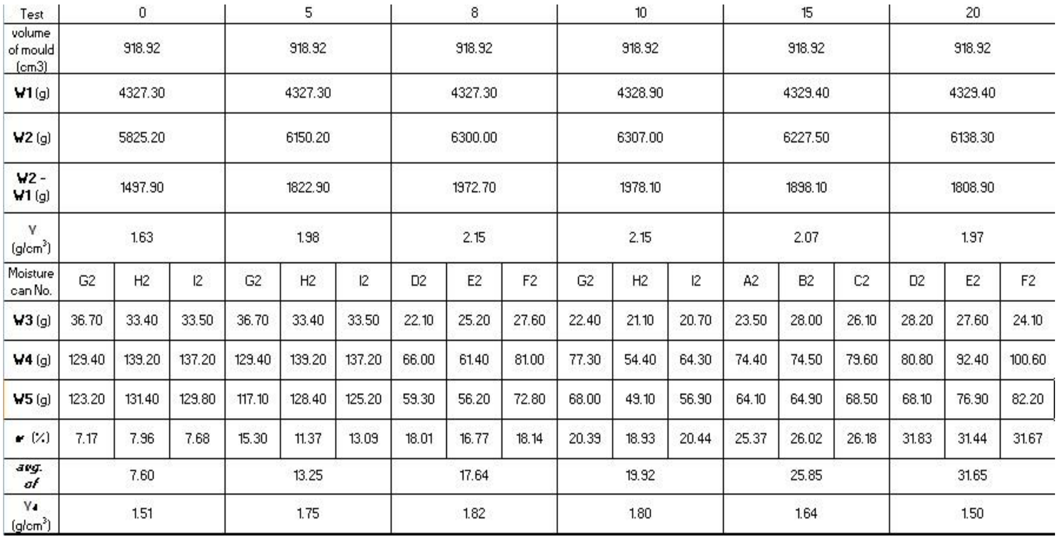
Compaction Results on Different Percentage of Sodium Hydroxide

0% NaOH compaction test results and calculation



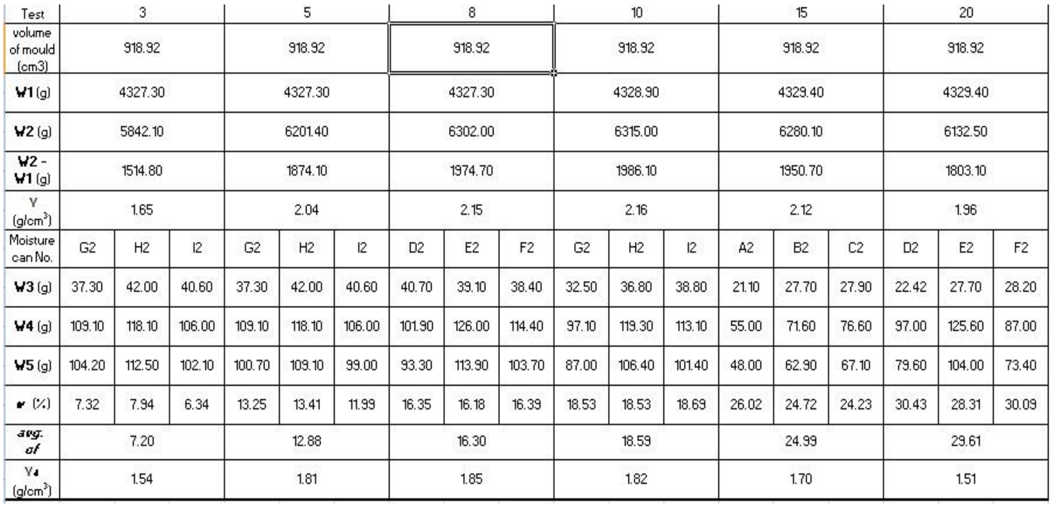
Test	0			5			8			10			15			20		
volume of mould (cm3)	918.92			918.92			918.92			918.92			918.92			918.92		
W1 (g)	4329.40			4328.90			4328.90			4329.40			4329.40			4329.40		
W2 (g)	5802.00			6108.30			6220.60			6230.00			6113.90			6042.60		
W2 - W1 (g)	1472.60			1779.40			1891.70			1900.60			1784.50			1713.20		
γ (g/cm^3)	1.60			1.94			2.06			2.07			1.94			1.86		
Moisture can No.	G2	H2	I2	D2	E2	F2	G2	H2	I2	A2	B2	C2	D2	E2	F2	G2	H2	I2
W3 (g)	36.70	33.40	33.50	37.30	42.10	40.30	21.10	20.60	28.70	40.40	32.60	37.30	22.10	27.60	22.10	80.40	82.00	27.50
W4 (g)	129.40	139.20	137.20	138.70	166.80	131.10	57.39	75.90	82.70	125.50	136.90	123.30	94.60	98.90	91.90	184.60	184.80	160.90
W5 (g)	123.60	132.60	131.10	124.80	149.80	118.70	51.50	66.90	73.80	109.80	117.70	107.20	79.20	82.30	75.90	158.50	160.00	127.10
w (%)	6.67	6.65	6.25	15.89	15.78	15.82	19.38	19.44	19.73	22.62	22.56	23.03	26.97	30.35	29.74	33.42	31.79	33.94
avg. w	6.53			15.83			19.52			22.74			29.02			33.05		
γ_d (g/cm^3)	1.50			1.67			1.72			1.69			1.51			1.40		

5% NaOH compaction test results calculation



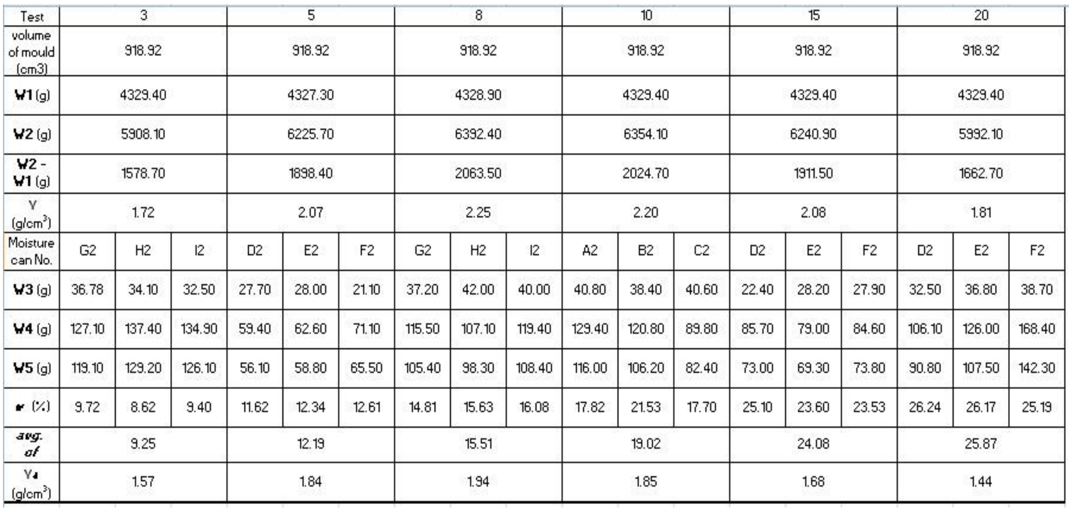
Test	0			5			8			10			15			20		
volume of mould (cm3)	918.92			918.92			918.92			918.92			918.92			918.92		
W1 (g)	4327.30			4327.30			4327.30			4328.90			4329.40			4329.40		
W2 (g)	5825.20			6150.20			6300.00			6307.00			6227.50			6138.30		
W2 - W1 (g)	1497.90			1822.90			1972.70			1978.10			1898.10			1808.90		
γ (g/cm^3)	1.63			1.98			2.15			2.15			2.07			1.97		
Moisture can No.	G2	H2	I2	G2	H2	I2	D2	E2	F2	G2	H2	I2	A2	B2	C2	D2	E2	F2
W3 (g)	36.70	33.40	33.50	36.70	33.40	33.50	22.10	25.20	27.60	22.40	21.10	20.70	23.50	28.00	26.10	28.20	27.60	24.10
W4 (g)	129.40	139.20	137.20	129.40	139.20	137.20	66.00	61.40	81.00	77.30	54.40	64.30	74.40	74.50	79.60	80.80	92.40	100.60
W5 (g)	123.20	131.40	129.80	117.10	128.40	125.20	59.30	56.20	72.80	68.00	49.10	56.90	64.10	64.90	68.50	68.10	76.90	82.20
w (%)	7.17	7.96	7.68	15.30	11.37	13.09	18.01	16.77	18.14	20.39	18.93	20.44	25.37	26.02	26.18	31.83	31.44	31.67
avg. w	7.60			13.25			17.64			19.92			25.85			31.65		
γ_d (g/cm^3)	1.51			1.75			1.82			1.80			1.64			1.50		

10% NaOH compaction test results calculation



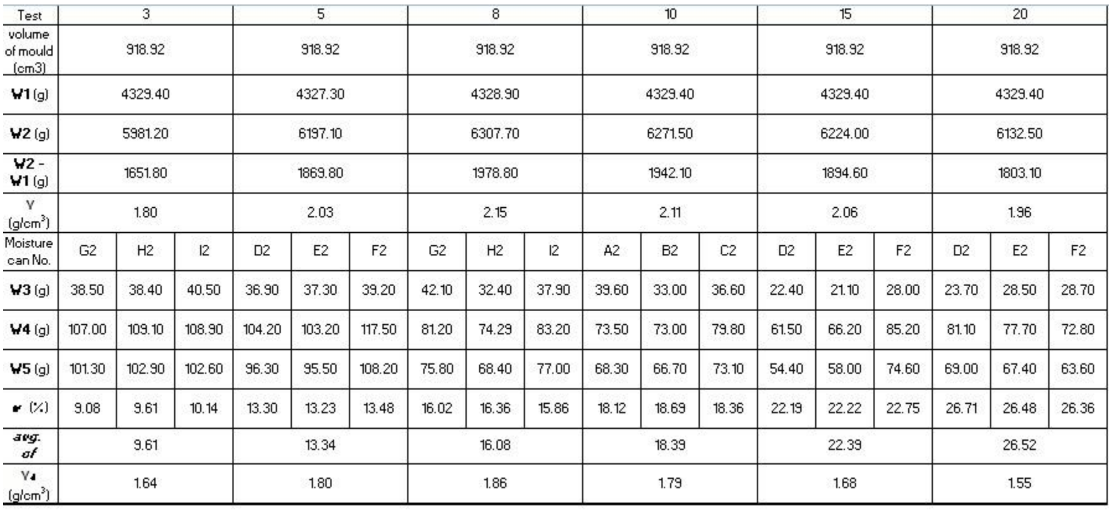
Test	3			5			8			10			15			20		
volume of mould (cm3)	918.92			918.92			918.92			918.92			918.92			918.92		
W1 (g)	4327.30			4327.30			4327.30			4328.90			4329.40			4329.40		
W2 (g)	5842.10			6201.40			6302.00			6315.00			6280.10			6132.50		
W2 - W1 (g)	1514.80			1874.10			1974.70			1986.10			1950.70			1803.10		
γ (g/cm^3)	1.65			2.04			2.15			2.16			2.12			1.96		
Moisture can No.	G2	H2	I2	G2	H2	I2	D2	E2	F2	G2	H2	I2	A2	B2	C2	D2	E2	F2
W3 (g)	37.30	42.00	40.60	37.30	42.00	40.60	40.70	39.10	38.40	32.50	36.80	38.80	21.10	27.70	27.90	22.42	27.70	28.20
W4 (g)	109.10	118.10	106.00	109.10	118.10	106.00	101.90	126.00	114.40	97.10	119.30	113.10	55.00	71.60	76.60	97.00	125.60	87.00
W5 (g)	104.20	112.50	102.10	100.70	109.10	99.00	93.30	113.90	103.70	87.00	106.40	101.40	48.00	62.90	67.10	79.60	104.00	73.40
ω (%)	7.32	7.94	6.34	13.25	13.41	11.99	16.35	16.18	16.39	18.53	18.53	18.69	26.02	24.72	24.23	30.43	28.31	30.09
avg. ω	7.20			12.88			16.30			18.59			24.99			29.61		
γ_d (g/cm^3)	1.54			1.81			1.85			1.82			1.70			1.51		

15% NaOH compaction test results calculation



Test	3			5			8			10			15			20		
volume of mould (cm3)	918.92			918.92			918.92			918.92			918.92			918.92		
W1 (g)	4329.40			4327.30			4328.90			4329.40			4329.40			4329.40		
W2 (g)	5908.10			6225.70			6392.40			6354.10			6240.90			5992.10		
W2 - W1 (g)	1578.70			1898.40			2063.50			2024.70			1911.50			1662.70		
γ (g/cm^3)	1.72			2.07			2.25			2.20			2.08			1.81		
Moisture can No.	G2	H2	I2	D2	E2	F2	G2	H2	I2	A2	B2	C2	D2	E2	F2	D2	E2	F2
W3 (g)	36.78	34.10	32.50	27.70	28.00	21.10	37.20	42.00	40.00	40.80	38.40	40.60	22.40	28.20	27.90	32.50	36.80	38.70
W4 (g)	127.10	137.40	134.90	59.40	62.60	71.10	115.50	107.10	119.40	129.40	120.80	89.80	85.70	79.00	84.60	106.10	126.00	168.40
W5 (g)	119.10	129.20	126.10	56.10	58.80	65.50	105.40	98.30	108.40	116.00	106.20	82.40	73.00	69.30	73.80	90.80	107.50	142.30
ω (%)	9.72	8.62	9.40	11.62	12.34	12.61	14.81	15.63	16.08	17.82	21.53	17.70	25.10	23.60	23.53	26.24	26.17	25.19
avg. ω	9.25			12.19			15.51			19.02			24.08			25.87		
γ_d (g/cm^3)	1.57			1.84			1.94			1.85			1.68			1.44		

20% NaOH compaction test results calculation

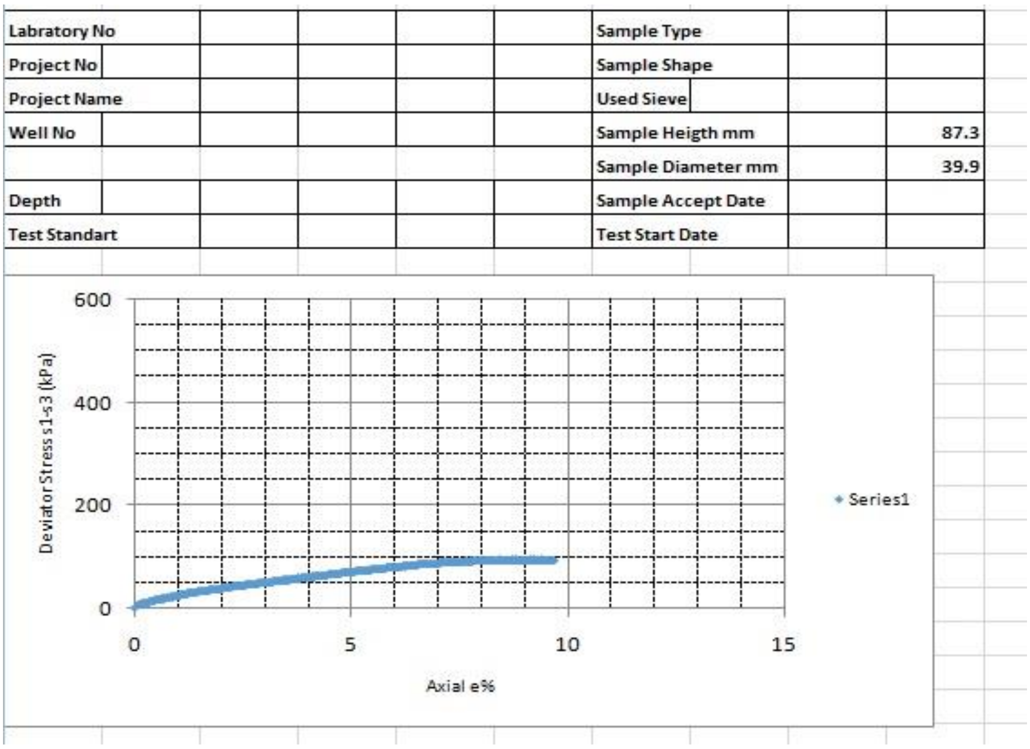


Test	3			5			8			10			15			20		
volume of mould (cm3)	918.92			918.92			918.92			918.92			918.92			918.92		
W1 (g)	4329.40			4327.30			4328.90			4329.40			4329.40			4329.40		
W2 (g)	5981.20			6197.10			6307.70			6271.50			6224.00			6132.50		
W2 - W1 (g)	1651.80			1869.80			1978.80			1942.10			1894.60			1803.10		
γ (g/cm^3)	1.80			2.03			2.15			2.11			2.06			1.96		
Moisture can No.	G2	H2	I2	D2	E2	F2	G2	H2	I2	A2	B2	C2	D2	E2	F2	D2	E2	F2
W3 (g)	38.50	38.40	40.50	36.90	37.30	39.20	42.10	32.40	37.90	39.60	33.00	36.60	22.40	21.10	28.00	23.70	28.50	28.70
W4 (g)	107.00	109.10	108.90	104.20	103.20	117.50	81.20	74.29	83.20	73.50	73.00	79.80	61.50	66.20	85.20	81.10	77.70	72.80
W5 (g)	101.30	102.90	102.60	96.30	95.50	108.20	75.80	68.40	77.00	68.30	66.70	73.10	54.40	58.00	74.60	69.00	67.40	63.60
ω (%)	9.08	9.61	10.14	13.30	13.23	13.48	16.02	16.36	15.86	18.12	18.69	18.36	22.19	22.22	22.75	26.71	26.48	26.36
avg. ω	9.61			13.34			16.08			18.39			22.39			26.52		
γ_d (g/cm^3)	1.64			1.80			1.86			1.79			1.68			1.55		

APENDIX 3

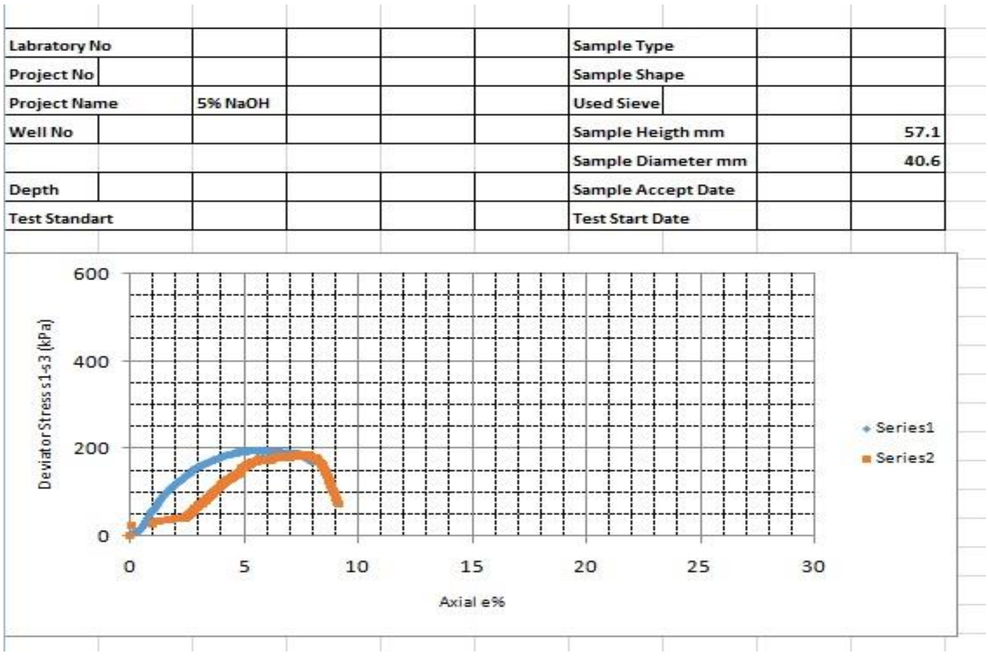
Unconfined Compression Strength Results on Different Percentage of Sodium Hydroxide

0% NaOH Unconfined compression strength laboratory results



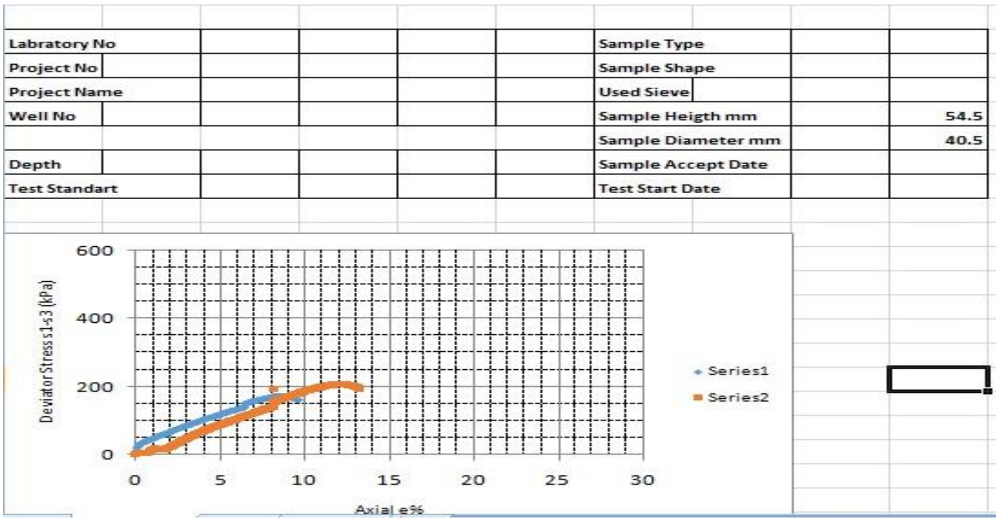
Labratory No					Sample Type		
Project No					Sample Shape		
Project Name					Used Sieve		
Well No					Sample Heigth mm		87.3
					Sample Diameter mm		39.9
Depth					Sample Accept Date		
Test Standart					Test Start Date		

5% NaOH Unconfined compression strength laboratory results



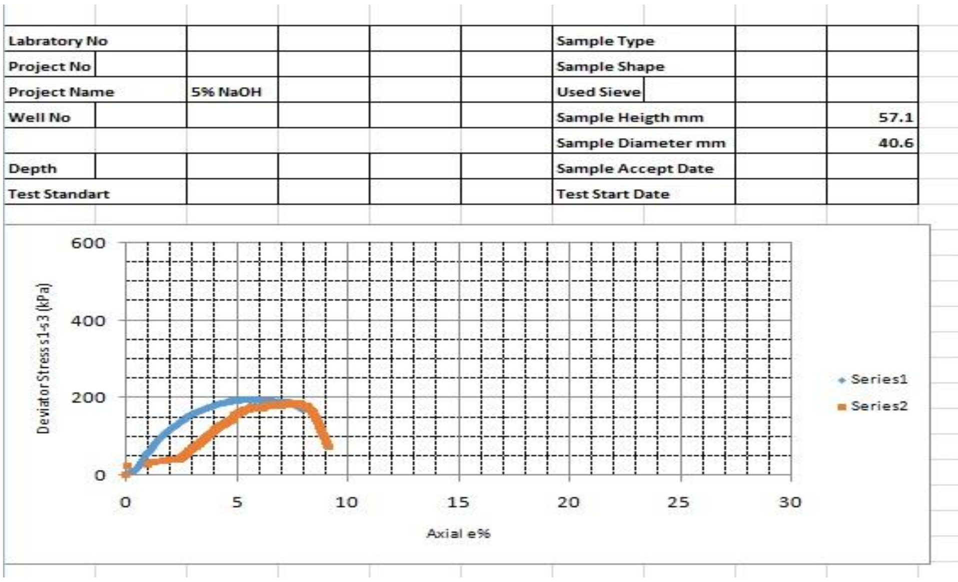
Labratory No					Sample Type		
Project No					Sample Shape		
Project Name	5% NaOH				Used Sieve		
Well No					Sample Heigth mm		57.1
					Sample Diameter mm		40.6
Depth					Sample Accept Date		
Test Standart					Test Start Date		

10% NaOH Unconfined compression strength laboratory results



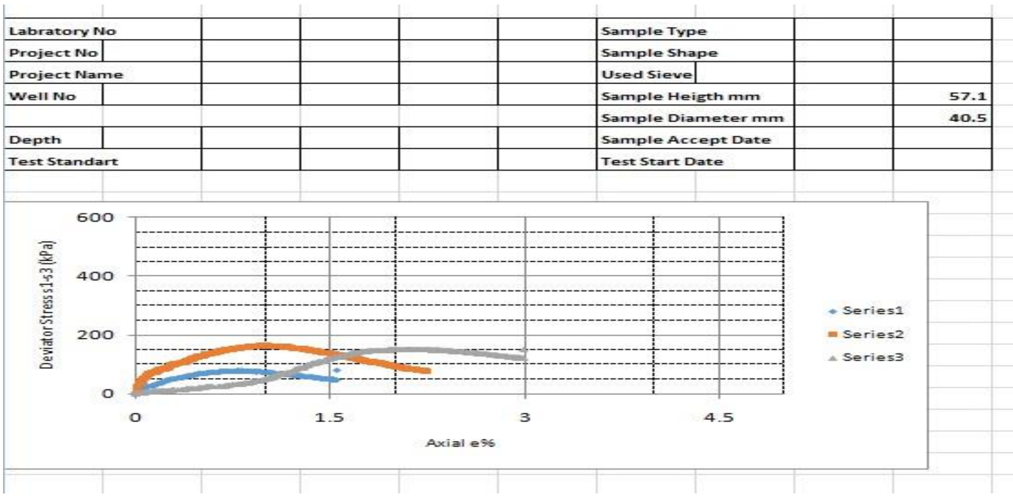
Labratory No					Sample Type		
Project No					Sample Shape		
Project Name					Used Sieve		
Well No					Sample Heigth mm		54.5
					Sample Diameter mm		40.5
Depth					Sample Accept Date		
Test Standart					Test Start Date		

15% NaOH Unconfined compression strength laboratory results



Labratory No					Sample Type		
Project No					Sample Shape		
Project Name	5% NaOH				Used Sieve		
Well No					Sample Heigth mm		57.1
					Sample Diameter mm		40.6
Depth					Sample Accept Date		
Test Standart					Test Start Date		

20% NaOH Unconfined compression strength laboratory results



Labratory No					Sample Type		
Project No					Sample Shape		
Project Name					Used Sieve		
Well No					Sample Heigth mm		57.1
					Sample Diameter mm		40.5
Depth					Sample Accept Date		
Test Standart					Test Start Date		