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CLAY SOIL STABILIZATION WITH WASTE SODA LIME GLASS POWDER

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BY
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Supervisor
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By
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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 that are not original to this work.

Aram Kamal AL-KAKI

ABSTRACT

CLAY SOIL STABILIZATION WITH WASTE SODA LIME GLASS POWDER

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This study was carried out with an intention to observe any sign of improvement of clayey soil due to addition of waste soda lime glass powder (WSLGP). The clay used in the study was collected from Sulaymaneyah city, Iraq. Waste soda lime glass powder was crushed and sieved through number 200 (75 µm) sieve was stabilizer. WSLGP mixed with clay in varying proportions namely 3%, 6%, 9%, and 12% in dry weight of clay. In order to investigate the effect of WSLGP on strength and consistency of clay, specific gravity, atterberg limits, compaction, unconfined compressive strength (UCS), swelling, and California bearing ratio (CBR) tests were carried out on the mixtures. Three different curing times was used for the mechanical tests. All samples were cured in the air. 3, 7, and 28 days of curing were applied for unconfined compression test samples. CBR tests were carried out after 4 days of curing. The test results indicated that the addition of WSLGP into clay has a significant effect on the strength and consistency of clay. It was found that there was an apparent reduction in optimum moisture content, liquid limit, plastic limit, plasticity index, and swelling of clay for all percentages of WSLGP. Whereas, it was found that same additive caused increase in maximum dry density, and CBR value for all percentages. The test results also showed that curing time has a positive effect on compressive strength. In general, it was found that geotechnical parameters of clay soil are improved substantially by the addition of waste soda lime glass powder into clay.

Kywords: Clayey Soil, Waste soda lime glass powder, stabilization .

ÖZET

KİL ZEMİNİN ÖĞÜTÜLMÜŞ ATIK SODA ŞİŞE CAMI TOZU İLE İYİLEŞTİRLMESİ

AL-KAKI, Aram Kamal
Yüksek Lisans Tezi, İnşaat Mühendisliği Bölümü
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Bu çalışmada öğütülmüş atık soda şişe camının (ÖASŞC) kille karıştırılması durumunda kilin geoteknik özelliklerinin iyileşmesine olan etkisi araştırılmıştır. Çalışmada kullanılan kil Irak'ın Süleymaniye kentinde elde edilmiştir. Atık soda şişeleri öğütülerek 200 nolu elek altında kalan kısmı kilin kuru ağırlığının %3, 6, 9 ve 12 oranlarında kile katılmıştır. ÖASŞC kille yukarıda verilen oranlarda karıştırıldıktan özgül ağırlık, kıvam limitleri, serbest basınç dayanımı, şişme ve CBR testleri yapıldı. Serbest basınç dayanımı yapılmadan önce numuneler üç, yedi ve 28 küre tabi tutuldu. CBR deneyleri numuneler dört gün suda bekletildikten sonra yapıldı. Deney sonuçları ÖASŞC kile karıştırılmasının kilin kıvam limitleri ve mukavemeti üzerinde önemli bir etkisi olduğunu gösterdi. Karıştırılan her orandaki ÖASŞC kilin optimum su muhtevasında, likit ve plastik limitinde, şişmesinde kayda değer azaltmalara sebep olduğu gözlendi. Ayrıca, katılan atık katkı maddesi kilin maksimum kuru birim hacim ağırlığını ve CBR oranını artırmıştır. Deney sonuçlarından kürleme süresinin mukavemeti artırdığı belirlendi.

Anahtar kelimeler: Killi zemin, Atık soda cam şişesi tozu, iyileştirme.

DEDICATION

With all humility, I would like to dedicate this thesis to; my beloved Parents, true rare treasures in my life; my wife (Aven), and dearest thing to me in this universe my son (Rochyar).

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LIST OF SYMBOLS/ABREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society of Testing and Materials
CBR	California Bearing Ratio
Cc	Compression Index
FAA	Federal Aviation Agency
Gs	Specific Gravity
WSLGP	Waste soda lime glass powder
HDPE	Plastic high density polyethylene
ISSS	International Society of Soil Mechanics
PI	Plasticity Index
PL	Plastic limit
LL	Liquid Limit
MDD	Maximum Dry Density
MIT	Massachusetts Institute of Technology
OMC	Optimum Moisture Content
UCS	Unconfined Compressive Strength
USDA	U.S. Department of Agriculture

CHAPTER 1

INRTODUCTION

1.1 General

In civil engineering construction work, such as constructing buildings, roads, bridges, runways, etc., the base soil represents the foundation. In addition, soil is the most significant raw material in construction. Accordingly, soil should have properties that make for a strong foundation.

One of the soil types is clay; in general, clay has undesirable engineering properties . Clays have low shear strength , which also decreased when wet or with other physical problems . It expands when wetted and shrinks when dried. This behivior is very undesirable. Cohesive soil can be crawl over time under constant weight, particularly when the shear stress nears its shear strength, making it vulnerable to sliding. They develop large lateral pressures. This tends to decrease elasticity modulus values. For these reasons, clays are usually bad construction materials for foundations. The estimated annual cost of damage to non-military engineering structure built on expansive soil was estimated at $220 million in the United Kingdom and numerous billions of dollars all over the world (Gourly et.al., 1993).

In geotechnical engineering, soil improvements are required when a given site does not have acceptable engineering properties to bolster structures, foundations, and roads. One of the reasons for this is to adjust the construction to the geotechnical conditions at the site. Another reason is to attempt to balance out or enhance the engineering properties of the soils at the site. Contingent upon the circumstances, this second approach may be the most economical solution to the problem (Holtz and Kovacs, 1981).

Soil improvement is a procedure of changing soil properties to be stronger and have greater durability. In a wider sense, this also includes the compaction, pre consolidation and others such operations. .

Soil stabilization decreases the permeability and compressive, it improves the bearing capacity and enhances Soils overall performance. .

Binding proxies traditionally used are, lime, cement, bitumen, and chemical materials, amomg other. There are a few methods for soil stabilization, including compaction, and boosting materials in the soil to be improve it . Soil improvement is done in two ways: mechanical improvement and chemical improvement. Mechanical improvement is a process of stabilization, that enhances soil properties by mixing materials and resulting in the target soil changing classification and engineering properties. Chemical stabilization creates soils that can be incorporated into cements containing a pozzolanic reaction. The purpose of soils stabilization are:

1- to decrease, or fully prevent, water absorption in soil, which causes swelling, shrinking and abrasion by occlusion in all voids and pores.

2- to decrease cracking by giving flexibility that permits the soil to swell and contract to some extent.

3- to increase the effect of resistance and strength of the soil property, and decrease its inclination to swell and shrink, by linking the particles of soil with each other.

One of the biggest problems for the environment is waste material and how to get rid of it . environmental or ecological advantages of alternative materials incorporate (1) the redirection of non-reused waste from landfills to helpful applications, (2) the diminishment in the negative impacts of cement powder, in particular for the utilization of nonrenewable natural assets, (3) the decrease in the utilization of power, for cement generation and (4) a decrease in the corresponding emission of greenhouse gases. The financial advantages of utilizing alternative materials are best acknowledged in circumstances where the expense of the alternative material is not as much as that of cement powder while giving practically identical execution. This cost must consider the source the alternative material, its transportation and preparation, and ought to consider investment funds also through redirection: for example, tipping charges and landfill administration costs. The engineering or technical advantages of alternative materials are acknowledged when a specific use for such material might be produced, such that the utilization of the alternative materials is more alluring than utilization of cement made with OPC alone (Federico and Chidiac, 2009) . There are many waste materials that can be a benefit to soil stabilization, such as fly ash, lime, coal, and race husk.

Another useful waste material is glass . Hypothetically, glass is a 100% recyclable material; it can be reused with out any loss of quality. According to EPA official statistics (US EPA, 2002, 2005), the municipal solid waste (MSW) stream in the USA contains around 5.3% of waste glass or 12.5 million tons (Geiger, 1994; Glass Packaging Institute, 1999; US EPA, 2002). In 2003, just 18.8% of this sum was reused (US EPA, 2005). Therefore, in spite of the clear straightforwardness of glass recuperation, its reusing rate is among the lowest, to a normal MSW recuperation level of 30.6% (US EPA, 2005). Glass have different types, one of which is called soda lime glass, or soda lime silica. It is one of the most prevalent types of glass, and comes from commercially produced glass containers (bottles and jars) used for drinks and food, windowpanes, and other consumer items. Due to the wide availability, and large quantity of soda-lime glass, it is necessary to know the behavior of soda lime glass, and its suitability to engineering. The introduction of glass waste in cement raised alkali content in cement. It additionally heled in the brick and ceramic industry and keeps the raw materials, and reducted energy spending and the volume of waste sent to depots. Glasses and glass powder are also used in areas of civil engineering: for example, in the cement, such as pozzolana (supplementary cementations materials), and coarse aggregates. Its recycling rate is close to 100%, and it is used in concrete without adverse effects on the durability. Therefore, use in civil engineering is ideal for recycling. Soda lime glass is used as a pozzolanic material, as well as its being used in concrete as an additive (Yixin Shao and Damian Rodriguez, 2000).

1.2 Objective of the study

In this study, waste soda lime glass powder passing from sieve No. 200 (75 µm) was used to determine his effectiveness on the clay soil properties which was chosen from Sulaymaneyah Governorate, northern Iraq. In some regions of the Sulaymaneyah governorate, the soil has problems, that adversely affect construction projects, so it is important to find a way to stabilize this soil . The clay soil was mixed with additions of waste soda lime glass powder in varying proportions namely 3%, 6%, 9%, and 12% of dry weight of clay soil. Tests performed on clay soil included maximum dry density, liquid limit, plastic limit, plasticity index, unconfined compressive strength, swelling, and California bearing ratio .

1.3 Layout of the thesis

Theise thesis consists of six chapters. A brief commentary of the chapters' contents is presented below:

Chapter 1: introduction. This chapter expresses the background to the study, the reasons of completing this thesis, the issue articulation, the objective of the study and finally the research structure.

Chapter 2: literature review. This briefly summarizes a review of previous studies performed by various researchers on treated/stabilized soils that are relevant to the research.

Chapter 3: clay Soil properties and stabilization. This briefly summarizes the clay soil properties and stabilization.

Chapter 4: materials and experimental work.This chapter highlights two topics, the first one is materials that have been used . The second is the explanation of experimental work that was done to achieve the aim of the study.

Chapter 5: results and discussion, this chapter concentrates on the analysis of the acquired investigate results and also their discussion . There is also Comparison between the results of untreated soils and treated soils .

Chapter 6: conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter presents the review of literature relevant to the present topic of research. There have been many studies in the past documenting improvement on the properties of soil by using different additives for the purpose of engineering . Some of these studies are given below:

2.2 Soil Improvement by Waste Glass

Achmad Fauzi et al.,(2016) studied the effects of crushed glass waste and plastic high density polyethylene (HDPE) waste as additives in stabilized soil. They concluded that the atterberg limit values were reduced when content of waste plastic and waste glass were increased, and the values of OMC decreased and MDD increased when content of HDPE waste and glass waste were increased. The values of California bearing ratio were increased when content of HDPE waste and glass increased. In addition the values of cohesion decreased and friction angle (ϕ) increased when content of HDPE waste and glass waste were increased.

Nuruzzaman and Akhtar Hossain (2014) used soda-lime glass powder to improve clay soil, by adding glass dust which was passed through a sieve 300 μm, and mixing 3%, 6%, 9% and 12% of the glass dust with clay soil. They concluded that the properties of the clay soil were improved by the addition of glass dust by comparing the behavior of treated and untreated soil. They found that,and the MDD values increases with the addition of soda lime glass dust, the OMC values decreases with the addition of glass dust. The atterberg limits values decreases with the addition of glass dust. In consolidation test both values of compression index and swell index decreases with the addition of glass dust, and the UCS values for the soil decreases with the addition of glass dust without curing time. .

In order to investigate the effects of glass dust and cement in the property of soil clay, J. Olufowobi et al.,(2014) they mixed 1%, 2%, 5% and 10% of normal glass passed through sieve number 400 with 15% cement ,on the property of clay soil. They concluded that the ratio amount of the glass powder needed to obtain optimum results in engineering properties of the clay soil located between 5% and 10% of mass of the clay, because the maximum corresponding values from each of the California bearing ratio and compaction experiments were obtained at 5% glass dust content. However the maximum values for the shear strength experiment were obtained at 10% glass dust content. In addition, it can be concluded based on these investigation results that glass dust can be effectively utilized soil improve since it was able to make significant stabilizations of clay soil properties . Such enhances included an increase in the value of the maximum dry density from 25.37 kN/m3 for the untreated sample up to 25.90 kN/m3 for the sample containing 5% of glass dust by mass of the clay soil. The maximum California bearing ratio values of 14.90% and 112.91% were acquired at 5% from glass dust content for both the unsoaked and soaked treated samples respectively addition, the highest values of cohesion and angle of internal friction of 15.0 and 17.0 respectively, were acquired at 10% glass dust content.

2.3 Clay Soil Improvement by Different Waste Materials

Gati Sri Utami (2014) found that addition of 10% lime to stabilization of clay soil in Pakuwon area give the optimum CBR values. According the results, he found the values of (LL), (PL) and (PI) reduced with increasing addition of lime mixture. Liquid limit values largely reducede in the 15% lime addition 67% to 45.33%, giving overall decrease of of 32.34% in the untreated soil. The plasticity index values reduced most in a mixture of 15% i.e. from 33.96% to 12.76%, ensue from the reduce of 65.48% of the untreated soil. For free swelling test, amixture 15% of lime by soaked with water for 24 hours presented a reduction in the value of a large swelling from a swelling value of 31.67% to 17.33%, or in other words 45.27% reduced . From the tests results compacting a mixture of lime 15% with 3 days of curing, can increase the amount of maximum dry density of 1.793% to 1.833% with an increase of 2.23% of the untreated soil.

Talaat A. Ahmed and Ahmed O. Kamel (2013) studied the effect of adding dust shield polymer to soil. According to their paper, the values of LL and PI of clay soil decreases, and the plastic limit of clay soil property increases with increase amount of dust shield. An increase in the values of maximum dry density and a reduction in OMC occurred in soil with the addition of dust shield. Swelling values of the soil reduced when the soil was treated with an additive. The values of California bearing ratio and unconfined compressive strength of clay soil increase when the additive is increased up to 2.0%. So, the dust shield can be utilized as a great improvement of soil “foundation” of high traffic areas.

Khushbu S. Gandhia (2013) showed that when adding rice husk ash and marble dust to clay soil, it has the ability to improve CBR, and swelling, therefore, their analysis concluded that marble dust is more effective than rice husk ash for the improvement of expansive soil in all respects.

Arpan Laskar and Sujit Kumar Pal, (2013) demonstarted the individual effect of waste plastic filaments on compaction and consolidation properties of clay soil. Compaction and consolidation tests were conducted on unreinforced and strengthened soil. The test after effects of compaction tests demonstrate that (MDD) of plastic fortified soil diminishes with expanding fiber content. The (OMC) was 17.10%, for soil alone and soil blended with waste plastic strands which is autonomous of the measure of filaments. As plastic fiber does not ingest water, OMC is autonomous of filaments substance. With the expansion of plastic strands in soil, the compression index (Cc) and coefficient of volume change (mv) of soil declines to 0.50% fiber content .In any case, the qualities increments with further consideration of plastic fiber of 1.00% in soil. The estimations union of coefficient increase with the expansion of plastic strands in soil for viewpoint proportions 2, 4 and 8. 90% of aggregate pressure occurs in 96 seconds for a 800 kN/m2 load with the plastic filaments in soil of perspective proportion 8 and fiber substance of 1.00%. These waste plastic fiber strengthened soil of present study empowering for potential use in the field of geotechnical enhancing to design development the quality and diminishing the settlement.

Akshaya Kumar Sabat.,(2012) used waste ceramic dust to improve the clay soil. They concluded that the LL, PL and PI continue to reduced dependent on the rate of addition of ceramic dust . A 30% The addition ceramic dust changes the clay soil from CH group to CL group. The max dry density continues expanding and optimum water content continues diminishing with increase in rate of expansion of earthenware dust .The unconfined compressive strength continues expanding with increase in the rate of artist expansion of artistic dust .The soaked CBR continues expanding with increase in rate of artic dust expansion of fired dust. There is 150% expansion in doused CBR esteem when contrasted with untreated soil, when 30% ceramic dust was included. The attachment esteem continues diminishing and point of inner erosion continues expanding with expansion in rate of expansion of artistic dust .The swelling weight continues diminishing with expansion of ceramic dust. There is a 81.5% diminishment in swelling weight of soil compared untreated soil, when 30% ceramic dust was included. From the monetary investigation, it was found that up to 30% ceramic dust can be used for fortifying the subgrade of adaptable asphalt with a generous recovery in development expense.

Khelifa Harichane et al. ,(2010) conducted found that the treatment of thetreating soil with the a blend of lime-natural pozzolana results in an general stabilization of the durability of the clayey soils. The specimens improvement shows showed superiority and survived an entire 12 cycles of wet-dry testing. Natural pozzolana is useful in when mixed with lime in order in enhancingto enhace durability conduct of the clayey soils. At the point when regular pozzolana is added to a soil-lime blend, weight reduction of blend abatements. The curing period has a possibley impact on mass misfortune percentages. Residual compressive quality increments essentiallyincreases when contrasted with beginning compressive quality. This conduct result is comparable for both clayey soils settled with the blend lima-characteristic pozzolana . For the red clayey soil, the curing period noticeably affects remaining strength .The test aftereffects results of tests demonstrate that the blend lime-normal pozzolana can successfully enhance the solidness of clayey soils from poor to amazing.high quality. Additionally, more soils ought to be explored and criteria for soil-lime-normal pozzolana solidness, taking into account remaining quality might demonstrate suitable.

Tamadher T. Abood and et al., (2007) were conducted to investigated the influence of adding (2%, 4%, and 8%) of three complexes chlorides (NaCl, $MgCl_2$, $CaCl_2$)

on the engineering properties of silt clay soil. The soil was selected from southern Iraq. The soil was experimented for its compaction (max dry unit weight, moisture content), Atterberg limits (LL, PL, and PI) and unconfined compression. They found that the addition of three complexes chlorides (NaCl, MgCl2, CaCl2) leads to reduce both the LL , PL and PI for the silt clay soil. The max dry density increased and the OMC reduced with the adding of three complexes chloride. The values of UCS for the silt clay soil increased with the addition of three complexes (NaCl, MgCl2, CaCl2). This addition helped enhance soil quality and other soil properties.

Celestine O. Okagbue, (2007) studied the lime contained in wood can as ash, as well as the mechanical properties of clay soil . The results showed that wood ash reduces the maximum dry density and flexibility over strength of clay in spite of the increase in the strength of the mission not exceeding 14 days. 22% higher strength further development after 7-14 days in the treatment of 10% of the wood ash clay mixture. It is believed that "Lyme" 10% of the optimum use of wood ash content quickly in the first two weeks of treatment did not leave any lemon whatsoever to continue pozzolanic. The reaction is usually the responsibility of increasing the strength of mud blends lemon implications of these results that Wood, despite the containment of Lyme ash to the chemical element cannot be used for the purposes of construction soil amendment.

2.4 Using Waste glass in concrete

N. Tamanna et al.,(2012) were conducted that the , the glass powder can be used as a partial replacement of cement. Replacement of 10% cement with glass powder reveals the higher compressive strength at 28 days than other levels of replacement. Finer size glass particle exhibits comparatively better result than coarser particles. Particle size, finer than 38µm shows almost the same strength as Portland cement, due to the similar particle size distribution. Utilization of waste glass in cement replacement would be beneficial for environment by saving landfill and by reducing CO2 at atmosphere.

CHAPTER 3

CLAY SOIL PROPERTIES AND STABILIZATION

3.1 General Information of Soil

Soils consist of solid particles, and together with the air and water in void spaces, they form a three-phase system. A large part of earth's surface is covered by soil, it is used extensively as building and materials bases (Das, 2008). Civil engineers divide the materials at the earth's crust into two categories:(1) rock and (2) soils (Grim, 1968). Terzaghi and Peck (1948) defined soil as "a natural aggregate of mineral grains that can be separated by such gentle means as agitation in water. Soil is a stage in extended operation of decay of the origin rock and its physic -chemical transformation. Depending on the situation of the origin rock and climatic weather, soil appears in a myriad of forms with a myriad of characteristics. In general, soil can be regarded an on-site and loose rock material composed of decomposed material parent rocks with their , shape and physical properties, Soil forms the soil as a result of the great the geological cycle that occur constantly and relentlessly throughout geological time scale. The three main stages of the cycle are erosion, transport and deposition, and movement of the earth. Erosion is process of the exposed rocks being degraded by physical and chemical operation from weathering. The transfer cycle is the movment of materials to new locations by wind, water and glaciers. Finally, as the soil is deposit it in different terrain. The atmosphere, and hydrosphere is in reactors chemical operation and wide with the earth's crust to produce the earth's surface the crust (Lambe, 1969). Each interaction of the chemical process is complex and consists closely associated with the physical operation. The reaction is cited as follows: (Atmosphere + Biosphere + Hydrosphere) + Lithosphere Weathered lithosphere + residual materials + dissolved chemical elements. Weathering is at its highest point power where the interfaces between the hydrosphere, biosphere and lithosphere interfere) (Scott,1974) . in other words, upper soil zones in temperate wet climatic regions and rock weathering process are the characteristcs of parent rock, topography, weather condition, vegetation and time. The processes involved in the formation of soil by weathering of rocks include oxidation, carbonation, hydrolysis and hydration. Weathering is an involuntary reaction involving geologic material and capacity and is a change towards the reduction of the free energy of the system (Lambe, 1969).

3.1.1 Classification of Soil Mineral Components

There are many methods available for classification of soils. The choice of method depends upon the specific use intended for the soil. Geological classifications of soils differ from those used in soil engineering and from those used in agriculture. Geologic classifications are mostly genetic but partly descriptive, mostly in terms of surficial deposits. The major sub-divisions in the geologic classification of surficial deposits are (Raymond and Benno , 1975) :

A-Transported :

(1) Fluvial deposits .

(2) Alluvial deposits, such as alluvial fans and deltas .

(3) Aeolian deposits .

(4) Glacial fluvial deposits .

(5) Glacial deposits .

(6) Volcanic deposits .

(7) Marine deposits .

(8) Mass-wasting products, such as mud flows , slide rock, talus, rock glaciers, slope wash, etc.

B- Residual :

(1) Soils - zonal soils, a zonal soils, intraoral soils .

(2) Marine and lacustrine deposits .

(3) Organic-mineral complexes such as muskeg .

To facilitate the identification of the soils nature, the mineral elements grain are divided into parts.

Pebbles range in size from 20-200mm. They constitute the raw material that is as result of the disintegration of the parent rock from which they draw their basic characteristics. They also have been carried out from other locations. Young pebbles still have sharp corners. Strongly gravel survived, as well as those, which it was carried by waterways, or is rounded glaciers, (Gunther, 1998).

Gravel ranging in size from 2 to 20 mm. consist of small grains of raw materials that result from the disintegration of parent rocks and other gravel. They also have been carried out by waterways, and hence are rounded, although the angular gravel is also present. As well as constitute a gravel structure of the soil and impose an end to the property capillary and shrinkage, (Gunther, 1998).

Sand ranging in size from 0.06 to 2 mm. often consists of silica or quartz particles. Signs of internal friction element of the high sandy soil. The least adsorption of these surfaces inflation and shrinkage limits. Open architecture and permeability are typical of sands, (Gunther, 1998).

Silt grain size is smaller than 0.002 mm. From physical and chemical standpoint component silt almost identical to sand element, the only difference being size. Silt gives soil stability and increases internal friction. Due to the high degree of permeability of silty, the soil is a very delicate to frost. They are subject to small-scale swell and inflation shrinkage, (Gunther, 1998).

Clay soil grains are smaller than 0.002 mm. They differ from sand and silt particles not only in size but also in chemical structure and physical properties. In chemical terms they are hydrated alumino-silicates formed by the leaching operation acting on the primary minerals in rock. Mineral clay is the key to the small diameter of mineral grains and their habit of crystals, which resemble paper. These two factors give clay is very high relative to the area of the mass of material in the clay soil mineral crystal grain, (Gunther, 1998). Table 3.1 explains some agencies classify of the soil, (Das, 2008).

Table 3.1 Soil—separate size limits (Das, 2008)

Agency	Classification	Size limits (mm)
USDA	Gravel	> 2
	Very coarse sand	2–1
	Coarse sand	1–0.5
	Medium sand	0.5–0.25
	Fine sand	0.25–0.1
	Very fine sand	0.1–0.05
	Silt	0.05–0.002
	Clay	< 0.002
International Society of Soil Mechanics (ISSS)	Gravel	> 2
	Coarse sand	2–0.2
	Fine sand	0.2–0.02
	Silt	0.02–0.002
	Clay	< 0_002
Federal Aviation Agency (FAA)	Gravel	> 2
	sand	2–0.075
	Silt	0.075–0.005
	Clay	< 0.005
Massachusetts Institute of Technology (MIT)	Gravel	> 2
	Coarse sand	2–0.6
	Medium sand	0.6–0.2
	Fine sand	0.2–0.06
	Silt	0.06–0.002
	Clay	< 0.002
AASHTO	Gravel	76.2–2
	Coarse sand	2–0.425
	Fine sand	0.425–0.075
	Silt	0.075–0.002
	Clay	< 0.002
Unified (U.S. Army Corps of Engineers, S. Bureau of Reclamation, and American Society for Testing and Materials)	Gravel	76.2–4.75
	Coarse sand	4.75–2
	Medium sand	2–0.425
	Fine sand	0.425–0.075
	Silt & Clay (fines)	< 0.075

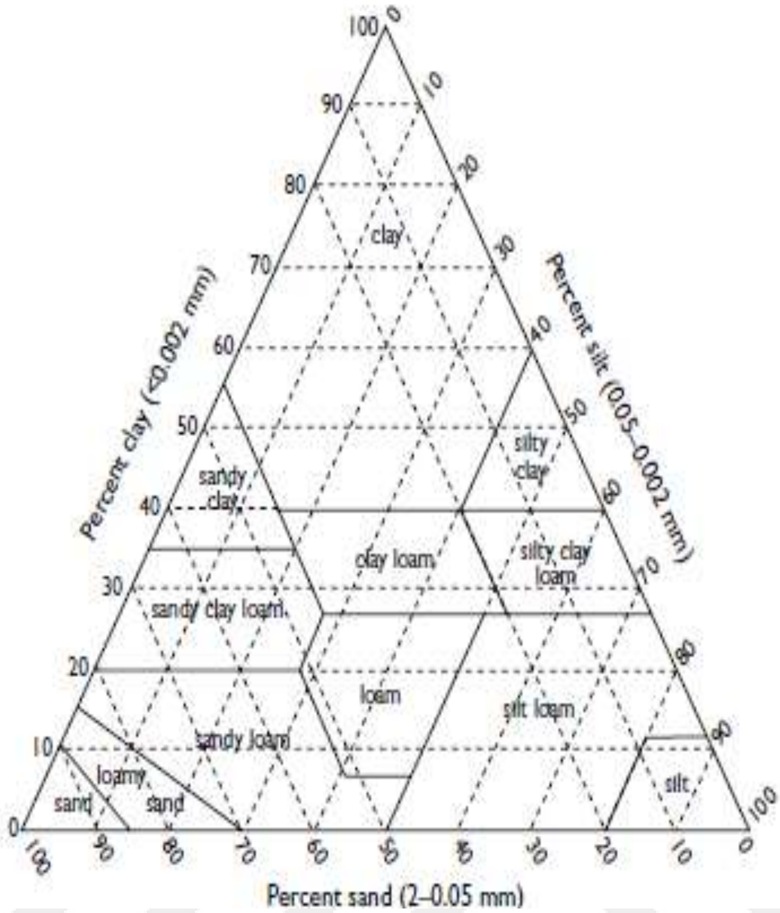

Figure 3.1 USDA textural soil classification system (Hsai-Yang and John. , 2006)

3.1.2 Clay Minerals

Chemically, the mineralogical composition of clay soil can be described as a combination of two simple structural units: Clay minerals are aluminum silicate, iron and magnesium, most of clay soil minerals and sheet structures or layers can be different shapes (John and et al, 2015). It is described in many classification systems as clay minerals particles that reach the actual diameter of (2 µm) or less (Shin, 1975). In addation, it was found that all particle diameter of less than (2 µm) are not necessarily clay minerals (Sarsby, 2000). This and grain size are not enough to describe the mineral mud; hence there is a need to study the mineral composition, which is probably the basic property of the soil fine-grained (Chen 1975). Das (2010) realized as compounds aluminosilicate clay soil minerals coming from the combination of two basic units are the tetrahedron octahedron silica and aluminum.

Each tetrahedral unit is shaped by a silicon particle encompassed by four oxygen molecules and the mix of indistinguishable units results in the development of a silica sheet in which neighboring tetrahedra offer three oxygen iotas at the base of every tetrahedron. Then again, an octahedron comprises of an aluminum molecule encompassed by six hydroxyls. The mix of octahedral units prompts the arrangement of octahedral sheet additionally called gibbsite sheet. At the point when the aluminum molecule is supplanted by the magnesium, the octahedral sheet is named a brucite sheet (Das, 2010). Those basic units and their combination are explained in Figure 3.1.

Based on stuides by Chen (1975), Sarsby (2000) and Das (2008), there exist various clay soil minerals among which the essential ones are kaolinite, illite and montmorillonite. Every one of them are comprised of a mix of silica-gibbsite sheets and are portrayed by high particular surface i.e. the surface range per unit mass. By et al. (1975) states, "the little grain estimate and coming about vast surface are because of the clay soil mineral's weathering so as to start point or diagenetic adjustment of previous minerals".

Table 3.2 Surface area and cation exchange capacity of some specific clay soil minerals (Das, 2008)

Mineral of Clay soil	Specific surface (m2/g)	Cation exchange capacity (me/100 g)
Chlorite	5 -50	20
Illite	80 – 100	25
Kaolinite	10 – 20	3
Montmorillonite	800	100
Vermiculite	5 – 400	150
Halloysite ($4H_2O$)	40	12
Halloysite ($2H_2O$)	40	12

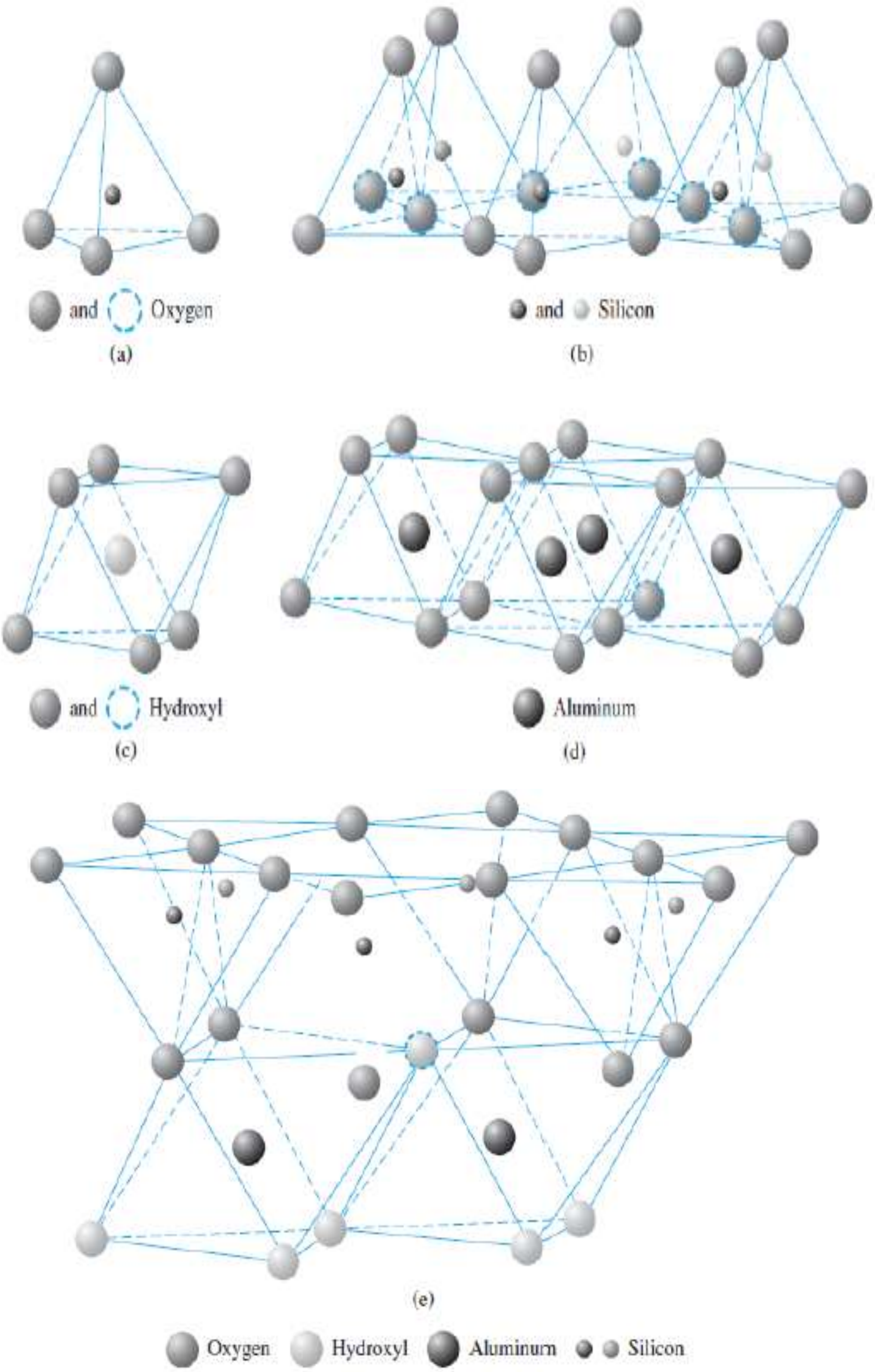

Figure 3.2: (a) Silica tetrahedron; (b) Silica sheet; (c) alumina octahedron; (d) octahedral (gibbsite) sheet; (e) elemental silica-gibbsite sheet (Das, 2010).

The basic idealized crystalline structural unit of a clay mineral is composed of a silica tetrahedron block and an aluminum octahedron block. Aluminum octahedron block may have Aluminum (Al_3+) or magnesium (Mg_2+). If only aluminum is present, it is called gibbsite [$Al_2(OH)_6$]; if only magnesium is present, it is called brucite [$Mg_3(OH)_6$]. Various clay minerals are formed as these sheets stack on top of each other with different ions bonding them together (Oweis and Khera, 1998). A silica tetrahedron and a silica sheet, also an octahedron and an octahedron sheet are presented in Figure 3.2 and Figure 3.3, respectively. Also, these figures consist of schematic representations of silica and octahedron sheets.

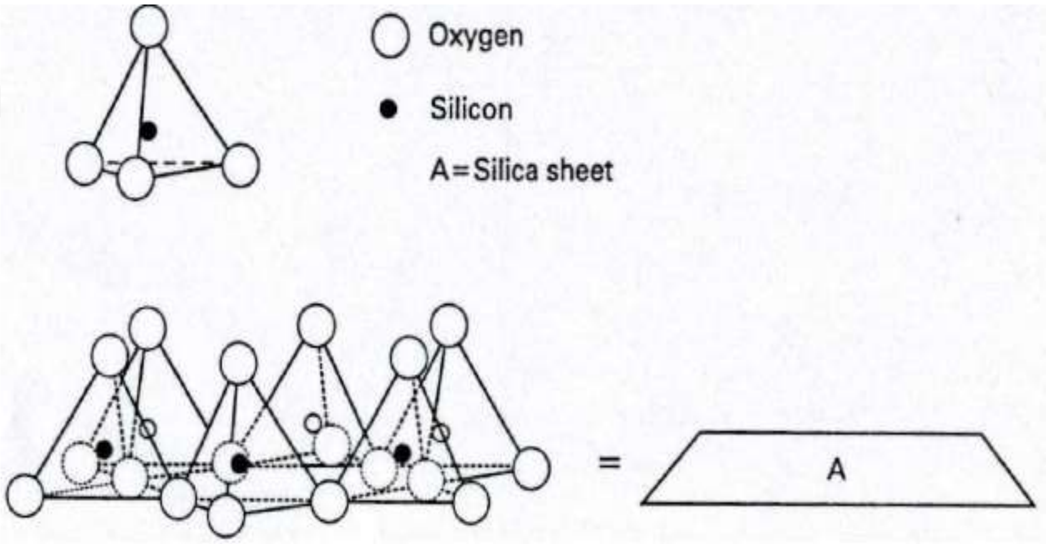

Figure 3.3 A Silica Tetrahedron and a Silica Sheet (after Oweis and Khera, 1998)

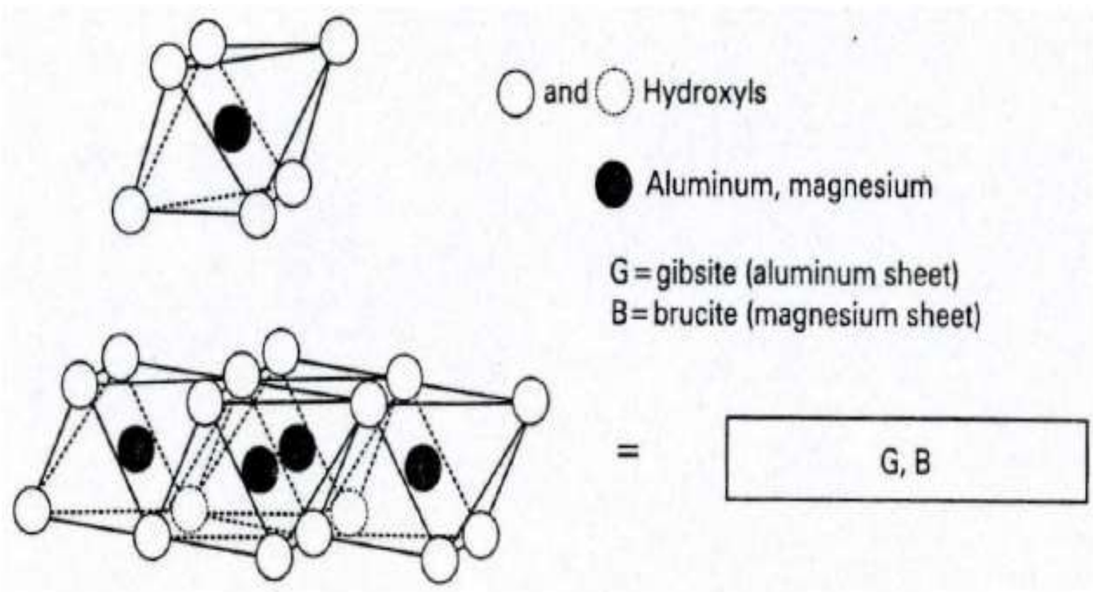

Figure 3.4 An Octaheron and an Octaheron Sheet (after Oweis and Khera, 1998)

Generally clay-minerals can be split into three general groups on the basis of their crystalline arrangements (John and et al, 2015) such as:

• Kaolinite group

• Illite group

• Montmorillonite group

3.1.2.1 Kaolinite Group

Kaolinite is made out of a mix of rehashing layers of basic silica-gibbsite sheets held together by hydrogen holding in 1:1 cross section. The assessed particular surface of kaolinite is 15m2/g. (Das, 2010).

The surface range of clay soil particles per unit mass is by and large alluded to as particular surface. The sidelong measurements of kaolinite platelets are around 1000–20,000 Å with thicknesses of 100–1000 Å. (Das, 2008).

Kaolinite precious stones are comprised of tetrahedron and octahedron sheets. The holding between progressive layers is by van der Waals powers and hydrogen bonds. The solid holding does not allow water to enter the cross section. In this way, kaolinite minerals are steady and don't extend under immersion. Kaolinite is the most copious constituent of lingering earth depositsThe holding is adequately solid that there is no interlayer swelling in the vicinity of water (Mitchell and Soga, 2005).

The structural formula of kaolinite is $(OH)_8Si_4A1_4O_{10}$ is mineral is often referred to as having a 1: 1 lattice. The theoretical composition of kaolinite, is approximately 46.54% Si_2, 39.50% $A1_20_3$ and 13.96 % H_2O, The interlayer distance of each unit cell is 7.2A°. Compared to other clay minerals, the degree of perfection of the crystal is high and the amount of isomorphous substitution is low. In general kaolinite may be considered to be a well-crystallised clay mineral with relatively little physicochemical activity (Grim, 1962).

Kaolinite minerals are characterized by their relatively low liquid limit and activity (Young and Warkentin, 1966; Dennon and More, 1986)

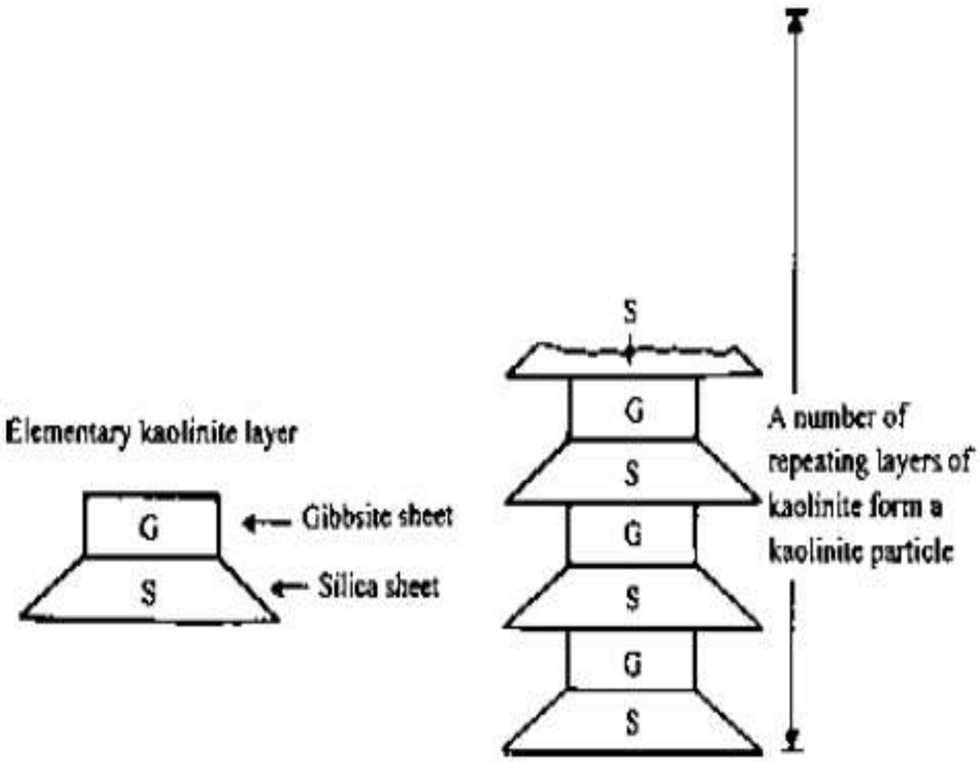

Figure 3.5 Symbolic structure for kaolinite. (Das, 2008).

3.1.2.2 Illite Group

Illite is made out of a gibbsite sheet sandwiched between two silica sheets reinforced together by potassium particles which are adjusted by the negative charge left by the substitution of aluminum for some silicon in the tetrahedral sheets. This marvel comprising in substitution of a component by another without change of crystalline structure is called isomorphous substitution. The particular surface of illite particles is evaluated to 80m2/g. The sheets are around 7.2 Å thick. The rehashing layers are held together by hydrogen holding and optional valence powers. (Das, 2010).

The surface region of dirt particles per unit mass is by and large alluded to as particular surface. The sidelong measurements of Illite particles have horizontal measurements of 1000 - 5000å and thicknesses of 50–500å. (Das, 2008).

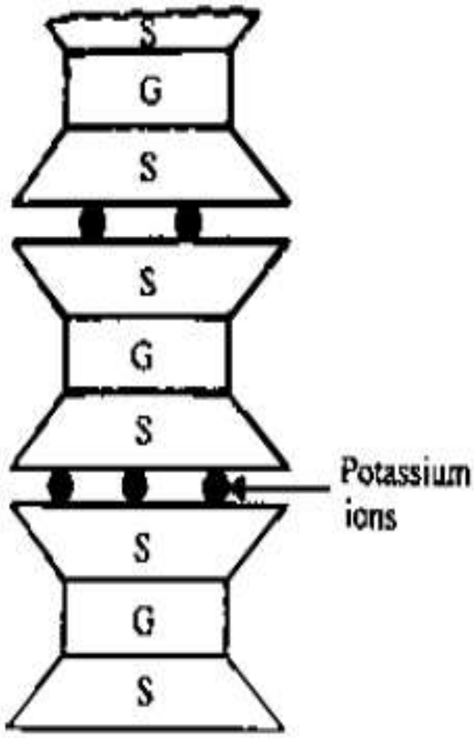

Figure 3.6 Symbolic structure for Illite. (Das, 2008).

3.1.2.3 Montmorillonite Group

Montmorillonite is consists of weathering of volcanic ash under poor drainage conditions or in marine waters. The fundamental building sheets for smectite are the same with respect to illite aside from there bengis no potassium particle present. The space between the joined sheets is filled with water particles and replaceable cations. There is an exceptionally feeble bond between the joined sheets because of these particles. Significant swelling of montmorillonite can happen because of extra water being consumed between the consolidated sheets (Oweis and Khera, 1998).

The montmorillonite formula as listed by (Grim .1968), is $Si_8Al_4O_{20}$ $(OH)_4$. nH_2O, and the composition is approximately 66.7 % $Si0_2$,28.3 % $A1_203$, and 5% H_20. In the silicate tetrahedral sheet aluminium can partly replace the silicon, and magnesium can replace aluminium. Iron, zinc, lithium, and other atoms can also replace aluminium. This replacement is often referred to as isomorphous substitution which is considered to be a prime factor which influences the "Cation Exchange Capacity", (Berman, 1963). Soils containing large proportions of montmorillonite are poor foundation materials, because they have the tendency to absorb large amounts of water and show a big volume change between the wet and dry seasons (Mitchell, 1976). The surface area of clay soil particles per unit weight is in general referred to as specific surface. The lateral dimensions of montmorillonite particles have lateral dimensions of 1000–5000 Å with thicknesses of 10–50 Å . (Das, 2008). Table 3.3 showns ratio of linear extensibility for every clay mineralogy.

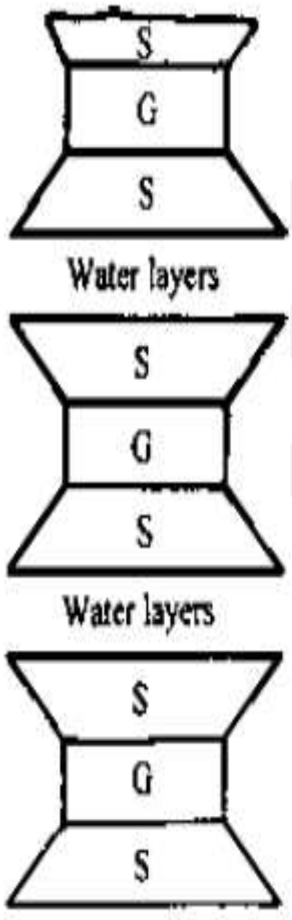

Figure 3.7 Symbolic structure for Montmorillonite. (Das, 2008).

Table 3.3. Ratio of Linear Extensibility (LE) to Percent Clay (John and et al, 2015)

Clay soil Mineral	LE/Percent
Kaolinite	< 0.05
Illite	0.05–0.15
Montmorillonite	> 0.15

Clay soil activity is defined as the ratio of the plasticity index to the percent by weight finer than (2 µm). Skempton recommended three classes of clay as indicated by activity. The recommended classes are "inactive" for activities under 0.75, "ordinary" for activities around 0.75 and 1.25, and "active" for activities more prominent than 1.25. Active clays give the most potential to development (John and Erik , 2015). Typical activity values for various clay minerals are shown in Table 3.4. Sodium montmorillonite has the most expansion potential, which is reflected by the extraordinarily high value of activity in Table 3.4.

Table 3.4. Typical Activity Values for Clay Minerals (John and et al, 2015)

Mineral	Activity
Kaolinite	0.33–0.46
Illite	0.9
Montmorillonite (Ca)	1.5
Montmorillonite (Na)	7.2

Table 3.5 Summary of occurrence of clay minerals in soils (Raymond and Benno , 1975)

Clay mineral group	Occurrence
Kaolinite	Highly weathered soils with good drainage .Generally in older soils. Common in tropical and subtropical areas .
Chlorite	Areas of metamorphic parent rock . Common in marine sediments and sedimentary rocks .Not normally present in dominant proportions.
Clay mica	In soils derived from weathering of sedimentary rocks. Dominant mineral in slat e an d shale .
Montmorillonite	Result s from weathering of volcanic rock s or ash under poor drainage . Common in sediments of arid areas and often mixed with clay mica .
Allophane	Results from weathering of volcanic ash under adequate drainage . Common in areas with recent volcanic activity such as Japan ,New Zealand and western South America .

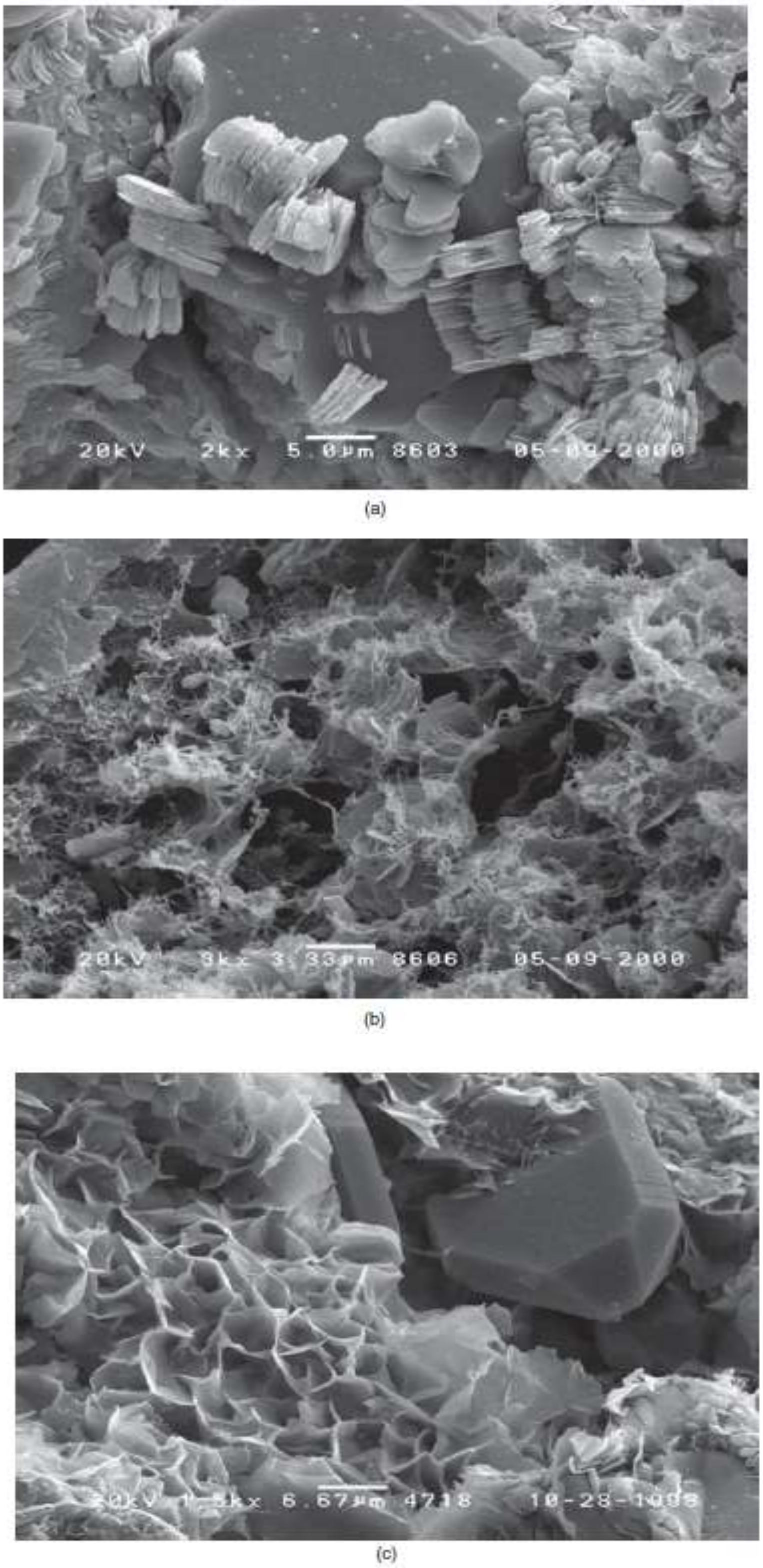

FIGURE 3.8 Scanning electron micrographs: (a) kaolinite; (b) illite; (c) montmorillonite (reproduced by permission of OMNI/Weatherford Laboratories).(John and et al, 2015)

3.1.3 Clay Ion Exchange

Ion exchange is the substitution of one ion adsorbed on the clay cross section surface by another. The physical properties of clay are reliant on the replaceable ions. Ion exchange is of incredible significance in the connected sciences where clay materials are utilized. The plastic properties of the clay are altogether different depending on the kind of the interchangeable cation present .

Grim (1968) demonstrated that clay surface is normally negatively charged, and which is the reason for cation attraction in the molecule surface. He found that the fundamental wellsprings of the negative charge on the clay surface are:

1- Broken bonds around the edges of the silicate-aluminate units that leave uneven charges which are adjusted by adsorbed cations. The quantity of broken bonds per unit mass and hence the exchange capacity, increases as the particle size decreases.

2- Change inside of the grid structure of trivalent aluminum $A1^{3+}$ for quadrivalent silicon Si^{4+} in the tetrahedral sheet and of lower valence particles $Mg^{2+}$for trivalent aluminum $A1^{3+}$ in the octahedral sheet result in unequal charges inside of the clay structure of a percentage of the clay minerals. This charge irregularity may be adjusted either by different grids (i. e. OH^{-}) for O^{2-} adsorption of positive cations. Accordingly, clay particles have negatively charged surfaces and attract positively charged cations (Abdi, 1992).

The quantity of cations that are replaceable is characterized as the cation exchange capacity and is normally communicated in milliequivalents of cations per 100 grams of oven dry soil (meq/100g). The milliequivalent may be characterized as one milligram of hydrogen particles (H^{+}) or the measure of whatever other cation that will supplant it on the clay soil mineral surface. The cation exchange capacity ought to be measured at pH 7. At higher PH levels more cations are adsorbed, maybe in order to increase dissociation of weakly bonded Si-OH^{-} groups on exposed clay crystal edges. Underneath pH 5 the cation interchange limit is consistent (Grim, 1968). Table 3.5 gives the cation interchange capacity for the three basic clay minerals. It can be seen from Table 3.5 that the huge net negative charge conveyed by the montmorillonite particles and its extensive particular surface territory implies that the cation exchange capacity of montmorillonite contrasts highty with that of kaolinite and illite.

Table 3.6 Values of cation exchange capacities, (Wu, 1976)

Clay Mineral	Exchange Capacities (meq/100g)
Kaolinite	3-15
Illite	10-40
Montmorillonite	80-150

3.1.4 Some Typical Clay Soil Characteristics

Some characteristic properties of clay particles, includeing cohesion, adhesion, plasticity, consistency and activity . Hunt (2007) describes those properties as follows:

- The cohesion of clay soil is defined as its ability to cohesion itself. It results from a bond creating at the contact surfaces of clay soil particles, brought on by electrochemical fascination strengths. Two components are in charge of the cohesion of clay particles in particular the high specific surface of the particles (surface range per unit weight), and the electrical charge on the essential silicate structure coming about because of ionic substitutions in the crystal structure. Adhesion of clay soil is its capacity to stick to other material that comes into contact with .

- Plasticity is the ability of a material to experience variation in shape without undergoing a variation in volume, with its moisture content held constant.

- Consistency is described as the relative facility with which a soil can be deformed. It includes cohesion and adhesion as well as its ability to resist deformation and split. As it were, soil uniformity reference to the characterization of the durability of a soil at differents moisture contents to mechanical fatigues or manipulations. The consistency of soils is most characterized at three soil moisture grades: wet, moist and dry. With reduced moisture content, clays pass from the fluid condition (very soft) meanwhile a plastic state (firm), to a semi solid state, and lastly to a rigid brick such as state. The moisture contents at the transmission between these various conditions are known by the Atterberg limits, which vary with the clay type and its purity.

3.2 Soil Stabilization

In geotechnical engineering experience the soil at a particular location is often less than ideal for its intended reason. It would seem sensible in such cases to just move the structure or facility. However, contemplations other than geotechnical predominatingly govern the site of a structure, and the engineer is compelled to design for the current site. One of the possibilities is to conform the foundation to the geotechnical conditions at the location. Another probability is to attempt to stabilize, treatment or improve the engineering properties of the soils at the location. Contingent upon the circumstances, this second way may be the most economical resolution for the trouble, (Craig, 1994).

Stabilization is characterized as the procedure of enhancing soil aggregate properties by mixing in materials that in increase the load bearing capacity, immovability and resistance to weathering or uprooting. It can be characterized as the procedure of changing the soil properties by mechanical or chemical method in this manner enhancing the required engineering properties of soils. There are three objectives for soil improvement in particular strength change, permeability, control and improvement of soil durability and resistance to weathering,(J. Olufowobi et al., 2014).

3.2.1 Soil Stabilization Techniques

Ssoil stabilization techniques can be divided into four major groups, as follows (Hausmann 1990 and Alqasimi 1993) :

3.2.1.1 Mechanical Stabilization

Soil density is increased by the utilization of external mechanical forces, including compaction of surface layers by static, vibratory, or impact rollers and plate vibrators; and profound compaction by overwhelming packing at surface or vibration at profundity (Alqasimi 1993). The mechanical technique for stability involves soil compaction and densification by utilization of mechanical energy. There is a clear relationship between dry density and mechanical length. The material is more compact, and has high mechanical strength,(Hausmann,1990).

The main effect of compaction is to tighten up the soil particles which results in (Gunther, 1998) :

- An increase in the number of points of contact between soil particles .

- A reduction in the proportion of spaces, that is in the porosity of the soil.

3.2.1.2 Hydraulic Stabilization

Free-pore water pressure is a force out of soil via drains or wells. This is achieved through pumping from boreholes or trenches in granular soils, and by preloading or electrokinetic stabilization in fine-grained soils (Alqasimi, 1993) .

3.2.1.3 Physical Stabilization

Physical improvement includes the controlled blending of different portions of soil to acquire a soil with a specific grain size distribution. Limits have been established which indicate optimum particle size distribution for soils for specific uses physical adjustment includes the controlled blending of different divisions of soil to get a soil with a specific grain size circulation (Eades, 1962). This technique involves physically mixing additives with surface layers or columns of soil at depth. Additives include natural soils, industrial by-products or waste materials, (Alqasimi, 1993)

3.2.1.4 Chemical Stabilization

This process manages enhanceinge the inserting so as to engineering properties of soil chemicals or other such materials that are generally financially effective. These additional substances react with the soil, which aremostly earth minerals, with resulting precipitation of new and insoluble minerals, which entwine the soil, (Ingles, 1994). Chemical added substances, for example, lime, concrete, fly slag, and other synthetic mixes have been utilized as a part of soil change for a long time with different degrees of accomplishment (Al-Rawas, 2002). Considering the establishing specialists initially, the materials habitually used are Portland concrete, lime, mix of lime and fly slag, and sodium silicate. Portland cement has been used broadly to improve existing layers streets and additionally settle the characteristic subgrade soils. Diverse admixtures that have come into expansive use as of late are lime and fly powder admixtures. Fly slag is a by-proudect of impact heaters and is for the most part high in silica and alumina. On the other hand, the measure of fly fiery remains stays required for adequate conformity is for the most part high, making its use limited to territories with accessibility of substantial amounts of fly cinder at moderately low cost(J. Olufowobi et al.,2014).

3.2.2 Stabilization Processes

The general stabilization operation can be put into four different procedures cation exchange, flocculation, agglomeration, and pozzolanic reactions (Prusinski and Bhattacharja, 1999). Each of the four procedures will happen in cement treated subgrade soils while in the event of lime treated soils cementitious hydration will be missing because of the absence of calcium aluminate hydrate (C-A-H) after hydration of the stabilizer. Cement supplies hydration products, which boost the strength and support the amount of base materials as well as increase the treatment performance (Wang, 2002).

3.2.2.1 Cation Exchange

Cation trade starts the adjustment handle rapidly, and is trailed by flocculation and agglomeration.

Earth ingests cations of specific sort and amount to shape a twofold layer. Trade responses can happen because of changes in the normal conditions, and basic changes in the physical and physicochemical properties of the dirt might come to fruition. Case in point, the monovalent cations can be traded effectively with cations of higher valence, for instance, calcium. Upon particle trade, the higher charge thickness of divalent or trivalent particles results in an immense abatement of the thickness of the twofold layer, and diminishment in development and versatility, (Wang, 2002).

Clay is negatively charged particles adsorb cations of particular sort and quantity. The simplicity of substitution or cation swaps of relies on a few variables, principally the valence of the cation. Higher valence cations easily swap cations of lower valence. For ions of the same valence, the size of the hydrated ion gets to be imperative; the bigger the ion, the greater its substitution power. If other conditions are equivalent, trivalent cations are held more firmly than divalent and divalent cations are held more firmly than monovalent cations, (Mitchell and Soga, 2005). A typical replaceability series is

$Na^{+} < Li^{+} < K^{+} < Rb^{+} < Cs^{+} < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+} < Fe^{3+} < Th^{4+}$

The exchangeable cations may be present in the surrounding water or are gained from the stabilizers.

An example of the cation exchange (Sivapullah,1996);

$Ca^{2+} + Na^{+}\text{- Clay} \Longrightarrow Ca^{2}\text{+ Clay} + (Na^{+})$

These cations may be present naturally in the water surrounding clay particles, or supplied artificially with different stabilizers, such as lime or other pozzolanic or cementitious materials for soil stabilization applications.The thickness of the diffused double layer decreases as the divalent ions (Ca^{2+}) from stabilizers are replaced with monovalent ions (Na^{+}) of clay. Thus, swelling potential decreases.

3.2.2.2 Flocculation and Agglomeration

Flocculation and agglomeration change the clay soil composition from that of a plastic, fine grained material to one of a granular soil. Flocculation is the procedure of mud particles modifying their structure from a level, parallel structure to a more irregular introduction. Agglomeration is thought to happen as the flocculated dirt particles start to frame frail bonds at the edge-surface interfaces of the mud particles, due to the confirmation of cementitious material at the mud molecule interface, (Wang, 2002).

3.2.2.3 Pozzolanic Reaction

A pozzolanic reaction is an auxiliary procedure of soil stabilization. One essential step for the arrangement of extra cementing materials is the arrangement of silica and alumina from clay components. The high pH environment of a soil bond system boosts the solvency and reactivity of the silica and alumina present in clay particles.

The level of the crystallinity of the minerals and particle size distribution are a few variables affecting dissolvability. It is assumed that calcium particles join with silica and alumina breake down from the clay lattice to form extra cementitious material (C-S-H and C-A-H) ,(Wang, 2002).

$Ca^{2+} + 2(OH)^{-} + SiO^{2}$ (Clay Silica) $\Longrightarrow$ CSH

Ca2+ + 2(OH) - + Al2O3 (Clay Alumina) $\Longrightarrow$ CAH

Time dependant pozzolanic reactions play a major role in the stabilization of the soil, since they are responsible for the improvement in the various soil properties (Show et al., 2003).

3.2.2.4 Cementitious Hydration

Cement hydration produces cementitious material. C-S-H and C-A-H shape a system that serves as the "paste" that gives structure and quality in a bond treated soil. The quickest quality increments happen between one day and one month; maller additions in quality (because of proceeded with hydration and arrangement of cementitious material) keep on happening for a considerable length of time, ,(Wang, 2002).

3.2.3 Objectives of soil stabilization

The objectives of improving the soil include the following (Hausmann 1990}:

1- Increase strength of the soil.

2- Reduce mutilation under anxiety (build stress-strain modulus).

3- Reduce compressibility (volume decrease due to a reduction in air voids or water content under load).

4- Control shrinking and swelling (improve volume stability) .

5- Control permeability, reduce water pressures, redirect seepage.

6- Prevent damaging physical or chemical changes due to environmental conditions (freezing/thawing, wetting/drying).

CHAPTER 4

MATERIALS AND METHOD

4.1 General

This chapter will present all of the materials uesd and the detailed procedures of all the laboratory tests performed to achieve the objectives of this study. All the samples used in this study were molded in the laboratory according to the available standard specifications by the American Society of Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO), or based on the literature review.

4.2 Materials

In this study, the materials utilized in implementation were clay soil, waste soda lime glass, and water.

4.2.1 Soil

In this study, the soil sample was provided from the Bazian district in the city of Sulaymaneyah, northern Iraq.

In order to ensure no confusion with other particle materials, such as agricultural organic materials located on the surface of the soil with the soil, for the soil particles taken to be sample, the top surface of untreated soil was removed and the soil was excavated to a 1 m below the ground level . The sample was then taken from the soil to be a process of study.

4.2.2 Water User

Water used in the experiments was clean water and free of any impurities so that was safe to drink ; water temperature was about (25°C±2)

Fig 4.1 Sample of clay soil used

Table 4.1 Summarizes of various properites of clay soil sample

Properites	Value
MDD	1.82 gm/cm3
Specific Gravity	2.72
OMC	15.25 %
LL	46.5%
PL	28.68%
PI	17.82%
CBR	2.5 %
Free swelling	5.5 %
Unconfined compressive strength	239.99 Kpa
Soil Type (Unified Soil Classification System)	The group symbol of soil is CL (clay of low plasticity)

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4.2.3 Soda Lime Glass

Glass metal water bottles with a green color available in most markets in Iraq was used for this study. Bottle glass waste was passed through sieve number 200 # (75 μm) obtain glass powder . It was first washed then dried, and broken and crushed manually into dust sizes by use of hammer and mortar. The chemical composition and the physical properties of lime soda glass are shown in Tabe 4.2 . Silica is the main composition of sand which is cohesion less so that the important property to improve the of clay soil. Soda lime glass consists of 10.5% lime in it. This will supply some additional strength to the treated soil if hydrated. Figure 4.2 shows a sample of the soda lime glass powder .

Table 4.2 Summarizes of various properties of Soda lime glass (Thomas and Terese , 2005)

Properites	Value
Silica (Si02)	74%
Sodium oxide (Na20)	13%
Lime (CaO)	10.5 %
Alumina (Al203)	1.3%
Another Components accumulate	1.2%
Density at 20°	2.52 g/cm^3
Young's modulus at 20°	72 Gpa

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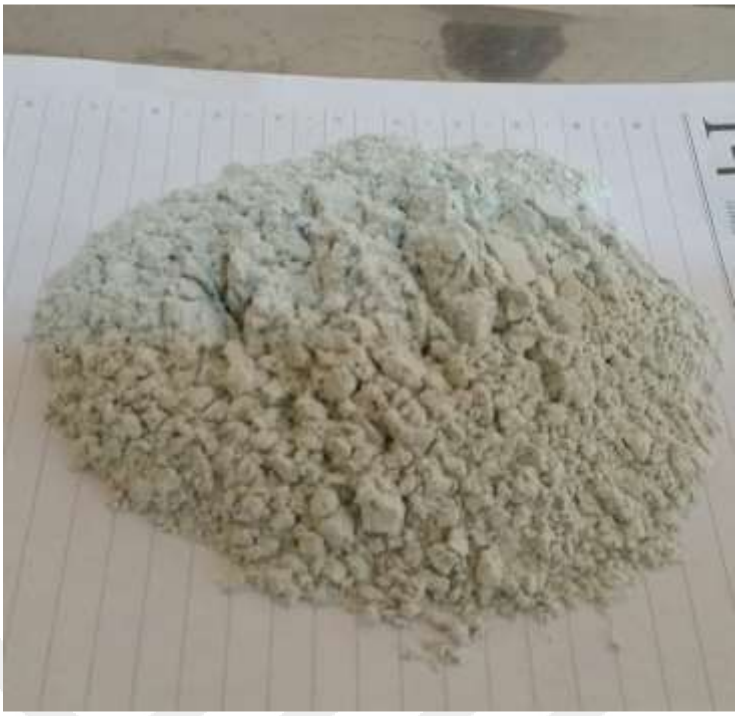

Fig 4.2 Sample of Soda lime Glass powder Used

4.3 Experimentals

The samples utilized in this investigation were molded in the laboratory in accordance with the available standard specifications procedures provided by the American Society of Testing and Materials (ASTM) or American Association of State Highway and Transportation Officials (AASHTO) or depending on the literature review. The tests were performed on the untreated clay in order to determine it is physical properties include, grain size distribution (sieve and hydrometer) test, max dry density (MDD) , optimum moisture content (OMC), atterberg limit , specific gravity, California bearing ratio , swelling test and unconfined compression . Tests were also conducted on the treated soil sample with various percentages of soda lime glass include, MDD , OMC, atterberg limit test, California bearing ratio test , swelling test and unconfined compression test. In this investigation, the percentage of soda lime glass content added for treated clay soil sample were 3%, 6%, 9% and 12% of the of clay soil weight .

4.3.1 Grain Size Analysis for the Soil (Sieve and hydrometer) Test

This tests were carried out in accordance with ASTM D 422-63. This test was method used to find the distribution of particle sizes in soils. The distribution of

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particle sizes larger than 75 µm (retained on the No. 200 sieve) is found by sieving analysis, while the hydrometer test to determined the sedimentation process for particle sizes smaller than 75 µm . The purpose of these two tests was for classification and to find the type of soil chosen to conduct this study . Soil classification is the process of soils into diverse gatherings such that the clay in a specific gathering have comparable conduct. As there are a wide assortment of soils covering the earth, it is useful to systematize or characterize the dirts into general gatherings of comparable conduct. Soils, all in all, may be named cohesionless and firm or as coarse-grained and fine-grained. These terms, on the other hand, are excessively broad and incorporate an extensive variety of building properties. Henceforth, an extra method for order is important to make the terms more significant in building practice. These terms are arranged to frame soil characterization frameworks. Resultes of this test find the soil consists of 0.3% gravel , 1.5% sand , 40.8% silt and 57.4% clay. The atterberg limits tests results found L.L= 46.5% and P.L = 28.68%. therefore, as according to (Unified Soil Classification System) the group symbol of soil is CL clay of low plasticity.

Figure 4.3 hydrometer test

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4.3.2 Specific gravity of the soil

The specific gravity of the soil test was carried out in accordance with ASTM – D 854. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature, Apparatus needed for this test were pycnometer, balance, funnel, vacuum pump, and spoon.

The procedure included the weight of the unfilled spotless and dry pycnometer.10g of dry clay soil was put in the pycnometer and the weight of the pycnometer containing the dry clay soil sample was recorded. Distilled water was added to fill about half to three-fourths of the pycnometer. The clay soil sample was soaked for 10 minutes. A partial vacuum was applied to the sample for 10 minutes in order to evacuate entagled air. The vacuum was then stopped and removed from the pycnometer. The pycnometer was then filled with distilled water and its outside cleaned with a fully dry material. The weight of the pycnometer and substance was recorded. The pycnometer was emptied, cleaned, and filled with distilled water. This weight was also determined and recorded. The specific gravity was then found by using the following formula:

Specific Gravity, $GS = W_0 / W_0+(W_A-W_B)$ (4.1)

Where:

W_0 = wt. of dry clay sample .

W_A = wt. of pycnometer with distilled water.

W_B = wt.of pycnometer with water and clay .

4.3.3 Moisture – Density Test

This test is carried out to find the relationship between the dry density and moisture content of a soil sample for a specified compact effort. The compact effort is the amount of mechanical load that is applied to the mass of the soil. This characteristics soil test was carried out in accordance with AASHTO T180, to find the MDD and OMC for the samples .For this test apparatus use:

Mold cylinder shape volume equal to (2149.19 cm^3), mechanical hammer, oven, accurate balance, straight edge, trowel, pan mixing, cans, and room temperature equal to 25±3 . This experment was conducted for natural clay soil and with all addional Soda lime glass for clay soil .

4.3.4 Atterberg Limit

This test was carried out accoreding to ASTM D 4318 .It is crucial to implement several simple tests to characterize the plasticity of clay to parry shrinkage and cracking when fired. Atterberg as described as amount of water contents in some limits or critical phases in the soil behavior. If know where the water content of our sample relative to the Atterberg limits, Then we already know a lot about the response of the sample geometry. This test used following apparatus;

liquid limit device, flat grooving tool with gage ,porcelain (evaporating) dish, cans, accurate balance, Wash bottle filled with distilled water, oven. This test was conducted to determine the hardness of mud and the parameters measurement and reduction of plastic (PL) and the liquid limit (LL). This experiment was conducted for natural clay soil as well as for all soda lime glass percentages in the clay soil. Soil behavior in the long Plasticity index (PI) is determined using this formu ;

$$PI = LL - PL \tag{4.2}$$

Where :.

PI = Plasticity index.

LL= liquid limit .

PL= Plastic Limit .

4.3.4.1 Plastic Limit

Plastic limit ischaracterized as the minimum moisture content and expressed as a rate of the weight of the oven dried soil at which the soil can be moved into threads one-eighth inch in diameter without the soil breaking into pieces. This is additionally the moisture content of a solid at which a soil changes from a plastic state to a semi solid state .

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Casagrande (1932) suggested that the simple way to do this test is by rolling a string of soil (on a glass plate) until collapsing in a diameter of 3 mm. The sample reflects the will of the wet side effect of reducing plastic If the subject can be traced in diameter less than 3 mm, and the dry side if the subject breaks and breaks down before it reaches the 3 mm diameter.

The procedure for finding the PL included moulding and rolling the already completely blended specimen with the palms to a threadlike formed stick of around 3 mm diameter. The plastic limit was indicated by the moisture content compared to the point at which the stick first crumbled.

4.3.4.2 Liquid Limit

Liquid limit is characterized as the concept that the water content in the clay soil changes from plastic to liquid. However, the transition from plastic to liquid gradually to a range of water contents, and shear strength for the soil is not actually zero in the liquid end.

Figure 4.4 liquid limit test

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4.3.4.3 Plasticity Index

Known as plasticity index (PI) is the water content of the soil when it plastic. Therefore it is numerically equal to the difference between the LL and the reduction of PL. We found many engineering properties to link the pilot with PI, and it is also useful in the classification of fine-grained soil engineering.

4.3.5 California bearing ratio test

The California bearing ratio is a penetration experiment for an estimation of the mechanical strength of soil . It was developed by the California Department of Transportation in the 1930’s . There are a range of factors that affect the CBR of a particular material , the most important of these being soil type, density, moisture content and method of sample

In order to prepare the test, aside from having the same material properties, moisture conditions are also pivotal, (Carter and Bentley,1991). Moisture that was in material components vary by zone climate conditions, and the CBR test is used to simulate the worst possible conditions (Emery, 1987) .

The CBR experiment is used for penetration testing to assess natural terrestrial soil's ability to design pavements. This test was carried out according to AASHTO T193 and T180. This experiment was conducted for natural clay soil and with all percentage additions of soda lime glass in clay soil.

4.3.5.1 Description of Apparatus

Required device for a California bearing ratio experiment are as follows :

- A mold cylinder shape with an interior diameter of 15.24 cm. and a height of 17.78 cm. with an extension collar of 5 cm. tallness and a punctured base plate.
- A metal circular disk 12.7 cm. diameter and 6.14 cm. height..
- A mechanical compaction with a rammer of mass 4540 gm, as, shown in figure 4.5.
- A dial gage in order to measureing of swelling.

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- A metal Piston of circular cross – section with diameter of 4.963 cm. A. = 3 in 2 and not less than 10 cm. in L.

- Mechanical Loading Device, shown in Figure 4.6 .

- A suitable tank for maintaining the water level of 2.5 Centimeter above the top of sample .

- A oven dry - 110 ± 5°C (230 ± 9°F) .

- Containers for moisture content.

- Miscellaneous: Tools such as spoons, mixing pans, straightedge, balances filter paper, etc.

4.3.5.2 Test procedure .

The sample is prepared by weightingt the soil and, according to soil weight, adding the glass powder by (3% , 6% ,9% and 12%). The mix cured for four days, after wich water is added according to optimum moisture content for each addition. The soil is ten compacted in five layers by applying 10, 30 and 65 blows respectively in three CBR molds by using the mechanical compaction device (see Figure 4.5) with a 4540 gm rammer. The compacted densities of the three specimens ranged from 95 percent to 100 % of the MDD as is the case with the AASHTO T180 compaction test. The mold is then immersed in water to allow free access of water. The sample is placed in water for 96 hours . After 4 days, the sample is removed from tank and allowed to drain for 15minutes and reading dialgauge on specimen and calculate swell as a percentage of initial sample height. After that puting it in the loading Device (see Figure 4.6)

The test is conducted on natural soil or compacted under soaked conditions . The results obtained are compared with the curves of the standard tests for signal soil strength. Testing was conducted using the pressure required for the measurement to penetrate the soil sample with a standard area of the piston which is then divided by pressure required to achieve an equal amount of penetration level crushed rock material .There is 4 day curing time used 4 day for sample when mix the soil with soda lime glass powder with out water. Applied load on the penetration compress so that the penetration is approximately 1.25mm/min. The load readings are recorded at (0.64 , 1.27, 1.91, 2.54, 3.81, 5.08 and 7.62 mm). Plot curves between load and penetration for each specimen. Any necessary corrections to the curves are applied. depend on the load at (2.54 and 5.08 mm), the CBR value for every specimen blow are found using the formula :

$$\text{CBR value} = (\text{Load} / \text{standard load}) * 100 \tag{4.3}$$

California bearing ratio actual is calculated by plotting a graph between CBR values and dry densities of all the three specimens and then calculating the California bearing ratio against value of 95 % MDD .

Figure 4.5 Mechanical compactor

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Figure 4.6 CBR test

4.3.6 Swelling Test

It was found that excessive swelling often causes serious damage to foundations and structures overlying structure .The possibility of swelling in the soil is affected by factors including mineralogy, fraction clay, etc. Soil with Smectite usually has much higher swelling pressure of the soil with kaolinite. There are different ways to modify and improve the properties of swell, however, usually preferred to add chemical addatives (Transportation Research Board, 1987).

In this experimental study the “Swelling Method ’’ AASHTO T 193 and T180 was used to detrmine the value of swelling. A 4-day curing time was used for the sample of soil mixed with soda lime glass powder without water, and after that each sample was submerged in water for 96 hours. This experiment was conducted for natural clay soil and soil with all percentage additions of soda lime (3%, 6%, 9% and 12%). Clay soil swelling is determined by using this formula :

$$\text{Swell}(\%) = (\Delta H/116.43) * 100 \quad (4.4)$$

Where :

ΔH= the variation in the premier rise of the specimen after it is submerged by water for 96 hours .

116.43= is the standard height of the specimen before the inundated by water.

Figure 4.7 Swelling test

4.3.7 Unconfined compressive strength

The soil samples that are tested in unconfined compression are usually made of fine-grained soils, fully or partially saturated, with low permeability. When these soils are

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loaded rapidly, they deform practically at constant volume under undrained conditions, and undergo pore pressure changes that do not bave enough time to dissipate. The UCS experiment is a particular unconsolidated undrained (UU) triaxial experiment without confining pressure (Jean-Pierre Bardet , 1997) . This test was done according to ASTM (D2166-65).

4.3.7.1 Description of Apparatus

- Compression device (digital machine see Figure 4.7).

- Sample Extruder.

- Digital dial gauge .

- Weighing balance .

- Oven.

- Miscellaneous , including Split mould, 38mm diameter, 76mm long and carving tools, remolding apparatus, water content cans, and data sheets, as required.

4.3.7.2 Test procedure

The sample is prepared by weighing the soil and, according to soil weight, adding the glass powder by 3% , 6% ,9% and 12%. Water is added to the large mold according to optimum moisture content for each sample. An examining tube is pushed into the extensive form and the inspecting tube loaded with the dirt is uprooted. For undisturbed examples, examining tube is pushed into the mud sample. The dirt specimen is saturated in the testing tube. The split form is carefully coated with a small layer of oil. The mold is then measured. Using the specimen extractor and knife, the sample is expelled out of the testing tube into the split mold. The two ends of the samples in the split mold are trimmed and the mold is measured. The sample is then removed from the split mold by breaking the mold into two sections. The length and width of the sample is measured with vernier calipers.

The samples were kept in plastic bages and allowed to cure for 3 days and 7 dayes. After curing, tests were than completed by placing the sample on the base plate of the pressure machine and changing the upper plate to reach the example. The dial

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gage is conformed to zero. Pressure is applied to bring about a pivotal strain. The dial gages force reading is recorded every 30 seconds.

The axial strain and the axial normal compressive stress are given by the following relations :

$$\sigma = P/A \tag{4.5}$$

Where:

σ = compressive stress (kPa) .

P = compressive force (kN).

A = corresponding cross-sectional area of the specimen (mm2).

$$\epsilon = \Delta L/Lo \tag{4.6}$$

Where:

ϵ = axial strain under the given load.

ΔL = length change of specimen (mm).

Lo = initial length of tested specimen (mm).

$$A = Ao/1- \epsilon \tag{4.7}$$

Where:

Ao = initial cross-sectional area of the specimen (mm^2).

The unconfined compressive strength (qu) is the maximum value σ, is also equal to the diameter of Mohr's circle as indicated .

The undrained shear strength (su) is typically taken as the maximum shear stress or ,

$$S_u = ½\ qu \tag{4.8}$$

Where:

qu = maximum value of compressive stress.

Figure 4.8 Digital machine for unconfined compressive strength test

CHAPTER 5

RESULTS AND DISCUSSION

This chapter presents and analyses the results obtained from all experimental work that were performed on the untreated and treated clay soils that were described in Chapter 4 and also include discussion on the obtained results .

5.1 Soil Properties of Untreated Soil Sample

Tables 5.1, 5.2, 5.3 and Figure 5.1 summarize all results of various basic engineering properties for untreated soil that was used in this study .

From the analysis of tests results, it was found that the type of soil sample used was CL (clay of low plasticity) and A-7 according to the unified soil classification system and AASHTO classification, respectively.

Table 5.1 Result of basic engineering properties of soil sample

Maximum Dry Density		1.82 gm/cm3
Specific Gravity		2.72
Optimum Moisture Content		15.25 %
Gravel		0.3 %
Sand		1.5 %
Silt		40.8 %
Clay		57.4 %
Liquid Limit		46.5%
Plastic Limit		28.68%
Plasticity Index		17.82%
CBR		2.5 %
swelling index		5.5 %
Unconfined compressive strength		239.99 Kpa
Soil Type	Unified Soil Classification System	CL
	AASHTO	A-7

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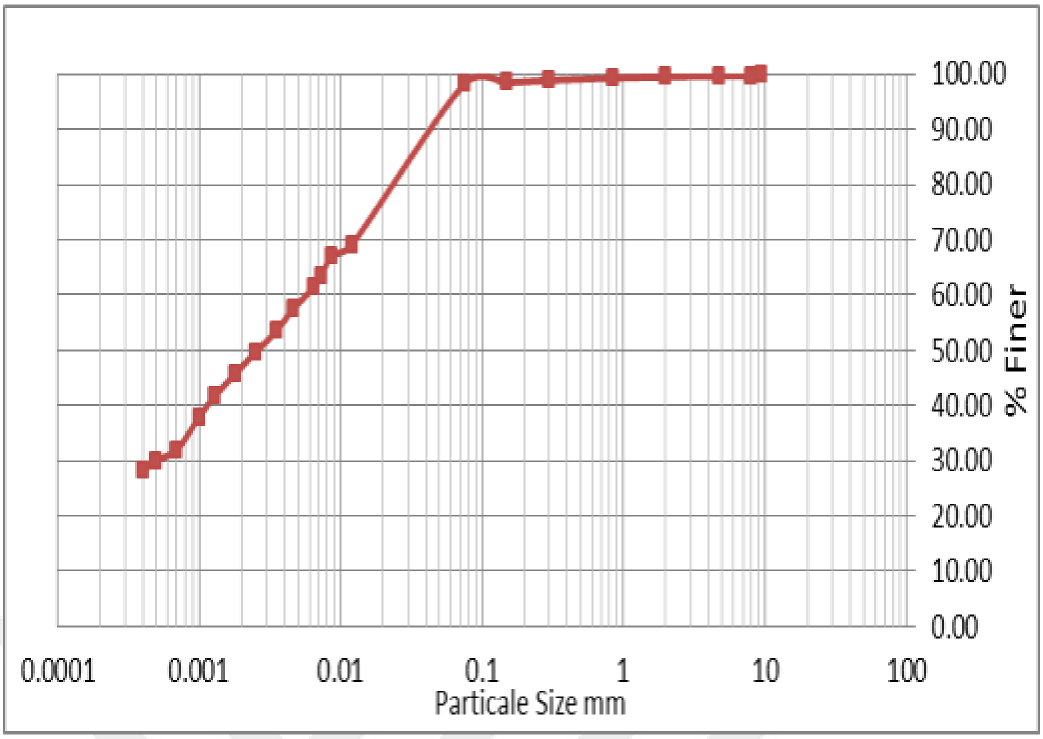

Figure 5.1 Grain size distribution curve of soil for both sieve and hydrometer test

Table 5.2 Result of grain size analysis test

Sieve NO.	Sieve Size mm	Wt. Retaind soil (gm)	Cum.retained	% cumulative retained	% finer
3/8″	9.5	0	0	0.00	100.00
5/16″	8	1.2	1.2	0.24	99.76
4	4.75	0.2	1.4	0.28	99.72
10	2	0.8	2.2	0.44	99.56
20	0.85	1.15	3.35	0.67	99.33
50	0.3	2.2	5.55	1.10	98.89
100	0.15	2	7.55	1.51	98.49
200	0.075	1.3	8.85	1.77	98.23
pan	__	490.23	499.08		
Sum. gm		499.08			

Table 5.3 Results of hydrometer analysis test

Elapsed (t) min	Real hydr. Reading (R)	Water density @ Temp. (Gw1)	K Constant	particale Size (D) mm	% passing for combind test
1	1.031	0.99564	0.04214	0.012	69.17
2	1.03	0.99564	0.04214	0.0086	67.21
3	1.028	0.99564	0.04214	0.0073	63.3
4	1.027	0.99564	0.04214	0.0064	61.34
8	1.025	0.99564	0.04214	0.0046	57.43
15	1.023	0.99564	0.04214	0.0035	53.52
30	1.021	0.99564	0.04214	0.0025	49.61
60	1.018	0.99564	0.04214	0.0018	45.69
120	1.017	0.99564	0.04214	0.0013	41.78
240	1.015	0.99564	0.04214	0.001	37.87
480	1.012	0.99564	0.04214	0.0007	32
960	1.011	0.99564	0.04214	0.0005	30.04
1920	1.01	0.99564	0.04214	0.0004	28.09

5.2 Moisture – Density Relations Test

This experiment was performed to find the maximum dry density (MDD) and optimum moisture content (OMC) for untreated and treated clay soil .

Table 5.4 and Figure 5.2 show the results of dry density and moisture content for untreated and treated soil, From this reults the MDD and actual OMC for each sample were found .

Test results in Figure 5.3 and Table 5.5 show that the values of maximum dry density of clay soil increases with increased in addition of glass powder and that this increase is linear. The largest percentage increase in maximum dry density was 5.49 % when 12 % soda lime glass was mixed with clay soil. The reason behind this result is that glass density higher than density of clay soil and also involves the fineness of glass powder (Nuruzzaman and Akhtar Hossain, 2014) .

Test results in Figure 5.4 and Table 5. show that the values of OMC decreased in a liner fashions with the increases in addition of soda lime glass powder. The largest percentage decrease in optimum moisture content was 21.6% when 12% soda lime glass powder was mixed with clay soil. The reason behind this decrease may that absorption capability of glass is much less than of clay soil .

From the analysis of tests results, it was found that the soda lime glass powder has a good ability to improve the property of max dry density and optimum moisture for clay soil.

Table 5.4 Result of moisture – density relations test

Soil Sample (untreated and treated)	Dry Density gm/cm^3	Moisture content %
Soil + 0% from Soda Lime Glass	1.69	9.72
	1.82	15.63
	1.64	23.67
Soil + 3% from Soda Lime Glass	1.75	8.63
	1.86	14.63
	1.69	21.46
Soil + 6% from Soda Lime Glass	1.71	8.81
	1.88	14.8
	1.69	22.69
Soil + 9% from Soda Lime Glass	1.66	7.14
	1.89	15.35
	1.69	20.2
Soil + 12% from Soda Lime Glass	1.77	7.33
	1.92	11.39
	1.85	15.09

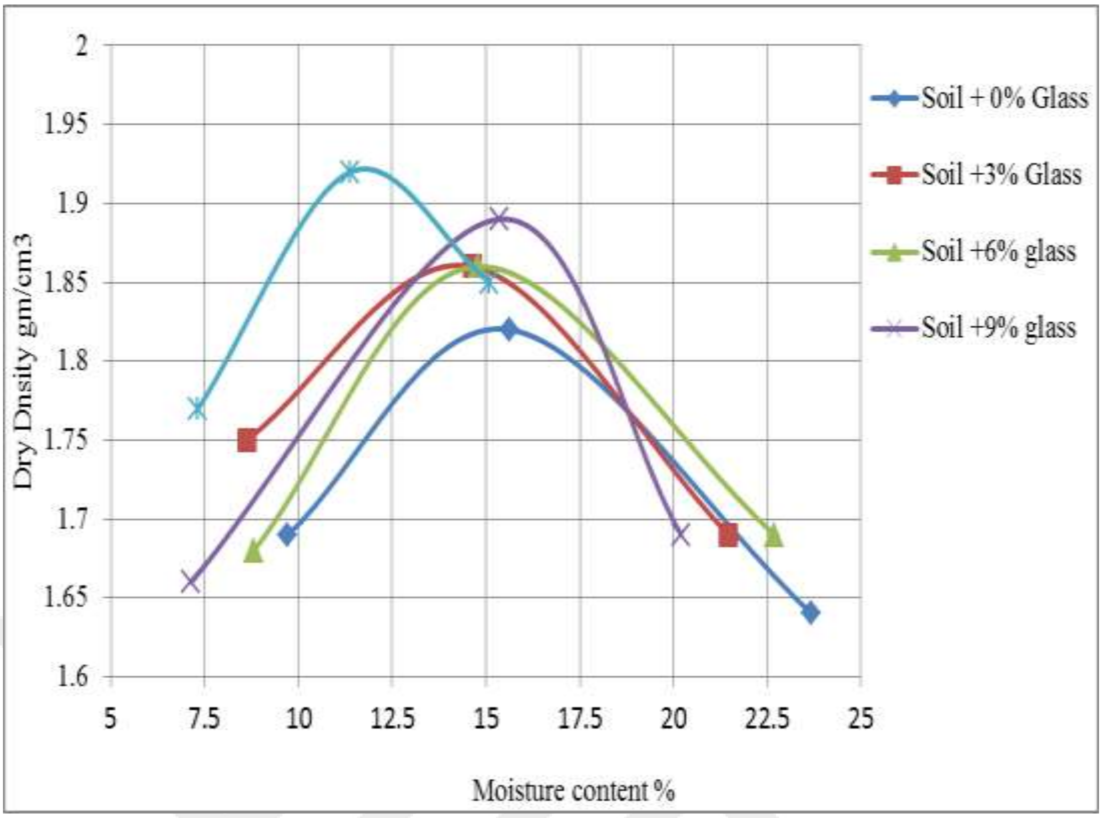

Figure 5.2 Relationship between dry density and moisture content of clay soil

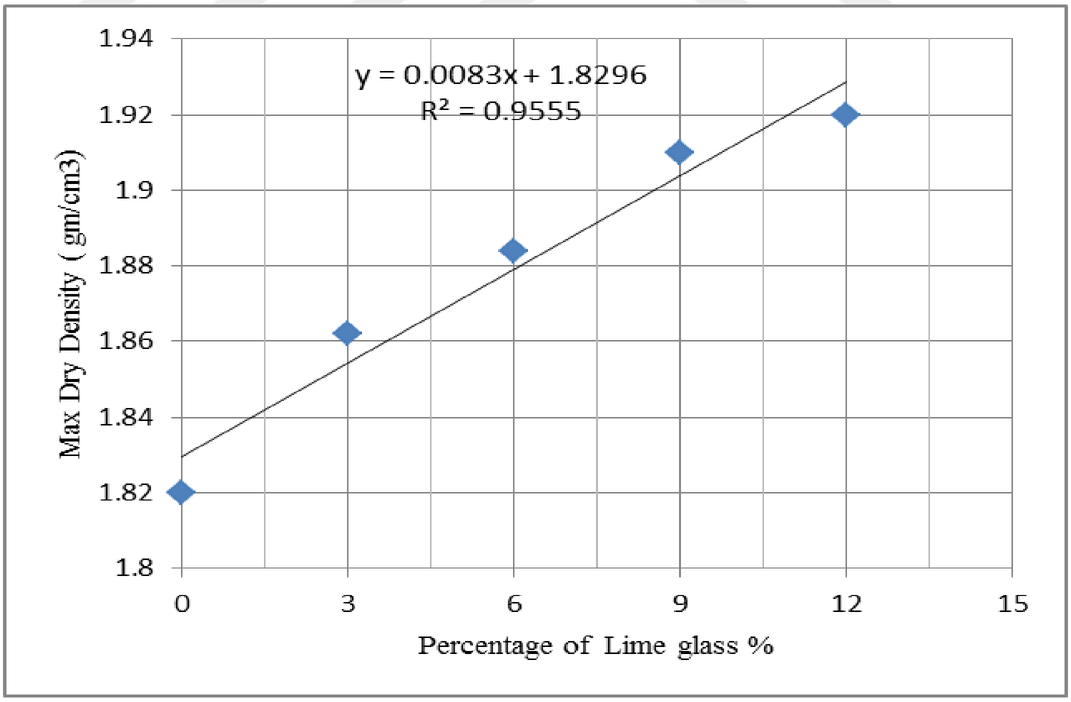

Figure 5.3 Relationship between max dry density of clay soil with percentage of soda lime glass powder

Table 5.5 Percentage changes of max dry density and optimum moisture content

NO.	Additive %	MDD (gm/cm^3)	OMC %	%Change	
				MDD	OMC
1	0	1.82	15.25	----	----
2	3	1.862	14.5	+ 2.3 %	- 4.9 %
3	6	1.884	14.1	+ 3.51 %	- 7.54 %
4	9	1.91	13.1	+ 4.94 %	- 14.09 %
5	12	1.92	11.95	+ 5.49 %	- 21.6 %

+: Increase; -: Decrease

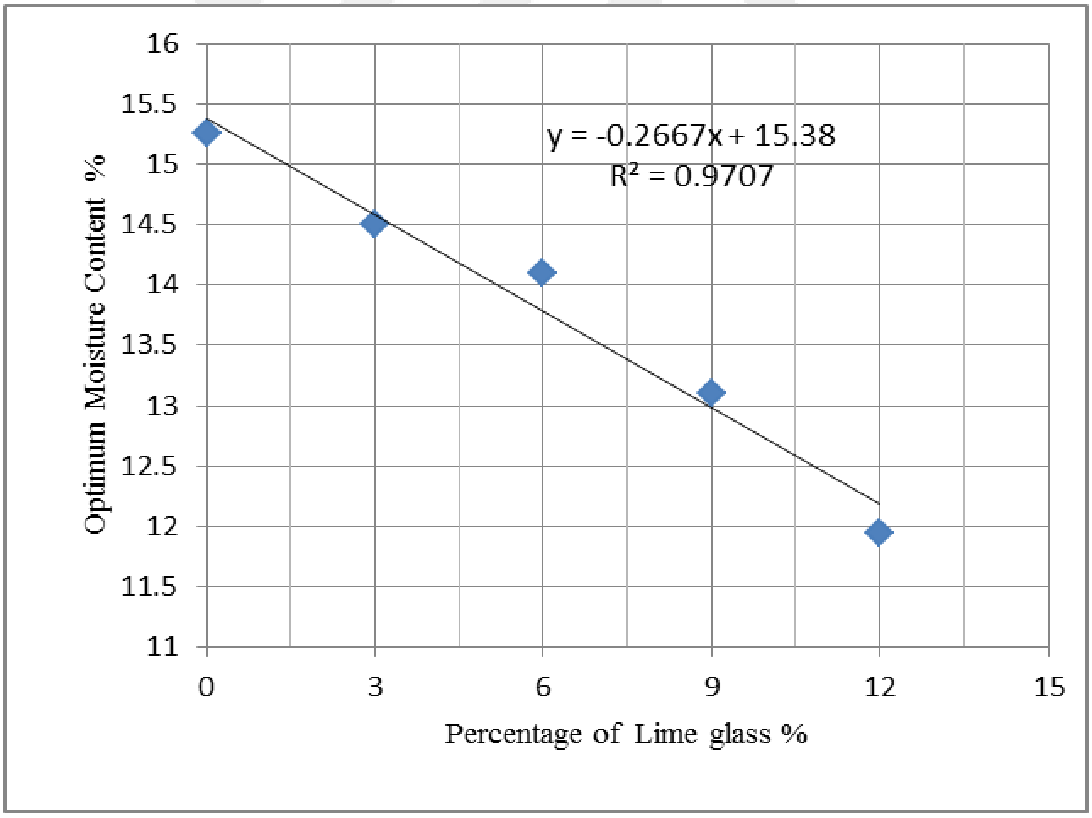

Figure 5.4 Relationship between optimum moisture content of clay soil with percentage of soda lime glass powder

5.3 Atterberg Limits Test

The atterberg limits tests were carried out in accordance with ASTM D 4318.

Test results in Table 5.6 and Figure 5.5 show that the values of liquid limit for clay soil samples decreased due to increases in soda lime glass powder added . The largest percentage decrease of liquid limit was to (40 %) when it was mixed with (12 %) soda lime glass powder .

Test results in Table 5.6 and Figure 5.6 show that the values of plastic limit for clay soil samples decreases due to the increased percentage of soda lime glass powder added . The largest percentage decrease of liquid limit was (37.48 %) when (12 %) soda lime glass powder was added to clay soil .

Test results in Table 5.6 and Figure 5.7 show that the values of plastic index for clay soil sample decreased due to increases in percentage of soda lime glass powder added . The largest percentage decrease of plastic index was to (44.05 %) when (12 %) soda lime glass powder was mixed in clay soil .

From the analysis of tests results, it was found that soda lime glass powder with mixed with clay soil lead to an improvement in the required liquid limit , plastic limit and plastic index properties. The reason behind this result is that soda lime glass powder is cohesionless (Nuruzzaman and Akhtar Hossain, 2014).

Table 5.6 Percentage changes of LL, PL and PI

NO.	Additive %	LL%	PL%	PI%	%Change		
					LL	PL	PI
1	0	46.5	28.68	17.82	___	___	___
2	3	35.5	22.41	13.09	- 23.66 %	- 21.86 %	- 26.54 %
3	6	31	18.78	12.22	- 33.33 %	- 34.52 %	- 31.43 %
4	9	29.9	18.16	11.34	- 35.70 %	- 36.68 %	- 36.36 %
5	12	27.9	17.93	9.97	- 40.00 %	- 37.48 %	- 44.05 %

+: Increase; -: Decrease

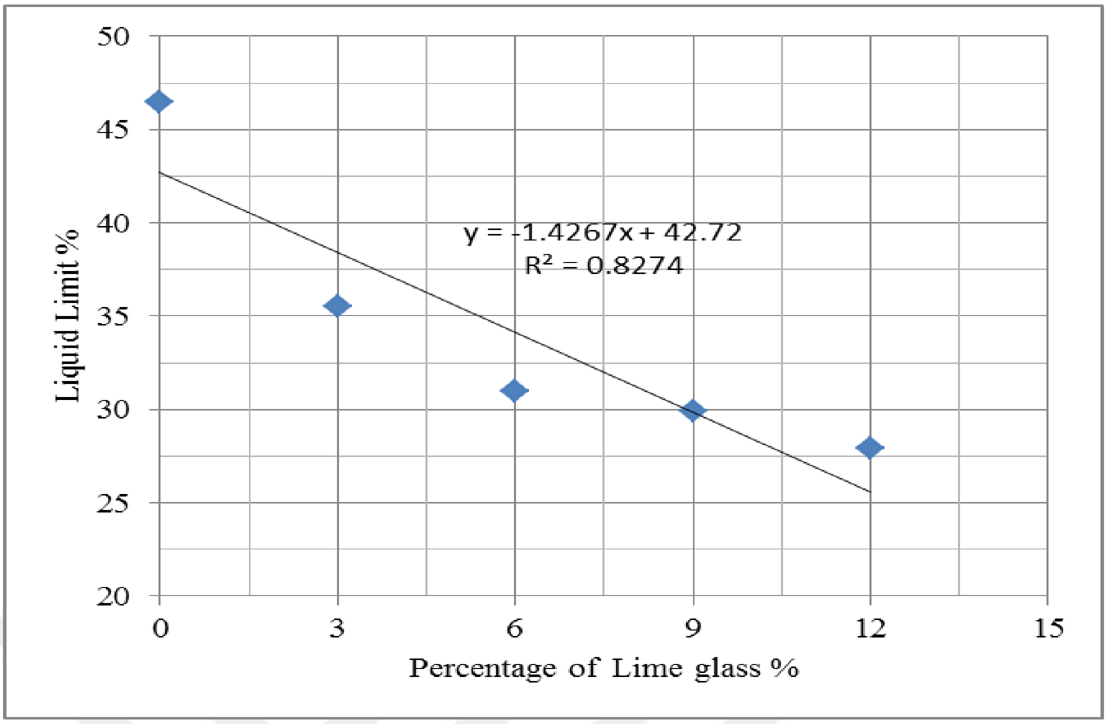

Figure 5.5 Relationship between liquid limit of clay soil with percentage of lime glass powder

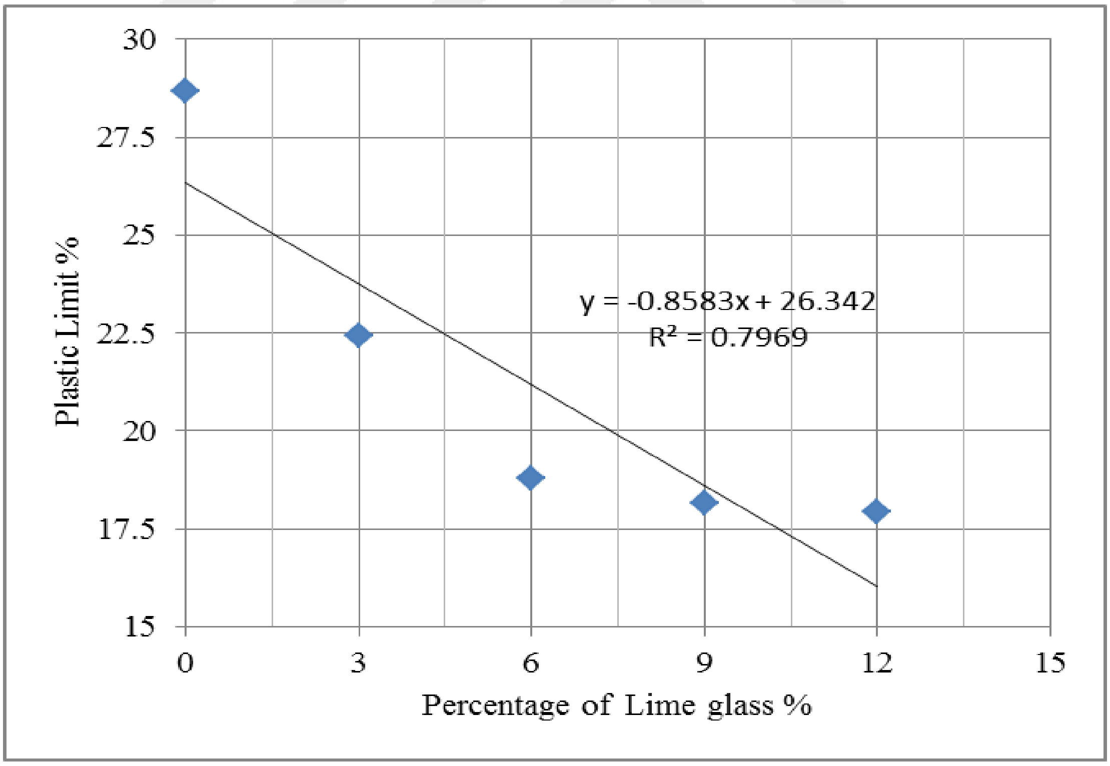

Figure 5.6 Relationship between plastic limit of clay soil with percentage of lime glass powder

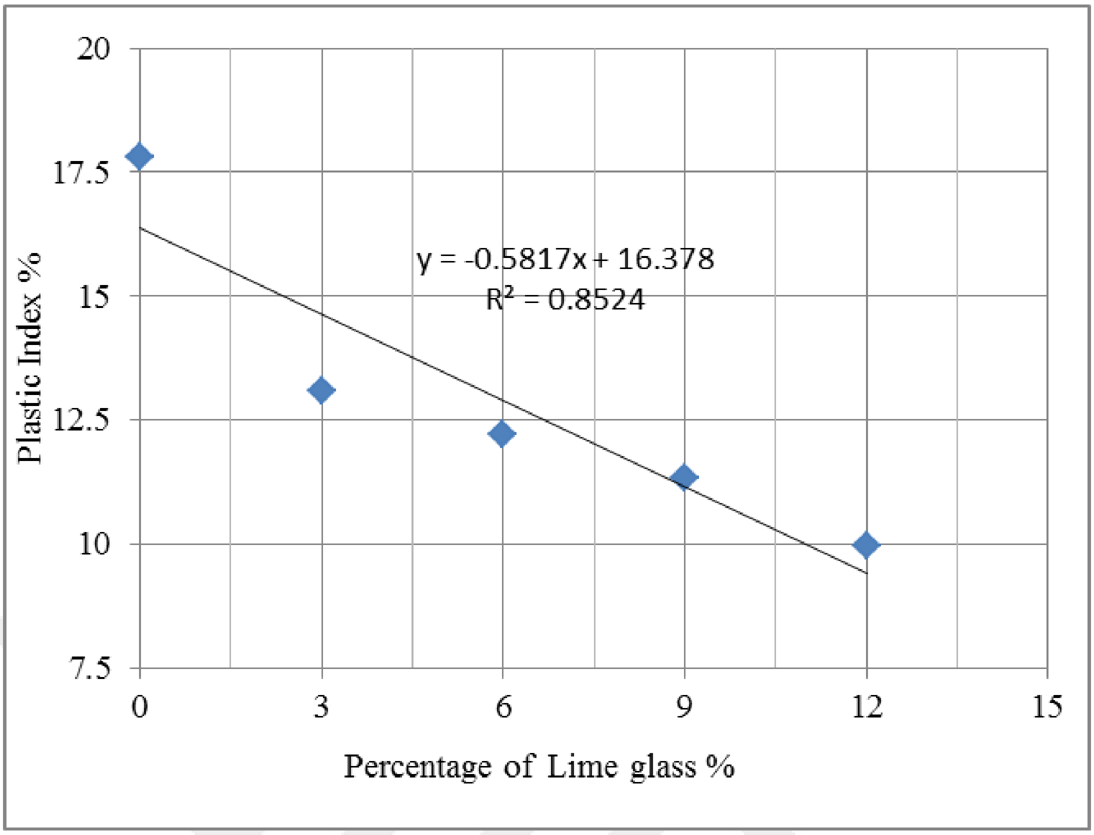

Figure 5.7 Relationship between plastic index of clay soil with percentage of Lime glass powder

5.4 California Bearing Ratio (CBR) Test

The California bearing ratio test was carried out accordance with AASHTO T 193 and T180. After 4-days curing time the following results were found:

Test results in the Figures 5.8, 5.9 and 5.10 show that the relationship between resistance load and penetration for the CBR test for each (10, 30 and 65) blows. These results show that the clay soil sample resistance load increased with the addition of soda lime glass powder .

Test results in Figure 5.11 show the relationship between CBR values and dry density. The dry density increased with increases in addition of soda lime glass powder to clay, and increase in the values of the dry density lead to increased CBR values.

Test results in the Table 5.7 and Figure 5.12 show that the CBR values increased due to increases in percentage of soda lime glass powder mixed with clay soil . The largest percentage increases of CBR value was 140 % when clay soil was mixed with 12 % soda lime glass powder.

According to general specifications for roads and bridges of Iraq (S.O.R.B), minimum CBR value for constructing the base of road muste be not less than 4% . From the analysis of tests results, it was found that the untreated clay soil value was 2.5% , so this value is not acceptable in order to construct the base of road for this it is need to improvment. From the results shown above, it was found that mixing waste soda lime glass powder to clay soil lead to a CBR value 4%. From these results conclude that soda lime glass has strong ability to improve of clay soil . The glass powder can be considered a pozzolanic-cementitious material (Matos and Sousa, 2012), for this may be it was affected positive in the CBR property.

Table 5.7 Percentage changes of CBR test

NO.	Additive %	CBR Value %	Change in CBR Value %
1	0	2.5	—
2	3	3.1	+ 24 %
3	6	4	+ 60 %
4	9	5.55	+ 122 %
5	12	6	+ 140 %

+: Increase; -: Decrease

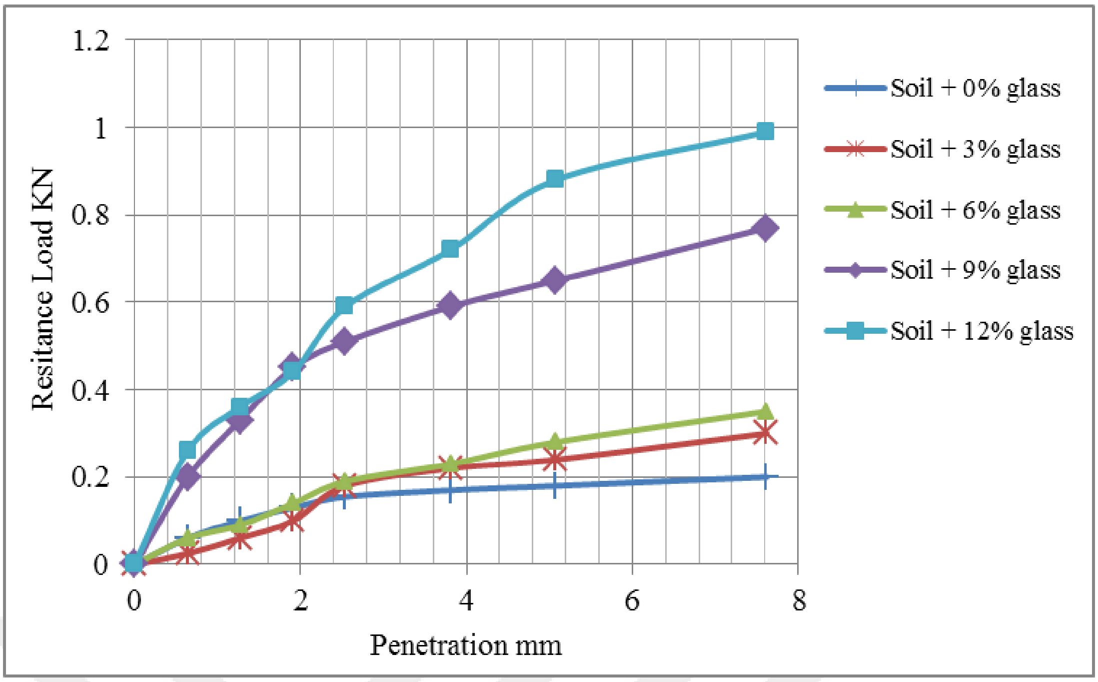

Figure 5.8 Relationship between resistance load and penetration in the CBR test for 10 Blows

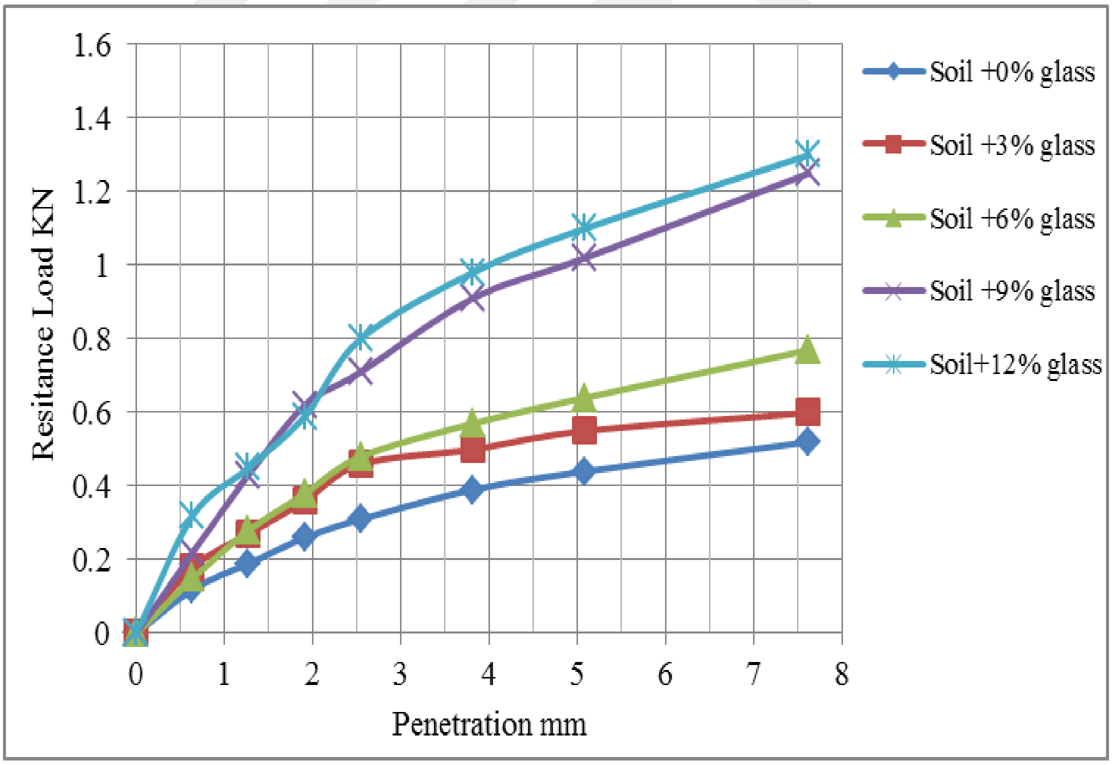

Figure 5.9 Relationship between resistance load and penetration in the CBR test for 30 Blows

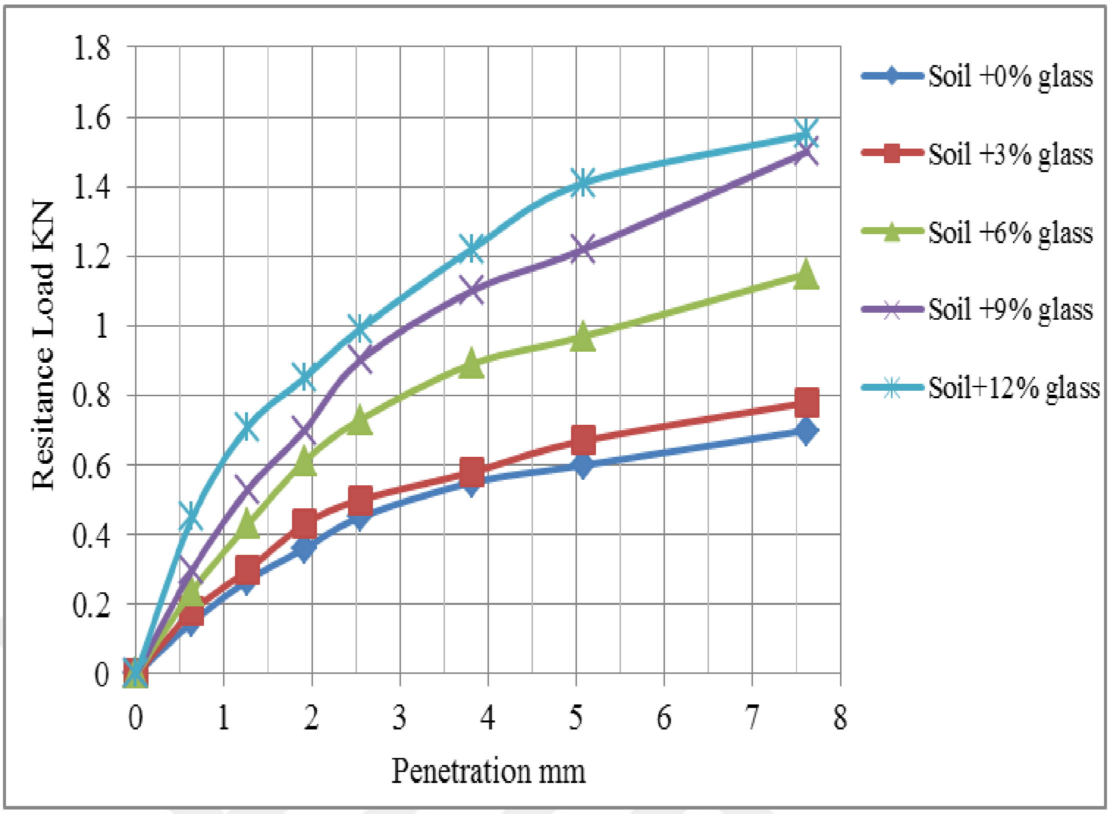

Figure 5.10 Relationship between resistance load and penetration in the CBR test for 65 blows

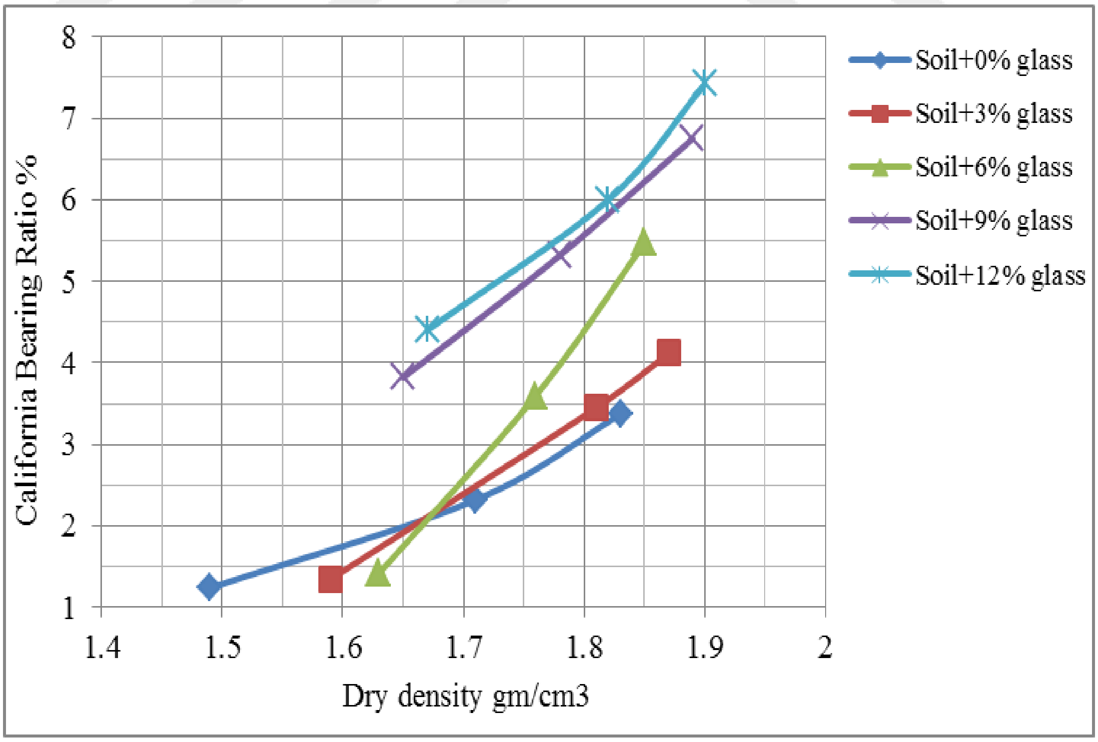

Figure 5.11 Relationship between CBR values and dry density

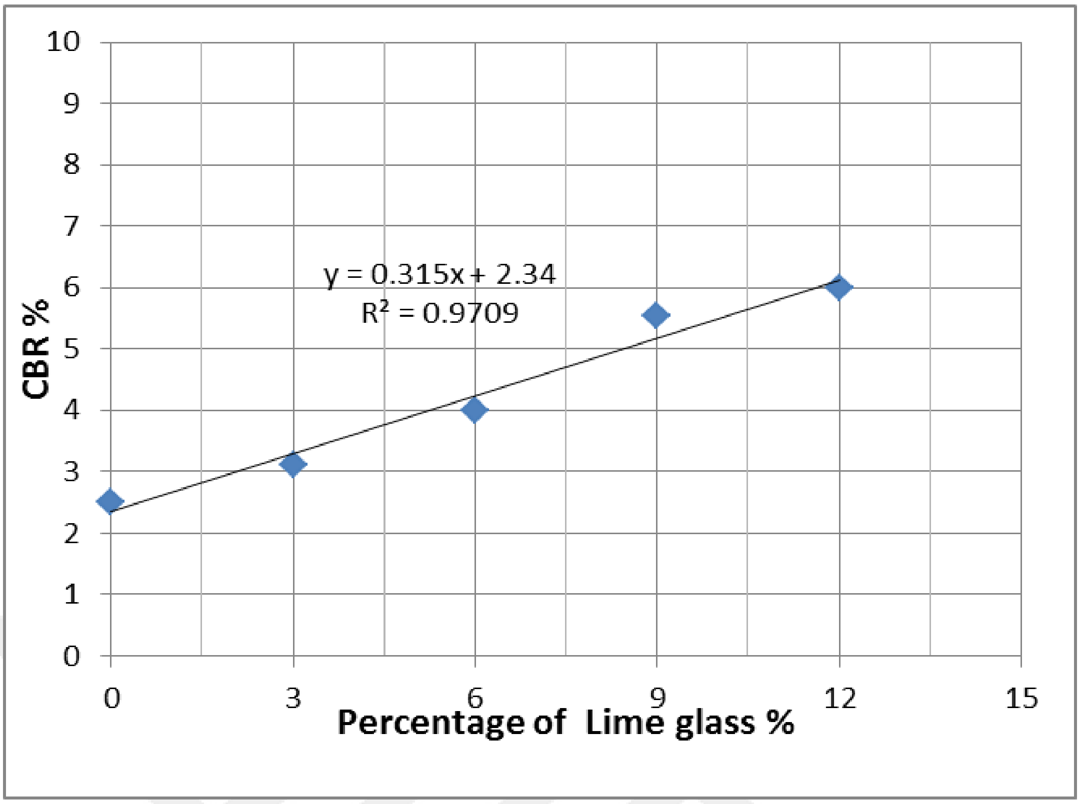

Figure 5.12 Relationship between CBR values of cay soil and percentage of lime glass powder

5.5 Swelling Test

Test results in Figure 5.13 and 5.14, and Table 5.8 show that the values of swelling decreased due to increases in the addition of soda lime glass powder to clay soil . The largest percentage decrease of liquid limit was 70 % when the clay soil was mixed with 12% soda lime glass powder .

From the analysis of tests results, it was found that the mxing of soda lime glass powder with clay soil lead to improvement of the required swelling engineering properties of clay soil, this can be explain by occurrence of chemical reactions between lime glass powder and clay soil mineral. The reason behind this result is the non–cohesive property of soda lime glass powder (Nuruzzaman and Akhtar Hossain, 2014) .

Table 5.8 Percentage changes of swelling test

NO.	Additive %	Swelling Value %	Change inSwelling %
1	0	5.5	—
2	3	4.5	- 18.18 %
3	6	3.1	- 43.63 %
4	9	2	- 63.63 %
5	12	1.65	- 70 %

+: Increase; -: Decrease

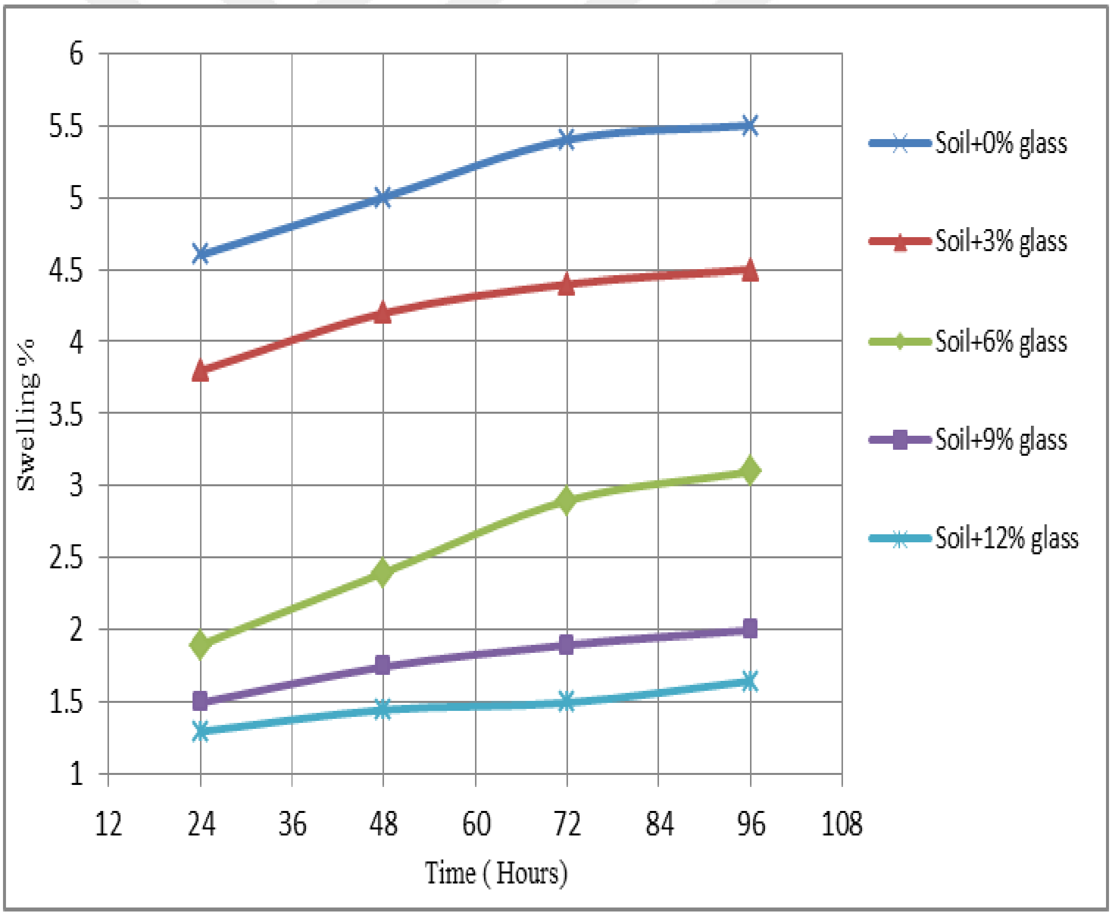

Figure 5.13 Relationship between swelling of clay soil with time

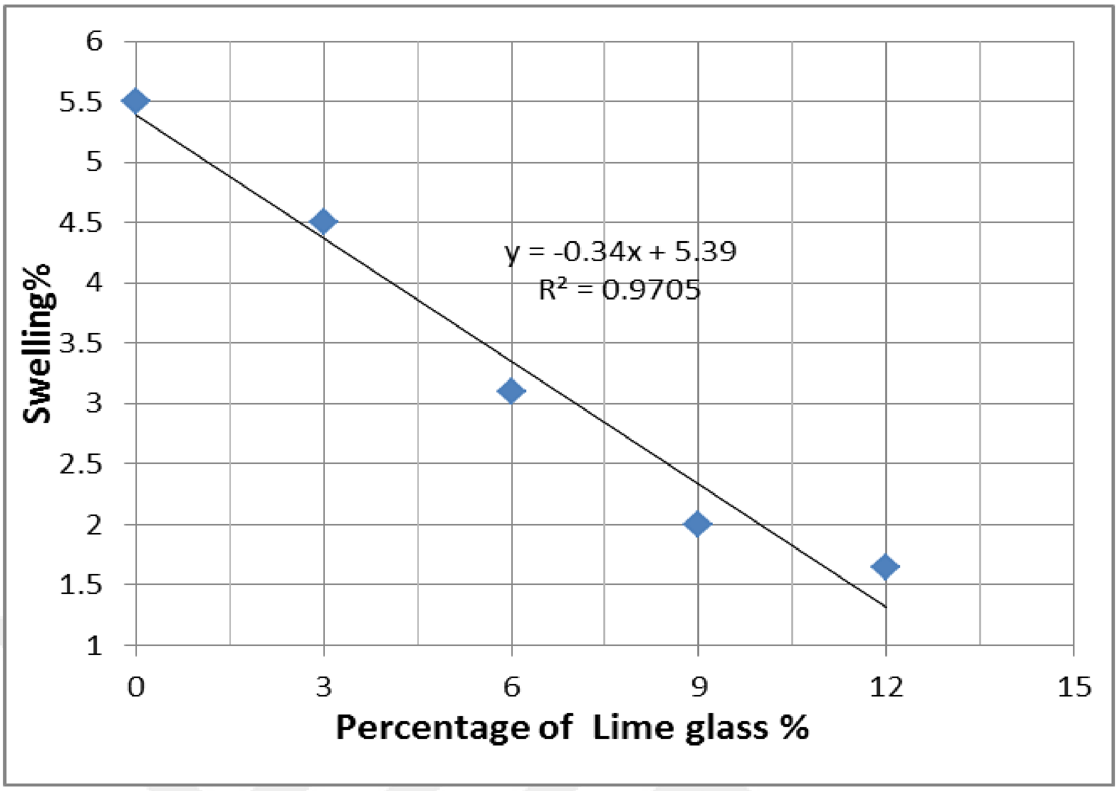

Figure 5.14 Relationship between swelling of clay soil with percentage of lime glass powder

5.6 Unconfined Compressive Strength Test

The unconfined compressive strength test was carried out in accordance with ASTM D2166. Three different curing times was used for the mechanical UCS tests. All samples were cured in the air at 3 and 7 days also 28 days curing was applied for the 6% addition.

Test resulls in Table 5.9 and Figures 5.1, 5.16 and 5.17 show that the unconfined compressive strength of clay in general increased with addition of soda lime glass powder at curing times of 3, 7 and 28 days .

For 3- days curing time, the values of UCS increased at 3%, 6% and 9% compared with the untreated clay soil . The largest percentage increases of UCS value was 116.221% when 6% soda lime glass to was mixed with clay soil, but in the 12% addition UCS started to decrease by 1.625% . This decrase may be due to the decrease in adhesive strength between the surface of the waste glass and clay soil (Park et al., 2004) . For curing time of 7 days, the values of UCS increased at all percentages of soda lime glass . The largest percentage increases of UCS value was 142.713% when clay soil was mixed with 6% soda lime glass.

The test results also showed that curing time has a positive effect in compressive strength. Through a comparison between the curing time and UCS values at 6% , it was found that this values increases 518.91 Kpa at 3 days 582.49 Kpa at 7 days and 722.89 Kpa at 28 days.

Table 5.9 Percentage changes of unconfined compressivestrength test

NO.	Additive %	UCS at 3 days (Kpa)	Change in UCS %	UCS at 7 days (Kpa)	Change in UCS %
1	0	239.99	-----	239.99	-----
2	3	362.57	+ 51.064	419.6	+ 74.84
3	6	518.91	+ 116.221	582.49	+ 142.713
4	9	410.48	+ 71.0404	500.31	+ 108.471
5	12	236.09	- 1.625	295.8	+ 23.255

+: Increase; -: Decrease

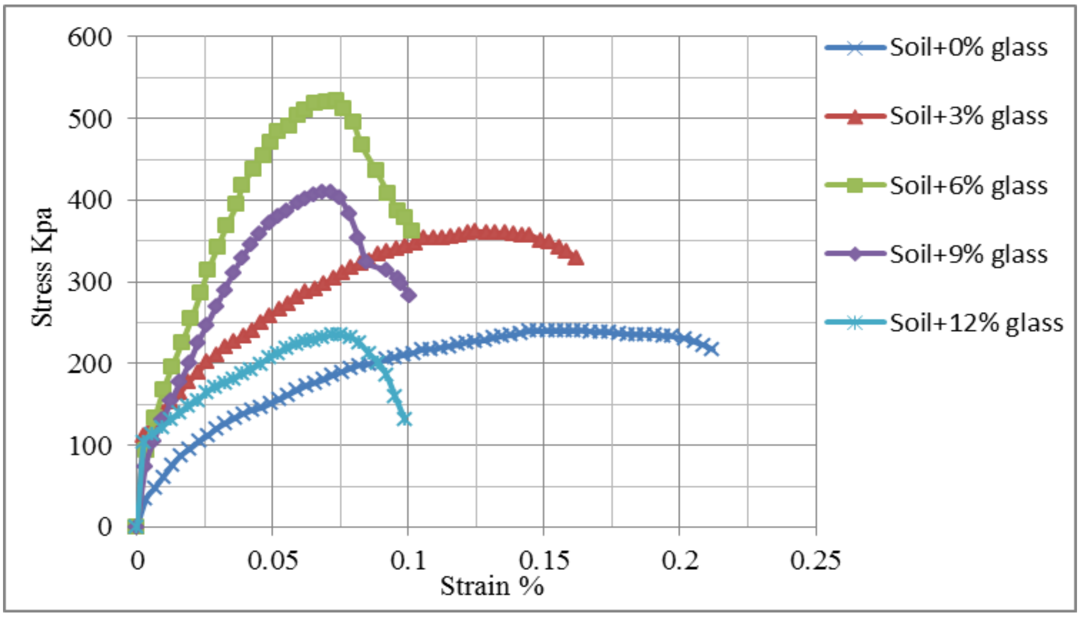

Figure 5.15 Relationship between stress and strain in the unconfined compressive test at 3 days curing

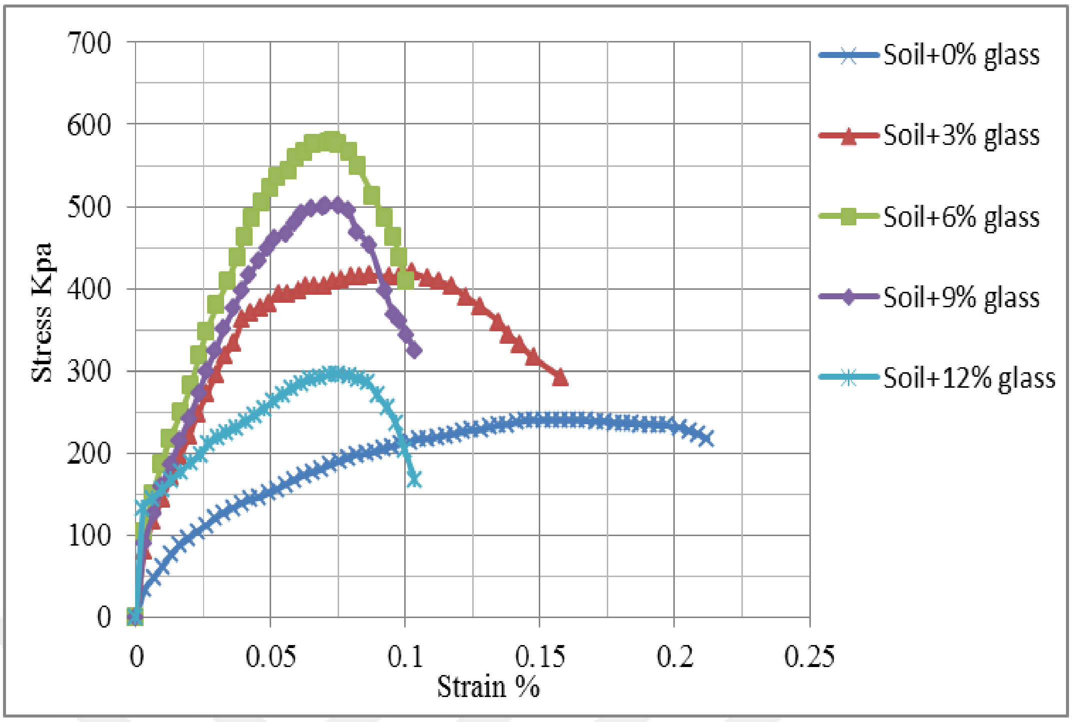

Figure 5.16 Relationship between stress and strain in the unconfined compressive Test at 7 days curing

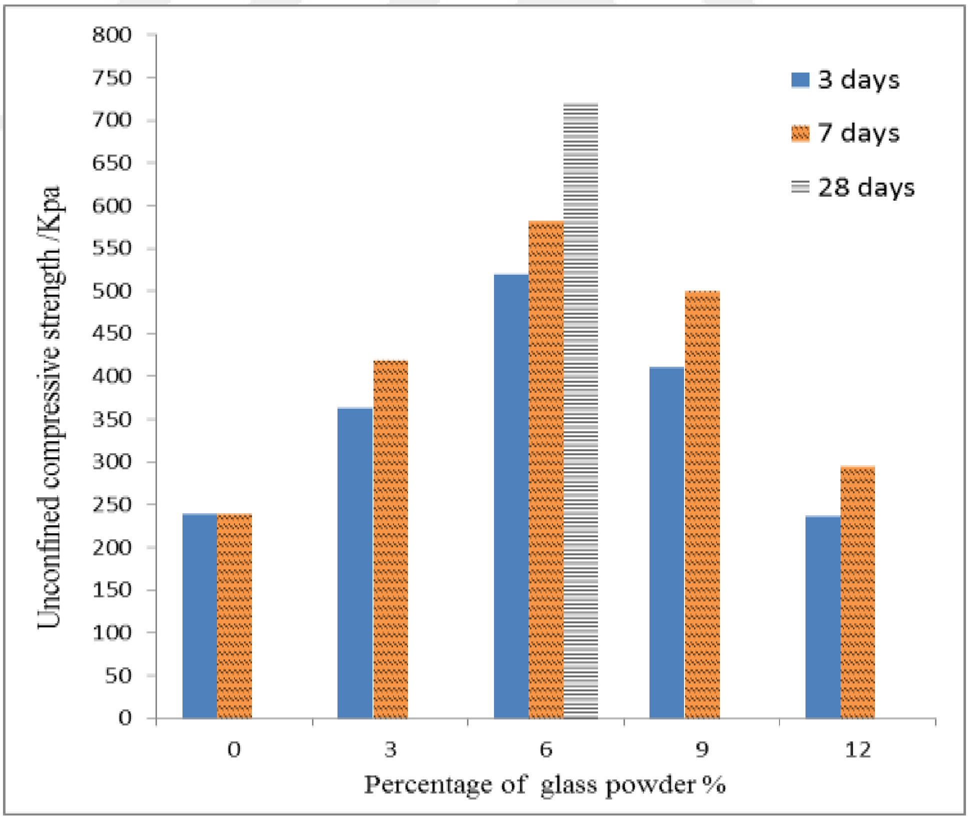

Figure 5.17 Effect of curing time on unconfined compressive strength of clay Soil

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this research, substantial and required results have been found by mixing 3%, 6%, 9%, and 12% waste soda lime glass powder with clay soil. According to test results and subsequent calculations it can be concluded:

1- Addition of soda glass powder to clay soil has an ability to improve maximum dry density of clay soil. This study illustrated an increase in the MDD value from 1.82 gm./cm^3 for the untreated clay soil sample to 1.92 gm./cm^3 for the sample containing 12% powdered soda lime glass by mass of the soil.

2- From the results, it has been found that values of optimum moisture content decreases with the addition of soda lime glass powder. This indicate an improvement of OMC of soil. This study showned a decrease in value of OMC from 15.25% for the untreated clay soil sample to 11.95% for the sample containing 12% soda lime glass powder by mass of the soil.

3- For untreated clay soil sample, the liquid limit was 46.5%, plastic limit 28.68%, and plasticity index 17.82%. As for the soil stabilization mixture of 3%, 6%, 9% and 12%, expermintal results showed that the value of liquid limit (LL), plastic limit (PL), and plasticity index (PI) decreased with increasing percentage of soda lime glass powder.

4- Addition of soda glass powder to clay soil has a great ability to improve California bearing ratio of clay soil. This study showed an increase in the CBR value from 2.5% for the untreated clay soil sample to 6% for the sample containing 12% powdered soda lime glass by mass of the soil.

5- The results show that adding soda glass powder to clay soil can be use efficiently to reduce the swell potential of soil. This study found a decrease in value swelling from 5.5% for the untreated clay soil sample to 1.65% for the sample containing 12% soda lime glass powder by mass of the soil.

6- The results show that in general, adding soda glass powder to clay soil causes, the value of unconfined compressive strength the clay soil at 3-days and 7-days curing time increase .

6.2 Recommendation

The following recommendations can be made for future research:

1- Further research is recommended in order to determine the accuracy of the effect of the soda lime glass powder on clay soil characteristics and the optimal amount of this additive to achieve clay soil stability.

2- The soil sample can be selected from other types and other places to find out about the best soil behavior with soda lime glass powder.

3- In future research it is recommended to use other particle sizes and curing time of soda lime glass powder in order to know the effectiveness of particle sizes and curing time on soil stabilization.

4- The cost of soda lime glass powder stabilization of soil can be estimated and compared with other stabilizing materials in order to know the extent of this materal economic viability.

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