INFLUENCE OF STYRENE BUTADIENE RUBBER ON ENGINEERING PROPERTIES OF SOILS

YAHYA KADHIM HUSSEIN

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INFLUENCE OF STYRENE BUTADIENE RUBBER ON ENGINEERING PROPERTIES OF SOILS

By

YAHYA KADHIM HUSSEIN

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Yahya Kadhim Hussein

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LIST OF ABBREVIATION

Abbreviation	Description
ADVPC	Advanced Pressure/ Volume Controller
Al	Aluminum
ANOVA	Analysis of Variance
ASHTO	American Association Of State Highways and Transportation Officials
ASTM	American Standard Testing Methods
BS	British Standard
BCS	Black Cotton Soil
C	Carbone Ion
C1	1 day curing time
C28	28 days curing time
Ca	Calcium
CBR	California Bearing Ratio
CCD	Central Composite Design
Cc	Coefficient of Gradation
CH	High Plasticity Clay Soil
CL	Low Plasticity Clay Soil
Cl	Chloride
CM	Silty Clay Soil
CU	Consolidation Un-drained
Cu	Coefficient of Uniformity
DOE	Design of Experiment

DST	Direct Shear Test
FBI81	Liquid Chemical (Trade Name)
Fe	Iron
FTIR	Fourier Transformed Infrared
GC	Clayey Gravel Soil
GM	Silty Gravel Soil
GP	Poorly Graded Gravel Soil
G_s	Specific gravity
GW	Well Graded Gravel Soil
H	Hydrogen Ion
K	Potassium
kPa	Kilo Pascal
LL	Liquid Limit
MDD	Maximum Dry Density
Mg	Magnesium
MH	High Plasticity Silty Soil
ML	Low Plasticity Silty Soil
MS	Sandy Silt Soil
N	Nitrogen
Na	Sodium
NBT	Next Base Technology
O	Oxygen Ion
OCR	Over Consolidation Ratio
OH	High Plasticity Organic Soil

OL	Low Plasticity Organic Soil
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
PVA	Polyvinyl Alcohol
SBR	Styrene Butadiene Rubber
SC	Clayey Sand Soil
SF	Silica Fume
Si	Silicon Ion
SiO_2	Silica
SM	Silty sand Soil
SP	Poorly Graded Sand Soil
SS	Sodium Silicate
SS299	Liquid Chemical (Trade name)
SW	Well Graded Sand Soil
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
UU	Un-consolidation Un-drained
wc	Water Content
#	Opening Sieve Size

LIST OF SYMBOLS

Symbol	Description	Unit
a_v	Compressibility coefficients	-
C	Cohesive Strength	kN/m^2
C_c	Compression Index	-
C_r	Swelling Index	-
C_v	Coefficient of Consolidation	m^2/yr
e	Void Ratio	%
k	Permeability Coefficient	m/s
M_s	Mass of Solid	g
M_v	Coefficient of Volume Compressibility	m^2/N
n	Porosity	%
P_c	Apparent Pre-Consolidation pressure	kN/m^2
P_o	Existing Effective Pressure	kN/m^2
pH	Acidic indicator	-
q	Deviator Stress	kN/m^2
q_u	Compressive Strength	kN/m^2
t	Time	s
T_v	Time factor	-
V	Total volume	cm^3
V_m	Volume of mold	cm^3
W_d	Dry soil weight	g
ρ_d	Dry density	g/cm^3

$\rho_{dmax.}$	Maximum dry density	g/cm^3
$\rho_{dmin.}$	Minimum dry density	g/cm^3
ρ_t	Total density	g/cm^3
σ	Normal stress	kN/m^2
τ	Shear strength	kN/m^2
Ø°	Internal friction angle	degree

PENGARUH STIRENA BUTADIENA GETAH ON KEJURUTERAAN HARTA TANAH

ABSTRAK

penstabilan tanah adalah penting untuk penambahbaikan sifat tanah yang tidak diingini. penggunaan teknik bahan kimia tambahan untuk menstabilkan tanah Malaysia dengan tekstur yang berbeza untuk membuat mereka lebih sesuai untuk tujuan pembinaan telah disiasat dalam kajian ini dengan menggunakan tiga sampel tanah, iaitu, kurang digredkan tanah berpasir (SP), tanah pasir berkelodak (SM), dan keplastikan tinggi berkelodak tanah (MH). Jenis-jenis tanah yang digunakan telah disifatkan dan dikelaskan mengikut USCS menggunakan taburan saiz, keplastikan, dan pemadatan ujian zarah. Cecair kimia penstabil stirena-butadiena getah (SBR), yang dihasilkan di Malaysia NBT II, telah bercampur dengan tanah di pelbagai peratusan bergantung kepada saiz bijian tanah. 6%, 8%, 10%, dan 12% telah digunakan untuk SP, 2.5%, 5%, 7.5%, 10%, dan 12.5% untuk SM, dan 1%, 2.5%, 5%, 7.5%, 10% , dan 12.5% bagi MH. Di samping itu, menyembuhkan masa 1, 7, 14, dan 28 hari telah digunakan untuk menilai kesan tempoh pengawetan ke atas sifat tanah. Ujian kekuatan ricih, seperti ricih langsung, kekuatan mampatan tak terkurung (UCS), tiga paksi, dan nisbah galas California (CBR) ujian telah dijalankan untuk menganggarkan sifat kekuatan tanah. Penyatuan dan kebolehtelapan ujian ini juga adalah untuk mengukur kebolehmampatan dan kebolehtelapan tanah. Darjah suhu kesan ke atas kekuatan tanah telah disiasat di tanah SP telah digunakan 30, 50, dan 100^{o}C. Sebaliknya telah menggunakan teknik semburan untuk mengkaji kesan kaedah semburan pada ketumpatan dan kekuatan mampatan tanah. Keputusan menunjukkan penurunan dalam indeks keplastikan SM dan MH, manakala tiada keplastikan dikesan di SP. Parameter kekuatan ricih (c, Ø^{o}) dipengaruhi dengan penambahan penstabil perpaduan meningkat pada 68.2%, 120.5%, dan 8600% untuk MH, SM, dan SP, masing-masing. Sudut geseran dalaman menurun sebanyak 29.5% dan 201% dalam MH dan SP, masing-masing, dan peningkatan sebanyak 19.6% dalam SM. Pekali kebolehtelapan menurun masing-masing kepada 60.2% dan 1590% dalam SM dan SP, dan meningkat kepada 384,1% dalam MH. The UCS MH, SM, dan SP meningkat sebanyak 154.7%, 12.6%, dan 5596%, masing-masing, selepas 28 hari pengawetan. The CBR MH, SM, dan SP meningkat sebanyak 120%, 76.9%, dan 678% masing-masing, apabila direndam. Sampel direndam untuk MH, SM, dan SP dipamerkan meningkat CBR sebanyak 128%, 72.7%, dan 264% masing-masing. Kebolehmampatan tanah menurun apabila jelas tekanan pra-pengukuhan meningkat sebanyak 62.5% pada MH dan 300% dalam SM. Indeks mampatan ketara menurun sebanyak 255,9% dalam MH dan 660% dalam SM. Kesan suhu ke atas SP adalah bahawa kekuatan mampatan meningkat SP dengan suhu meningkat. Selain itu, satu hari pengawetan pada 100^{o}C menyebabkan kekuatan mampatan yang sama seperti 28 hari menyembuhkan dalam 30^{o}C. Keputusan teknik semburan mempamerkan ketumpatan rendah dan penurunan dalam kekuatan mampatan, tidak seperti keputusan teknik menguli. Hasil kajian menunjukkan perubahan ketara dalam sifat-sifat geoteknik daripada tanah tertakluk kepada 28 hari untuk merawat. The SBR optimum yang diperlukan untuk penstabilan tanah telah diperhatikan 2.5%, 5%, dan 8% untuk MH, SM, dan SP, masing-masing. Kimia cecair yang digunakan sebagai penstabil dipamerkan keputusan yang baik dari segi peningkatan tanah. Keplastikan, kekuatan ricih, kebolehmampatan dan kebolehtelapan tanah bertambah baik selepas bercampur dengan SBR.

INFLUENCE OF STYRENE BUTADIENE RUBBE R ON ENGINEERING PROPERTIES OF SOILS

ABSTRACT

Soil stabilization is important to the improvement of undesirable soil properties. The use of the chemical additive technique to stabilize Malaysian soils with different textures to make them more suitable for construction purposes was investigated in this study by using three soil samples, namely, poorly graded sandy soil (SP), silty sand soil (SM), and high-plasticity silty soil (MH). The soil types used were characterized and classified according to USCS using particle size distribution, plasticity, and compaction tests. The liquid chemical stabilizer styrene-butadiene rubber (SBR), produced in Malaysia as NBT II, was mixed with the soils at various percentages depending on the grain size of the soils; 6%, 8%, 10%, and 12% were used for SP, 2.5%, 5%, 7.5%, 10%, and 12.5% for SM, and 1%, 2.5%, 5%, 7.5%, 10%, and 12.5% for MH. In addition, curing times of 1, 7, 14, and 28 days were used to evaluate the effects of curing time on the soil characteristics. Shear strength tests, such as direct shear, unconfined compressive strength (UCS), triaxial, and California bearing ratio (CBR) tests, were conducted to estimate the strength properties of the soils. Consolidation and permeability tests were also performed to measure the compressibility and permeability of the soils. Temperature degrees effect on soil strength was investigated on SP soil were used 30, 50, and 100^{o}C. On the other hand was used the spray technique to investigate the effect of spray method on density and compressive strength of soils. The results showed a decrease in the plasticity index of SM and MH, whereas no plasticity was detected in SP. The shear strength parameters (c, Ø^{o}) influenced by stabilizer addition increased the cohesion at 68.2%, 120.5%, and 8600% for MH, SM, and SP, respectively. The internal friction angle decreased

by 29.5% and 201% in MH and SP, respectively, and increased by 19.6% in SM. The permeability coefficient decreased to 60.2% and1590% in SM and SP respectively, and increased to 384.1% in MH. The UCS of MH, SM, and SP increased by 154.7%, 12.6%, and 5596%, respectively, after 28 days of curing. The CBR of MH, SM, and SP increased by 120%, 76.9%, and 678%, respectively, when unsoaked. The soaking samples for MH, SM, and SP exhibited increased CBR by 128%, 72.7%, and 264%, respectively. The compressibility of the soils decreased when the apparent pre-consolidation pressure increased by 62.5% in MH and 300% in SM. The apparent compression index decreased by 255.9% in MH and 660% in SM. The effect of temperature on SP is such that the compressive strength of SP increases with increasing temperature. Moreover, one day curing at 100^{o}C resulted in the same compressive strength as 28 days of curing in 30^{o}C. The results of spray technique exhibit low density and a decrease in compressive strength, unlike the results of the kneading technique. The results showed significant changes in the geotechnical properties of the soils subjected to 28 days of curing. The optimum SBR required for soil stabilization was observed to be 2.5%, 5%, and 8% for MH, SM, and SP, respectively. The liquid chemical used as stabilizer exhibited good results in terms of soil improvement. The plasticity, shear strength, compressibility, and permeability of the soils improved after being mixed with SBR.

CHAPTER 1

INTRODUCTION

1.1 Overview

There is a severe shortage of desirable soil due to its extensive demand for domestic and industrial applications. As a consequence, the undesirable soil must be looked for as alternative and therefore efforts should be concentrated on making it a useful entity and productive enough in the near future, given the fast depletion of desirable soil in nature. The design solution may include the expensive option of removal and replacement of the undesirable soils. The replacement soils are manufactured from boulder, crushed stone or lightweight aggregates, and therefore costs higher and include the use of limited natural resources. Another design option includes utilizing ground improvement alternative such as sand drain, stone columns, grouting and chemical stabilization. Soil stabilization is the technique of increasing the strength and durability with decreasing compressibility, permeability, shrinkage limits and swelling by using mechanical and/or chemical methods.

The chemical stabilization technique has been used since long time, wherein cement based reinforcements were used at the beginning of the 20th century to stabilize the unpaved roads (Nia and Naeini, 2009; Zhu and Liu, 2008). Soil stabilization can be divided into two broad categories; traditional stabilizers such as cement, lime, ash in different sources (fly ash, rice husk ash, leaf boom ash) and bituminous products. These types of stabilizers have been heavily researched and their stabilization mechanisms have been discussed extensively (Marto et al., 2013). Nontraditional soil stabilization additives consist of a wide range of chemical agents that are different in their composition and in the mode they react with the soil

(Tingle et al., 2007). Most traditional stabilizers are generally in powder form; therefore require special equipment for its application on site. As a result, the additional application cost due to this new equipment used and increases the market price of cement and lime cost. Moreover, these types of stabilizers have limited use and can only be used in specific types of soils (Ogunribido, 2012). This calls our attention to the development of alternative stabilizers. In this direction, several researchers have introduced the polymeric materials in the form of liquid chemicals such as epoxy resin polymer (Naeini and Ghorbanalizadah, 2010), sodium hydroxide, polyvinyl alcohol (PVA), bitumen emulsion, and aquapol resin (Ahmed, 1995) for use in soil stabilization. Unfortunately, not much work has been done in this field and the effect of using geotechnical materials and their fundamental stabilization mechanism are yet to be explored (Marto et al., 2013).

1.2 Problem statement

The field of civil engineering deals with large quantity of soil, mostly required in the construction of many earth structures such as roads. Therefore it is important to estimate the suitability of a soil with considerations of strength, settlement, permeability, bearing capacity, consistency and the density (Sridaran and Nagaraj, 2005; Olarewaju et al., 2011).

The problems associated with soil can occur during construction or also after construction. This is due to the fact that the soil is unable to achieve the required specification. Generally it is because the bearing capacity of the soil is too weak to support the superstructure above it. The existing soil at a construction site is not always suitable for supporting structures such as buildings, bridges, highways and similar other civil constructions. Therefore, the use of the soil improvement technique is very essential in order to improve the soil characteristics (Kolias et al., 2005).

Traditional stabilizers include lime, cement, and ash, either used separately or mixed together. Cost, curing time, and performance are the major criteria for evaluating the stabilizer used in soil improvement. Research has shown the harmful effect of the use of lime on soil equipment, which lead to sulfate attacks, particularly quick lime (Amu and Salami, 2010). Cement is not always adequate for soil improvement, particularly in saturated soil. By contrast, the use of ash can increase organic and water contents and decrease the strength and pH of soil. Furthermore, non-classical equipment used at worksites increases project costs (Moayed and Allahyari, 2012). Given these problems, the researchers propose the use of new stabilizers, which are easy to put into practice, needs no new equipment, promote health, made from local materials, and do not affect the environment.

Vyas et al. (2011) studied the effects of different polymers on dispersive soil, and their results indicate that the aggregate size of soil increased. Thus, the polymer used binds soil particles. Decreased LL, PL, and PI indicate that rain water softens soil to a lesser extent, thereby making it more suitable for road construction or dam lining. Rauch et al. (2002) stated the following on liquid chemical-soil reaction: "Liquid chemical stabilizers may work through a variety of mechanisms, including encapsulation of clay minerals, exchange of interlayer cations, breakdown of clay mineral with expulsion of water from the double layer, or interlayer expansion with subsequent moisture entrapment."

Andmarto et al. (2013), Liu et al. (2011), and Nwanko (2001) used organic polymer as an ecological stabilizer in soils. Wue and Fing (2006) investigated the functions of ecological engineering by improving the recoverability of ecosystems (after small-scale hazards, such as surface erosion).

The new polymer, styrene butadiene rubber (SBR), was used in this study as an eco-friendly polymer to study the ability of this stabilizer to improve soil characteristics. The polymer state, soil properties, and behavior of the polymer-stabilized soil were evaluated to determine the mechanisms of the effect of polymer content and curing time on three types of soil. The liquid polymer utilized in this study is easy to apply, non-toxic, can be handled by an unskilled labor, and requires no additional equipment. The specifications of SBR are presented in Appendix A5.

1.3 Objective of study

The main purpose of this study is to determine if SBR is suitable for the improvement of soil for engineering purposes. This evaluation was performed using three different soil types with different percentages of SBR. The more specific objectives of this study are as follows:

1. To investigate the ability of SBR to improve soil characteristics when mixed with different soil types.
2. To evaluate and compare changes in the soil characteristics at different SBR percentages.
3. To determine the effects of curing time on different soil characteristics.
4. To investigate the effects of temperature on sandy soil strength.
5. To investigate the effects of the spray technique on soil density and strength.

1.4 Scope of work

Chemical stabilization improves the quality and general properties of soil. However, the required level of improvement differs from soil to soil and from project to project. Improvement does not depend only on the type and amount of stabilizer but also on the environmental conditions of the specific site, the construction procedures, and the properties of the soil itself. Considering the conditions that affect the properties of stabilized SBR-soil mixtures, an optimum dosage of SBR should be determined. This dosage should be economical and must satisfy the minimum strength requirements.

This study aims to make the soils being studied suitable as a construction material in earthworks, such as sub-bases and paved roads. For such structures, basic soil properties, such as consistency limits, permeability, specific gravity, and sieve analysis, as well as engineering soil properties, such as strength and settlement, are the main parameters that require detailed understanding. The strength of stabilized soils can be expressed in terms of direct shear, unconfined compression strength, and CBR. Triaxial tests and can be improved using SBR. The three soil types used in this study varied in grain texture from coarse to fine. Basic and engineering soil property tests were conducted on these soils after mixing with SBR to evaluate the effect of the polymer reaction.

Strength is frequently the primary criterion to be optimized, with compressibility considered thereafter. Therefore, to optimize the geotechnical soil properties of all soils used in this study, the following parameters were investigated:

1. SBR content.

2. Curing period (1, 7, 14, and 28 days).
3. Curing temperature for sandy soil (30 °C, 50 °C, and 100 °C).

Temperature affects soil engineering performance (Aiban, 1998). George et al. (1992) observed that increasing the curing temperature of the samples beyond room temperature increased their compressive strength. This improved sandy soil involved the use of a liquid stabilizer that is sensitive to changes in temperature. Increasing the temperature beyond 50 °C directly affected the shear parameters (c and Ø°) (Aiban, 1998).

A design of experiment program used for statistical analysis (ANOVA) and a mathematical model are needed to compare the experimental results. The mathematical model can be used as a basis for analyzing the effect of SBR on the soils in geotechnical projects and numerical modeling software.

1.5 Layout of the thesis

This thesis is organized into five chapters and has three appendices. Chapter 1 provides a general introduction of the research problem, the scope of work, the research objectives, problem statement and the layout of the thesis. Chapter 2 presents background information about chemical stabilizers in general and also regarding engineering ground improvement using admixtures. It also reviews previous studies related to ground improvement using liquid chemical with a brief description of geotechnical engineering tests and further discusses the limitation in evaluating the desert soil for each test. Chapter 3 provides the research methodology adopted in this research and presents an overview of the experimental tests and specimen preparation and curing time. It also presents the procedure used in the device operation. Furthermore, the data analysis equations used in determining the results are also explained. In chapter 4 the results of the experimental test are described. The test results are discussed in terms of changes in the engineering properties of soils. This chapter deals with the different types of soils utilized in this study and compared the results with the control soil. The features of the soil mixed with a stabilizer and their characteristic properties are discussed in detail. Chapter 5 finally presents the conclusions drawn from this study and provides recommendations for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The soil is the cheapest construction material available having wide use of earth works. The designers search for high quality of soil to use. In recent years with population growth the desirable soils have become less so the need to utilize substandard soil by improving its performance is the need of the hour (Shankarar et al., 2009; Harichane et al., 2011).

2.2 Soil types and problems

In geotechnical engineering the soil is used with wide expression covering all deposits in the earth's crust (Bryan, 1988). There are many ways to classify the soil, such as, Massachusetts Institute of Technology (MIT), American Association of State Highways and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS) (Bunga et al., 2011). In civil engineering applications AASHTO is mostly used in construction of highways and road works, whereas the USCS is employed in other Geotechnical engineering works. The USCS has classified the soil into four main categories based on particle size (gravel, sand, silt and clay). Each one has unique characteristics like color, texture, structure, and mineral content. Complex soil profiles are composed of two or more of the basic soil types and the depth of the soil also varies. The soil is formed slowly due to the erosion of the rock (the parent material) into tiny pieces near the Earth's surface. Organic matter decays and mixes with inorganic material such as rock particles, minerals and water to form soil (Bryan, 1988).

There are a wide variety of soils in nature and no two sites have identical soil conditions. It is therefore necessary to evaluate the physical properties and engineering behavior of the soils (Head, 1990). Moreover, these soils are affected by many factors such as the clay content, the type of clay minerals, organic content and the water table level. Further, the natural water content affects the void ratio and the soil with high natural water content has the largest void ratio (Amu and Babajide, 2011).

Civil engineering practices require large quantities of soil, e.g. in many earth structures such as embankments it is important to estimate the suitability of the soil with considerations of strength, settlement, permeability, bearing capacity, consistency and the density (Sridaran and Nagaraj, 2005; Olarewaju et al., 2011).

In engineering construction, the problems with soil occur during construction and even after construction. This happens as the soil cannot reach the required specifications, such as when the bearing capacity of the soil is too weak to support the superstructure above it. The existing soil at a construction site cannot always be totally suitable for supporting structures such as buildings, bridges, highways, etc. Therefore, soil improvement is one of the important solutions to improve the soil characteristics (Kolias et al., 2005).

Chemical additives such as cement, lime and ash are some of the popular stabilizers used for soil improvement since long time (Zhu and Liu, 2008). The stabilization technique improves one or more of the basic and/or soil engineering properties such as density, increase in its cohesion, friction resistance, reducing compressibility and reduction in the plasticity index (Olarewaju et al., 2011). Non-traditional stabilizers have been used in the recent times as alternative stabilizers since the traditional stabilizers are either expensive or scarce (Amu et al., 2010). To evaluate the stabilizing effect on geotechnical soil properties laboratory tests were conducted on soil specimens before and after mixing them with undesirable soil.

2.3 Soil improvement

In geotechnical engineering, engineers always encounter problems where the properties of the original materials at construction sites are not adequate to reach the required specifications. These problems cover all soil types, for example the soft soils such as clay give a large settlement during construction because of the alteration of the chemical materials in the soils and the settlement due to high organic material content of the soils. This leads to problems even after the construction is complete, such as differential settlement (Amu et al., 2011).

The sandy soil can considered a poor soil in loose-unconfined state due to low bearing capacity and low shear strength with high permeability and collapsibility. Due to these problems become necessary to improve this soil by stabilization (Aiban, 1994). Sand stabilization effect of different factors such as type and amount of stabilizer, climate, the amount of clay content and type and amount of mineral composition. The temperature is an important parameter effect on strength especially in the hottest regions in the world. The difference in temperature degrees effect on the soil engineering performance (Aiban, 1998). George et al., (1992) referred to increase the curing temperature of the samples more than room temperature caused an increase in compressive strength. Improves sandy soil used liquid stabilizer sensitive to temperature change. Increase temperature degrees over than 50^{o}C directly effect on shear parameters (c and Ø°) (Aiban, 1998).

Consequently, soil improvement is a very important study in geotechnical engineering. Without this step, failures will occur which can cause loss of life, money and effort. Hence, before any construction, site investigation should be carried out to evaluate the kind of soil improvement required at the site. One such technique of soil improvement is a soil stabilization (Ozdogan, 2010).

2.4 Soil stabilization

Soil stabilization technique is utilized for improving the engineering properties of substandard soil for its use in construction material, particularly in geotechnical applications. The stabilization process includes the ability to improve the performance of a material. This improvement is accomplished by increasing its strength, durability and bearing capacity by decreasing the compressibility, permeability, shrinkage limits and swelling. The performance is expected to be at least equal to that of a good quality original material (Amu and Salami, 2010). Stabilizing operations are applied by using mechanical and/or chemical methods.

Cement is one of the primary chemical stabilization material used since the beginning of 20th century and was used to stabilize unpaved roads (Nia and Naeini, 2009). Soil stabilization can be divided into two broad categories - traditional stabilizers and non-traditional stabilizers. Traditional stabilizers such as cement, lime, ash in different sources (fly ash, rice husk ash, leaf boom ash) and bituminous products have been the focus of research over several years and their stabilization mechanisms have been well explored (Marto et al., 2013). Nontraditional soil stabilization uses additives that consist of a wide range of chemical agents which are different in their composition and in the way they react with the soil (Tingle et al., 2007). Since most traditional stabilizers are in powder form they need special equipment to apply them at the sites. The additional application cost due to use of new equipment accounts for additional cost and the increases of the market price of cement and lime. This coupled with its limited use in specific types of soils demands search for alternative stabilizers (Ogunribido, 2012). The use of polymeric materials in the form of liquid chemicals such as epoxy resin polymer (Naeini and Ghorbanalizadah, 2010), sodium hydroxide, polyvinyl alcohol (PVA), bitumen emulsion and aquapol resin (Ahmed, 1995) for soil stabilization is growing consistently. Unfortunately, few researchers have dealt with this field and the understanding of the effect on the geotechnical materials and their fundamental stabilization mechanisms are yet to be studied (Marto et al., 2013).

2.4.1 Nontraditional additives

Nia and Naeini, (2009) used the acrylic resin polymer with three clayey soils in different percentages with curing time. They found that 4% polymer gives higher unconfined compression strength than other percentages. On the other hand they found the inverse relation between the plasticity index and UCS as an increase in the plasticity index caused a decrease in UCS. The US Army engineering research and development center published this research on silty sand soil treated with six polymer emulsion with same doses of 2.75% including acrylic vinyl acetate copolymer, polyethylene-vinyl acetate copolymer, acrylic copolymer, polymeric proprietary inorganic acrylic copolymer, acrylic vinyl acetate copolymer, and acrylic polymer. The UCS and toughness tests conducted on soil specimens showed maximum strength in soil specimens treatment in case of polyethylene-vinyl acetate copolymer at 28 days curing when compared with other chemicals (Bayoumi et al., 2008).

Expansive soil that was stabilized with nontraditional stabilizer developed by Nanjing University is named water soluble polymer. About $3L/m^2$ polymer was sprayed to the soil specimen (240 *160* 40mm) and the results showed a reduction of the expansion percent by about 27.5% (Huang and Liu, 2012b). Clayey soils were also stabilized by nontraditional stabilizer to improve UCS. Waterborne polymer with different percentages (2, 3, 4 and 5%) with different curing time was used. The results showed that by adding 4% stabilizer at 8 days curing time led to an economic beneficent soil (Naeini et al., 2012).

Shubber et al., (2008) carried out the stabilization of gypseous sandy soil using two types of bitumen grades, rapid curing cutback bitumen (RC-250) and slow curing cutback bitumen (S-125). Different bitumen percentages were used (3, 5, 7 and 9%) with different moisture contents. The results showed that 3% bitumen gives a great effect at both types used in strength, stiffness, compressibility, permeability and deformation characteristics. On the other hand the S-125 cutback bitumen gives better results than the RC-250 cutback bitumen.

Naeini and Ghorbanalizadeh, (2010) and Naeini and Mahdavi (2009) studied the effect of epoxy resin polymer and poly methyl mehta acrylate (PMMA) emulsions on sand soil after mixed sand with different silt percentages. They found an increase in the compressive and shear strength for any increase in the stabilizer percentages. They also found that the compressive and shear strength increases with an increase in the curing time.

2.4.1.1 Polymer stabilizer

Polymer stabilizer can aid in dust control on roads and highways, particularly on unpaved roads, in water erosion control, and in the fixation and leaching control of waste and recycled materials. They can also be used in building construction underneath the foundation, especially in a small building less than four stories (Bell, 1996, Cai et al., 2006). While applying this technique, it is necessary to ensure that the properties of the stabilized geomaterials and their mixtures are applicable for usage in the design of foundations, embankments, road shoulders, sub grades, bases, and surface courses as well (Das, 2000). Chemical stabilization comprises the use of chemicals and emulsions as compaction aids to soil, binders and water repellents, and as a modifier to the clay behavior.

In chemistry this means that the clay minerals consist of layers with a variety of loosely associated ions on the surface of these layers and surrounded by a hydrosphere of the absorbed water molecules, which is strongly attracted to clay mineral surfaces. It is well established that a large number of clay particles can aggregate in smaller size units with high surface area. As a result, the ions of clay minerals would be highly dispersed over the surface (Shankarar et al., 2009). In addition, the presence of water ions can enhance the ionic exchange with those of clay in such an environment and enhance the hydrophilicity of clays. This action causes undesired plasticity when the quantity of water molecules and the mobility of cations and anions in clay-water system increase (Ali, 2012). To reduce the plasticity of clays, the stabilizer may act as a coat surrounded on clay particles to prevent the ion exchange between water and clay molecules. Hence, the water molecules will become free to drain out of the soil body under a small load. The type of the soil and the type and properties of the stabilizer will affect the efficiency and effectiveness of the stabilization operation. On the other hand they will also affect the associated moisture content during compaction as well as the long-term moisture content (Dhakal, 2012). Furthermore, the liquid stabilizers can be applied as a local soil stabilizer in construction site work with no specific instruments required, as shown in Figure 2.1. The degree of dilution in water, the way of applied in situ and the price with the no healthy harm are the major factors in the selection of stabilizer.

Step1 : Mixing the liquid stabilizer in mix plant

Step 2: Spray the stabilizer by danker jetting

Step 3: Compaction work

Figure 2. 1: Multi-steps of liquid chemical applied in site work

2.4.1.2 Styrene Butadiene Rubber (SBR)

The organic liquid chemical SBR, as shown in Figure 2.2, is a random copolymer derived from styrene and butadiene monomers. SBR has two classes, namely, emulsion SBR (E-SBR) and solution SBR (S-SBR) (Matzen and Straube, 1992). S-SBR has several potential applications in various industries (Adomast, 2011).

SBR has been used to increase the strength and durability of concrete mixtures (Bayoumi et al., 2008). Essa and Hassan (2008) found that the initial and final setting times of fresh concrete decreased with increasing dosage of SBR. They also used SBR as a bonded layer between old and new concrete, thereby increasing the compressive and flexural strengths of the bonded samples compared with samples with old and new concrete without a bond layer.

Shfii et al. (2011) found that SBR can improve the physical properties, performance, and durability of asphalt emulsion. They also found that the method by which polymer is added to asphalt depends on the physical properties of the polymer. Normally, the pre-blended method is used for solid polymers and the post-blended method is used for liquid polymers. By contrast, the results of Ronghui et al. (2007) showed that mixing SBR with modified asphalt can reduce or even eliminate permanent deformation caused by pressure induced by the tires of vehicles passing over the asphalt.

According to the SBR specifications published by Corrotech construction chemical (2011), SBR is a milky-white, latex polymer designed to improve the physical properties and integrity of cement, mortars, screeds, or renders, and functions as a bonding agent/sealer for concrete, plaster, and other porous substrates. SBR also improves the durability and compressive, tensile, and flexural properties of modified mixes while reducing permeability, thereby making SBR suitable for horizontal or vertical applications, both internally and externally. As presented in the data sheet in Appendix A5, SBR is inexpensive, widely available, non-toxic, and readily soluble in water.

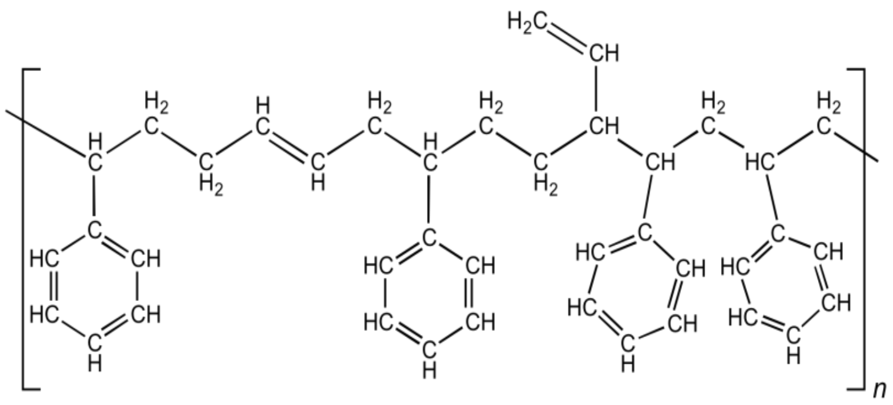

Figure 2. 2: Scheme of Styrene - Butadiene

2.4.1.3 Mix design

Due to the very recent use of the liquid chemicals as stabilizers in geotechnical engineering there are few available data in this field. The optimum percentage to be used with soil type could not be fixed despite the research communities efforts. The different percentage by weight (3%, 6%, 9 %, and 12%) from SS299 as a liquid chemical was used with lateritic soil to improve the engineering properties. The researchers found the compressive strength increase with the liquid chemical increase (Marto et al., 2013). Two types of liquid chemicals were used with black cotton soil (BCS) to improve its strength. Sodium silicate SS at (3%, 4.5%, and 6%) had a negative effect on the compressive strength by decreasing the compressive strength with liquid chemical increase. But using the RBI grade 81 with the same soil (BCS) with 2%, 4%, and 6 % denominations gave a positive effect by increasing the compressive strength with an increase in the RBI 81 percentage (Madurwar, et al., 2013). Silica fume (SF) was also used by the silty clay soil as percent by weight 5%, 10% and 15% to improve the compressive strength but only slightly effect found to increase in percentage of SF (Al-Azzawi et al., 2012). Figure 2.3 presents the above results.

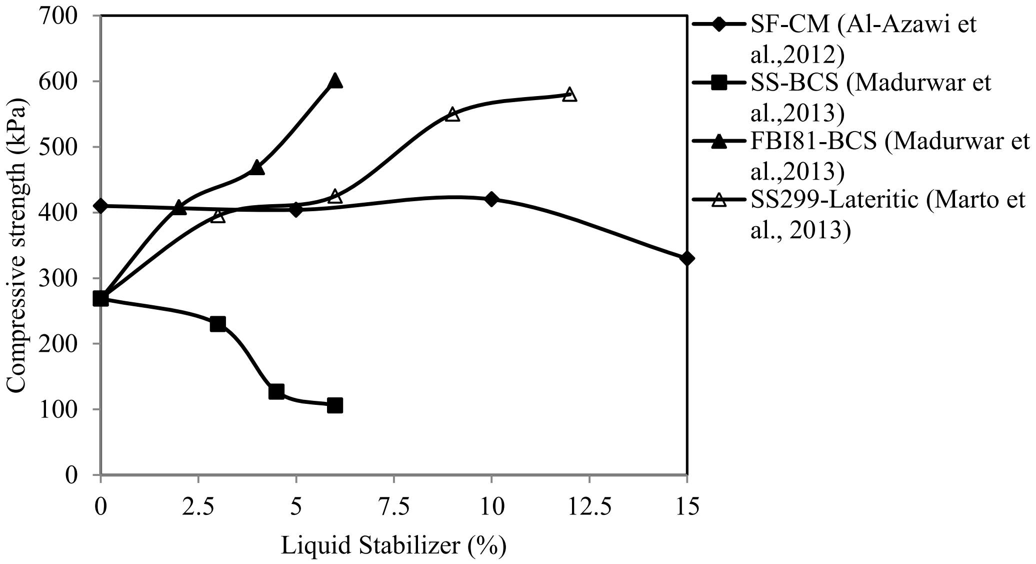

Figure 2. 3: Effect of different liquid stabilizer on compressive strength of soil

2.5 Soil testing

Laboratory tests were carried out to determine the physical and engineering soil properties. The tests conducted on a soil specimen can be divided into two basic categories: classification tests and engineering properties tests (Head, 1990). All laboratory tests with objectives are presented in Table 2.1. From test results can evaluate the ability of soil utilization in different geotechnical applications. The engineering specifications identify the limitation of soil usage in different earthwork and give advice on how to treat the substandard soil before using it.

2.5.1 Specific gravity

Particle density refers to the average mass per unit volume of the solid particles in a sample of soil, where the volume includes any sealed void contained within the solid particles (BS, 2000). It is rarely possible to use particle density as an index for soil classification. But knowledge of the particle density is essential in relation to some other soil tests, especially to determine the porosity and void ratio. The specific gravity is particularly important when compaction and consolidation properties are considered. The particle density must also be known for computation of particle size analysis (Head, 1990). Soil classification used specific gravity to estimate sesquioxide content that directly affects in tropical and semi-tropical soils. Specific gravity is also directly affected by iron-oxide content – when iron-oxide content increases specific gravity increases, as shown in Figure 2.4 (Lohnes and Demirel, 1973).

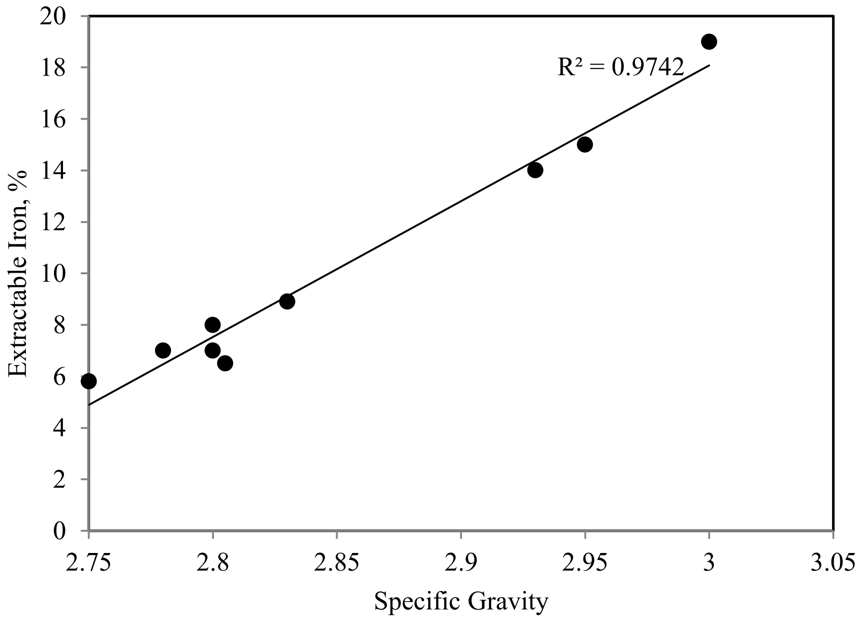

Figure 2. 4: Relation between extractable iron content and specific gravity (Lohnes and Demirel, 1973).

(Akoto and Singh, 1981) found the particle size effect on specific gravity value when using 2 mm and 5 mm particle size for lateritic soil shows that the specific gravity increase with particle size increase. The similar conclusion presented by (Fall et al., 1997). On the other hand the mineralogy composition directly affected specific gravity value as illustrated in Table 2.2.

Table 2. 1**:** Soil tests and their uses,(Karol, 2003)

Type of test	**Used of data**
Specific gravity of solids	Necessary for hydrometer analysis, void ratio, and density calculation
Mechanical analysis (Sieve) and Hydrometer	Soil classification, estimate frost susceptibility, compaction characteristics shear strength, permeability
Atterberg Limits (Liquid limit, Plastic limit, Shrinkage limit)	Soil classification, preliminary indication of behavior such as sensitivity of clays to loss of strength on remolding, and estimate of compressibility of normal loaded clay
Water content	Correlation with compressibility, compaction and strength
Permeability (Constant Head, Falling Head)	Flow problems such as flow net, and drainage
Consolidation	Settlement prediction
Shear tests (direct shear, Triaxial, and Unconfined compression)	Investigation of stability of foundation, slopes, retaining walls.
Compaction	Specification of placing of fill
Field density	Control of placing of fill
California Bearing Ratio (CBR)	Design criteria for flexible pavement
Ignition test	Loss of weight of ignition identifies organic materials

Table 2. 2: Specific gravity of some soil types. (Venkatramaiah, 2007)

Soil type	Specific gravity rang
Quartz sand	2.64 – 2.65
Silt	2.68 – 2.72
Silt with Organic	2.4- 2.5
Clay	2.44 – 2.92
Bentonite	2.34
Loess	2.65 – 2.75
Lime	2.7
Peat	1.26 – 1.8
Humus	1.37

2.5.2 Gradation

A soil consists of an assemblage of discrete particles of various shapes and sizes. The objective of the particle size analysis is to group these particles into separate sizes, and to determine their relative proportion, by mass, of each size range.

The grain size of the soil affects all other soil properties. It is inversely related to compressive strength. Increase in grain size causes decrease in its compressive strength (Lasisi and Ogunjide, 1984). On the other hand Naeini and Mahdavi (2009) and Naeini and Ghorbanalizadeh (2010) found a reduction in the shear and compressive strength owing to increase in the silt content. The results obtained were contrary to the findings presented by Lasisi and Ogunjide (1984).

The permeability of the soil is affected by grain size of soil as illustrated in Table 2.3. The permeability coefficient increased as the grain size of soil increased and vice versa (Karol, 2003). Substandard soil showed non-uniformity in grain size due to the poor distribution in sieve analysis. These types of soil can be treated by mixing them with other soil or by modifying those using chemical additives. Type of additive and quantity depends on the grain size of the soil used.

Table 2. 3: Effect of grain size of soil particles on permeability coefficient. (Brown, 2001; Karol, 2003)

Type of soil	**Grain size mm**	**Permeability (k, cm/s)**
Clean gravel	0.5 and over	10^{2} – 10
Clean sand	0.1 – 0.5	10 – 10^{-2}
Silty sand / Sandy silt	0.05 – 0.1	10^{-2} – 10^{-4}
Silt	0.5 and less	10^{-4} – 10^{-7}
Clay	0.05 and less	10^{-7} and less

2.5.3 Atterberg limits

Atterberg limits refer to the percentage of the quantity of water required when the soil has a particle size less than 0.425 mm. These limits distinguish the fine soils from coarse soil.

The consistency of clay soil cannot depend only on moisture content to define its state. Atterberg limits are more accurate which is, defined by state of clay soils and moisture relations. For example two different clays X and Y can have the same moisture content. If in clay X the moisture content is greater than liquid limit, the soil will be in liquid state (i.e. Slurry). If for clay Y the same moisture content lies between the plastic and liquid limit, it will be in a plastic state and would be of a firm consistency (Head, 1990).