Republic of Iraq

Ministry of Higher Education & Scientific Research

University of Kerbala

College of Engineering

Civil Engineering Department

Improving Dynamic Characteristics of Rubberized Subgrade Soils

A Thesis

Submitted to the College of Engineering of the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

Written By:

Safaa Mohammed Ali

Supervised By:

Assistant Professor Dr. Alaa M Shaban

Assistant Professor Dr. Raid R.A. Almuhanna

May 2023 Shawwal1444

بسم الله الرحمن الرحيم

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ

صدق الله العلي العظيم

(المجادلة: من الآية 11)

Abstract

In the pavement, the subbase, base, and subgrade layers are visible as important components of the foundation. The foundation needs to be sufficiently strong to withstand the load of the traffic. The weak subgrade soil, such as (soft clay soil, loose poorly graded sand soils, and gypseous soils,....etc.), must be improved to minimize any failures in the pavement structure. This improvement can be carried out by implementing differernt soil stabilization methods. The aim of this study is to improve the characteristics of a weak subgrade sandy soil that has a gypsum content of about 12% (moderately gypsiferous), and classified as a loose poorly graded sand soil. This soil was collected from the construction site of the International Airport Project of Kerbala City. To determine the extent to which the properties of this soil can be enhanced, the soil was stabilized using a 10% cement with two differernt types of waste granulated tire rubber (GTR) known as crumbs and chips. Three different percentages of granulated tire rubber were utilized 5%, 10%, and 20% as a replacement of the soil. A comprehnsive testing program was conducted to evaluate the characteristics of the treated soil. The testing program was divided in two phases : the first phase consists of three laboratory tests including: (1) modified Proctor test, (2) California bearing ratio test, and (3) unconfined compressive strength. All specimens of cemented sand-GTR mixtures were cured for 1, 3, and 7 days. The unconfined compressive strength and bearing resistance of the cemented-sand are significantly reduced by the addition of granulated tire rubber. The highest reduction in Unconfined Compression Strength (UCS) and Elastic Modulus (Es) was 24% and 80%, respectively, at 20% tire crumbs content comparing with cemented soil results. The addition of wasted tire chips significantly reduces the cemented sand's unconfined compressive strength and bearing

resistance. The highest reductions in UCS and Es were 20.5% and 80%, respectively, at 20% tire chip content comparing with cemented soil results.The second phase involves performing three in-situ tests including: (1) dynamic cone penetration test (DCP), (2) light weight deflectometer test (LWD), and (3) sand replacement method. All specimens of cemented sand-GTR mixtures were cured for 3 days. The results of these tests showed that the dynamic cone penetation index (DCPI), surface deflection, dynamic modulus, and field dry density were improved significantly as a consequence of use of cement. However, these soil parameters decrease with increasing GTR replacement.

The obtained results from the experimental work were also used as input parameteres in a theoretical model generated by software package known as KENPAVE to evaluate performance of the stabilized subgrade soils under different axle load values. Utilizing cement improves shear resistance, increases compressive stress, increases the allowable number of load repetitions (N_d), and decreases the damage ratio. When the percentage of GTR is increased, decreasing the allowable number of load repetitions (N_d) and increasing the damage ratio. The 10% is the best percentage of crumbs and chips for use as mechanical stabilizers based on the results of the experimental results and from comparing the results, it turns out that chips are better than crumbs. Additionally, economic analysis of the soil replacement process and soil stabilization process was conducted by determining the cost of these processes and comparing them. The stabilization process is saving provides 15% cost of the replacement process, it was concluded that using GTR-cement mixtures has a sustainable and economical potential in stabilizing the local gypseous subgrade soils.

Supervisor certificate

We certify that the thesis entitled **“Improving Dynamic Characteristics of Rubberized Subgrade Soils”** was prepared by **Safaa Mohammed Ali** under our supervision at the Department of Civil Engineering, Faculty of Engineering, University of Kerbala as a partial of fulfilment of the requirements for the Degree of Master of Science in Civil Engineering.

Signature:

Assist. Prof. Dr. Alaa M Shaban

Date: / / 2023

Signature:

Assist. Prof. Dr. Raid R. Almuhanna

Date: / / 2023

Linguistic certificate

I certify that the thesis entitled " **Improving Dynamic Characteristics of Rubberized Subgrade Soils**" which has been submitted by **Safaa Mohammed Ali** has been proofread and its language has been amended to meet the English style.

Signature:

Dr. Hamid Gittan Jewad

Date: / / 2023

Examination committee certification

We certify that we have read the thesis entitled "**Improving Dynamic Characteristics of Rubberized Subgrade Soils**" and as an examining committee, we examined the student "**Safaa Mohammed Ali**" in its content and in what is connected with it and that in our opinion it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Supervisor
Signature:
Assist.Prof.Dr. Alaa M Shaban
Date: / / 2023

Supervisor
Signature:
Assist.Prof.Dr. Raid R Almuhanna
Date: 21 / 5 / 2023

Member
Signature:
Asist.Prof.Dr. Aymen J Kadem
Date: / / 2023

Member
Signature: Dr: Ali Hameed
Prof.Dr. Ali H Naser
Date: / / 2023

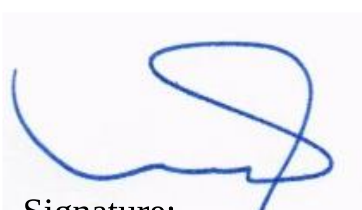
Chairman
Signature: Prof. Ali A.A Alwash
Prof.Dr. Ali Abdul Ameer Alwash
Date: / / 2023

Signature: Sadjad AH
Prof.Dr. Sadjad Amir Hemzah
Head of the Department of Civil Engineering
Date: / / 2023

Signature: L. Sh. Rasheed
Name: Prof. Dr. Laith Sh. Rasheed
Dean of the Engineering College
Date: / / 2023

Dedication

This thesis is devoted to: almighty Allah; the Holy Prophet Muhammad (Peace be upon him and his Household) . My parents, my family, my brothers, sisters, and friends for their love and their continuous support. To my supervisors for their valuable advice, support, and patience throughout this period.



Signature:

Safaa Mohammed Ali

Date: / / 2023

Acknowledgements

In the name of ALLAH (SWT), the most compassionate and merciful, I have to thank and praise our God, who gave me health and the necessary strength to carry out the present research. I am extremely grateful to my supervisors “Assistant Professor Dr. Alaa M Shaban and Assistant Prof. Dr. Raid R.A. Almuhanna” for their help, encouragement, support, and patience throughout this period. Without their enormous knowledge, always made the time and effort to respond to my queries. Appreciations also to the staff of highway materials and soil materials laboratories in the College of Engineering at the University of Kerbala.

Signature:

Safaa Mohammed Ali

Date: / / 2023

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BFC	Blast Furnace Cement
CBR	California Bearing Ratio
Cc	Coefficient of Curvature.
Cu	Coefficient of Uniformity
Dc	Degree of Compaction
DCP	Dynamic Cone Penetration Test
DCPI	Dynamic Cone Penetration Index
DCPS	Dynamic Cone Penetration Slope
DCPT	Dynamic Cone Penetration Toughness
Es	Elastic Modulus
FAO	Food and Agriculture Organization
GTR	Granulated Tire Rubber
HAC	High Alumina Cement
Ks	Subgrade Reaction Modulus
LWD	Light Weight Deflectometer
MDD	Maximum Dry Density
N_d	Allowable Number of load repetitions prevent rutting
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
Qu	Strength of UCS
SRC	Sulfate Resistance Cement
SRM	Sand Replacement Method

TDF	Tire Derived Fuel
UCS	Unconfined Compressive Strength
CSH	Calcium Silicate Hydrates
CAO	Hydrated Lime
C3S ,C2C	Calcium Silicates
RCS	Rubberized Cement Soil

List of Symbols

NSS	Natural Subgrade Soil
CSS	Cemented Subgrade Soil
C5CrNs	10% Cement + 5% Crumbs + NSS
C10CrNs	10% Cement + 10% Crumbs + NSS
C20CrNs	10% Cement + 20% Crumbs + NSS
C5ChNs	10% Cement + 5% Chips + NSS
C10ChNs	10% Cement + 10% Chips + NSS
C20ChNs	10% Cement + 20% Chips + NSS
C	The amount of adhesion
θ	The friction angle
σ	The effective stress
μ	Poison’s ratio
Ed	Dynamic modulus
$\boldsymbol{\delta d}$	Surface deflection
Dc	Degree of compatibility
PI	Plasticity Index
PL	Plastic Limit
PLT	Plate Load Test
Qty	Quantity

Chapter One : Introduction

Chapter One
Introduction

1.1 Background

Pavements are implemented in many layers including surface course, base, subbase, and subgrade. The subgrade soil represents the natural foundation layer that supports a pavement system. Properties of subgrade soils have a prominent role in controlling the pavement design in which thickness of the pavement layers are determined. Often, the subgrade has poor properties due to many causes such as the high proportion of fine particles, high gypsum content, presence of organic matter in soils .... etc.

One of the most common treatments for weak soil at any construction site could be a replacement of it with a restricted thickness of suitable filling materials. For some projects, the replacement method cannot be considered as a feasible solution because of a huge amount of work and high cost of implementation.

Sand with high gypsum content is a type of soil that has good properties in the case of dry conditions, however, it exhibits weak characteristics when it is exposed to water. Gypsum dissolves in water creating voids and cavities in the soil structure resulting in soil collapse. This problem affects the design and construction of roads in terms of cost and time which relies on suggested soil treatment methods. Previously, it was common to replace soil to carry out roads in such cases.

Researchers sought to find many ways to stabilize the soil so as to improve its properties and thereby reduce the cost of soil replacement and construction time. Different stabilization methods have been proposed to stabilize and improve characteristics of gypseous subgrade. Stabilizing methods are typically classified into four categories:

- Chemical Stabilization
- Physical Stabilization
- Mechanical Stabilization
- Biological Stabilization.

Increasing soil shear resistance, controlling its deformability, and reducing its permeability is an important aim of any soil stabilization method. **(Pancar and Akpinar, 2016).**

Chemical stabilization is an effective treatment strategy for weak soil, that is based on changing the soil-water interactions. Three mechanisms to achieve chemical stabilization **(Maaitah, 2012)**.

- The first way, remove water sensitivity by removing the water grain from the soil such as the addition of chemical compounds which have a high bonding to soil particles than water.
- The second way, soil sensitivity is decreased to water by adding positive ion salts. Positive ions are attracted to the surfaces of negative charges. and dried so it cannot be moistened again.
- The third way, the soil gets to be permeable but remains porous to water and structurally steady through treatment by large molecular-type ionic compounds.

These large particle chains bind soil particles to the electrostatic and polar forces where the aggregates are created **(Fathi et al., 2021)**.

Mechanical Stabilization improves soil characteristics by enhancing inter-particle friction or interlock between soil particles and the material used. Additionally, changing particle graduation such as adding waste materials or industrial waste or fiber with good properties to improve weak soil characteristics. Sometimes the percentage of soil is replaced by waste materials. This stabilization is related to the soil material's physical characteristics.

Biological stabilization is known as the bio-mediated process. In geotechnical engineering and bio-mediated soil, enhancement techniques have been used as progressive and current options that can be used to avoid landslide and liquefaction in soft soil that generally effects in foundation deformation Biological stabilization has substantial consequences on soil characteristics, consisting of improving shear strength and decreasing soil permeability **(Umar et al., 2016).**

Rapid soil evaluation is used by examining the dynamic cone penetration test, and light weight deflectometer test because soil information is usually limited and is often collected from within the base area, the designer or researcher may also need to evaluate the soil in other places on the site where information about the variety of soil strength with depth can be obtained, which can be critical to the development of the most effective treatment for unsuitable subgrade. Also, one may acquire information from a large number of locations very rapidly, allowing one to understand how soil conditions vary across the site and adjust effectively. One receives reliable and timely information regarding soil conditions in the field and construction time.

1.2 Research Problem

In Iraq, large areas are included with gypseous soils, specifically in the west, southwest, and northwest areas, and cover approximately 20-30% of Iraq's total area **(Schanz et al., 2018).**

Most of the soil in Kerbala is sandy soil that has gypsum content. Notably, subgrade characteristics affect road design in terms of thickness and number of layers. It is not reasonable to create roads on weak subgrade soil and the cost of soil substitution is becoming expensive compared to scientific and practical solutions. The most famous solution in pavement implementation projects for this type of soil is the process of stabilization of subgrade soil by chemical methods.

The use of Portland cement in the subgrade stabilization represents the chemical method for several reasons:

- Increase strength and stiffness characteristics of the soil
- Availability of cement industry in the city
- Cost is relatively affordable compared to costs of other chemicals.
- Easy access in local markets
- Easy handling of this article for past knowledge and common uses by technical cadres.

There are two problems associated with using cement:

- Impaction of cement production on environment
- Brittleness behavior.

To reduce the brittle behavior resulting from the use of cement and increase the resilience of the subgrade, another material must be coupled with cement such as fiber or waste tires. An enormous number of tires accumulated every year; all parts of the world including developed and developing countries are facing the problem. The disposal of such a large quantity of waste tires has a large effect on the environment. Also, Waste tires can cause serious human health problems when disposed of by burning method they cause environmental air pollution **(Hassan, 2014)**.

Utilizing such tire waste in subgrade soil mechanical stabilization to improve soil properties is an appropriate sustainable solution to such major environmental issues.

1.3 Research Aim

The aim of this research is to examine the effectiveness of using a combination of Portland cement and ground tire rubber as stabilizing agents to improve geotechnical characteristics of subgrade gypseous sandy soils in Karbala city. Portland cement acts as a hydrophilic chemical stabilizer to enhance stiffness and strength of the sand through providing a cohesive bond between the soil particles, whereas the ground tire rubber acts as a hydrophobic mechanical stabilizer to promote resilience and ductility of the cemented sand and provide a waterproofing coat around gypseous soil particles.

1.4 Research Objectives

In order to achieve the aim this research, the following objectives were proposed and carried out:

1) Collecting subgrade samples having various gypsum contents from different roadway construction projects, then choosing the subgrade soil which has a highest content of gypsiferous materials to be considered in this work.

2) Performing laboratory conventional tests to determine basic physical, mechanical and chemical properties of the selected subgrade soils.
3) Using Portland cement as a hydraulic binder to improve strength characteristics of the natural subgrade soil with a high gypsum content. The optimum cement content was specified based on previous findings stated in literature studies.
4) Assessing the effects of type, size and content of ground tire rubber through selecting two different types of the waste tire rubber including: [A] tire chips: irregular shapes of shredded waste tires with a maximum size of 19 mm, and [B] tire crumbs: powder of granulated waste tires with a maximum size of (2 to 6) mm. These two types of waste tries were utilized at three different content ratios.
5) Evaluating strength and stiffness characteristics of stabilized subgrade soils using a series of laboratory and in-situ tests including: Compaction test, California bearing ratio test – CBR, unconfined compressive test – UCS, Light weight deflectometer – LWD, Sand replacement methods – SRM, and Dynamic cone penetration test – DCP. These tests were performed on subgrade soils treated for three different curing times.
6) Analyzing tests results using theoretical approaches: use of KENPAVE package program to assess structural performance of stabilized subgrade layers subjected to a typical traffic load.

1.5 Thesis Layout

This thesis comprises of six chapters which present the review, experimental and theoretical works that have been achieved in this thesis:

Chapter One	gives an overview of the importance of the subgrade layer in pavement structures and the subgrade stabilization methods.

It also introduces the research problem and explains the research aim and objectives of this study, and describes the structure of the thesis.

Chapter Two	Provides informative descriptions and hypotheses for soil stabilization. In addition to the problems of sandy soils with high gypseous content and cement-stabilized soils. It contains the latest research in the field of soil stabilization.
Chapter Three	Illustrates the experimental work methodologies which include the definition of soil samples collected and their specific characteristics defined using: CBR, UCS, DCP, SRM, and LWD testing procedures.
Chapter Four	Displays and discusses the results of the experimental work conducted for natural and treated subgrade soils using different proportion of cement and waste ground tire rubber.
Chapter Five	Discusses the results of statistical analysis and the theoretical models developed with the use of KENPAVE package.
Chapter Six	Presents the conclusions obtained from the experimental and hypothetical works and gives suggestions and recommendations for futures studies.

Chapter Two: Literature Review

Chapter Two

Literature Review

2.1 Introduction

There are in many parts of the world in arid and semi-arid regions, collapsibility soils when exposed to large amounts of water; there are many types of problematic soils, one of which is the collapsible gypseous soil. In Iraq,gypseous soil are formed from gypsum rocks and sediment which cover large area, generally in the northwest, west, and southwest regions, and cover about 20-30% of Iraq's total area which is equal to about approximately 7.3% of the total area of gypseous soils in the world **(Schanz et al., 2018)**, summrized in **Figure 2.1.**

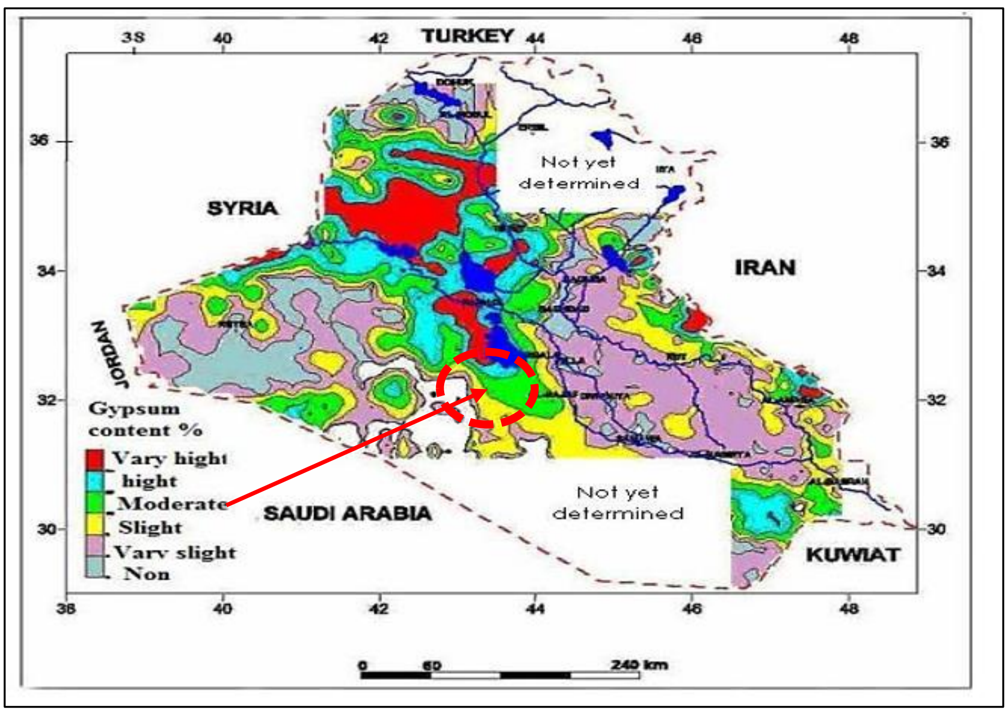


Figure 2.1: Distribution of The Gypseous Soils in Iraq ***(Al-Kaaby, 2007).***

Gypseous soils are classified into different types depending on gypsum content. Soil is divided into two main groups regarding gypsum content namely; soil with over 50% known as gypsiferous soil, and it has less than 50% which divided into five sub-groups as listed in **Table 2.1.**

*Table 2.1: Classified The Gypseous Soils(**Barazanji 1973**)*

Gypsum content, %	Classification
Non- gypsiferous	0.0 - 0.3
Very- slightly gypsiferous	0.3 – 3.0
Slightly gypsiferous	3 - 10
Moderately gypsiferous	10 - 25
Highly gypsiferous	25 - 50
Gypsiferous soil to be described by the other fraction such as sandy gypsiferous soil	> 50

Gypseous soils are regarded as stable soil in the event of drought. But when exposed to water it becomes weak soil and tends to have sudden large adjustments in size and become collapsible, especially with increased loading on it. Gypsum mineral (hydrocalcium sulfate $CaSO_4.2H_2O$.), the largest part of the proportion of gypsum soil components with the rest of the soil components, is involved in the formation of gypsum soil structure, and in the form of different crystals **(Karim et al., 2015).** When soil is exposed water will dissolve gypsum in water in the following reaction:

$$CaSO_4 \cdot 2H_2O \rightarrow Ca2^{++} + SO_42^{-} + 2H_2O \qquad \text{.................. eq2.1}$$

It adds calcium ions (Ca_2+) and sulfate ions ($SO_4$2-) but does not add or take away hydrogen ions (H+) **(Sawyer et al., 2003),** Therefore, it does not act as a liming and causes a void in the soil structure. The considerable collapse of soil demands three important conditions:

- Partly saturated structure unstable causes a large void ratio.
- A high adequate value of an applied or present stress
- A weak soil bonding

Gypsum is hydrated calcium sulphate ($CaSO_4.2H_2O$), which has a 20% solubility in water. Nevertheless, the amount of dissolve increases significantly if the water also contains salt **(Mansour et al., 2008).**

Gypseous soils are relatively soluble materials in their nature and the types of problems related to them. The failures include collapse and settlement, which can affect all construction such as pavements and other construction engineering systems. In civil engineering, when the soil has gypsum content enough to change the properties of this soil when exposed to water. When designing for any project to be implemented, the soil is examined for its impact and problems. When construction projects or pavement are carried out on this type of soil, the soil is replaced with other soil with conforming and acceptable specifications to the engineering specifications on which the project is designed.

Soil replacement is an acceptable solution to such problems but at the expense of financial cost and difficulty working. Sometimes especially large projects are replaced by layers of soil at different depths and this is unreasonable and it is not logical to like these problems in addition to the high cost of transporting materials and the cost of processing the soil to be worked on. Researchers tended to address such problems, reduce the high cost of the soil replacement process, utilize the soil on the site itself and treat it in different ways to obtain the required specifications.

Researchers (**Shaban, 2016; Ali, 2021; Amjaad, 2021; and ….etc)** used different materials with desirable specifications:

- Increasing the interconnection between the soil particles as they were exposed to water.
- These materials are available, and easily accessible
- Inexpensive when used compared to replacement prices.

This process is called soil stabilization. There are different types of soil stabilization:

- Chemical stabilization
- Mechanical
- Biological stabilization, and other methods.

Soil stabilization is defined as replacing a certain percentage of soil to obtain desired engineering specifications. The ratio is determined after laboratory and field tests are carried out in accordance with international standards.

2.2 Cement Stabilization

2.2.1 Chemical Interactions

Portland cement is considered the oldest stabilizing material used since the invention of soil stabilization technology in 1960's. Chemical interactions between used substances and soil particles themselves are the basis for stabilizing soil in this way. It is used to increase the bearing capacity or strength of the soil and serves as a moisture barrier in preventing water from penetrating into the pavement structure. It may be considered as a hydraulic binder because it can be used alone to bring about the stabilizing action required and is a primary stabilizing agent **(Sherwood, 1993).**

Numerous types of cement are available in the market; these are ordinary Portland cement (OPC), blast furnace cement (BFC), sulfate resistant cement (SRC), and high alumina cement (HAC). The selection of cement type usually depends on its availability, appropriate prices, type of a soil to be treated, and desired final strength. The cement reaction takes place after the hydration process. The process starts when cement is mixed with water and other components for the specified application resulting in hardening. Specifically, mentioned water reacts with the most reactive compounds which are dicalcium silicate and tricalcium silicate. The Calcium Silicate Hydrates (CSH) phase, which is the main contributor to strength in the mixture, is formed during the first reaction cement when the calcium silicates chemically react with the water to produce a hard paste-gel that coat other components.

Encloses the soil as glue, but it will not change the structure of the soil while the hardening (setting) of cement. **(Ash et al., 2019),** The first reaction involves tricalcium silicate:

Tricalcium Silicate + Water → Calcium Silicate Hydrate + Calcium Hydroxide (lime) + Heat

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO.2SiO_2.4H_2O + 3Ca(OH)_2 + Heat \text{ .... } eq2.2$$

In most civil engineering and construction literature, this is generally expressed in shorthand as follows:

$$2C_3S + 6H_2O \rightarrow C_3S_2H_3 + 3Ca(OH)_2 + Heat \qquad \text{....... } eq2.3$$

Treatment of the behavior of weak soil by using cement to stabilize the soil. Usually, the best solution to this challenge is to increase the shear parameters and decrease the compressibility of the foundation soil using cemented soil technique **(El-Hanafy et al., 2020).** The calcium silicates, C3S and C2S are the two major cementitious elements of Portland cement responsible for strength development **(Al-Tabbaa et al., 2005).**

2.2.2 Advantages of Using Cement

When replacing a proportion of soil with a percentage of cement gets the following:

- The cement increases the bonding between of the soil particles
- Reduces the optimum water ratio that needs for the maximum dry density
- Reduces the gypsum ratio in the sandy soil
- Increases the soil efficiency
- Reduces the impact of water on the soil.

Cementation of sandy soil leads to decrease compressibility, and permeability of the material, increases stiffness, shear strength, compressive strength, brittle behavior, and reduced Plasticity, durability, and volumetric stability, there provide differences in the resistance against distortions imposed by the load **(Mashhadban et al., 2016; Kheira et al., 2019, and El-Hanafy et al., 2020)**. When added cement, reduction in water content and alteration in the grain size distribution which is higher than that of sand separately, and The changes in compaction parameters (γdry, Wopt) **(Ates et al., 2016)**.

A complex series of chemical reactions with cement hydration is considered a complex process **(MacLaren et al., 2003)**. This process can be affected by:

- Water cement ratio
- Curing time and curing temperature
- Additives materials presence
- The surface of the mixture
- Presence of impurities.

2.2.3 Cement with Granular Soil and Previous Studies

Applying the cement stabilization process to the granular soils improves several soil characteristics like decreased volumetric change, increase strength and stiffness, and decrease cohesionless **(Afrin, 2017).** According to the Mohr-coulomb theory, the shear strength of a soil is a characteristic of its adhesion and friction angle, as seen in the following relation:

$$\tau = c + \sigma tan\theta \qquad \text{.............. } eq2.4$$

Where, C is the amount of adhesion, σ is the effective stress, and θ is the friction angle. While using cement with soil as a stabilizer will increase soil adhesion, improving from the angle of internal friction.

Most preceding research has recommended that the addition of cement to granular soil increases behavior brittleness of the soil (i.e., unfavorable effect of cement stabilization). The high brittleness of cemented-soil mixtures causes cracks in stabilized soil mass under dynamic loading conditions obtained from traffic loads. The famous type of crack in the cement-stabilized subgrade is shrinkage crack. Cement-treated materials begin to lose their moisture through evaporation immediately after they are placed if suitable curing is not exercised. The loss of moisture then will lead to the drying and subsequent improvement of shrinkage cracks. Further, the final strength of the cement-treated substances will be decreased as hydration of the cement is hampered due to a lack of sufficient moisture in the combine. **Table 2.2** summarizes the optimum the cement content inspected in many past experimental studies.

Table 2.2: Soil-Cement Stabilization as Investigated by Different Studies

Authors	Soil type	Cement Content by weight %	Findings
Zhang, 2008	clayey silt	2.5 - 12.5	▪ lower soil–cement loss volumetric changes thus good durability.
Shooshpasha, 2015	Sand	2.5 - 7.5	▪ Reduced displacement at failure. ▪ Increased strength parameters. ▪ Changed soil behavior to a noticeable, and brittle behavior.
Choobbasti, 2015	Sand	5 - 15	▪ The increase of MDD of sand was noted with the increase in the cement content
Al Aghbari, 2015	Sand	2 - 12	▪ The results showed substantial ▪ Improvements in MDD, UCS, and shear strength parameters.
Ates, 2016	Sand	5 - 20	▪ Cement increased the engineering properties. ▪ Mechanical strength of sandy soils.
Ashraf et al, 2017	Sandy salt and some clay	0 - 10	▪ Increase compressive strength ▪ Increase unconfined compressive strength.
Choobbasti et al, 2017	Sand	0 - 12	▪ Increasing stiffness, shear strength, compressive strength, and brittle behavior. ▪ Decreasing compressibility and permeability of the material
Sharafi et al., 2019	Sand	0 - 9	▪ Improving the compressive and shear strength, and ▪ Increasing the plasticity of the soil.
Solihu, 2020	SC (Silty Sands)/SM (Clayey Sands)	2 - 6	▪ Improve the strength properties of soils and durability
El-Hanafy et al., 2021	Sand	3 - 15	▪ Increasing cement content leads to an increase of cohesion, Young's modulus and friction angle.

2.3 Mechanical Stabilization(Granulated Tire Rubber Stabilizations)

In order to increase soil stability and shear strength without changing their chemical properties, a technology named mechanical stabilization has been used. In mechanical soil stabilization, the grading of soil is changed by mixing it with other types of different materials such as waste materials, fiber, and granulated tire rubber. This stabilization method is related to the soil material's physical parameters. The mechanical stabilization method is considered to enhance the soil.

A waste management system based on material recycling, energy recovery, or go to disposal. The current rate of end-life tires production worldwide is over 1 billion per year, including passenger vehicle tires and truck tires **(WBCSD, 2008).** This number is increase to develop over time with increased population and quantity of cars on roads. Annually, more than 1/2 of one billion end-of-life tires are estimated to be discarded and destined in landfills international without any treatment.

Waste tire recycling may be challenging, but it is not impossible to achieve. Many researchers have therefore turned to the use of waste materials in soil stabilization processes and other works, such as the use of rubber in backfill beside the shearing wall for some projects and other extensive uses. Tires have a mixed composition of elastomer compounds, carbon black, and steel wire, in addition to several other organic and inorganic components (**Tasalloti et al., 2021**). **Table 2.3** summarized component of tires. From the view of geotechnical engineering, tires can be recycled as granulated rubber and mixed with granular soils, making them a great source of cheap, economically acceptable, and hard construction material with excellent engineering properties. **Figure 2.3** show grain size of scrap tire according to the American Standard for Testing and Material **ASTM D6270-17.**

Table 2.3. Typical Composition of Tires ***(Grammelis et al., 2021)****.*

Composition	Passenger Cars	Trucks
Rubber	47%	45%
Carbon Black	21.5%	22%
Steel	16.5%	25%
Fiber	5.5%	0%
Zinc Oxide	1%	2%
Additives	7.5%	5%

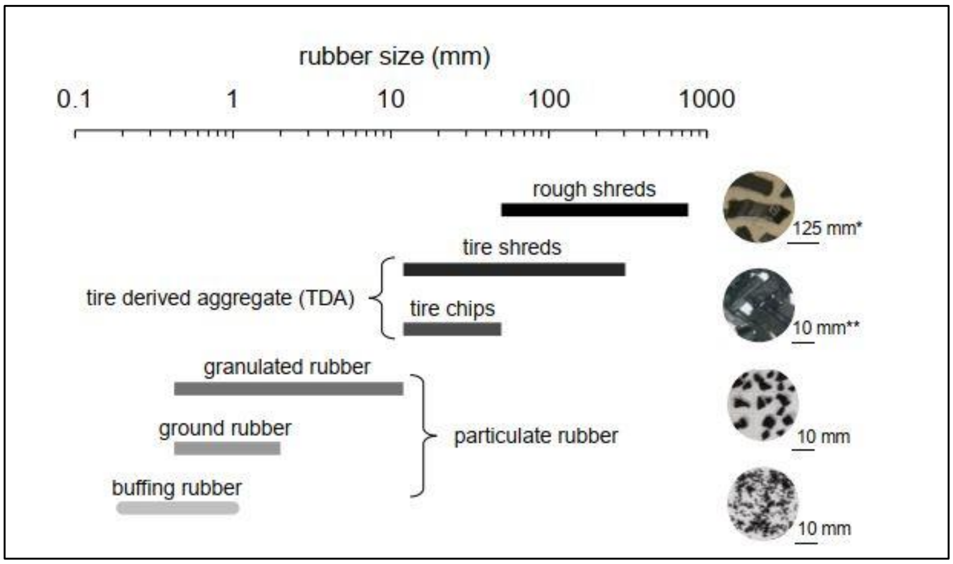


Figure 2.3:Summarized Granulated Tire Sizes

Mechanical properties and the durability of cemented soil are changing when added rubber, which could be a key perspective of development material **(Wang et al., 2021).**

Rubber plays a positive part in the support of durability of rubberized Cement Soil (RCS) **(Cokca et al., 2004).** Increased the resistance of sulfate erosion significantly, when the addition of 5% tire rubber in concrete **(Yung et al., 2013).** Because of environmental pollution created in generating tire-derived fuel (TDF); Recycling and reuse of scrap tires are always considered the preferred option **(Sheikh, 2010).**

In modification projects of soil use rubber tires to treat the desirable properties of compacted soils. Additionally, advantages of geotechnical properties include environmental sustainability, the decreased necessity of importing and exporting soil, and lower construction costs **(Tiwari et al., 2014).** Shear strength of sand was once improved as an end result to increase each friction angle and cohesion after adding tire chips to sand and a substantial discount in specific gravity and maximum dry density with a little reduction in optimum moisture content was marked by means of improved tire chip content material in sand due to the low unit weight of tire chips **(Al-Neami, 2018**). **Table 2.4** explain plastic waste fiber percent and waste tire rubber.

Table 2.4: Summary of Plastic Waste Fiber Percent and Waste Tire Rubber

Authors	**Soil Type**	**Fiber or GTR by weight%**	**Findings**
Choudhary et al., 2010	Sand	0.25 - 4	▪ Increased the CBR value. ▪ Increased strength and deformation behavior of subgrade soils substantially.
Poweth et al., 2014	Clay	0.25 - 0.75	▪ Using the waste plastic as granules in the soil solves the problem of disposing of the waste and it does not exhibit any substantial reduction in the strength of the soil.

Table 2.4: Summary of Plastic Waste Fiber Percent and Waste Tire Rubber.Continued

Mashiria et al., 2015	Sand	0 - 40	▪ Effectively address growing environmental concerns. ▪ Provide solutions to geotechnical problems associated with low soil shear strength and high dilatancy.
Anvari et al., 2017	Sand	0 - 30	▪ The internal friction angle of sand ▪ Increases and Adding granulated rubber leads to greater yielding strain. ▪ Less tangent stiffness of sand.
Peddaiah et al., 2018	Silty Sand	0.4	▪ The results explain that there is a substantial increment in maximum dry unit weight(MDD), Shear Strength Parameters, and CBR value with plastic reinforcement in soil.
Paulinus et al., 2018	Silty Clay, Poorly Graded Sand	0.75 - 7.5	▪ Reduced in the plastic index to the corresponding percentage ratio of additives. ▪ The swelling potential of treated soil reduced.
Paschal et al., 2020	Clay	0.25 – 7.5	▪ Reduction in the plastic index to the soil and potential swelling.
Amuthan et al., 2020	Sand	0 - 100	▪ The test results show that the mixture possesses higher liquefaction resistance.
Zhuang et al., 2020	Sand	30	▪ Increasing contact areas and bias towards the major principal direction of sand–rubber contacts.

2.4 Rapid Evaluations of Subgrade Soil

Most of the traditional methods for the evaluation of subgrade soil layers are laboratory methods. These methods are expensive, slow, and do not give an actual representation of field conditions, so these reasons prompted researchers and highway agencies to find quick and nondestructive fields. These are many and varied ways such as dynamic cone penetrometer device , falling weight deflectometer device, and light weight deflectometer.

The Light-Weight Deflectometer (LWD) is a portable, lightweight instrument used for determining the deflection of unbound layers, granular layers, and backfilling materials and determine their bearing capacity. LWD can determine a surface modulus (MPa) value based on the force necessary to produce a specific deflection (mm) for that soil type. It also provides a measure of deformation and compaction. Surface deflection is the most reliable and objective method for determining stiffness and, consequently, the degree of compaction of a material.

Based on the static plate load test, which calls for a loaded vehicle, the LWD offers an easy, quick, and repeatable test that accurately evaluates compaction characteristics. With the assistance of its integrated GPS interface, it also records the coordinates of each test site. Because it is lightweight and portable,can test in small locations where a standard static plate test would be impossible. Can test on a variety of material types, including treated soils, stabilized soils, unbound mixes, hydraulically bonded mixtures, and cold recycled mixtures including bitumen.

In-situ studies, the findings of conducted on intact materials have always been considerably more suggested than those on damaged samples since they are more realistic. Due to the soil structure's differences from those seen in nature, it is very impossible to create samples that are identical to undelivered ones. Additionally, a lot of samples need to be taken from the site and tested in the laboratory in order to accurately evaluate soil properties. This technique is regarded as being difficult, very time-consuming, and expensive.

It is essential to do in-situ experiments in geotechnical studies, dynamic Cone Penetrometer being one such example. Through field tests, several researchers have established recommendations for assessing the mechanical qualities of the subgrade and layers of road pavement.

The Dynamic Cone Penetrometer is one of the most effective and efficient devices to evaluate soil strength on-site. It additionally serves for recording the development of granular layers and subgrade soils in pavement sections. The DCP testing tool is used by highway agencies to find the most effective approaches for their sites, particularly where soft soils are involved. can discover how the strength of the soil changes with depth, which is important for developing an appropriate solution for subgrade soils that are not suited. could rapidly gather information from a large number of locations, allowing you to understand how the site's soil conditions fluctuate and optimize reactions.

Additionally, the CBR cannot be easily determined in the field, so several researchers conducted various correlations between CBR and DCP. The DCP used in this research, according to the **ASTM** standard **D 6951-18.**

2.5 Summary

Subgrade soil is regarded as the base for the pavement structure and other constructions, as described in the literature review. The stabilization of subgrade soil is known as a successful development for enhancing soil characteristics because weak subgrades can damage constructions. Where previous studies have shown cementation of sandy soil leads to decrease compressibility, and permeability of the material, increases stiffness, shear strength, compressive strength, brittle behavior, and reduced Plasticity, durability, and volumetric stability. In order to reduce the undesirable effects of the use of cement, rubber material has been taken in order to increase the flexibility of the material and reduce the environmental impact resulting from it being harmful to the environment and achieving sustainability. Additionally, using nondestractive test for evaluating stabilization subgrade soil by using DCP test amd LWD test. In order to generally evaluate the different soil parameters of the stabilized soil using different laboratory tests, a range of stabilization methods (such as chemical, mechanical, etc.) were applied.

Chapter Three: Experimental Work

Chapter Three
Experimental Work

3.1 Introduction

This chapter provides a brief description of the methodology of this research work, properties of a subgrade soil and its site location, and stabilized materials. As well, this chapter summarizes the laboratory tests including modified proctor test, unconfined compressive strength (UCS), california bearing ratio test (CBR). The field tests which have been simulated was also described in this chapter.

3.2 Methodology

To achieve the purpose of this research work, subgrade soil was collected from different places, and the choice soil was from an under construction project of the International Airport of Karbala City because it has high gypsum content. The gypseous subgrade soil was treated using of two types of stabilizing materials; Portland cement, and ground tire rubber (GTR) as two type (a) crumbs and (b) chips.

Laboratory testing models have been organized and tested to simulate in-situ conditions of subgrade sandy soils. As shown in **Figure 3.1** different laboratory tests have been carried out on every soil sample to define the fundamental soil properties including; sieve analysis, standard and modified Proctor tests, laboratory CBR, and Unconfined compressive strength (UCS) conducted on each percent of soil.

To recognize the extent to which the soil's sand properties are improved when replacing a percentage of the soil with cement and the extent to which they are improved when replacing another percentage of the soil with ground tire rubber. how a great deal of soil is affected through these materials, and select the most effective ratio of rubber by evaluating the effects of the ratios used (5%, 10%, and 20%).

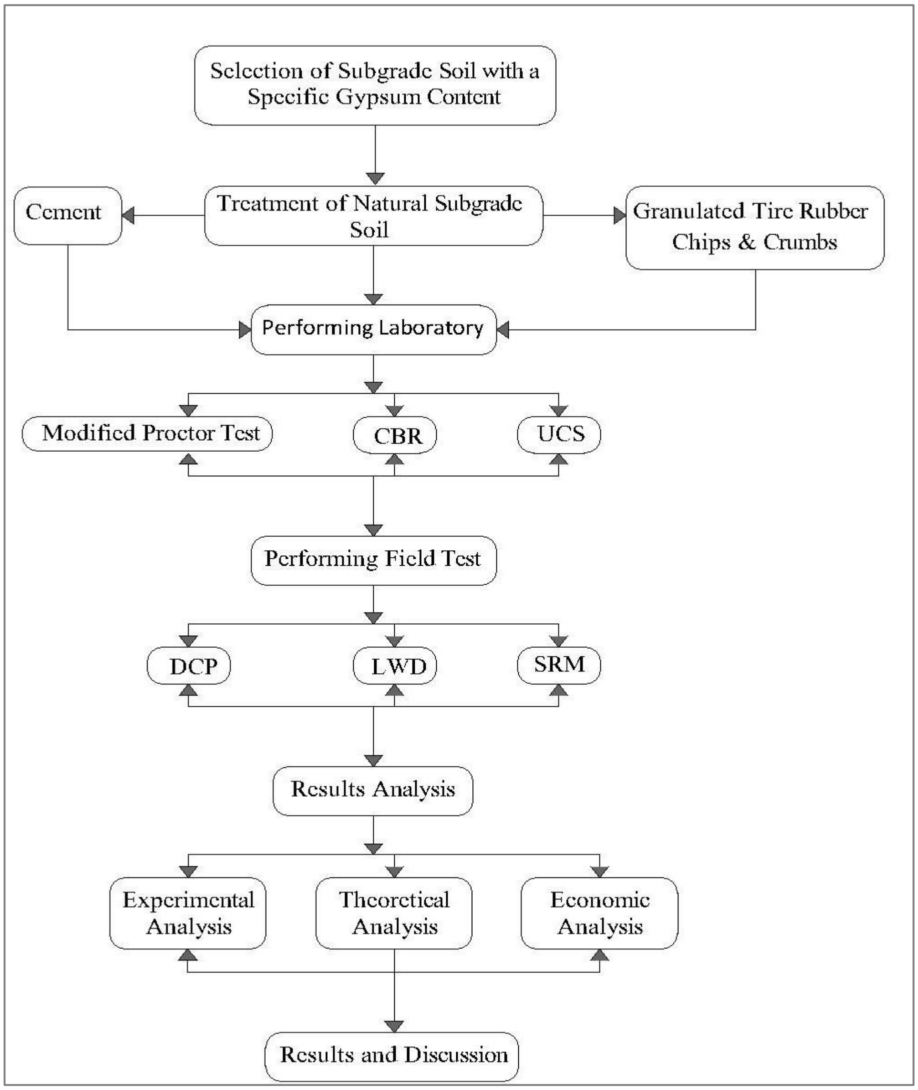


Figure (3.1): Schematic Research Methodology

3.3 Materials Properties

3.3.1 Subgrade Soils

In order to ensure the economic considerations and to sustain the local practice, evaluated subgrade soils in this work have been accrued from the airport project in Karbala city. **Figure (3.2)** shows an aerial photo of a projects site.

Figure (3.2): Aerial Photo of The Sample Site in Karbala City

Table 3.1 summarized soil collected classification and characteristics according to the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification (USC) that showed soil classified as (A-3) and as a poorly graded sand (SP). The curve for grain size distribution is explained in **Figure 3.3.** Also, the standard and modified proctor compaction test according to **ASTM D-698** and **ASTM D1557,** respectively showed that the MDD and OMC by removal of air voids as shown in **Figure 3.4**. While in **Figures 3.5** and **3.6** explained the unsoaked and soaked CBR test curves, respectively.

Table 3.1: Basic Properties of Subgrade Soil

Property	Test Results	Specification
Soil Classification	A-3	AASHTO M 145
	(SP)	AASHTO M 145
OMC %	11.72	ASTM D 1557
Max Dry Density gm/cm^3	2.0514	ASTM D 1557
Uniformity Coefficient (C_u)	3.1578	ASTM D 2487
Curvature Coefficient (C_c)	1.07	ASTM D 2487
Specific Gravity (Gs)	2.59	ASTM D 854
CBR soaked %	17	ASTM D 1883
Gravel fraction	1	ASTM D 2487
Sand fraction	95	ASTM D 2487
CBR unsoaked %	29	ASTM D 1883
Plasticity Index	NP	ASTM D 4318
Gypsum content %	11.61	BS1377-3
SO_3%	5.4	BS1377-3
pH %	6.02	BS1377-3
TSS %	8.90	BS1377-3

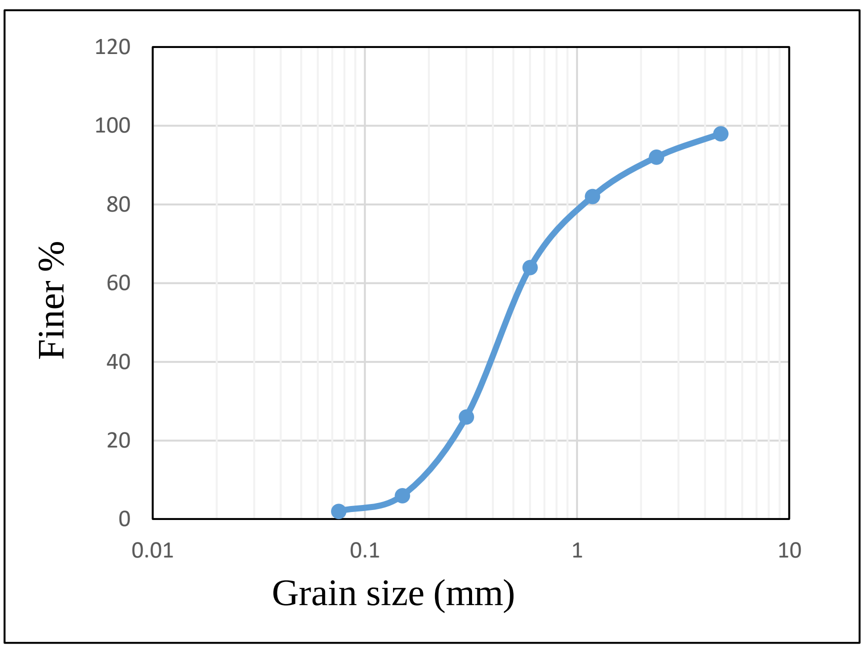


Figure (3.3): Grain-Size Distribution of NSS

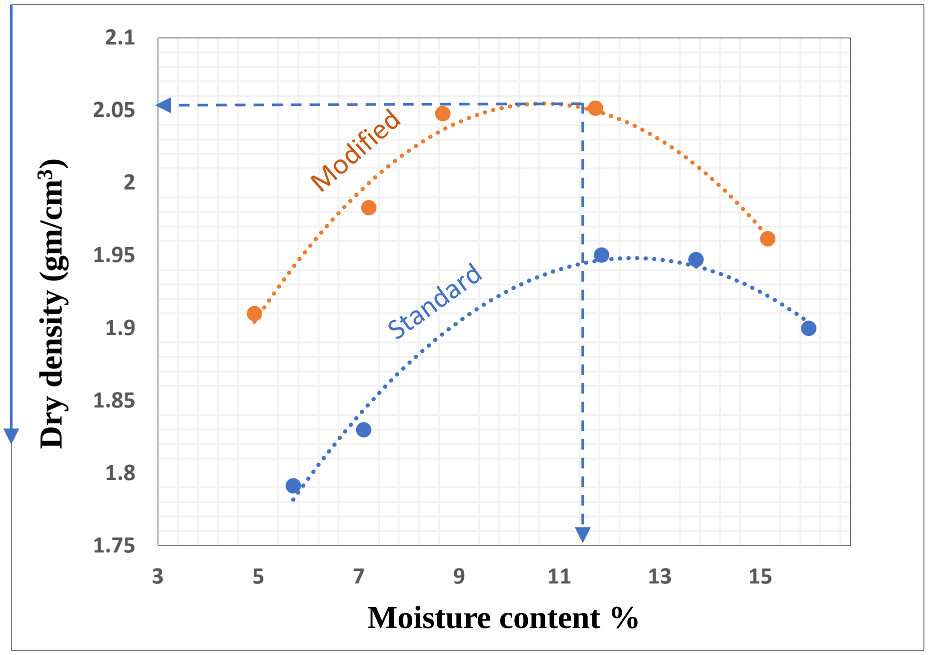


Figure (3.4): Standard and Modified Proctor Compaction Curves Test for NSS

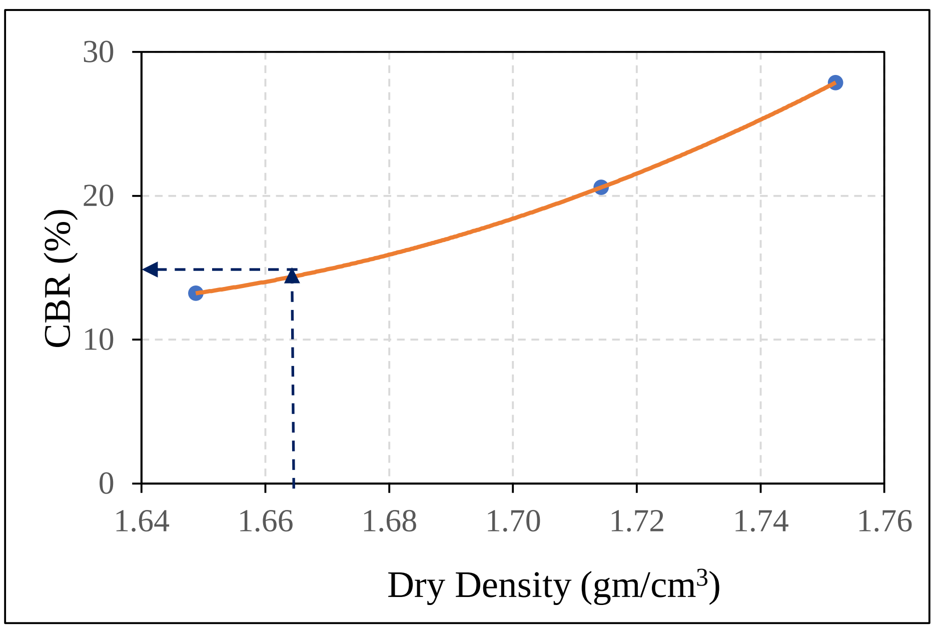


Figure (3.5): Determination of Soaked CBR for NSS

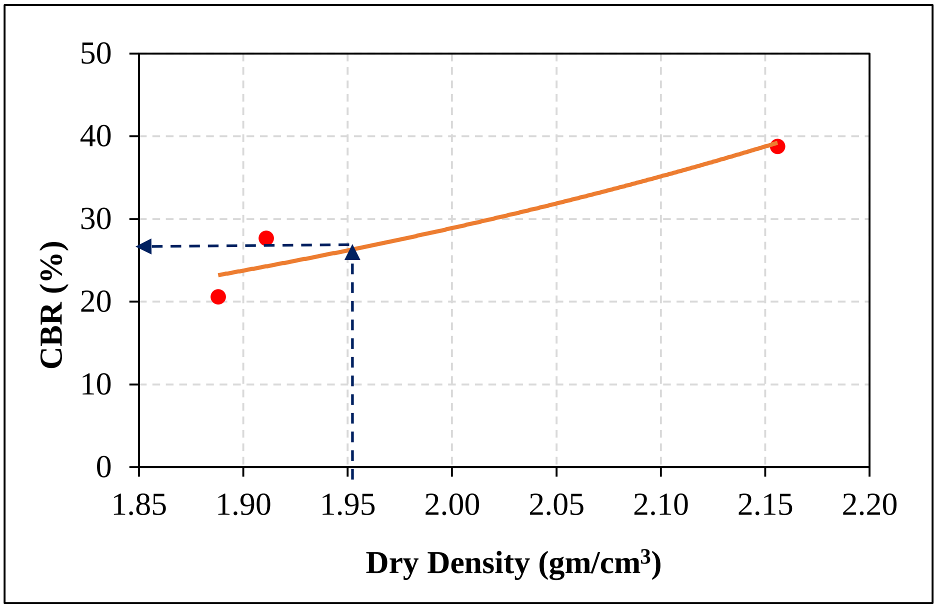


Figure (3.6): Determination of Unsoaked CBR for NSS

3.3.2 Sulfate Resistant Cement (SRC)

A sulfate resistant cement (SRC) was used in this study as a bonding material with strong adhesive characteristics to increase the bonds between soil particles. As listed in **Tables (3.2)** and (**3.3)**, the physical and chemical tests were carried out to identify the physical and chemical properties of the cement. Cement material has been chosen, for the ease of obtaining cement and its availability in the local markets, in addition to its excellent prices comparing with chemical materials such as Nanosilica. In this study, was using 10% cement content because there are a number of previous research examined the use of cement in improving soil properties and Iraqi building materials specification recommends the use of cement to stabilize granular soils by 6-10%. A series of laboratory tests, including a modified proctor compaction test, CBR test (soaked only), unconfined compressive strength (UCS), test was performed to identify the geotechnical characteristics of the cemented subgrade soil. The soil sample used to be mixed with cement at the optimum water content and compacted in the mold for the CBR test. Then, the samples have been cured in molds in which each humidity and temperature have been controlled for 1, 3, and 7 days. **Figure 3.7** showed MDD and OMC of cemented soil.

Table 3.2: Physical Properties of the Cement According to ***(IQS – No.5/1984).***

Physical Properties	Test Results	Specification
Specific surface area (cm^2/kg)	3000	≥ 2500
Initial setting time (min.)	155	≥ 45 min
Final setting time (min.)	260	≤ 10 hrs.
Compressive strength at 3 days (MPa)	28.7	≥ 15
Compressive strength at 7 days (MPa)	31.8	≥ 23

Table 3.3: Chemical Properties of the Cement According to ***(IQS – No.5/1984)***

Oxide (%)	Test Results	Specification
SiO_2	20.2	18 – 24
CaO	64	60 – 69
Al_2O_3	3.4	4 – 8
Fe_2O_3	3.8	2 – 4
MgO	3.5	≤ 5%
SO_3	2.1	≤ 2.5%
Fe_2O_3/ Al_2O_3	0.74	0.3 – 2.7
Free lime	0.99	0.66 – 1.02
LOS	3.6	Max. 4%
L.S.F	0.94	1.02 – 0.66
In.	0.8	Max. 1.5%
C_3S	64.02	45 – 65
C_2S	12.48	10 – 25
C_3A	10.6	7 – 12
C_4AF	13.99	11 – 15

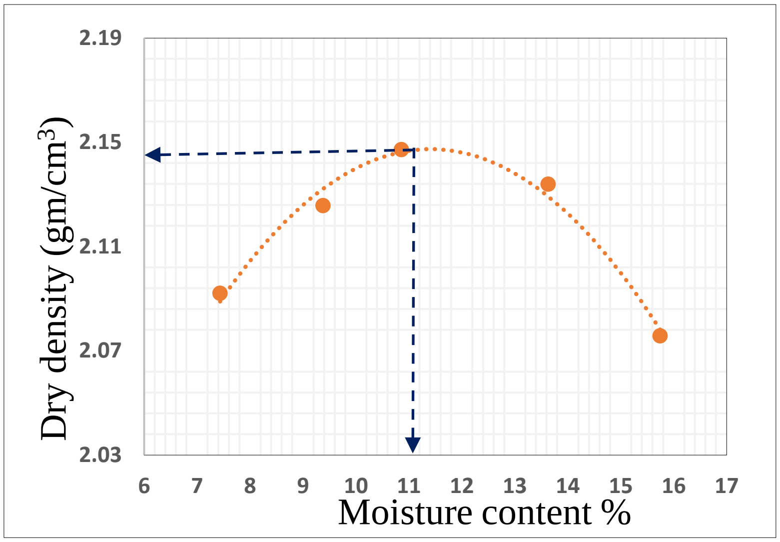


Figure (3.7): Modified Proctor Compaction Curves Test for CSS

3.3.3 Ground Tire Rubber (GTR).

Granulated or ground tire rubber is a product of the consumption of rubber tires. This study uses two types of GTR: crumbs and chips. Crumb which has a precise gravity of 0.40 and maximum particle measurement of 5 mm used to be used as a substitute for sand soil. The crumbs have been provided by using a local tire recycling producer in Al-Najaf city located in southeast Iraq.

Figure (3.8): Partical-Size of Crumbs and Chips

Chips that have a specific gravity of 1.13 and maximum particle measurement of 3 cm used to be as substitute for sand soil. The chips have been provided by using a local tire recycling producer in Al- Diwaniyah city located in southeast Iraq. The curve for grain size distribution is explained in **Figure (3.9)** for Crumbs and **Figure (3.10)** for Chips.

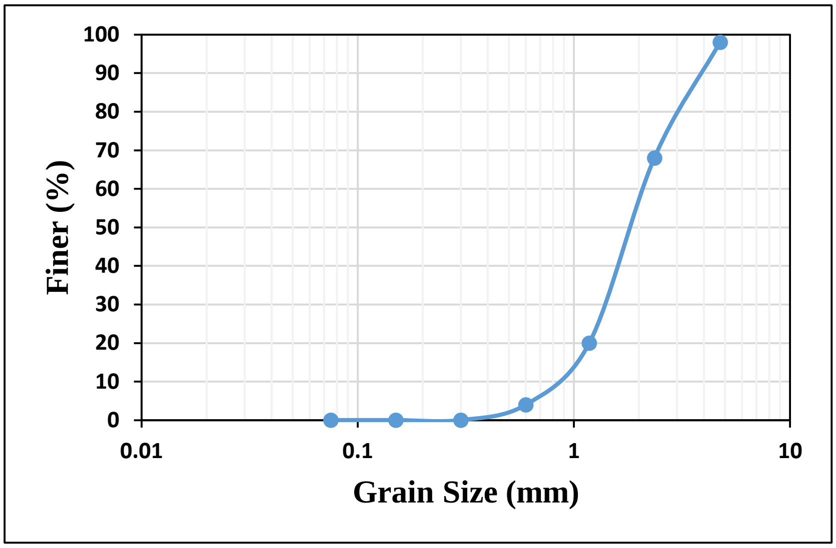


Figure (3.9): Grain-Size Distribution of Crumbs

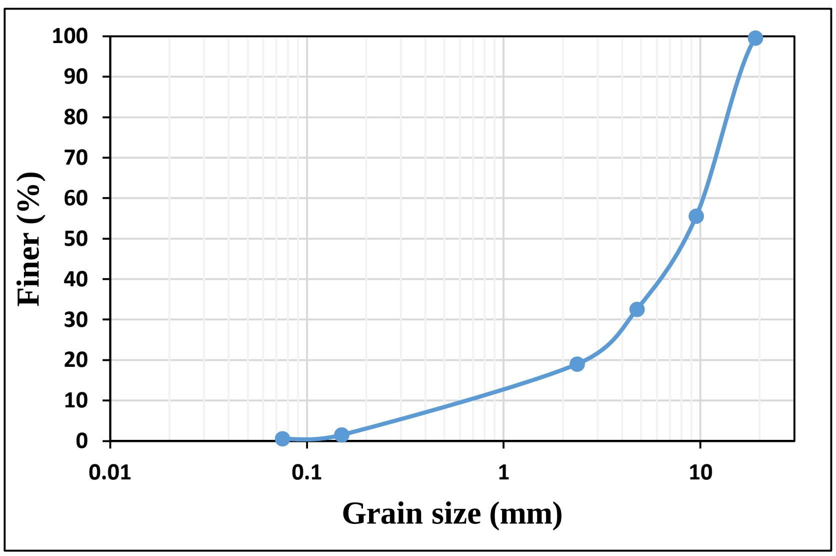


Figure (3.10): Grain-Size Distribution of Chips

3.4 Soil Preparation

Soil processing from the site and grain size inspection work for soil classification according to geometric specifications. Proctor screening for optimum water content and maximum dry density to be used in other tests. Testing preparation of laboratory as follow: preparation of two soil models for the work of the inspection of the CBR for natural subgrade soil and the work of the CBR soaked and unsoaked. Preparation of two models of cemented subgrade soil for the inspection of CBR and for each curing time combined 6 CBR models of proven soil and according to curing age as (1,3,7) day, two models for each curing age, taking into account water soaked for 48 hours. Similarly, when using rubber in soil stabilization with cement, two models for each curing time and for each used rubber ratio. means for each percentage used 6 models where the total of CBR models becomes 26 models because three percentages of GTR used (5%,10%, 20%). **Table 3.4** summarized Proportion of replacement and **Table 3.5** showed the number of each test sample.

Table 3.4: Soil – Cement – GTR Mixtures

Mixture	Content (%)		
	Sand	Cement	GTR
NSS: Natural Sandy Subgrade	100	0	0
CSS: Cemented Sand Subgrade	90	10	0
CSS+05%Crumb	85	10	5
CSS+10%Crumb	80	10	10
CSS+20%Crumb	70	10	20
CSS+05%Chips	85	10	5
CSS+10%Chips	80	10	10
CSS+20%Chips	70	10	20

Table 3.5: Summarized Number of Different Laboratory Tests

Soil Type	Test Name	Total Number of Sample	Curing Time		
			1 Day	3 Days	7 Days
NSS	Standard Proctor	5	-	-	-
	Modified Proctor	5	-	-	-
	Unsoaked CBR	6	-	-	-
	Soaked CBR	6	soaked in water not less than 48 hrs.		
	UCS	Not formed	-	-	-
CSS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C5ChNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C10ChNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C20ChNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C5CrNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C10CrNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
C20CrNS	Modified Proctor	6	2	2	2
	Soaked CBR	6	2	2	2
	UCS	6	2	2	2
Total number of Lab. Samples		148			

Preparation of large soil model:

- The simulation of the pavement is three layers and each layer has a 20 cm thickness and density, the optimum percentage of water used to prepare it.
- The soil in its natural state is prepared in the form of bags at a certain weight depending on the soil density obtained from the modified proctor test.
- The soil is prohibited by the desired weight by calculating the density and known size of the model.
- The optimal water ratio is prepared and mixed in a mechanical mixer and brushed in the form of layers.
- Work experiment to find out how many times a compacter machine passes over the soil by calculating the number of times by using the sand replacement method. To get a rate of degree of compaction, 90% and above.
- For cemented soil, the same steps are to prepare for natural soil taking into account the replacement of 10% from the soil by cement and the use of optimal water percentage of the proctor test as well as density to calculate the weight of the cement while taking into account curing time of 3 days.
- In the case of the use of granulated tire rubber with cemented soil, the same steps shall be taken, taking into account the replacement of a proportion of natural soil with granulated tire rubber. Each working ratio

shall have a full three-layer inspection model in the case of chips & crumbs.

- LWD, DCP, and SRM respectively are tested in steel molded. Starting to equip the cemented models in Steel Model it is to equip the first and second layers from the bottom to the top like the previous models where the stabilization is in the last layer only. The quantities are processed inside distributed baggage in the structure of practically calculated weights to be mixed and disseminated inside the model and then rectified well.
- The number of models in the simulation case is 8 models by ratios for each one and the method of stabilization is checked for each form that is separate from the other. Tests are done according to **Figure (3.11)**.

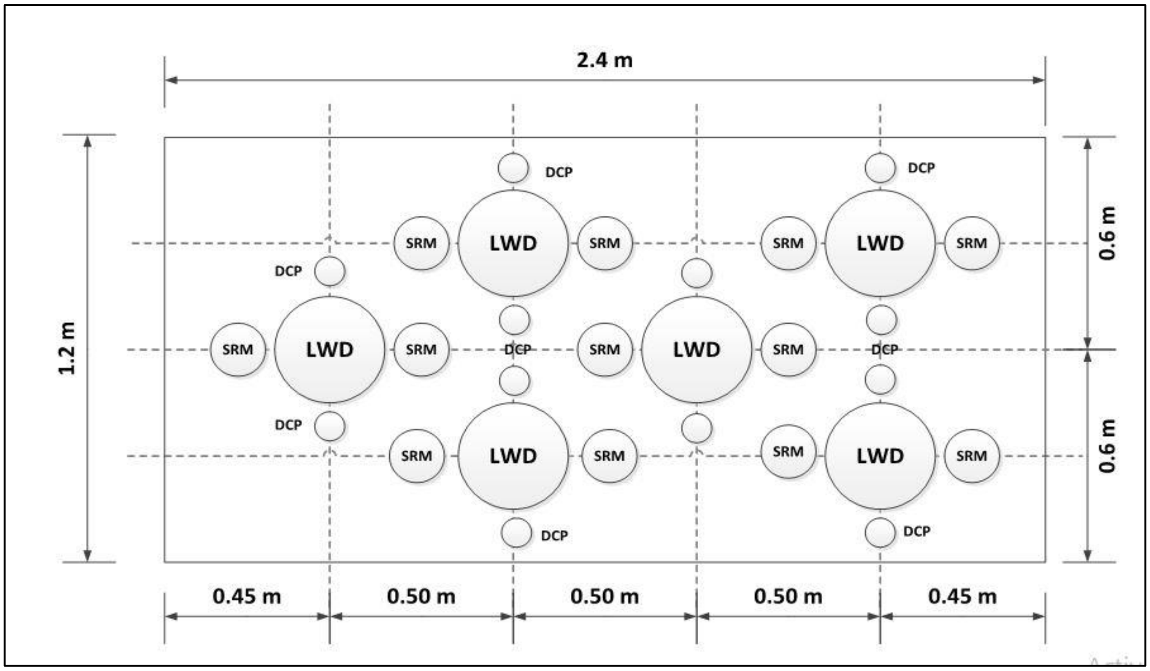


Figure (3.11): Explain Outline of Tests in Steel Module

LWD: Light weight deflectometer test

DCP: Dynamic cone penetration test, and SRM: Sand replacement method

3.5 Experimental Testing Program

3.5.1 Laboratory Tests

In order to achieve the objectives of this study, all specimens of subgrade, sand, and cemented sand-GTR stabilized mixtures were subjected to three standard laboratory testing methods for purposes of characterization:

3.5.1.1 Compaction Test

The maximum dry density(MDD) and optimum moisture content (OMC) play an essential role on the geotechnical behavior of the treated soil. A series of the standard and modified Proctor test was conducted according to the **ASTM D-698** and **ASTM D1557** respectively**.**

3.5.1.2 California Bearing Ratio Test

The California bearing ratio(CBR) test was conducted on natural and treated soil specimens as per the standard **ASTM D 1883**. The soaked CBR tests were carried out to assess the feasibility of using the cemented sand-GTR stabilized mixtures as a subgrade soil layer.

3.5.1.3 The Unconfined Compression Strength Test

The unconfined compression strength test (UCS) is utilized for the purpose of characterization of structural stability of cemented sand-GTR stabilized mixtures in various engineering applications. The UCS tests were performed depending on the results of the compaction test according to maximum dry density and optimum moisture content. Two identical specimens of each combination were prepared to diminish the error that might be obtained from variation of testing conditions and for making results more reliable**. Figure (3.12)** explain the unconfined compressive sample and its failure after testing.

Figure (3.12): Unconfined Compression Strength Module

3.5.2 Field Tests

3.5.2.1 Testing Setup

To simulate field conditions of pavement-layered soil systems, the laboratory testing device has been designed and manufactured; it's called a Steel model. As shown in **Figures 3.13** and **3.14**.

It is composed of the elements:

1. Loading steel frame
2. Hydraulic loading system
3. A significant steel box measuring 1.5 m in width and 2.4 m in length and 1.25 m in depth was constructed and utilized to compact and test the sample of subgrade material that is shown in **Figures (3.13)** and **(3.14)**.

In order to provide more than one point for testing, the box must be wide than 0.60 meters.

Figure (3.13): Laboratory Steel Model

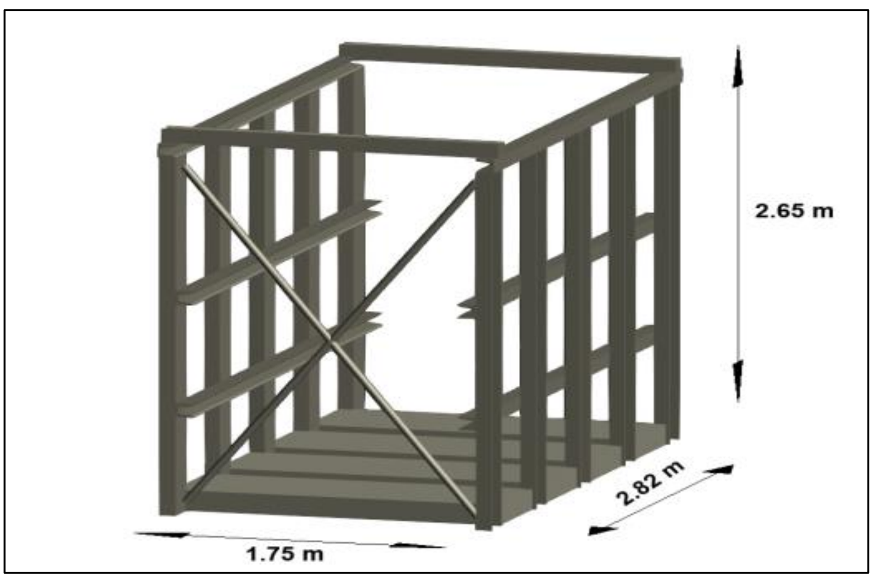


Figure (3.14): Scheme of The Loading Frame Steel Structure

3.5.2.2 Light Weight Deflectometer

The dynamic subgrade parameters had been examined under a non-destructive device using LWD. The LWD Zorn was used. LWD device consist of:

- The loading plate is placed in contact with the testing surface to perform a uniform distribution load, it has a 30 cm diameter.
- A 10-kg falling weight drops from 116-cm height, the falling weight is typically operated by means of one individual and negligible resistance or friction. As referred to in **(ASTM E 2583, 2011),** a half-sine formed load on the measuring surface occurs when the dropping weight reaches the loading pad.
- Control units to measuring vertical deflections.

Three drops were conducted on each test stage, as considered in **Figure (3.15),** to minimize the effect of loose soil particles that should purpose destructive plastic deformation.

The LWD parameters measured during this research as explained in **(Shaban et al., 2016)** are:

- **Ed:** dynamic modulus in (MPa).
- **$\boldsymbol{\delta d}$:** surface deflection (obtained from double speed integration versus pulse wave time signals reported by the accelerometer device located within the circular loading plate.)
- **Dc**: degree of compatibility (is determined by dividing the mean value of surface deflection by the mean value of the velocity of dynamic impact load generated in a subgrade layer. An indication of the compaction characteristics is given by this parameter. Generally, no further compaction

is needed if the degree of compatibility is smaller than or equal to 3.5. However, more compaction is advised if the degree of compatibility is higher than 3.5).

Integration impulse velocity readings of an accelerometer constant inside a circular loading plate calculate the surface deflections; surface soil modulus based on the elastic half-space theory of Boussinesq by used vertical deflections produced from accelerometer readings.

Figure (3.15): LWD Tests Device ***(Shaban et al., 2016).***

3.5.2.3 Dynamic Cone Penetration Test (DCP).

Soil strength may be analyzed in situ with the use of a device called dynamic cone penetration (DCP). Additionally, it contributes to checking up on the state of the subgrade soils and granular layers under different pavement layers. When calculating the CBR of the compacted soil subgrade under a pavement structure, (DCP) is used. With the included extension rod, users can take readings down to a depth of 800 mm, and with it removed, you may go as deep as 1200 mm. Correlations between CBR and DCP measurements allow the results to be analyzed and compared with CBR standards for pavement design. The following is the testing procedure:

1- Once the equipment has been calibrated, the zero reading is recorded. To achieve this, users must first place the DCP on a stable surface while making sure it is standing upright and then record the zero reading in the appropriate spot on the display sample as summarized in **Figure 3.16.**

2- Carefully, the weight is transferred from the device's base to the handle in a vertical direction. The operator should let the weight drop freely without trying to slow it down or stop it from hitting the handle.

3- Reading on a scale is often taken after a certain number of blows have been performed. To get an accurate result, it is necessary to adjust the number of blows between measurements to match the thickness of the layer being broken through. Readings taken after 1–2 blows may be suitable for weak subbase layers and subgrades, while readings taken after 5–10 blows are normally adequate for appropriate quality granular bases **(ASTM - D6951).**

4- The DCP is removed by pressing the weight upwards towards the handle when the test is over. Care must be taken since too much force might shorten the device's useful life.

With the results of this analysis, researchers can better understand the soil conditions in the field. Soil data may be collected from a large number of places rapidly, allowing researchers to immediately assess site-wide variations in soil conditions and take appropriate action. Although engineers usually just need to evaluate soils in the immediate area of the foundation area, additional information on the soil may be required from farther afield. In order to create the best solution for inadequate subgrade soils, it is essential to have data on the variation of soil strength with specified depths.

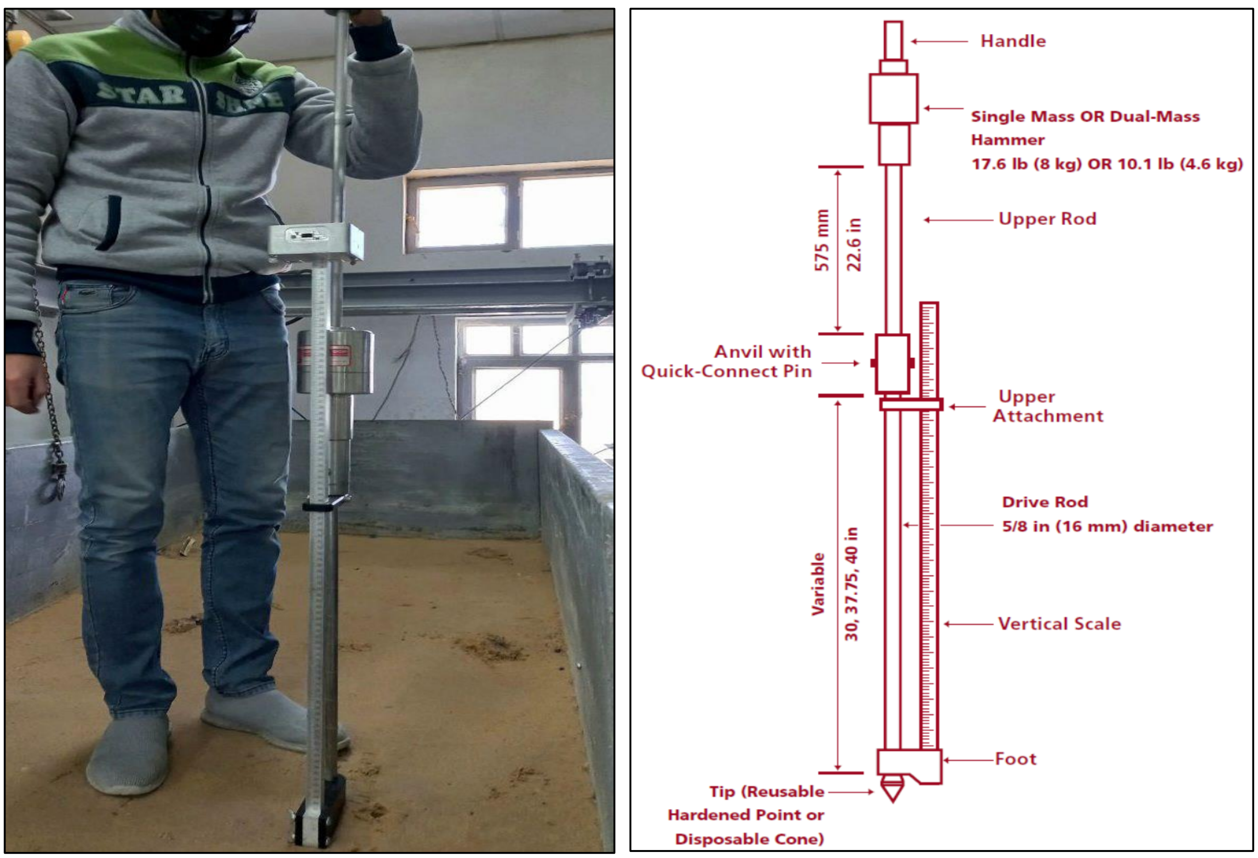


Figure (3.16): Dynamic Cone Penetration Test (DCP) Device

3.5.2.4 Sand Replacement Method

Actual moisture content and density of the compacted soil can be determined using SRM, according to **ASTM D1556 (2010).** The SRM utilized for soils without large portions of rock or coarse material exceeding 1.5 inches (38 mm), however, it is additionally excellent for saturated, relatively plastic, or natural soils that are compressed or deformed of the test pit excavation. Shown in **Figuer 3.17**. At each percent of cement and GTR content in each aspect ratio, in order to perform this test, twelve test points were selected. To calculate the degree of compaction.

Figure (3.17): Sand Replacement Method

Chapter Four : Results and Discussions

Chapter Four

Results and Discussions

4.1 Introduction

This chapter contains the results of the experimental testing methods and discusses them according to their type, starting with natural subgrade soil and then soils stabilized using cement and granulated tire rubber (GTR). In the laboratory, CBR, density, and UCS tests are used. There are also simulation investigations of the LWD test, DCP, and SRM tests.

4.2 Laboratory Testing Result

4.2.1 Compaction Test

Using modified Proctor test to determine the maximum dry density and optimum moisture content for natural subgrade soil and stabilizing soil. The densities of natural subgrade soil (NSS), and stabilized soil are summarized in **Table (4.1).**

Table 4.1: Summary of MDD and OMC Results

Soil Mixture	OMC (%)	MDD (gm/cm^3)
NSS: Natural Sandy Subgrade	11.7	2.05
CSS: Cemented Sand Subgrade	11.0	2.15
CS+05%Crumb	11.0	1.89
CS+10%Crumb	11.5	1.83
CS+20%Crumb	12.5	1.54
CS+05%Chips	12.0	1.91
CS+10%Chips	11.0	1.84
CS+20%Chips	11.5	1.70

In the NSS state, the results showed that the OMC is equal to 11.7 % resulting in a MDD equals to 2.05 gm/cm^3. While the results of the CSS states exhibit a MDD 2.15 gm/cm^3 at OMC 11 %. Because cement functions as a bond material and interacts with water to develop the characteristics that make it a bond material, the moisture content is reduced, and the maximum dry density is increased this agrees with the findings showed that while the optimal moisture content significantly reduces with an increase in cement percentage, the maximum dry unit weight of sand increases with an increase in cement content **(El-Hanafy, et al., 2021).**

When using granulated tire rubber (GTR: crumbs) in the cemented sand mixture (i.e., subgrades soils stabilized using cement), the OMC ranged from 11% to 12.5%, while MDD varied from 1.54 gm/cm^3 to 1.89 gm/cm^3, as shown in **Figure 4.1**. The decrease in the maximum dry density is attributed to low tire crumbs density as well as the particles of crumbs have a high elastic response under the compaction process, resulting in a low of compaction efficiency

When using granulated tire rubber (GTR: chips), the OMC ranged from 11% to 12%, while MDD varied from 1.70 gm/cm^3 to 1.91 gm/cm^3, as shown in **Figure 4.2**. The decrease in maximum dry density is also attributed to low tire chips density. Additionally, rubber particles are partially encircled by cement as a bonding agent, which lessens the impact of cement on the soil mixes and, as a result, decreases the maximum density.

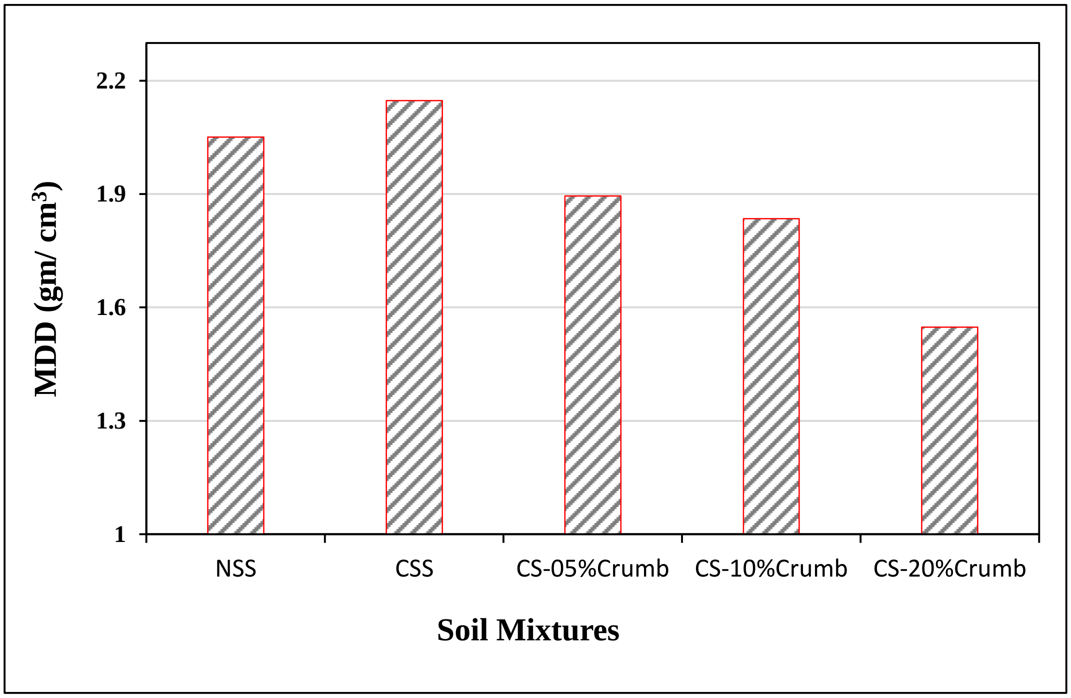


Figure 4.1: Results of MDD for Cemented Sand Treated with Crumbs

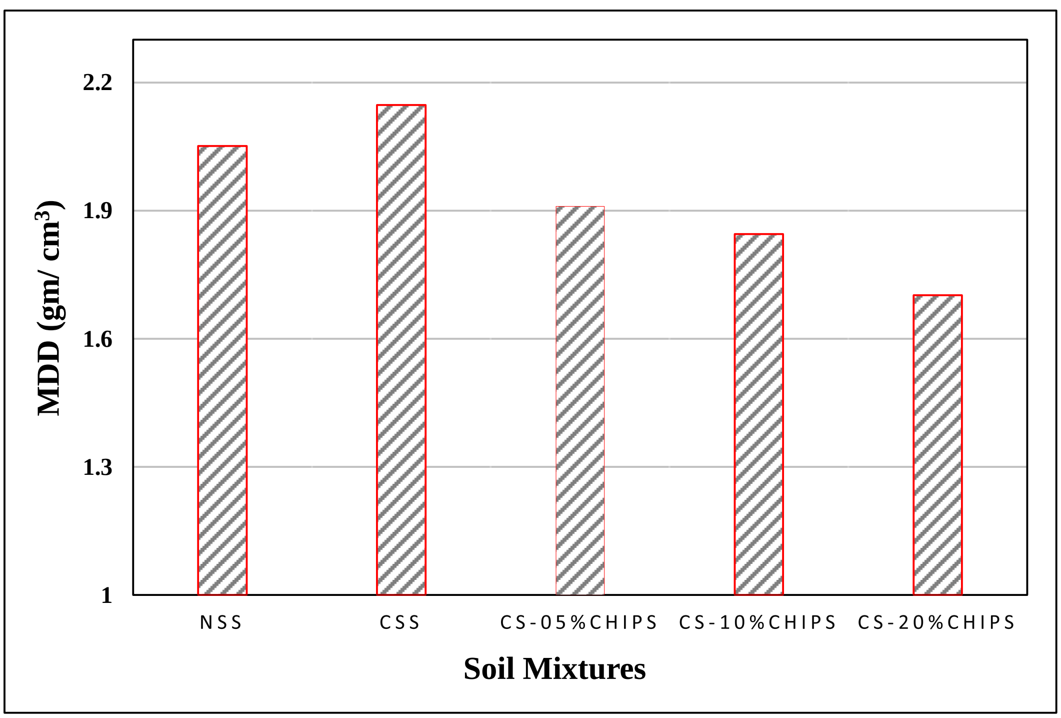


Figure 4.2: Results of MDD for Cemented Sand Treated with Chips

4.2.2 California Bearing Ratio (CBR) Test

The California bearing ratio (CBR) test was performed on subgrade soil to determine its bearing resistance of soil.

For the natural subgrade soil, the CBR value of natural sand soil is equal to 17%, this result is approach to the finding of other researchers such as **(Ali et al., 2021)**, who found CBR equal to 18%.

For the cemented soil, the CBR values are ranged from 68% to 149% for three times of curing. Cementitious materials, which improve the bond strength between cement and soil particles, are resulting the interaction between soil particles and cement is enhanced with cement, which increases the value of CBR. Additionally, using cement reduces the amount of gypsum in the soil and the impact of the soil upon the water. The CBR value increases as curing time increases as shown in **Figure 4.3**. This means the higher the curing age of the soil stabilized in cement, the greater the chemical reactions of the cement, and it is reaching its final stages as a binding substance and acting more than an adhesive between material particles.

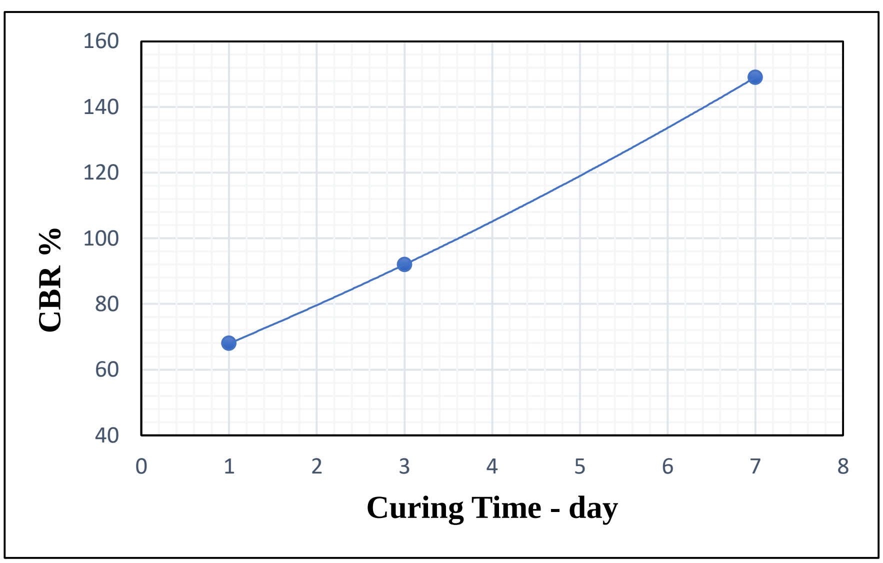


Figure 4.3: Showed The Effect of Curing Time on CBR value for Cemented Soil

For cemented soil – crumbs stabilized soil, the CBR values are ranged from 45% to 122% for three times of curing as summarized in **Table 4.2**. CBR values for all curing times decreased when GTR - crumbs replacement increase percent to the cement-treated soil. Showing that there is a decreased effect of the gypsum ratio in the soil, this reduction demonstrates that a proportion of cement increases the interconnection of soil particles and fills voids in the soil. **Figure 4.4** showed results of CBR for cemented sand treated with crumbs.

Table 4.2: Results of CBR Tests for Cemented-Sand- Crumbs Mixtures

Crumbs Content (%) in Cemented Sand Mixes	CBR %		
Curing Time (days)	1	3	7
0	68	92	149
5	66	85	122
10	63	78	99
20	45	47	67

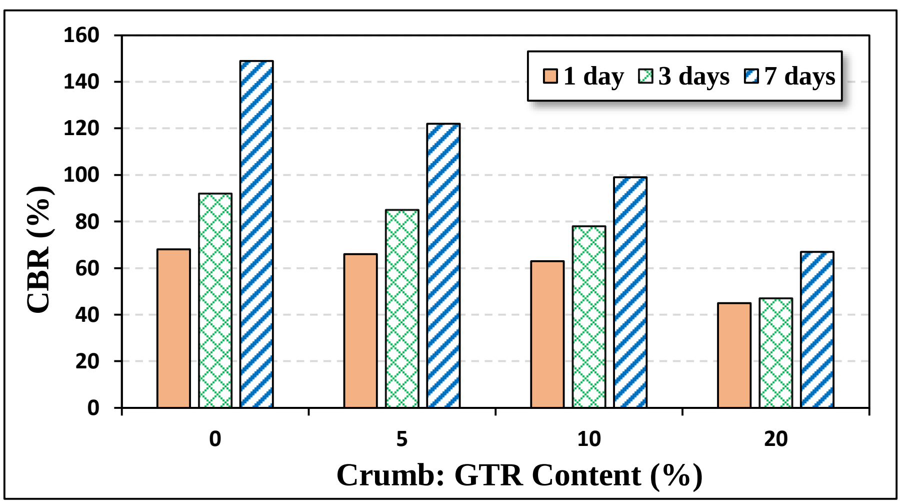


Figure 4.4: Results of CBR for Cemented Sand Treated with Crumbs

For cemented soil – chips stabilized soil, the CBR values are ranged from 54% to 126% for three times of curing as summarized in **Table 4.3**.

While having CSS the highest CBR value, chips behave in the same way in the crumbs state. The decreased CBR values of cement-sand-GTR combinations are attributed to the higher compressibility of used tire chips, which results in decreased soil bearing resistance as presented in **Figure 4.5.**

Table 4.3: Results of CBR Tests for Cemented-Sand- Chips Mixtures

Chips Content (%) in Cemented Sand Mixes	CBR%		
Curing Time (days)	1	3	7
0	68	92	149
5	70	86	126
10	69	82	114
20	54	55	60

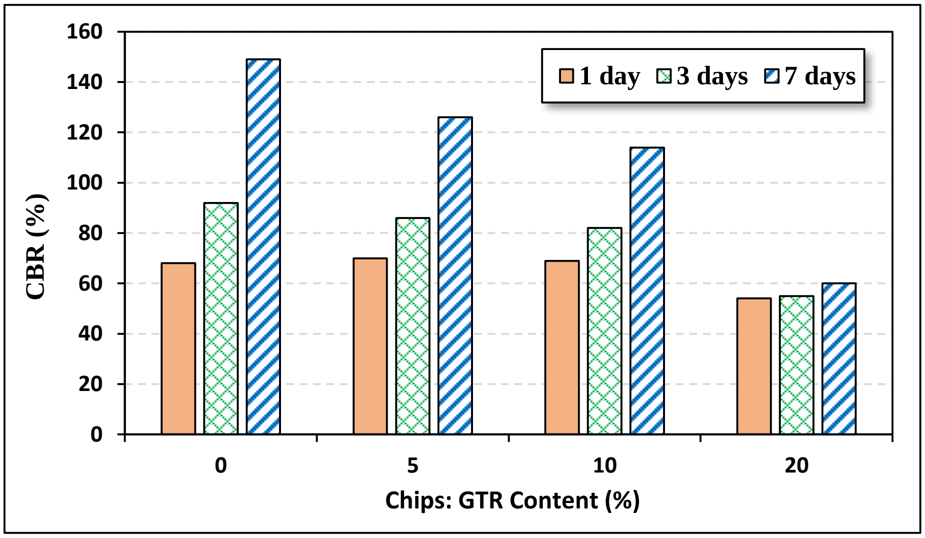


Figure 4.5: Results of CBR for Cemented Sand Treated with Chips

To determine the difference between chips and crumbs by comparing results and proportions according to **Figuers 4.6 , 4.7, and 4.8.**

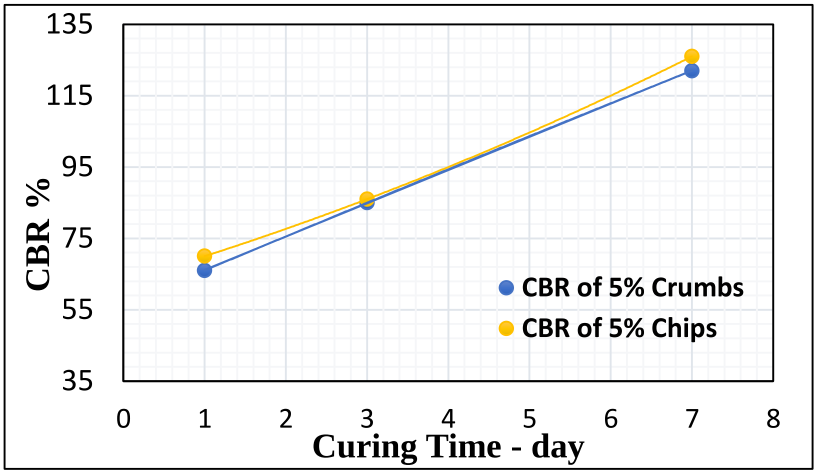


Figure 4.6: Results of CBR for Cemented Sand Treated with 5% GTR

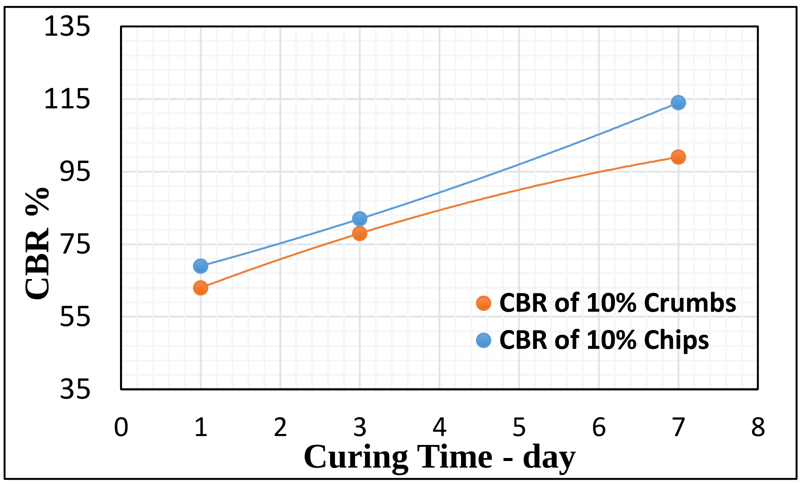


Figure 4.7: Results of CBR for Cemented Sand Treated with 10% GTR

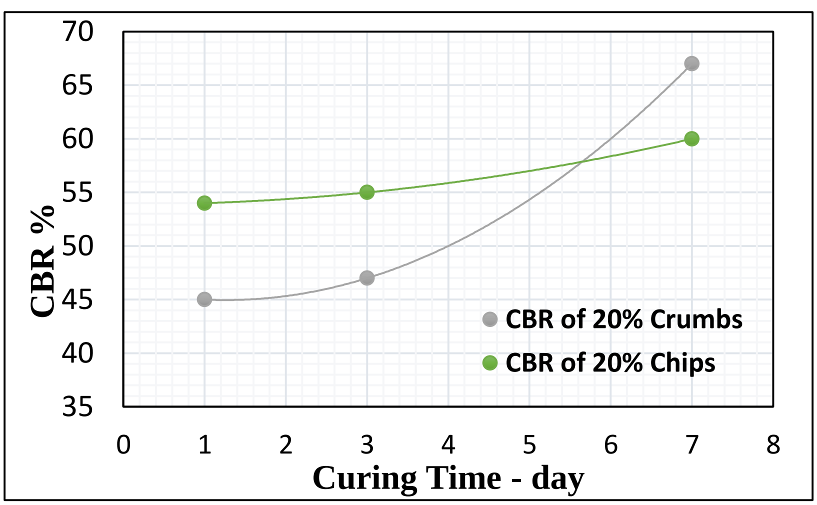


Figure 4.8: Results of CBR for Cemented Sand Treated with 20% GTR

4.2.3 Unconfined Compressive Strength (UCS) Test.

The three important soil characteristics that were identified by evaluating the stress-strain response from the UCS tests were unconfined compressive strength (qu), elastic modulus (Es), and toughness (T) of soil.

For natural subgrade, the soil samples were unable to be tested with unconfined compressive strength because soils cohesiveness could not be tested in an unrestricted condition.

For the cemented soil, the UCS (qu) values ranged from 1443 kPa to 2942 kPa, and elastic modulus varied from 122 MPa to 193 MPa for three times curing as summarized in **Table 4.4** , as shown in **Figures 4.10** and **4.11**, the results showed that increasing curing time increases the compressive strength and elastic modulus of soils as a result of the production of calcium silicate hydrate (CSH) during the hardening process of cement-sand mixtures, using cement reduces the amount of gypsum in the soil and the impact of the soil upon the water. Also, the soils toughness (T) which represent its capacity to absorb energy was calculated in this work. As listed in **Table 4.5**, the results showed that toughness varied from 18 kJ/m^3 to 23.4 kJ/m^3. The results also exhibited the toughness value increase with increasing curing time, as summarized in **Figure 4.9**.

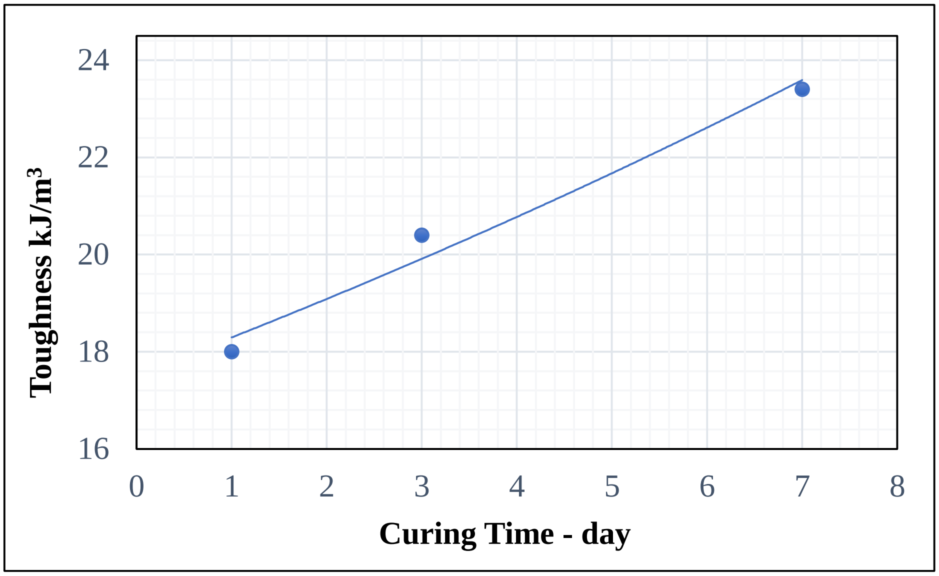


Figure 4.9: Showed The Effect of Curing Time on Toughness value for Cemented Soil

For cemented soil – crumbs stabilized soil, the UCS(qu) values are ranged from 356 kPa to 1305 kPa for three times of curing, and elastic modulus varied from 10 MPa to 70 MPa as summarized in **Table 4.4**. Crumbs were added in proportion to the cemented soil, reduction in qu and Es was because the crumbs are weak material and have good energy absorption potential, as shown in **Figures 4.10** and **4.11**, this proportion causes a decrease in the gypsum content in the soil. Toughness (kJ/m^3) is the ability of soil to absorb energy (area under stress-strain curve). When analyzing the stress-strain diagram, result showed that the soil toughness increases with increasing crumbs content. The toughness values are ranged from 20.1 kJ/m^3 to 32.7 kJ/m^3 for three times of curing as summarized in **Table 4.5** and **Figure 4.12.** The results also exhibited the T value increase with increasing crumbs content due to the high resilience behavior of crumbs under static and dynamic loading conditions.

Table 4.4: Summary of q_u and E_s of Cemented-Sand-Crumbs Mixtures

Crumb Content (%) in Cemented Sand Mixes	Curing Time (days)					
	1		3		7	
	q_u kPa	Es MPa	q_u kPa	Es MPa	q_u kPa	Es MPa
0	1443	122	2083	152	2942	193
5	548	38	1030	52	1305	70
10	418	28	645	41	810	48
20	356	10	393	14	482	17

Table 4.5: Summary of Toughness of Cemented Sand Mixtures -Crumbs

Crumb Content (%) in Cemented Sand Mixes	Curing Time (days)		
	1	3	7
	Toughness kJ/m^3		
0	18.0	20.4	23.4
5	20.1	21.4	23.0
10	22.3	24.2	24.1
20	24.9	26.8	32.7

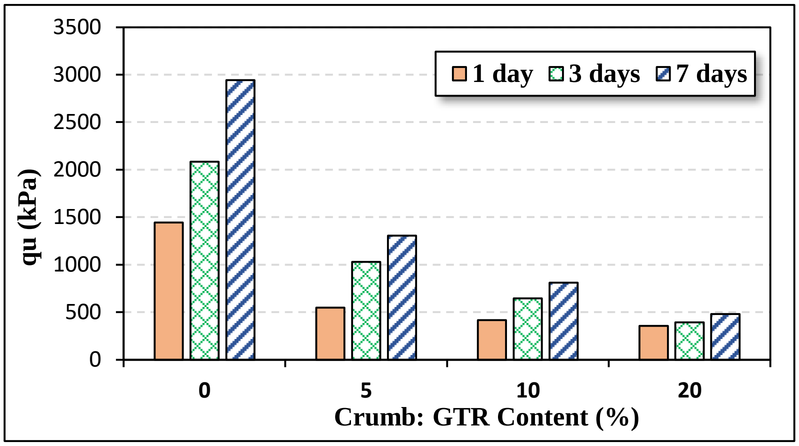


Figure 4.10: Results of UCS of Cement-Sand-Crumb Mixtures

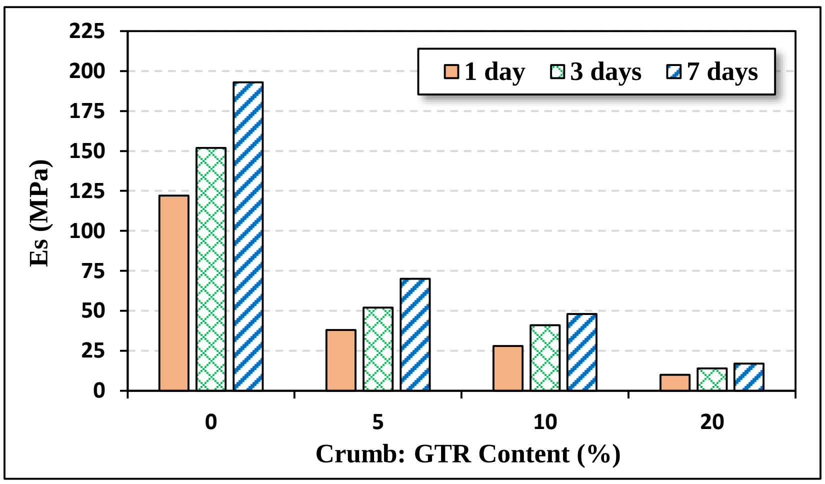


Figure 4.11: Results of Elastic Soil Modulus of Cement- Sand-Crumb Mixtures

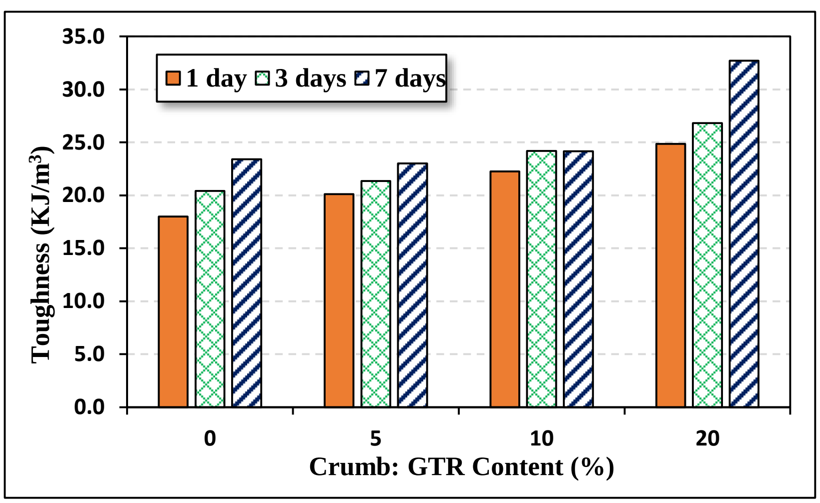


Figure 4.12: Results of Toughness of Cement- Sand-Crumb Mixtures

For cemented soil – chips stabilized soil, the UCS(qu) values are ranged from 390 kPa to 2186 kPa for three times of curing, as shown in **Figure 4.13**, and elastic modulus ranged from 13 MPa to 136 MPa as shown in **Figure 4.14**, and summarized in **Table 4.6**. Chips were added in proportion to the cemented soil; the reduction in qu and Es was caused by the chips weak material, which was the source of this reduction. **Table 4.7**, showed the toughness values are ranged from 22.7 kJ/m^3 to 34.8 kJ/m^3 for three times of curing, as a result of the high resilience behavior of the chips under static and dynamic loading conditions, the results also showed that the T value increased with increasing chips content, as summarized in **Figure 4.15**. The effect of the chips on cemented soil characteristics depends on the surface area and bonding strength of the contact between the rubber particles and the cemented soil.

*Table 4.6**:** Summary of qu and Es of Cemented-Sand-Chips Mixtures*

Chips Content (%) in Cemented Sand Mixes	Curing Time (days)					
	1		3		7	
	q_u kPa	Es MPa	q_u kPa	Es MPa	q_u kPa	Es MPa
0	1443	122	2083	152	2942	193
5	1434	61	1846	102	2186	136
10	738	50	1111	68	1369	80
20	390	13	716	23	793	23

Table 4.7: Summary of Toughness of Cemented Sand Mixtures - Chips

Chips Content (%) in Cemented Sand Mixes	Curing Time (days)		
	1	3	7
	Toughness kJ/m^3		
0	18.0	20.4	23.4
5	22.7	25.3	27.7
10	22.4	28.3	29.2
20	23.0	29.5	34.8

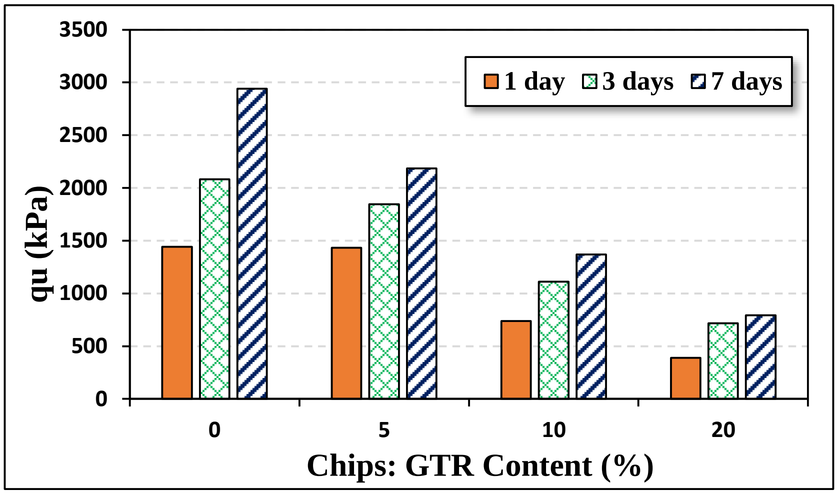


Figure 4.13: Results of UCS of Cemented-Sand-Chips Mixture

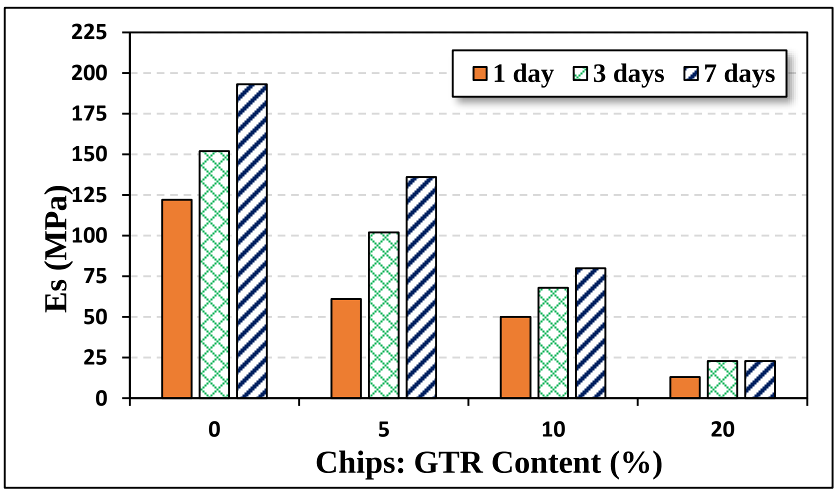


Figure 4.14: Results of Elastic Soil Modulus of Cemented- Sand-Crumbs Mixtures

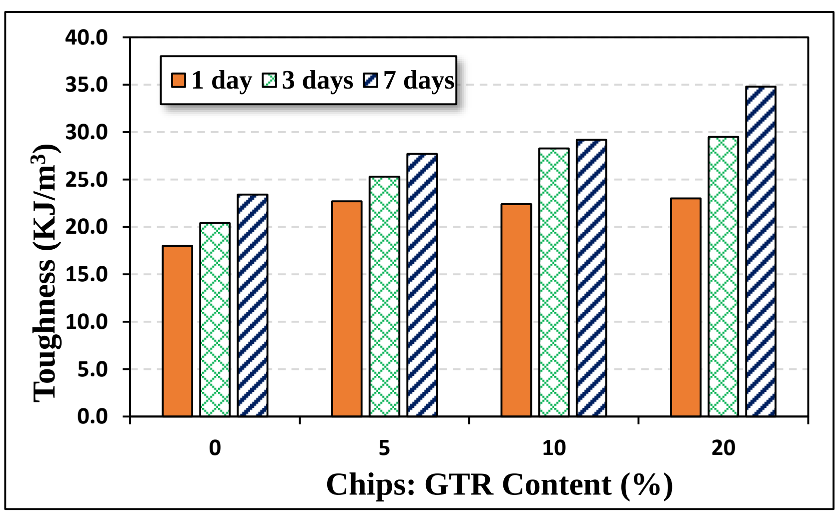


Figure 4.15: Results of Toughness of Cement- Sand-Chips Mixtures

4.3 Field Testing Results

A representative model of a subgrade soil which consists of 3 layers with a 60 cm thickness was built in the pavement materials lab, as illustrated in **section 3.3.** The density and moisture content of each soil layer is achieved based on the results of the modified Proctor test carried out in the lab. After completing the subgrade testing model, the following tests were carried out: LWD, DCP, and SRM. The results of these tests are discussed as follows:

4.3.1 Dynamic Cone Penetration (DCP):

A portable, rapid, in-situ test named the dynamic cone penetrometer (DCP) is used to evaluate the strength of pavement layers. The DCP calculates the soil resistance to penetration. In this study, the following DCP parameters were determined: average dynamic cone penetrometer index (DCPI), dynamic cone penetrometer slope (DCPS), and dynamic cone penetrometer toughness (DCPT), as summarized in **Table 4.8.**

Table 4.8: Summary of Dynamic Cone Penetration Test (DCP) Results

Soil Mixture	Average DCPI mm/blow	DCP Slope mm/blow	DCP Toughness mm^2
NSS	25	26	7800
CSS	6.17	2	812
CS+05%Crumb	4.15	2	1155
CS+10%Crumb	5.27	3	2975
CS+20%Crumb	8.65	10	3300
CS+05%Chips	4.58	1.6	674
CS+10%Chips	5.02	2	1050
CS+20%Chips	7.28	4	2409

For the natural subgrade soil, the value of DCPI had an average of 25 mm/blow. This results are comparable to those obtained by **(Laith.et al., 2022),** as shown **Figure 4.16** The DCPS had a 26 mm/blow, and DCPT had a 7800 mm^2.

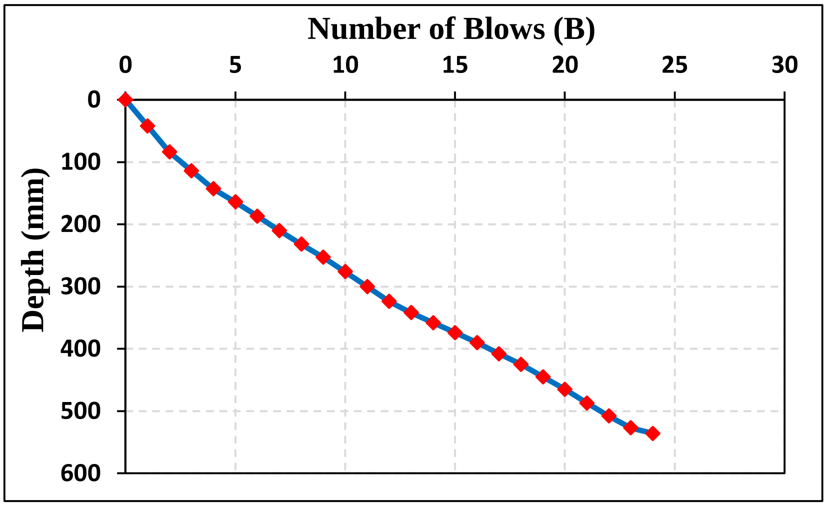


Figure (4.16): Typical curve of DCP Index (mm/Blow) for NSS

For cemented soil, the value of DCPI had an average of 6.17 mm/blow, this results in a reduction in DCPI value, the cement functions as a bonding material, increasing the cohesiveness of soil particles, as a result, cement increased cohesiveness and the ability to function as a bonding material, which significantly strengthens the soil structure, leading to a decreases in soil penetration. DCPS had a 2 mm/blow, and DCPT had an 812 mm^2. Cement also increases soil brittleness and reduces its energy absorption. as summarized in Ta**ble 4.8.**

For cemented soil – crumbs stabilized soil, the value of DCPI values is ranged from 4.15 mm/blow to 8.65 mm/blow for three percentage of crumbs, the value of DCPS values is ranged from 2 mm/blow to 10 mm/blow for three percentage of crumbs, and the value of DCPT values is varied from 1155 mm^2 to 3300 mm^2 for three percentage of crumbs, as summarized in **Table 4.8**.

When compared to cemented soil results, the impact of crumbs properties on soil behavior with loads has been noted, and for different tests, increasing the percentage of crumbs increased the value of DCPI, DCPS, and DCPT, crumbs improve the geotechnical properties of soil such as increased resilience to soil and reduction of the brittle behavior of cemented soil.

For cemented soil – chips stabilized soil, the value of DCPI values is ranged from 4.58 mm/blow to 7.28 mm/blow for three percentage of chips, the value of DCPS values is ranged from 1.6 mm/blow to 4 mm/blow for three percentage of chips, and the value of DCPT values is varied from 674 mm^2 to 2409 mm^2 for three percentage of chips, as summarized in **Table 4.8**. The effect of chips properties on soil behavior under loads has been determined when compared to results for cemented soil, increasing the percentage of chips increased the value of DCPI, DCPS, and DCPT. Chips also enhance the geotechnical properties of soil by increasing its resilience and reducing the brittle behavior of cemented soil. To determine the difference between chips and crumbs by comparing results of the DCP test and proportions according to **Figures 4.17,4.18, and 4.19.**

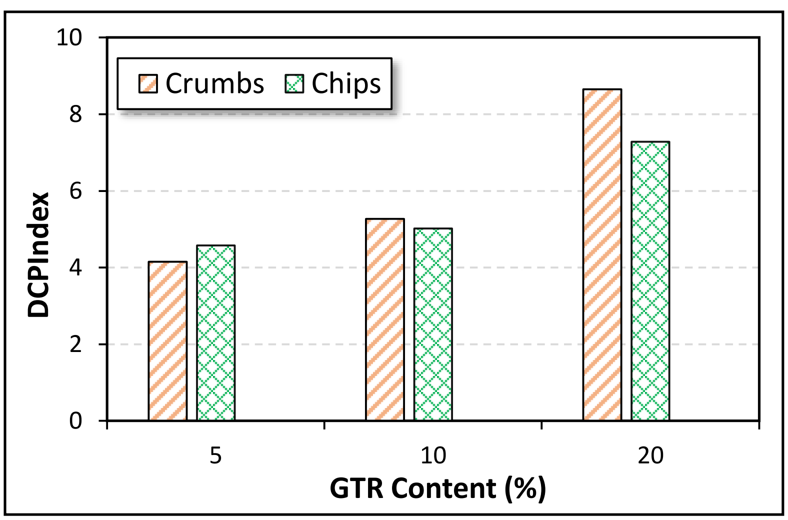


Figure 4.17: Results of DCPIndex for Cemented Sand Treated with GTR

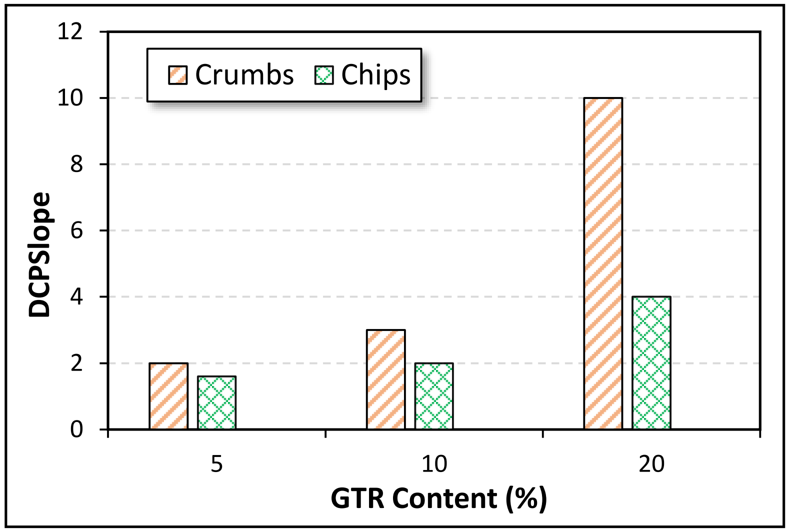


Figure 4.18: Results of DCPSlope for Cemented Sand Treated with GTR

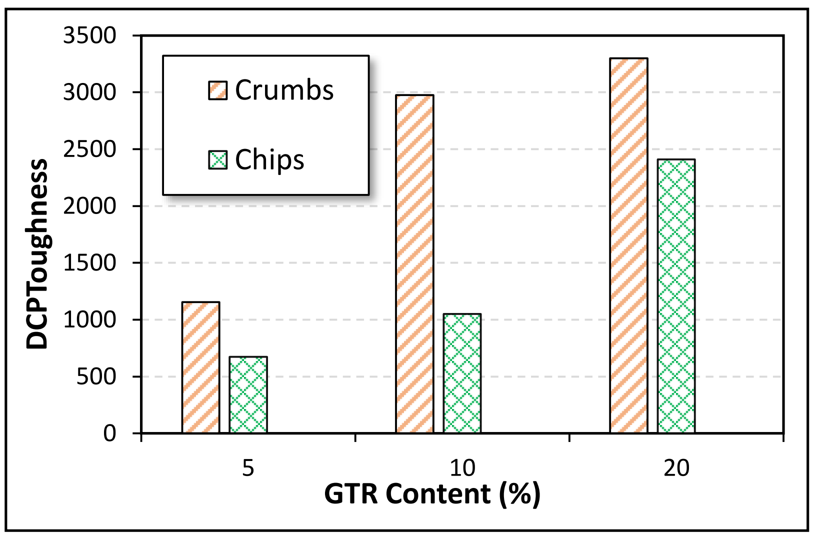


Figure 4.19: Results of DCPToughness for Cemented Sand Treated with GTR

4.3.2 Light Weight Deflectometer (LWD):

Six testing points were selected at which the soil properties were evaluated. For the natural subgrade soil, the values obtained from three consecutive drops were averaged to obtain these results. According to the results, the vertical deflections had a range from 0.57 mm to 0.87 mm, with an average of 0.65 mm, as shown **Figure 4.20**. Dynamic modulus values ranged from 25.95 MPa to 42.06 MPa, with 35.33 MPa acting as the average. The degree of compatibility average value was 3.66 ms, as summarized in **Table 4.9**.

Table 4.9: Summary of Light Weight Deflectometer (LWD) Results.

Property	Points	Mean Surface Deflection (mm)	Dynamic Modulus Ed (Mpa)	Degree of Compatibility Dc (ms)
NSS	1	0.57	39.82	3.30
	2	0.68	33.09	3.88
	3	0.61	37.07	3.78
	4	0.54	42.06	3.20
	5	0.66	33.99	3.76
	6	0.87	25.95	4.05
Average		0.65	35.33	3.66
CSS	1	0.32	70.53	2.87
	2	0.32	70.98	2.82
	3	0.20	110.29	2.55
	4	0.21	105.14	3.05
	5	0.20	111.94	3.06
	6	0.20	115.38	3.60
Average		0.24	97.38	2.99
C5ChNS	1	0.43	52.33	2.38
	2	0.39	57.69	2.33
	3	0.32	69.66	2.53
	4	0.19	117.80	2.61
	5	0.43	52.82	2.74
	6	0.28	81.23	3.29
Average		0.34	71.92	2.65
C10ChNS	1	0.46	49.23	2.29
	2	0.60	37.25	2.51
	3	0.52	42.94	2.20
	4	0.35	63.92	2.56
	5	0.43	52.20	2.43
	6	0.33	69.02	2.69
Average		0.45	52.43	2.45

Table 4.9: Summary of Light Weight deflectometer (LWD) Results. Continued

C20ChNS	1	0.80	28.23	2.40
	2	1.67	13.51	3.16
	3	0.81	27.78	2.56
	4	1.18	19.00	2.87
	5	0.66	34.14	2.30
	6	0.73	30.70	2.57
Average		0.97	25.56	2.64
C5CrNS	1	0.38	60.00	2.59
	2	0.30	75.25	2.98
	3	0.28	80.65	2.44
	4	0.32	70.09	2.78
	5	0.29	78.95	2.49
	6	0.34	66.77	2.53
Average		0.32	71.95	2.63
C10CrNS	1	0.52	43.27	2.28
	2	0.59	38.40	2.32
	3	0.40	56.39	2.23
	4	0.69	32.80	2.31
	5	0.56	40.47	2.32
	6	0.65	34.88	2.33
Average		0.57	41.04	2.30
C20CrNS	1	0.97	23.27	2.66
	2	1.30	17.28	2.99
	3	1.37	16.42	3.13
	4	1.35	16.64	3.10
	5	1.82	12.38	3.69
	6	1.87	12.01	3.68
Average		1.45	16.33	3.21

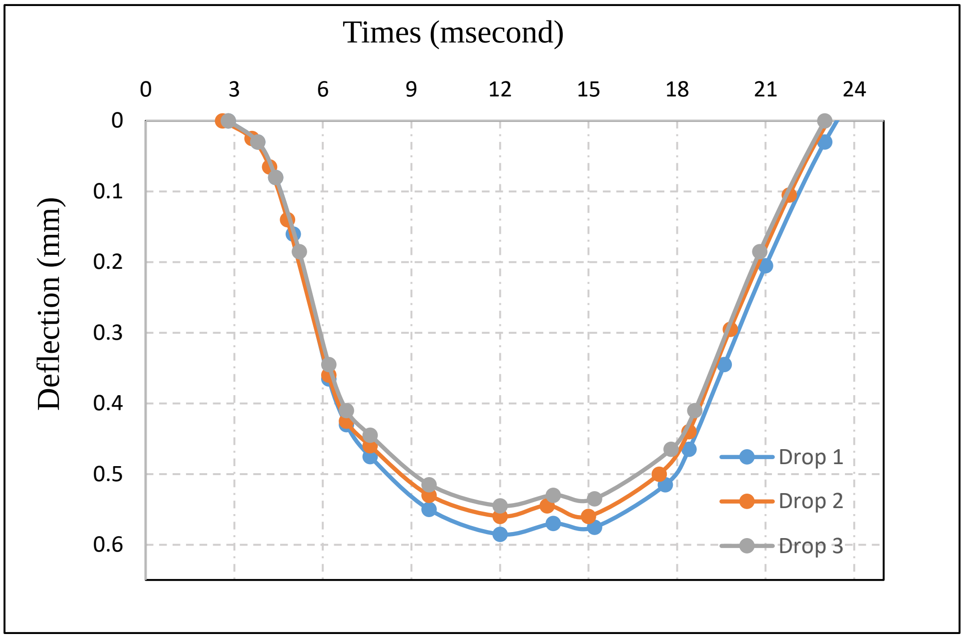


Figure (4.20): Average Time-Deflection Curve of NSS

For cemented soil, the vertical surface deflections varied from 0.2 mm to 0.32 mm, with an average of 0.24 mm. Dynamic modulus values ranged from 70.53 MPa to 115.38 MPa, with 97.38 MPa acting as the average. The degree of compatibility average value was 2.99 ms, as summarized in **Table 4.9.** The cement effectively improves the bonding between the soil particles, decreasing void ratio and enhancing the shears parameters strength, reducing the vertical deflection, and increasing the value of elastic modulus.

For cemented soil – crumbs stabilized soil, the verticals surface deflections values are ranged from 0.28 mm to 1.87 mm for three percentage of crumbs, and the average value of the verticals deflections for three percent of crumbs 5%,10%, and 20% are 0.32 mm,0.57 mm, and 1.45 mm respectively. the elastic modulus values are ranged from 12.01 MPa to 80.65 MPa for three percentage of crumbs, and the average value of the elastic modulus for three percent of crumbs 5%,10%, and 20% are 71.95 MPa,41.04 MPa, and 16.33 MPa respectively. When increasing the percentage of crumbs, the vertical deflections increase and decrease the value of elastic modulus, increasing crumbs content because of the high resilience behavior of crumbs under static and dynamic loading. The degree of compatibility average value for three percent of crumbs 5%,10%, and 20% are 2.63 ms, 2.3 ms, and 3.21 ms respectively as summarized in **Table 4.9**. Comparing results with cemented soil results determine the effect of crumbs properties on soil behavior with loads and for various tests, the degree of compatibility will increase with the percent of crumb increase, crumbs have low compatibility due to the high elastic response during the compaction process.

For cemented soil – chips stabilized soil, the verticals surface deflections values are varied from 0.19 mm to 1.18 mm for three percentage of chips, and the average value of the verticals surface deflections for three percent of chips 5%,10%, and 20% are 0.34 mm,0.45 mm, and 0.97 mm, respectively. The elastic modulus values are ranged from 13.51 MPa to 117.8 MPa for three percentage of chips, and the average value of the elastic modulus for three percent of chips 5%,10%, and 20% are 71.92 MPa,52.43 MPa, and 25.56 MPa respectively. The degree of compatibility's average value for three percent of chips 5%,10%, and 20% are 2.65,2.45, and 2.64 respectively as summarized in **Table 4.9.** When results were compared to those from tests using cemented soil, it became apparent how the characteristics of the chips affected the response of the soil to loads in various tests. Because chips have a high resilience behavior under static and dynamic loading. when increasing chips content, increases the vertical surface deflections, decreases dynamic modulus, and increases the degree of compatibility.

4.3.3 Sand Replacement Method (SRM):

The sand replacement method (SRM) was performed in this experimental investigation to determine the field densities of stabilized soils as summarized in **Table 4.10**.

Table 4.10: Summary of Sand Replacement Method Test (SRM) Results.

Soil type	Wet density gm/cm^3	Dry density gm/cm^3
NSS	2.05	1.84
	2.06	1.85
	2.05	1.84
	2.03	1.83
	2.04	1.83
	2.04	1.84
Average	2.05	1.84
CSS	2.1	1.9
	2.13	1.92
	2.17	1.95
	2.13	1.92
	2.16	1.94
	2.15	1.95
Average	2.14	1.93
C5CrNS	1.82	1.64
	1.86	1.69
	1.96	1.78
	1.87	1.69
	1.87	1.7
	1.86	1.7
Average	1.88	1.7
C10CrNS	1.78	1.6
	1.89	1.6
	2.17	1.79
	1.94	1.73
	1.89	1.7
	1.8	1.7
Average	1.92	1.69
C20CrNS	1.63	1.44
	1.62	1.43
	1.61	1.42
	1.66	1.47
	1.68	1.49
	1.61	1.5
Average	1.64	1.46

Table 4.10: Summary of Sand Replacement Method Test (SRM) Results. Continued

C5ChNS	1.93	1.72
	1.91	1.71
	1.97	1.76
	1.86	1.67
	1.98	1.77
	1.97	1.76
Average	1.94	1.74
C10ChNS	1.93	1.74
	1.91	1.72
	1.9	1.71
	1.89	1.71
	1.89	1.71
	1.89	1.71
Average	1.91	1.72
C20ChNS	1.86	1.68
	1.73	1.56
	1.86	1.67
	1.72	1.58
	1.7	1.55
	1.7	1.55
Average	1.77	1.6

For the natural subgrade soil, the average value of dry density is 1.84 gm/cm^3, as summarized in **Table 4.10.**

For cemented soil, the value of dry density had a range of 1.9 gm/cm^3 to 1.95 gm/cm^3, with an average of 1.93 gm/cm^3.The dry density increasing when cement is used in soil stabilization. Because cemented soil increased cohesiveness and bounding between particles, the soil's structure is improved and decreasing the void ratio between the soil particles.

For cemented soil – crumbs stabilized soil, dry density values are ranged from 1.42 gm/cm^3 to 1.79 gm/cm^3 for three percentage of crumbs, and the average value of the dry density for three percent of crumbs 5%,10%, and 20% are 1.7 gm/cm^3, 1.69 gm/cm^3, and 1.46 gm/cm^3, respectively, as sun *Table 4.10: Summary of Sand Replacement Method Test (SRM) Results.Continued*

percentage of crumbs increased. dry density is reduced due to the nature of tire crumbs which are considered a lightweight stabilizing material.

For cemented soil – chips stabilized soil, dry density values are ranged from 1.55 gm/cm^3 to 1.76 gm/cm^3 for three percentage of chips, and the average value of the dry density for three percent of chips 5%,10%, and 20% are 1.74 gm/cm^3, 1.72 gm/cm^3, and 1.6 gm/cm^3, respectively. The effect of chips particle size on cemented materials varies based on the strength and area of the connection at the interface between the chips particle and the cemented soil particles. Increased chips content resulted in a decreased dry density, which reduces the impact of cement and decreases the soil's structural strength, and increasing the resilience property.

4.4 Summary

This chapter contained the findings from testing done to characterize the stabilizing subgrade soil utilizing cement and granulated tire rubber as stabilizing materials. The results are divided into two phases;

Results obtained from the laboratory tests for using cement to stabilize soil, compaction test, CBR test, and UCS test, which include an increase in the maximum dry density, CBR, bearing resistance of the stabilizing subgrade soil, and compressive strength of the stabilizing subgrade soil. Using GTR increasing the toughness of stabilizing soil.

Results obtained from the field tests for using cement to stabilize soil, LWD, DCP test, and SRM, which include an increase in DCPI, DCPS, average surface deflection, dynamic modulus of the stabilizing subgrade soil, and dry density of the stabilizing subgrade soil. Using GTR increases the DCPT of stabilizing soil and increase the resilience of stabilize soil.

Chapter Five : Theoretical analysis

Chapter Five

Theoretical Analysis

5.1 Introduction

In this chapter, the structural evaluation of different pavement sections (i.e., stabilized and unstabilized) was performed in a variety of ways using a software package known as (KENPAVE).

The KENPAVE software relies on design information that follows user specifications. In order to provide the researcher or designer a knowledge of the stress and pressure imposed on the layers of the pavement as a result of varied loads passing the road during the period of use or in the case of the construction design of the pavement.

Compared to conventional methods of analysis, this software saves researcher's time and enables the researcher to quickly evaluate and select the best outcomes after comparing a range of road design possibilities. The software supports both SI and English units.

The KENPAVE software is divided into two parts;

- Asphalt to evaluate or design the flexible pavement (i.e., LAYERINP, KENLAYER, LGRAPH, ...etc.), as shown in **Figure 5.1**.
- Concrete to evaluate or design the rigid pavement (i.e., SLABSINP, KENSLABS, SGRAPH, ...etc.), as shown in **Figure 5.1**.

KENLAYER can used to model layered systems with one, two, four, or two or three wheels, each of which has a different behavior either linear elastic, nonlinear elastic, or viscoelastic. Maximum load groups per period, whether single or multiple therefore each year can be divided into a maximum of 12 periods, each with a different combination of material attributes, allowing for damage analysis and evaluate the state of the pavement, **(Huang, 2004).**

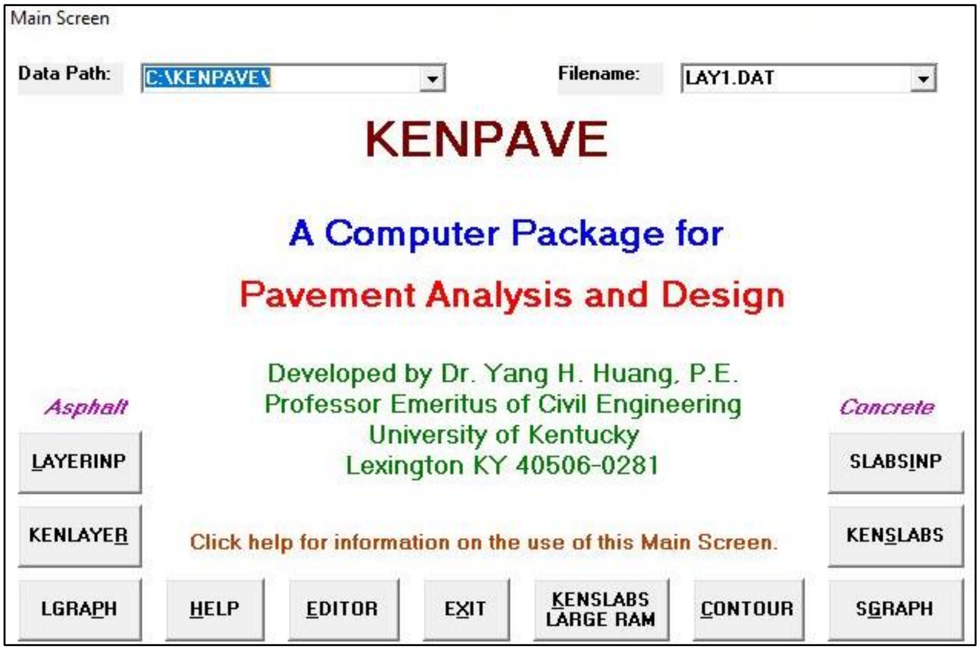


Figure (5.1): The Main Screen Capture of KENPAVE

5.2 Structural Analysis

5.2.1 Geometry of Pavement Sections

The analysis of the results is an actual model of a road implemented in the Province of Kerbala**.** The Kerbala Governorate is constructing the road portion of the southern ring road shown in **Figure 5.2.**

Figure (5.2): Aerial View of the Southern Ring Road

In order to obtain the best results for the researcher, a section of the southern ring road in Karbala governorate, consisting of three layers, was used to compare the results after their analysis using the KENPAVE program according to the characteristics of each layer and illustrates typical cross section of the selected pavement system as shown in **Figure 5.3** as a **case study**.

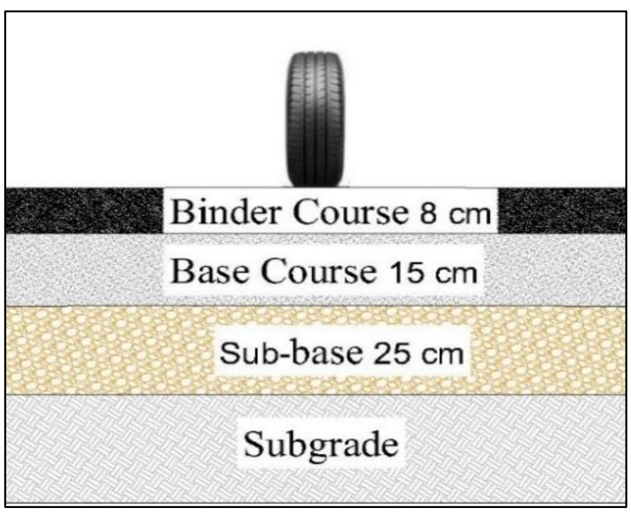


Figure (5.3): The Selected Pavement Section (case study)

5.2.2 Loading and Boundary Conditions

Required inputs for the structural design of flexible pavement system were entered into the KENPAVE program according to pre-defined parameters of each pavement layers. The parameters of each pavement layer is summarized in **Table 5.1**. The properties of stabilized soils (i.e., cemented sand, cemented – sand with crumbs, and cemented – sand with chips) were used as inputs to define subgrade soil characteristics.

Table 5.1: Summary of Input for The Structural Design of Control Section

Layer	Type	Thickness (mm)	Poisson's Ratio	**γ** (**kN**/m³)	E (kPa)
1	Binder Course	80	0.35	22.8	3750,000
2	Base Course	150	0.35	21.2	189,000
3	Subbase	250	0.35	21.2	112,000
4	Subgrade	/	0.40	17.8	76,000

The following loading conditions were utilized to determine the pavement layer behavior under different axle load:

1. Traffic load (single axle dual tires).
2. Contact pressure (500 kPa).
3. Contact area (115 mm).
4. The axle loading as (60,120,180,240, and 300) kN, to determine the pavement layer behavior under different axle loads.
5. Design life in this study 20 years.

5.2.3 Results and Comparisons

The analysis and comparison process depends on three main parameters as follow:

- First parameter is the allowable number of load repetitions (Nd) to limit rutting this is related to the vertical compressive strain (ϵ_c) on top of the subgrade by:

$$Nd = f4 * (\epsilon c) - f5 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad eq5.1$$

  Where:

  N_d: allowable number of load repetitions.

  ϵ_c: vertical compressive strain on top of the subgrade layer.

  f_4 and **f_5**: $1.05*10^{-7}$, 4 respectively, (**Huang, 2004).**

- Second parameter is damage ratio which is computed using the following equation:

$$Damage\ ratio = \frac{1}{Nd} \quad \dots\dots\dots\dots\dots eq5.2$$

  Where:

  N_d**:** allowable number of load repetitions.

- Third parameter is rutting life which is computed using the following equation:

$$Rutting\ life = \frac{design\ life}{damage\ ratio} \quad \dots\dots\dots\dots\dots eq5.3$$

To compare the results, the axle load is restricted to 60 kN in order to illustrate the impact of soil stabilization with cement in addition to the impact of rubber on improving its properties. Additionally, analyzing each case of stabilized soil by using different axle loads to determine compressive stress and compressive strain.

For the natural subgrade soil, the allowable number of load repetitions (Nd) value equal to 1,269,282 the compressive stress is 48.28 kPa, the compressive strain is $5.363*10^{-4}$, the damage ratio and rutting life equal to 7.88E-07 and 2.54E+07 respectively as shown in **Figure 5.4**, in Figure **5.5,** and as summarized in **Table 5.2**.

For the cemented soil, the allowable number of load repetitions (Nd) value equal to 1,638,974 the compressive stress is 56.04 kPa, the compressive strain is $5.031*10^{-4}$, the damage ratio and rutting life equal to 6.10E-07 and 3.28E+07respectively as shown in **Figure 5.4**, in **Figure 5.5**, and as summarized in **Table 5.2**.

Noted increasing Nd with using cement content because the cement increase stiffness of soil, increasing shear resistance, and increasing compressive stress. Decreasing the damage ratio, increasing rutting life, and decreasing the compressive strain. Because cement is a substance that connects soil particles and improving soil properties, and reduces the proportion of void ratio which they get due to the effect of gypsum in the soil when exposed to water. Increasing loads decrease the allowable number of load repetitions (Nd) values, increasing the compressive stress, increasing the compressive strain, and the damage ratio, decreasing the rutting life.

For cemented soil – crumbs stabilized soil, as shown in **Figures 5.4** and **5.5**, the allowable number of load repetitions (Nd) values for three percent of crumbs 5%,10%, and 20% are 1,614,447, 1,576,647, and 1,287,430 respectively. the compressive stress values ranged from 48.65 kPa to 55.51 kPa and the compressive strain values varied from $5.344*10^{-4}$mm to $5.05*10^{-4}$ mm for three percentage of crumbs, the damage ratio values for three percent of crumbs 5%,10%, and 20% are 6.19E-07, 6.34E-07, and 7.77E-07 respectively, and the rutting life values for three percent of crumbs 5%,10%, and 20% are 3.23E+07, 3.15E+07, and 2.57E+07 respectively, as summarized in **Table 5.2**.

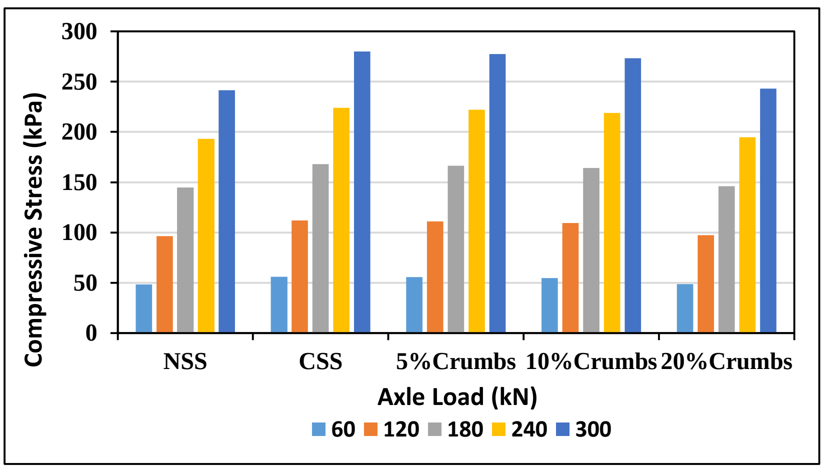


Figure (5.4): Effect Axle Load on Compressive Stress of Crumbs

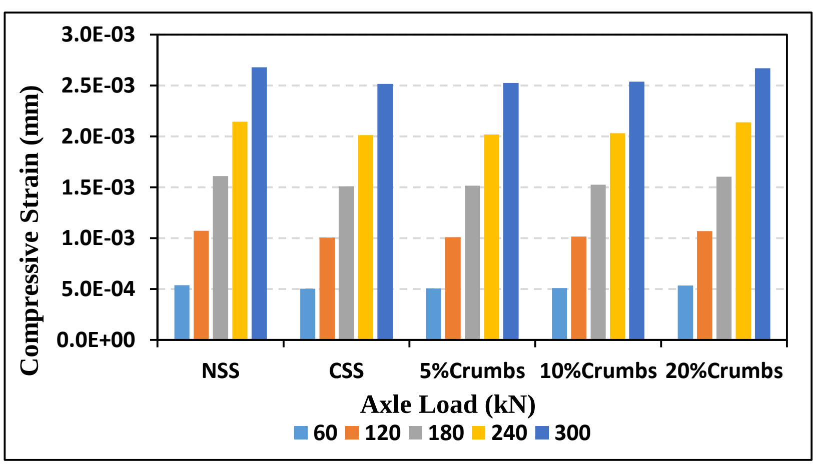


Figure (5.5): Effect Axle Load on Compressive Strain of Crumbs

Comparing results with cemented soil results noted the impact of crumbs properties on soil behavior with loads and for various tests, when increasing the percentage of crumbs, the compressive strain decreased and increase value the compressive strain. Additionally, decreasing the allowable number of load repetitions (Nd) when increasing the percent of crumbs, and increases the damage ratio. Consider to rutting life decrease when increasing the percentage of crumbs. This behavior shows, consistent with the fact that the gypsum ratio in the soil is decreasing. crumbs, which have the capacity to withstand compressibility under different loading, increase the material's resilience.

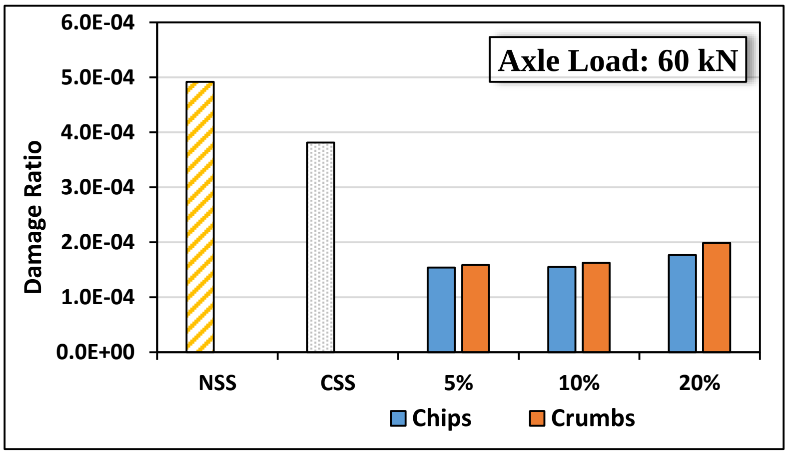


Figure (5.6): Explain The Damage Ratio of Chips and Crumbs

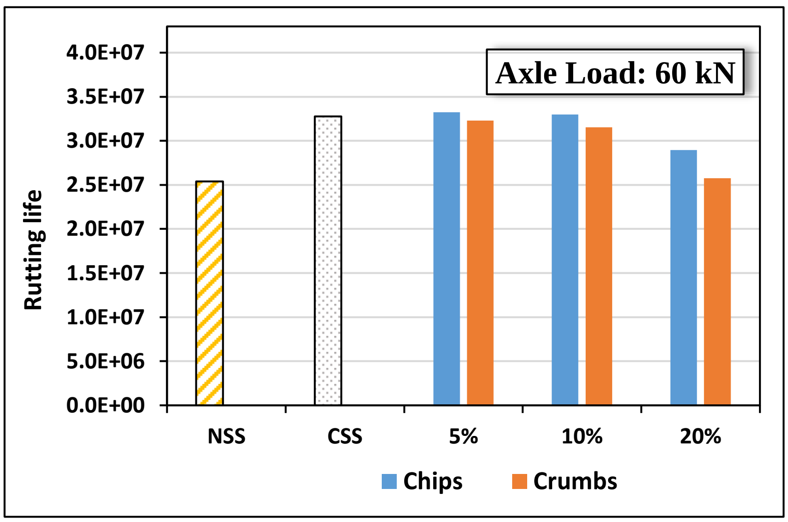


Figure (5.7): Explain The Rutting Life of Chips and Crumbs

For cemented soil – chips stabilized soil, the allowable number of load repetitions (Nd) values for three percent of chips 5%,10%, and 20% are 1,661,315, 1,649,441, and 1,447,172 respectively, the compressive stress values are ranged from 51.95 kPa to 56.43 kPa, as shown in **Figure 5.8**, and the compressive strain values are ranged from $5.19*10^{-4}$ mm to $5.014*10^{-4}$ mm for three percentage of chips, as shown in **Figure 5.9**, the damage ratio values for three percent of chips 5%,10%, and 20% are 6.06E-07, 6.06E-07, and 6.91E-07 respectively, and the rutting life values for three percent of chips 5%,10%, and 20% are 3.32E+07, 3.30E+07, and 2.89E+07 respectively.

When results from different tests were compared to those from cemented soil, it became clear how the properties of the chips affected the behavior of the soil under loads. Increasing the percentage of chips the compressive strain decreasing. Additionally, increasing the percentage of chips decreasing the number of load repetitions (Nd) and increases the damage ratio, and determine the reduction in rutting life. That improve the material's resilience and have the ability to withstand under static and dynamic load conditions, as summarized in **Table 5.2.**

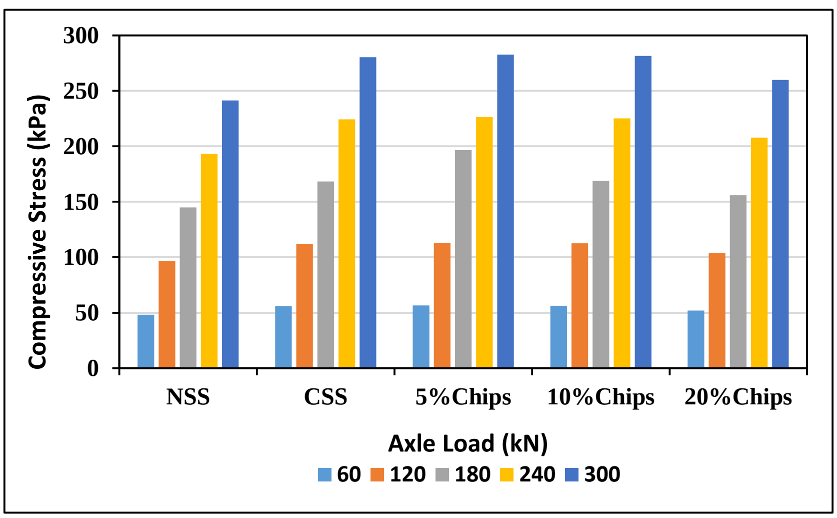


Figure (5.8): Effect Axle Load on Compressive Stress of Chips

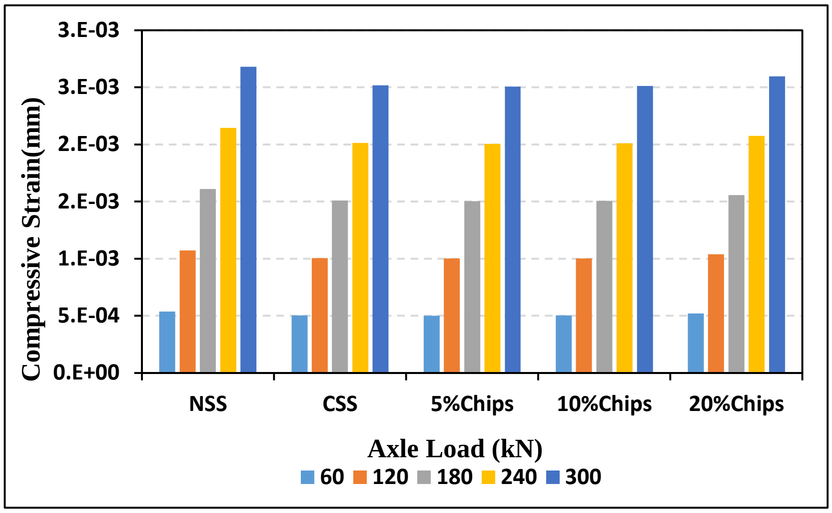


Figure (5.9): Effect Axle Load on Compressive Strain of Chips

Table 5.2: Summary of KENLAYER Program Analysis Results

Property	Axle Load kN	Comp. Stress kPa	Comp. Strain mm	Nd	Damage Ratio	Rutting Life
Nss	60	48.28	$5.363*10^{-4}$	1,269,282	7.88E-07	2.54E+07
	120	96.45	$1.071*10^{-3}$	79,806	1.25E-05	1.60E+06
	180	144.83	$1.609*10^{-3}$	15,667	6.38E-05	3.13E+05
	240	193.11	$2.145*10^{-3}$	4,960	2.02E-04	9.92E+04
	300	241.39	$2.681*10^{-3}$	2,033	4.92E-04	4.07E+04
Css	60	56.04	$5.031*10^{-4}$	1,638,974	6.10E-07	3.28E+07
	120	111.95	$1.005*10^{-3}$	102,926	9.72E-06	2.06E+06
	180	168.11	$1.509*10^{-3}$	20,251	4.94E-05	4.05E+05
	240	224.15	$2.013*10^{-3}$	6,395	1.56E-04	1.28E+05
	300	280.18	$2.516*10^{-3}$	2,621	3.82E-04	5.24E+04
C5CrNs	60	55.51	$5.05*10^{-4}$	1,614,447	6.19E-07	3.23E+07
	120	110.91	$1.009*10^{-3}$	101,304	9.87E-06	2.03E+06
	180	166.54	$1.515*10^{-3}$	19,932	5.02E-05	3.99E+05
	240	222.06	$2.02*10^{-3}$	6,307	1.59E-04	1.26E+05
	300	277.57	$2.525*10^{-3}$	2,584	3.87E-04	5.17E+04
C10CrNs	60	54.70	$5.08*10^{-4}$	1,576,647	6.34E-07	3.15E+07
	120	109.27	$1.015*10^{-3}$	98,930	1.01E-05	1.98E+06
	180	164.09	$1.524*10^{-3}$	19,465	5.14E-05	3.89E+05
	240	218.78	$2.032*10^{-3}$	6,159	1.62E-04	1.23E+05
	300	273.48	$2.540*10^{-3}$	2,523	3.96E-04	5.05E+04

Table 5.2: Summary of KENLAYER Program Analysis Results, Continued

C20CrNs	60	48.65	$5.344*10^{-4}$	1,287,430	7.77E-07	2.57E+07
	120	97.19	$1.068*10^{-3}$	80,706	1.24E-05	1.61E+06
	180	145.94	$1.603*10^{-3}$	15,903	6.29E-05	3.18E+05
	240	194.59	$2.138*10^{-3}$	5,026	1.99E-04	1.01E+05
	300	243.24	$2.672*10^{-3}$	2,060	4.85E-04	4.12E+04
C5ChNs	60	56.43	$5.014*10^{-4}$	1,661,315	6.02E-07	3.32E+07
	120	112.69	$1.002*10^{-3}$	104,165	9.60E-06	2.08E+06
	180	196.63	$1.504*10^{-3}$	20,521	4.87E-05	4.10E+05
	240	226.17	$2.006*10^{-3}$	6,485	1.54E-04	1.30E+05
	300	282.71	$2.507*10^{-3}$	2,659	3.76E-04	5.32E+04
C10ChNs	60	56.16	$5.023*10^{-4}$	1,649,441	6.06E-07	3.30E+07
	120	112.46	$1.003*10^{-3}$	103,750	9.64E-06	2.08E+06
	180	168.88	$1.507*10^{-3}$	20,359	4.91E-05	4.07E+05
	240	225.17	$2.009*10^{-3}$	6,446	1.55E-04	1.29E+05
	300	281.46	$2.511*10^{-3}$	2,642	3.79E-04	5.28E+04
C20ChNs	60	51.95	$5.19*10^{-4}$	1,447,172	6.91E-07	2.89E+07
	120	103.78	$1.037*10^{-3}$	90,798	1.10E-05	1.82E+06
	180	155.84	$1.557*10^{-3}$	17,867	5.60E-05	3.57E+05
	240	207.78	$2.07*10^{-3}$	5,654	1.77E-04	1.13E+05
	300	259.73	$2.595*10^{-3}$	2,316	4.32E-04	4.63E+04

5.3 Economic Analysis

In this analysis, a pavement section was selected to determine actual construction cost of stabilizing process compared with replacement process.

The selected untreated pavement section has the following dimensions: length = 1000 m, width = 12 m, and thickness = 60 cm, to examine the cost of constructing stabilized pavement section was compared with that of the untreated pavement section. **Table 5.3** present the overall cost in the case of the soil replacement process.

Table 5.3:Summarized Cost of The Replacement Process

Items description	Qty	Unit	Price IQD/Unit	Amount IQD
Cleaning the site, removing a layer with a thickness of 20 cm, loading the soil, and transporting it away from the construction site in accordance with the necessary standard and technical requirements.	2400	m^3	2,000	4,800,000
Purchasing and transferring new soil in order to replace weak soil and according to technical and engineering requirements	2400	m^3	5,000	12,000,000
According to the project's technical and engineering requirements, the new soil is leveled to the necessary road level and compacted well.	2400	m^3	2,500	6,000,000
On-site staff and a site engineer are working to establish the level, and effectively complete the job until the new soil work is finished.	2400	m^3	1,250	3,000,000
Total cost of replacement process for first layer with 20cm thickness	25,800,000 IQD			
The effect of the loading on the subgrade layer at a depth greater than 60 cm will become a thickness replacement of 60 cm or more. Assumed 60 cm replacement only.	Total cost = 3 * 25,800,000			
Total cost of replacement process with 60 cm depth	77,400,000 IQD			

relative to the treated pavement section selected C10ChNS state and the selected treated pavement section has the following dimensions: length = 1000 m, width = 12 m, and thickness = 20 cm, and Volume = 2400 m^3, as summarized in **Table 5.4**.

The difference between the replacement process and the stabilization process in the pavement = 77,400,000 - 65,898,000 = 11,502,000 IQD. The stabilization process is saving = 11,502,000 IQD as a percent saving 15% from replacement process, as shown in **Table 5.5**. Additionally, reduce the environmental impact of the waste tire rubber from their accumulations.

Table 5.4: Summarized Cost of The Stabilization Process

Items description	*Qty*	*Unit*	*Price IQD/Unit*	*Amount IQD*
Cleaning the construction site, remove a layer of road that is 20 cm thick, and then arrange this into stocks such that installation materials may be added to it. Additionally, a part of the soil should be removed, cement and rubber inserted, and then the soil must be fully compacted in accordance with standards specifications.	2400	m^3	3,000	7,200,000
On-site staff and a site engineer are working to establish the level, follow up, and effectively complete the job until the new soil work is finished.	2400	m^3	1,250	3,000,000
Preparing and purchasing sulfate-resistant Portland cement for use in chemical soil stabilization and accordance with engineering requirements	441.6	ton	80,000	35,328,000
Waste materials (granulated tire rubber)	679	m^3	30,000	20,370,000
The total cost of stabilization methods, with 20 cm thickness of soil.	65,898,000 IQD			

Table 5.5: Summarized The Comparison of Results

Replacement Process Cost	Stabilization Process Cost
Replacement shall be on three layers and each layer 20 cm thick, taking into account the engineering specifications of the implementation.	The satbilization shall be on one layer with a thickness of 20cm, taking into account the engineering specifications of the implementation.
The quantity of soil being replaced is considered to be a loss of soil for ineffectiveness.	The quantity of soil being stabilized is effective.
Using new soil and the duration of the work in case of replacement is longer from the stabilization process	Do not use new soil and the duration of work is less than the replacement process.
Total cost of replacement process with 60 cm depth = 77,400,000 IQD	The total cost of stabilization methods, with 20 cm thickness of soil = 65,898,000 IQD

5.5 Summary

Theoretical analysis is an essential tool for evaluating the chemical and mechanical soil stabilization and the effect of these materials on the elastic modulus of the soil under different axle load cases. This chapter showed using cement increases Nd, compressive stress, rutting life, and decreasing compressive strain, and damage ratio. Using GTR decreases Nd, compressive stress, rutting life, and increasing compressive strain, and damage ratio. Additionally, It was determined that utilizing GTR-cement combines has a sustainable and economical potential in stabilizing the local gypseous subgrade soils since the stabilization procedure saves 15% of the cost of the replacement process.

Chapter Six : Conclusions and Recommendations

Chapter Six
Conclusions and Recommendations

6.1 Conclusions

This study aimed to determine the improvement in the properties of subgrade soil stabilized by using cement and granulated tire rubber depending on the performances of laboratory tests, simulation tests, and theoretical analysis.The main conclusions can be listed below:

1. Using cement in loose subgrade sand soils, improves soil properties such as density, CBR value, and unconfined compressive strength. Additionally, increased curing age also improves soil properties stabilized with cement.
2. It was found that the soil toughness increases with increasing GTR content (i.e., crumbs and chips) leading to a significant reduction in the brittleness of cemented-sand mixtures.
3. The unconfined compressive strength and bearing resistance of the cemented-sand are significantly reduced by the addition of granulated tire crumbs. The highest reduction in UCS and Es was 24% and 80%, respectively, at 20% tire crumbs content.
4. The addition of wasted tire chips significantly reduces the cemented sand's unconfined compressive strength and bearing resistance. The highest reductions in UCS and Es were 20.5% and 80%, respectively, at 20% tire chip content.
5. Strength and stiffness parameters of the stabilized sand mixtures decrease with increasing GTR content (i.e., chips and crumbs). However, these parameters of the stabilized soil are still greater than those of the natural subgrade soils.

6. It was found a reduction in dynamic modulus with increasing crumbs and chips content in stabilized cemented-sand. However, the dynamic measurements of the GTR-cemented sand mixtures are better than those obtained from the natural subgrade sand soil.
7. Dynamic cone penetration index increases with in increasing crumbs and chips content in the soil. When using GTR show a decrease in DCPIndex, increasing GTR content increased DCPIndex, these results were found after comparing with the cemented subgrade soil.
8. Incorporating 10% cement and 5 to 10% GTR into unstable subgrade soils could reduce the cost of stabilization besides minimizing the environmental impact of wasted tires.
9. The 10% is the best percentage of crumbs and chips for use as mechanical stabilizers based on the results of the experimental results.
10. From comparing the results, it turns out that chips are better than crumbs.
11. The stabilization process is saving provides 15% cost of replacement process.

6.2 Recommendations and Further Study

1- Future studies should consider the effect of the ground water table on characteristics of the strength of the stabilizing soil.

2- Assessing the effectiveness of using cement and GTR as stabilizing materials in soft cohesive soils.

3- Evaluating the potential use of GTR in earth embankment and retaining walls.

4- Use others materials for mechanical stabilization such as waste plastic materials and other pozzolanic materials such as fly ash and slag.
5- Using numerical finite element simulation to evaluate the performance of unbound pavement materials stabilized using granulated tire rubber.

Referances

AASHTO M145, 2012,"Standard Specification for Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes," American Association of State and Highway Transportation Officials, Washington, DC.

AASHTO T222, 2007, "Nonrepetitive static plate load test of soil and flexible pavement components for use in evaluation and design of airport and highway pavements. “American Association of State Highway and Transportation Officials, Washington.

Afrin, H., 2017. A review on different types soil stabilization techniques. International Journal of Transportation Engineering and Technology, 3(2), pp.19-24.

Agriculture Organization of the United Nations. Soil Resources, Management and Conservation Service, 1990. Management of gypsiferous soils (Vol. 62). Food & Agriculture Org.

Ahmed, A., Kamau, J., Pone, J., Hyndman, F. and Fitriani, H., 2019. Chemical reactions in Pozzolanic concrete. Mod. Approaches Mater. Sci, 1, pp.125-137.

Akbariyeh, N. 2015, "A new technique for the estimation of the elastic moduli of pavement layers from light weight Deflectometer data." The university of Texas at arlinton, August 2015.

Al-Aghbari, M.Y. and Mohamedzein, Y.E., 2015. Improvement of bearing capacity of strip footings on dune sands geogrids. In 2nd Intl. Conference on Trends in Multidisciplinary Business and Economic Research (Vol. 2, pp. 135-143).

Ali Q. Fathi, 2021, “Applications of Plastic Waste Fiber and Lime Materials in Stabilizing Sustainable Pavement Foundation Layer”, Submitted to the Department of Civil Engineering at the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

AL-Kaaby, F.S., 2007. Distribution of the gypsiferous soil in Iraq. North Carolina Department of Transportation Geotechnical Engineering Unit – Geopavement Section Materials and Tests Unit – Field Operations Section.

Al-Neami, M.A. 2018, “Stabilization of sandy soil using Recycle Waste Tire Chips,” International Journal of GEOMATE, 15(48).

Al-Tabbaa, A. and Perera, A. 2005, “Binders and technologies – applications,” Stabilisation/Solidification Treatment and Remediation, pp. 399–413.

Amjaad H.A.& Raid R. A. A., and A. Shaban, 2021,” Evaluation Subgrade Reaction Modulus of Subgrade Soils Sustainability Stabilized by Plastic Waste Materials”. Submitted to the Department of Civil Engineering at the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

Amuthan, M. S., Boominathan, A., & Banerjee, S. 2020,” Undrained cyclic responses of granulated rubber-sand mixtures”. Soils and Foundations, 60(4), 871-885.

Anvari, S.M., Shooshpasha, I. and Kutanaei, S.S., 2017,” Effect of granulated rubber on shear strength of fine-grained sand”. Journal of Rock Mechanics and Geotechnical Engineering, 9(5), pp.936-944.

Ashraf, M.S., Azahar, S.B. and Yusof, N.Z. 2017, “Soil improvement using MICP and biopolymers: A Review,” IOP Conference Series: Materials Science and Engineering, 226, p. 012058.

ASTM D1556,2010, Standard Test Method for Density and Unit Weight of Soil in Place by “the Sand-Cone Method”.

ASTM D1557–12, 2012, "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort," American Society for Testing and Materials (ASTM), West Conshohocken, PA.

ASTM D1883–09, 2009, "Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils," American Society for Testing and Materials (ASTM), West Conshohocken, PA.

ASTM D2487 – 11, 2005, "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)," American Society for Testing and Materials ASTM, West Conshohocken, PA.

ASTM D4318 – 10, 2005, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils”, American Society for Testing and Materials ASTM, West Conshohocken, PA.

ASTM D6951,2009. “Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications," American Society for Testing and Materials ASTM, West Conshohocken, PA.

ASTM D854 – 14, 2014, “Standard Test Methods for Specific Gravity of Soil Solids by Water Pecnometer", American Society for Testing and Materials (ASTM), West Conshohocken, PA.

ASTM E2583-07, 2011, "Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)." ASTM International, West Conshohocken, PA.

ASTM. D6270- 17 ,2017,” Standard practice for use of scrap tires in civil engineering applications”. West Conshohocken.

Ateş, A. 2016, “Mechanical properties of sandy soils reinforced with cement and randomly distributed glass fibers (GRC),” Composites Part B: Engineering, 96, pp. 295–304.

Barazanji, A.F., 1973. Gypseous soil of Iraq. State University of Ghent, Belgium (Ph. D. Thesis).

Boutouba, K. et al. 2019, “Shear strength enhancement of cemented reinforced sand: Role of cement content on the macro-mechanical behavior,” Studia Geotechnica et Mechanica, 41(4), pp. 200–211.

BS1377-3 1990,‘Soils for civil engineering purposes — Chemical and electro-chemical tests’. Burmister, D.M., 1958. ‘Evaluation of pavement systems of the WASHO road test by layer system method’, Highway Research Board Bulletin, 177, 26–54.

Cheng, Z., Wang, J., & Li, W. 2020,"The micro-mechanical behaviour of sand–rubber mixtures under shear": An experimental study based on X-ray micro-tomography. Soils and Foundations, 60(5), 1251-1268.

Choobbasti, A.J. and Kutanaei, S.S. 2017, "Microstructure characteristics of cement-stabilized sandy soil using nanosilica," Journal of Rock Mechanics and Geotechnical Engineering, 9(5), pp. 981–988.

Choobbasti, A.J., Vafaei, A. and Kutanaei, S.S. 2015, "Mechanical properties of sandy soil improved with cement and Nanosilica," Open Engineering, 5(1).

Choudhary, A.K., Jha, J.N. and Gill, K.S. 2010, "A study on CBR behavior of waste plastic strip reinforced soil," Emirates Journal for Engineering Research, vol. 15, no. 1, pp. 51-57.

Cokca, E. and Yilmaz, Z. 2004, "Use of rubber and bentonite added fly ash as a liner material," Waste Management, 24(2), pp. 153–164.

El-Hanafy, A.M. and AbdelAziz, M.H., 2021,"Effect of using cemented sand as a replacement layer beneath a strip footing". HBRC Journal, 17(1), pp.1-17.

Grammelis, P., Margaritis, N., Dallas, P., Rakopoulos, D. and Mavrias, G., 2021," A review on management of end of life tires (ELTs) and alternative uses of textile Fibers". Energies, 14(3), p.571.

Iraqi Specifications No. (5), 1984 for Portland Cement.

Karim, H.H., Schanz, T. and Ibrahim, A.N., 2015, "October. Microstructural Characterization of Iraqi Gypseous Soils". In Proceedings of the 2nd International

Conference of Buildings, Construction and Environmental Engineering, American University of Beirut (BCEE2) (pp. 17-18).

Laith.A.& Raid R. A. A., and A. Shaban, 2021." Evaluating Performance of Portable Dynamic Cone Penetrometer in Characterizing Subgrade Reaction Modulus of Sandy Soil". Submitted to the Department of Civil Engineering at the University of Kerbala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

Little, D.N., 1995. Stabilization of pavement subgrades and base courses with lime.
Maaitah, O.N. 2012, "Soil Stabilization by chemical agent," Geotechnical and Geological Engineering, 30(6), pp. 1345–1356.

MacLaren, D.C. and White, M.A. 2003, "Cement: Its chemistry and properties," Journal of Chemical Education, 80(6), p. 623.

Makusa GP ,2012, " Soil stabilization methods and materials in engineering practice, state of the art review". Lulea University of Technology, Sweden.

Mansour, Z.M., Chik, Z. and Taha, M.R. 2008, "On the procedures of soil collapse potential evaluation," Journal of Applied Sciences, 8(23), pp. 4434–4439.

Mashhadban, H., Beitollahi, A. and Kutanaei, S.S. 2016, "Identification of soil properties based on accelerometer records and comparison with other methods," Arabian Journal of Geosciences, 9(6).
Mashhadban, H., Beitollahi, A. and Kutanaei, S.S., 2016, "Identification of soil properties based on accelerometer records and comparison with other methods". Arabian Journal of Geosciences, 9, pp.1-8.

Mashiri, M.S., Vinod, J.S., Sheikh, M.N. and Tsang, H.H., 2015, "Shear strength and dilatancy behaviour of sand–tyre chip mixtures". Soils and Foundations, 55(3), pp.517-528.

Neaz Sheikh, M., Mashiri, M.S., Vinod, J.S. and Tsang, H.H., 2013, "Shear and compressibility behavior of sand–tire crumb mixtures". Journal of Materials in Civil Engineering, 25(10), pp.1366-1374.

Pancar, E.B. and Akpınar, M.V. 2016, "Comparison of effects of using geosynthetics and lime stabilization to increase bearing capacity of unpaved road subgrade," Advances in Materials Science and Engineering, 2016, pp. 1–8.

Paschal A.M., Nnaji G. O., and Kennedy E. C., 2020, "Modification of Expansive Clay Soil using Fiber and Cement in Combined Measures for Highway Pavement", Global Scientific Journal: 8(1).

Paulinus A. P., Prince L. L., and Charles K., 2018, "Performance Characteristics of Stabilized Soils using Irvinga Gabonesis Fiber and Lime as Stabilizer", International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online) Vol. 6, Issue 2, pp: (35-42).

Peddaiah, S., Burman, A. and Sreedeep, S., 2018, "Experimental study on effect of waste plastic bottle strips in soil improvement". Geotechnical and Geological Engineering, 36, pp.2907-2920.

Poweth, M.J., Haneef, F.M., Jacob, M.T., Krishnan, R. and Rajan, S., 2014, "Effect of plastic granules on the properties of soil". International Journal of Engineering Research and Applications, 4(4), pp.160-164p.

Sawyer, John E., 2003, "Gypsum: an old product with a new use" Integrated Crop Management News. Paper 1654.

Schanz, T. and Karim, H.H.2018, “Geotechnical characteristics of some Iraqi gypseous soils,” MATEC Web of Conferences, 162, p. 01005.

Shaban, A., and Cosentino, P., 2016, " Comparative Analyses of Granular Pavement Moduli Measured from Lightweight Deflectometer and Miniaturized Pressuremeter Tests." Transportation Research Record: Journal of the Transportation Research Board, Vol. 2016, No.2579, pp. 48-58.

Sharafi, H., & Shekarbeigi, M. 2019, “Experimental evaluation of the behavior of Sandy Soil–Cement Mixture”. Revista Ingeniería UC, 26(3), 258 272.

Sherwood, P., 1993, “Soil stabilization with cement and lime”.

Shooshpasha, I. and Shirvani, R.A. 2015, “Effect of cement stabilization on geotechnical properties of sandy soils,” Geomechanics and Engineering, 8(1), pp. 17–31

Shooshpasha, I. and Shirvani, R.A., 2015, “Effect of cement stabilization on geotechnical properties of sandy soils”. Geomech Eng, 8(1), pp.17-31.

Solihu, H. 2020, “Cement soil stabilization as an improvement technique for rail track subgrade, and Highway Subbase and base courses: A Review,” Journal of Civil and Environmental Engineering, 10(3).

Tasalloti, A., Chiaro, G., Murali, A. and Banasiak, L., 2021, “Physical and mechanical properties of granulated rubber mixed with granular soils”—a literature review. Sustainability, 13(8), p.4309.

Tiwari, B. et al. 2014, “Improving geotechnical behavior of clayey soils with shredded rubber tires—preliminary study,” Geo-Congress 2014 Technical Papers [Preprint].

Umar, M., Kassim, K.A. and Ping Chiet, K.T. 2016, “Biological process of soil improvement in Civil Engineering: A Review,” Journal of Rock Mechanics and Geotechnical Engineering, 8(5), pp. 767–774.

Wang, F. et al.2021, “Experimental study on the erosion resistance of rubberized cement-soil,” Soils and Foundations, 61(3), pp. 734–751.

Younis, K.H., 2014, “Restrained shrinkage behaviour of concrete with recycled materials”, (Doctoral dissertation, University of Sheffield).

Yung, W.H., Yung, L.C. and Hua, L.H. 2013, “A study of the durability properties of waste tire rubber applied to self-compacting concrete,” Construction and Building Materials, 41, pp. 665–672.

Zhang, Z. and Tao, M.2008, “Durability of cement stabilized low plasticity soils,” Journal of Geotechnical and Geoenvironmental Engineering, 134(2), pp. 203–213.

الخلاصة

الطرق من اهم المنشاءت الرئيسية للبلد ومقياس لتطور البلدان من حيث سهولة التنقل والتجارة عن طريقها. يتكون نظام الطرق من عدة طبقات تصمم وفق المعايير الخاصة للطرق مثل الاحمال المرورية وكذلك تضاريس وطبيعة التربة من المناطق المراد الانشاء عليها. نوع التربة ومقاومتها للاحمال هي العنصر الجوهري في عملية تصميم الطرق وتحديد استخدامها, ولعلهُ نسبة كبيرة او شاسعة من مناطق العراق هي تربة رملية وذات محتوى جبسي متفاوت من منطقة الى أخرى, في محافظة كربلاء جزء كبير من التربة الجبسية لذلك تتمحور هذه الدراسة حول هذه التربة لما فيها من مشاكل عديدة أولا عند تعرضها للماء ولتغطية التوسع العمراني المفروض في المحافظة نتيجه تزايد عدد السكان ومتطلبات الطرق فيها.تم اخذ نماذج من التربة من مناطق مختلفة وفحص نسبة الجبس فيها حيث تم اختيار تربة قريبة من مشروع مطار كربلاء الدولي لانها تحتوي على اعلى نسبة جبس من النماذج التي تم فحصها. التربة الجبسية ذات قوة تحمل جيدة في حالة الجفاف لكنها خطرة عند تعرضها للماء حيث يتفاعل الجبس مع الماء ويترك فجوات فيها مما يُزيد قابلية الانهيار في هذه الترب. الهدف من هذه الدراسة هو تحسين خصائص التربة الرملية الضعيفة والتي تحتوي على نسبة من الجبس تصل إلى حوالي 12٪ ومصنفة على أنها تربة جبسية معتدلة. حيث تم تثبيت التربة باستخدام الأسمنت بنسبة 10 ٪ مع نوعين مختلفين من نفايات الإطارات المطاطية (granulated tier rubber GTR) المعروفة باسم crumbs, and chips. استُخدمت ثلاث نسب مختلفة من الإطارات المحببة بنسبة 5 ٪ و 10٪ و 20٪ كبديل للتربة و تم إجراء برنامج عملي لاجراء الفحوصات لتقييم خصائص التربة المُعالجة و تقسيمه إلى مرحلتين: المرحلة الأولى تتكون من ثلاثة اختبارات مختبرية تشمل:

Compaction test & california bearing ratio(CBR) test and unconfined compression strength (UCS) test , حيث تم علاج جميع عينات مخاليط GTR الرملية الأسمنتية لمدة 1 و 3 و 7 أيام .

. يتم تقليل قوة الضغط غير المحصورة ومقاومة التحمل للرمل الأسمنتي بشكل كبير عن طريق إضافة حبيبات المطاط. كان أعلى انخفاض في Es , UCS وهي 24٪ و 80٪ على التوالي ، بنسبة 20٪ من فتات الإطارات مقارنة بنتائج التربة الأسمنتية. تقلل إضافة رقاقات الإطارات المهدورة بشكل كبير من قوة الانضغاط غير المحصورة للرمل الأسمنتي ومقاومة التحمل. كانت أعلى التخفيضات في Es , UCS وهي 20.5٪ و 80٪ على التوالي عند 20٪ من محتوى رقاقة الإطارات مقارنة بنتائج التربة الأسمنتية.

وتتضمن المرحلة الثانية إجراء ثلاثة اختبارات في الموقع بما في ذلك: (1) اختبار اختراق المخروط الديناميكي (dynamic cone penetration test DCP) ، (2) فحص الهطول خفيف الوزن

light weight deflectometer (LWD)، و (3) طريقة استبدال الرمال sand replacement method (SRM). تم علاج جميع العينات من مخاليط GTR الأسمنتية لمدة 3 أيام.

أظهرت نتائج هذه الاختبارات تحسنًا ملحوظًا في مؤشر اختراق المخروط الديناميكي (DCPI) وانحراف السطح والمعامل الديناميكي وكثافة الحقل الجاف نتيجة استخدام الأسمنت. ومع ذلك ، تنخفض معايير التربة هذه مع زيادة استبدال GTR مقارنة مع التربة المثبتة بالاسمنت لكن تبقى النتائج افضل من التربة الطبيعية نفسها بدون معالجة.

أيضًا استخدام النتائج التي تم الحصول عليها من العمل التجريبي كمعامِلات إدخال في نموذج نظري تم إنشاؤه بواسطة برنامج KENPAVE لتقييم أداء تربة التربة المستقرة تحت قيم تحميل محوري مختلفة. يُحسن استخدام الأسمنت مقاومة القص ، ويزيد من إجهاد الضغط ، ويزيد Nd ، ويقلل من نسبة الضرر. عند زيادة النسبة المئوية لـ GTR ، يتم تقليل العدد المسموح به لتكرار الحمل (Nd) وزيادة نسبة الضرر. حيث تظهر النتائج ان افضل نسبة من المطاط وعلى نوعية هي 10% ومن خلال مقارنة النتائج نلاحظ ان استعمال قطع المطاط chips افضل من crumbs.

. بالإضافة إلى ذلك، تم إجراء التحليل الاقتصادي لعملية استبدال التربة وعملية تثبيت التربة من خلال تحديد تكلفة هذه العمليات ومقارنتها. توفر عملية التثبيت 15 ٪ من تكلفة عملية الاستبدال ، وقد خلص إلى أن استخدام مخاليط الأسمنت GTR له إمكانات مستدامة واقتصادية في تثبيت تربة الطبقة السفلية المحلية.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة المدنية

تحسين الخصائص الديناميكية لطبقات الرصف الطبيعية المثبتة بالمطاط

رسالة مقدمة الى مجلس كلية الهندسة جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية

من قبل:

صفاء محمد علي

باشراف :

أ.م. د. علاء محمد جواد هادي

أ.م. د. رائد رحمان المحنة

شوال - 1444 **مايو - 2023**