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**SANDY SOIL IMPROVEMENT BY USING
RECYCLED ECO-FRIENDLY MATERIAL**

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Master's Thesis

Supervisor

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Signature

DEDICATION

This thesis is dedicated to the beloved man who has meant and continues to mean so much to me. Although he is no longer with us, his memories continue to guide my life. to my father Khalid, who loved me unconditionally and taught me the value of hard work. Thank you so much; you will never be forgotten. My dissertation is also dedicated to my family and many friends a special thanks to my loving mother, grandmother, aunt, brother, and Nazar whose words of encouragement and push for tenacity still ring in my ears. My sister Aya has never left my side and is very special to me This dissertation is also dedicated to my many friends who have helped me throughout the process. I will be eternally grateful to them for everything they have done for me, especially Lubna for her kind words of encouragement, Noor for lifting my spirits whenever I felt down, and Lara for the many hours she has spent calming me down and encouraging me to keep going Special thanks to Dr. Faris Waleed, who was my first mentor on this journey.

ABSTRACT

SANDY SOIL IMPROVEMENT BY USING RECYCLED ECO-FRIENDLY MATERIAL

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The soil in Iraq is diverse, with the soil in northern Iraq differing from that in the centre and south. Large portions of Iraq are covered in sandy soil, which is dry and fragile. To construct on such soil, it must be improved. The use of additives such as oil derivatives, polymers, and chemicals in soil enhancement is damaging to the environment as a result, the world has recently tended to upgrade and reinforced the soil using environmentally and sustainable resources. The objective of this research is to use environmentally friendly recycled materials to improve the engineering properties of sandy soils in Iraq. Jute fibers were employed as an additive in this study since they are considered an environmentally and sustainable material. Jute fibers were utilized in this study in two methods (ODFS and RDFS) to investigate the possibility and the amount of their effectiveness in improving sandy soils. The results demonstrated that adding jute fibers to the soil improved its engineering properties significantly and reduces settlement. The study also showed using jute fibers as sheets (ODFS) is more effective than mixing the fibers with the soil (RDFS).

Keywords: Soil Improvement, Jute Sheet, Sandy Soil, Natural Fibers, Recycled Materials.

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ABBREVIATIONS

ODFS	:	Oriented Distributed Method
RDFS	:	Randomly Distributed Method
Cc	:	Coefficient of Curvature
Cu	:	Coefficient of Uniformity
Gs	:	Specific Gravity



1. INTRODUCTION

1.1 INTRODUCTION

Soil is considered an essential element in construction. Therefore, for a civil engineer, soil is a very important element. Most construction works are built on foundations consisting of soil, this soil must be strong enough to bear the loads and to function efficiently as the foundation of any building. Soil has physical, chemical, and mineral properties. Soil improvement is the method by which these properties are improved.

Because soil is the least costly material for construction, the researchers' fundamental goal was to find a technique to improve the properties of weak soils to meet engineering standards. Sandy soil is common in Iraq, particularly in the country's southern and eastern regions. Because of urban development and city expansion, some engineers frequently encounter weak sandy soils during work, which must be modified.

Soil improvement with additives is very common and widely used since it is one of the simplest ways to improve soil and has a lower economic cost than other techniques of stabilization. Recently, there has been a movement in several fields to incorporate environmentally friendly materials in order to protect the environment from pollution. Most researchers are currently investigating the use of these materials in soil improvement and geotechnical engineering.

Instead of using chemical additives that are harmful to the environment, such as oil and its derivatives, eco-friendly materials can be recycled. The goal of this study is to improve sandy soil by using eco-friendly recycled materials and to determine how effective these materials could be in geotechnical engineering.

1.2 SOIL CLASSIFICATION

It is fundamental for an engineer to be able to differentiate between the classification of soil and the description of soil. Soil description includes information about both material and mass features, soil classification delegates a soil to one of a limited number of groups based on material properties. Therefore, soil classification is completely separate from the soil situation at the construction site [1]. The systems for soil classification classify and subclass

soils according to their engineering characteristics including grain size distribution, and liquid and plastic limit. The American Association of State Highway and Transportation Officials (AASHTO) System and the Unified Soil Classification System are the two main classification systems currently in use (also ASTM). The AASHTO system is primarily used to classify roadway subgrades.

It is not employed in the construction of foundations. Reverse the AASHTO the Unified Soil Classification is employed in almost all geotechnical operations. A. Casagrande presented the Unified Soil Classification System in 1942, which was later refined and authorized by the United States Bureau of Reclamation and the United States Army Corps of Engineers [2]. The methodology is now used in nearly all geotechnical projects.

1.3 SOIL IMPROVEMENT

The soil considers to be poor if it doesn't meet the minimum requirement for engineering properties and/or has been determined to provide insufficient performance for the design specifications. Many ground improvement approaches have been utilized to evaluate and treat many ground condition issues, as well as to improve desirable engineering characteristics of existing or available soils. Furthermore, they usually provide more economical alternatives to traditional methods of improvement.

Whenever buildings are constructed on difficult soils, it is essential that soil engineering properties must be improved. The most significant types of problematic soils are expansive soil, collapsible soil, liquefiable soil, dispersive, silty fine sands, and highly organic weak soils [3]. In general, Soil improvement is a procedure used to improve the geotechnical qualities of soil at a particular location. The main idea is to find a method or methodology that will work during construction and be considered a long-term solution [4].

1.3.1 Soil Improvement Purpose

Soil improvement is a major and important element of soil mechanics and geotechnical engineering, and it comprises a variety of methods and approaches that can be utilized to handle the problematic soils [5]. The prime objective of soil improvement is to improve soil properties such as shear strength to avoid failure and increases the bearing capacity, stiffness, prevent settlement, as well as to manage permeability and surface runoff [6].

Soil improvement main purpose is to support one or more of the main soil functions, as Schaefer et al. (2012) point out, the basic functions to be improved by ground improvement are [7]:

- a. Increase shear strength and bearing capacity,
- b. Increase density,
- c. Decrease permeability,
- d. Control deformations,
- e. Increase drainage,
- f. Accelerate consolidation,
- g. Decrease imposed loads,
- h. Provide lateral stability,
- i. Increase resistance to liquefaction,
- j. Transfer embankment loads to more competent subsurface layers.

1.3.2 Soil Improvement Techniques

Humans have used simple methods such as planting beds of grass or trees to hold the weight of people and animals over the soft ground. Only recently have substantial advances been made in engineering through compaction, consolidation, or the addition of materials through penetration or mixing. These processes began both during and after Industrialization, with a focus on the early 20th century.

Through the efforts of Terzaghi and others, a greater knowledge of soil mechanical properties developed over these years; effective ground research became possible, and machinery and material developed, and all this led to the development of geotechnical engineering and also led to the invention of many ways to solve engineering problems. Deep vibration treatment and grout injection or mixing are the two main approaches used

nowadays [8]. The processes of soil improvement can be carried out using one of the methods shown in (Figure 1.1).

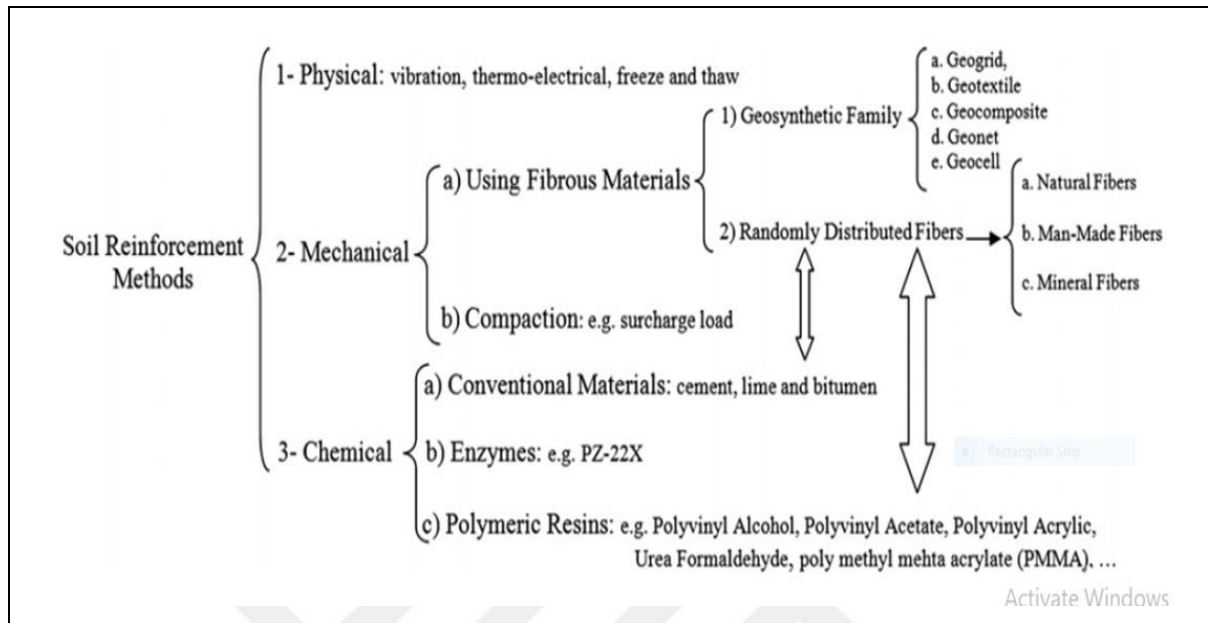


Figure 1.1: Soil Reinforcement Methods [9].

Geotechnical engineering has developed rapidly in the previous fifty years and now has a significant position in all scientific domains of engineers [10]. The aforementioned stabilization techniques, particularly chemical and mechanical techniques, are related to major environmental concerns such as climate change due to enormous carbon-dioxide emissions, high expenses, pollution of the environment (air, land, and water), loss of nonrenewable resources, and the increasing prevalence of heavy and toxic substances concerning the geo-environmental [11].

With the advancement of technology and the world, many methods have been established and new methods and additives have been invented to improve and strengthen the soil, to meet the required engineering properties. We now have many ways to improve weak soils without the need to expand global pollution.

1.4 THESIS BACKGROUND

The strength and durability of any building are determined not only by the structural design and the strength of the materials used in its construction but also by the state of the soil on which the foundation is built [12]

Soils are the most commonly and easily accessible of all materials used in construction. Most soils, on the other hand, are classified as problematic due to their inherent mechanical properties, such as strength and bearing capacity, which are frequently less than optimal for typical civil engineering applications [13].

Soil is a porous material with weak tension behavior and geotechnical qualities that vary depending on environmental variables. Because of population expansion and urbanization, there is a high demand for unstable and erosive soils with weak geotechnical features. These soils must be treated Before beginning any building work. Soil improvement with additives is one of the most common techniques of soil improvement, especially for the shallow foundation. Various additives derived from industrial wastes have been used in engineering studies to improve soils in recent years.

However, some of these materials consider being harmful to the environment such as plastic waste, in the other hand sustainable materials are environmentally friendly materials that are employed as a stabilizer to reduce the negative effects on soil caused by the presence of pozzolanic and chemical processes that lead to the bound of soil particles by cementitious durability [14]. building has a significant impact on the future sustainability of urban areas [15] [16]. In this thesis we will be using natural fibers as a soil reinforcement material to improve soil properties, natural materials are both environmentally friendly as well as effective soil reinforcing materials [17].

Because of their considerable strength, low cost, and wide availability, natural and synthetic fibers have gotten the attention of geotechnical engineers as an acceptable solution for soil reinforcement. Using fibers in soil stabilization applications was primarily accomplished by studying the behavior of the fibers in the plant roots composed implanted in the soil. As a result of this study, natural fibers are now used in soil stabilization. The very first example of fibers reinforcing technology, which is currently one of the most prominent research subjects, dates back 5000 years. The use of tree branches as tensile elements in the Great Wall of China and woven mats in Babylonian ziggurats [18]. However, soil improvement is not always the option. The engineer may be required to remove the soil and replace it with soil that has better engineering properties than the prior one.

1.5 THESIS PROBLEM

The soil is the most fundamental aspect of civil engineering, particularly geotechnical engineering, however, we frequently find weak or unstable soils that prevent the engineer from starting or completing a project. The study attempts to improve Iraq's sandy soils using eco-friendly and recyclable additives. The goal is to enhance the soil at a low economic cost when compared to other techniques of improvement, in addition to preserving the environment. The focus of the thesis is to determine how effective these materials can be in terms of soil improvement and environmental protection, as well as their economic cost. The main idea is to find a method or methodology that will work during construction and be considered a long-term solution.

1.6 THESIS SCOPE

This study looked at a laboratory analysis of the engineering behavior of soil reinforcement with recycled eco-friendly additives (jute fibers). The following were included in the scope of the study:

- a. Local sand from Karbala, south of Iraq was used as a geotechnical soil.
- b. Jute fibers from the local market were used as an additive and were used in different percentages.
- c. Laboratory experiments on sand soil were performed in order to determine their engineering properties. These tests include sieve analysis, direct shear test, and proctor compaction test.

1.7 THESIS OBJECTIVE

Improving the soil through the use of sustainable environmentally friendly materials has received much interest due to its numerous benefits, including the fact that it is a material that does not lead to soil pollution, and these materials are also considered to have a lower financial cost when compared to other additives. Many researchers discussed this subject, and many tests and theories were undertaken, as well as a lot of sustainable materials, all to improve the properties of weak soils and reinforce the soil.

Despite this, there is still a gap in this sort of additive and the amount to which these additives can be beneficial to the soil in terms of environmental, economic, and soil stability. The main objective of this study is to investigate the engineering properties of sandy soil in Iraq that is reinforced by Jute fibers (an eco-friendly material that is recycled from plants), as well as the extent to which these fibers can have a positive effect on strengthening the soil and improving its engineering properties, as well as the economic impact.

- a. To assess the mechanical properties of sandy soil by conducting laboratory experiments on the soil before and after reinforcing with jet fibers and analyzing how far these properties improved.
- b. To propose and support the use of eco-friendly recycled materials in the construction industry, particularly in the geotechnical engineering field.
- c. Discussion and analysis of the economic and environmental aspects resulting from the use of jet fibers as a soil reinforcement material.

1.8 THESIS LAYOUT

Chapter one: Introduction and Thesis Background

Chapter two: Literature Review

Chapter three: Thesis material and Methodology

Chapter four: Test Results and Discussion

Chapter five: Conclusion and Future work

2. LITERATURE REVIEW

2.1 INTRODUCTION

Many studies in the field of soil improvement with eco-friendly acceptable additives will be covered in this chapter. However, this chapter discusses eco-friendly and sustainable materials, as well as the impact of these materials on soil improvement. Furthermore, this chapter also highlights natural fibers specifically jute fibers as an eco-friendly recycled material since it was employed as an additive to the soil in this research. Lastly, a summary and conclusions discussed in this chapter are listed.

2.2 SOIL IMPROVEMENT USING ECO-FRIENDLY MATERIAL.

The soil improvement method contributes to getting the specific properties required for construction. In order to improve geotechnical features such as bearing capacity, compressibility[19], shear strength, and durability, the weak soil should be treated. All soil improvement techniques are classified into two types: mechanical and chemical improvement techniques. Improvement in mechanical methods can be accomplished through the physical process of vibration or compaction, or by combining other mechanical instruments such as nailing or strands [20].

However, chemical improvement is One of the most common and effective soil improvement techniques. Cement, lime, fly ash, and bitumen are common additives mixed with soil to improve workability and compaction properties, increase shear strength, and reduce ground settlement. Because of these benefits, soil stabilization by chemical binders has been frequently used in many regions [21]. Cement and lime are the most commonly utilized chemical reinforcing materials for chemical ground improvement.

However, their use leads to several environmental issues, including CO₂ emissions from cement manufacturing, the effect of vegetation growing, contaminated groundwater, and the production of heat islands, to mention a few. Cement production generated roughly 6% of global CO₂ in 2002, As a result, there is a great need for sustainable and environmentally friendly ground renovation solutions [22].

Limited use of unrenewable resources now is universally acknowledged as a critical requirement for a more sustainable society. Furthermore, increased waste valorization and waste material reuse are unquestionably crucial steps toward environmental sustainability. Geotechnical design, which is included in most civil engineering projects, can play a significant role in the long-term viability of the construction industry [23] [24].

On the other hand, the dumping of waste such as fly ash, marble and brick powder, construction, and demolition (C&D) waste, wastes from agricultural works, and so on has become a significant hazard to the ecosystem and requires actual solutions. The direct discharge of such garbage into open land or bodies of water pollutes the environment [25]. However, recently the world is moving to reuse materials to minimize waste and the impact of these materials on the environment, therefore reusing wastes in several fields, including industrial and agricultural, has recently become highly popular.

These wastes have been identified as sustainable materials. Eco-friendly materials or sustainable materials can be classified into four categories according to their resources [26]:

- a. Industrial waste such as cement kiln dust, fly ash, ceramic dust, brick dust, stone dust, crushed tiles, wood, and sawdust ash.
- b. Agriculture Waste such as rice husk ash, bagasse ash, plant fibers, and coconut shell ash.
- c. Domestic Waste such as waste tires, eggshells, plastic bottles, and other daily waste.
- d. Mineral Waste such as zinc waste, and silica fumes.

Recycled fibers from agricultural waste (plant fibers), also known as natural fibers, were utilized in this research.

2.3 FIBERS

Fibers in civil engineering application can be categorized into two groups synthetic fibers and natural fibers.

2.3.1 Synthetic Fibers

Synthetic fibers, also known as artificial fibers or man-made fibers, account for over half of all fibers consumption, with applications in every aspect of fibers and material technology [27]. Synthetic fibers are widely applied in engineering applications and are classified as organic or inorganic based on the material from which they are made, such as polymers.

Petroleum is the primary raw material utilized in the manufacture of synthetic polymers. The non-biodegradability of polymeric materials creates a financial and environmental concern in the control of landfill dumping. However, because synthetic fibers are homogeneous, they are an excellent choice for produced composites. They are also hydrophobic, making them suitable for use in construction applications and geotechnical industries [28] the figure below (Figure 2.1) shows examples for synthetic fibers.

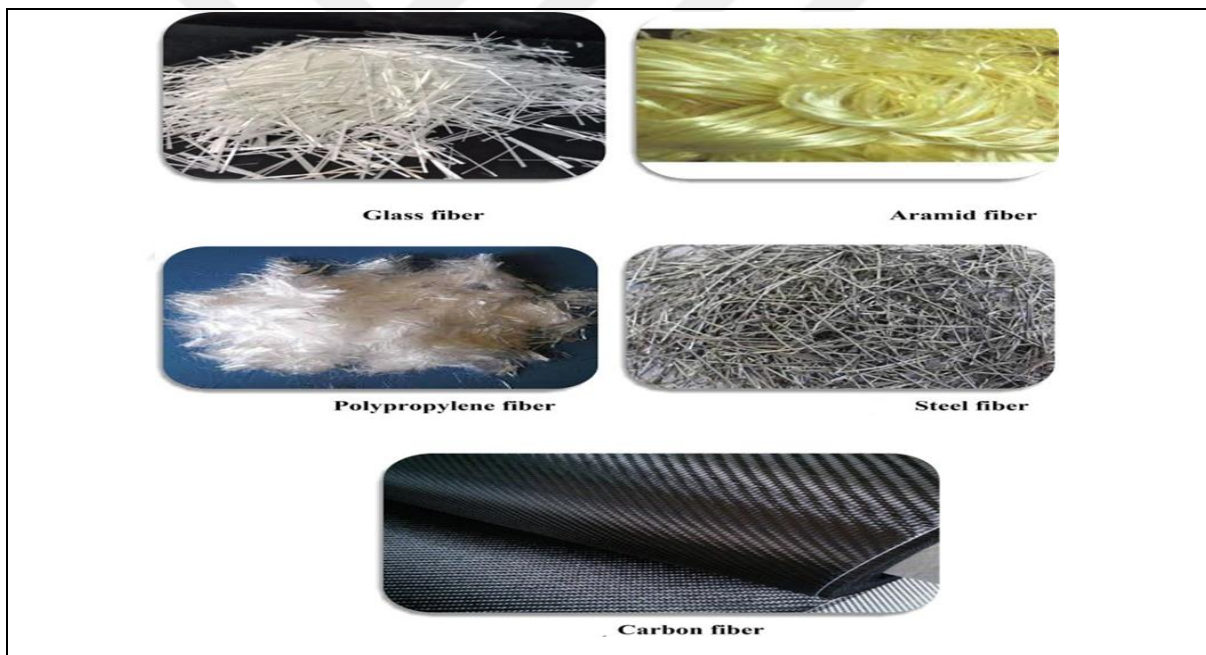


Figure 2.1: Different Types of Synthetic Fibers [29].

2.3.2 Natural Fibers

Due to the rising carbon emissions, the use of low-carbon and low-cost materials that are eco-friendly and could be recycled as well as effective for the stabilization of soils has recently gained significant attention. Fibers as an additive in soil improvement has received significant attention in recent decades due to the large amount of fibers available from

industrial items, waste, and plants. If these fibers are handled correctly, they can be applied as additives to improve the foundation soil. Rubber fibers and polypropylene fibers, on the other hand, are synthetic and nondegradable.

Natural fibers as sustainable resources in soil improvement give a cost-effective and eco-friendly solution that has drawn the interest of researchers and engineers [17]. Natural fibers are considered to be strong, light, inexpensive, and renewable. However, when a high elastic modulus is not required, these low-cost natural fibers can be a suitable option for expensive and non-renewable manufactured fibers like carbon fibers.

The addition of fibers improves the strength characteristics of poor soils [30]. Additionally, according to surveys, synthetic fibers use more energy and are more expensive than natural fibers [31].

Therefore, natural fibers are the best solution as a sustainable alternative material in different applications. Figure 2.2 shows different types of fibers that are commonly used in geotechnical engineering and as a reinforcement material.



Figure 2.2: Various Types of Fibers [32].

2.3.3 Natural Fibers Classification

Plants, animals, and mineral sources all contain natural fibers. Natural fibers are categorized and classified based on their resources into the following categories [33]:

- a. Animal Fibers such as: wool, silk, hair/fur, alpaca fibers.
- b. Mineral fibers: glass fibers, aluminum oxide, silicon carbide, and boron carbide.
- c. Plant fibers: are cellulose fibers. they are classified as:
 - i. Seed fibers: cotton and kapok.
 - ii. Leaf fibers: sisal, agave, abaca, henequen, pineapple fibers.
 - iii. Stalk fibers: such as straws of wheat, rice, barley, maize, rye, and oats.
 - iv. Cane, fruit, grass and reed fibers: bamboo, bagasse, Sabai, communis, phragmites, and coconut (coir) fibers.

2.3.4 Natural Fibers and Their Properties

New forms of fibers have been discovered in recent years since they have become a major component in agriculture, construction, and industry. Table 2.1 shows some of the most common types of fibers and their use [34].

Table 2.1: Natural Fibers and Their Principal Characteristics [35].

Fibers	Fiber's length (mm)	Fiber's diameter (mm)	Main properties
Flax	Up to 900	12-16	Water absorbs and desorbs quickly.
Jute	Up to 4000	17-20	Low thermal conductivity, moderate moisture retention, high insulation, and anti-static properties, growing in tropical areas with humidity levels ranging from 60 to 90%
kenaf	6	20-30	Excellent durability
Ramie	Up to 1900	25-30	Rapid absorption and desorption of water, low elasticity, easy dying
Abaca	Up to 3000	-	High mechanical strength, buoyancy, resistance to salty water damage
Pina	Up to 200	-	Resistant to saltwater, wear-resistant
Raffia	Up to 1500	-	Rough
Coir	Up to 350	12-25	High concentration of lignin, high

			strength, less flexibility than cotton, unsuitability for dyeing, good resistance to saltwater damage and microbial action
Cotton	100-650	11-22	Rapid moisture absorption, high tensile strength
Bamboo	Up to 90	10-20	Excellent durability, high stability, tenacity, flexibility, resistance to ultraviolet radiation, and permeability
Cornstalk	Up to 3000	40	Lightweight, strong
Silk	Up to 1500	10-13	Good absorbency, low conductivity, easy dying finish
Wool	Up to 152	16-40	Good thermal and acoustic insulation, high deformability, high durability
Glass	-	5-24	Fire resistant

2.4 ULTIMAT BEARING CAPACITY

a. The ultimate bearing capacity of sandy soil

The ultimate bearing capacity (q_u) is defined as the maximum stress that would cause the shear failure of the underlying soil directly beneath and next to a foundation, figure (2.3) shows bearing capacity failure in a soil sample.

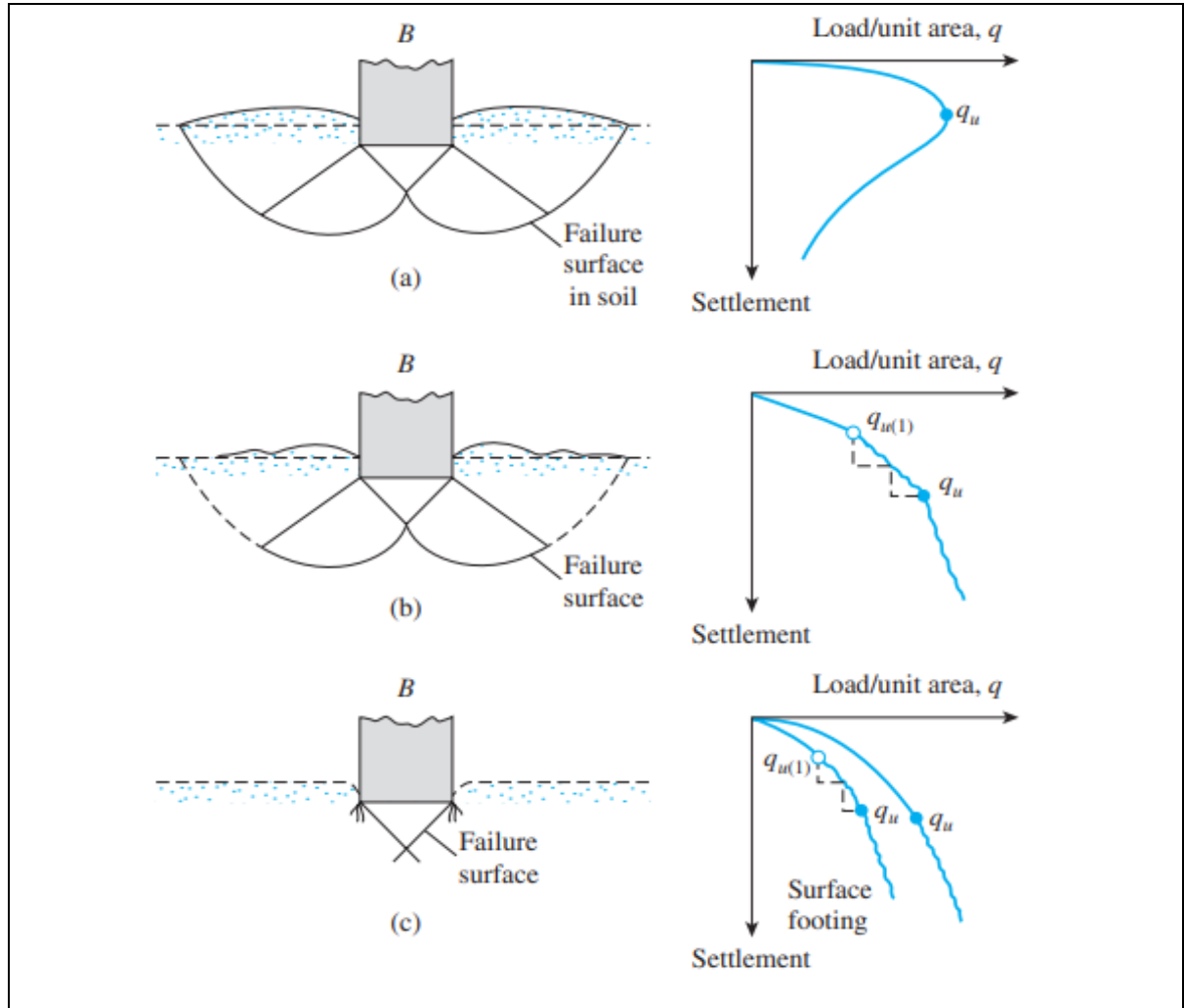


Figure 2.3: The Nature of Soil Failure: (a) General Shear Failure: (b) Local Shear Failure: (c) Punching Shear Failure [2].

b. Terzaghi bearing capacity theory

Terzaghi (1943) was the first to propose a whole theory for determining the ultimate bearing capacity of foundations. Terzaghi proposed that the failure surface in the soil at ultimate load for a continual, or strip, foundation be assumed to be comparable to that shown in Figure [2]. According to Terzaghi ultimate bearing capacity for a strip or continues foundation expressed as:

$$q_u = C'N_c + qN_q + \frac{1}{2}\gamma BN_\gamma \quad (2.1)$$

Where c cohesion of soil, N_c, N_q, N_γ is the bearing capacity factors and,

For foundations on a sand soil (cohesion is zero) the bearing capacity is:

$$q_u = qN_{q(eq)}\lambda_{qs} + \frac{1}{2}BN_{\gamma(eq)}\lambda_{\gamma s} \quad (2.6)$$

$N_{q(eq)}$ and $N_{\gamma(eq)}$ equivalent factors related to friction angle $\phi = \phi_{eq}$

$$\phi_{eq} = \frac{2(\phi_1 + \phi_2)}{3} \quad (2.7)$$

Figure (2.3) shows the failure under a strip foundation on sand soil.

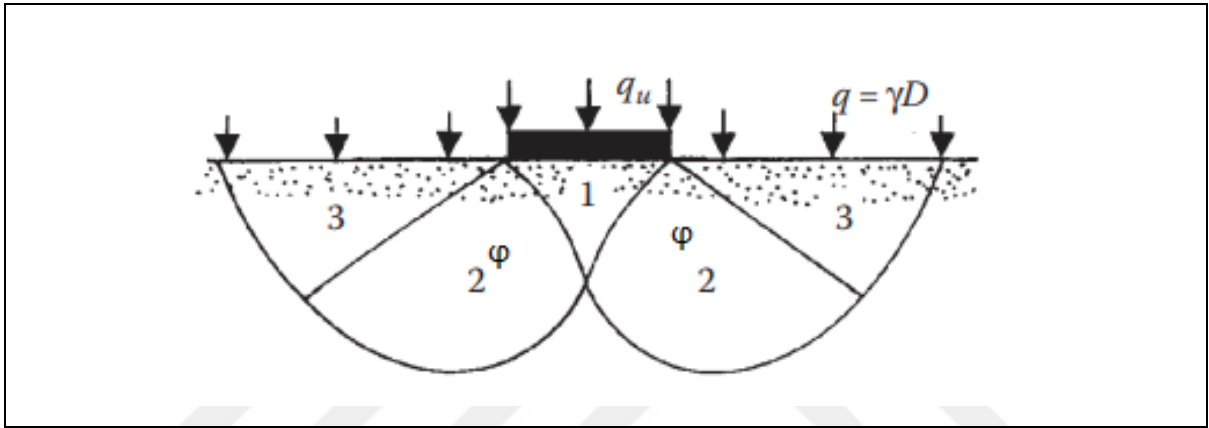


Figure 2.5: Strip Footing on Sand Soil [36].

d. The Ultimate Bearing Capacity of Reinforcement Soil

1) $D_f = 0$ (D_f is the depth of footing)

$$q_u = 0.5(B' + \Delta B')\gamma N_\gamma + \gamma d N_q \quad (2.8)$$

Where q_u = the ultimate bearing capacity.

B' = effective width.

$\Delta B'$ = the increment of footing after soil reinforced.

γ = unit weight of soil.

$N_\gamma N_q$ = bearing capacity factors.

d = depth under footing.

$$\Delta B' = 2d \tan \beta \quad (2.9)$$

$$\tan \beta = 0.68 - 2.07/(h/B') + 0.743(CR) + 0.03(b/B') \quad (2.10)$$

CR = Cover Ratio.

b = reinforcement width.

and h = the spacing between the layers.

However, the equation is only valid when:

$$0 \leq \tan \beta \leq 1$$

$$1 \leq b/B \leq 10$$

$$0.25 \leq h/B \leq 0.5$$

$$1 \leq N \leq 5$$

$$0.02 \leq CR \leq 1$$

$$0.3 \leq d/B \leq 5$$

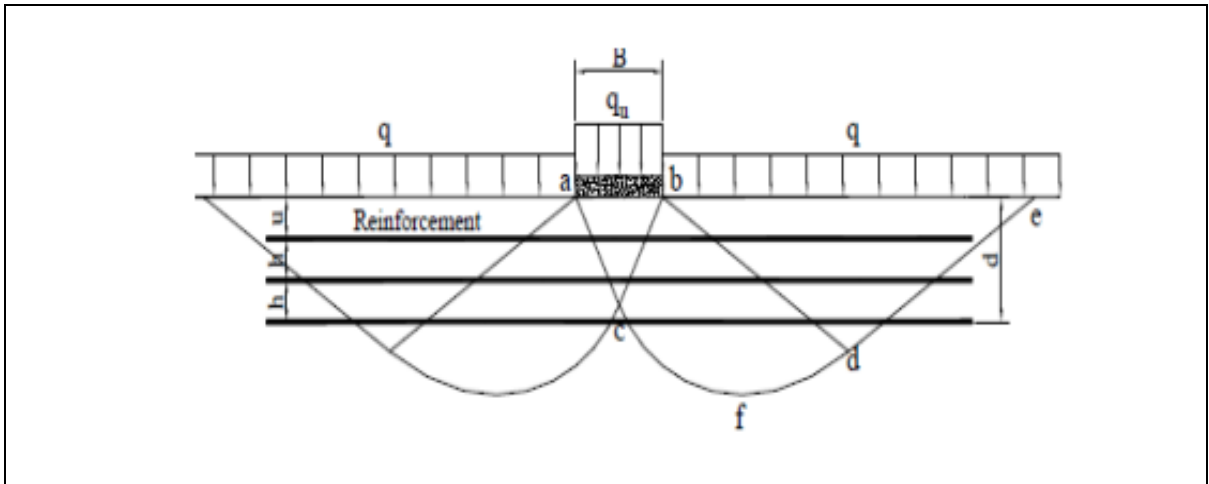


Figure 2.6: Failure in Reinforced Zone [37].

2.5 MECHANISM OF REINFORCING SOIL WITH FIBERS.

Soil is an important building material that is used a lot. The majority of construction projects are based on soil foundations. To work with soils, we must understand their attributes and

the factors that affect their behavior[38] [39]. Soil reinforcing aims to improve strength, bearing capacity, and ductility, as well as reduce settlement and reduce lateral deformation [40].

Natural fibers have attracted much interest and acceptance as an additive material for soil stabilization at shallow levels[41] [42]. Fibers incorporated in the soil might vary in shape, texture, stiffness, content, length or aspect ratio, orientation, and so on, with content, length, and direction being the main practical issues in geotechnical applications. Fibers-reinforced soil can be divided into two varieties as shown in figure (2.6) based on their application method [11]:

- a. Oriented Distributed Method (ODFS).
- b. Randomly Distributed Method (RDFS).

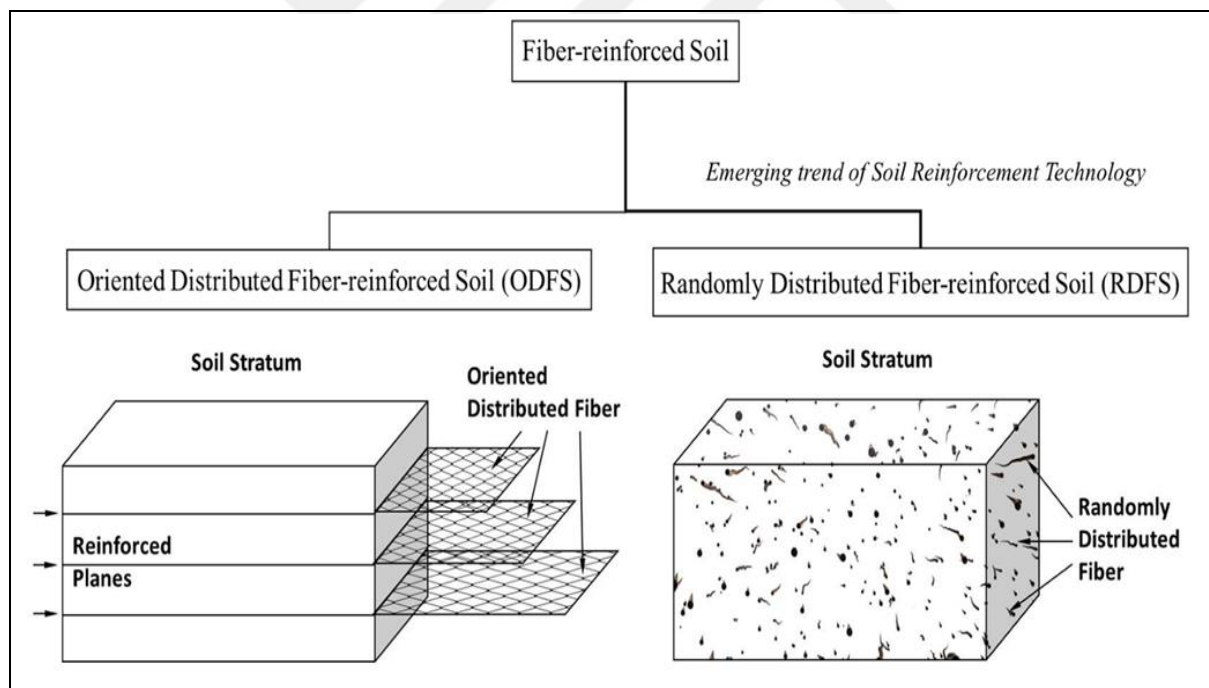


Figure 2.7: Fiber Reinforcement Methods of Soil [11].

In fibers reinforced with oriented distribution method it is commonly accepted that fibers orientation with regard to the main stress direction has a significant impact on fibers contributions to reinforced material shear strength increase.

Figure (2.7) shows different forms of fibers orientation distribution [43]. The method of oriented distribution fibers reinforced soil (ODFS) is comparable to traditional geosynthetic procedures in which materials such as geo-grids, geo-cells, geo-mats, geo-textiles, and so on were added to weaker surfaces of the soil.

The method of oriented distribution (ODFS) is comparable to traditional geosynthetic procedures in which materials such as geo-grids, geo-cells, geo-mats, geo-textiles, and so on were added to weaker surfaces of the soil. Although it is commonly established that the (ODFS) method mobilizes supplemental frictional strength along fibers-reinforced surfaces, un-reinforced areas must rely on their own strength to survive, there are still opportunities to develop failure through weak un-reinforced areas [11].

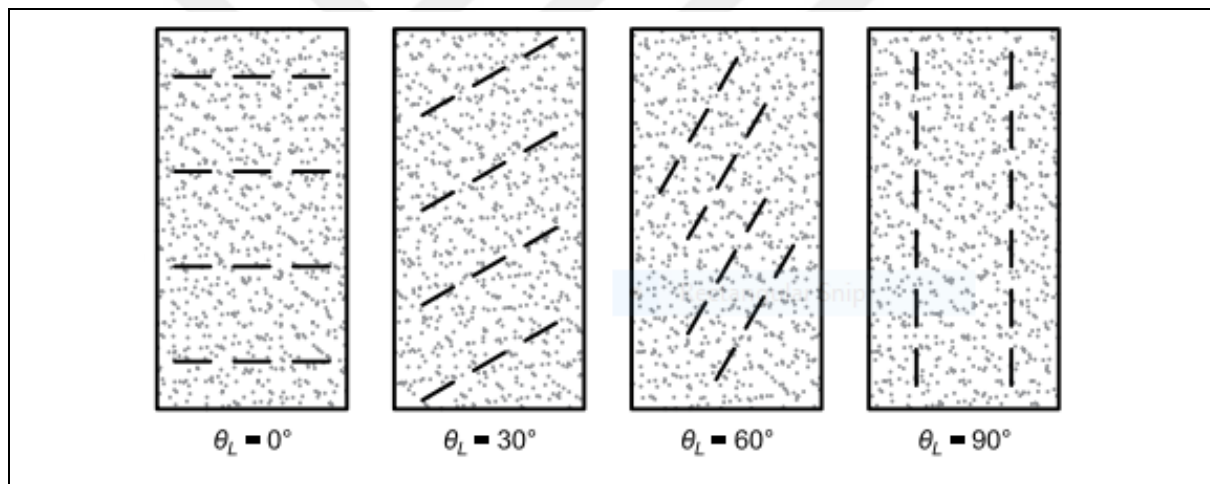


Figure 2.8: Considered Fibers Orientation Distribution forms [43].

Figure (2.8) shows the frictional action between the fibers and the soil surface, as well as the bridging action when a tensile force is applied to the soil body. The frictional action can cause soil particles to bond together more tidily, whereas the bridging action can withstand tensile stress [44].

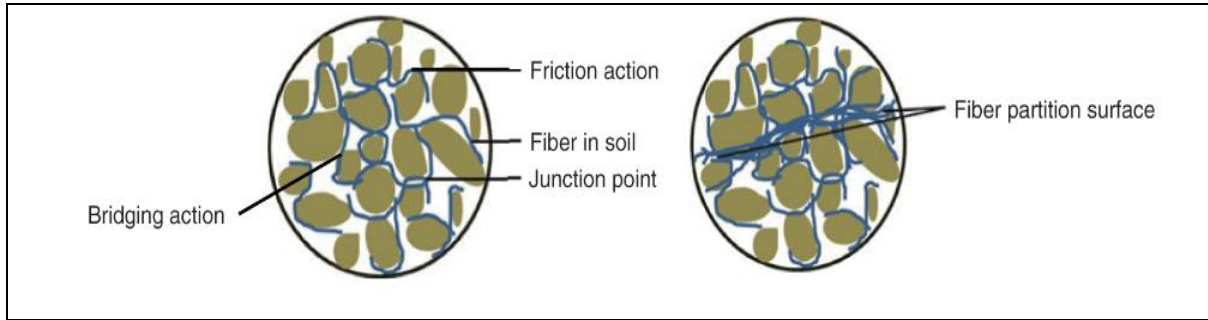


Figure 2.9: Mechanism of Soil Reinforced with Fibers [44].

In contrast to ODFS, randomly distributed fibers-reinforced soil (RDFS) is one of the most recent procedures in which fibers of a specific type and quantity are mixed into the soil and set in place [45]. This method of reinforcement approach takes advantage of the same function of plant roots, which reinforce the soil by adding friction and tangles.

The mechanism of this method is shown in figure (2.9). Stressed soil particles tend to densify; stress causes deformation in the shape of the fibers, and this deformation causes connecting and interlocking between the soil particles and the fibers. Similarly, the soil particles are driven to enhance the friction with the fibers, resulting in the transfer of tensile stress to the fibers [11].

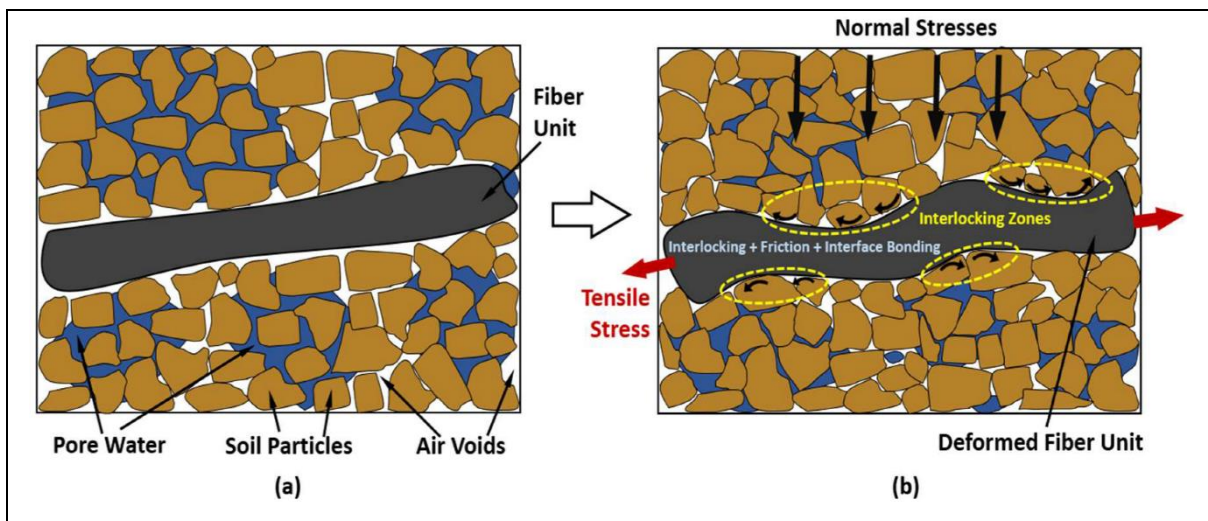


Figure 2.10: The Behavior of a Randomly Distributed Fibers at Two Stages: (a) The Initial Stage and (b) the Deformation Stage [11].

2.6 LITLITURE REVIEW SURVEY

Lal et al 2020, conducted a study of an expansive soil characteristic was improved with a jute fibers sheet, where CBR and triaxial tests were performed on both reinforced and unreinforced soil. The sheets were added in three layers, and the soil sample was about 38mm Diameter and 76mm Hight. The result showed that using jute fibers in layers has a great enhancement on the strength and stiffness of soil. [46], However, the result also showed that using two layers of jute fibers sheet is more effective than using three layers of fibers sheet since the cohesion was 153.52 Kpa with two layers and 54.96 Kpa with three layers.

Zhang et al 2021, did an experimental study to evaluate the behavior of micaceous soil reinforced with a mixture consisting of jute fibers and lime, the soil consisted of 80% kaolinite and 20% ground mica by weight with liquid and plastic limits of 48.7% and 36.9% respectively. An unconfined compression test was performed on a total sample set of 28 samples these samples were categorized into three groups the first one used only jute fibers as a reinforcement material, the second one consisted of jute and lime, and the last group of samples was consisting of jute and slag lime. All these samples were cured for a period of 7 days and 28 days [47], however, the results of the tests indicated that the addition of fibers alone, or fibers combinations with lime or slag-lime, enhanced the UCS and stiffness of micaceous soils. The bigger the amount of fibers, the greater the measured strength and stiffness. The combination of fibers and slag-lime stabilization is more effective in strengthening micaceous soils. The ideal, cost-effective dosage for micaceous soil was discovered to be 1% fibers and 3% slag-lime.

Singla, 2020, investigated the optimum cement-jute mixture and the effect of this mixture on strengthening the mountainous clay soil subgrade. The pycnometer test, Casagrande's test, plastic limit test, stander, and modified proctor tests were performed. The jute fibers used were 6 mm in diameter and added in different percentages (0.4,0.7,1,2,4) % and for the cement, the percentages were 1,3,5 and 7% of the sample weight. [48] The result showed that the optimum jute cement mixture value was 5% for cement and 0.4% for jute. For CBR it was found that the cement-jute mixture increased CBR by 0.88 times, however, the addition of cement has been approved to reduce MDD.

Dar & Bhalla, n.d, evaluate the use of two stabilizers (jute fibers and stone dust) separately on soil properties. 21 specimens were prepared, 15 of them used jute fibers as stabilizer material and the rest of them used stone dust each one in different percentages (0.25,0.50,0.57, and 1%) for the jute and (10,20,30,40, and 50%) for the stone dust. [49] The maximum CBR value were conducted when used jute and with a percentage of 1%, they also found that using jute with length 90mm and 2 mm in diameter gives the best result.

Aravind et al., n.d, investigated the ability of use geo-jute material as a soil stabilizer and how could this material effect on the construction cost. This study involved various of laboratory tests (Sieve analysis, Specific gravity test, Atterberg's limit test, Standard proctor test, Unconfined compression test) geo jute dimensions 20mm diameter 25mm length.[40] Laboratory test result of the study showed using geo-jute was effective in stabilized the clay soil, the optimum percentage that gives the best result was 1%.

Islam et al, 2021, They conducted an experimental study on sandy soil in Dhaka. The basis of the study was for the purpose of improving this soil using jute fibers. Sieve Analysis, Specific Gravity Test, Direct Shear Test, Proctor Compaction Test were conducted. [50], The results of the tests found that the friction angle increases with the addition of jute fibers. Maximum dry density obtained at 1% of jute and This indicates that the fibers led to an increase in strength, as well as to an increase in soil stability.

Prasanna & Mendes, 2020, carried out research on improving soil using jute fibers, the soil used in this research was undistributed sample taken from Ponda-Margao highway, from 3 different locations. As for the fibers, they were brought from local stores and were used after cutting them to 30 mm in length. After sieve analysis, it was found that the soil was poorly graded soil, Reinforced and unreinforced samples were subjected to multiple tests. [51], After comparing the results, it was concluded that fibers with a ratio of 0.5 and 1% led to an increase in OMC and MDD, however, for the direct shear test cohesion increases with increasing fibers content until it reaches 1% after this percentage, a slight decrease in cohesion is observed, and the maximum improvement in CBR value observed between 1% and 2%. Consequently, they conclude that jute fibers could use as a soil stabilizer.

Araya-Letelier et al.,2021, The effects of varied Jute Fibers doses (0.5, 2 %) and lengths (7, 15, and 30 mm) on the physical, thermal, mechanical, fracture, and durability performance

of AMs, a type of earth-based construction material widely used internationally, are investigated in this work. The inclusion of 2.0 percent of Jute Fibers increased the capillary water absorption of AMs, which may impair AM durability, according to the results of the experiments, this study recommended the use of Jute Fibers in AMs, particularly AM J-2.0-15, because the incorporation of JFS greatly improved the cracking control, ductility, heat resistance, and water erosion resistance efficiency of AMs [52].

Kantha & Deepthi, 2019, In the current investigation, soil samples were generated with 0.25 percent, 0.5 percent, 0.75 percent, and 1% Jute fibers additions. The average length of Jute fibers used in this study is roughly 10-15mm. Initially, the proctor test was used to establish the Optimal Water Content (OMC). Several tests, such as CBR and UCS, were carried out at certain OMCs. The CBR test was performed in both dry and wet states, with the highest results obtained when 0.75 percent Jute fibers was added. The test also revealed that the UCS of treated soils was greater than that of untreated soils, rising from 0.97 to 8.8 kg/cm². The study also conducted that the strength increased as the curing period increased [53].

Shah & Bharamjeet 2018, investigate the improvement of locally available soil using some jute fibers and evaluate the features of mixed soil using different lengths of Jute. Soil samples were taken at the suggested site in Pulwama. The samples were tested by various of tests, the tests included particular gravity test, Atterberg limits test, compaction test and Direct Shear test, the work done in two stages with and without the jute fibers. However, according to the result it was conducted that the use of jute decreases maximum dry density (MDD), and for the optimum moisture contain it noticed increase when the jute fibers percentage was 0.5%. The incorporation of Jute Unconfined Compressive strength rises from 26.33KN/m² at 0% Jute Fibers to 69.8KN/m² at a percentage of 0.5%. It also increases the angle of internal friction; nevertheless, in virtually all situations, it stayed unchanged at 1.0 percent concentration[54].

Ashraf & Manzoor, n.d, in order to improve road quality with economical cost in India, an experiment study was carried out using locally available soil that had been modified with jute fibers. The proportion of jute fibers by dry weight of soil is 0.2 percent, 0.4 percent, 0.6 percent, and 1%, while the length was 30mm, 60mm, 90mm, and 2mm in diameter. Regular soil, as well as reinforced soil, were subjected to various laboratory tests. The influence of

jute fibers length was studied. [55], it was discovered that the CBR value increased when jute length increased. It was also observed that the CBR value was optimum at 0.6 percent fibers content, hence it was conducted that 0.6 percent content of fibers is optimal, and Jute is an excellent solution for low-volume road building on unstable subgrades.

Alqaissi et al., 2022, study the effect of jute fibers on soft clay soil, to make unreinforced and reinforced specimens for the experimental work, jute fibers was utilized. The JF was selected as a reinforcing material with various contents, particularly (0.5, 1, 2, and 3 %). The fibers were cut into two lengths (2 cm and 4 cm). 27 laboratory tests were performed on the obtained sample, including standard Proctor compaction tests, consolidation tests, and unconfined compression tests. They used Randomly Distributed Fibers-reinforced Soil (RDFS) technique in adding the fibers. However, [56], the result of tests showed that the MDD decreases, and OMC increases with the used of Jute fibers. Mixing clay with Jute fibers with a percentage of 0.5% decreases the MDD by 5% less than the untreated clay, it also enhanced the strength of the clay, particularly for Jute 3% with a length of 4 cm, and the specimen becomes more ductile as the strength index (I_d) = 1.49. nevertheless, compression index (C_c) reached its minimum value at Jute fibers percentage of 3% and 2 cm length.

Ahanger & Bawa, 2018, conducted an experiment study on the effect of jute fibers on CBR values of subgrade soil. The soil samples were in their maximum dry density, however the result showed that the CBR values increased with the added of jute fibers, the best result recorded when jute fibers contained was 0.75%. Although the OMC is great at 0.75 percent and 1%, [57].

Faiq 2018 studied the possibility of using jute fibers as a low cost material for walls, panels, roofs construction. The study included investigations on concrete samples reinforced with jute fibers, the fibers were added with lengths of 2 cm and 4 cm and in percentages of (0.5, 1, 1.5) % of cement. 42 cubic samples with dimensions (100 mm, 100 mm, 100 mm), and 42 other cylindrical samples with dimensions (100 mm, 200 mm) were prepared. Tests were carried out (Splitting Tensile Strength, Compressive Strength Test) on samples at 7 days and 28 days old. [58] Result showed that using jute fibers as a reinforced material leads to decreasing in compressive strength by (4.3-12.3 %). However, the use of jute fibers in

different length and fibers content improved tensile strength by 19.4%, thus the study concluded that the optimum value to get the best results is 1% of jute with 5cm length.

Fadhil et al., 2021, conducted a study on the effect of using waste plastic fibers on the properties of lime-stabilized sand soil. Plastic fibers waste (low-density polyethylene) was used with varying lengths (5, 10, and 20) mm and at varying percentages (1, 2, and 3) % of the soil. The results proved that the addition of 10 mm length waste plastic fibers at a content of 3% reduced the deflection of around 21% and an increase in dynamic modules of around 28% when compared to soil untreated [59].

Jaber et al., 2021, The effect of recycled plastic waste on the strength of subbase was studied. The aim of their study was to prove the possibility of using plastic waste in civil engineering applications in a smart and innovative way. Five fractions were used of polyethylene terephthalate. The fraction ranged from 2.5 to 12% of subbase volume in the shape of cylinder with 2.5D and 4 H. According to the result [60], the addition of plastic waste grains considerably affected the performance of the subbase. California bearing ranged from 6 to 36 percent. They suggested that 10% of recycled waste is the optimum.

Yuna et al., 2022, SEM test and drop-weight test have been used in this research to investigate the micro-interaction mechanism and impact strength of granite residue soil samples reinforced with glass fibers and SH Polymers. Mohr-Coulomb strength lines were utilized to quantitatively examine the effect of glass fibers when combined with the equal thin boundary layer hypothesis. According to the SEM observations, the granite soil layer consolidated with 3.5 percent SH polymers had a tighter interaction between the clay particles. Furthermore, with the inclusion of glass fibers, these flake clay particles were bonded to the fiberglass along the long axis, establishing a flake clay particle and fibers cemented system [61]. However, the result showed that 3 % of fibers considered to be the optimum since the resistance reached it maximum value with about 32,16 KN.

Jassim et al., 2022, Conducted a study on the effect of waste marble dust material on subgrade soil properties by using different percentages of marble dust (MD) (0,3,6,9,12,15). The study performed by series of laboratory tests included particle size distribution, maximum dry density, optimum moisture content, and unconfined compressive strength (UCS). The studies found that adding marble dust to clay specimens reduces the cost of

building structures on poor soil and that use reduces pollution. However, the result shows using marble dust in soil reduced plasticity index and increased the maximum dry density as the marble dust content increased. Furthermore, the optimum percentage of MD to reach maximum value of unconfined compressive strength was 3%. [62], they also studied the effect of this experiment on the vertical displacement for flexible pavement on clayey subgrade by using a simulation model for paving application under actual traffic loading. It was determined that stabilizing the subgrade soil with (3%) waste marble dust might reduce vertical displacement for flexible pavement by approximately (55.3 percent).

Taha et al. 2018, Investigated the effect of using nanocarbons as a reinforcement material for soil with (0, 10 and 20%) of bentonite mixed with it. two types of nanocarbons (CNTs, CNFs) were added in different percentages (0, 0.05, 0.075, 0.1 and 0.2%) to the soil. The soil was considered clayey sand according to the United Classification System. Indirect tensile strength and unconfined compressive strength tests were conducted on three soil samples. The tests result showed that using nanocarbons enhanced unconfined compressive strength, Young's modulus, and indirect tensile strength, however Carbon nanofibers demonstrated superior performance when compared to carbon nanotubes, because of the ratio of their small diameters, it may spread reinforcing elements on a smaller scale [63].

Tiwari, Satyam, and Puppala 2021, Studied the impact of using recycled ash and natural fibers to manage the expanding strength of expansive soil and durability qualities. Recycled ash was employed to chemically treat the soil, and coir fibers (CF) were used as a reinforcement material against cracking. The compensation of these materials was added in different percentages (5, 10, 15, 20) % for recycled ash and (0.25, 0.5, 1)% for coir fibers. freeze-thaw cycles method was used to investigate the effect of these material on the chemical and mechanical characteristics of soil samples,[64] however the result concluded that the use of this mixture of materials has a clear and effective effect on improving soil properties, especially for road applications, also it was proved that recycled as reduced swelling and control plasticity.

Jiang et al. 2021, evaluated the efficacy of waste materials silica fume as an additive for improving soft soil stabilized with cement, unconfined compressive and scanning electron microscopy tests were performed on the samples with different silica fume contents and

curing time. The result of the laboratory tests showed a noticeable improvement for the soft soil, increases cement hydration effectiveness, increased UCS value. It was noticed that adding 1.5% of silica fume the UCS was 4.05 MPa. However, Silica fume raises the water demand, leading to the formation of tiny cracks [65].

(Zhao et al., 2021), conducted an experimental study on the effect of using three types of fibers (glass, Polyester, and hemp) on the physical and chemical characteristics of calcareous sand soil treated by MICP. Fibers were applied in different percentages (0, 0.1, 0.15, 0.2, 0.25, 0.3 0.35, 0.4) % of sample weight, unconfined compressive strength test, and water absorption test were carried out on a cylindrical sample of 39.1 mm in diameter and 80 mm height [66]. However, the result showed that the use of fibers improved ductility and strain of soil, UCS increased, and water absorption decreased.

2.7 SUMMERY

According to the literature reviewed, the use of sustainable materials in improving and reinforcing the soil has become quite widespread in recent years, because the world is turning to the use of sustainable and recycled materials in a variety of industries. However, it can be summed up that the soil used in the reviewed literature ranged from sand to clay, and the jute fibers used as a reinforcement material as sheets between soil layers as well as fibers mixed with the soil. The fibers used in percentages ranged from (0,25 to 5) % of dry soil weight.

However, different material with different percentages used also as a recycled material to improve soil properties, such as natural fibers like coir fibers, lime, marble and stone dust, silica fume, biopolymer, as well as glass fibers.

Furthermore, lots of tests carried out to determined physical and mechanical properties of soils included, CBR (California Bearing Ratio), triaxial test, sieve analysis, unconfined compressive stress, stander and modified proctor test, pycnometer, as well as Casagrande's test, and plastic limit. The studies proved that the use of recycled material and natural fibers improved soil properties and can be used in civil engineering applications, especially with shallow foundations and road construction. However, the studies didn't cover the economic benefits of using these materials.

This thesis aims to improve the bearing capacity of sandy soil, especially the sandy soil in Iraq, by using environmentally friendly materials with a low economic cost compared to other materials such as oil derivatives, which have a negative impact on the environment instead of their material cost.



3. METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the materials used in the research and their properties. laboratory experiments, tools, and specimens used to accomplish the research's aims are also described in this chapter. Furthermore, this chapter gives an introduction to laboratory work, sample preparation, and equipment used.

3.2 RESEARCH MATERIAL

The material used in this research included: soil and jute fibers sheet.

3.2.1 Soil

The type of soil used in this research is sandy soil, samples were taken from the city of Karbala in southern Iraq. The maximum and minimum dry unit weight of soil were measured according to ASTM (Du 253-00) and ASTM (Du 254-00) respectively, the maximum dry unit weight is 17.97, and the minimum dry unit weight is 15.41. the specific gravity of the sand is 2.7 determined according to the British standard BS (1377:1990). The grain size is analyzed according to ASTM (D422-63).

According to the grain size distribution curve shown in figure (3.1), the sand is classified as poorly graded. The value of the coefficient of uniformity (C_u) and curvature (C_c) are 3.1 and 0.8 respectively. The Properties of sand are listed in Table 3.1 and determined according to the laboratory test. According to sieve analysis, the Grain Size Distribution curve, the results of coefficient of uniformity C_u and coefficient of curvature C_c together with Figure 3.2, it can be concluded that the soil specimen used in the research is classified as poorly graded.

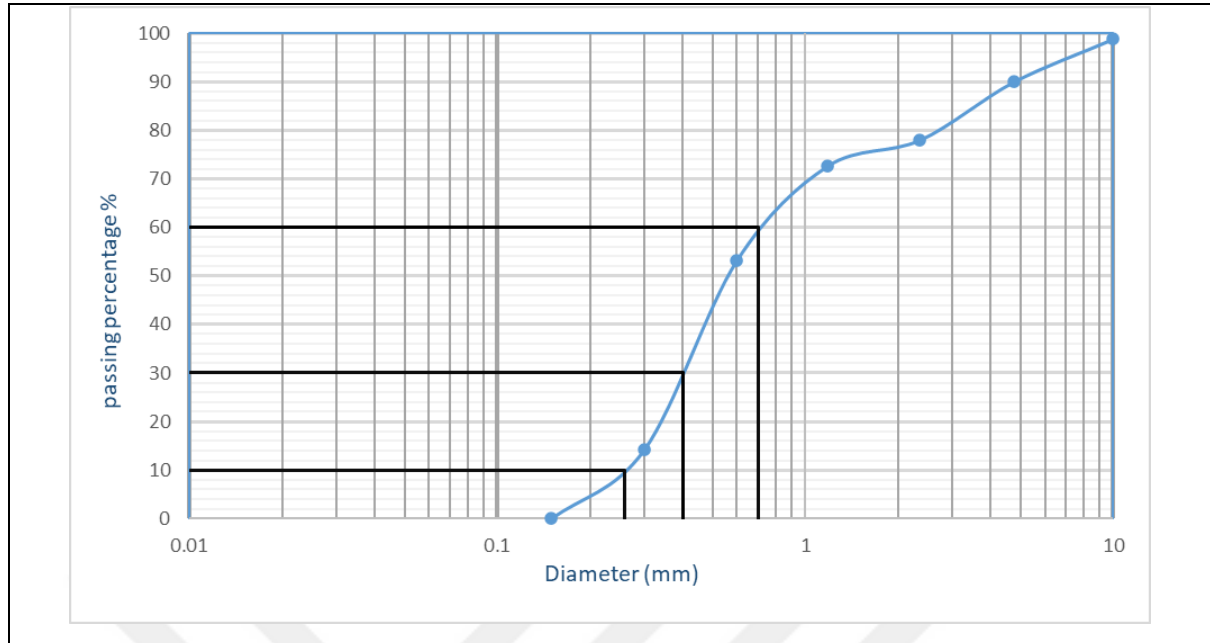


Figure 3.1: Grain Size Distribution Curve for The Sand Sample.

Table 3.1: Soil Properties.

Properties	value
Specific gravity, G_s	2.67
Void ratio	$e_{max} = 0.83, e_{min} = 0.57, e_{used} = 0.73$
Dry unit weight	$\gamma_{max} = 17.97, \gamma_{min} = 15.41, \gamma_{used} = 15.4$
Relative density	$Dr = 31\%$
The angle of internal friction	$\phi = 28$

The angle of internal friction value was determined from the direct shear test.

3.2.2 Jute Fibers

The Jute fibers sheet was used in this research as a reinforcement material (properties of used jute). The fibers were obtained from a local shop in Baghdad. There are various types of jute fibers useable as shown in figure 3.1, Jute fibers sheets used in the research are shown in figure (3.3). technical properties of jute fibers as reported by different authors are listed

in Table (3.1). chemical, physical, and thermal properties of jute sheets are listed in Table (3.2).



(a)

(b)

(c)

(d)

Figure 3.2: (a) Jute Plant; (b) Raw Jute Fabric; (c) Unidirectional Jute Fibers; (d) Woven Jute Fibers [67].



Figure 3.3: Jute Fibers Sheets Used in The Research.

Table 3.2: Jute Fibers Properties as Documented by Different Authors [67].

Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Length (cm)	Diameter (cm)	Density (g/cm ³)
393-773	26.5	1.5-1.8			1.3
460-553	2.5-1.3	1.16	150-360	.005-0.028	1.3
393-773	2.5-26.5	1-2		.0025-.02	1.3-1.45
400-800	10-30	1.5-1.8			1.46
393 394	55 55	1.5-1.8		.001	1.3
300-700	20-50				
393-773	26.5	1.6-4.0			1.3
393	55	1.5-1.8			1.3
					1.3

Table 3.3: Physical and Mechanical Properties of Jute Fibers.

Physical and chemical property	value
Color	Yellow-brown
Moisture regains	12 - 14%
Cellulose	55 – 63%
Heating action	Not degrade
Oxidizing agents	Not affected
Conductivity	Very good

3.3 RESEARCH EQUIPMENT

A general concept about the equipment, tools, and machines that are used in the research. Each part is described and shown below.

3.3.1 Machine

general view of the equipment used illustrate in figure (3.4), it shows the mold and the compression machine which used to apply the axial load on the footing.



Figure 3.4: Test Machine.

3.3.2 Sand Container

A steel box with dimensions of (210,420,420) mm was used to perform a series of tests on the soil. The box consists of three glass sides (to reduce friction between the soil and the box) and a metal one, the thickness of the box is 3 mm.

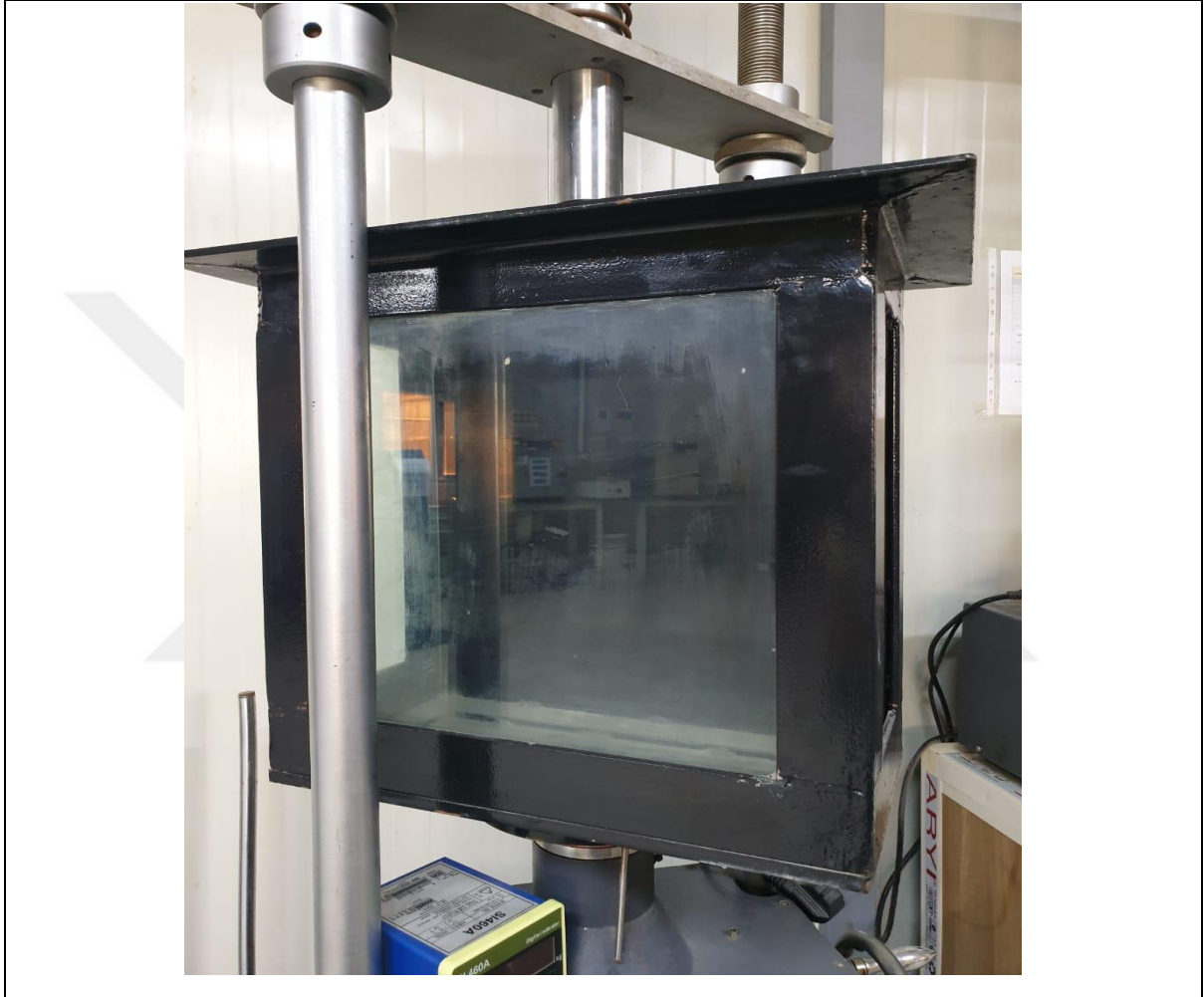


Figure 3.5: Sandbox.

3.3.3 Footing

6 models of the footing used in the study were designed with different dimensions and thicknesses as shown in Figures (3.5a) and (3.5b). The footing models were made from steel sheets welded together to form the desired thickness.



(a)

(b)

Figure 3.6: Footing Models.

3.3.4 Hand Scraper

A hand scraper was used to level the soil in the mold at any depth and on each layer of jute fibers sheets. A leveling instrument was used to check the level of each layer of soil.

3.3.5 Load Cell

A digital indicator SI460 with dimensions of 90mm x 96mm x 116mm and capacity of 15 ton (147 KN) used in order to measure the applied axial load on footing.



Figure 3.7: Load Cell.

3.4 TEST PROGRAM

Two techniques were used in this research Oriented Distributed Technique and Randomly Distributed Technique. Figure (3.9) is an illustration of the experimental model studied during the test for (ODT); it shows the square foundation on a layer of soil reinforced with jute fibers. Table 3.4 and Table 3.5 show the tests conducted on the reinforced and unreinforced soils to determine the bearing capacity.

RDT is done by mixing jute fibers after cutting the fibers into small pieces with soil by percentage of the soil weight.

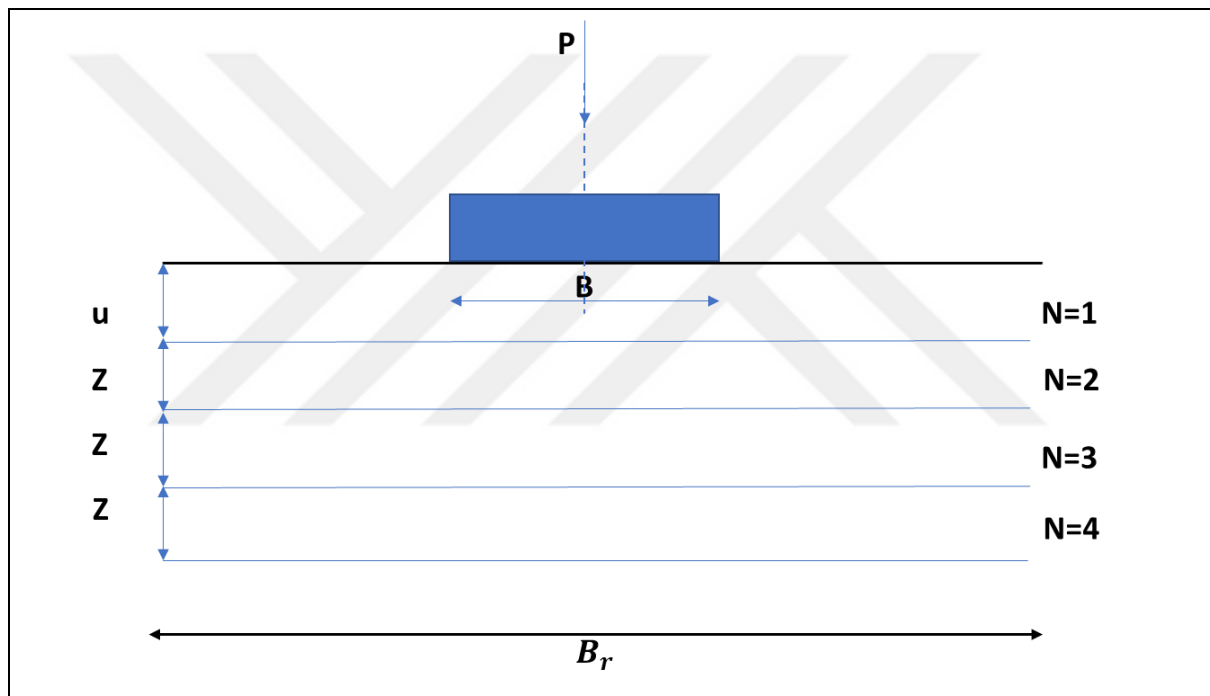


Figure 3.8: Foundation Parameter.

Table 3.4: Testing Program.

B(mm)	Br/B	Footing thickness (mm)	Depth ratio u/B	Vertical spacing ratio z/B	Number of layers
80		5			
100		5			
120		5			
140		15			
Optimum B		5			
		10			
		15			
Optimum B	1	Optimum	0.25 0.5 1		1
	1.2	Optimum	0.25 0.5 1		1
	1.5	Optimum	0.25 0.5 1		1
	2	Optimum	0.25 0.5 1		1
Optimum B	Optimum Br/B	Optimum	Optimum depth ratio	0.25 0.5 0.75 1	2 2 2 2
Optimum B	Optimum Br/B	Optimum	Optimum depth ratio	Optimum	1 2 3 4

Where:

p vertical load (KN),

B footing width (mm),

B_r jute fibers sheet width (mm),

u depth of first layer of jute sheet (mm),

z vertical spacing between layers (mm).

3.5 TEST PROCEDURE.

Soil was added to sandbox by raining technique to achieve the desired density, which is a common method utilized by many scientists and researchers such as (Albusoda & Hussein, 2013, Yoo & Shin, 2003, Fattah et al., 2020, Vaid & Negussey, 1984). According to figure (3.10) it was concluded that the height of drop is 14 cm, which is the required height to get relative density of 31%, void ratio (0.73), and dry density (15.4). For each test, soil is placed with a drop height of 13 cm, until the desired height is reached and when jute fibers are added.

After completing the preparation of the mold, the loading device is adjusted and calibrated, the calibration and adjustment of the device is carried out before each test. One examination is repeated from 3 to 4 times, the average of the tests is taken to obtain the best result.

For the RDT jute fibers cut by hand into small pieces about 12 cm and mixed with soil, then placed in the sand container. The soil compacted very well before placing the footing on the top of it and start the examination.

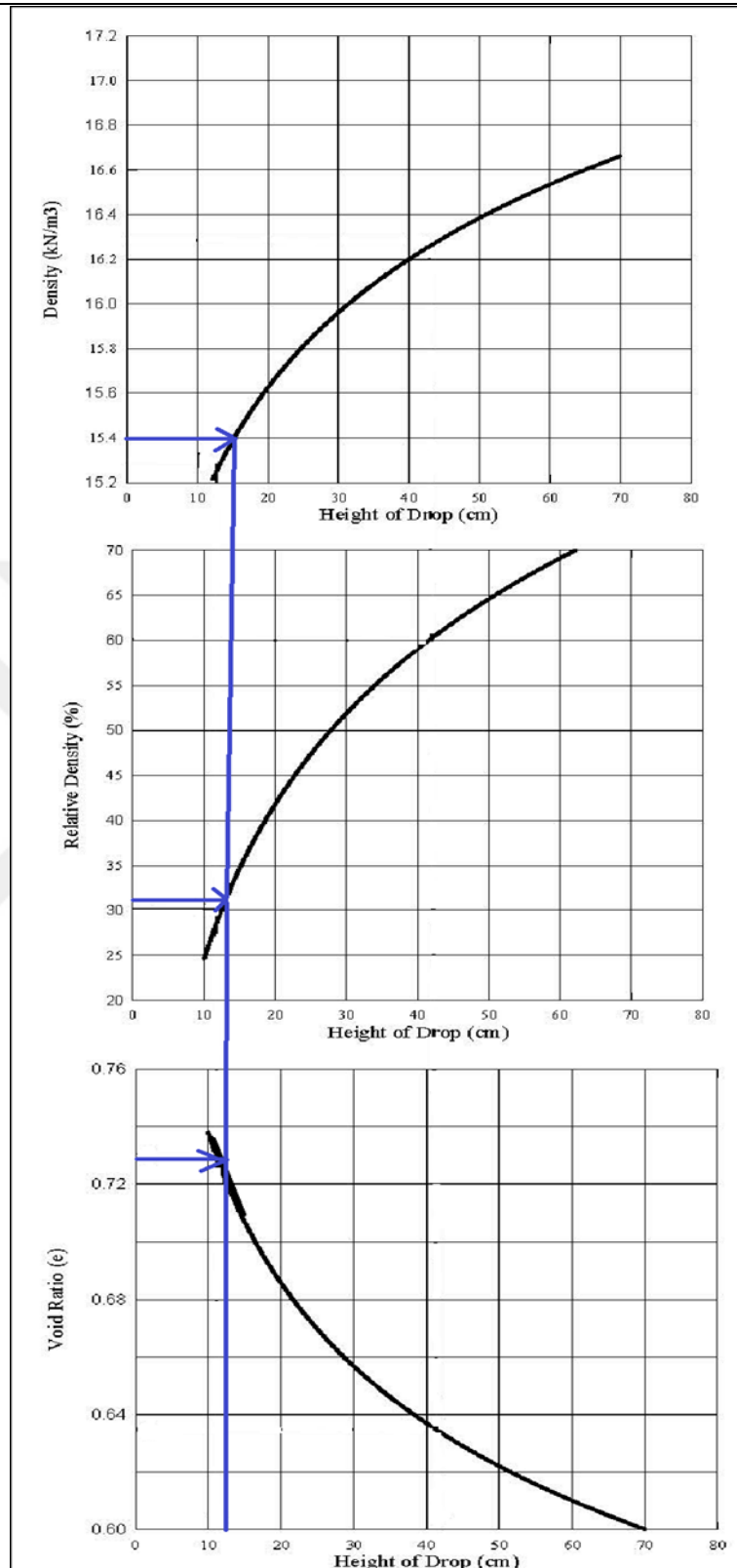


Figure 3.9: Density Calibration Curves.

4. RESULT

4.1 INTRODUCTION

The behavior of unreinforced and reinforced soil was examined and discussed in this chapter. Focusing on the effect of different parameters such as footing width, footing thickness, the width of jute fibers sheets, depth of the first layer of jute fibers, spacing between layers, as well as the number of layers.

The test results, analysis, and discussions are presented in this chapter. This chapter discusses the sieve analysis test, direct shear test, and proctor compaction test. On both reinforced and unreinforced soil, direct shear tests and proctor compaction tests were performed. To assess the effect of jute fibers sheets on the examined soil, the unreinforced soil was used as a baseline.

4.2 RESULT AND DISCUSSION OF TESTS CONDUCTED ON UNREINFORCED SOIL.

Sieve analysis, direct shear test, and proctor compaction test were performed on unreinforced soil in order to determine the type of soil and its engineering properties to be compared later with the results of the soil and its properties after reinforcement.

As mentioned in chapter three this thesis was conducted using materials such as sandy soil and jute fibers sheet, the jute fibers sheet properties were submitted in tables 3.2 and 3.3 and soil sample properties shown in Figure 4.1.

4.2.1 Particle Size Distribution Test

Particle size distribution is defined by the Canadian Soil Information System as the quantities of different soil components in a soil sample, commonly given as weight percentages [68]. The grain size distribution provides a comprehensive and statistical representation of the relative qualities as a proportion of total dry weight (mass) [69]. Particle size distribution is important for the soil in order to know the classification and properties of the soil.

As determined in chapter 3.2.1, the soil was determined as poorly graded according to the particle size distribution test which was carried out on a sandy soil sample. The tests result is shown in Table 4.1.

Table 4.1: Particle Size Distribution Test Results.

Property	value
Specific Gravity	2.7
Consistency limits	
a) Liquid limit (%)	0
b) Plastic limit (%)	0
c) Plasticity index (%)	0
Particle size analysis	
a) Sieve Analysis (sieve number)	
10	100
4.75	90.98
2.36	78.92
1.18	72.73
0.6	53.23
0.3	14.22
0.15	0
b) Gravel percentage	0
c) Sand percentage	99.86
d) Silt percentage	0.14
e) Clay percentage	0
f) D_{60} (mm)	0.802
g) D_{30} (mm)	0.401
h) D_{10} (mm)	0.253
i) C_u uniformity coefficient	3.1
j) C_c curvature coefficient	0.8

4.2.2 The Effect of Footing Width

The effect of footing width on the soil after applying the center load varied depending on the width of the foundation; four different types of foundations with varying widths were utilized in this experiment to establish the optimum footing.

Figure (4.1) shows load-settlement curves when using four footing widths, ($B=80$, $B=100$, $B=120$, $B=140$) mm. It can be noticed that the change of footing width causes a reduction in settlement while the applied load increases. The optimum reduction in settlement and load increase occurs when the footing width is optimum, the optimum value for footing width is $B=140$ mm.

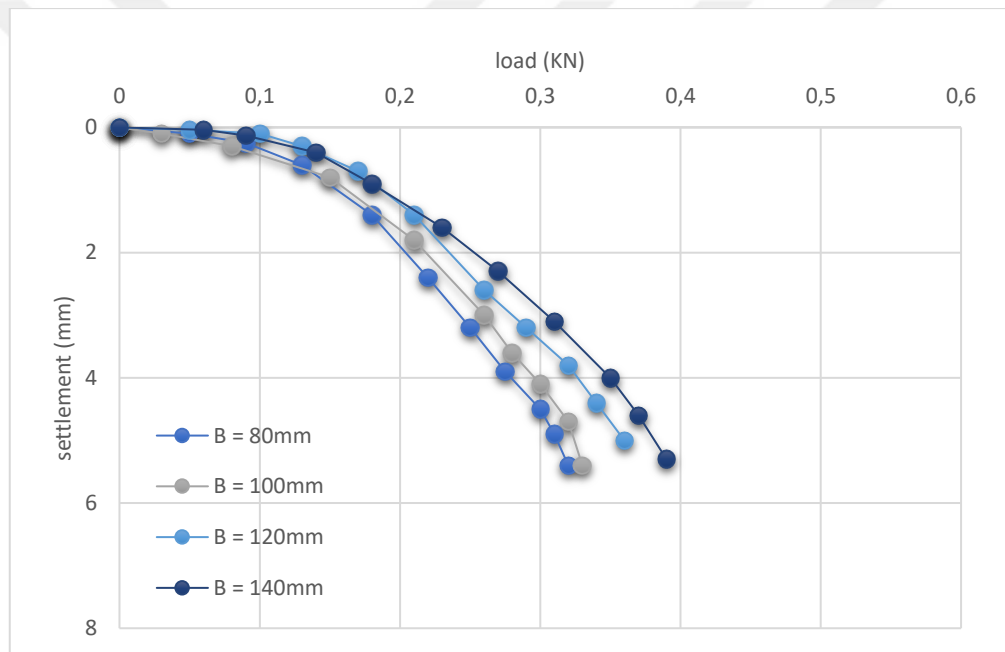


Figure 4.1: Load-Settlement Curves with Different Footing Widths.

The result shows that footing with width of $B=140$ mm is considered to be optimum, because the maximum settlement for unreinforced soil occurs when the footing width is 140 mm.

4.2.3 The Effect of Footing Thickness

After determined the optimum footing the second test was conducted to determine the optimum footing thickness, three footing models were used, all the three models were with dimensions of $140\text{mm} \times 80\text{mm}$ and with three different thickness (T) (5mm, 10mm, 15mm). Figure 4.2 shows the load-settlement curve with different thickness.

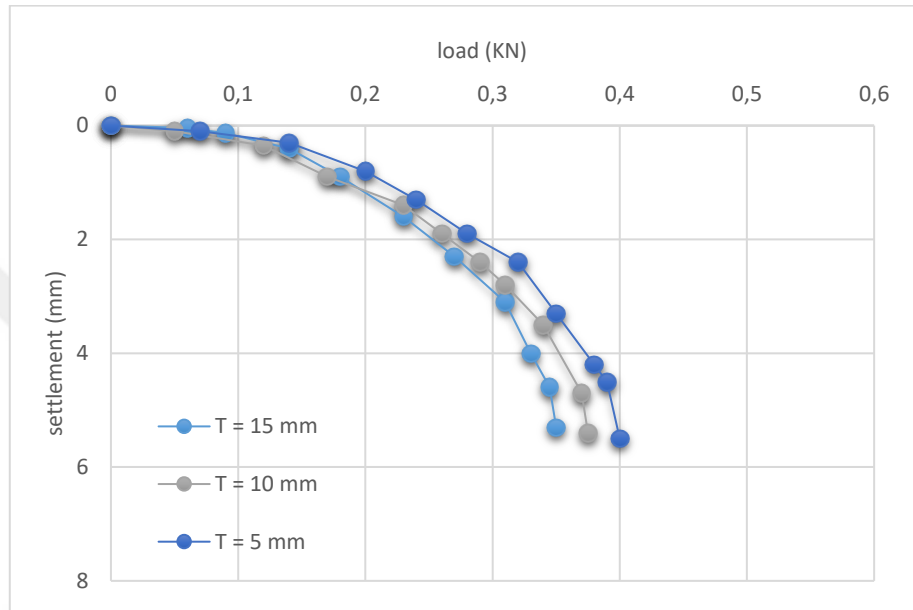


Figure 4.2: Load-Settlement Curves with Different Footing Thickness.

For unreinforced sandy soil sample footing with dimensions of $(140\text{mm} \times 80\text{mm} \times 15\text{mm})$ is considered to be the optimum. It can be concluded that with an increase in the load applied to the footing, the higher the thickness, the higher the settlement. However, footing with dimensions of $140 \times 80 \times 15 \text{ mm}$ will be taken in the next tests for reinforced samples.

4.3 RESULT AND DISCUSSION OF TESTS CONDUCTED ON REINFORCED SOIL (USING ORIENTED DISTRIBUTED METHOD (ODFS)).

Soil reinforced with jute fibers sheets using the oriented distribution method where the fibers placed as sheets between soil layers. Proctor compression and shear tests were performed on soil reinforced with jute fibers and the results were compared to unreinforced soil to determine the influence of the jute fibers on the soil.

4.3.1 The Effect of First Layer Depth

The depth ratio is defined here as the ratio between u and B (where u = depth of first layer and B = footing width). The width of footing taken as 140 mm; three percentages of depth ratio were tested in order to determine the optimum depth of the first layer of jute fibers sheet. The depth ratio percentages were (0.25, 0.5, 1) %.

Figures from 4.3 to 4.6 show the load - settlement curves for $Br/B = 1, 1.2, 1.5,$ and 2 where (B = footing width and Br = reinforcement width). The figures are plotted for different depth ratios for the first layer (u/B = unreinforced, 0.25, 0.5, and 1.0). It can be seen that the change in depth ratio causes reduction in settlement and increasing in load for unreinforced sand. The optimum reduction in settlement and increasing in load when the depth ratio is optimum value.

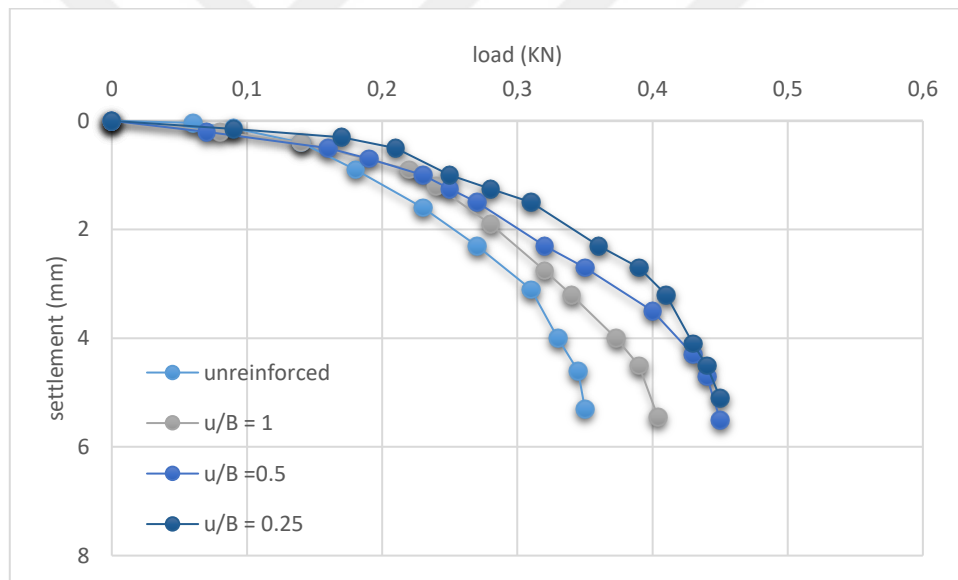


Figure 4.3: Load- Settlement Curves for $Br/B = 1$.

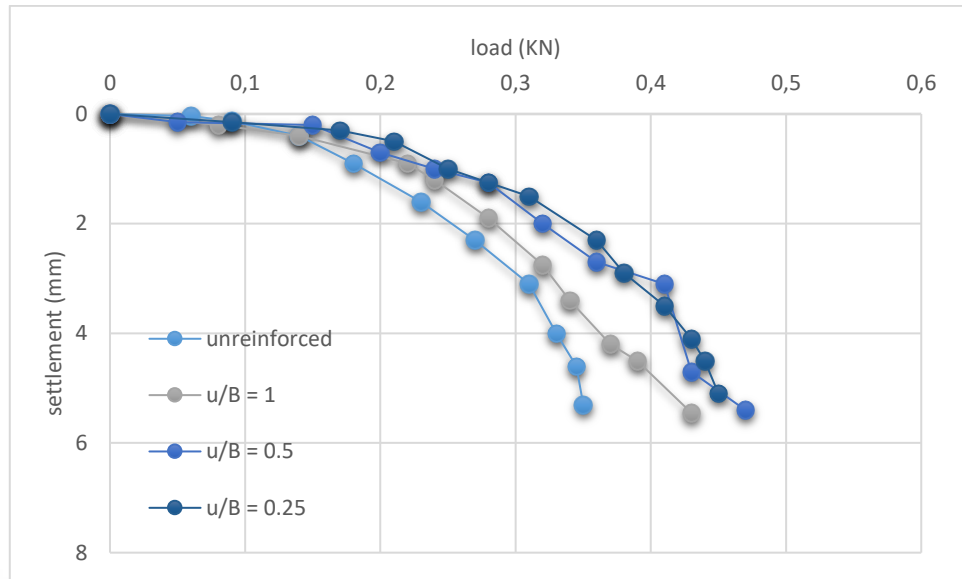


Figure 4.4: Load- Settlement Curves for $Br/B = 1.2$

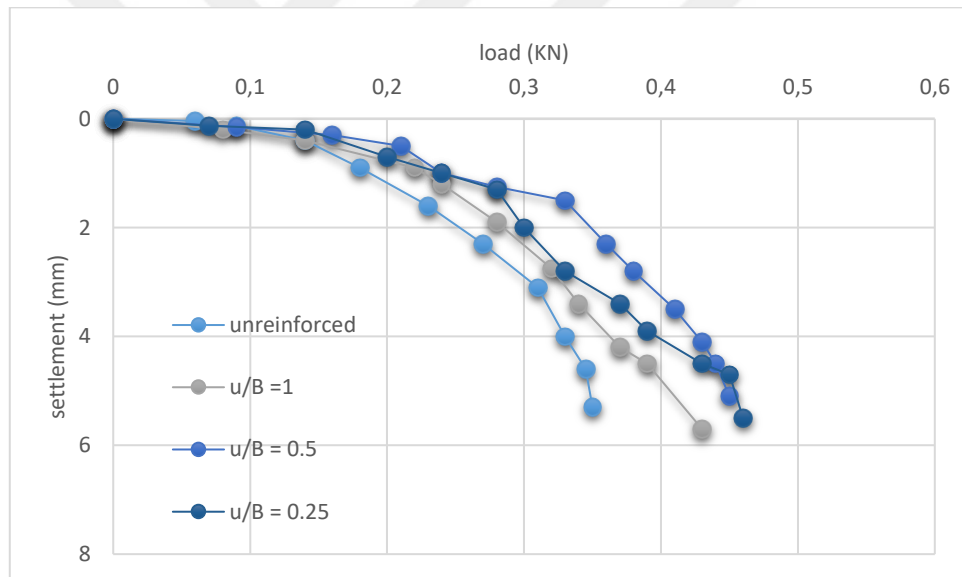


Figure 4.5: Load- Settlement Curves for $Br/B = 1.5$

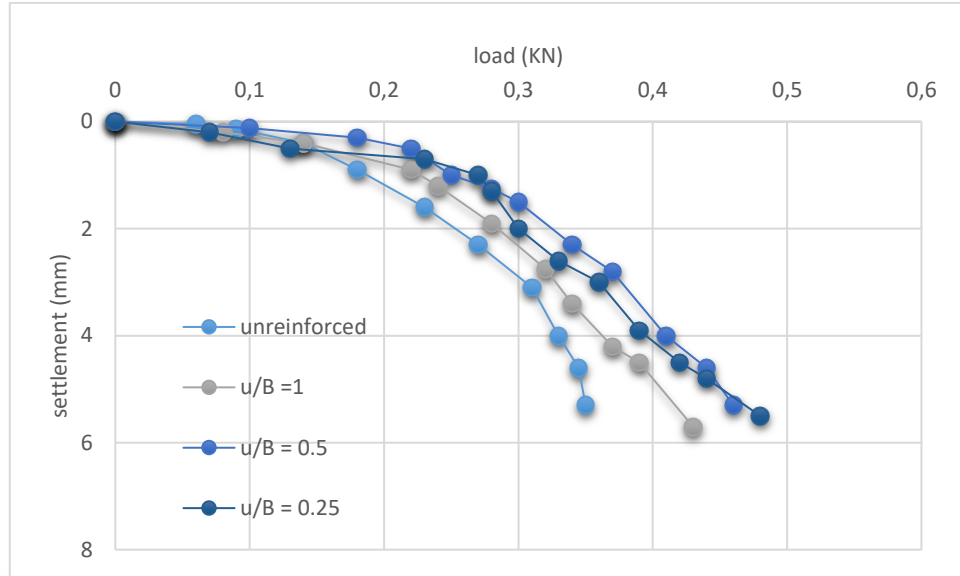


Figure 4.6: Load- Settlement Curves for $Br/B = 2$

The above results illustrated that for a depth ratio equals 1 ($u = B$), the Load and settlement are equal to unreinforced state. Increasing the depth ratio above 1 does not lead to a change in the properties of the sand above the reinforced layer. When the depth ratio ($u/B = 1.0$), there is no change in load and settlement according to the unreinforced state because the depth of the first layer (u) is large and the properties of the sand above the reinforced layer remain unchanged, such as quick arrangement compaction and lateral movement.

It can be seen that the change in depth ratio (u/B) from unreinforced state to ($u/B = 0.25, 0.5$) causes reduction in settlement and increasing in load carrying. The optimum reduction in settlement and increasing in load carrying when the depth ratio is in the optimum values. The optimum values of depth ratio (u/B) are (0.5 and 0.25) for Br/B values of (1, 1.2, 1.5, 2).

The variation of maximum load carrying value with change in footing width and depth ratio values can be noticed in Table (4.2).

Table 4.2: The Load Carrying for Different Depth Ratios at Br Values.

Depth ratio u/B	0.25	0.5	1
$Br/B = 1$	0.44	0.45	0.41
$Br/B = 1.2$	0.45	0.46	0.43
$Br/B = 1.5$	0.45	0.47	0.43
$Br/B = 2$	0.46	0.49	0.44

The minimum settlement is when $Br/B = 2$ and increased with decreasing this value, because the less the area of reinforcement under the foundation, the greater the settlement.

The maximum load carrying increased with increasing the value of Br/B for different depth ratio, the maximum load carrying is when $Br/B = 2$, the maximum load applied on the footing with $Br/B = 2$ the load carrying is 0.48 KN at a depth ratio of 0.5.

The above results for center load show that the optimum depth ratio is less than (B) where B (footing width). These findings are similar to those found by Selvadurai and Gnanendran, (1989) [70] The results of using geogrids to improve the load carrying of footings located on slop fill revealed that when $(u \leq B)$, the failure path is penetrated below the reinforcement, while when $(u > B)$, the failure occurs at the soil geogrid interface (i.e. the failure path is limited in narrow zone) and the deep location of the geogrid layer at $(u > 2B)$ does not lead to any improvement in either the carrying load or the stiffness of the footing. If the depth ratio is less than the optimum, consider the sand particles to change quickly from loose to dense, and with applied load, the edge of the sand particles fracture and crush, resulting in a reduction in bearing capacity[71]; however, when the depth ratio is greater than the optimum depth ratio, expect large settlement for loose sand with applied load, and failure to occur quickly.

The results show that the increase in the width of the reinforced material, increases the load and decreases the settlement. However, an increase after the optimum width does not lead to an increase in the applied load.

Figures (4.7) show the settlement reduction percentage ($R_s\%$), [$R_s = \{(1 - \text{settlement of reinforced sand} / \text{settlement of unreinforced sand})\} * 100$] versus depth ratio for different values of Br/B , at (load=0.1kN).

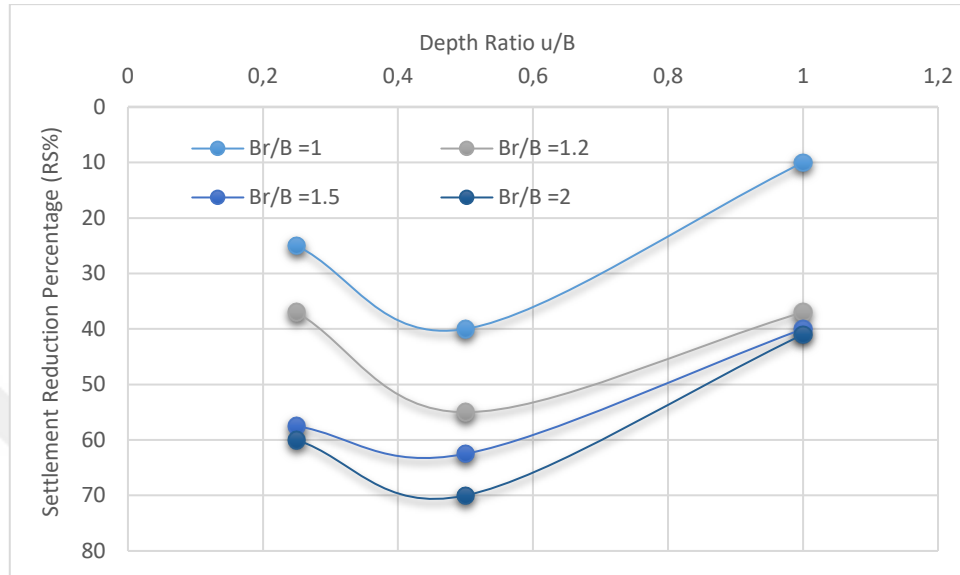


Figure 4.7: Settlement Reduction Percentage Versus Depth Ratio at Load =0.1kN.

Table (4.3) indicated clearly that the settlement reduction percentage increases with reinforcing the soil by jute fibers sheets.

The result also indicated that the maximum settlement reduction percentage occurs at depth ratio of $u/B = 0.5$.

Table 4.3: Shows Settlement Reduction Percentage for Different Br/B Values.

Br/B	1	1.2	1.5	2
Depth ratio u/B	0.5	0.5	0.5	0.5
Settlement Reduction Percentage ($R_s\%$)	42%	55%	62%	70%

The results show that the settlement reduction percentage was optimum when depth ratio is optimum and then the settlement reduction percentage decreases with change in depth ratio from optimum value to other values of depth ratio. The minimum reduction in settlement for different jute fibers sheets width when $Br/B = 1$. Table 4.4 shows the values of settlement reductions percentage for different loads values.

Table 4.4: Settlement Reduction Percentage for Different Br/B Values.

Br/B	Load (KN)	Settlement (mm)	Settlement reduction percentage (Rs) %
1	0	0	0
	0.05	0.08	20
	0.1	0.23	42
	0.25	1.25	30
	0.35	2.7	41.3
1.2	0	0	0
	0.05	0.08	20
	0.1	0.2	55
	0.25	1.1	38.8
	0.35	2.3	50
1.5	0	0	0
	0.05	0.06	40
	0.1	0.25	37.5
	0.25	1	44.4
	0.35	2.1	54.35

Table 4.4: Settlement Reduction Percentage for Different Br/B Values.

2	0	0	0
	0.05	0.06	40
	0.1	0.15	62.5
	0.25	1	44.4
	0.35	2.05	56

Figures (4.8) illustrate the load versus settlement reduction percentage for different jute fibers sheets width at depth ratio $u/B = 0.5$. It can be seen that the general behavior of the settlement reduction percentage decreases with increase in load.

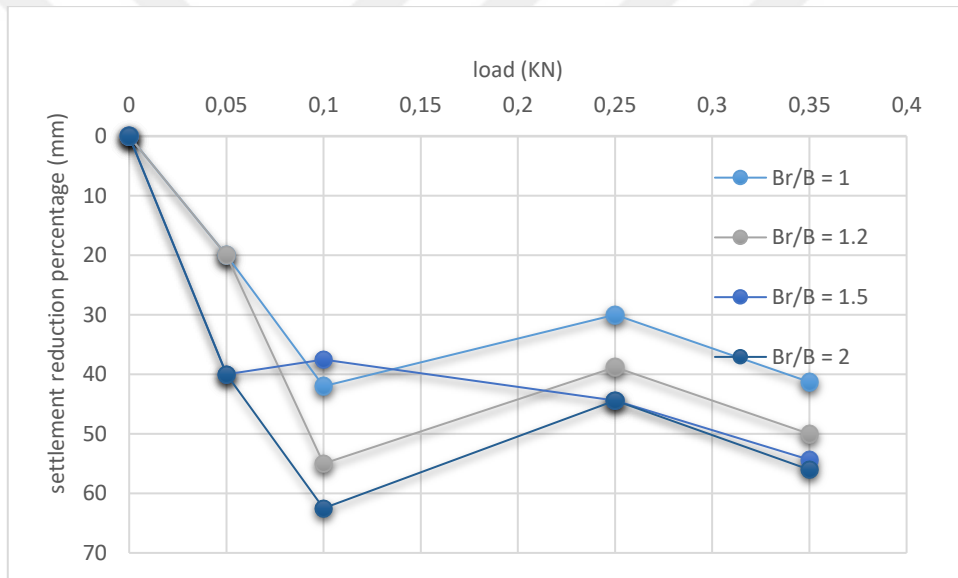


Figure 4.8: Load Versus Settlement Reduction Percentage for $u/B=0.5$.

Regarding the above data from table 4.4 and the figure 4.8, it can be observed that the settlement reduction percentage increases with the increase of the reinforced area of the jute fibers under the foundation.

Similar to the situation the soil resistance, the increase in the reinforcing area caused a rise in the soil resistance to the load placed on the foundation.

However, the settlement reduction percentages begin to decrease gradually with the increase of the load placed on the foundation, as it was noted that the settlement reduction percentages begin to decrease when the load increases above 25 Newton.

Figure (4.9) shows that the rate of bearing improvement percentage $[(Pr/P) - 1] * 100$ (where Pr and P is the maximum load for reinforced and unreinforced sand, respectively.), versus depth ratio values for central load and different Br/B values.

In general, the behavior of bearing improvement percentage decreases with increasing depth ratio for different reinforced material width.

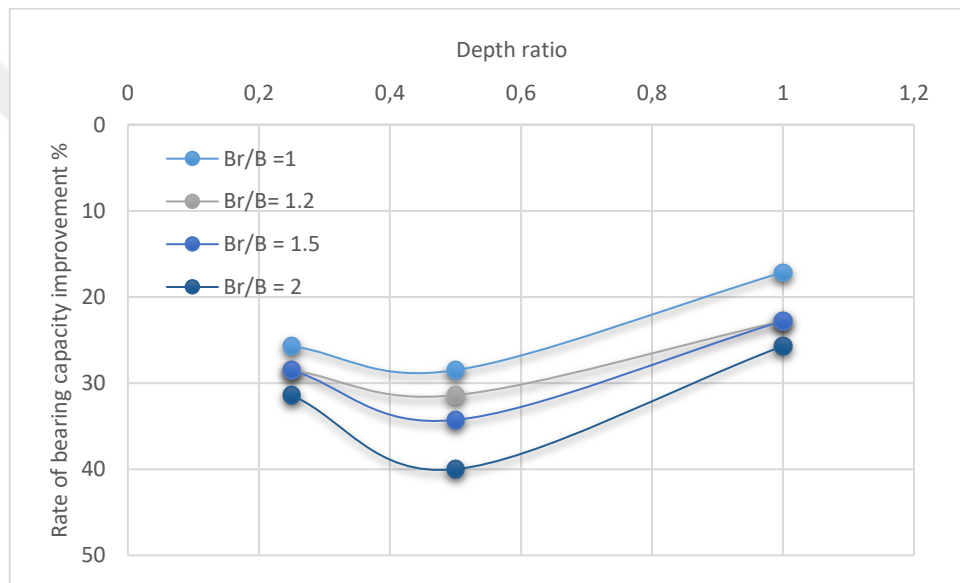


Figure 4.9: Rate of Bearing Capacity Improvement Percentage Versus Depth Ratio.

It can be seen that the maximum bearing improvement percentage at $Br/B = 2$ and then the rate of bearing improvement percentage decreases with decreasing jute fibers sheet width value.

Table 4.5 also shows the maximum Rate of Bearing Improvement with different width ratio Br/B at optimum depth ratio of $u/B = 0.5$.

Table 4.5: Rate of Bearing Improvement Percentage (%) at Depth Ratio ($u/B=0.5$) for Different Br/B Values.

Br/B	1	1.2	1.5	2
Bearing Capacity Improvement Percentage (%)	28.5	31.4	34.28	40

The result illustrates that the rate of Bearing Improvement increases with the increase of reinforced material width, the maximum value of improvement at optimum depth ratio was 33% when the width of jute sheet ratio Br/B equals to 2.

4.3.2 The Effect of Vertical Spacing Between Layers

In order to determine the optimum vertical spacing between jute fibers sheets two sheets were added to the soil, the percentage of vertical spacing taken were z/B (1.5, 1, 0.75, 0.5).

The effect of vertical spacing ratio between reinforced layers (z/B) where (z = vertical spacing between layers and B = footing width), on the load carrying of footing was investigated as shown in Figure (4.10) for ($Br/B=2$) and depth ratio 0.5.

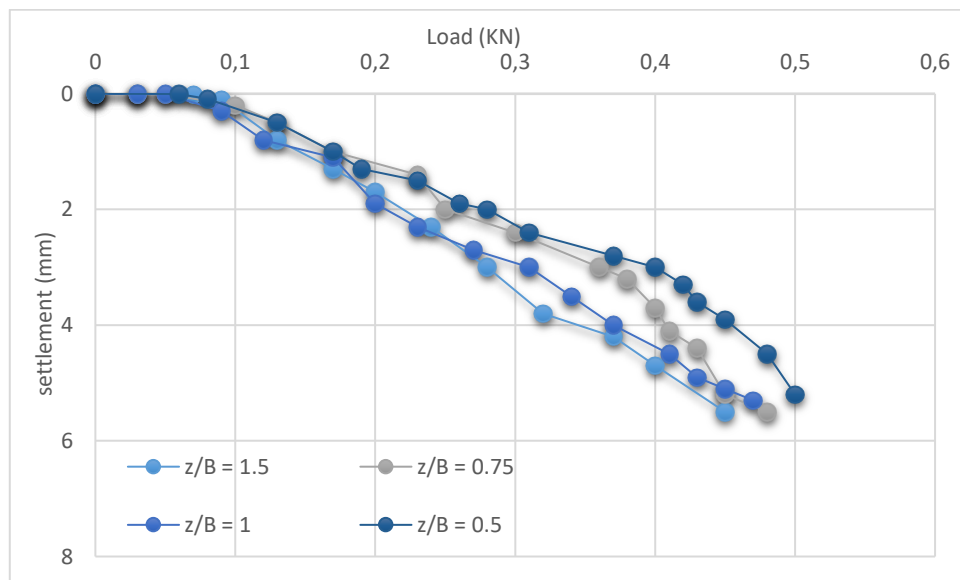


Figure 4.10: Shows Load-Settlement Curves for Different Vertical Spacing.

Figure 4.10 indicates that the load carrying decreases and settlement increases with increasing vertical spacing values. The maximum load carrying is at $z/B=0.5$, for width ratio values of $B_r/B = 2$, as shown in table 4.6.

Table 4.6: The Load Carrying at $B_r/B = 2$ with Changing Vertical Spacing Ratio.

Vertical Spacing Ratio (z/B)	0.5	0.75	1	1.5
Load Carrying (kN)	0.5	0.48	0.47	0.45

It can be seen that the maximum load carrying changes with variations of vertical spacing ratio. $z/B=0.5$ obtains the maximum load carrying for $B_r/B = 2$ at the dial gauge. Fukuda et al. (1987) demonstrated that the optimum vertical spacing between reinforcement is $2/3B$ by testing concentric loads placed on a footing with polymer grid reinforcement. A greater value of (z/B) than (1.5) results in the same load carrying; the influence of jute sheets lessens as the vertical spacing ratio increases.

It can be seen that the optimum settlement reduction percentage at depth ratio of 0.5 B_r/B occurs at vertical spacing ratio of 0.5.

Figure 4.11 shows that the settlement reduction percentage decreases with increasing vertical spacing ratio. For vertical spacing ratio ($z/B=1.5$) the settlement reduction percentage is 19% while for ($z/B= 0.5$) the settlement reduction percentage is 88%.

In Maximum settlement reduction percentage occurs at vertical spacing $z/B = 0.5$

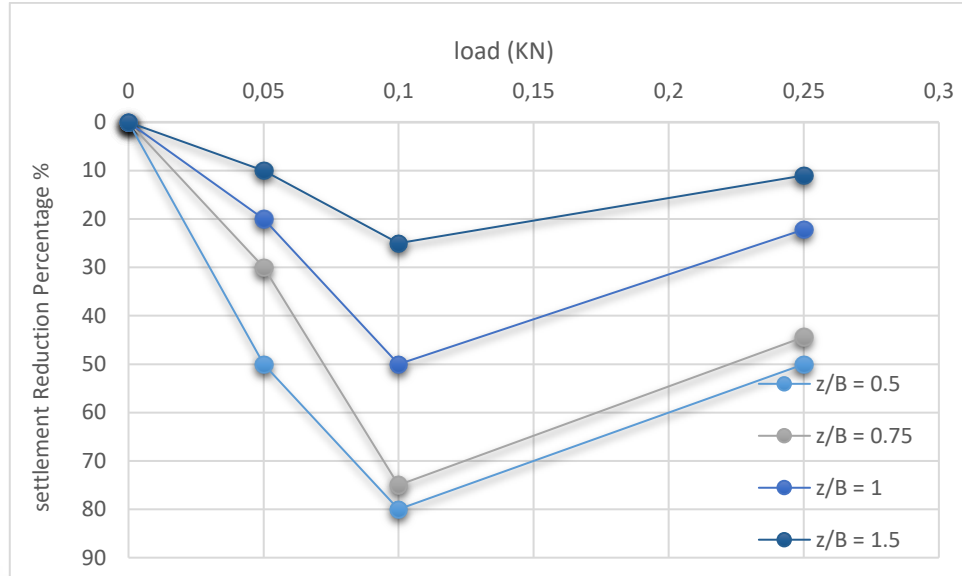


Figure 4.11: Load Versus Settlement Reduction Percentage for Different Vertical Spacing Ratio.

It can be seen that the general behavior for the settlement reduction percentage decreases with increasing load for different vertical spacing ratio and the optimum reduction settlement when vertical spacing is optimum value ($z/B=0.5$).

The rate of bearing improvement percentage which is defined $[(Pr/P) - 1] * 100$ (where Pr and P are the maximum loads for reinforced and unreinforced soil, respectively), figure 4.12 shows the rate of bearing improvement versus vertical spacing ratio ($z/B=0.5, 0.75, 1.0$ and 1.5) for $Br/B=2$.

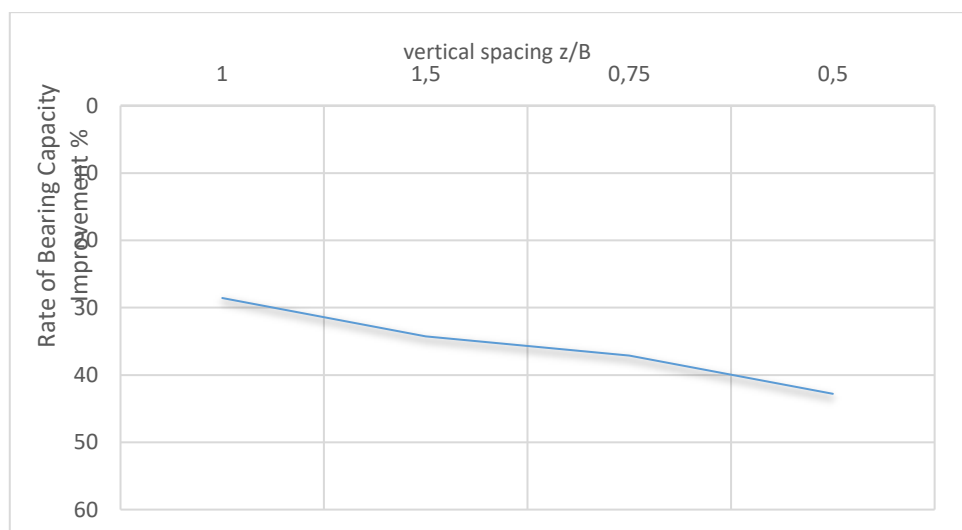


Figure 4.12: Rate of Bearing Capacity Improvement (%) Versus Vertical Spacing Ratio.

The results illustrate that the maximum rate of bearing improvement percentage is at ($z/B=0.5$), and then decreases with increasing the vertical spacing. It can be seen that the rate of bearing improvement percentage is equal to (0) for vertical spacing ratio is equal to 1.5.

For vertical spacing (z/B) greater than 1.5 no improvement can be noticed in either the carrying load or the stiffness of the footing.

Table 4.7 shows the Rate of bearing improvement percentage for different spacing values between two sheets of jute fibers.

Table 4.7: Rate of Bearing Improvement (%) with different Spacing Ratio.

z/B	1.5	1	0.75	0.5
Rate of Bearing Improvement (%)	28.57	34.28	37.14	42.8

4.3.3 The Effect of Number of Reinforcing Layers

The bearing value changes more drastically with the number of the reinforcement layer (N) than other parameters. Figures (4.13) show a typical variation of the bearing with settlement dial gauge for different number of reinforcing layers (N).

Figure (4.13) shows the load -settlement for optimum depth ratio, optimum vertical spacing ratio, different number of reinforcement layers (N).

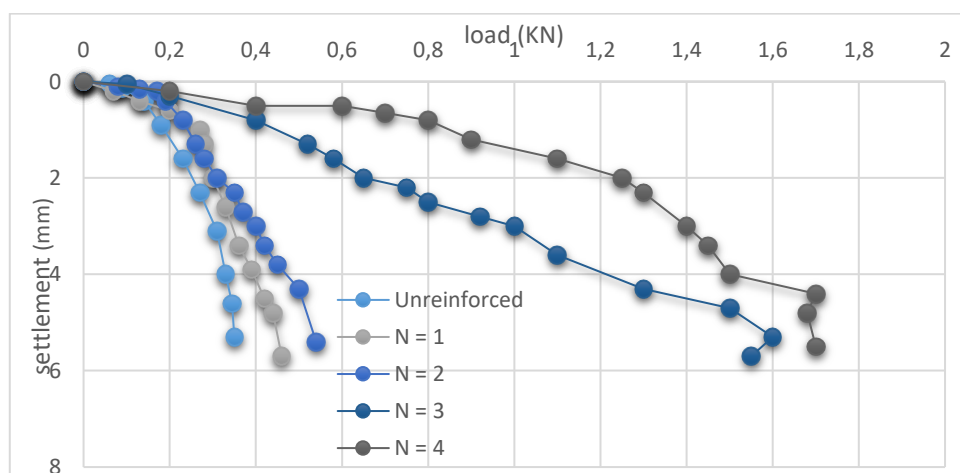


Figure 4.13: Load-Settlement Curves for Different Layers of Jute Fibers.

It can be noticed that using more than two layers of jute fibers sheet increases soil strength, the settlement decreases with increasing number of reinforcement layers from (0, 1, 2, 3, to 4) due to the soil become more rigidly of soil with increasing number of layers.

Table 4.8 shows the percentage of settlement reduction ($R_s\%$) for different jute fibers sheets number when $B_r/B = 2$ and $u/B = 0.5$ and vertical spacing between layers $z/B = 0.5$.

Table 4.8: Settlement Reduction Percentage for Different N Value.

N	Load KN	Settlement	Settlement Reduction percentage ($R_s\%$)
1	0	0	0
	0.05	0.06	20
	0.1	0.15	42
	0.25	1	30
	0.35	2.05	41.3
2	0	0	0
	0.05	0.05	50
	0.1	0.08	80
	0.25	0.9	50
	0.35	2.4	47.8
3	0	0	0
	0.05	0.03	70
	0.1	0.05	87.5
	0.25	0.5	72.2
	0.35	0.7	85.41
4	0	0	0
	0.05	0.02	80
	0.1	0.03	92.5
	0.25	0.2	88.8
	0.35	0.5	89.13

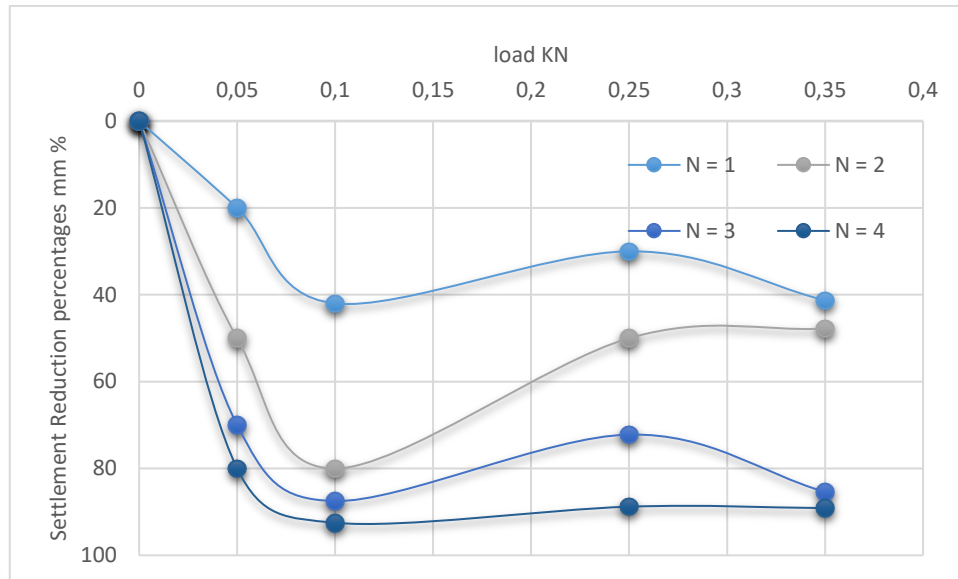


Figure 4.14: Load Versus Settlement Reduction Percentage for Different Jute Sheet Numbers.

Figure (4.19) shows settlement reduction percentage and the number of reinforcement layers at different loads for $B_r/B=2$. It can be seen that the settlement reduction percentage ($R_s\%$) increases with the increase of jute fibers layers between soil, it can be seen that the optimum settlement reduction percentage at reinforced number ($N=4$).

The optimum settlement reduction percentage can be noticed at ($N=4$) is (90 %). It can be seen that the increase in the number of reinforcement layers causes a reduction in settlement values for the same load intensities.

Table 4.9: Rate of Bearing Improvement.

Number of jute sheets layer	1	2	3	4
Rate of bearing improvement%	15%	35%	280%	320%

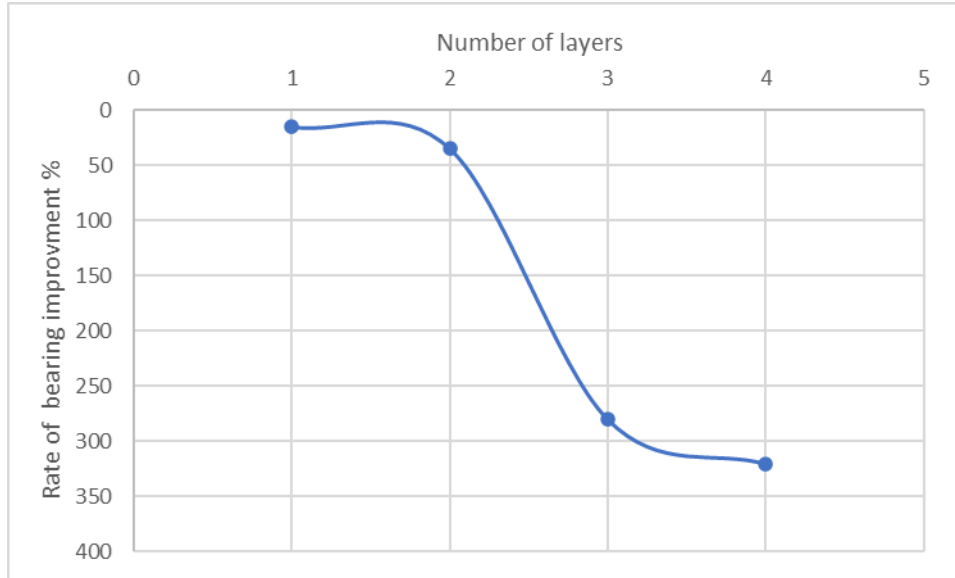


Figure 4.15: Rate of Bearing Improvement for Different Number of Layers.

This graph shows how the rate of bearing improvement increases as the number of reinforcement layers increases. This is because reinforcement creates a stiffening effect. This stiffening refers to the frictional interaction that occurs within the mass of reinforced soil as the number of reinforcement layers' increases, resulting in more bonds between the soil and reinforcement material and a more stable mass structure.

4.4 RESULT AND DISCUSSION OF TESTS CONDUCTED ON REINFORCED SOIL (RANDOMLY DISTRIBUTED METHOD (RDFS)).

Soil reinforced with jute fibers using random distribution method where the fibers cuts into small pieces and mixed with the soil. compression and shear tests were performed on soil reinforced with jute fibers and the results were compared to unreinforced soil to determine the influence of the jute fibers on the soil.

Figure 4.21 shows load- settlement curves for unreinforced soil and soil reinforced with jute fibers mixed into the soil.

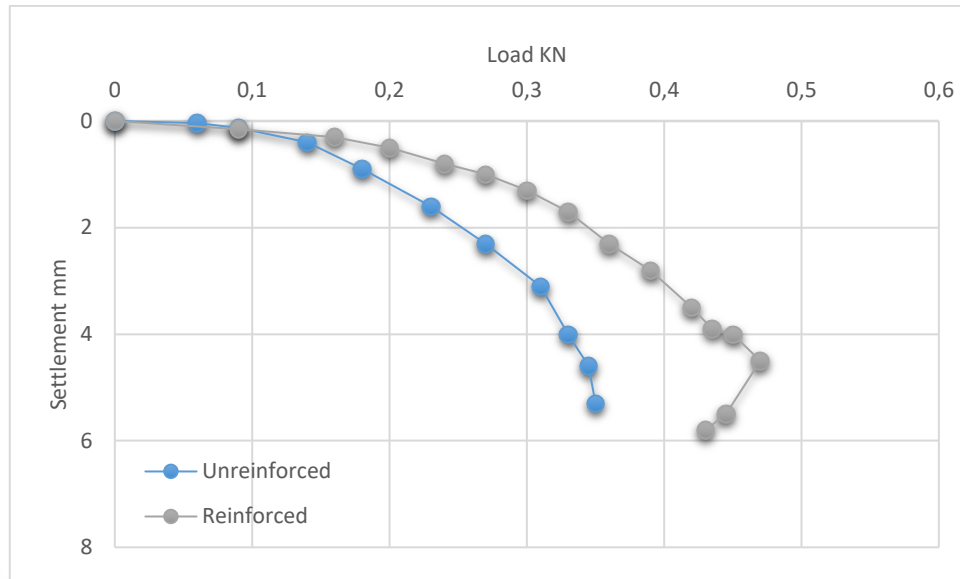


Figure 4.16: Load-Settlement Curve for RDFS Method of Reinforcement.

Figure 4.21 indicates that the load carrying increases and settlement decreases after mixing jute fibers with the soil. The rate of bearing improvement percentage which is defined $[(\frac{Pr}{P} - 1) * 100]$ for reinforced was found to be equal to 12.5%. However, this percentage is considered to be small compared to the first method of improvement (ODFS), and it is due to the fact that the soil is sandy and dry and does not contain water content. Therefore, the bonding between the soil particles and the jute fibers is weak and does not lead to improving the properties of the soil.

The Bearing capacity of soil is the maximum load applied on the foundation that doesn't lead to shear failure in the soil. In another definition it is the maximum load applied without causing deformation to the soil. According to the curves discuss above it can be seen that the soil started to settle after applying the load, it can be noticed the value of settlement is small in the initial stages of loading in a manner that is permissible as it considers a flexible settlement. However, with increasing in the applied load, the percentage of settlement increase until the percentage of the of settlement become very large compared to the increase in the load.

Therefore, the moment when the soil beings to settle rapidly, while the load continues to increase at the same rate, is considered the point of soil failure.

5. DISCUSSION AND CONCLUSIONS

5.1 CONCLUSIONS

The research aims into the effectiveness of enhancing sandy soil with eco-friendly material. After completing laboratory testing on the soil samples taken from the city of Karbala, the result indicates that the type of soil is sand, and it is poorly graded.

As the globe and scientists have recently moved to employ sustainable materials in many applications, the possibility of improving this soil by using recycled environmentally friendly materials has been studied, jute fibers were used as a sustainable material to improve the properties of sandy soil and its bearing capacity in this study.

The jute fibers were firstly added according to oriented distribution method; this method indicates that the additives material placed as sheets between soil layers. laboratory tests including the Proctor test, sieve analysis test, and compressive strength tests were conducted. on the reinforced and unreinforced soil. The inclusion of jute fibers was demonstrated to increase the soil resistance. Also, the result shows that when the number of jute fibers layers increases from $N=1$ to $N=4$, the soil bearing capacity increases and settlement decreases. Secondly, random distribution method is used by mixing the soil with jute fibers and cutting it into small pieces. In general, although this method achieved a percentage of soil improvement, it is considered insignificant compared to the first method.

The study proved that the soil resistance increases by adding jute fibers, and this proves the effectiveness of the fibers as an additive to reinforce sandy soils in the examination area for shallow foundations. The experiment is successful in terms of strengthening sandy soils and increasing their bearing capacity by using sustainable and low-cost materials.

The improvement achieved by laying sheets of jute fibers between the soil layers is quite similar to the usage of geogrid in soil improvement activities. It creates a layer that supports the soil.

5.2 FUTURE WORK

The effectiveness of fibers with clay and gypsum soils in Iraq can be studied. It is also possible to conduct laboratory studies on the possibility of improving asphalt roads by using jute fibers material, as it has proven its effectiveness in shallow foundations. In the next work, an analytical study of the difference between soil improvement using recycled materials and other additives can be studied.



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