BEARING CAPACITY OF FIBER REINFORCED SOIL

WAN NURATIQAH ILYANI BINTI WAN YUSOFF

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

During previous era, earth reinforcement is one of the method used that proven effective and reliable method to increase the strength and stability of soils. As an effective way for the soil stabilization, the technique is used today in a variety of applications ranging from retaining structures and embankments to subgrade stabilization beneath footings and pavements. Nowadays, randomly distributed fiber reinforced soils have attracted increasing attention in geotechnical engineering. A series of California Bearing Ratio (CBR) Test were done in this study. River sand and wire mesh fiber was selected as material for this testing. There are various laboratories testing for determination of soil classification that take place before CBR testing. For the sample preparation, 1 mm diameter of wire mesh fiber was cut in a range of 0.5-1 cm length. Different percentage of fibers that used for the testing are included 1%, 3%, and 5%. Fibers were mix homogeneously with fine sand. In the current study, optimum moisture content (10%), +2% of moisture content (8.5%), and -2% of moisture content (11.24%) were used as control moisture for the testing. Optimum moisture content was developed from Standard Proctor Compaction Test. Results indicates that the CBR value increases with increasing percentage of fiber. For the reinforced soil, the results show that it is higher in CBR value compared to unreinforced soil. Besides that, according to bearing capacity of fiber reinforced soil in the CBR value, the optimum value of fiber content is 3%. The addition of 3% fiber shows the most obvious of the increases value of CBR. Inclusion of further higher fiber content will not provide the soil more strength than optimum value. In addition, sample with optimum moisture content (10%) shows the greatest gain. Very high moisture content will reduce the strength of the soil. In order to improve the result, the other test for determining of bearing capacity can be done such as plate load test which is require big scale test. Small scale size of the CBR test apparatus limits the amount of the fiber inclusion.

ABSTRAK

Semasa era sebelum ini, tetulang bumi adalah salah satu kaedah yang digunakan di mana kaedah ini terbukti berkesan dan boleh dipercayai bagi meningkatkan kekuatan dan kestabilan tanah. Sebagai cara yang berkesan bagi penstabilan tanah, teknik ini digunakan pada hari ini dalam pelbagai aplikasi sebagai contoh untuk mengekalkan struktur dan benteng bagi penstabilan subgred di bawah asas dan jalan raya yang bertar. Pada masa kini, tanah serat secara rawak bertetulang telah menarik banyak perhatian dalam kejuruteraan geoteknikal. Ujian Satu siri Nisbah Galas California (CBR) telah dilakukan dalam kajian ini. Pasir sungai dan serat jejaring dawai dipilih sebagai bahan untuk ujian ini. Terdapat pelbagai ujian makmal untuk menentukan pengkelasan tanah yang dijalankan sebelum ujian CBR. Untuk penyediaan sampel, 1 mm serat jejaring dawai dipotong dalam lingkungan 0,5-1 cm panjang. Peratusan gentian yang berbeza telah digunakan untuk ujian ini iaitu sebanyak 1%, 3% dan 5%. Gentian digaul bersama dengan pasir halus. Dalam kajian ini, kandungan lembapan optima (10%), +2% daripada kandungan kelembapan optima (8.5%), dan -2% daripada kandungan kelembapan optima (11.24%) telah digunakan sebagai lembapan kawalan untuk ujian ini. Kandungan lembapan optima dihasilkan dari Ujian pemadatan. Keputusan menunjukkan bahawa nilai CBR meningkat dengan peratusan peningkatan serat. Bagi tanah bertetulang, keputusan menunjukkan bahawa ia adalah lebih tinggi dalam nilai CBR berbanding tanah tanpa tetulang. Selain itu, mengikut keupayaan galas tanah bertetulang gentian nilai CBR, nilai optima kandungan gentian ialah 3%. Penambahan gentian 3% menunjukkan dengan jelas nilai peningkatan CBR. Penambahan lebih banyak kandungan serat tidak akan memberi kekuatan tanah lebih tinggi daripada nilai optima. Di samping itu, sampel dengan kandungan lembapan optima (10%) menunjukkan peningkatan paling tinggi. Kandungan kelembapan yang sangat tinggi akan mengurangkan kekuatan tanah. Bagi meningkatkan hasil, ujian lain untuk menentukan keupayaan galas boleh dilakukan seperti ujian beban plat yang memerlukan ujian berskala besar. Saiz kecil-kecilan radas ujian CBR menghadkan jumlah kemasukan gentian.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In soil structures, the use of fibres as reinforced soil is not a new soil reinforcement technique. The concepts that involve the soil reinforcement using fibres have been used since ancient times. For example, ancient civilizations used straw and hay to reinforce mud blocks in order to create reinforced building blocks to improve their properties. Moreover, for building the Great Wall of China, the clay soil was mixed tamarisk branches. Then, synthetic fibres have been used since the late 1980s.Utilizing the same reinforcement mechanism, for the past few decades, there are few numbers of researcher doing experimental and numerical studies on fibre reinforced soil. Thus, earth reinforcement can be described as an effective and reliable technique for increasing the strength and stability of soils (Donald H. Gray et al., 1983).

Foundation is the lowest part in building structure and it is part of structure that direct contact with the soil. Since it is the lowest part, its main function is to transfer load from building to the soil. As the load is applied from structure to soil, settlement occur which is proportional to the load. The structure must be properly design because if it is not properly design, it may cause overstressing to the soil, then it will effect the soil which is either it will cause settlement or shear failure of the soil. Besides that, when the loading increase, settlement progressively increases, and it will cause the soil transforms from the state of elastic equilibrium to plastic equilibrium which is the distribution of soil reaction changes and failure of soil occurs. Furthermore, there are three principal modes of shear failures which are includes general shear failure, local shear failure and punching shear failure. It is depends on the relative compressibility and characteristics of soil. For general shear failure, basically, it occurs in relatively incompressible soil with finite shearing strength which is the failure is accompanied by considerable bulging on the soil surface. The bulging of surface soil may be evident on the side of the foundation undergoing a shear failure.Then, for local shear failure, it occurs in relatively compressible soil. The failure is complemented by visible sheared zone after bulging has taken place. Punching shear failure takes place due to the relatively great compressibility of soil and probably will be evaluated by determining the rigidity index of the soil. Figure 1.1 shows general shear failure, and figure 1.2 shows punching shear failure.

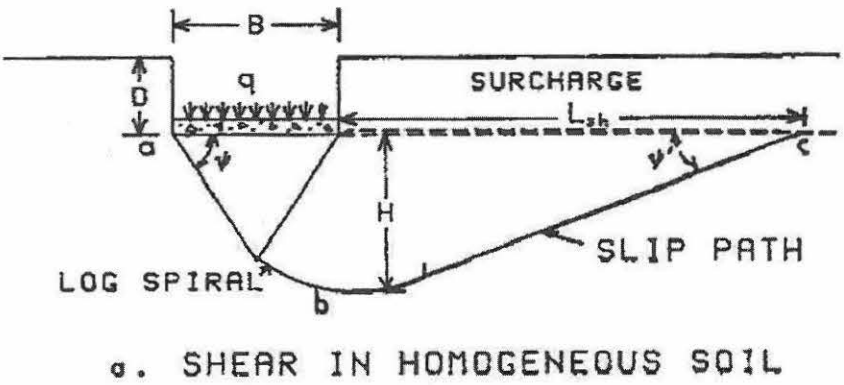

Figure 1.1: General Shear Failure

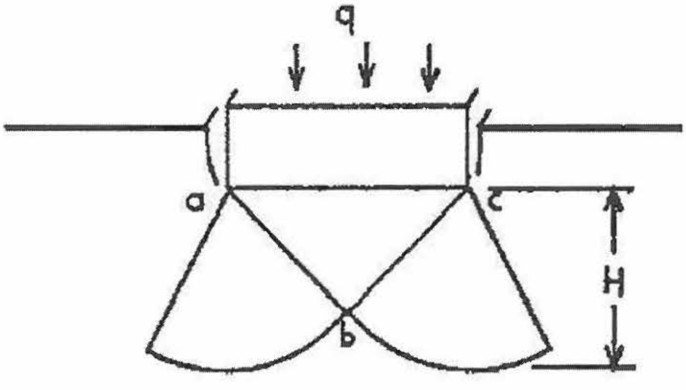

Figure 1.2: Punching Shear Failure

The bearing capacity of soils must be evaluate properly while designing foundations. Thus, bearing capacity can be described as the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements.A number of equations based on theoretical analysis and experimental investigations are available to determine the ultimate bearing capacity equation which are include Terzaghi's analysis, Meyerhof's analysis and also can be Hansen's modification. Thus, bearing capacity is one of the important aspects in soil engineering.

There are few factors that influencing ultimate bearing capacity. It is included type and strength of soil, foundation width and depth, soil weight in the shear zone, and also surcharge. According to Gilbert Gedeon (1958), bearing capacity analysis suppose to be a uniform contact pressure which is occur between the foundation and underlying soil. Bearing capacity analysis is generally accepted method when this analysis is to assume that the soil below the foundation along a critical plane of failure (slip path) is on the verge of failure. It is also to calculate the bearing pressure applied by the foundation required to cause this failure condition. Thus, this can be described as the ultimate bearing capacity (qu). The general equation for ultimate bearing capacity (qu) can be expressed as shown below:

$$q_f = cN_c + \bar{\sigma} N_q + 0.5\gamma B N_\gamma \tag{1.1}$$

Where,

qu	= ultimate bearing capacity pressure
c	= soil cohesion (or undrained shear strength,Cu)
B	= foundation width
N_c, N_Υ, N_q	=dimensionless bearing capacity factors for cohesion, soil weight in the failure wedge, and surcharge

Many studies have demonstrated that inclusion of fibres into soil can improves the engineering response of soil. According to Hoe I. Ling (2003), the person that proposed the principle of reinforced earth (Vidal, 1969) is Henri Vidal. He has described reinforced earth as a material that has been formed by combining earth and reinforcement. By his definition, earth have been shown as covers all types of ground that found in nature, or can be described as produced by physical or chemicals means which is included both granular soils and earth that exhibits some slight cohesion.The reinforcement which is strong in tension effectively combines with the soil which is strong in compression. Thus, reinforcement has been defined as all linear components that can withstand major tensile stresses.

Soil mass is generally a discrete system which consists of soil grains. It cannot bear tensile stresses and this is particularly true in the case of cohesion less soil like sand. Soils are also can be weak or soft soil and this type of soil can cause settlement or bearing capacity failure of soil. So, to improve the strength of soil, the construction leads to various ground improvement techniques such as soil stabilization and reinforcement (KalpanaVineshMaheshwari et al., 2011). Thus, soil reinforcement can be an effective and reliable technique for improving strength and stability of soils. One of the techniques in improving soil strength is inclusion of fibers into soil. Fibers are simply added into soil same way as added additive, lime or cement into concrete to form reinforced concrete. It can be shown that the concept of reinforced soil is same as the reinforced concrete. But, in soil, we do not use RC or steel to reinforce it. Thus, fiber reinforced soil can be defined as a soil mass that contains randomly distributed, discrete elements such as fibers, which is it can provide an improvement in the mechanical behavior of the soil (Sayyed Mahdi Hejazi et al., 2011).

There are some advantages when inclusion of fibers into soil. The maintenance of strength isotropy and the absence of potential planes of weakness that can develop parallel to the oriented reinforcement is one of the advantages of fiber reinforced soil (GopalRanjan et al., 1996). Fiber reinforced soil can be one of the main soil improvement technique. It is beneficial for all type of soils like silt, clay, and also sand. Then, fiber reinforced soil are also can increase ductility, increase seismic performance, provide erosion control and facilitate vegetation development, and so on. Besides that, unlike lime, cement, and other chemical stabilization methods, the construction using fiber-reinforcement is not greatly affected by weather conditions. Fiber-reinforcement has been reported to be helpful in discarding the shallow failure on the slope face and thus reducing the cost of maintenance.

Fibers can be classified into two main categories which are synthetic fiber and natural fiber.Synthesis means to make and synthetic means man-made, so synthetic fibers are called man-made fibers. A synthetic fiber is also a chain of small units joined together. Each small unit is actually a chemical substance. Synthetic fibers have been employed in many fields as innovative engineering materials since it is main reinforcement agents for soil improvement (Hongtao Jiang et al., 2010). The common types of synthetic fibers are polypropylene, polyester, polyethylene, glass, nylon, steel, polyvinyl alcohol (PVA) fibers (Sayyed Mahdi Hejazi et al., 2011). Synthetic fiber is more prefer to use than natural fiber because they have more strength and resistance compared to natural fiber. However, natural fibers are more preferred to use as erosion control since they are eco-friendly. Natural fibers have been used for a long time in many developing countries like use in cement composites and earth blocks because of their availability and low cost (Sayyed Mahdi Hejazi et al., 2011). The various types of natural fibers are including coir, sisal, jute, hemp, bamboo, banana, etc. Usually, it has been available at India. They are considered in design in order to minimize cost, but it is not effective as synthetic fiber. Therefore, fiber reinforced soil is the effective way to improve soil strength.

There are many test can be used in determination of bearing capacity soils. The California Bearing Ratio (CBR) was developed by The California State Highways Department. It is a simple penetration test to developed and evaluate the strength of road subgrades. CBR-value is used as an index of soil strength and bearing capacity. Bearing capacity soil can be measured by using California Bearing Ratio (CBR) test and also plate load test. Small scale test can be conducted in laboratory by CBR test compared to plate load test which acquire larger scale test than CBR test. Several studies were conducted on small size samples in triaxial, C.B.R., unconfined compression and direct shear tests (KalpanaVineshMaheshwari et al, 2011). Figure 1.3 show CBR test apparatus that will be conducted in laboratory.

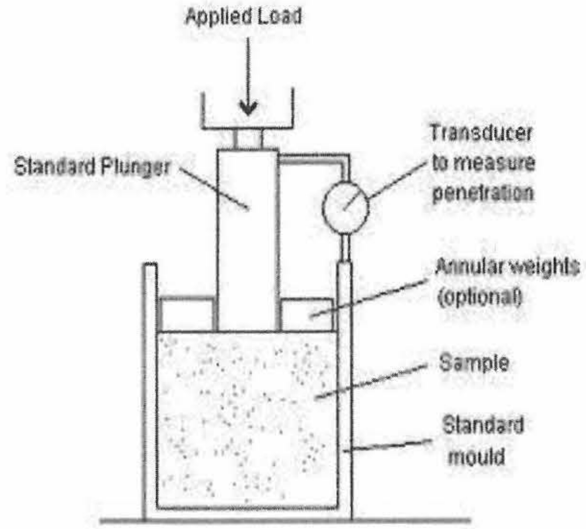

Figure 1.3: California Bearing Ratio (CBR) Test

1.2 PROBLEM STATEMENT

Load from foundation will be transferred into soil since foundation is the lowest part in the building. The foundation must be design properly to make sure it is not cause overstressing to the soil. Overstressing the soil can cause settlement to the soil and also can cause bearing capacity failure. Figure 1.4 shows an example of the bearing capacity failure of a large foundation at Transcona Grain Elevator. This failure alerted engineers to the mechanism of how surface loads may exceed the shear strength of the soils beneath the foundation

Figure 1.4: Failure at Transcona Grain Elevator

Generally, soil mass is a discrete system which is it consist of soil grains. Sometimes, we have weak soil. Weak or soft soil cannot bear tensile stress. There have some soils that cannot be stable when external loads are imposed on them. To improve the soil strength, fibre reinforced soil can be added into the soil. A combination of soil and reinforcement suitably placed to bear the tensile stresses developed and it is also can improve the resistance of soil in the direction of greatest stress. Thus, the bearing capacity of weak or soft soil may be substantially increased by placing various forms of fiber reinforced soil.

1.3 OBJECTIVES

The objectives of the study are including:

I. To determine the effect of fibre on bearing capacity soil.
II. To study the effect of fibre on optimum strength.
III. To determine the value of optimum fibre content.

1.4 SCOPE OF STUDY

Scopes of this study include the following procedures:

i. Laboratory work to determine properties of soil (river sand).

ii. Laboratory testing to determine bearing capacity of fibrereinforced soil and non-reinforced soil.

1.5 SIGNIFICANT OF STUDY

Reinforced soil have been widely known a long time ago which is it can improve the shear strength of soil especially on weak and soft soil.The investigation can be contributed to good application of soil by giving the opportunity for the student to undergo laboratory work while reviewing the properties of reinforced soil and unreinforced soil that have difference on bearing capacity between them. There are few studies have undertaken to determine the effect of fibre on bearing capacity soil. Thus, it is hoped that the investigation will be the sequel of efforts in using fibre reinforced soil to improve the soil strength while doing construction work in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In the past few decades, there are few numbers of researcher doing experimental and numerical studies on fiber reinforced soil. Earth reinforcement can be described as an effective and reliable technique for increasing the strength and stability of soils (Donald H. Gray et al., 1983). Sometimes, we have weak soil or soft soil that can not support too much pressure from building and it is also can cause bearing capacity failure of the soils. Thus, the soils need to be reinforced to improve the strength of the soil. Reinforced soils have become oneof the most economical methods of soilimprovement because of the ease of constructionand the low cost compared with other similartechniques.

Inclusion fiber into soil can increased the strength, increased stability of soils and also can affect bearing capacity of soils. The concept of fiber reinforced soil is same as fiber reinforced concrete which is fiber will be added into concrete mix to improve the concrete strength. Fiber reinforced soil can be defined as a soil mass that contains randomly distributed, discrete elements such as fibers, which is it can provide an improvement in the mechanical behavior of the soil (Sayyed Mahdi Hejazi et al, 2011).The stress–strain-strength properties of randomly distributed fiber reinforced soils are also a function of fiber content, aspect ratio, and fiber surface friction along with the soil and fiber index and strength characteristics (TemelYetimoglu et al, 2004).

2.2 LITERATURE REVIEW

GopalRanjan, R. M. Vasan, H. D. Charan (1994). Fiber reinforced soil can be described as a potential composite material which is it can be an advantage in improving the structural behaviors of soil. For randomly distributed fibers, one of the main advantages are included the maintenance of strength isotropy and the absence of potential planes of weakness that can develop parallel to the oriented reinforcement. Then, the fiber reinforcement can improve shear strength of sand. The most important is when it compared to sand alone without the presence of fiber, it exhibits greater extensibility and small loss of post –peak strength. A study was undertaken to investigate the stress-strain behavior of plastic fiber reinforced sand and the increasing in shear strength of sand due to fiber inclusions. Four different samples with different percentage of fiber content that content at ranging from 1-4% were tested in the triaxial state. Plastic fibers will be used in this investigation. Table 2.1 shows properties of fiber reinforcement.

Table 2.1: Properties of Fiber Reinforcement

Properties of Fibre Reinforcement

Type of fibre	*Diameter (d) (mm)*	*Aspect ratio (l/d)*	*Specific gravity* G_f	*Tensile strength (kPa)*	*Tensile modulus (kPa)*	*Skin friction angle* $\delta°$
Plastic-1	0·3	60	0·92	3×10^4	2×10^6	21
Plastic-2	0·3	90	0·92	3×10^4	2×10^6	21
Plastic-3	0·3	120	0·92	3×10^4	2×10^6	21
Plastic-4	0·5	75	0·92	3×10^4	2×10^6	21

Source: Ranjan, G. et al (1994)

In the present investigation, plastic fiberswere cut to length from locally available continuous fibers.The effect of the fiber reinforcement content on the shear strength was investigated. For the testing, triaxial compression tests has been done. From the result, it shown that the stress-strain behavior of the reinforced sand is very much different from unreinforced sand. Due to the result, as the fiber content is increased, the increase in stress for the same magnitude of increase in strain is much higher. Then, the strength of reinforced sand increases with the increasing of fiber content.

Table 2.2: Increase in Shear Strength of Fiber-Reinforced Sand

Increase in Shear Strength of Fibre-Reinforced Sand (Confining Stress, σ_3 = 300 kPa)

Fibre content w_f *(%)*	*Axial strain = 20%*		*Axial strain = 10%*	
	Major principal stress (kPa)	*% Increase in stress*	*Major principal stress (kPa)*	*% Increase in stress*
0·0	1 040	—	1 058	—
1·0	1 490	43	1 320	25
2·0	1 892	81	1 520	44
3·0	2 190	111	1 730	64
4·0	2 395	130	1 840	74

Source: Ranjan, G. et al (1994)

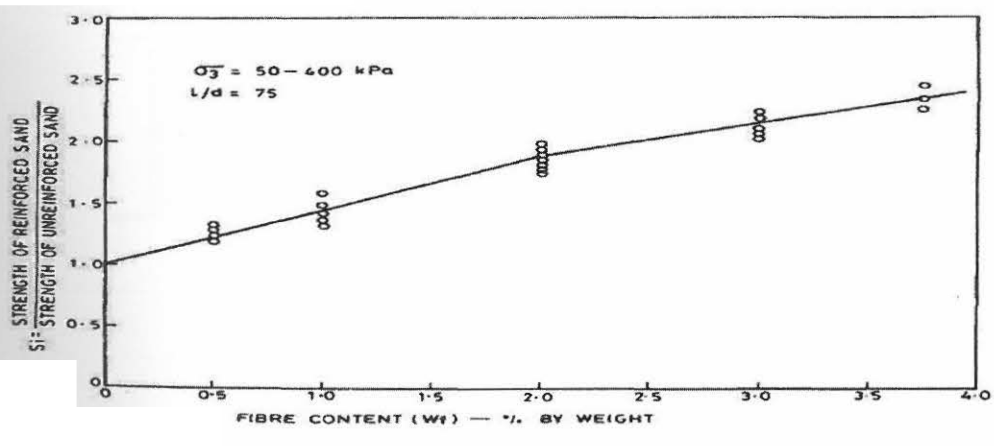

Figure 2.1: Effect of Fiber Content on increase in strength of reinforced sand

Source: Ranjan, G. et al (1994)

The increasing in shear strength approximately linearly with increasing of fiber content up to 2% by weight which is the gain strength is not appreciable.

YildizWasti, Mustafa DenizhanBütün (1997). In this study,a series of laboratory model tests on a strip footing supported by sandreinforced by randomly distributed polypropylene fiber and mesh elements wasconducted in order to compare the results with those obtained from unreinforcedsand and with each other. It is also to assess the relative reinforcing efficiency of mesh and fiber elements at the same inclusion ratio.For conducting the model tests, uniformsand was compacted in the test box which is the model footing was made out of steel plate of 20 mm thickness and measured 50 mm (width) x 250 mm (length). The model test was shown at figure 2.2.

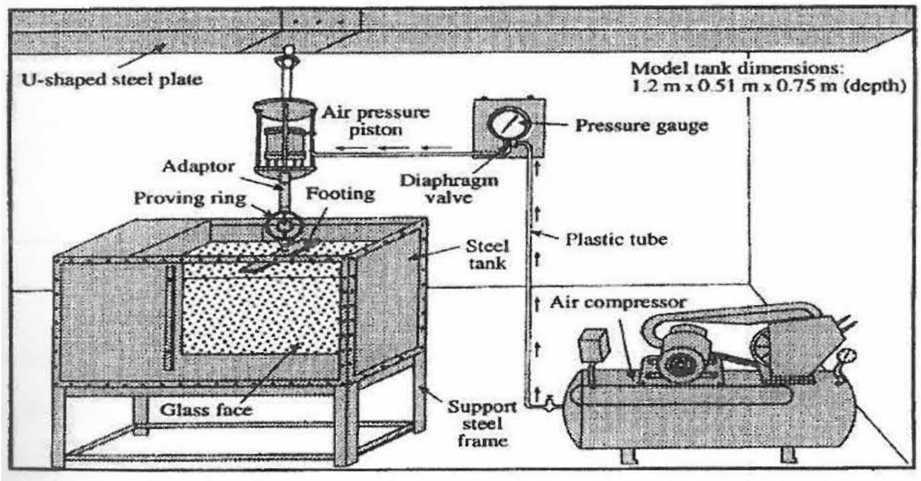

Figure 2.2: Testing Equipment

Source: Wasti, Y. et al (1997)

The sand was placed in the box at its optimum moisture content andmaximum dry density. Three types of reinforcement, two sizes of meshelements having the same opening size and one size of fiber element cut fromthe meshes, were used in varying amounts in the tests. Polypropylene was used as fiber in the testing.One size of fiber and two sizes of mesh were performed at inclusion ratios of 0.075, 0.10 and 0.15% by dry weight are used for tests on unreinforced sand and sand reinforced, which are comparable to the suggested mesh reinforcement contents of 0.10-0.20% for practical applications.The test was carried out 18 times including the repeat tests.According to the results of the tests performed, table 2.3 shows the summary of the result than obtain from this investigation.

Table 2.3: Settlement at Failure for the Unreinforced and Reinforced Cases

Reinforcement type	*Settlement at failure* ($s_{u(R)}$) *(mm)*		
	0·075% inclusion	*0·10% inclusion*	*0·15% inclusion*
Big mesh	6·80	9·31	10·75
Small mesh	5·90	6·01	8·30
Fibre	5·75	5·00	7·78
None		(s_u = 6·40)	

Source: Wasti, Y. et al (1997)

Results indicated thatreinforcement of sand by randomly distributed inclusions caused an increase inthe ultimate bearing capacity values and the settlement at the ultimate load ingeneral. The effectiveness of discrete reinforcing elements was observed todepend on the quantity as well as the shape of the inclusions. The larger meshsize was found to be superior to other inclusions considering the ultimatebearing capacity values. For the mesh elements there appears to be an optimuminclusion ratio, whereas fibers exhibited a linearly increasing trend onthe basis of an increase in ultimate bearing capacity for the range of reinforcement amounts employed.

TemelYetimoglu, Omer Salbas (2003).A study was undertaken to investigate the shear strength of sands reinforced with randomly distributed discrete fibers. Direct shear tests have been conducted in this study to investigate the effect of the fiber reinforcement content on the shear strength. In this study, Polypropylene fibers (Duomix F20/5.1, produced by Bekaert in Belgium) were used as reinforcement. Therefore, 0.10%, 0.25%, 0.50%, and 1.00%of fiber was added into soil by total weight of sand.The added fibers were mixed thoroughly by hand to achieve a fairly uniform mixture.

Table 2.4: Summary of Test Results for Reinforced and Unreinforced Sand

ρ (%)	σ_{nf} (kPa)	τ_f (kPa)	Δl_f (mm)	ϕ (deg)	c (kPa)
0.00	103	92.3	2.00	42.3	0.0
	211	171.5	3.00		
	319	304.5	3.50		
0.10	104	85.8	2.25	42.1	0.0
	210	177.9	2.75		
	320	299.5	3.75		
0.25	105	90.5	3.00	41.8	0.0
	211	184.8	3.00		
	320	289.5	3.75		
0.50	104	86.4	2.25	40.6	0.0
	211	193.1	3.00		
	323	269.0	4.25		
1.00	105	77.9	3.00	40.4	0.0
	212	160.2	3.50		
	321	289.7	4.00		

Source: Yetimoglu, T. et al (2003)

The results of the testsindicated that peak shear strength and initial stiffness of the sand were not affected significantly by the fiber reinforcement which is for reinforced and unreinforced sands remain practically the same. The horizontal displacements at failure were also found comparable for reinforced and unreinforced sands under the same vertical normal stress. However, fiber reinforcements could reduce soil brittleness providing smaller loss of post-peak strength. Thus, there appeared to be an increase in residual shear strength angle of the sand by adding fiber reinforcements.

Hongtao Jiang, Yi Cai, Jin Liu (2010). In the study, a series of tests were carried out to study the effect of fiber contentand fiber length on the strength of fiber reinforced soil, as well as the effect of aggregate size and fiber additives on the engineering properties of the fiber-reinforced soil. Polypropylene was used as fiber. Two experimental plans was proposed which are Plan A is concerning fiber characteristic variation, and for Plan B with interest in soil nature change.Different fiber lengths (10, 15, 20, and 25 mm) and different percentages of fiber content (0.1, 0.2, 0.3, and 0.4%) by weight of the parent soil were prepared tests designed in Plan A while for Plan B, it was designed to analyze the influence of aggregate size on the engineering properties of fiber-reinforced soil. Different aggregate size (<1, 1-2, 2-5, and 5-10 mm) was mixed with 0.4% fiber by weight of the parent soil to prepare different fiber-soil admixtures required for Plan B. From the test results, it shown that the unconfined compressive strength, cohesion, and internal friction angle of fiber-reinforced soil were greater than those of the parent soil, then the UCS, cohesion, and internal friction angle of fiber-reinforced soil exhibited an initial increase followed by a rapid decrease with increasing fiber content and fiber length. Besides that, the optimal fiber content were found as 0.3% by weight of the parent soil and fiber length were found as 15 mm. Similar trends were found in the parent soil and the fiber reinforced soil that the strength declined with an increase in aggregate size. There was a critical size for aggregate breakage between 3.5 and 7.5 mm in average diameter. Thus, the presence of polypropylene fiber could effectively contribute to the increases in the strength and stability of the parent soil.

Freilich, B. J., Li, C., Zornberg, J. G. (2010). A study was undertaken to determine the long term strength of fiber reinforced clays and observe the physical behavior of the soil during shearing.For this study, isotropic consolidated drained (ICD) and isotropic consolidated-undrained(ICU with pore pressure measurement) triaxial tests were conducted on compacted soil specimens to obtain the effective stress parameters of both unreinforced and fiber-reinforced soil specimens. The fibers used are commercially available fibrillated polypropylene fibers known as Geo Fibers (Synthetic Industries, Inc.).Unreinforced and