A
MAJOR PROJECT
ON

SHEAR STRENGTH OF SAND REINFORCED WITH RANDOMLY DISTRIBUTED POLYPROPYLENE FIBERS

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MASTER OF ENGINEERING
(STRUCTURAL ENGINEERING)

SUBMITTED BY:

SANDEEP SOHAL

COLLEGE ROLL NO 12/STR/09
UNIVERSITY ROLL NO. 9082

Under the esteemed Guidance of,
Dr. A. K. GUPTA
(Professor & Head, CIVIL & ENVIRONMENTAL ENGINEERING)

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
DELHI COLLEGE OF ENGINEERING
UNIVERSITY OF DELHI
NEW DELHI
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CERTIFICATE

It is certified that the work presented in this thesis entitled **"SHEAR STRENGTH OF SAND REINFORCED WITH RANDOMLY DISTRIBUTED POLYPROPYLENE FIBERS"**
by Sandeep Sohal, University Roll No. 9082 in partial fulfillment of the requirement for the award of the degree of Master of Engineering in Structural Engineering, Delhi College of Engineering, Delhi, is an authentic record. The work is being carried out by him under our guidance and supervision in the academic year 2010-2011. This is to our knowledge has reached requisite standards.

The work embodied in this major project has not been submitted for the award of any other degree.

Sandeep Sohal

EnrollNo.12/STR/09

Roll No. 9082

This is to certify that the above statement made by SANDEEP SOHAL bearing roll no. 9082 is correct to the best of my knowledge.

Dr. A.K.GUPTA

Professor & H.O.D.

Project Guide

Department of Civil & Environmental Engineering

Delhi College of Engineering

Delhi-110042

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It is a matter of great pleasure for me to present my thesis report on **“SHEAR STRENGTH OF SAND REINFORCED WITH RANDOMLY DISTRIBUTED POLYPROPYLENE FIBERS”**

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SANDEEP SOHAL

M. E. (Structural Engineering)

College Roll No. 12/STR/09

University Roll No. 9082

Department of Civil & Environment Engineering

Delhi College of Engineering

Delhi-110042

ABSTRACT

A study was undertaken to investigate the shear strength of sands reinforced with randomly distributed monofilament polypropylene fibers by carrying out direct shear tests. The effect of the fiber reinforcement content on the shear strength was investigated. The results of the tests indicated that peak shear stress, post-peak shear stress and ductile behavior of sand were affected significantly by the fiber reinforcement. The horizontal displacements at failure were also found comparable for reinforced and unreinforced sands under the same vertical normal stress. Fiber reinforcement could reduce soil brittleness and 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.

The oven dried sand was mixed with the fibers at different percentages by dry weight of the sand. Two observation sets were taken to ignore the error which can be made during experimental work. The test results of these two sets showed that the shear strength of the sand increased with increasing the fiber content, also it was noticed that it showed significant effect at higher normal loads.

The effect of aspect ratio of the fiber on shear strength of the sand was also checked and concluded that if we increase the aspect ratio or length of the fiber at lower normal loads then shear strength is not so affected and on the other hand at higher normal loads shear strength increases more. Failure shear stress is decreased at lower normal loads with increased aspect ratio but at higher normal loads, it is increased.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Due to the increasing cost of high quality materials needed for different civil engineering projects, engineers are trying to improve the physical properties of local soils through a variety of methods and techniques. The word improvement means to increase the shear strength, reducing settlements, resists harsh environment conditions such as thawing and freezing, and decreases or eliminates all problems associated with weak soils. Soil stabilization could be applied to both sandy and clayey soil through mechanical and chemical methods. There are many common methods –mechanical or chemical-found in the literatures that were used to improve the physical properties of the soils.

Construction of buildings and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Improvement of certain desired properties like bearing capacity, shear strength and permeability characteristics of soil can be undertaken by a variety of ground improvement techniques such as the use of fibers as reinforcing material or soil stabilization .The concept of earth reinforcement is an ancient technique and demonstrated abundantly in nature by animals, birds and the action of tree roots. Constructions using these techniques are known to have existed in the fifth and fourth millenniums BC. This concept is used for the improvement of certain desired properties of soil like bearing capacity, shear strength etc. Presently, the soil reinforcement technique is well established and is used in variety of applications like improvement of bearing capacity; filter and drainage control etc., conventional methods of reinforcement consists of continuous inclusions of strips, fibers, and grids into an earth mass. But as a modification of the same technique, random inclusion of various types of fibers is also considered as a soil reinforcement material. These fibers act to interlock particles and group of particles in a unitary coherent matrix. This work investigates the use of monofilament polypropylene fiber for similar purpose.

Soil mass reinforced with randomly distributed monofilament fibers resembles the conventional earth reinforcement in many of its properties. The preparation is quite similar to that of admixture stabilization. Mostly the monofilament fibers are simply added and mixed with the sand for testing. One of the main advantages of randomly distributed fibers is the maintenance of strength isotropy and absence of potential failure plane that can develop parallel to the oriented reinforcement. Very limited information has been reported on the use of randomly distributed polypropylene fibers for soil reinforcement. Examples:- Some limited information available of the use of jute and coir fibers. Metals fibers, metal strips and artificial fibers of polymer compound had been considered.

Recently, engineers started to use different types of fiber in soil stabilizations. These fibers are found in the market as short, discrete materials with different aspect ratio and they can be mixed randomly with the soil, as cement, lime, or other additives at different percentages. The main reason of using randomly oriented fibers is to maintain strength isotropy and the lack of potential weak planes that may develop parallel to oriented reinforce-ment. Due to the encouraging findings of using discrete fiber with both sandy and clayey soils, the fibers are used in different construction applications such as retaining structures, embankments, subgrade and landfill liners and covers. The main objective of this study is to investigate the effect of of fibers on some physical properties of sandy soil. The parameters investigated in this study include shear strength proper-ties and angle of internal friction at different fiber per-centages and aspect ratios. The sandy soil was mixed with the fibers at different percentages by dry weight of the sand and different aspect ratios. The percentages of the fibers are 0.1%, 0.25%, 0.5%, 1.0%, and dry weight of the sand. The aspect ratio index of the fibers, which is dimensionless , was used in the analysis instead of the length. At each percentage, three different aspect ratios (L/D) of the fibers were used with constant diameter and variable length. Because of the length variation we can observe that how it will affect the shear strength of the sand. The aspect ratios which are used for fibers are 50,100 and 150.

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To study the effect of different percentage of monofilament polypropylene fibers on the peak shear strength at lower as well as higher normal loads.

2. To study the contribution of polypropylene fiber reinforcement to reduction in loss of post- peak shear stress of sand.

3. To study the ductile behavior of sand with increased percentage of fiber content.

4. To investigate the effect of the aspect ratio (L/D) of fibers on the shear strength of sand.

CHAPTER 2

LIERATURE REVIEW

2.1 GENERAL

Unlike systematically reinforced soils, only limited information has been reported on randomly distributed fiber-reinforced soils in the literature. However, an increasing number of experimental and numerical studies on the subject have been conducted by several researchers in the past few decades. These previous studies indicate that 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.

2.2 RECENT STUDIES

Gray and Ohashi (1983) have indicated, based on the direct shear test results that fiber reinforcement increased the peak shear strength and limited post-peak reductions in shear resistance. In their study, no increase in stiffness of the fiber –sand composite was observed.

Gray and Al – refeai (1986) conducted triaxial compression tests on a sand, indicated that randomly distributed discrete fibers increased ultimate strength, but resulted in a loss of compressive stiffness at low strains (less than 1%). They also showed that fiber reinforcements increased the axial strain at failure, and in most cases reduced post-peak loss of strength.

Bauer and Oancea (1996), based on their triaxial test results, indicated that the secant modulus as an indication of the stiffness within the initial vertical strain of 2% decreased with increasing polypropylene fiber contents up to 0.5%. They also that beyond this vertical strain the secant modulus remain fairly constant.

Michalowski and Zhao (1996) based on triaxial test results, indicated that the steel fibers led to an increase in the peak shear stress, and the stiffness prior to reaching failure. They also reported that polyamide fibers produced an increase in the peak shear stress for large confining pressures, but the effect was associated with a considerable loss of stiffness prior to failure and a substantial increase of the strain to failure.

Kumar et al. (1999),based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that the fibers increased the peak compressive strength, CBR value, peak friction angle and ductility of the specimens. They also reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3-0.4% of dry unit weight.

Kaniraj and havanagi (2001) based on unconfined compression tests on cement-stabilized fiber-reinforced fly ash-soil mixtures, concluded that randomly oriented polyester fiber inclusions increased the strength of the raw fly ash-soil specimens as well as that of the cement-stabilized specimens and changed their brittle behavior to ductile behavior. The disagreement among the reported results is attributed to the difference in the material properties and testing conditions.

T.Yetimoglu and O.Salbas (2002) based on direct shear tests on monofilament polypropylene fibers they concluded that the peak shear strength is insignificantly affected by fiber content. Hence, the values of peak shear strength angle can be considered identical for reinforced and unreinforced sand. Fiber reinforcements could provide smaller loss of post-peak strength and change the brittle behavior of the sand to a somewhat more ductile one. Hence, residual shear strength angle of the sand tends to be increased by adding the fiber reinforcements. Mohr-coulomb shear envelopes for fiber-reinforced sands, similar to that for unreinforced sand, are linear with a zero cohesion intercept. In other words, neither pseudo-cohesion nor a bilinear shear envelope was observed for fiber-reinforced sands.

Y. Cai, B. Shi, C.W.W.Ng and C. Tang(2006),A Series of tests were performed to study the effects of randomly distributed short pp-fiber reinforcement on the strength and mechanical behavior behavior of uncemented and cemented soil.

The inclusion of fiber reinforcement within uncemented and cemented soil caused an increase in the UCS, shear strength and axial strain at failure. Increasing fibre content could increase the peak axial stress and decrease the stiffness and the loss of post-peak strength, weakens the brittle behavior of cemented soil. It could be concluded from this study that the combination of discrete fiber and cement has the virtues of both fiber-reinforced soil and cement-stabilized soil, and therefore the addition of fiber-cement to soil can be considered as an efficient method for ground improvement.

Atom and Al-tamini (2010),based on the direct shear tests they concluded that the increase of the percentages of fibers will result in increasing the angle of internal friction of sand .The ductility of sand increased by addition of fibers. The increase in the aspect ratio resulted in increasing both the shear strength and angle of internal friction. But these results can be obtained at higher load, at lower loads shear strength decreased with aspect ratio. They used different percentage of fibers and aspect ratios and concluded on both higher and lower normal loads.

This research presents the results of using polypropylene fibers at different percentages and different aspect ratio to improve the some physical properties of sandy soil. Based on the test results of this study, the following conclusions may be drawn out:

1) The shear strength of sand increased by increasing the percentage flat profile fiber with high flexibility. The increase of in the percentage of the crimped profile fiber with high relative stiffness increased the shear strength at high normal stress.

2) The increase of the percentages of the both type of fiber will result in increasing the angle of internal friction of sand.

3) The ductility of sand increased by adding the monofilament type of fibers.

4) The increase in the aspect ratio resulted in increasing the both the shear strength of the sand and angle of internal friction. But better results can be obtained at higher normal loads.

Motivation for Present Study: They all cannot specified clearly that ductility is influenced using polypropylene fibers or not affected and clear effect cannot be seen in their research when aspect ratio is changed. Some of them said that increased aspect ratio has no effect on shear strength and some said that there is some loss in shear strength at higher aspect ratio at lower loads. Effect on shear angle of polypropylene fibers not defined clearly in all studies that this angle of internal friction is increased or decreased with increase of percentage of polypropylene fibers and aspect ratio.

CHAPTER 3
MATERIALS & EXPERIMENTAL PROGRAM

3.1 MATERIALS

3.1.1 Sand:-

A clean, oven- dried, Yamuna river sand was used in the tests. The sand was sieved through 4.75 mm sieve and washed through 0.075 mm sieve and dried in an oven. Some properties of the sand are given in Table 1.

3.1.2 Polypropylene Fibers:-

Monofilament polypropylene fibers were used as reinforcement. Some of their index and strength properties provided by the manufacturer are: diameter = .10 mm, length =15 mm, density = 9.1 kN/m^3, tensile strength = 600 MPa. Some properties of the fiber are given in Table 2. Polypropylene is widely used in the production of fibers, for use in carpeting, rope and twine, automobile interiors, textiles and in other applications. Fibers are one of the most important applications for polypropylene homopolymer. Due to its melt flow properties, fiber formation is easier when compared to other polymers. Its low density results in a higher yield of fiber per pound of material. Polypropylene chips can be converted to fiber/filament by traditional melt spinning processing, though the operating parameters need to be changed depending on the final products.

Polypropylene demonstrates an interesting example of the need for regularity of structure to secure crystallization in a polymer. During polymerization, the successive chain sequences of $--CH_2--CH(CH_3)$ can be added on in either a right-handed or a left handed screw direction, owing to the stereochemistry of the chain. If these forms occur at random, the chain will have an irregular shape and will not crystallize.

Polypropylene fibers are available in two different forms; monofilament and multifilaments. Monofilaments are ribbons of polypropylene composed of a single extruded filament produced by melt spinning followed by water quenching. The properties of monofilament and multifilament fibers vary considerably.monofilament fibers have greater young's modulus and lower tensile strength than multifilament fibers.

Structure of fiber: Polypropylene(PP) is a versatile thermoplastic material, which is produced by polymerizing monomer units of polypropylene molecules into very long polymer molecules or chains in the presence of a catalyst under carefully, controlled heat and pressure. Propylene is an unsaturated hydrocarbon, containing only carbon and hydrogen atoms:

CH_2=CH
l
CH_3
(propylene)

There are many ways of polymerization of the monomer r units, but PP as a commercially used material in its most widely used form is produced with catalysts that produce crystallize able polymer chain. Propylene molecules add to the polymer chain only in a particular orientation, depending on the chemical and crystal structure of the catalyst , and a regular, repeating three-dimentional structure is produced in the polymer chain. Propylene molecules are added to the main polymer chain, increasing the chain length , and not to one of the methyl groups attached to alternating carbon atoms that are termed as pendent methyl groups

A typical structure of polypropylene chain is shown below,

----CH_2 ---- CH ----CH_2 ---- CH ---- CH_2 ---- CH ----
l l l
CH_3 CH_3 CH_3

Polypropylene is one of the fastest growing classes of commodity thermoplastics, with a market share growth of 6-7% per year and the volume of polypropylene produced is exceeded only by polyethylene and polyvinyl chloride. PP is one of the lightest of all thermoplastics (0.9 g/cc). the reason for the popularity of the PP fiber is because of the versatility of the material. It has a good combination of properties, cheaper than many other materials that belong to the family of polyolefins and it can be manufactured using various techniques. These benefits are derived from the very nature and the structure of polypropylene

Table -1 **Index and strength parameters of Polypropylene fiber:-**
(provided by manufacturer)

Behavior parameters	Values
1. Fiber type	Monofilament
2. Density	0.85-0.93 gm/cc
3. Average radius	.05 mm
4. Average length	15 mm
5. Breaking tensile strength	600 MPa
6. Melting point	160-170 ◦c
7. Acid and alkali resistance	Strong

Fig 3.1:-monofilament polypropylene fibers (length=15mm)

Fig 3.2 :-monofilament polypropylene fibers (length=10mm)

Fig 3.3:- monofilament polypropylene fibers (length=5mm)

3.1.3 Preparation of samples:-

Fiber –sand samples were prepared using oven dried sand. The fiber to be added to the sand was considered as a part of the solids fraction in the void-solid matrix of the soil. The content of reinforcement is defined herein as

$$\mu = f/w \qquad (1)$$

where f is the weight of the fibers , and w is the weight of the dry sand. The tests were repeated at 0.1%, 0.25%, 0.50% and 1.00%

The designated fibers were weighed according to the prescribed reinforcement content and mixed into the sand in small increments until all of the fibers were effectively distributed within the sand. The added fibers were mixed thoroughly by hand to achieve a fairly uniform mixture. Once fibers were mixed into the sand, a segregation or floating tendency of fibers was noted. Much care was required to obtain reasonably uniform distribution of the fibers. The mixing of fibers into the sand increased in difficulty as the reinforcement content increased. However, the fiber-sand mixtures appeared acceptably uniform for the reinforcement contents evaluated.

It is to be noted that the choice of a small direct shear apparatus as the testing platform brings some inherent problems into the experiment study. This limits the amount of fiber inclusion. Other problems such as the imposed plane of shear failure, ambiguous stress state, and end effect in such a small sample size make it more difficult to model fiber-reinforced soil behavior realistically. Despite these limitations, direct shear device has been widely used for different theoretical and practical research projects in most laboratories all over the world due to its simplicity and other advantages. The device was also employed in some research similar to this study to highlight the complexity of fiber-reinforced soil behavior (Gray and Ohashi,1983)

3.2 EXPERIMENTAL INVESTIGATIONS:-

3.2.1. Sieve analysis:-

Yamuna river sand (wt. – 300 gm) was taken for sieve analysis and semi –log graph is plotted between sieve size and % finer to find effective size and soil classification.

Table 3.2.1:-

IS Sieve(mm)	Mass retained (gm)	% retained	Cumulative % retained	% finer
4.75	0	0	0	100
2.00	5.72	1.91	1.91	98.09
1.00	3.79	1.26	3.17	96.83
.600	2.95	.98	4.15	95.85
.425	39.12	13.04	17.19	82.81
.212	214.25	71.42	88.61	11.39
.150	27.17	9.06	97.67	2.33
.075	6.84	2.28	99.95	.053

$\sum$ = 300.0 gm

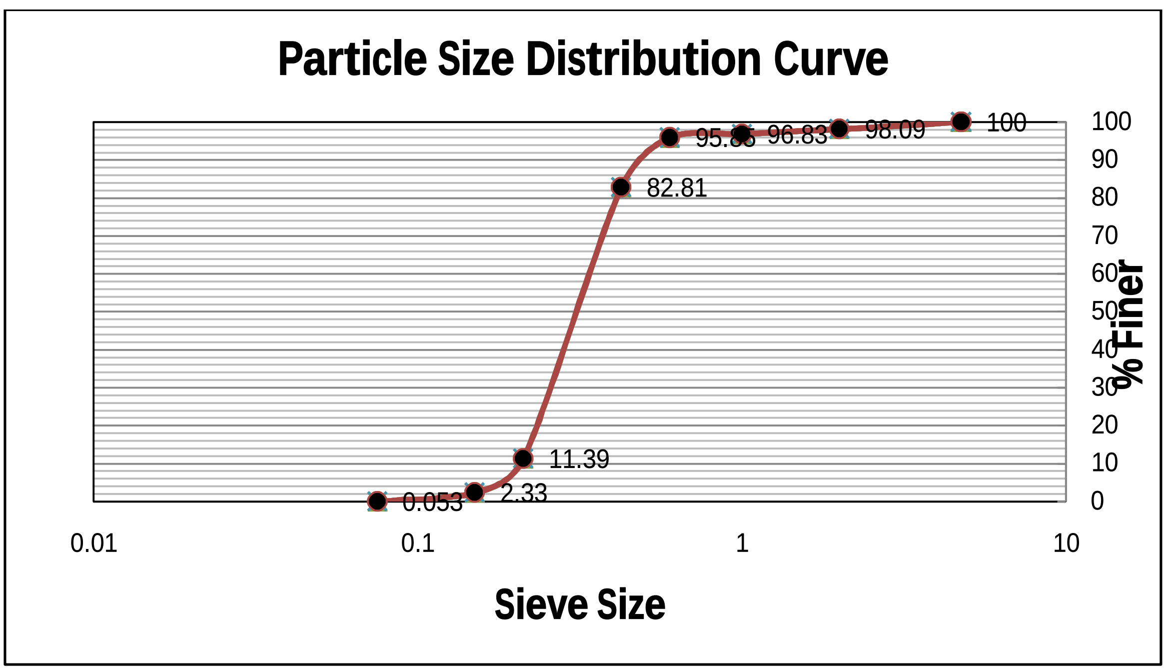


Fig 3.4:-particle size distribution curve

3.2.2. Specific gravity test:-

To determine the specific gravity (G) by pycnometer Sp. Gravity test was done with 100 gm Yamuna river sand.

	Observation-1	Observation-2	Observation-3
Empty pycnometer (A)	417.15 gm	417.15 gm	417.15 gm
Sand + pycnometer (B)	516.98 gm	517.11 gm	517.92 gm
Sand + water + pycnometer (C)	1285.97 gm	1285.32 gm	1285.88 gm
Water + pycnometer (D)	1224.46 gm	1224.36 gm	1224.67 gm
Specific gravity(G) = $\frac{(B-A)}{[(B-A)-(C-D)]}$	2.60	2.56	2.55

Average specific gravity (G) = 2.57

3.2.3 Standard Proctor Test :-

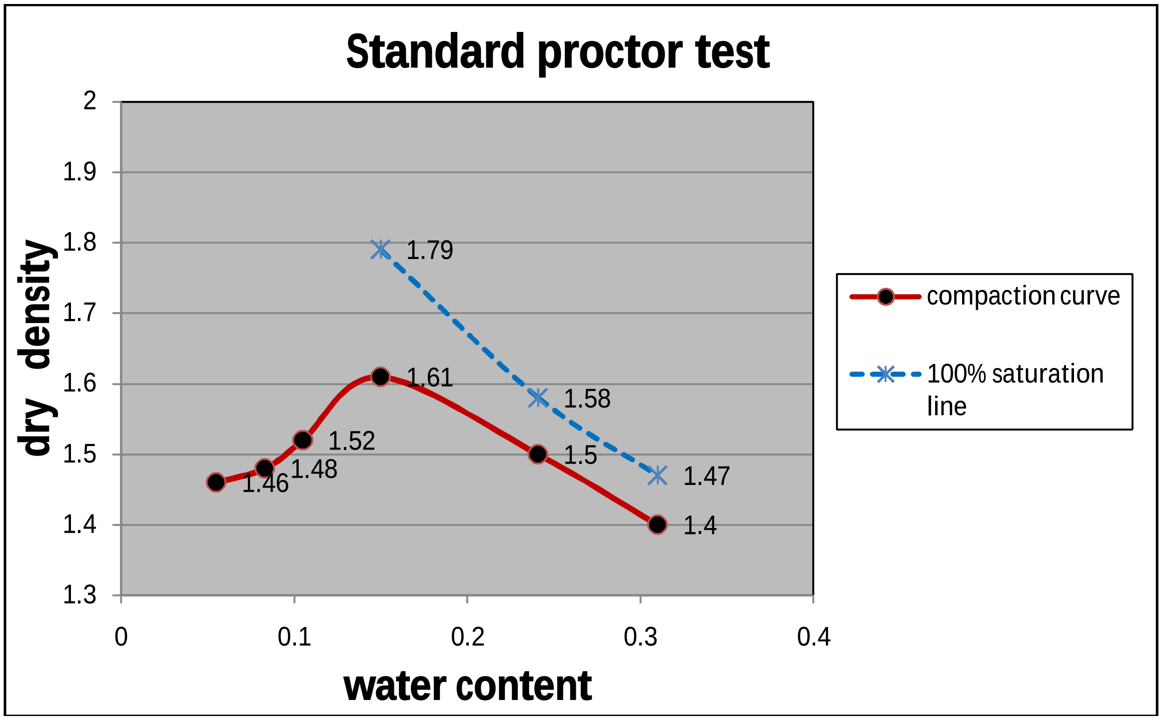


Fig3.4:-Standard Proctor Test

Table-2:-**Summary of Physical Properties of sand used in the study:-**

1. Specific gravity	2.57
2. Maximum dry density(g/cc)	1.57
3. Minimum void ratio	1.6
4. Optimum moisture content (%)	15.03
5. Coarse sand fraction [2mm-4.75mm] (%)	1.9
6. Medium sand fraction [425µ-1mm] (%)	15.29
7. Fine sand fraction [75µ-212µ] (%)	82.75
8. Effective grain size D_{10} (mm)	0.22
9. D_{60} (mm)	0.35
10. D_{30} (mm)	0.27
11. Coefficient of uniformity C_u	1.59
12. Coefficient of curvature C_c	0.947
13. IS Classification	SP
14. c(KPa)	0
15. □(deg)	17.49

3.2.4 Direct Shear test:-

The experimental work involved performing a series of direct shear tests. The tests were conducted inside a shear box of 60mm × 60 mm in plane and 30 mm in depth. The tests were performed at the vertical normal stresses of 50, 150 and 250 kPa in order to completely define the shear strength parameters (i.e., the angle of shear strength (□) and cohesion(c)) for both the unreinforced and reinforced sand. The loading rate was .625mm/min in the tests. Shear stresses were recorded as a function of horizontal displacement up to a total displacement of 6 mm to observe the post-failure behavior as well. A clean, oven-dried, Yamuna river sand was used in the tests. The sand was sieved through 4.75 mm standard sieve and washed through 0.075 mm sieve and dried in an oven. Some properties of the sand are given in table-1. Monofilament polypropylene fibers were used as reinforcement. Some of their index and strength properties, provided by the manufacturer are: diameter = 0.10 mm, length =15 mm, tensile strength = 600 MPa.

CHAPTER 4
RESULTS AND DISCUSSION

The shear stress-horizontal displacement curves obtained from the tests for reinforced sands with fiber content of μ = 0.1-1.0% are shown in Figs. 1to4 together with those for unreinforced sand. It is seen that initial stiffness (i.e., intial slope of the shear stress-horizontal displacement curves) at the same normal stress for reinforced and unreinforced sand remains practically the same. It can be also seen that the peak shear stresses and horizontal displacements at which peak shear stresses and horizontal displacements at which peak shear stresses mobilized are affected by fiber content. The values of normal stress, shear stress and horizontal displacement at failure for both reinforced and unreinforced sand are given in table. Also, the peak shear strength angle and cohesion obtained for reinforced and unreinforced sand are given in table. The analysis indicated that the shear envelopes for reinforced sand, similar to that for unreinforced sand, are linear with a zero cohesion intercept.

Since the horizontal displacements at failure were small for both unreinforced sand and reinforced sands in the tests (i.e., ≤ 5mm at failure), the strains developed in the fiber reinforcements were likely to be very small as well. hence strain level at failure seemed to be not high enough to mobilize operative tensile stresses in the reinforcement inclusions. But peak strength is significantly affected by fiber reinforcement especially at higher loads.

On the other hand, the results of testing suggest that the fiber reinforcement can change the brittle behavior of the sand to a somewhat more ductile one. It should be pointed out that similar results pertaining to the effect of fibers on the brittleness, peak and residual shear strength of sands were obtained in the previous studies. However, there has not been a general consensus regarding the effect of fiber content on the stiffness of sands. Bauer and Oancea (1996), based on their triaxial test results, indicated that the secant modulus as an indication of the stiffness within the initial vertical strain of 2% decreased with increasing polypropylene fiber contents up to r ¼ 0:5%: They also reported that beyond this vertical strain the secant modulus remains fairly constant. Consoli et al. (1998), conducting triaxial compression tests, showed that fiber reinforcement increased the peak and residual strengths, but decreased stiffness.

They also indicated that the cohesion intercept was slightly affected by fiber inclusions. Gray and Ohashi (1983), based on the direct shear test results, indicated that fiber reinforcement increased the peak shear strength and limited post-peak reductions in shear resistance. In their study, no increase in stiffness of the fiber–sand composite was observed.Gray and Al-Refeai (1986), conducting triaxial compression tests on a sand, indicated that randomly distributed discrete fibers increased ultimate strength, but resulted in a loss of compressive stiffness at low strains (less than 1%). They also showed that fiber reinforcements increased the axial strain at failure, and in most cases reduced post-peak loss of strength. Michalowski and Zhao (1996), based on triaxial test results, indicated that the steel fibers led to an increase in the peak shear stress, and the stiffness prior to reaching failure. They also reported that polyamide fibers produced an increase in the peak shear stress for large confining pressures, but the effect was associated with a considerable loss of stiffness prior to failure and a substantial increase of the strain to failure. Kumar et al. (1999), based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that the fibers increased the peak compressive strength, CBR value, peak friction angle and ductility of the specimens. They also reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3–0.4% of dry unit weight. Kaniraj and Havanagi (2001), conducting unconfined compression tests on cement-stabilized fiber-reinforced fly ash–soil mixtures, concluded that randomly oriented polyester fiber inclusions increased the strength of the raw fly ash–soil specimens as well as that of the cement-stabilized specimens and changed their brittle behavior to ductile behavior. The disagreement among the reported results is attributed to the difference in the material properties and testing conditions.

4.1 Effect of percentage of PP fibers on shear strength of sand:-

OBSERVATION SET-1:-

TABLE 4.1a:- Observations of Sand reinforced with 0.0% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	37	85	86	3570	10.36415	23.80952	24.08964
3	0.50	53	112	127	3540	14.97175	31.63842	35.87571
4	0.75	57	127	156	3510	16.23932	36.18234	44.44444
5	1.00	68	138	178	3480	19.54023	39.65517	51.14943
6	1.25	75	146	199	3450	21.73913	42.31884	57.68116
7	1.50	77	151	213	3420	22.51462	44.15205	62.2807
8	1.75	81	153	223	3390	23.89381	45.13274	65.78171
9	2.00	85	156	228	3360	25.29762	46.42857	67.85714
10	2.25	87	157	231	3330	26.12613	47.14715	69.36937
11	2.50	88	156	229	3300	26.66667	47.27273	69.39394
12	2.75	88	152	228	3270	26.91131	46.48318	69.72477
13	3.00	88	151	225	3240	27.16049	46.60494	69.44444
14	3.25	88	149	220	3210	27.41433	46.41745	68.53583
15	3.50	88	146	217	3180	27.67296	45.91195	68.23899
16	3.75	88	144	213	3150	27.93651	45.71429	67.61905
17	4.00	87	140	207	3120	27.88462	44.87179	66.34615
18	4.25	87	140	202	3090	28.15534	45.30744	65.37217
19	4.50	85	139	197	3060	27.77778	45.42484	64.37908
20	4.75	84	138	191	3030	27.72277	45.54455	63.0363
21	5.00	79	136	184	3000	26.33333	45.33333	61.33333
22	5.25	79	135	178	2970	26.59933	45.45455	59.93266
23	5.50	78	134	173	2940	26.53061	45.57823	58.84354
24	5.75	76	132	168	2910	26.11684	45.34811	57.73196
25	6.00	74	130	163	2880	25.69444	45.13056	56.59722

TABLE 4.2a:- Observations of Sand reinforced with 0.1% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	50	97	50	3570	14.0056	27.17087	14.0056
3	0.50	62	126	80	3540	17.51412	35.59322	22.59887
4	0.75	69	144	122	3510	19.65812	41.02564	34.75783
5	1.00	76	155	151	3480	21.83908	44.54023	43.3908
6	1.25	80	163	174	3450	23.18841	47.24638	50.43478
7	1.50	81	168	197	3420	23.68421	49.12281	57.60234
8	1.75	89	170	212	3390	26.25369	50.14749	62.53687
9	2.00	87	169	221	3360	25.89286	50.29762	65.77381
10	2.25	86	168	228	3330	25.82583	50.45045	68.46847
11	2.50	85	165	233	3300	25.75758	50	70.60606
12	2.75	84	162	236	3270	25.68807	49.54128	72.17125
13	3.00	83	159	237	3240	25.61728	49.07407	73.14815
14	3.25	82	156	237	3210	25.54517	48.59813	73.83178
15	3.50	81	152	235	3180	25.4717	47.79874	73.89937
16	3.75	80	148	236	3150	25.39683	46.98413	74.92063
17	4.00	79	144	235	3120	25.32051	46.15385	75.32051
18	4.25	78	142	232	3090	25.24272	45.95469	75.08091
19	4.50	78	135	229	3060	25.4902	44.11765	74.8366
20	4.75	78	136	225	3030	25.74257	44.88449	74.25743
21	5.00	77	135	222	3000	25.66667	45	74
22	5.25	77	136	218	2970	25.92593	45.79125	73.40067
23	5.50	75	135	215	2940	25.5102	45.91837	73.12925
24	5.75	73	133	214	2910	25.08591	45.70447	73.53952
25	6.00	71	133	211	2880	24.65278	46.18056	73.26389

TABLE 4.3a:- Observations of Sand reinforced with 0.25% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	37	80	86	3570	10.36415	22.40896	24.08964
3	0.50	49	94	100	3540	13.84181	26.55367	28.24859
4	0.75	56	99	133	3510	15.95442	28.20513	37.89174
5	1.00	64	105	158	3480	18.3908	30.17241	45.4023
6	1.25	72	121	178	3450	20.86957	35.07246	51.5942
7	1.50	77	133	196	3420	22.51462	38.88889	57.30994
8	1.75	87	149	213	3390	25.66372	43.9528	62.83186
9	2.00	92	157	219	3360	27.38095	46.72619	65.17857
10	2.25	96	163	225	3330	28.82883	48.94895	67.56757
11	2.50	99	167	229	3300	30	50.60606	69.39394
12	2.75	102	168	233	3270	31.19266	51.37615	71.25382
13	3.00	103	171	235	3240	31.79012	52.77778	72.53086
14	3.25	104	172	234	3210	32.39875	53.58255	72.8972
15	3.50	105	173	232	3180	33.01887	54.40252	72.95597
16	3.75	106	173	231	3150	33.65079	54.92063	73.33333
17	4.00	106	172	230	3120	33.97436	55.12821	73.71795
18	4.25	106	171	229	3090	34.30421	55.33981	74.11003
19	4.50	106	171	228	3060	34.64052	55.88235	74.5098
20	4.75	105	170	226	3030	34.65347	56.10561	74.58746
21	5.00	105	169	221	3000	35	56.33333	73.66667
22	5.25	103	165	218	2970	34.34343	55.55556	73.40067
23	5.50	101	163	215	2940	34.69388	55.44218	73.12925
24	5.75	99	160	212	2910	34.02426	54.98282	72.85223
25	6.00	96	156	209	2880	33.32222	54.16667	72.56944

TABLE 4.4a:- Observations of Sand reinforced with 0.5% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	37	39	89	3570	10.36415	10.92437	24.92997
3	0.50	44	72	120	3540	12.42938	20.33898	33.89831
4	0.75	64	96	141	3510	18.23362	27.35043	40.17094
5	1.00	79	117	169	3480	22.70115	33.62069	48.56322
6	1.25	91	132	190	3450	26.37681	38.26087	55.07246
7	1.50	100	152	209	3420	29.23977	44.44444	61.11111
8	1.75	106	158	221	3390	31.26844	46.60767	65.19174
9	2.00	109	166	230	3360	32.44048	49.40476	68.45238
10	2.25	112	172	236	3330	33.63363	51.65165	70.87087
11	2.50	116	174	242	3300	35.15152	52.72727	73.33333
12	2.75	117	178	244	3270	35.77982	54.43425	74.61774
13	3.00	116	180	246	3240	35.80247	55.55556	75.92593
14	3.25	116	181	248	3210	36.13707	56.38629	77.25857
15	3.50	116	182	248	3180	36.47799	57.2327	77.98742
16	3.75	116	182	248	3150	36.8254	57.77778	78.73016
17	4.00	116	183	248	3120	37.17949	58.65385	79.48718
18	4.25	114	181	245	3090	36.8932	58.57605	79.28803
19	4.50	113	179	243	3060	36.9281	58.49673	79.41176
20	4.75	113	177	241	3030	37.29373	58.41584	79.53795
21	5.00	110	175	239	3000	36.66667	58.33333	79.66667
22	5.25	108	173	236	2970	36.36364	58.24916	79.46128
23	5.50	106	169	233	2940	36.05442	57.48299	79.93197
24	5.75	106	165	230	2910	36.42612	56.70103	80.06873
25	6.00	103	163	227	2880	35.76389	56.59722	78.81944

TABLE 4.5a:- Observations of Sand reinforced with 1% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c=A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	44	61	105	3570	12.32493	17.08683	29.41176
3	0.50	62	91	157	3540	17.51412	25.70621	44.35028
4	0.75	79	116	192	3510	22.50712	33.04843	54.70085
5	1.00	92	132	219	3480	26.43678	37.93103	62.93103
6	1.25	102	145	243	3450	29.56522	42.02899	70.43478
7	1.50	108	148	260	3420	31.57895	43.27485	76.02339
8	1.75	114	155	273	3390	33.62832	45.72271	80.53097
9	2.00	119	161	281	3360	35.41667	47.91667	83.63095
10	2.25	122	166	288	3330	36.63664	49.84985	86.48649
11	2.50	124	170	288	3300	37.57576	51.51515	87.27273
12	2.75	124	174	289	3270	37.92049	53.21101	88.3792
13	3.00	125	178	290	3240	38.58025	54.93827	89.50617
14	3.25	126	182	288	3210	39.25234	56.69782	89.71963
15	3.50	125	185	284	3180	39.30818	58.1761	89.30818
16	3.75	124	187	281	3150	39.36508	59.36508	89.20635
17	4.00	123	189	279	3120	39.42308	60.57692	89.42308
18	4.25	123	192	275	3090	39.80583	62.13592	88.99676
19	4.50	123	191	273	3060	40.19608	62.4183	89.21569
20	4.75	122	190	271	3030	40.26403	62.70627	89.43894
21	5.00	122	189	269	3000	40.66667	63	89.66667
22	5.25	122	188	267	2970	41.07744	63.29966	89.89899
23	5.50	122	185	264	2940	41.4966	62.92544	89.79592
24	5.75	116	182	261	2910	39.86254	62.54296	89.69072
25	6.00	116	179	258	2880	40.27778	62.15277	89.58333

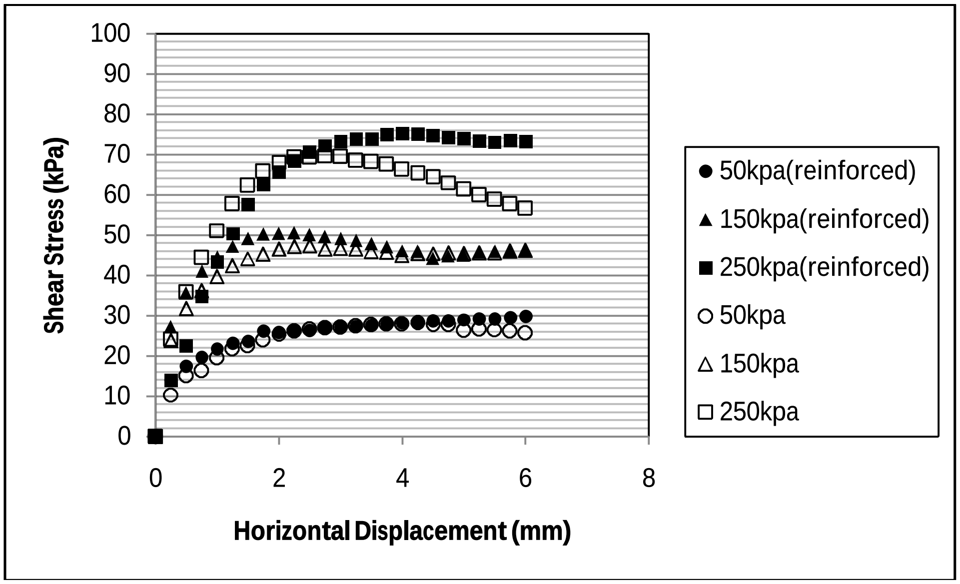


Fig4.1a:- Shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=0.1 %.

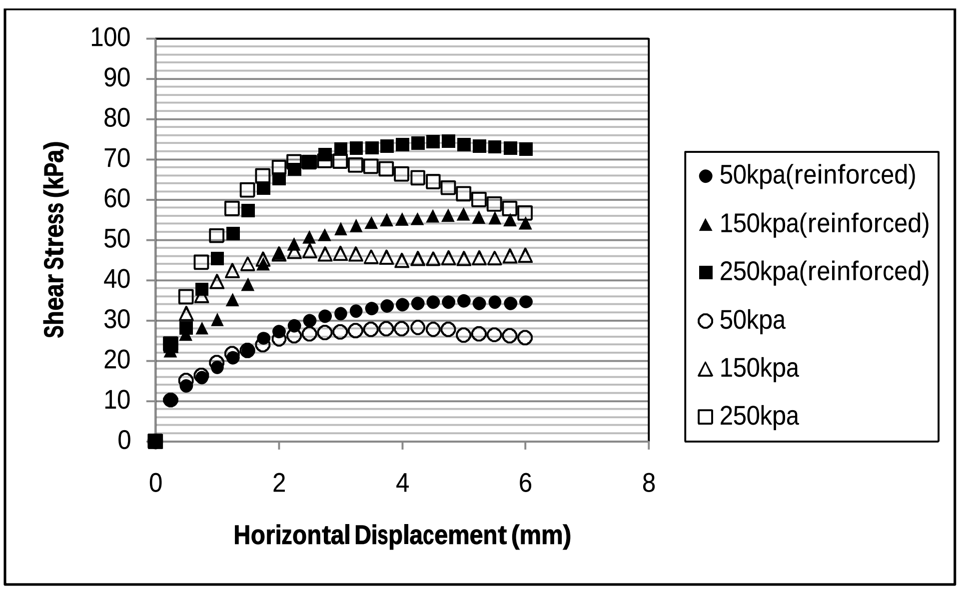


Fig4.2a: -shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=0.25%

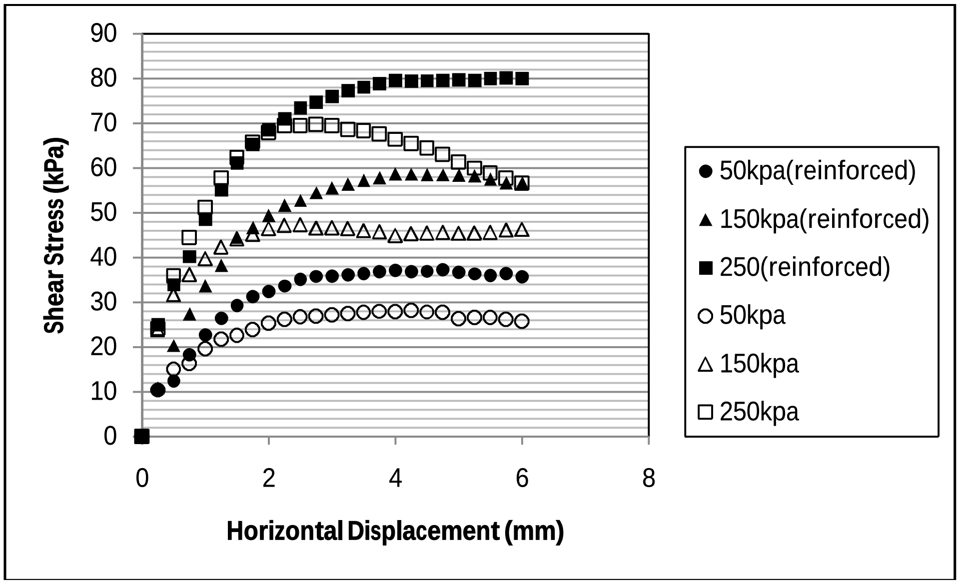


Fig 4.3a:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced sand with fiber content μ=0.5%

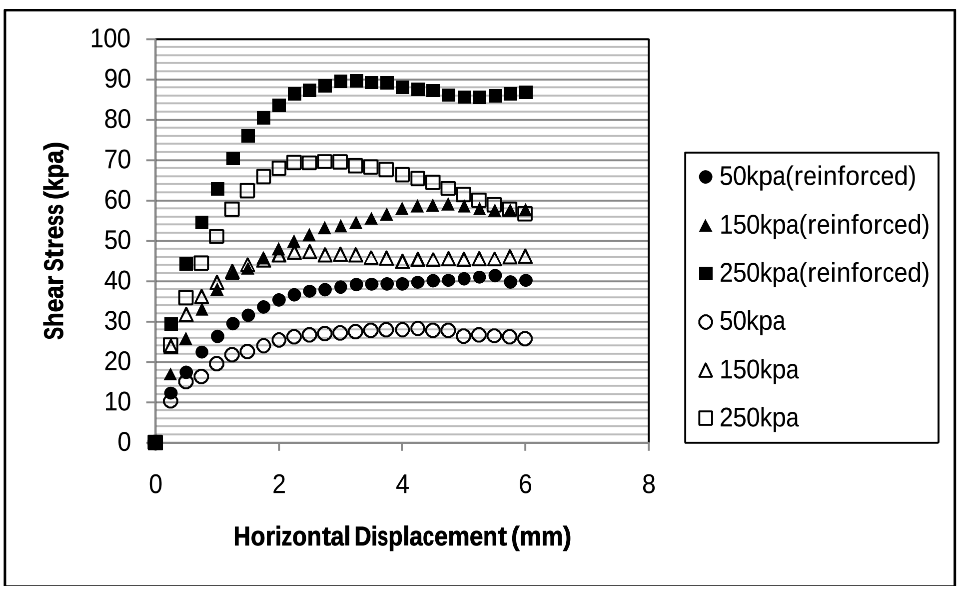


Fig4.4a:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=1.0%

4.1.1a Effect of percentage of fibers on shear angle (□) of sand:-

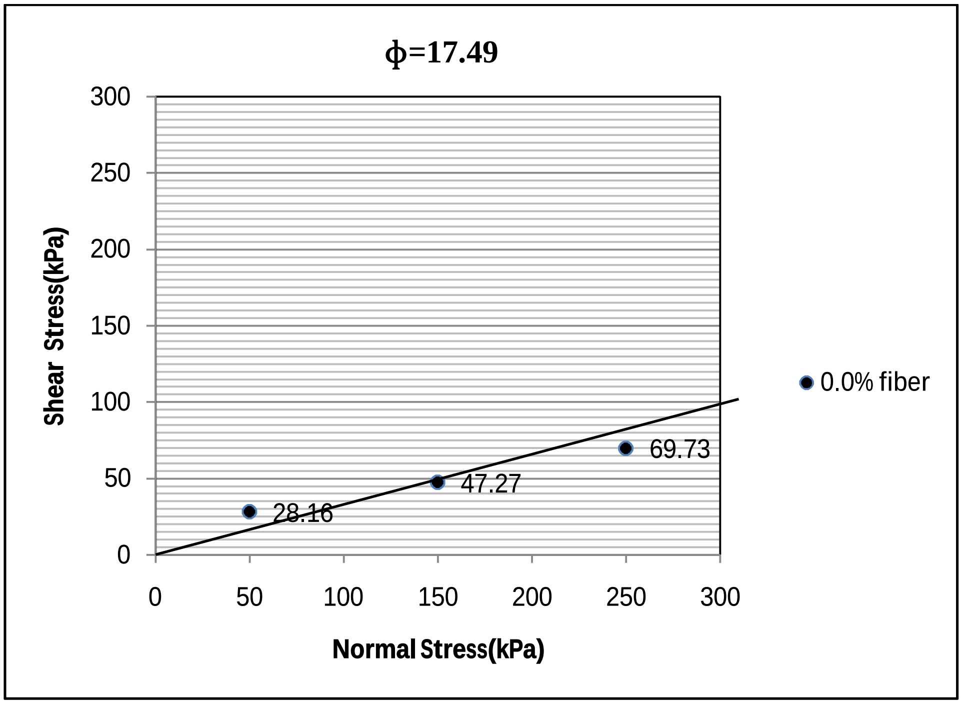


Fig4.5a:-Shear angle on 0.0% fiber content

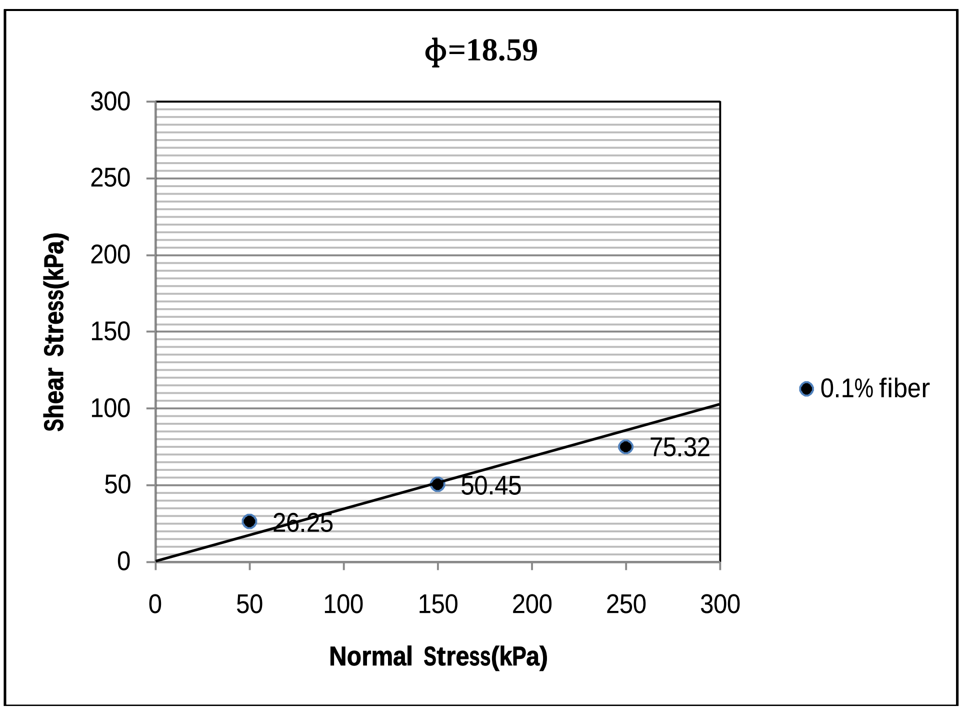


Fig4.6a:-Shear angle on 0.1% fiber content

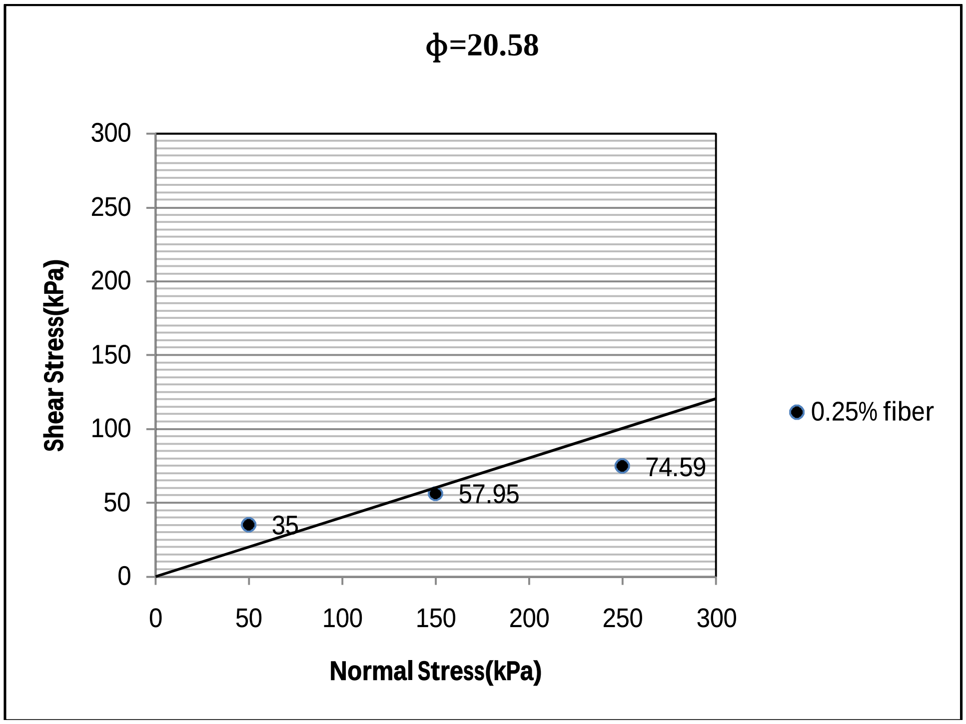


Fig4.7a:-Shear angle on 0.25% fiber content

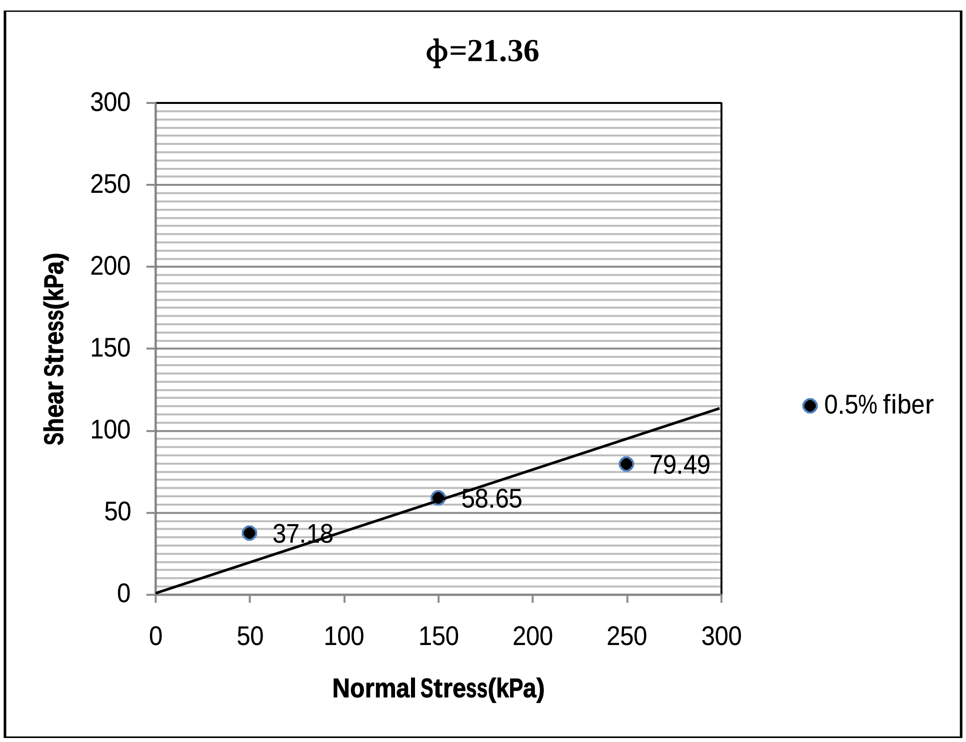


Fig4.8a:-Shear angle on 0.5% fiber content

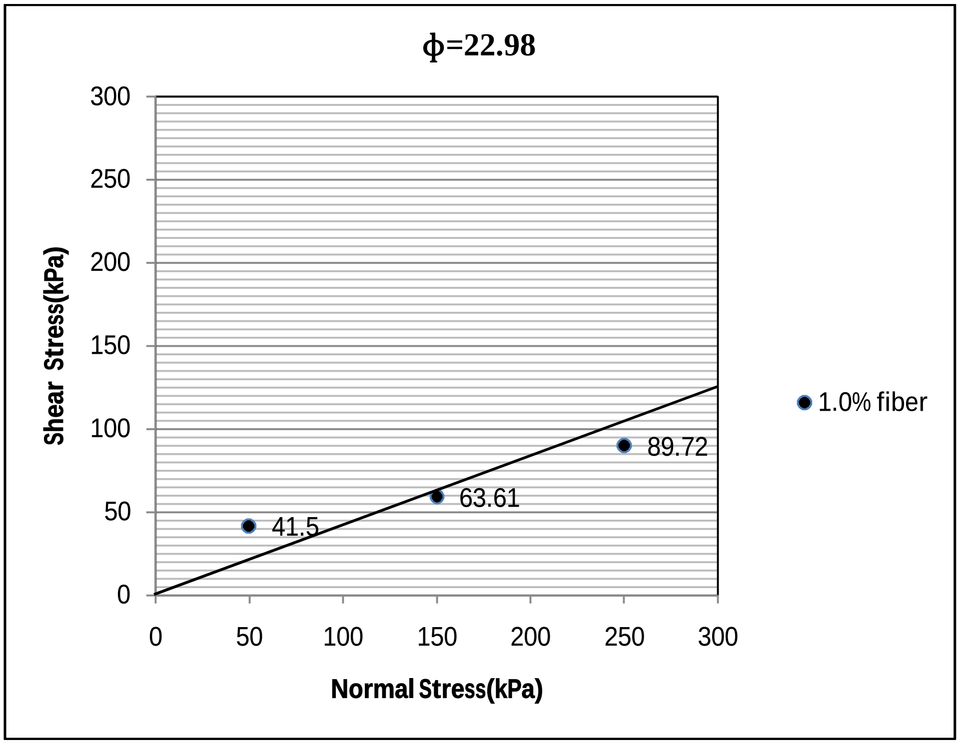


Fig4.9a:-Shear angle on 1.0% fiber content

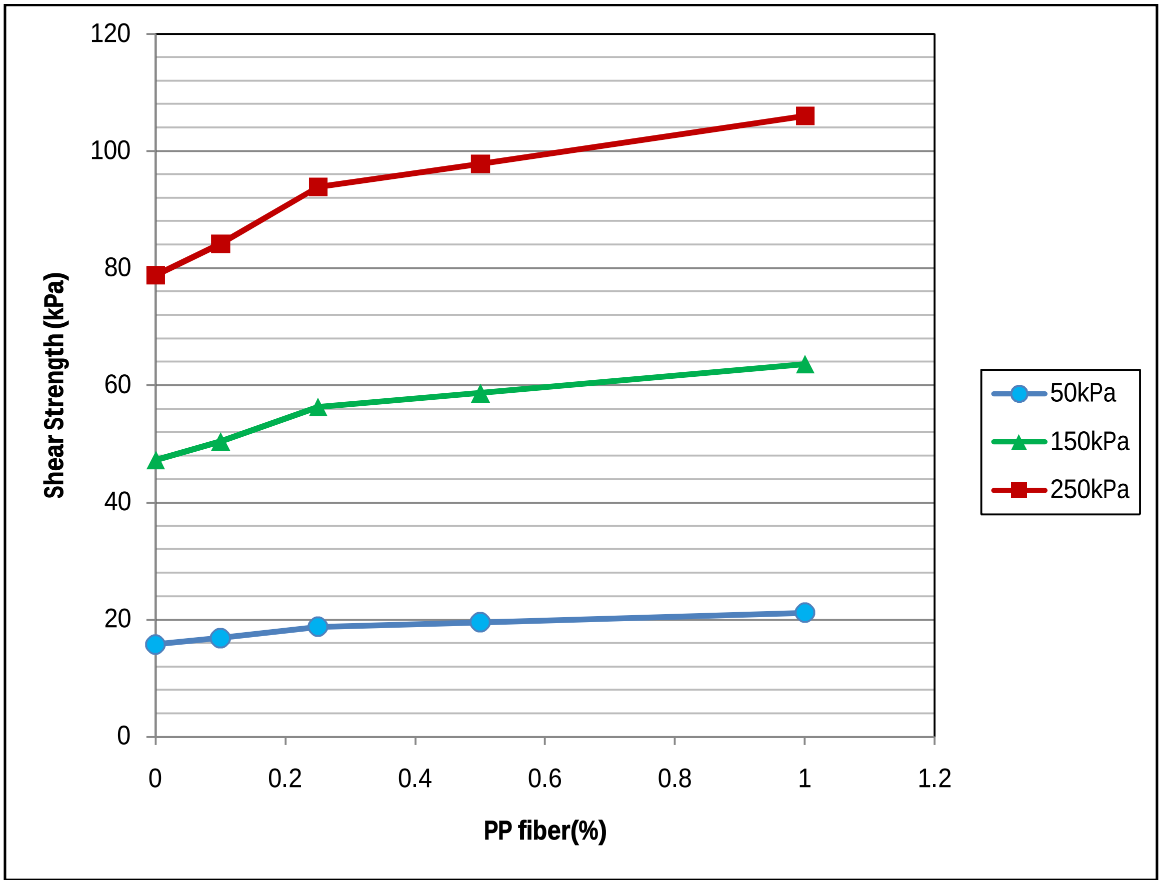
TABLE4.6a:-Summary of test results for reinforced and unreinforced sand :-

μ(%)	Normal Stress(kPa)	Shear Stress(kPa)	Horizontal Displacement(mm)	Shear angle(degree)	Cohesion (kPa)
0.0	50	28.16	4.25	17.49	0.0
	150	47.27	2.50		
	250	69.73	2.75		
0.1	50	26.25	1.75	18.59	0.0
	150	50.45	2.25		
	250	75.32	4.00		
0.25	50	35.00	5.00	20.58	0.0
	150	56.33	5.00		
	250	74.59	4.75		
0.5	50	37.18	4.00	21.36	0.0
	150	58.65	4.00		
	250	79.49	4.00		
1.0	50	41.50	5.50	22.98	0.0
	150	63.30	5.25		
	250	89.72	3.25		

TABLE4.7a:- Calculation of shear strength from shear angle:-

μ(%)	Normal Stress(kPa) (€)	Horizontal Displacement(mm)	Shear angle(□)	Shear Strength (kPa) €tan□
0.0	50	4.25	17.49	15.76
	150	2.50		47.27
	250	2.75		78.78
0.1	50	1.75	18.59	16.82
	150	2.25		50.45
	250	4.00		84.09
0.25	50	5.00	20.58	18.77
	150	5.00		56.32
	250	4.75		93.87
0.5	50	4.00	21.36	19.55
	150	4.00		58.66
	250	4.00		97.77
1.0	50	5.50	22.98	21.20
	150	5.50		63.61
	250	3.25		106.02

4.1.2a Variation of Shear Strength of sand with PP fiber % and Normal Stress:-



OBSERVATION SET-2:-

TABLE 4.1b:- Observations of Sand reinforced with 0.0% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	11	51	74	3570	3.081232	14.28571	20.72829
3	0.50	46	73	120	3540	12.99435	20.62147	33.89831
4	0.75	67	86	146	3510	19.08832	24.50142	41.59544
5	1.00	78	96	168	3480	22.41379	27.58621	48.27586
6	1.25	81	106	176	3450	23.47826	30.72464	51.01449
7	1.50	82	111	186	3420	23.97661	32.45614	54.38596
8	1.75	84	121	192	3390	24.77876	35.69322	56.63717
9	2.00	83	126	196	3360	24.70238	37.5	58.33333
10	2.25	82	131	199	3330	24.62462	39.33934	59.75976
11	2.50	81	133	202	3300	24.54545	40.30303	61.21212
12	2.75	79	131	198	3270	24.15902	40.06116	60.55046
13	3.00	77	129	196	3240	23.76543	39.81481	60.49383
14	3.25	75	127	194	3210	23.36449	39.56386	60.43614
15	3.50	74	125	192	3180	23.27044	39.30818	60.37736
16	3.75	73	123	190	3150	23.1746	39.04762	60.31746
17	4.00	71	120	189	3120	22.75641	38.46154	60.57692
18	4.25	69	117	188	3090	22.3301	37.86408	60.84142
19	4.50	67	114	186	3060	21.89542	37.2549	60.78431
20	4.75	64	111	185	3030	21.12211	36.63366	61.05611
21	5.00	61	106	183	3000	20.33333	35.33333	61
22	5.25	59	104	180	2970	19.86532	35.01684	60.60606
23	5.50	54	102	176	2940	18.36735	34.69388	59.86395
24	5.75	50	100	172	2910	17.18213	34.36426	59.10653
25	6.00	46	97	168	2880	15.97222	33.68056	58.33333

TABLE 4.2b:- Observations of Sand reinforced with 0.1% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	31	64	92	3570	8.683473	17.92717	25.77031
3	0.50	49	94	126	3540	13.84181	26.55367	35.59322
4	0.75	54	106	153	3510	15.38462	30.19943	43.58974
5	1.00	58	115	169	3480	16.66667	33.04598	48.56322
6	1.25	64	121	180	3450	18.55072	35.07246	52.17391
7	1.50	68	127	186	3420	19.88304	37.1345	54.38596
8	1.75	73	130	188	3390	21.53392	38.34808	55.45723
9	2.00	77	132	190	3360	22.91667	39.28571	56.54762
10	2.25	77	133	192	3330	23.12312	39.93994	57.65766
11	2.50	80	137	194	3300	24.24242	41.51515	58.78788
12	2.75	81	139	195	3270	24.77064	42.50765	59.63303
13	3.00	83	142	196	3240	25.61728	43.82716	60.49383
14	3.25	84	143	198	3210	26.16822	44.54829	61.68224
15	3.50	83	142	198	3180	26.10063	44.65409	62.26415
16	3.75	82	141	197	3150	26.03175	44.7619	62.53968
17	4.00	81	140	196	3120	25.96154	44.87179	62.82051
18	4.25	81	140	194	3090	26.21359	45.30744	62.78317
19	4.50	80	140	191	3060	26.14379	45.75163	62.4183
20	4.75	79	139	187	3030	26.07261	45.87459	61.71617
21	5.00	78	138	184	3000	26	46	61.33333
22	5.25	76	136	182	2970	25.58923	45.79125	61.27946
23	5.50	75	134	180	2940	25.5102	45.91837	61.22449
24	5.75	73	132	178	2910	25.08591	45.39175	61.16838
25	6.00	72	129	177	2880	25	44.72778	61.45833

TABLE 4.3b:- Observations of Sand reinforced with 0.25% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_{c=}A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	22	58	101	3570	6.162465	16.2465	28.29132
3	0.50	51	87	136	3540	14.40678	24.57627	38.41808
4	0.75	67	108	156	3510	19.08832	30.76923	44.44444
5	1.00	73	125	169	3480	20.97701	35.91954	48.56322
6	1.25	79	138	181	3450	22.89855	40	52.46377
7	1.50	81	145	186	3420	23.68421	42.39766	54.38596
8	1.75	87	148	191	3390	25.66372	43.65782	56.34218
9	2.00	90	151	195	3360	26.78571	44.94048	58.03571
10	2.25	92	153	197	3330	27.62763	45.94595	59.15916
11	2.50	94	154	198	3300	28.48485	46.66667	60
12	2.75	96	154	198	3270	29.3578	47.0948	60.55046
13	3.00	96	153	198	3240	29.62963	47.22222	61.11111
14	3.25	96	153	198	3210	29.90654	47.66355	61.68224
15	3.50	96	153	199	3180	30.18868	48.11321	62.57862
16	3.75	97	152	199	3150	30.79365	48.25397	63.1746
17	4.00	97	149	202	3120	31.08974	47.75641	64.74359
18	4.25	97	145	198	3090	31.39159	46.92557	64.07767
19	4.50	99	140	197	3060	32.35294	45.75163	64.37908
20	4.75	100	139	196	3030	33.0033	45.87459	64.68647
21	5.00	99	137	194	3000	33	45.66667	64.66667
22	5.25	97	136	193	2970	32.65663	45.79125	64.98316
23	5.50	96	135	191	2940	32.60333	45.91837	64.96612
24	5.75	94	134	189	2910	32.30698	46.04811	64.9481
25	6.00	92	133	186	2880	31.94442	46.18056	64.58333

TABLE 4.4b:- Observations of Sand reinforced with 0.5% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c=A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	29	28	56	3570	8.123249	7.843137	15.68627
3	0.50	53	54	106	3540	14.97175	15.25424	29.9435
4	0.75	72	81	140	3510	20.51282	23.07692	39.88604
5	1.00	88	106	166	3480	25.28736	30.45977	47.70115
6	1.25	99	118	189	3450	28.69565	34.2029	54.78261
7	1.50	106	129	205	3420	30.99415	37.7193	59.94152
8	1.75	112	141	216	3390	33.03835	41.59292	63.71681
9	2.00	114	153	225	3360	33.92857	45.53571	66.96429
10	2.25	113	162	232	3330	33.93393	48.64865	69.66967
11	2.50	114	166	241	3300	34.54545	50.30303	73.0303
12	2.75	114	169	242	3270	34.86239	51.68196	74.00612
13	3.00	114	170	243	3240	35.18519	52.46914	75
14	3.25	114	172	245	3210	35.51402	53.58255	76.32399
15	3.50	114	174	248	3180	35.84906	54.71698	77.98742
16	3.75	113	175	249	3150	35.87302	55.55556	79.04762
17	4.00	112	175	251	3120	35.89744	56.08974	80.44872
18	4.25	111	174	252	3090	35.92233	56.31068	81.5534
19	4.50	109	174	251	3060	35.62092	56.86275	82.02614
20	4.75	106	172	250	3030	34.9835	56.76568	82.50825
21	5.00	105	171	246	3000	35	57	82
22	5.25	104	170	246	2970	35.01684	57.23906	82.82828
23	5.50	103	169	245	2940	35.03401	57.48299	83.33333
24	5.75	102	168	244	2910	35.05155	57.73196	83.8488
25	6.00	101	165	240	2880	35.06944	57.29161	83.32778

TABLE 4.5b:- Observations of Sand reinforced with 1.0% fiber content

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c=A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		NORMAL STRESS				NORMAL STRESS		
		50 kPa	150 kPa	250 kPa		50 kPa	150 kPa	250 KPa
1	0.00	0	0	0	3600	0	0	0
2	0.25	41	45	74	3570	11.48459	12.60504	20.72829
3	0.50	56	78	111	3540	15.81921	22.0339	31.35593
4	0.75	66	99	140	3510	18.80342	28.20513	39.88604
5	1.00	79	121	159	3480	22.70115	34.77011	45.68966
6	1.25	86	129	180	3450	24.92754	37.3913	52.17391
7	1.50	91	141	194	3420	26.60819	41.22807	56.72515
8	1.75	96	150	205	3390	28.31858	44.24779	60.47198
9	2.00	100	158	213	3360	29.7619	47.02381	63.39286
10	2.25	103	164	220	3330	30.93093	49.24925	66.06607
11	2.50	107	168	224	3300	32.42424	50.90909	67.87879
12	2.75	113	171	228	3270	34.55657	52.29358	69.72477
13	3.00	117	174	232	3240	36.11111	53.7037	71.60494
14	3.25	118	176	240	3210	36.76012	54.82866	74.76636
15	3.50	119	177	248	3180	37.42138	55.66038	77.98742
16	3.75	120	178	251	3150	38.09524	56.50794	79.68254
17	4.00	120	182	254	3120	38.46154	58.33333	81.41026
18	4.25	121	184	260	3090	39.15858	59.54693	84.14239
19	4.50	119	187	266	3060	38.88889	61.11111	86.9281
20	4.75	118	186	267	3030	38.94389	61.38614	88.11881
21	5.00	117	185	271	3000	39	61.66667	90.33333
22	5.25	117	184	270	2970	39.39394	61.95286	90.90909
23	5.50	116	183	269	2940	39.45578	62.2449	91.4966
24	5.75	114	183	268	2910	39.17526	62.8866	92.09622
25	6.00	112	180	265	2880	38.88888	62.5011	92.01833

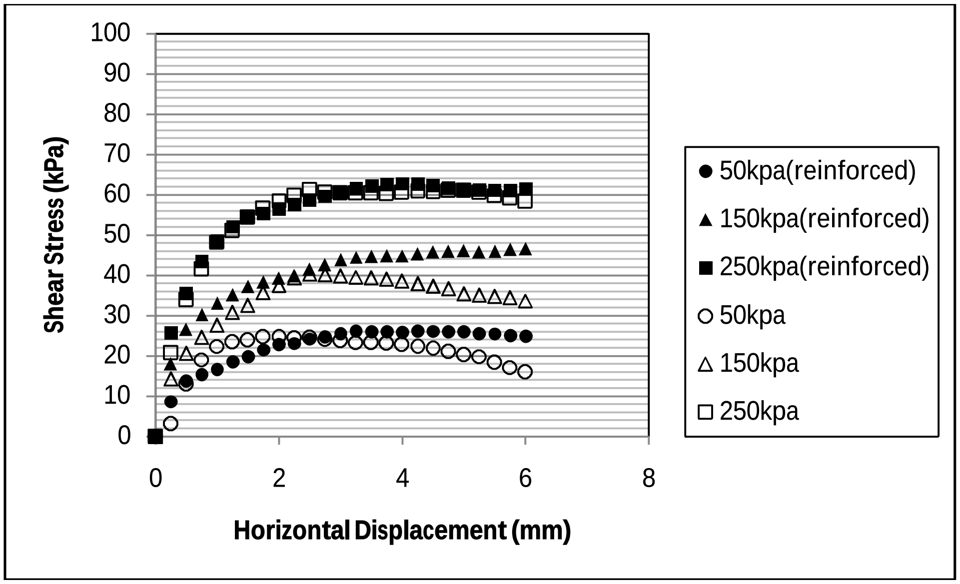


Fig4.1b:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=0.1%

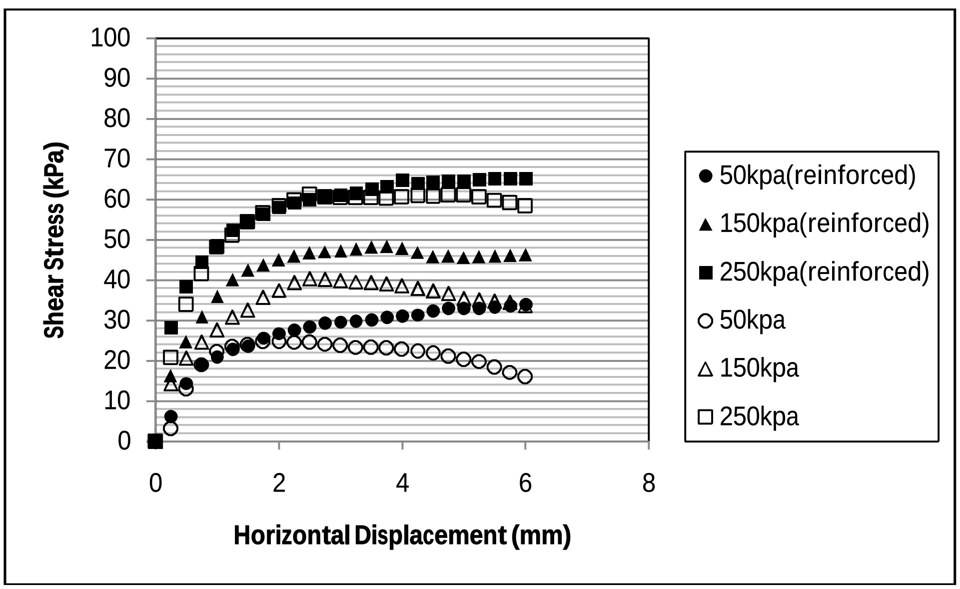


Fig4.2b:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=0.25%

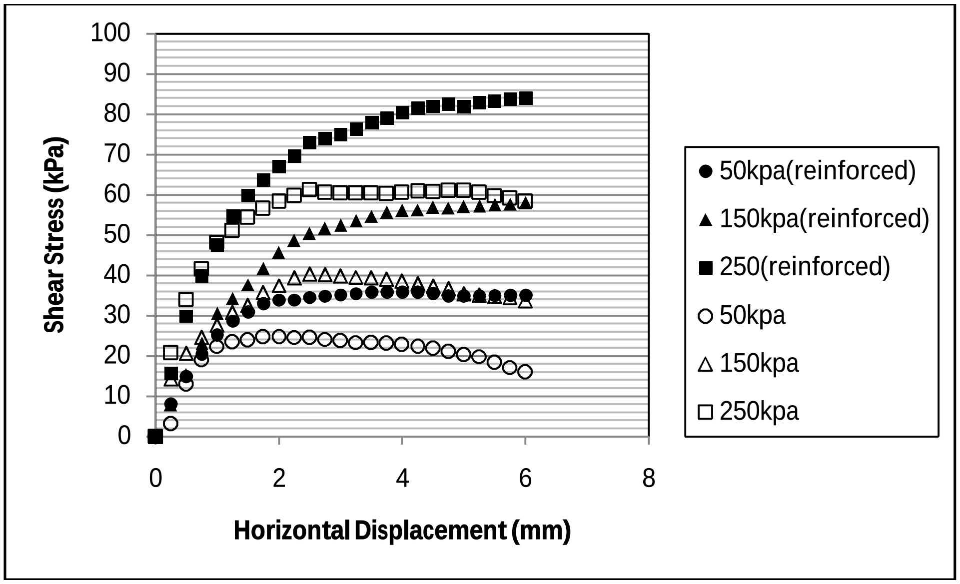


Fig4.3b:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=0.5%

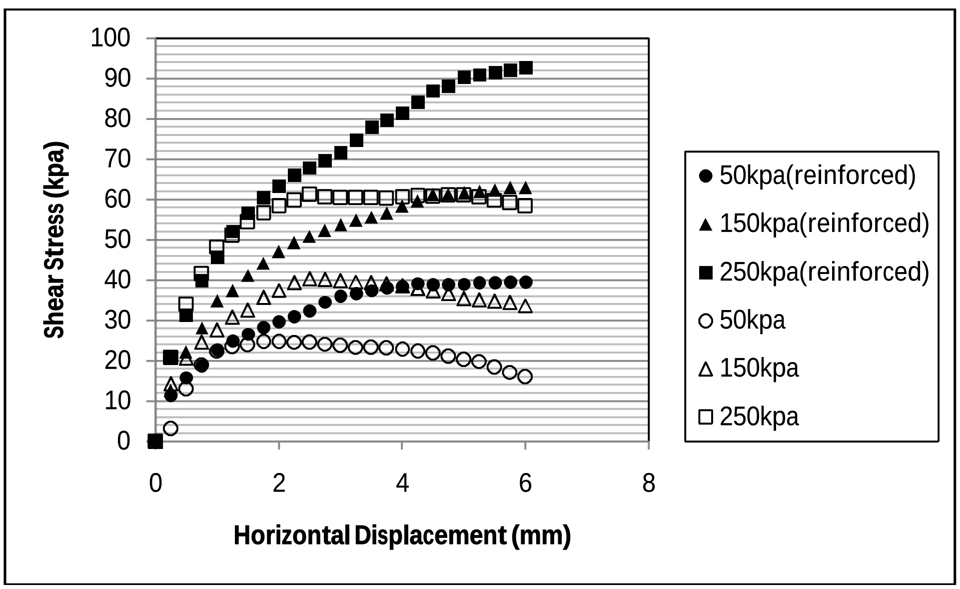


Fig4.4b:-shear stress-horizontal displacement response for unreinforced sand and sand reinforced with fiber content of μ=1.0%

4.1.1b Effect of percentage of fibers on shear angle (□) of sand:-

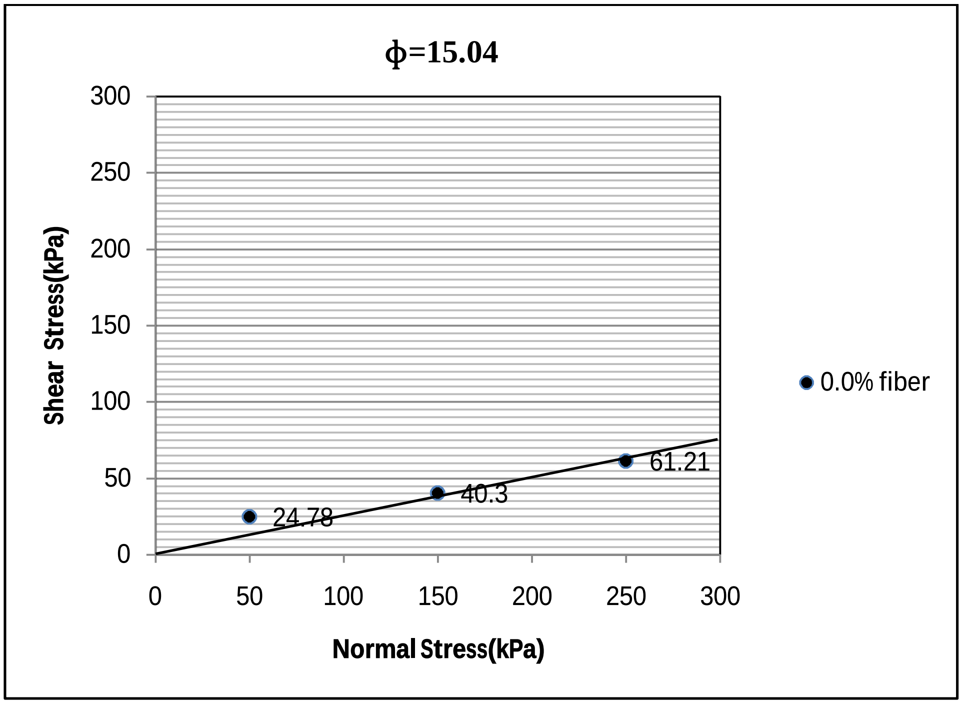


Fig4.5b:-Shear angle on 0.0% fiber content

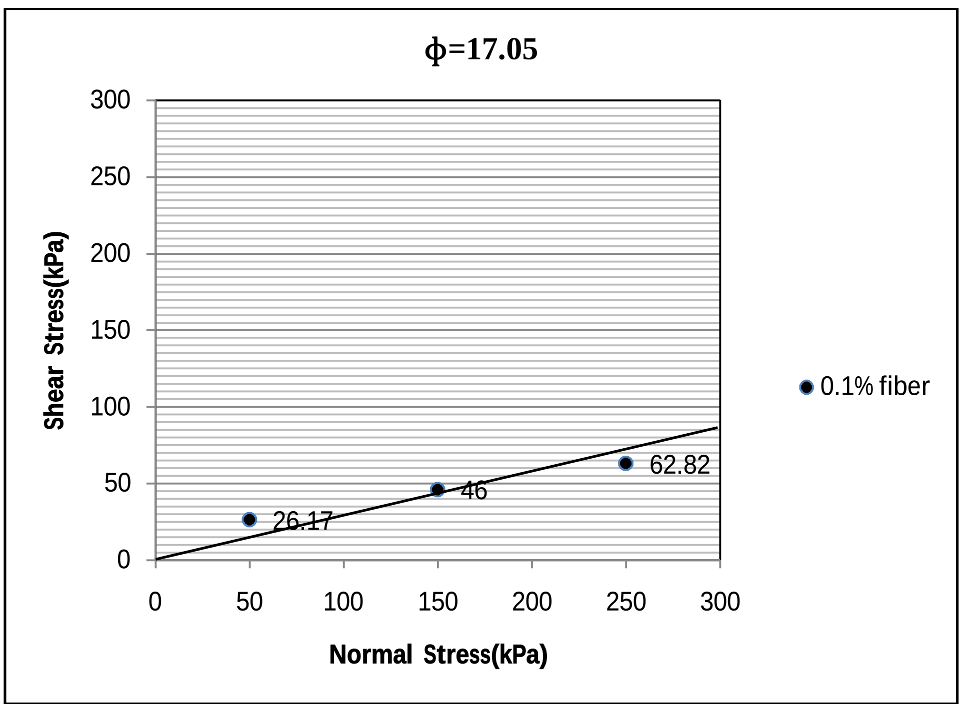


Fig4.6b:-Shear angle on 0.1% fiber content

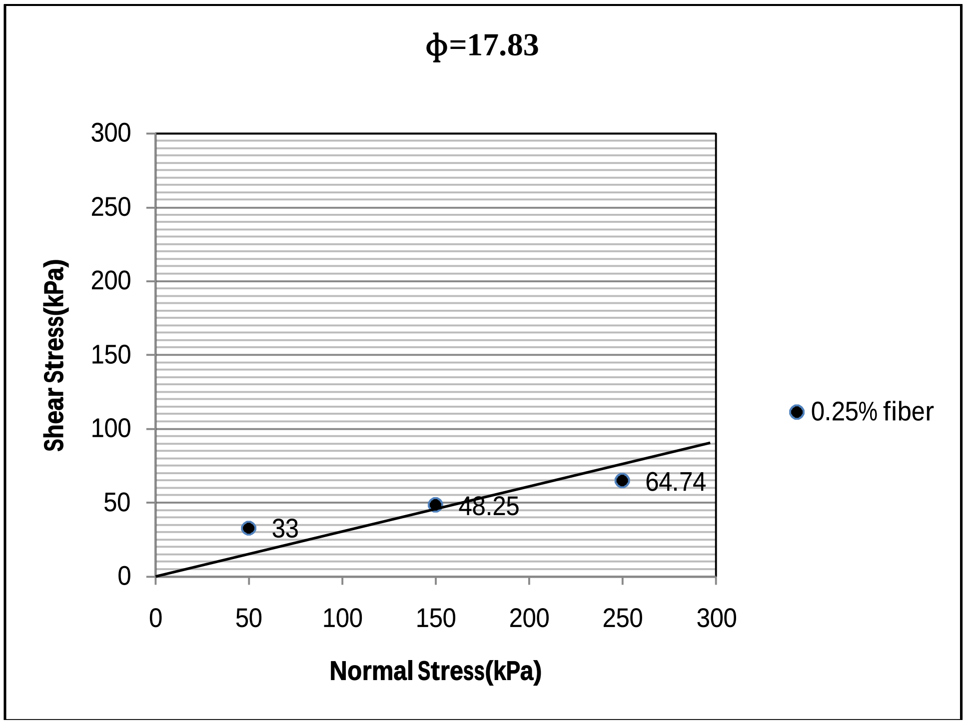


Fig4.7b:-Shear angle on 0.25% fiber content

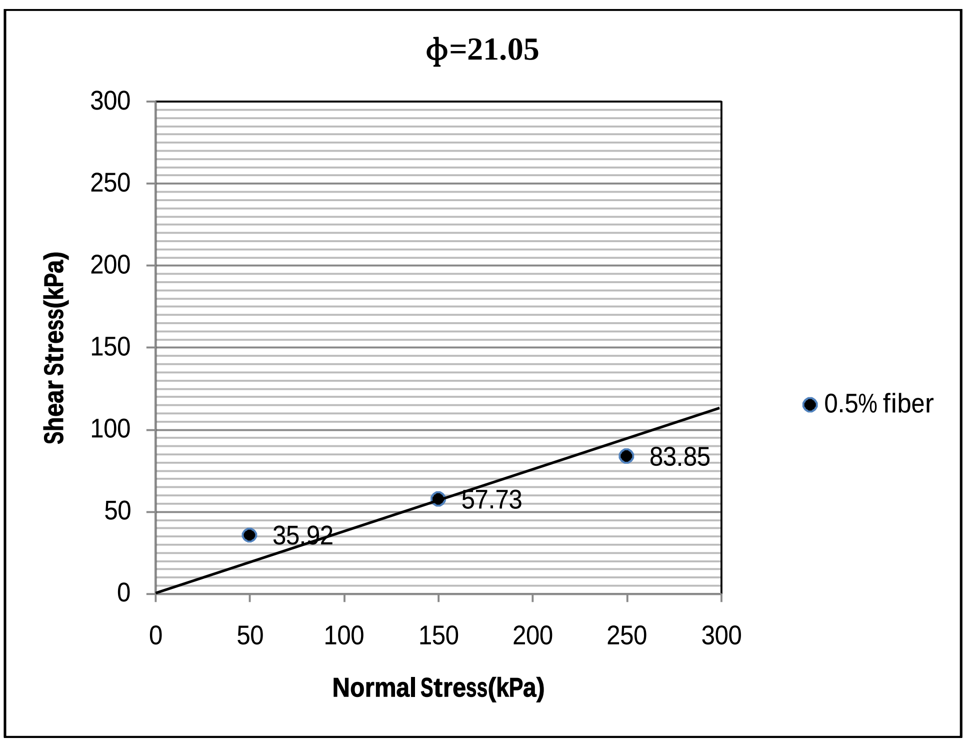


Fig4.8b:-Shear angle on 0.5% fiber content

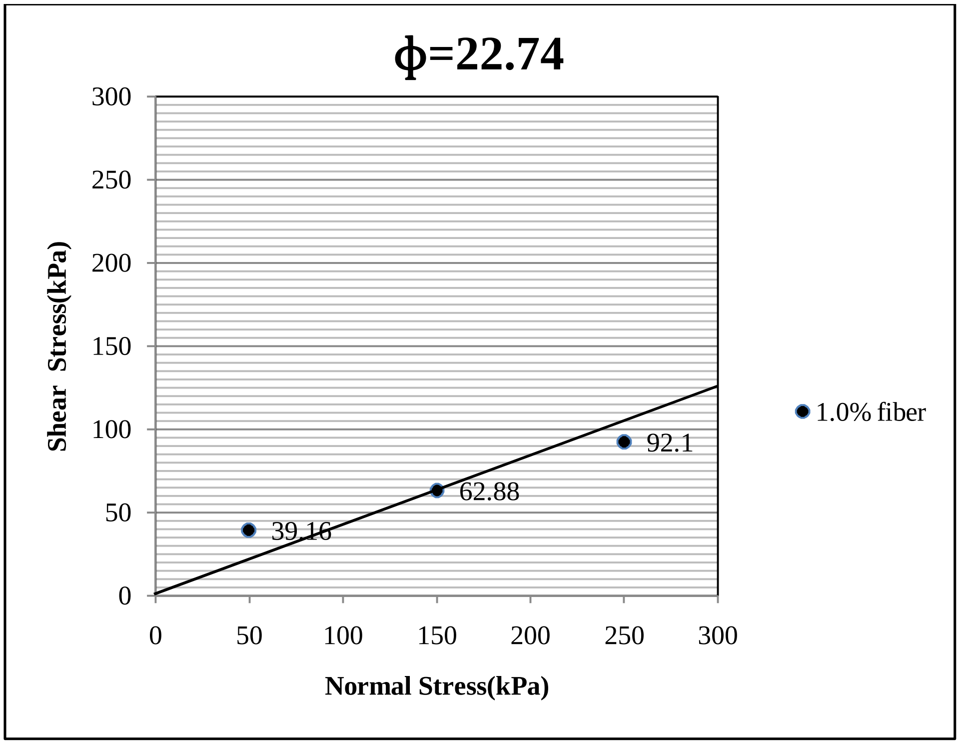


Fig4.9b:-Shear angle on 1.0% fiber content

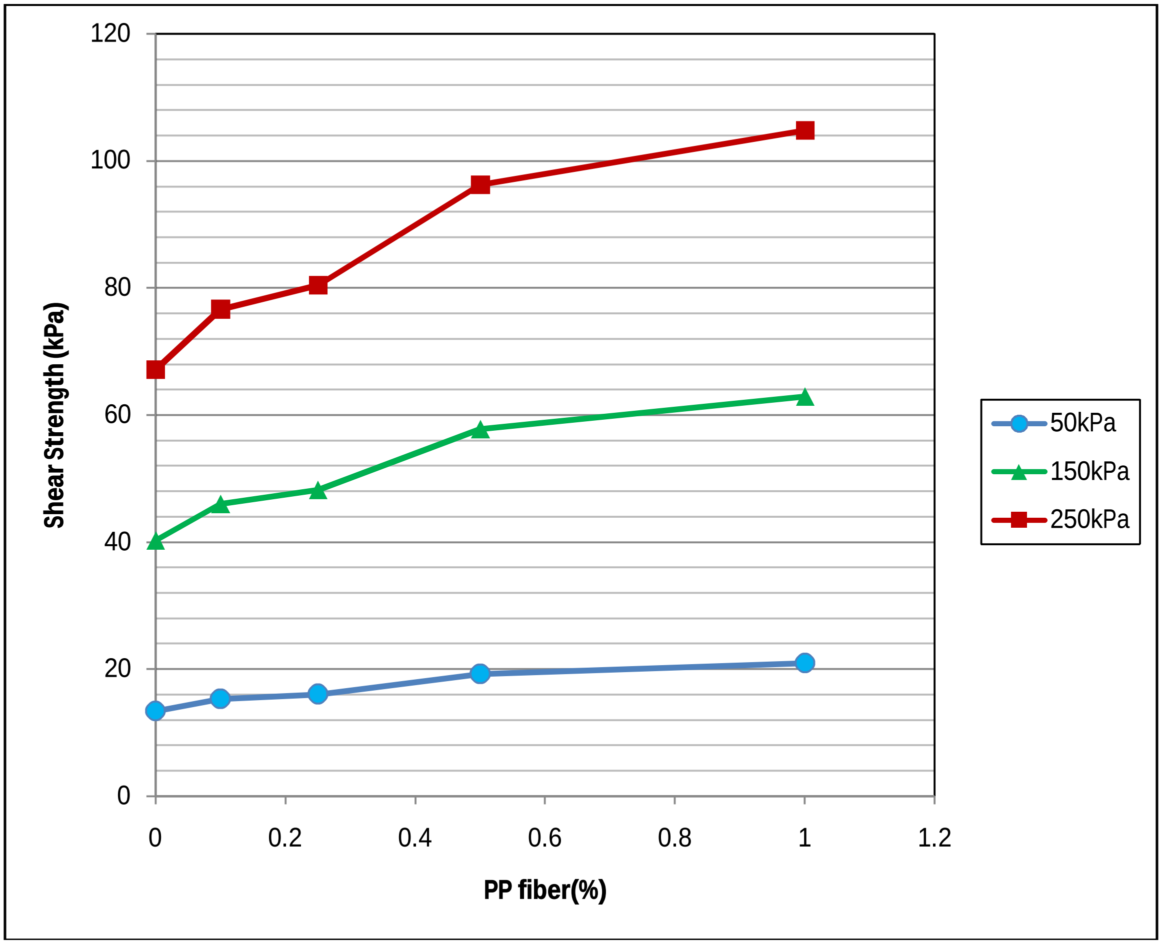
TABLE4.6b:-Summary of test results for reinforced and unreinforced sand :-

μ(%)	Normal Stress(kPa)	Shear Stress(kPa)	Horizontal Displacement(mm)	Shear angle(degree)	Cohesion (kPa)
0.0	50	24.78	1.75	15.04	0.0
	150	40.30	2.50		
	250	61.21	2.50		
0.1	50	26.17	3.25	17.05	0.0
	150	46.00	5.00		
	250	62.82	4.00		
0.25	50	33.00	4.75	17.83	0.0
	150	48.25	3.75		
	250	64.74	4.00		
0.5	50	35.92	4.25	21.05	0.0
	150	57.73	5.75		
	250	83.85	5.75		
1.0	50	39.16	4.25	22.74	0.0
	150	62.88	5.75		
	250	92.10	5.75		

TABLE4.7b:- Calculation of shear strength from shear angle:-

µ(%)	Normal Stress(kPa) (€)	Horizontal Displacement(mm)	Shear angle(□)	Shear Strength (kPa) €tan□
0.0	50	1.75	15.04	13.43
	150	2.50		40.30
	250	2.50		67.17
0.1	50	3.25	17.05	15.33
	150	5.00		46.00
	250	4.00		76.67
0.25	50	4.75	17.83	16.08
	150	3.75		48.25
	250	4.00		80.41
0.5	50	4.25	21.05	19.24
	150	5.75		57.73
	250	5.75		96.22
1.0	50	4.25	22.74	20.96
	150	5.75		62.87
	250	5.75		104.78

4.1.2b Variation of Shear Strength of sand with PP fiber % and Normal Stress:-



4.2 Effect of the Aspect Ratio (L/D) of the fiber on the shear strength of the sand:-

The effects of length of fibers on shear strength of sand were studied in this project. The aspect ratio which is defined as the length over diameter ratio (L/D) was used herein instead of length alone as an indication for fiber length. The three aspect ratios were studied under three different loads 50 kPa,150 kPa and 250 kPa. figures 4.10,4.11 and 4.12 show the effect of aspect ratio on shear strength under three normal loads 50 kPa,150 kPa and 250 kPa respectively at 0.5% monofilament fiber content by dry weight of the sand. It is clear from these three figures that the increase of aspect ratio resulted in increasing the shear strength. In figure 4.10 the failure shear stress of sand decreased from 48.26 kPa to 47.13 kPa when the aspect ratio increased from 50 to 100 under normal load 50 kPa. At the same time as shown in figure 4.12 the shear strength increased from 76.33 kPa to 79.48 kPa when the aspect ratio increased from 50 to 100 under normal load equal to 250 kPa.

It was also noticed that increased in the aspect ratio of fiber resulted in increasing the ductility of the sand. This observation is clear in figure 4.12. The sand in all samples at different aspect ratio and under different normal loads fails at higher strain than if there is no fiber. Figures show the effect of fiber on shear strength of sand under three normal loads 50 kPa and 250 kPa at 0.5% fiber content by dry weight of the sand

It is clear from figure 4.10 that the fiber has a small or no effect on shear strength if the aspect ratio is less than 100 (L = 1.0 cm). Increasing the aspect ratio of more than 100 will result in decreasing the shear strength. The failure shear stress decreased from 47.13 kPa to 43.56 kPa when the aspect ratio increased from 100 to 150 respectively. The reduction in shear strength was noticed in all samples tested under at small normal load equal to 50 kPa. This behavior can be attributed to the plastic-like-surface which makes the sand particles moves and slip over that surface easier resulted in decreasing the shear strength.

The effect of aspect ratio of fiber on shear strength under high normal load is shown in figure 4.12. This figure indicated the increase in the aspect ratio will increase the shear strength under normal load 250 kPa. The shear strength increased from 79.48 kPa to 86.60 kPa when the aspect ratio increased from 100 to 150. This can be explained as the following. As the normal load increased, the contact surface between sand and the crimpled surface of the fiber increased. This increase in the contact surface makes the sand particles harder to move and thus increasing the shear strength of the sand.

Table 4.8:- Effect of aspect ratio on stress-strain behaviour of sand at lower loads (50kPa)

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		L/D				L/D		
		50	100	150		50	100	150
1	0.00	0	0	0	3600	0	0	0
2	0.25	59	57	56	3570	16.52661	15.96639	15.68627
3	0.50	66	64	63	3540	18.64407	18.0791	17.79661
4	0.75	85	85	83	3510	24.21652	24.21652	23.64672
5	1.00	100	99	98	3480	28.73563	28.44828	28.16092
6	1.25	115	113	110	3450	33.33333	32.75362	31.88406
7	1.50	128	125	119	3420	37.4269	36.54971	34.79532
8	1.75	132	129	125	3390	38.93805	38.0531	36.87316
9	2.00	138	135	128	3360	41.07143	40.17857	38.09524
10	2.25	143	140	131	3330	42.94294	42.04204	39.33934
11	2.50	145	143	135	3300	43.93939	43.33333	40.90909
12	2.75	147	145	136	3270	44.95413	44.34251	41.59021
13	3.00	147	145	135	3240	45.37037	44.75309	41.66667
14	3.25	147	145	135	3210	45.79439	45.17134	42.05607
15	3.50	148	146	135	3180	46.54088	45.91195	42.45283
16	3.75	148	146	135	3150	46.98413	46.34921	42.85714
17	4.00	148	146	135	3120	47.4359	46.79487	43.26923
18	4.25	146	143	133	3090	47.24919	46.27832	43.04207
19	4.50	146	142	132	3060	47.71242	46.40523	43.13725
20	4.75	144	142	132	3030	47.52475	46.86469	43.56436
21	5.00	142	140	129	3000	47.33333	46.66667	43
22	5.25	141	140	127	2970	47.47475	47.13805	42.76094
23	5.50	141	135	122	2940	47.95918	45.91837	42.51701
24	5.75	140	134	125	2910	48.10997	46.04811	42.95533
25	6.00	139	132	127	2880	48.26389	45.83333	42.36111

Table 4.9:- Effect of aspect ratio on stress-strain behaviour of sand at medium loads (150kPa)

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c=A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		L/D				L/D		
		50	100	150		50	100	150
1	0.00	0	0	0	3600	0	0	0
2	0.25	57	57	58	3570	15.96639	15.96639	16.2465
3	0.50	72	78	91	3540	20.33898	22.0339	25.70621
4	0.75	90	95	115	3510	25.64103	27.06553	32.76353
5	1.00	115	122	136	3480	33.04598	35.05747	39.08046
6	1.25	127	134	151	3450	36.81159	38.84058	43.76812
7	1.50	136	145	161	3420	39.76608	42.39766	47.07602
8	1.75	146	154	167	3390	43.06785	45.42773	49.26254
9	2.00	157	163	175	3360	46.72619	48.5119	52.08333
10	2.25	165	171	181	3330	49.54955	51.35135	54.35435
11	2.50	166	172	183	3300	50.30303	52.12121	55.45455
12	2.75	167	173	183	3270	51.07034	52.9052	55.9633
13	3.00	167	173	184	3240	51.54321	53.39506	56.79012
14	3.25	167	174	185	3210	52.02492	54.20561	57.32087
15	3.50	167	174	184	3180	52.51572	54.71698	58.1761
16	3.75	165	173	183	3150	52.38095	54.92063	58.4127
17	4.00	162	170	180	3120	51.92308	54.48718	58.65385
18	4.25	160	167	178	3090	51.77994	54.04531	58.25243
19	4.50	158	165	176	3060	51.63399	53.92157	58.16993
20	4.75	155	163	174	3030	51.15512	53.79538	58.08581
21	5.00	152	161	172	3000	50.66667	53.66667	58
22	5.25	148	160	168	2970	49.83165	53.87205	57.91246
23	5.50	145	156	164	2940	49.31973	53.06122	57.14286
24	5.75	142	152	162	2910	48.79725	52.23368	56.35739
25	6.00	140	149	160	2880	48.61111	51.73611	56.25

Table 4.10:- Effect of aspect ratio on stress-strain behaviour of sand at higher loads (250kPa)

S. NO.	H.D. (mm)	SHEAR LOAD (N)			CORRECTED AREA $A_c = A_0(1-\Delta L/3)$ (mm^2)	SHEAR STRESS (kPa)		
		L/D				L/D		
		50	100	150		50	100	150
1	0.00	0	0	0	3600	0	0	0
2	0.25	65	87	108	3570	18.20728	24.36975	30.2521
3	0.50	92	118	139	3540	25.9887	33.33333	39.26554
4	0.75	121	141	160	3510	34.47293	40.17094	45.58405
5	1.00	150	170	188	3480	43.10345	48.85057	54.02299
6	1.25	165	180	209	3450	47.82609	52.17391	60.57971
7	1.50	175	200	228	3420	51.16959	58.47953	66.66667
8	1.75	189	205	240	3390	55.75221	60.47198	70.79646
9	2.00	199	215	249	3360	59.22619	63.9881	74.10714
10	2.25	209	230	255	3330	62.76276	69.06907	76.57658
11	2.50	222	240	261	3300	67.27273	72.72727	79.09091
12	2.75	225	242	263	3270	68.80734	74.00612	80.42813
13	3.00	235	245	265	3240	72.53086	75.61728	81.79012
14	3.25	237	247	267	3210	73.83178	76.94704	83.17757
15	3.50	240	248	267	3180	75.4717	77.98742	83.96226
16	3.75	240	248	267	3150	76.19048	78.73016	84.7619
17	4.00	240	248	267	3120	76.92308	79.48718	85.57692
18	4.25	235	244	264	3090	76.05178	78.9644	85.43689
19	4.50	232	240	262	3060	75.81699	78.43137	85.62092
20	4.75	231	237	260	3030	76.23762	78.21782	85.80858
21	5.00	229	235	258	3000	76.33333	78.33333	86
22	5.25	224	232	255	2970	75.42088	78.11448	85.85859
23	5.50	220	230	254	2940	74.82993	78.23129	86.39456
24	5.75	215	228	252	2910	73.88316	78.35052	86.59794
25	6.00	205	225	249	2880	71.18056	78.125	86.45833

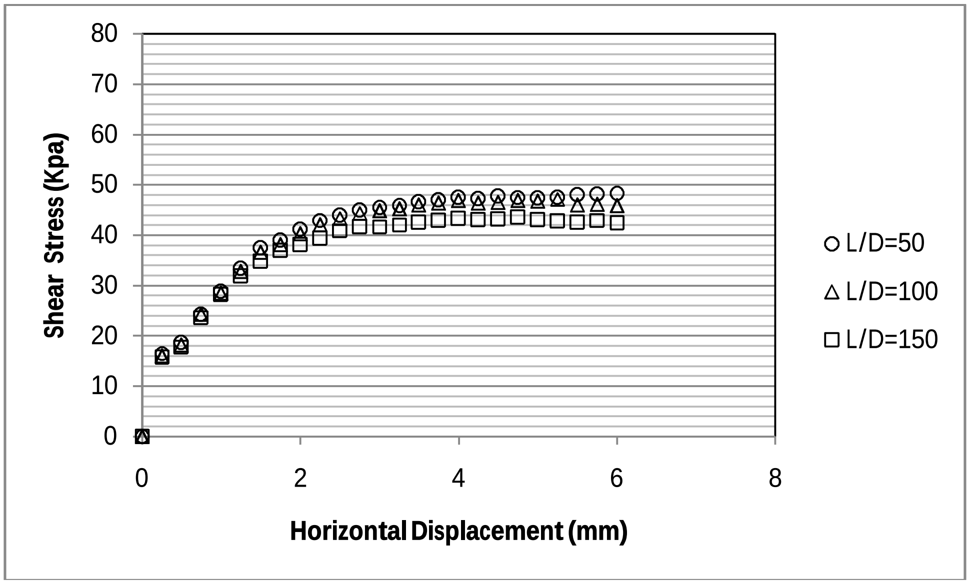


Fig4.10:-Effect of aspect ratio on stress-strain behaviour of sand at lower loads (50kPa)

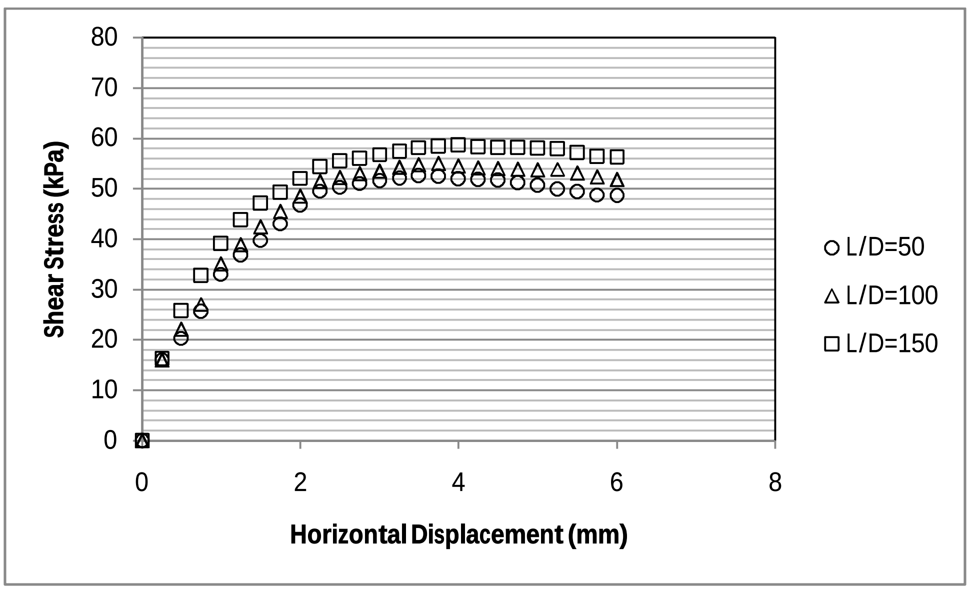


Fig4.11:-Effect of aspect ratio on stress-strain behaviour of sand at medium loads (150kPa)

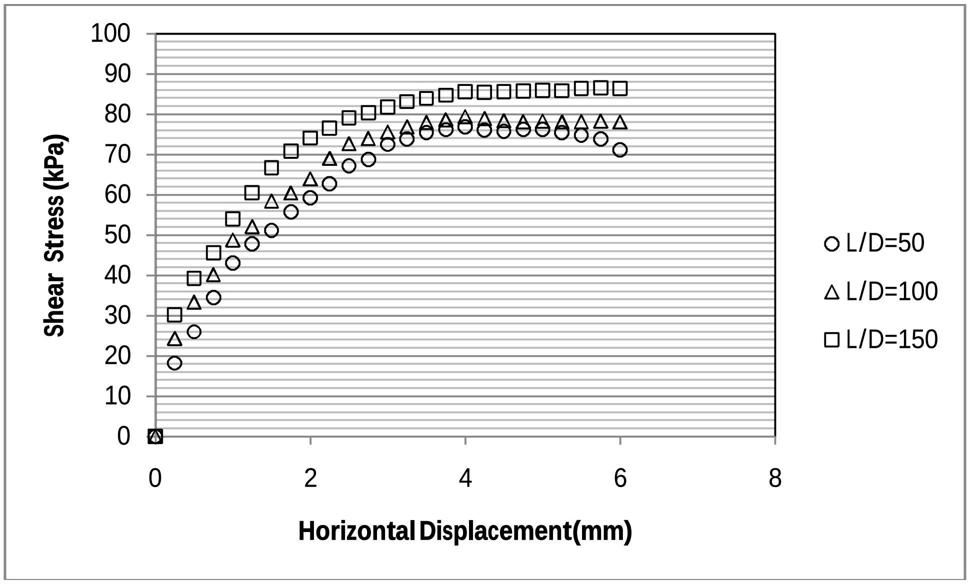


Fig4.12:-Effect of aspect ratio on stress-strain behaviour of sand at higher loads (250kPa)

4.2.1 Effect of Aspect Ratio(L/D) of fibers on shear angle(□) of sand:-

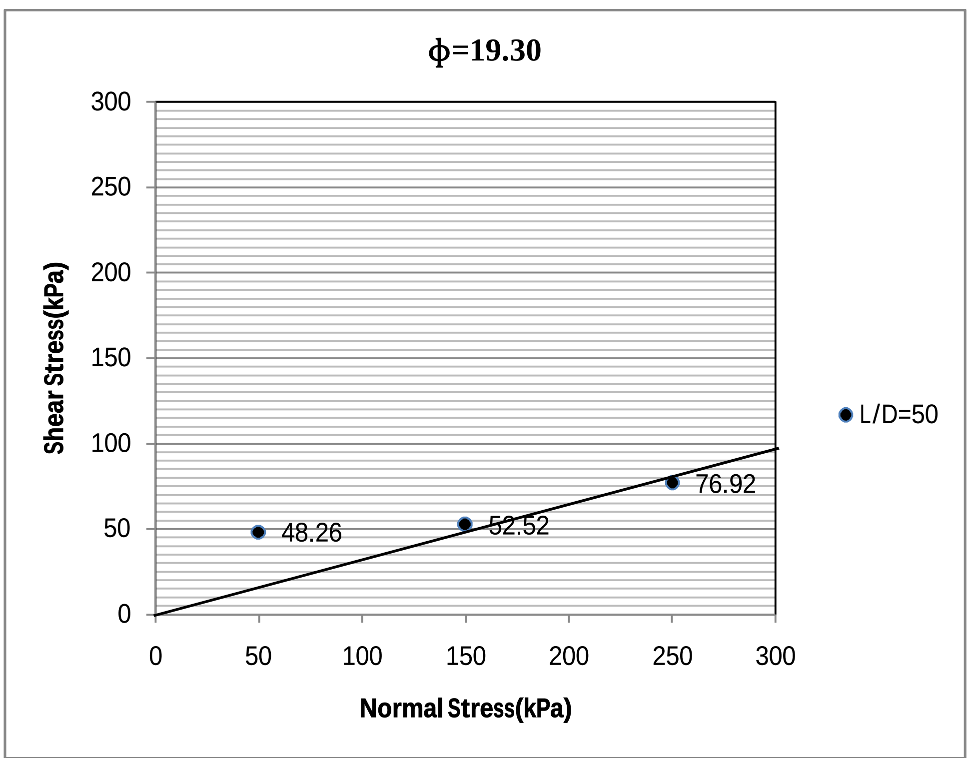


Fig4.13:-Shear angle on aspect(L/D) ratio=50

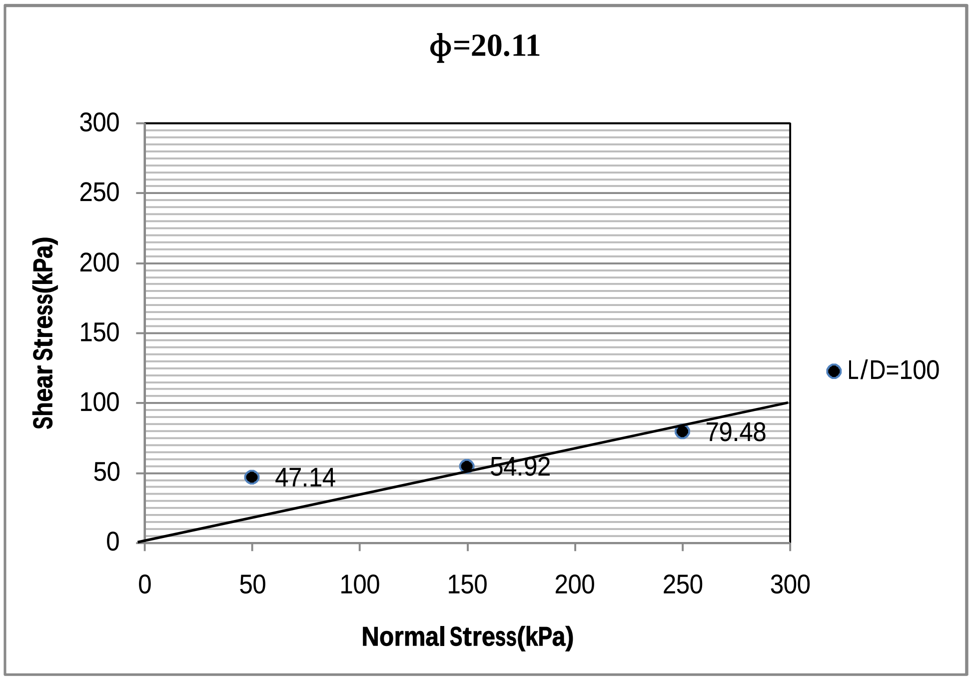


Fig4.14:-Shear angle on aspect(L/D) ratio=100

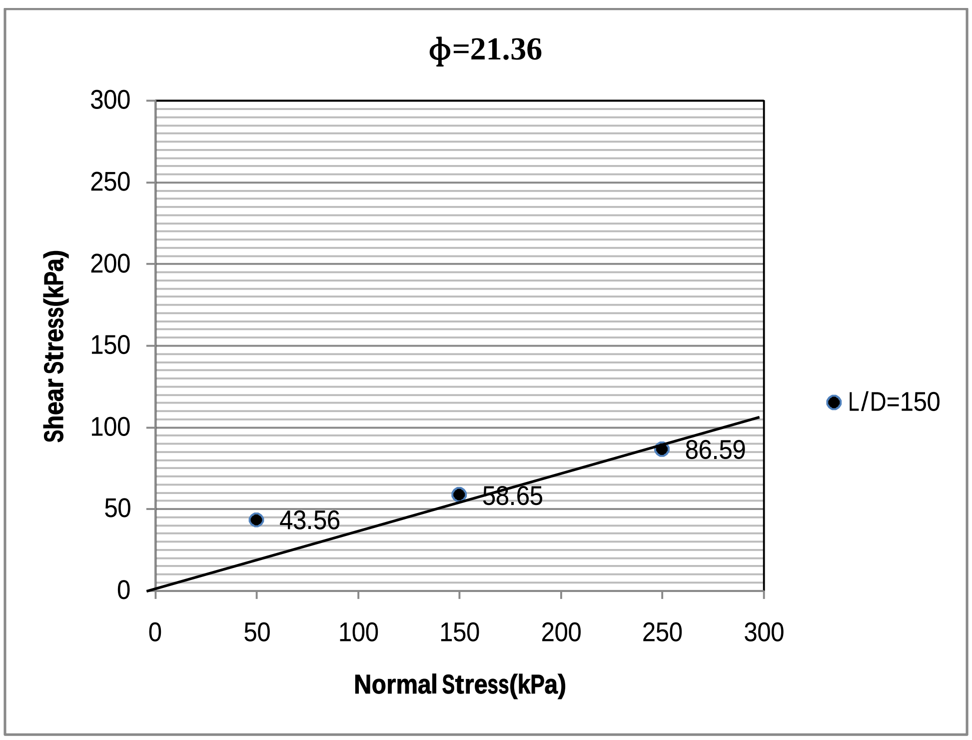


Fig4.15:-Shear angle on aspect(L/D) ratio=150

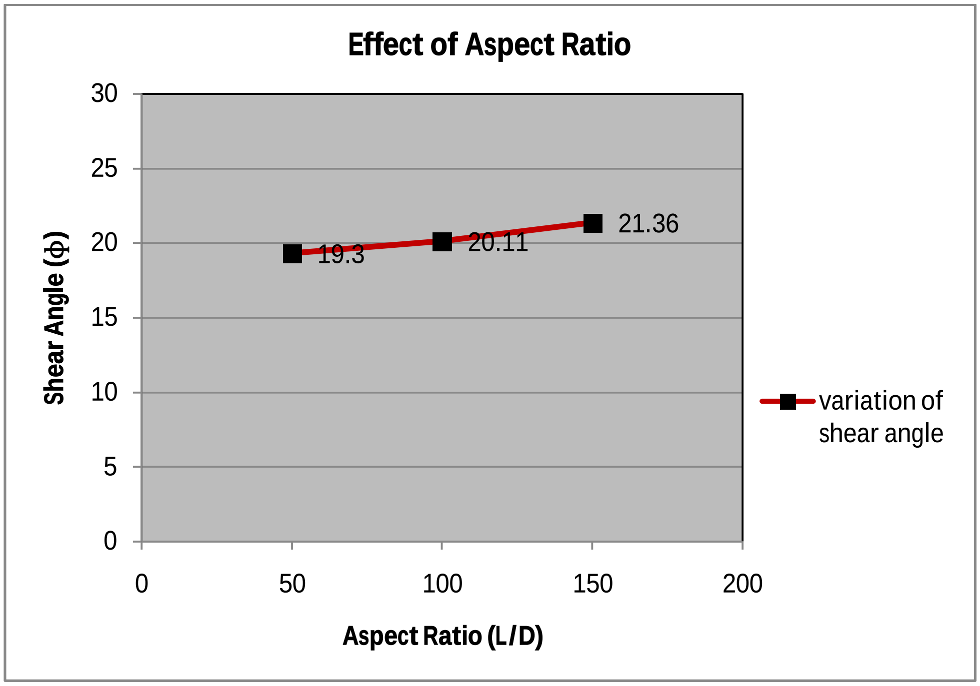
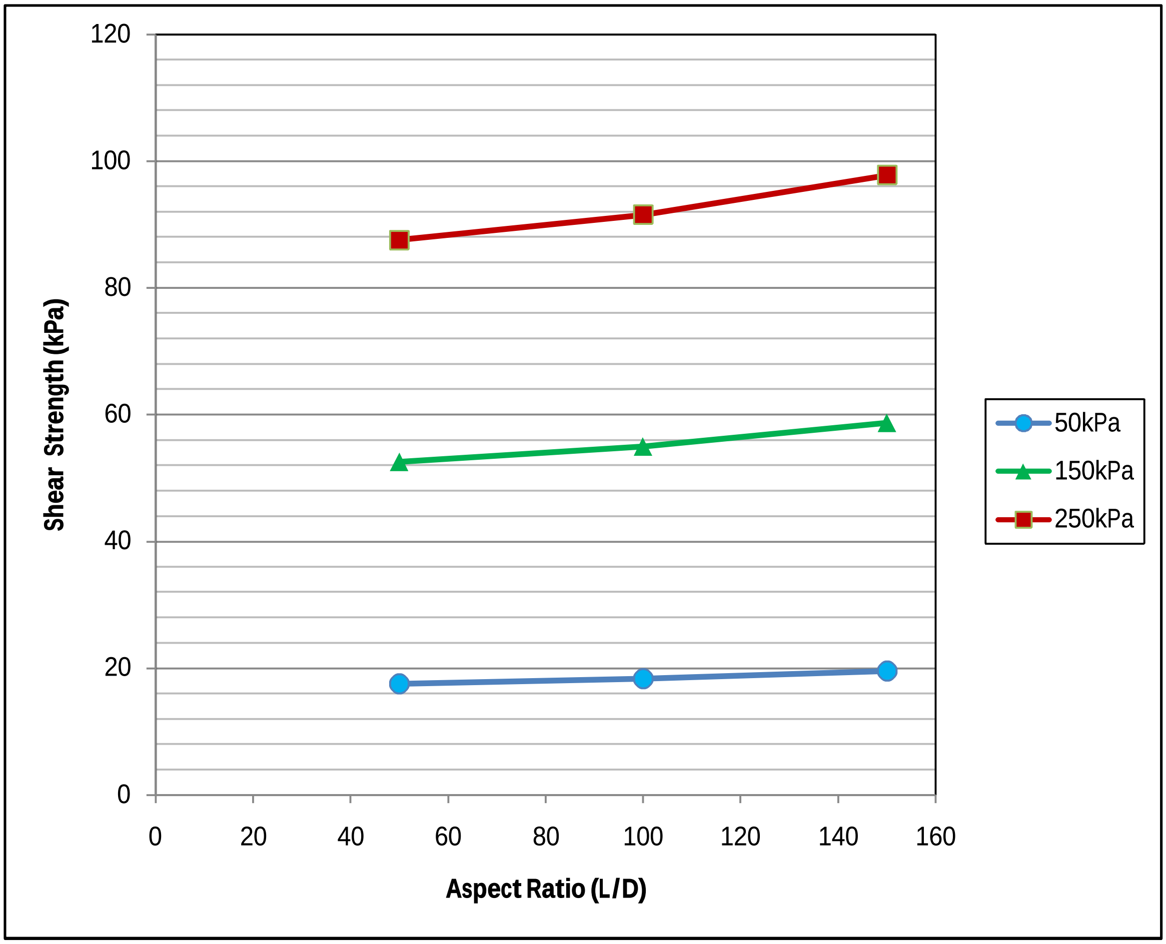


Fig4.16:- Effect of aspect ratio on shear angle

TABLE4.11:- Calculation of shear strength from shear angle for different Aspect Ratios:-

Aspect Ratio (L/D)	Normal Stress(kPa) (€)	Shear angle(degree)	Shear Strength (kPa) €tan□
50	50	19.30	17.51
	150		52.53
	250		87.55
100	50	20.11	18.31
	150		54.92
	250		91.54
150	50	21.36	19.55
	150		58.66
	250		97.77

4.2.2 Variation of Shear Strength of sand with Aspect Ratio and Normal Stresses:-



CHAPTER 5
CONCLUSIONS

This study presents the results of using monofilament polypropylene fibers at different percentages and aspect ratios to improve some physical properties of sandy soil. Based on the test results of this study, the following conclusions may be drawn out:

1. The reduction in the loss of post-peak shear stress is more pronounced for higher vertical normal stresses and fiber contents.

OBSERVATION SET 1:-

TABLE5a:- Percentage loss of post-peak shear stress

Normal Stress(kPa)	PP Fiber (%)	Peak Shear stress (kPa)	Post peak Shear Stress (kPa) (at 6 mm)	% loss
50	0.0	28.16	25.69	8.77
	0.1	26.25	24.65	6.10
	0.25	35.00	33.32	4.80
	0.5	37.18	35.76	3.81
	1.0	41.50	40.28	2.94
150	0.0	47.27	45.13	4.53
	0.1	50.45	46.18	8.46
	0.25	56.33	54.17	3.84
	0.5	58.65	56.60	3.49
	1.0	63.30	62.15	1.82
250	0.0	69.73	56.59	18.84
	0.1	75.32	73.26	2.75
	0.25	74.59	72.57	2.70
	0.5	79.49	78.82	0.84
	1.0	89.72	89.58	0.16

OBSERVATION SET 2:-

TABLE5b:- Percentage loss of post-peak shear stress

Normal Stress(kPa)	PP Fiber (%)	Peak Shear stress (kPa)	Post peak Shear Stress (kPa) (at 6 mm)	% loss
50	0.0	24.78	15.97	35.6
	0.1	26.17	25	4.47
	0.25	33	31.94	3.21
	0.5	35.92	35.07	2.37
	1.0	39.16	38.89	0.69
150	0.0	40.30	33.68	16.43
	0.1	46	44.73	2.76
	0.25	48.25	46.18	4.29
	0.5	57.73	57.29	0.76
	1.0	62.88	62.50	0.60
250	0.0	61.21	58.33	4.71
	0.1	62.82	61.46	2.15
	0.25	64.74	64.58	0.25
	0.5	83.85	83.33	0.62
	1.0	92.10	92.02	0.09

As tabulated above percentage loss reduction is more for higher fiber contents. In both observation sets for unreinforced sand it ranges from 4.53% to 35.6%, however for 1% fiber content varies from 0.09% to 2.94%. It also can be seen that percentage loss reduction is more for higher normal loads with greater fiber content.

2. The fiber reinforcements can change the brittle behavior of sand to a somewhat more ductile one. In observation set-1 unreinforced sand failed at 2.50 mm and 2.75 mm horizontal displacement and 1.0% reinforced sand failed at 5.25 mm and 3.25 mm displacement for 150 kPa and 250 kPa normal load respectively and in observation set-2

unreinforced sand failed at 2.5 mm and 1.0% reinforced sand failed at 5.75 mm for these loads.

3. But It is seen that initial stiffness (i.e., initial slope of the shear stress-horizontal displacement curves) at the same normal stress for reinforced and unreinforced sand remains practically the same for all cases.

4. Both Peak shear strength and ductility of soil is increased due to high fiber content especially at higher normal loads. In Set-1 at 0.1% fiber content shear strength is 15.76 kPa which is 21.20 kPa for 1% fiber content at 50kPa on the other hand it increases more than 25 kPa at higher normal loads (250kPa). Likewise in Set-2 at 50 kPa with 0.1% fiber content shear strength is 13.43 kPa which is 20.96 kPa with 1% fiber content and it increases more than 35 kPa at 250 kPa.

5. Shear strength is also increased with aspect ratio but this effect also can be seen only on higher normal loads, at lower normal loads shear strength is nearly not affected with increase in the aspect ratio but on further increasing failure (peak) shear stress is decreased.

6. Ductility of sand is also increased with the aspect ratio increased but only at higher normal load (Fig 4.12)

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