EVALUATION OF INTERFACE FRICTION BETWEEN BACKFILL AND FIBRE REINFORCED POLYMER (FRP) INCLUSIONS

A PROJECT REPORT

submitted in partial fulfilment of the requirements for the award of the Degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

May-2019

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"EVALUATION OF INTERFACE FRICTION BETWEEN BACKFILL AND FIBRE REINFORCED POLYMER (FRP) INCLUSIONS"** submitted in partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Ankur Jaret (151627) & Aatish Rajta(151643)** under the supervision of **Dr. Saurabh Rawat Assistant Professor** Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

Date: ....

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Civil Engineering Department	Civil Engineering Department	
JUIT, Waknaghat	JUIT, Waknaghat	

STUDENTS' DECLARATION

We hereby declare that the work presented in the Project report entitled **"Evaluation of Interface Friction Between Backfill and Fiber Reinforced Polymer (FRP) Inclusions"** submitted in partial fulfilment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of our work carried out under the supervision of **Dr. Saurabh Rawat .**This work has not been submitted elsewhere for the reward of any other degree/diploma. We are fully responsible for the contents of this project.

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ABSTRACT

The main aim of this project is to study the behaviour of fibre reinforced polymer sheets with different grating patterns and compare the results with the steel reinforcements which are presently used for backfill reinforcements. The tests to be performed include Sieve Analysis , Direct Shear Tests on different types of interfaces which include different grating patterns on steel and fibre reinforced polymer sheets. In brief the objectives of this project are as follows:-

To determine the interface friction between backfill with crumbed rubber and Fibre reinforced polymer plate using small Direct Shear Test. To study the variation of interface friction of fibre reinforced polymer plate through different grating patterns.

Presently steel reinforcements are used in backfills. These prove to be expensive and suffer from a major problem which is corrosion. Apart from that steel is also uneconomical due to it’s high cost. Fibre reinforced polymer may prove to be a better alternative for steel as it is light weight , corrosion resistant and economical in comparison to steel.

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Φ	Angle of internal friction
α	Angle of ribs
^{o}	Degree
k	10^3
C	Cohesion

CHAPTER 1

INTRODUCTION

1.1 General

The introduction chapter is divided into four sections. The first section is about use of reinforcement in backfill, second section is about problem with traditional reinforcement materials, third section is about FRP, fourth section is about crumb rubber.

1.2 Use of reinforcement in backfills

"Mechanically Stabilized Earth" walls are the walls in which reinforcements are provided for the better stability. These walls have alternating layers of backfill and soil reinforcement and reinforcements are fixed to a wall facing. Backfill material used is generally a mixture of coarse sand and crumb rubber. Crumb rubber is recycled rubber produced from automotive and truck scrap tyres. It is a waste and using it in backfill is a best way to utilize it.

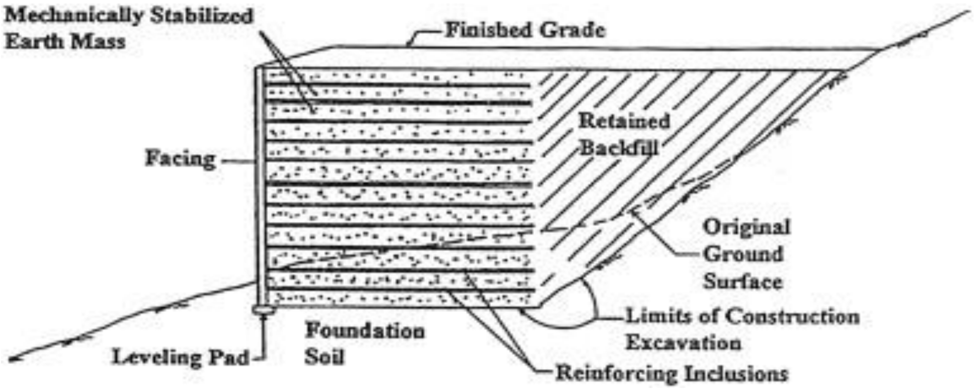

Figure 1.1 Mechanically Stabilized Earth Wall

1.3 Statement of the problem

For the reinforcement of backfill steel is used. Different soil reinforcement has unique properties for pullout and tensile capacity, corrosion and durability. Steel reinforcement has many drawbacks like it is expensive and is prone to corrosion when embedded in soil which reduces the life of the structure. Alternative for steel is Fibre Reinforced Polymer (FRP).

Figure 1.2 Corrosion in steel reinforcement

1.4 Fibre reinforced polymer

Fibre Reinforced Polymer (FRP) is a composite material which is made up of a polymer matrix reinforced with fibres. It is strong, corrosion resistant, durable, economical and light weight so it is easy to handle. Majority of the load in FRP is carried by the reinforcing phase which is usually of continuous fibre reinforcement and it also regulates its stiffness and strength and other phase is the matrix phase provides protection and support for sensitive fibres and also allows stress transfer from one fibre to another. Polyester, vinyl ester, epoxy, phenolic, thermoplastic etc are the different forms of matrix. Reinforcement fibres are made of carbon, glass and aramid etc. Glass Fibre reinforced polymer (GFRP), Carbon Fibre Reinforced Polymers (CFRP) etc are the different names of Fibre Reinforced Polymer (FRP). Factors such as type of fibre, resin matrix, fibre orientation and volume of fibres define the mechanical properties of FRP composites.

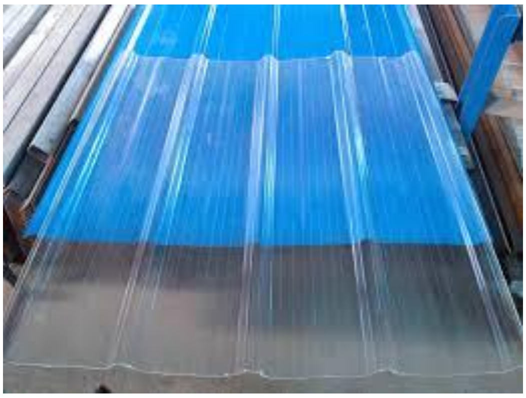

Figure 1.3 Fibre Reinforced Polymer (FRP)

Table 1.1 Comparison between FRP and steel

Property	**Advantage(Rating)**		**Rating Scale**
	FRP	**Steel**	**1. Very low**
Strength	**4-5**	**4**	**2. Low**
Weight	**5-6**	**2**	**3. Medium**
Durability	**4-5**	**3**	**4. High**
Ease of field construction	**5**	**3-4**	**5. Very high**
Fire	**3-5**	**4**	
Handling	**5**	**3**	
Toughness	**3-4**	**4-5**	
Acceptance	**2-3**	**5**	
Maintenance	**5**	**3**	

1.5 Crumb rubber

Crumb rubber is recycled rubber produced from automotive and truck scrap tyres. About 300 million tonnes of crumb rubber is produced every year and this number is growing every year. This waste is utilized by using it as backfill material. It is easily available in most part of the country and it is low in cost.

Figure 1.4 Scrap tyres and crumb rubber

1.6 Fibre Reinforced Polymer (FRP) in Civil engineering

Fibre Reinforced Polymer (FRP) is a composite material which is made up of a polymer matrix reinforced with fibres. It is strong, corrosion resistant, durable, economical and light weight so it is easy to handle.

FRP composites are very much different from traditional construction materials like aluminium and steel whereas steel and aluminium are isotropic and FRP composites are anisotropic. Due to anisotropic nature of FRP composites their properties are directional that means that the best mechanical properties are in the direction of the fibre placement.

For the construction of underwater pipes for greater depth fibre reinforced polymers are used because it provides significantly increased buoyancy due to its low density as compared to steel and one more advantage is it is corrosion resistant.

For strengthening of various structures constructed from concrete, masonry, timber, and even steel FRP bars, strips and sheets can be used and also used as internal reinforcement for concrete structure.

Figure 1.5 FRP pipes

Fibre Reinforced Polymer (FRP) is also used for construction of small bridges for pedestrian movements and also used in the maintenance of old bridges.

Figure 1.6 Bridges made of FRP

1.7 Mechanism of Direct Shear Test

Direct shear test is performed on three or four samples of a soil . Sample is placed in the shear box of the apparatus which consists of two square ring stacks; the contact between these two square rings is at approximately the mid-height of the specimen sample. A normal load or stress is applied normal to the sample, and on the lower portion of the box a shear load is applied laterally until the specimen fails. The load applied is recorded at frequent intervals to determine a stress strain curves for each normal stress. Several samples are tested at different values of normal stresses to determine the shear strength parameters, the soil cohesion and the angle of internal friction. The results of the tests on each sample are plotted on a graph with the peak stress on the vertical axis and the normal stress on the horizontal axis. The vertical intercept of the best fitting curve is the cohesion, and the slope of the line or curve is the friction angle.

1.8 Organization of report

Chapter 2 consists of literature review.

Chapter 3 consists of methodology adopted.

Chapter 4 consists of the results and discussion.

Chapter 5 consists of the conclusions.

Chapter 2

Literature Review

2.1 General

Reinforcement is needed to stabilize backfill in retaining walls. It is a composite structure consisting of alternating layer of backfill and soil reinforcement, fixed to a wall facing. Generally mixture of coarse sand and crumb rubber is used as a backfill material. Crumb rubber is recycled rubber produced from automotive and truck scrap tyres.

2.2 Literature review

1. Donald H. Gray, A. M. ASCE and Harukazu Ohashi(1983)

Direct shear test was performed to analyse the effect of natural and synthetic fibres on a dry sand. Small scale direct shear test was performed to calculate the effect of different types of fibres on dry sand.

After results it was concluded that by adding fibre in dry soil peak shear strength was increased. Test results showed that shear strength of the dry sand can be increased by adding different types of fibre as reinforcement.

Shear strength of the soil was directly influenced by the normal stress, with increase in normal stress shear strength of the sample increased.

Shear strength of the soil was increased by increasing the length of the reinforcement fibre but up to certain limit.

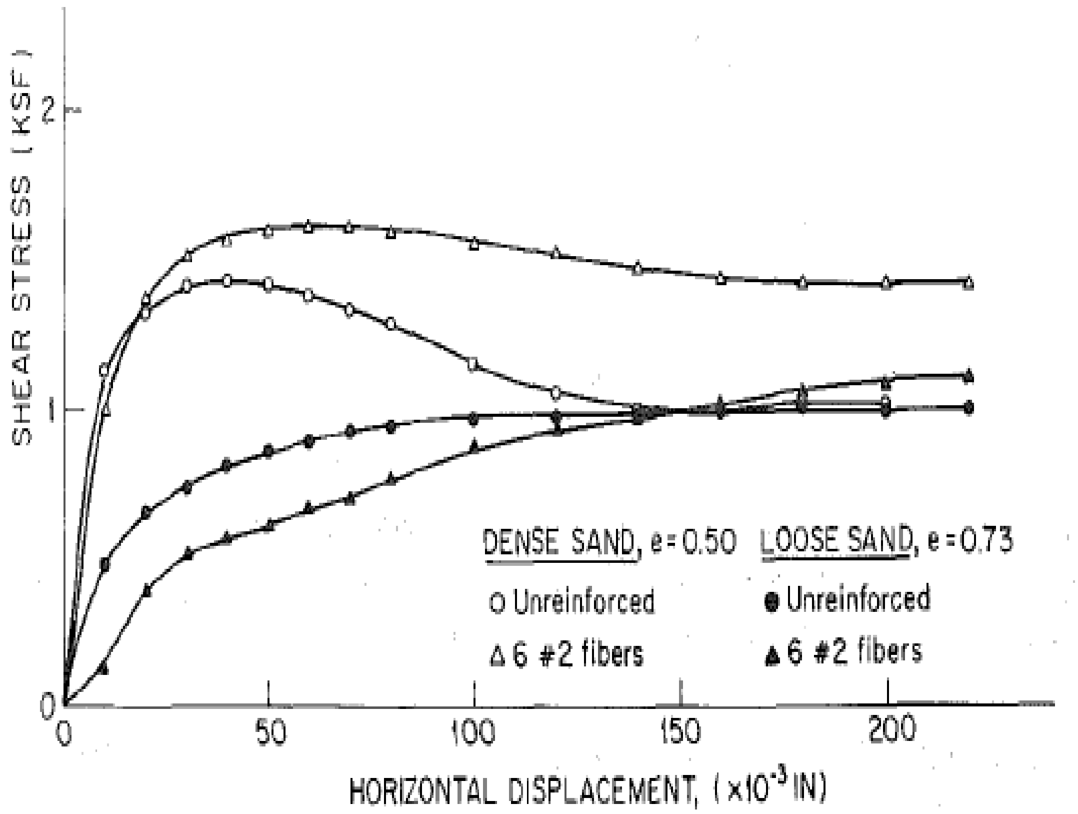

FIGURE 2.1 Graph between shear stress and horizontal displacement

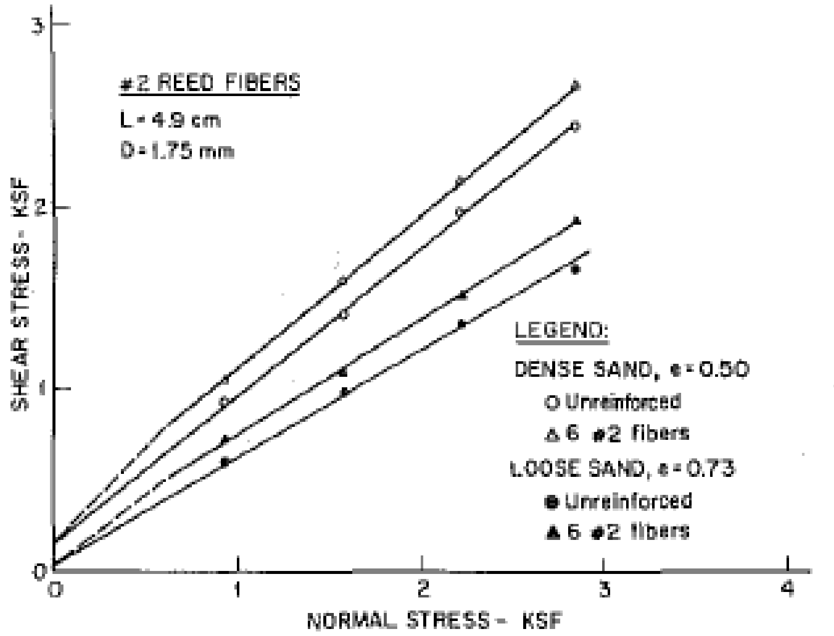

Figure 2.2 Graph between shear stress and normal stress

2. Mizyal Izgin, Yildiz Wasti Journal of Geotextiles and Geomembrane (1998)

Shear box test was performed to calculate geomembrane sand interface friction. Inclined board and standard size shear box test were used to calculate the shear strength. Angle of internal friction varied from 23 degree to 31 degree corresponding normal atress was varied from 14 kPa to 200 kPa.

With increase in normal stress shear strength of the sample increased. Test was carried out in standard direct shear apparatus of dimension 60mmx60mm based on the results of the inclined board tests and the normal load was varied from 14kPa to 200kPa. Straight line relationship through the origin was used to represent the relationship between shear strength and normal stress.

The direct shear box tests, on the other hand, produce envelopes with adhesion intercept, as well as higher interface friction angles. Mechanism of sliding in the inclined board test was more elastic than direct shear box test, direct shear box tests gave unconservative assessment of interface shear strength parameter.Degree of roughness of geomembrane was more sensitive with the rounded particles. With increase in normal stress value of internal angle of friction increased.

3. J. D. Frost1 and J. Han,2 Members, ASCE Journal (1999)

In this paper they studied the behaviour of interfaces between fibre reinforced polymers and sand. Different shear strength parameter was obtained for sub-rounded to rounded materials and sub-angular material sliding on Fibre Reinforced Polymer and steel sheet. There was very little influence of thickness of the soil specimen on the shear strength.

With the relative roughness interface friction coefficient increased linearly. Experimental data have shown that different shear stress horizontal displacement behaviour was observed for sub-rounded to rounded materials and sub-angular materials sliding on FRP or steel.

 Rounded materials yield more ‘‘brittle’’ interface behaviour than do angular materials. Strain softening is more evident in the characteristic shear stress–horizontal displacement behaviour for interfaces between rounded particles and relatively rough surfaces.

 On angularity of particles and the surface roughness of the FRP or steel both constant C and the power index m depended. With increase in relative roughness the interface friction coefficient increased linearly. Value of interface friction coefficient was slightly influenced by the initial density of the soil specimen.

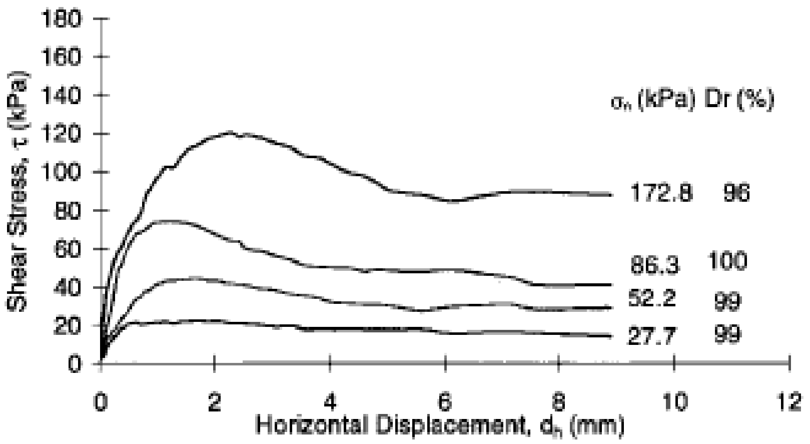

Figure 2.3 Graph between shear stress and horizontal displacement

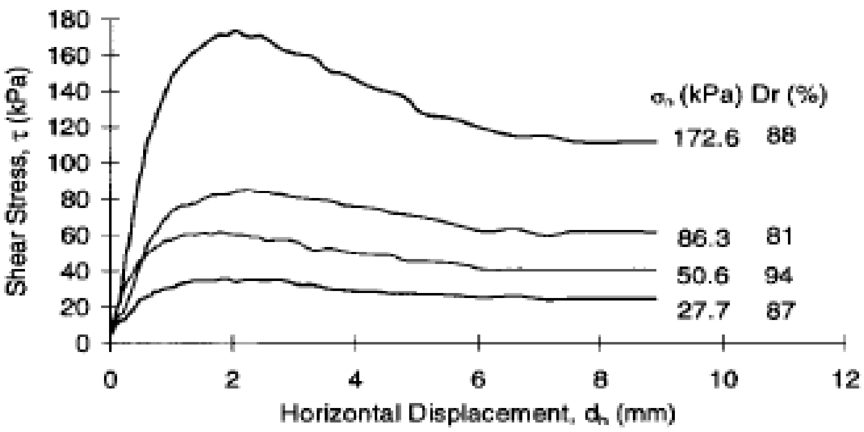

Figure 2.4 Graph between shear stress and horizontal displacement

Specimen preparation method, the thickness of the soil specimen and the rate of shearing had little influence on the interface behaviour as shown by the tests. Similar relationship was obtained between the peak interface friction coefficient and the relative roughness for both FRP and steel for the given material. If appropriate tests are performed to determine the interface properties then FRP material can be used in foundation application.

4.Temel Yetimoglu, Omer Salbas(2002)

In this paper they studied about the shear strength of the soil reinforced with discrete fibre randomly distributed. Effect of fibre content on the shear strength of the soil was observed.

Direct shear test was performed to study the effect of fibre content on the shear strength of the soil. Results showed that the mohr-coulomb shear envelop for unreinforced sand was same for sand reinforced with the fibre. Cohesion was found to be zero for both reinforced and unreinforced sand.

Amount of fibre in the sand directly affect the peak shear stresses, so for reinforced and unreinforced sand peak shear strength angle was considered identical. There was no effect on the initial stiffness of the sand due to fibre reinforcements.

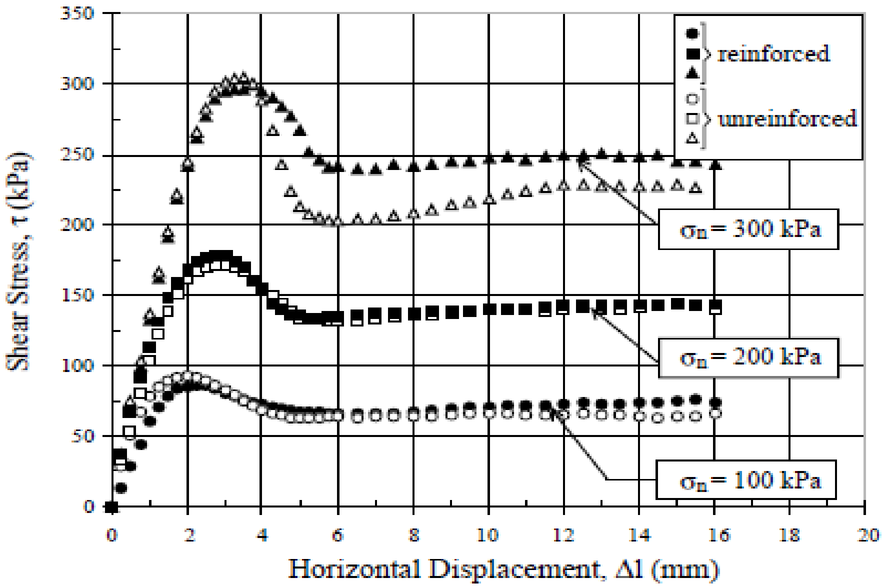

Figure 2.5 Graph of shear stress and horizontal displacement for unreinforced sand and reinforcedsand with fibre content of .1%

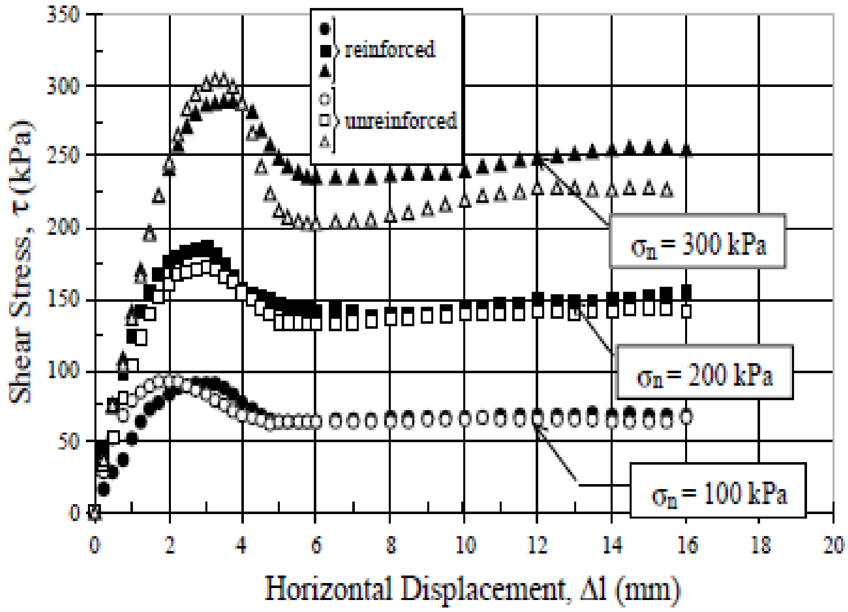

Figure 2.6 Graph of shear stress and horizontal displacement for unreinforced sand and reinforcedsand with fibre content of .25%

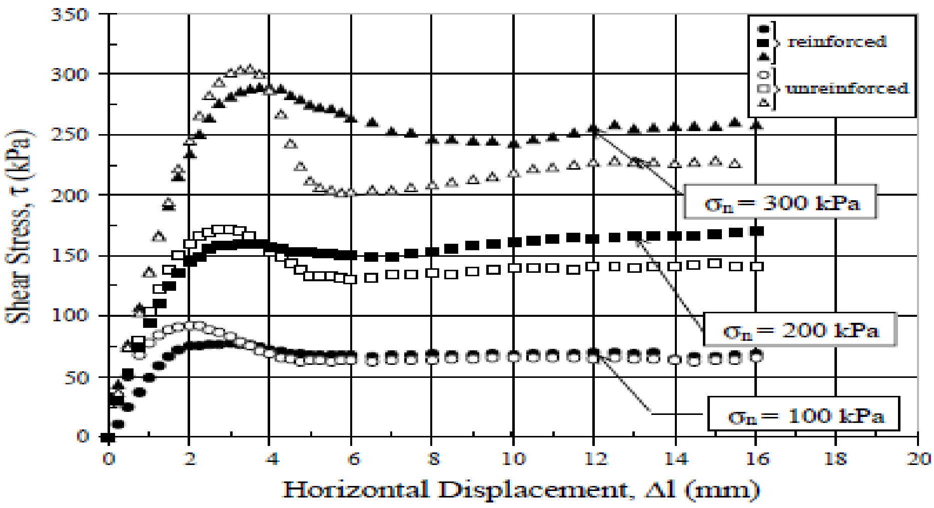

Figure 2.7 Graph of shear stress and horizontal displacement for unreinforced sand and reinforcedsand with fibre content of 1 %

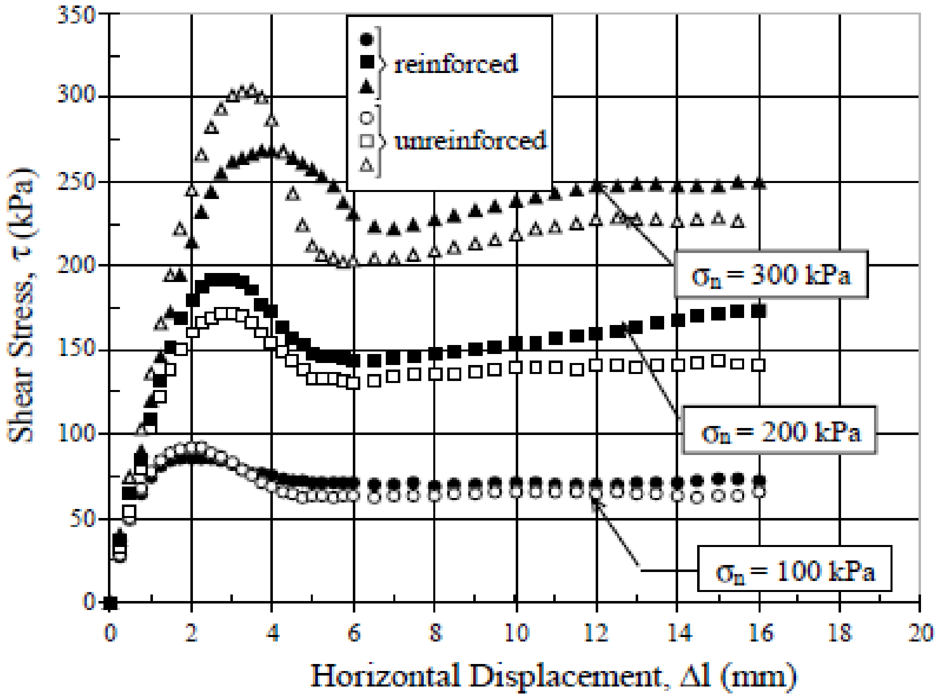

Figure 2.8 Graph of shear stress and horizontal displacement for unreinforced sand and reinforcedsand with fibre content of .5%

For reinforced and unreinforced sand horizontal displacement at failure was comparable under the same normal stress. Due to the mixing of fibre reinforcement in the sand its behaviour changed from brittle to a ductile and there was loss of peak strength in case of reinforced sand.

5. T. Tanchaisawat, D.T. Bergado , P. Voottipruex, K. (2004)

In this paper they studied about the interaction between two different types of geogrid reinforcements (geogrid A and geogrid B) and and mixture of crumb rubber and sand with different ratios. Sand and crumb rubber ratios used were 0:100, 30:70, 40:60 and 50:50 by weight.

Direct shear test was conducted to calculate the interaction between geogrid reinforcement and mixture of sand and crumb rubber.

The index and compaction tests of the tire chip–sand mixtures were also conducted. Crumb rubber and sand mixture had direct influence on the pullout resistant of the geogrig reinforcement. With the increasing normal stresses pullout resistant was affected.

At the normal stresses of 30 and 60 kPa failure due to slippage occurred in geogrid reinforcement. Tensile failure occurred at the high normal stresses of 90 and 120 kPa.

Crumb rubber and sand mixture directly affected the direct shear resistance with and without geogrid reinforcement which increased with the increasing sand content.

Direct shear resistance increased with increase in normal stress so applied normal stresses were significant factors for direct shear resistance.

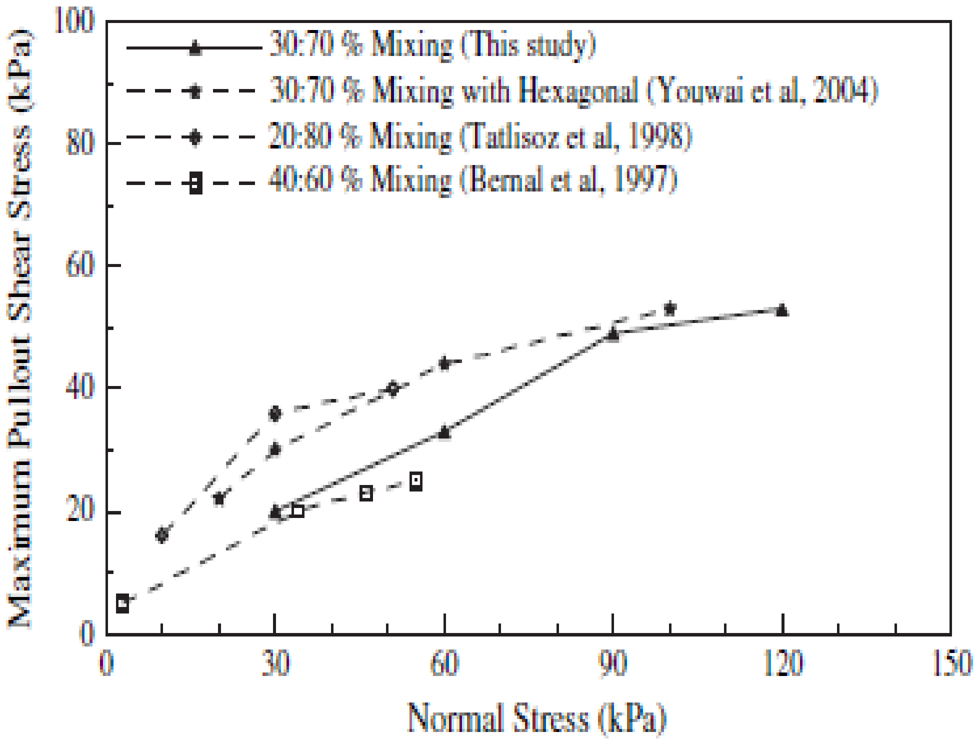

Figure 2.9 Graph between maximum pullout shear stress and normal stress

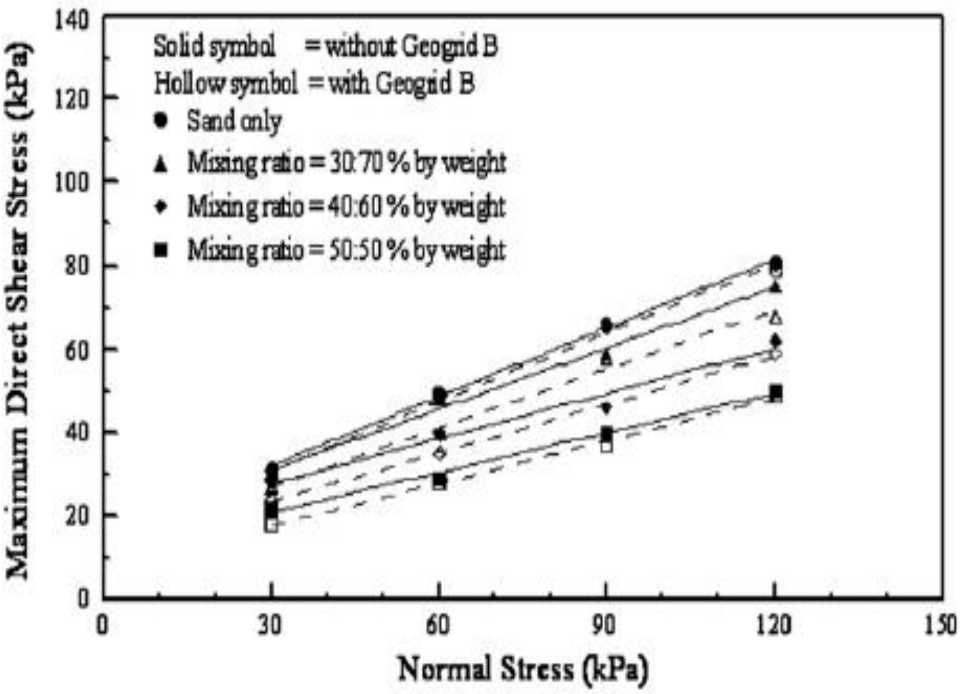

Figure 2.10 Graph between shear stress and normal stress

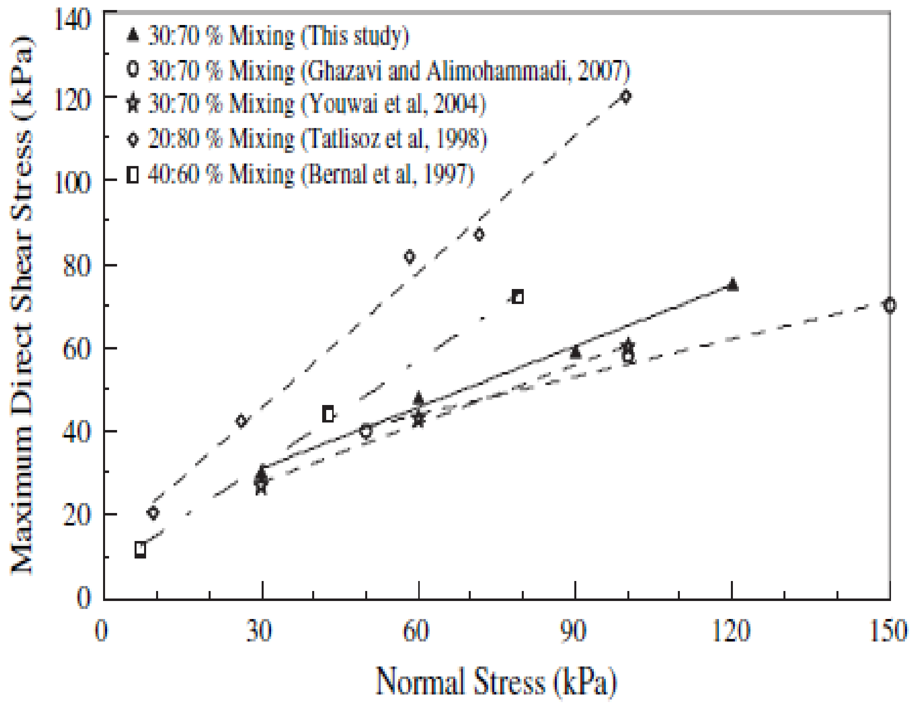

Figure 2.11 Graph between shear stress and normal stress

Crumb rubber and sand mixtures of 30:70 by weight yielded the highest direct shear and pullout resistance with both type of geogrids. Interaction coefficient for pullout mode was .87 and for direct shear mode was .89. for geogrid A and for geogrid B the interaction coefficient is 0.74 in pullout mode and 0.93 in direct shear mode. Geogrid B with bigger aperture size exhibited higher direct shear interaction coefficient than geogrid A. Geogrid Due to uniaxial reinforcement properties and its sufficient interaction characteristic with crumb rubber and sand mixture geogrid B was selected.

6. Martin Christ , Jun-Boum Park (2009)

In this paper the conducted tests to determine the strength properties of frozen rubber and sand mixtures. Mixture of rubber and sand mixture influenced the shear strength. With increase in tyre chip content in the specimen shear strength decreases. Test is performed for 5%, 10%, 15%, 20%, and 25% and shear strength decreased with increase in crumb rubber content.

Optimum content of tyre chips to be added is 15% by weight. Compressive strength decreased with increase in rubber and sand mixture ratio. Compressive strength of frozen silty-sand was greater than the compressive strength of the crumb rubber and sand mixtures at the same temperatures.

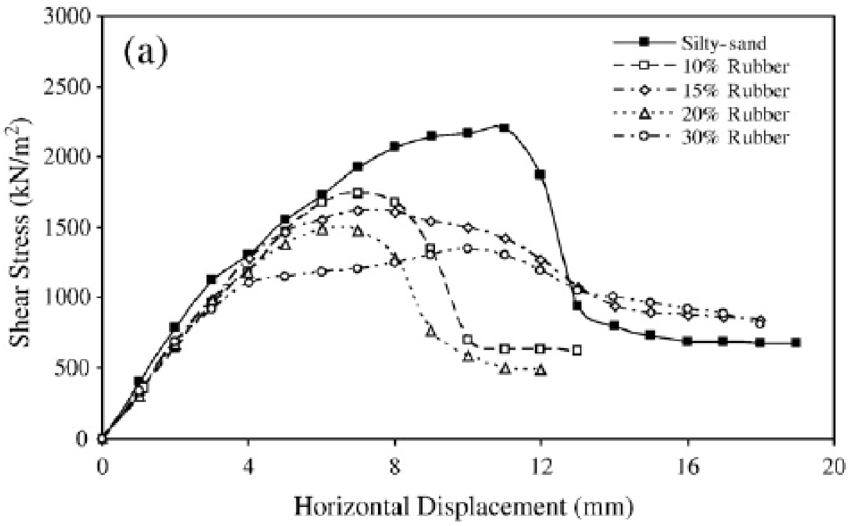

Figure 2.12 Graph between shear stress and horizontal displacement at 31.8Kn/m^2

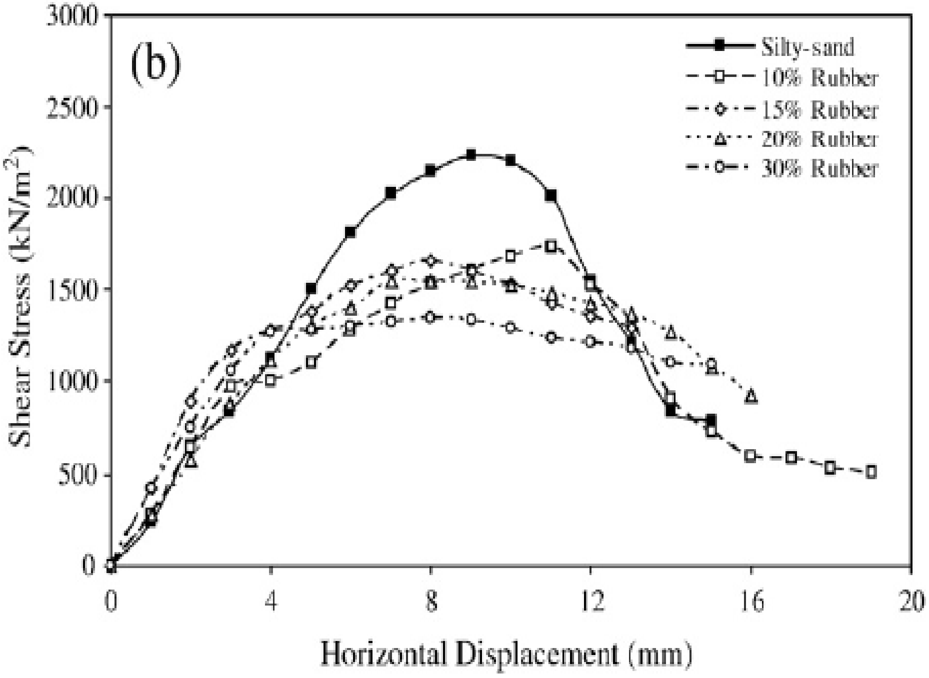

Figure 2.13 Graph between shear stress and horizontal displacement at 63.7Kn/m^2

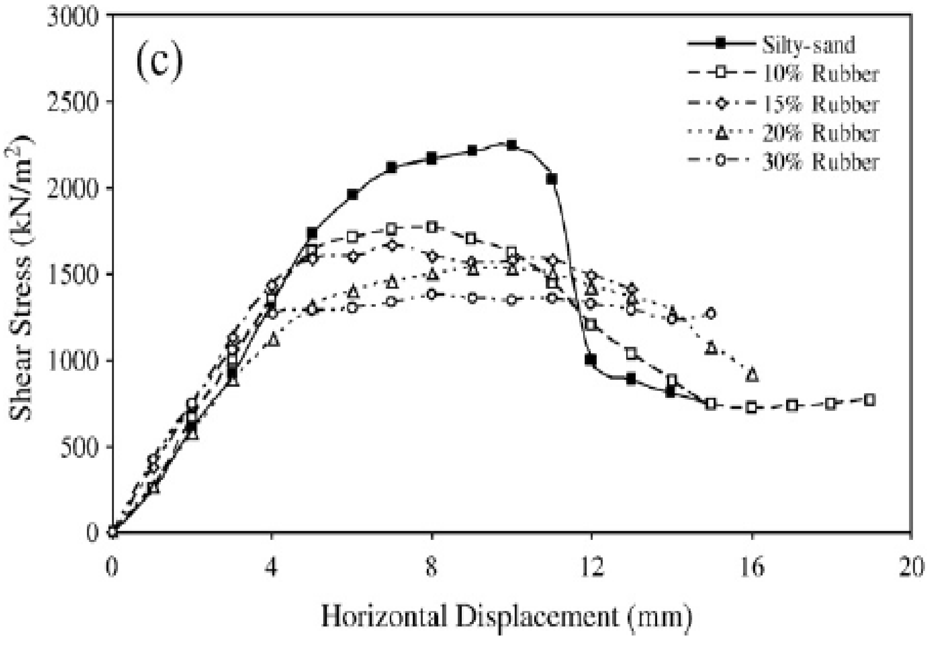

Figure 2.14 Graph between shear stress and horizontal displacement at 127.3Kn/m^2

Peak compressive strength of rubber and sand mixture increased linearly with decreasing temperature and with increase in the rubber mixing ratio peak compressive strength decreased. With decrease in temperature deformation modulus increased which indicated increase in stiffness. At the same temperature deformation modulus for silty sand was greater than the deformation modulus of sand and crumb rubber mixture.

7.Vahab Toufigh, Chandrakant S. Desai, Dist.M.ASCE, Hamid Saadatmanesh, M.ASCE, Vahid Toufigh, Saeed Ahmari and Ehsan Kabiri (2009)

This paper was about the constitutive modeling and testing of interface friction between backfill soil and Fiber-Reinforced Polymer with the help of small scale direct shear test. With increase in the normal load shear strength increased of the specimen.

Higher value of friction angle and higher tensile strength was obtained with the use of Fibre-Reinforced Polymer (FRP). %. With increase in normal load shear strength of the sample increased. Normal load was varied from 50kPa to 100kPa.

8. Seyed Mahmoud Anvari, Issa Shooshpasha, Saman Soleimani Kutanaei (2016)

Different rubber content is mixed with the sand and tested for shear strength by using direct shear test. Shear strength of specimen decreased with increase in rubber content in sand rubber mixture.

Optimum percentage of granulated rubber was 5% by weight. The maximum and minimum unit weight values were decreased with increase in the ratio of crumb rubber and sand mixture. For geotechnical applications like retaining wall backfill, foundation and embankments mixture of crumb rubber and granular sand works effectively as a lightweight material. Shear strength of the sample depended upon several factors like normal load, density and rubber content in the sample.

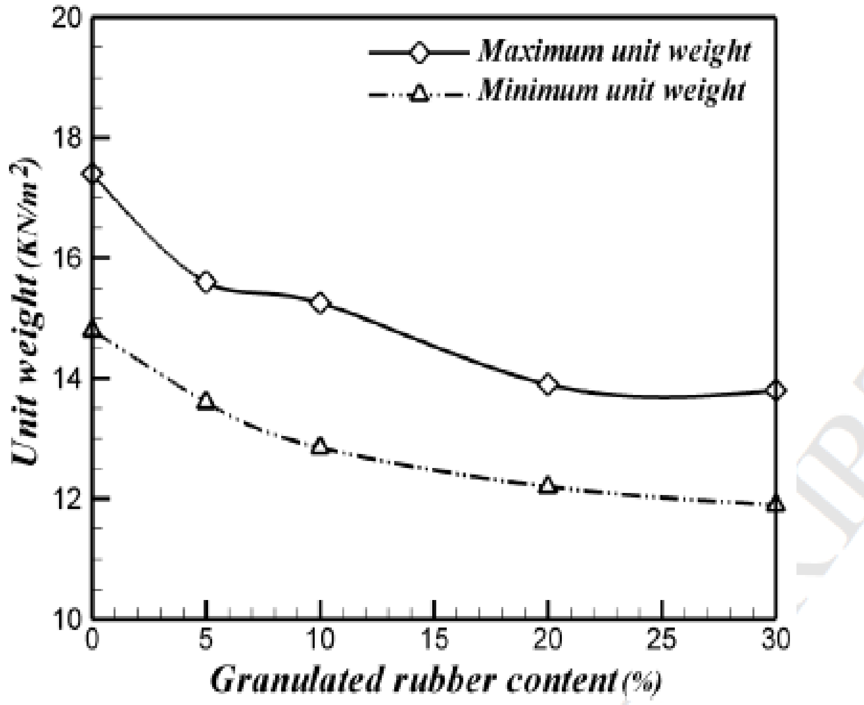

Figure 2.15 Variation of maximum and minimum unit weight of mixtures versus granulate rubber content

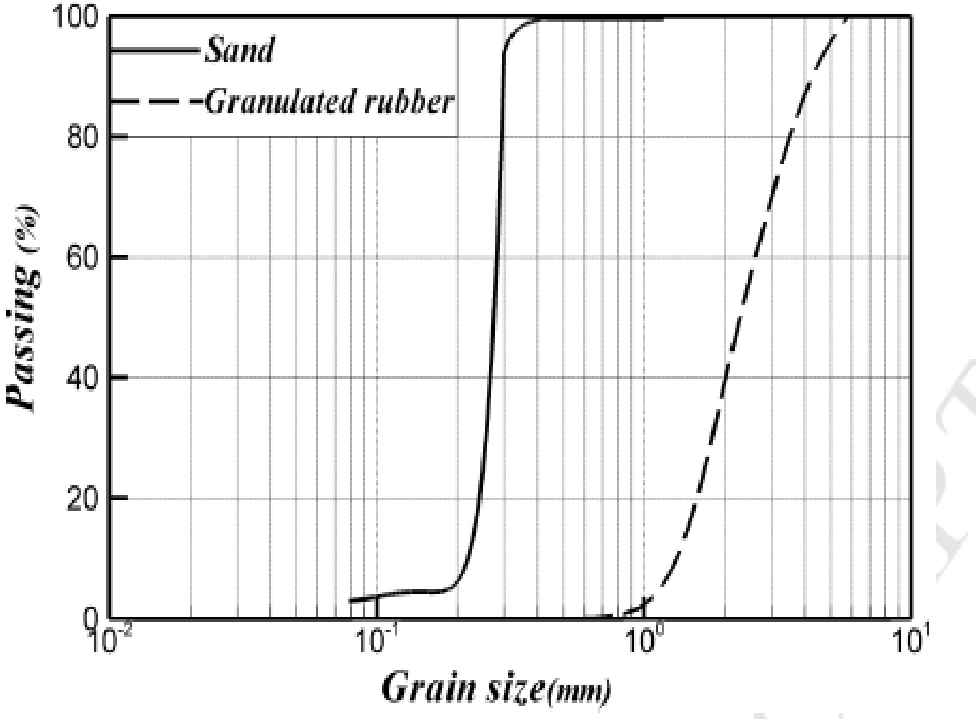

Figure 2.16 Grain size distribution curve for sand and granulate rubber

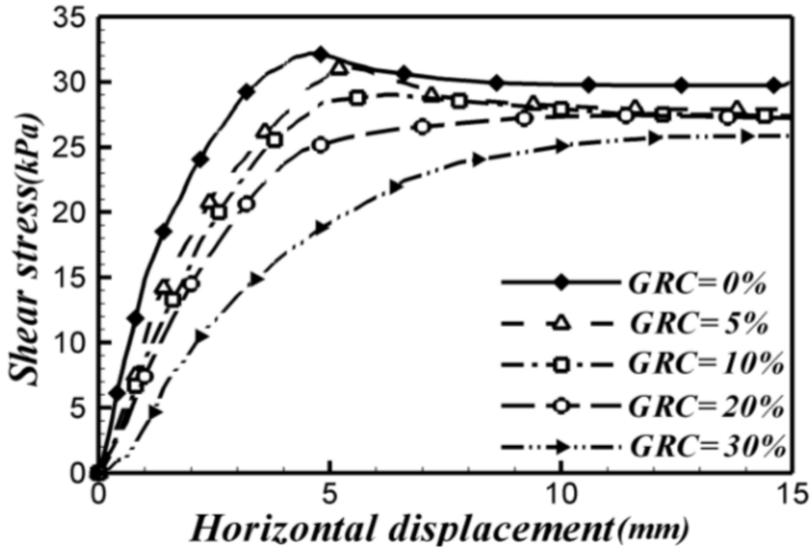

Figure 2.17 Graph between shear stress and horizontal displacement

Behaviour of dense sand and rubber mixture was same as that of loose sand. The results show that at normal stress, with an increase in granulated rubber content, shear modulus decreases. Adding granulated rubber leads sand to have more capacity in yielding strain.

With the use of rubber in the sand it became more ductile. Internal friction angle of sand increased up to an optimum rubber and sand ratio. As per tests results optimum percentage of crumb rubber was 5% which increased angle of internal friction from 35.1° to 39.2°.

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9. Mohsen Abbaspur, Esmail Aflaki Mohsen Abbaspur, Esmail Aflaki (2017)

This paper was about the reuse of the tire chips as soil reinforcement. Value of shear strength decreased after certain value of tire chip content in the mixture of sand and tire chip. Small scale direct shear test was performed to calculate the shear strength parameter.

Graph between shear strength and normal stress was plotted to measure the shear strength parameters. Maximum percentage of rubber fibres to be added was 5%. With increase in normal load shear strength of the sample increased. Normal load was varied from 20kPa to 100kPa.

10. J.S. Yadav, S.K. Tiwari (2017)

Soil cement optimization using crumbled rubber. With increase in rubber content shear strength of the soil decreased. At different crumb rubber percentage by weight samples were tested.

Maximum percentage of rubber to be added was determined 7.5% by weight.

CHAPTER 3

METHODOLOGY

3.1 General

First section of this chapter gives information about type and properties of material used. Second section of this chapter gives the description about the test to be performed under this project.

3.2 Material

3.2.1 Soil used

Sand is generally used as a backfill material. Backfill materials must have good drainage property so that water coming from the soil behind the wall can easily drain out without causing damage to the structure. Sand is very easily available and is lower in cost as compared to other materials and it has good drainage properties and does not hold water for a long time. Sand used in this project has been acquired from Solan.

Figure 3.1 Soil used

3.2.2 Crumb rubber

Crumb rubber is recycled rubber produced from automotive and truck scrap tyres. About 300 million of crumb rubber is produced every year and this number is growing every year. This waste is utilized by using it as backfill material. It is easily available in most part of the country and it is low in cost. Crumb rubber used in this project is acquired from Ghaziabad (Uttar Pradesh).

Crumb rubber content used in the tests is taken from the average %age recommended as per the research papers published on sand and tyre chip optimum content. Average tyre chip content is 12.5% by weight and the same has been used the same in the tests.

Figure 3.2 Crumb rubber

Table3.1 Recommended %age of crumb rubber

S. No.	Authors and year of publication	Journal Name	Recommended %age of crumb rubber
1.	Martin Christ et al. (2009)	Cold Regions Science and Technology	15
2.	T. Tanchaisawat et al.(2008)	Geotextiles and Geomembranes	30
3.	Seyed Mahmoud Anvari et al.(2016)	Rock Mechanics and Geotechnical Engineering	5
4.	Mohsen Abbaspur et al.(2017)	Cleaner Production	5
5.	J.S. Yadav et al.(2017)	Applies clay science	7.5

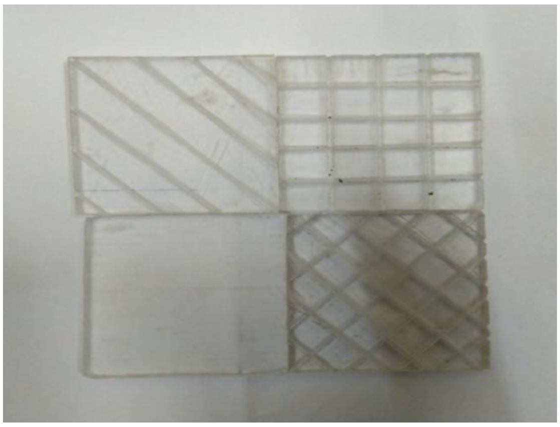
Average %age of crumb rubber = 12.5%

3.2.3 Fibre Reinforced Polymer (FRP)

Fibre Reinforced Polymer (FRP) is a composite material which is made up of a polymer matrix reinforced with fibres. It is corrosion resistant, strong and durable, economical, light weight so easy to handle. It is very strong and used for various constructions. It is low in cost as compared to steel sheets and it is easily available in every market. Fibre Reinforced Polymer used in the project has been acquired from Solan , Himachal Pradesh.

3.2.4 Grating pattern in FRP sheets

Calculations for spacing used in perpendicular, parallel and square gratings are done by using the length of ribs in standard anchor bar of 20mm diameter. Calculations for the length of grating line are following:



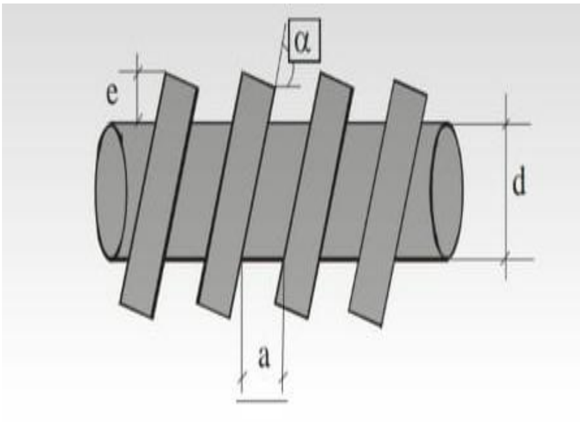


Figure 3.3 Fibre Reinforced Polymer **Figure 3.4** Geometric characters of bar

Table 3.2 Geometric and mechanical properties of steel bars

S. No.	Φ(mm)	α(°)	Rib height(cm)	a(cm)
1.	16	46	0.16	0.92
2.	20	45	0.18	1.17
3.	25	50	0.25	1.57

For 20 mm diameter bars

Number of ribs per 15 cm length = 11

Length of one rib = 8.886 cm

Total length of ribs in 15 cm length = (11×8.886) cm

$$=97.746 \text{ cm} \qquad (1)$$

Number of ribs per unit area = $\frac{97.746 \text{ cm}}{(2\times\pi\times1\times15)\text{cm}\hat{}2}$

$$=1.037 \text{ cm}^{-1} \qquad (2)$$

L)ength of ribs for (6×6) cm^2 =1.037 cm^{-1} × 36 cm^2

$$= 37.34 \text{ cm} \qquad (3)$$

Number of lines = $\frac{37.34 \text{ cm}}{6 \text{ cm}}$

$$= 7 \text{ lines} \qquad (4)$$

Spacing = $\frac{6 \text{ cm}}{(\text{number of lines} +1)}$`

$= \frac{6}{8}$

= 0.75 cm (5)

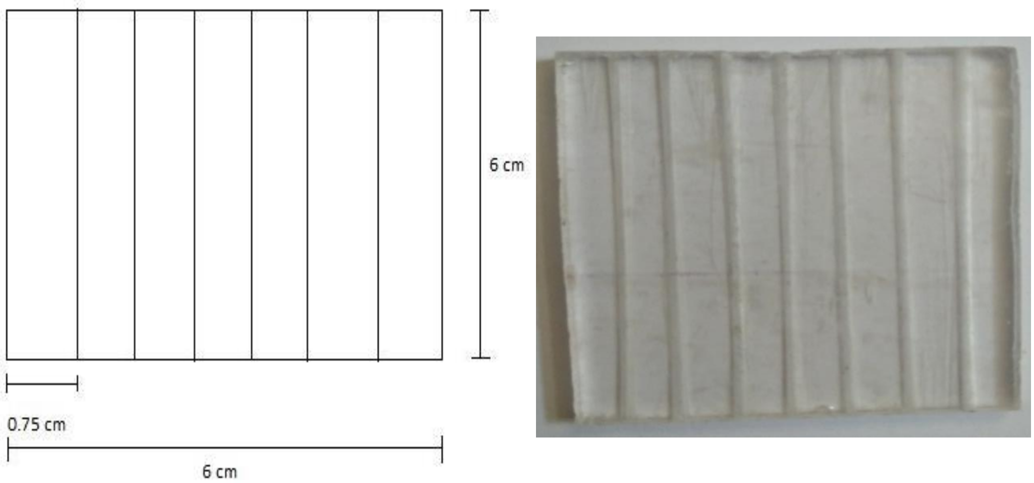


Figure 3.5 Perpendicular and parallel grating pattern

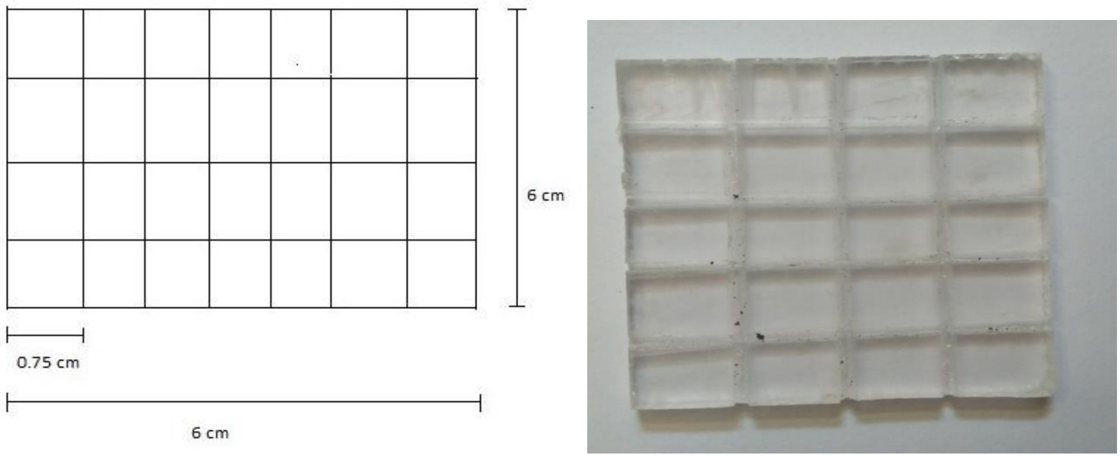


Figure 3.6 Square grating pattern

Angle of inclination and spacing used in angled grating pattern are same as used in the anchor bar of 20mm diameter. Angle of 45 degrees with horizontal and centre to centre spacing of 1.17cm has been used.

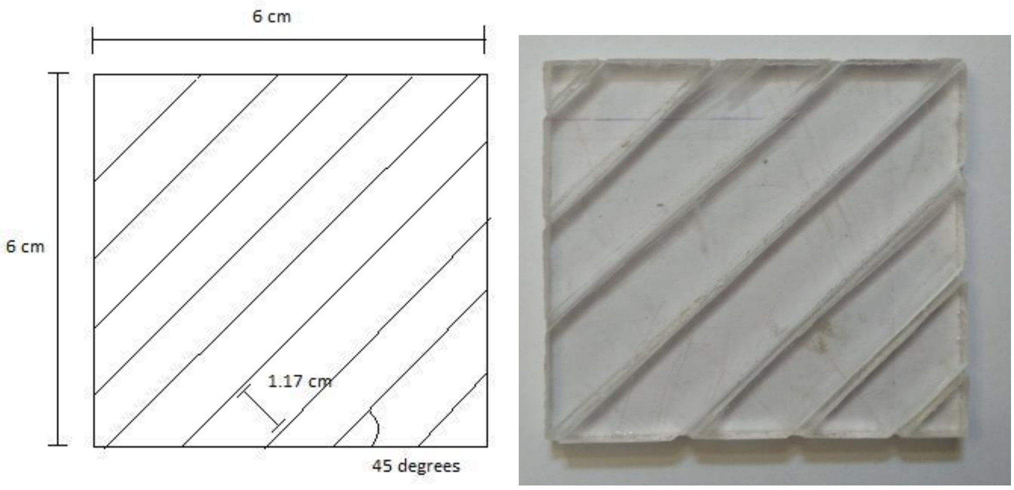


Figure 3.7 Angled grating pattern

3.2.4 Steel sheet

Steel is generally used as reinforcement in backfill. Different soil reinforcement has unique properties for pullout and tensile capacity, corrosion and durability. Steel reinforcement has many drawbacks like it is expensive and is prone to corrosion when embedded in soil which reduces the life of the structure. Steel sheet used in this project has been acquired from Solan, Himachal Pradesh.

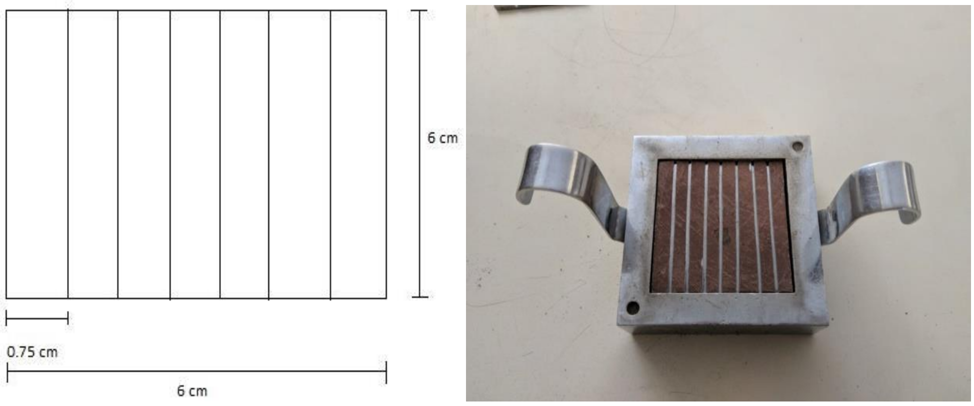


Figure 3.8 Perpendicular and parallel grating pattern

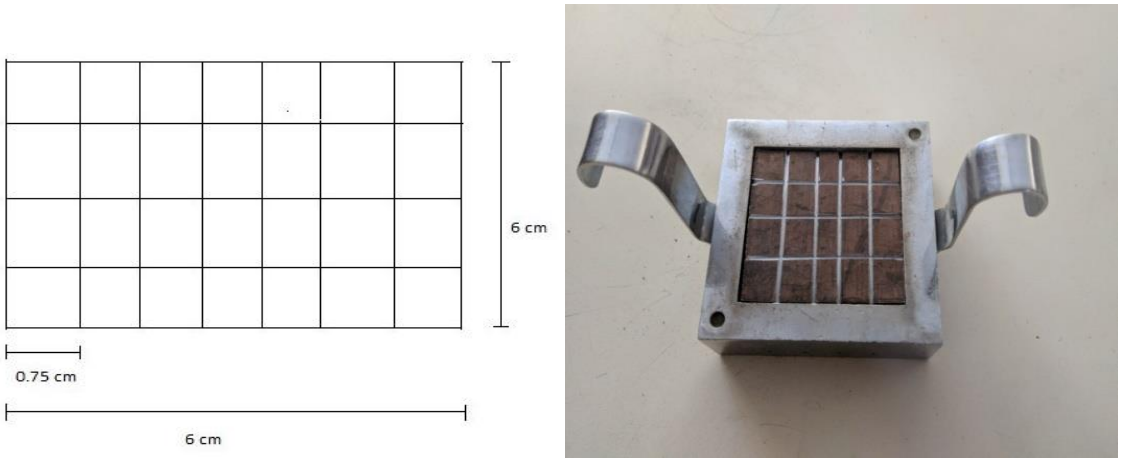


Figure 3.9 Square grating pattern

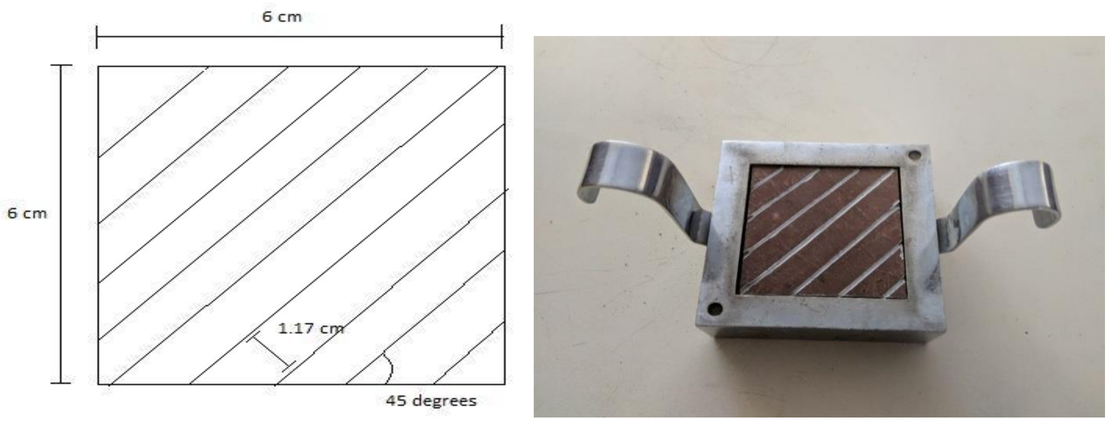


Figure 3.10 Angled grating pattern

3.3 Methodology of tests performed

3.3.1 Particle size distribution

Sieve analysis was carried out to determine the particle size distribution of the soil used in the tests. Oven dried sand was passed through the IS sieves and the weight of the soil retained on each soil was noted. Graphs were plotted between the sieve sizes and the percentage finer of the sample.

3.3.2 Direct Shear Tests for sand

Small scale direct shear test have been used (6cm×6cm) for all the tests. Sand oven dried for 24 hours and passing from 1.6 mm sieve was used for the test. Shearing rate of 1.25 mm/minute was applied. Normal load of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2 were used. Graph between shear stress and normal load was plotted to calculate the shear strength parameters.

Figure 3.11 Direct shear test apparatus

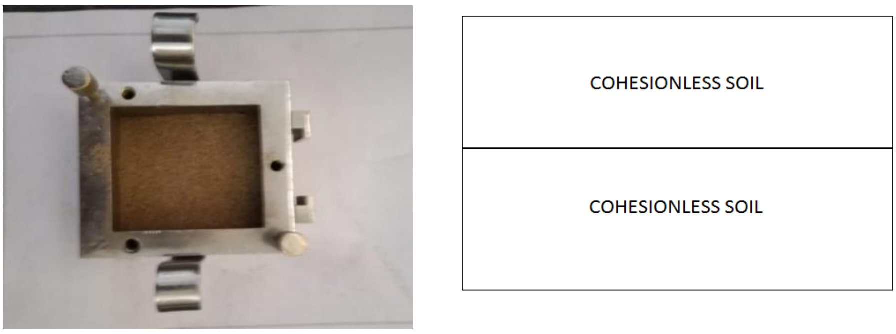


Figure 3.12 Shear box for sand to sand DST

3.3.3 Direct shear test for sand and crumb mixture

Crumb rubber 12.5% by weight was used in the mixture. Shearing rate of 1.25 mm/minute was applied. Normal load of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2 were used. Graph between shear stress and normal load was plotted to calculate the shear strength parameters.

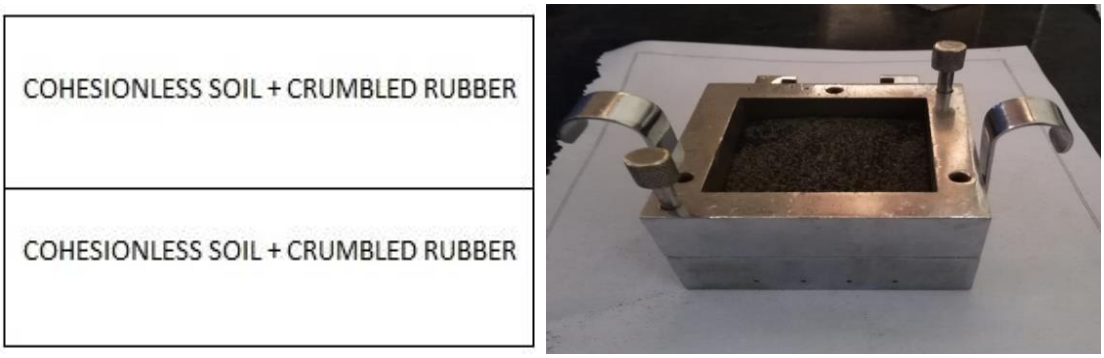


Figure 3.13 Shear box for sand-rubber mixture DST

3.3.4 Direct shear test for sand crumb rubber and FRP sheets

Crumb rubber 12.5% by weight was used in the mixture. Shearing rate of 1.25 mm/minute was applied. Normal load of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2 were used. Graph between shear stress and normal load was plotted to calculate the shear strength parameters. FRP sheet was placed between sand and crumb rubber mixture in the shear box as shown in the figure 3.11

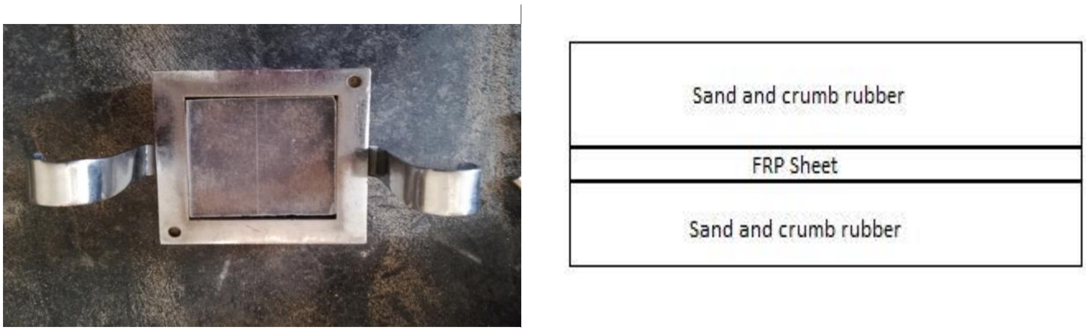


Figure 3.14 Shear box for sand rubber mixture and FRP sheet

3.3.4 Direct shear test for sand crumb rubber and steel sheets

Crumb rubber 12.5% by weight was used in the mixture. Shearing rate of 1.25 mm/minute was applied. Normal load of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2 were used. Graph between shear stress and normal load was plotted to calculate the shear strength parameters. FRP sheet was placed between sand and crumb rubber mixture in the shear box as shown in the figure 3.12

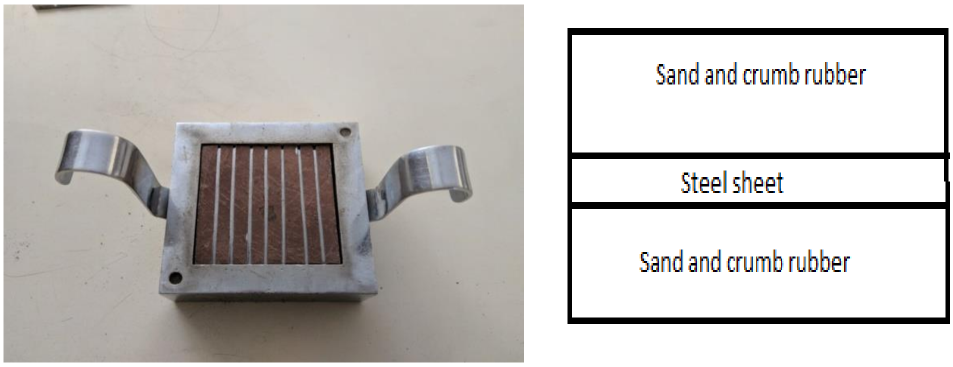


Figure 3.15 Shear box for sand rubber mixture and steel sheet

3.3.5 Area correction in Direct Shear Test

In direct shear test procedure sample undergoes constant horizontal displacement due to which shearing area keeps on changing. To counter this problem IS : 2720 (Part) has recommended an area correction factor $A = A^\circ(1 - \frac{\delta}{3})$.

Here A° = Initial area of specimen in cm^2, and

δ = displacement in cm.

During the experimental testing of samples this area correction factor was applied.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

This chapter gives an overview about the results of the practical testing which has been done so far. Tests were conducted on soil and FRP sheets with different grating patterns such as parallel to shear plane, parallel to shear plane**,** square grating. The spacing and depth the grating pattern were decided with reference to 20mm circular steel reinforcement bars which are normally used for backfill reinforcement in retaining walls.

Spacing between the grooves was 0.75 cm and the depth of the grooves was 2 mm and angle in case of crisscross grating was 45°. Stress versus horizontal displacement curves and failure stress versus normal stress curves were plotted.

4.2 Particle size distribution of sand and crumb rubber mixture (12.5% by weight)

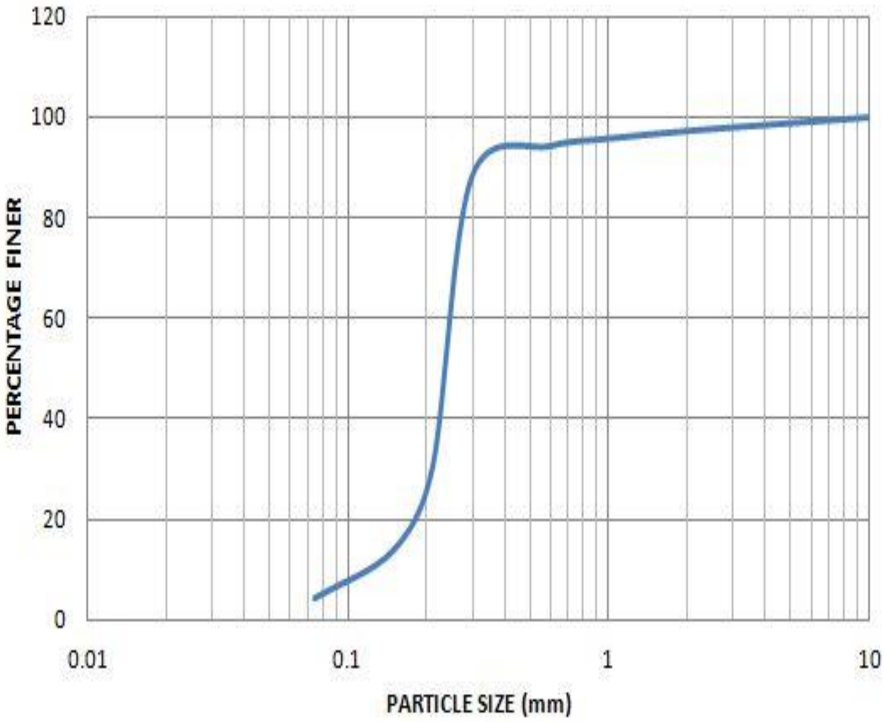
Coefficient of uniformity =**1.024**

Coefficient of curvature = **22.12**

Mixture of sand and crumb rubber passing from 4.75 mm sieve is 98.59% which is greater than 50% and weight passing from 0.075 mm sieve is 4.41% which is less than 50%, hence it can be concluded that soil is sand. Coefficient of uniformity and curvature do not satisfy the conditions of well graded soil, hence it can be concluded that soil used in the tests is poorly graded sand mixture of sand and crumb rubber.

Table 4.1 Calculation for %finer grain size

Sieve size(mm)	Weight retained(g)	%Retained	%cumulative retained	%Finer
4.75	14.2	1.2	1.411	98.59
0.075	112.4	9.5	95.59	4.41



Clay	Sand	Gravel

Figure 4.1 Particle size distribution curve

4.3 Sand to sand direct shear test

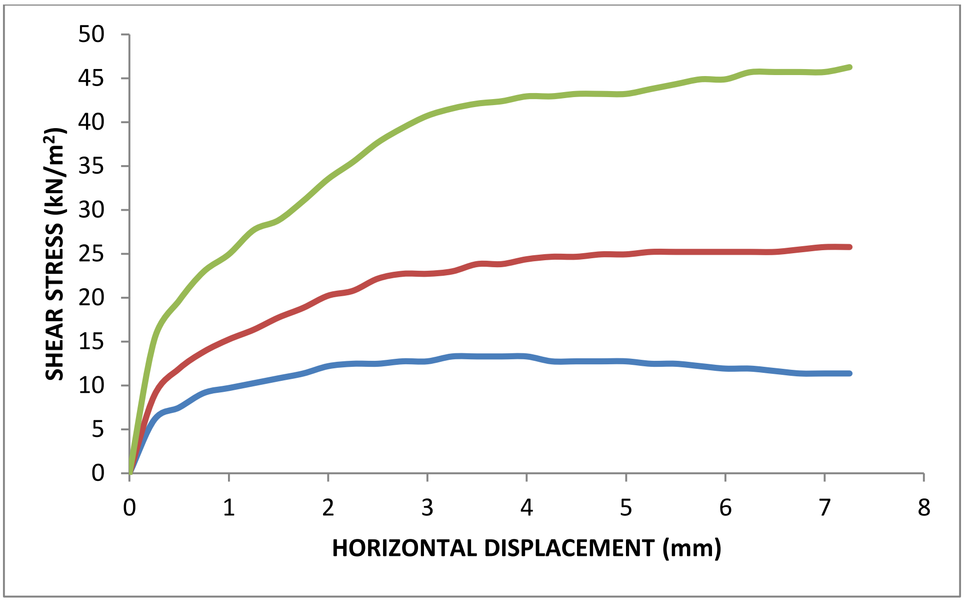


Figure 4.2 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 13.296 kN/m^2 at a horizontal displacement of 3.25 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear stress of 27.88 kN/m^2 at a horizontal displacement of 7.25 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 46.259 kN/m^2 at a horizontal displacement of 7.25mm.

Table 4.2 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	13.296	27.88	46.259

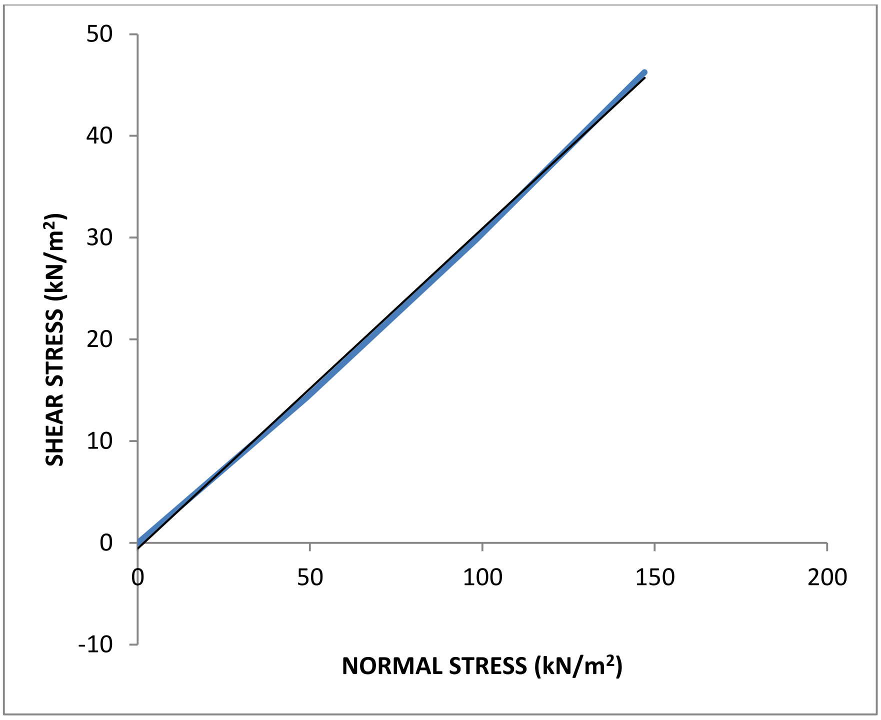


Figure 4.3 Variation of shear stress with normal load

Sample failed at a shear stress of 13.296 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress of 27.88 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 46.259 kN/m^2. Angle of internal friction for the sample was found to be 17.3°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction = 17.3°

4.4 Sand-Rubber mixture direct shear test

Rubber content=12.5% by weight of sample.

Table 4.3 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	15.735	32.686	48.198

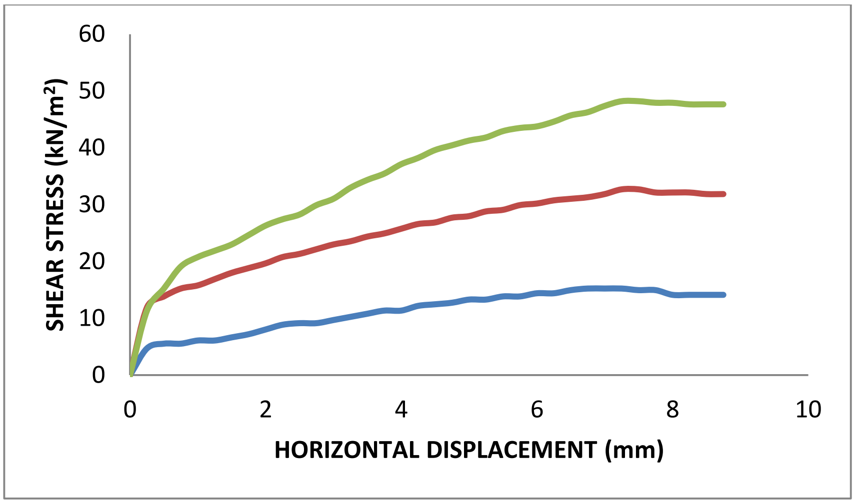


Figure 4.4 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 15.735 kN/m^2 at a horizontal displacement of 7.25 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 32.686 kN/m^2 at a horizontal displacement of 7.25 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 48.198 kN/m^2 at a horizontal displacement of 7.5 mm.

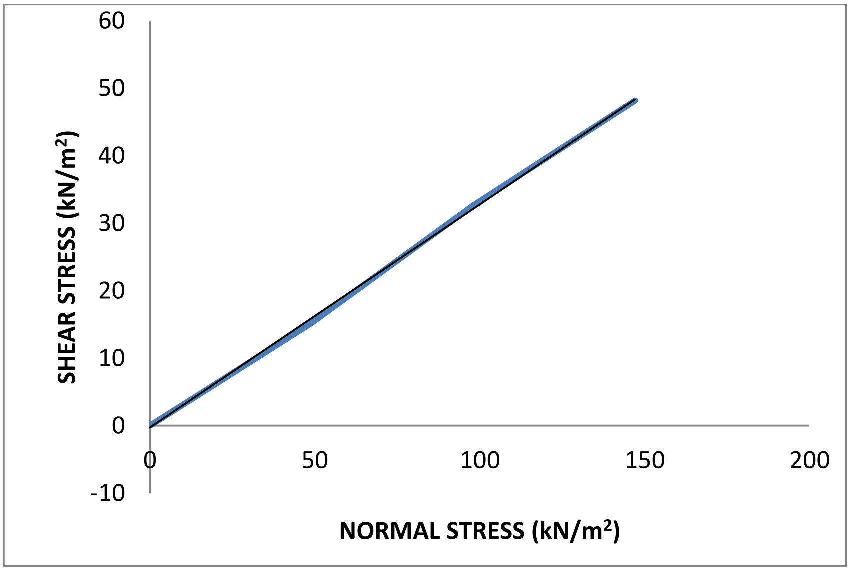


Figure 4.5 Variation of shear stress with normal load

Sample failed at a shear stress 15.735 kN/m^2 of for a normal stress 49.05N/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 32.686 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 48.198 kN/m$^{2.}$.Angle of internal friction was found to be 18.28° for the sample. This angle increased by 0.98° (5.6%) on addition of crumb rubber.

Cohesion (c) = 0 kN/m^2

Angle of internal friction = 18.28°

4.5 Direct shear test between sand-rubber mixture and FRP sheet

Rubber content = 12.5% by weight of sample.

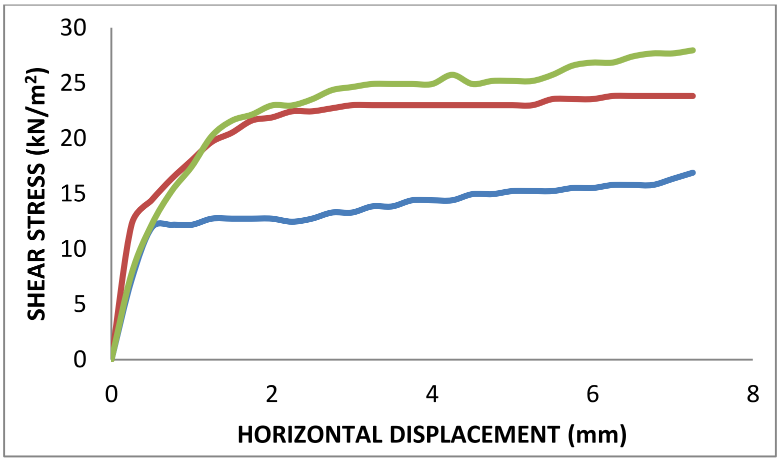


Figure 4.6 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 11.897 kN/m^2 at a horizontal displacement of 7.5 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 20.822 kN/m^2 at a horizontal displacement of 7.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 27.997 kN/m^2 at a horizontal displacement of 8 mm.

Table 4.4 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	11.897	20.822	27.997

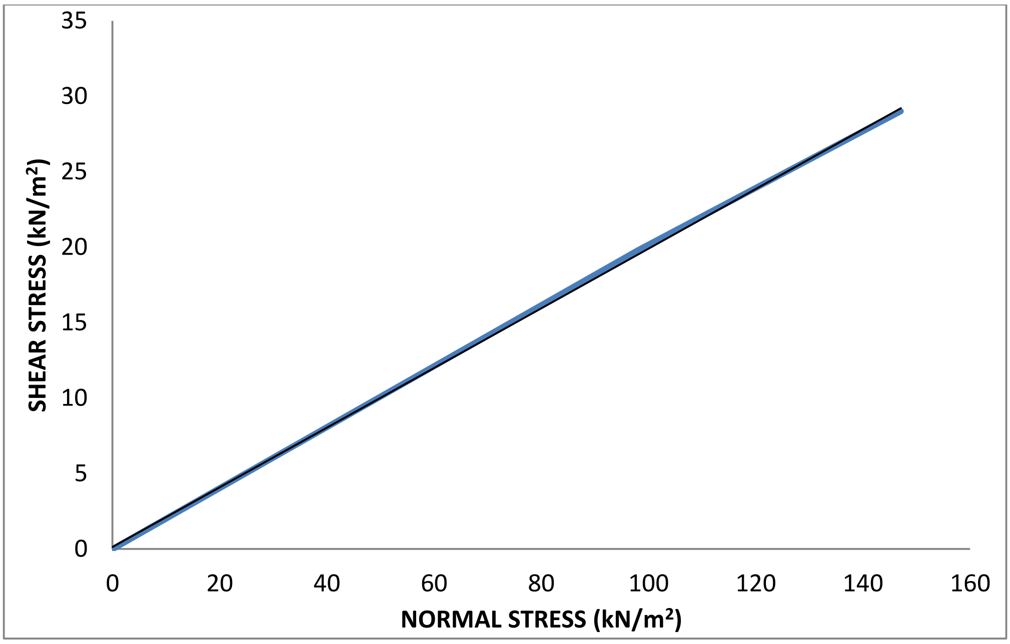


Figure 4.7 Variation of shear stress with normal load

Sample failed at a shear stress 11.897 kN/m^{2}of for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 20.822 kN/m^2 of and for a normal load 147.15 kN/m^2 the sample failed at a shear stress of 27.997 kN/m^2. Angle of internal friction for the sample was 10.72°. This value decreased by 7.56° (41.35%) from the condition when the sample only contained sand and crumb rubber.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =10.72°

4.6 Direct shear test between sand-rubber mixture and FRP sheet with grating perpendicular to the shearing plane

Rubber content = 12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

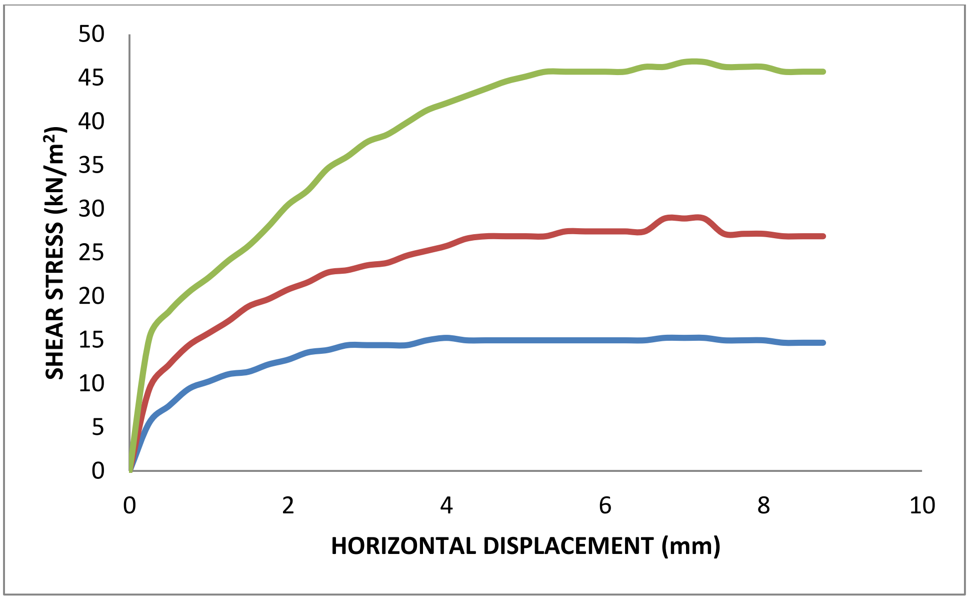


Figure 4.8 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 15.235 kN/m^2 at a horizontal displacement of mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 28.9 kN/m^2 at a horizontal displacement of mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 46.259 kN/m^2 at a horizontal displacement of 7 mm.

Table 4.5 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress (kN/m^2)	15.235	28.9	46.259

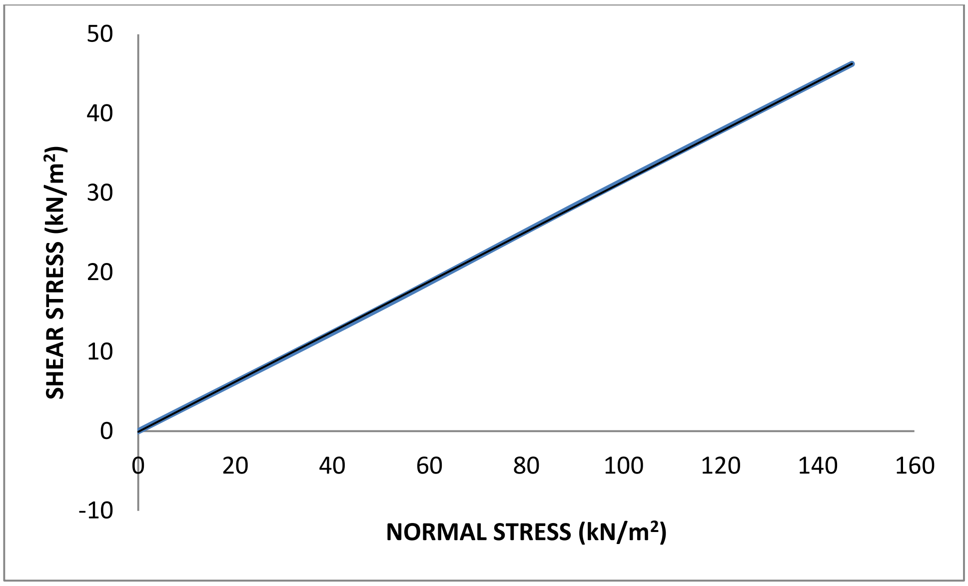


Figure 4.9 Variation of shear stress with normal load

Sample failed at a shear stress of 15.235 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 28.9 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 46.259 kN/m^2 .Angle of internal friction for the sample was found to be 17.38°. This value increased by 6.67° (62.2%) from the condition when there were no gratings on FRP sheet (10.72°). Hence the presence of gratings increased the value of angle of internal friction. This value is less than the value of angle of internal friction in case of sand and crumb rubber interface which was 18.28° and but the value was more than sand – sand interface where the value of angle of internal friction was found to be 17.3° .

Cohesion (c) = 0 kN/m^2

Angle of internal friction = 17.38°

4.7 Direct shear test between sand-rubber mixture and FRP sheet with grating parallel to shear plane.

Rubber content = 12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

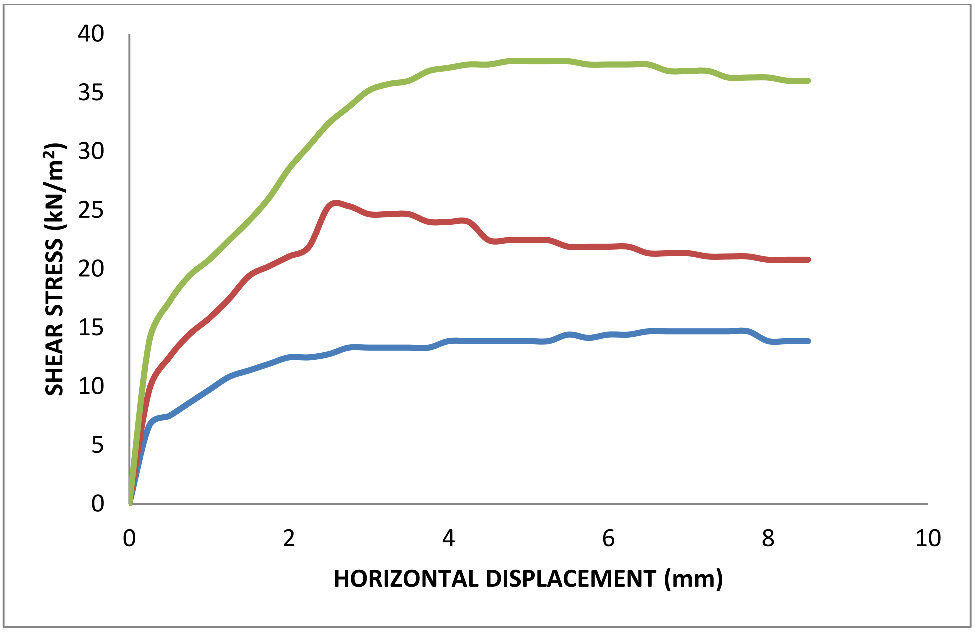


Figure 4.10 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 14.681 kN/m^2 at a horizontal displacement of 6 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 25.6 kN/m^2 at a horizontal displacement of 3.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 37.398 kN/m^2 at a horizontal displacement of 4.5 mm.

Table 4.6 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	14.681	25.6	37.398

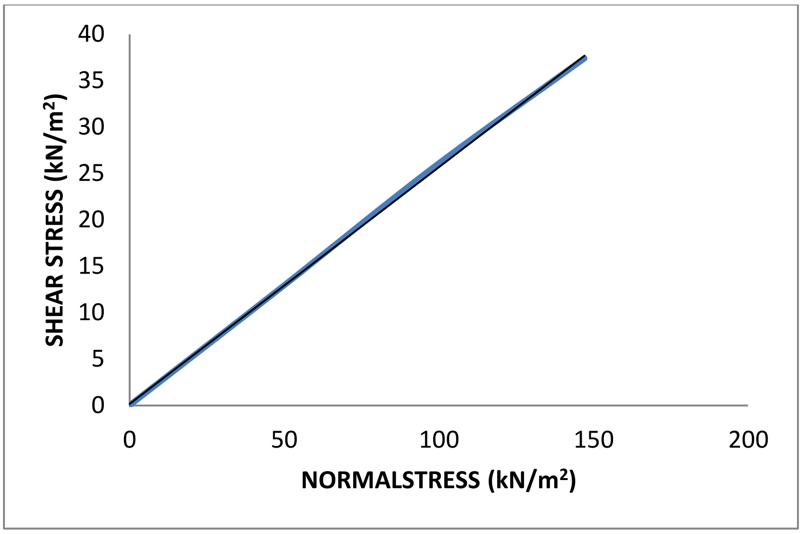


Figure 4.11 Variation of shear stress with normal load

Sample failed at a shear stress of 14.681 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 25.6 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 37.398 kN/m^2Value of angle of internal friction for the sample was found to be 14.09°. This value decreased by 3.29° (18.92%) from the condition where the grating pattern was parallel to shear plane (17.38°). This value is also less than the value of angle of internal friction in case of sand – sand interface where the value of this angle was found to be 17.3° and also less than the sand and crumb rubber interface where the value was found to be 18.28°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =14.09°

4.8 Direct shear test between sand-rubber mixture and FRP sheet with square grating

Rubber content=12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

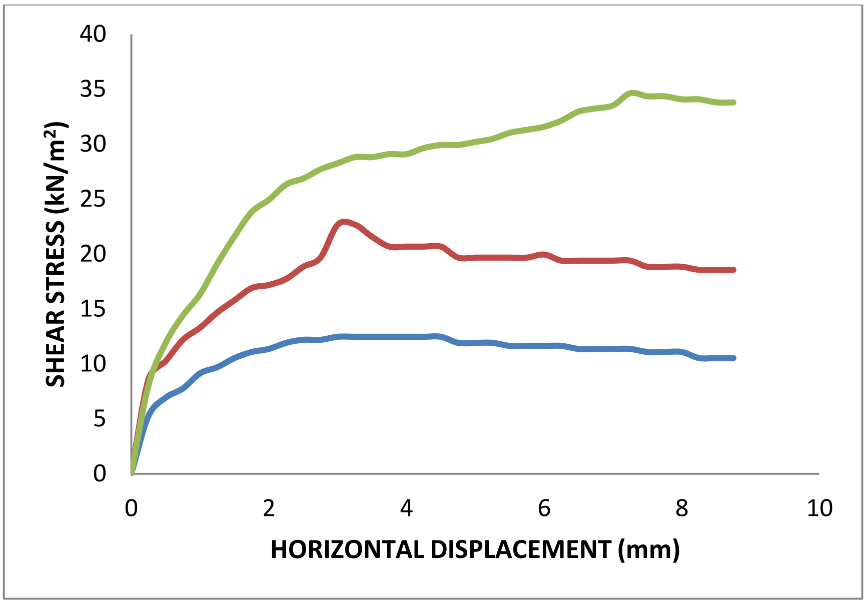


Figure 4.12 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 12.465 kN/m^2 at a horizontal displacement of 4.5 mm, for a normal load of 1 kg/cm^2 , the sample failed at a shear load of 22.66 kN/m^2 at a horizontal displacement of 3.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of34.071 kN/m^2 at a horizontal displacement of 7.5 mm.

Table 4.7 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	12.465	22.66	34.071

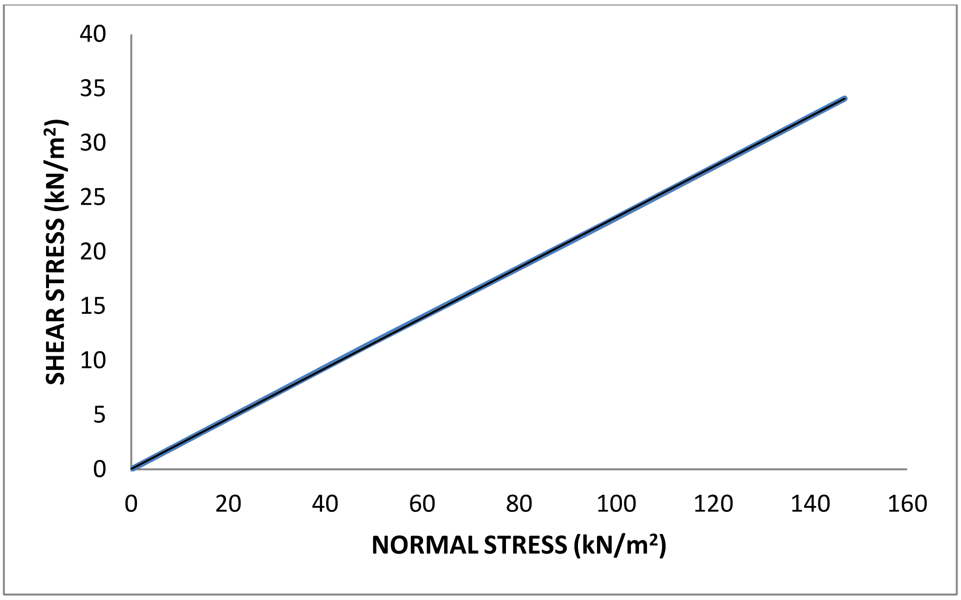


Figure 4.13 Variation of shear stress with normal load

Sample failed at a shear stress 12.465 kN/m^2 of for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 22.66 kN/m^2 of and for a normal load 147.15 kN/m^2 of the sample failed at a shear stress of 34.071 kN/m^2 . Value of angle of internal friction was found to be 12.90°. This value was found to be less than the value of angle of internal friction in case of gratings parallel to shear plane by 34.7% and gratings perpendicular to shear plane by 8.44% where the values were found to be 17.38° and 14.09 $^\circ$ respectively. This value was found to be 20.3% more than the value of angle of internal friction in case there were no gratings present on the FRP sheet where the value was 10.72°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =12.90°

4.9 Direct shear test between sand-rubber mixture and FRP sheet with angled grating

Rubber content=12.5% by weight of sample.

Grating spacing centre to centre = 1.17 cm

Depth and width of each grating = 2 mm

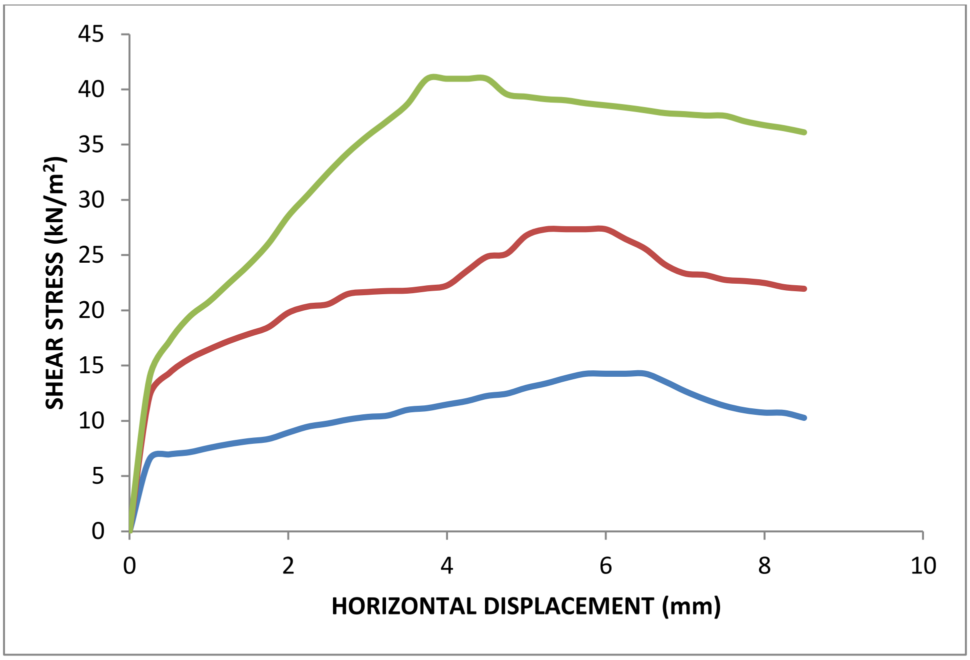


Figure 4.14 Variation of shear stress with horizontal displacement

.For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 14.26 kN/m^2 at a horizontal displacement of 6.5 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 27.34 kN/m^2 at a horizontal displacement of 7 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 40.95 kN/m^2 at a horizontal displacement of 7.5 mm.

Table 4.8 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	14.26	27.34	40.95

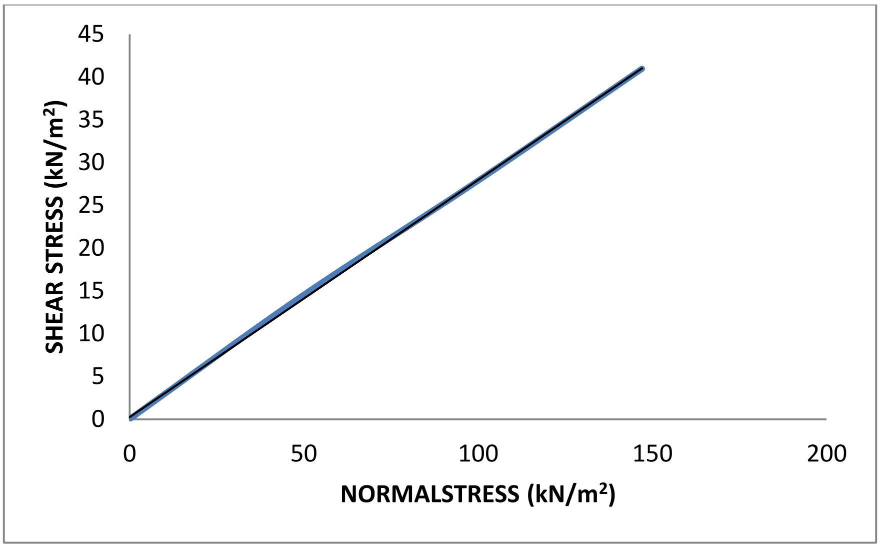


Figure 4.15 Variation of shear stress with normal load

Cohesion (c) = 0 kN/m^2

Angle of internal friction =15.49°

Sample failed at a shear stress of 14.26 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 27.34 kN/m^2 the sample failed at a shear stress 40.95 kN/m^2 of and for a normal load 147.1 kN/m^2 of the sample failed at a shear stress of 40.95 kN/m^2.

Table 4.9 Cohesion and angle of internal friction for different interface

S No.	Interface	Cohesion(c) (kN/m^2)	Angle of internal friction(°)
1.	Sand to sand	0	17.3
2.	Crumb rubber and sand mixture	0	18.28
3.	Plain FRP sheet	0	10.72
4.	FRP sheet with perpendicular grating to the shearing plane	0	17.38
5.	FRP sheet with parallel grating to the the shearing plane	0	14.09
6.	FRP sheet with square grating	0	12.9
7.	FRP sheet with angled grating	0	15.49

From table no. 4.9 it is observed that maximum angle of internal friction is in case of crumb rubber and sand mixture that is 18.28° and in case of FRP and crumb rubber and sand mixture interface maximum angle of internal friction is in case of FRP sheet with perpendicular grating to the shearing plane that is 17.38°.

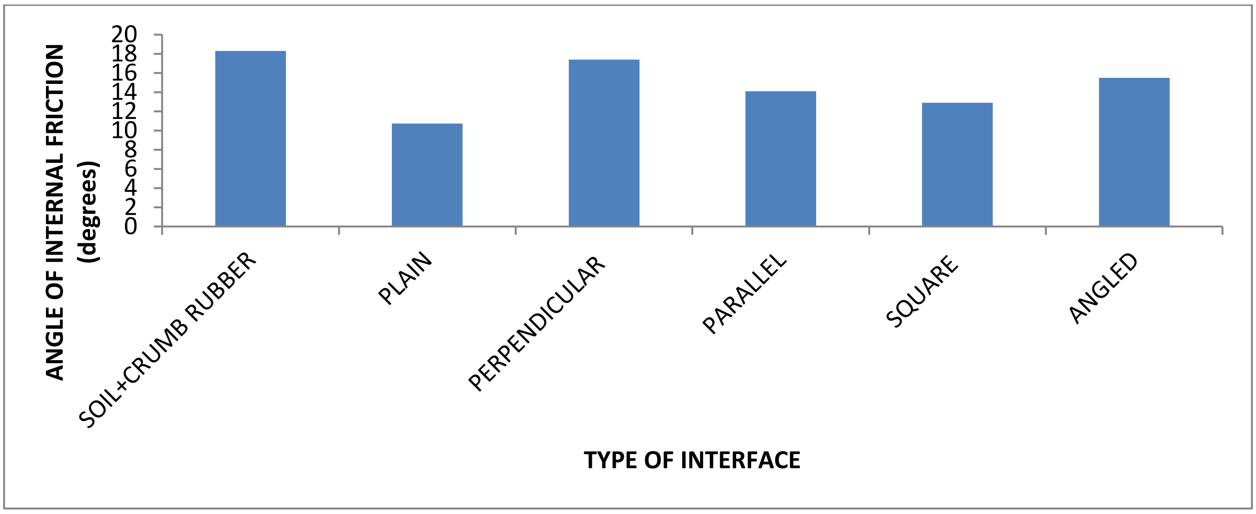


Fig 4.16 Comparison of values of angles of internal friction

4.10 Direct shear test between sand-rubber mixture and plain steel sheet

Rubber content = 12.5% by weight of sample.

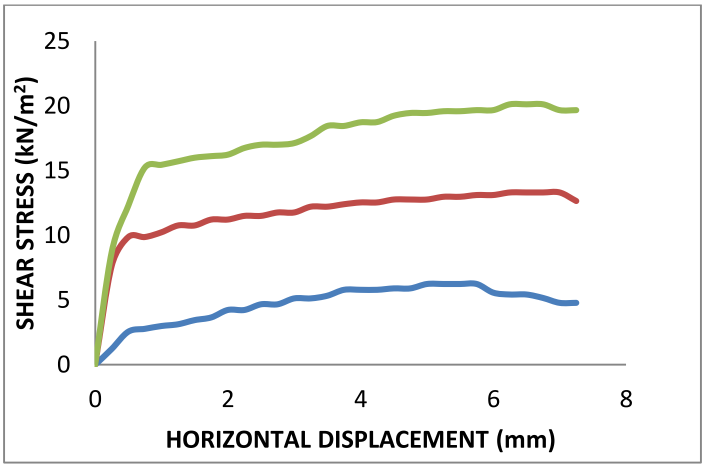


Figure 4.17 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 6.333 kN/m^2 at a horizontal displacement of 7 mm, for a normal load of 1 kg/cm, the sample failed at a shear load of 13.55 kN/m^2 at a horizontal displacement of 7.5 mm and for a normal load of 1.5

kg/cm^2 the sample failed at a shear load of 20.32 kN/m^2 at a horizontal displacement of 8 mm.

Table 4.10 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	6.333	13.55	20.32

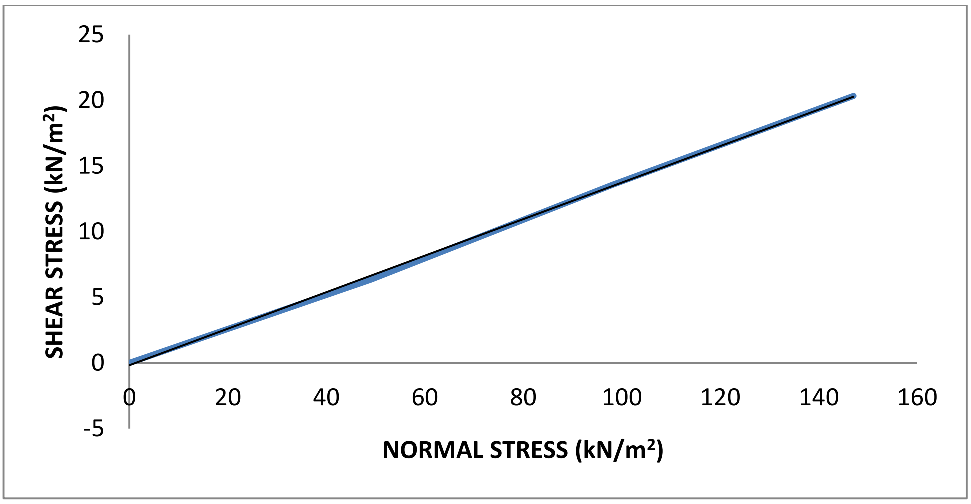


Figure 4.18 Variation of shear stress with normal load

Sample failed at a shear stress of 6.333 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 the sample failed at a shear stress 13.55 kN/m^2 of and for a normal load 147.15 kN/m^2 the sample failed at a shear stress of 20.32 kN/m^2.Value of angle of internal friction was found to be 7.9°. This value was found to be less than the value of angle of internal friction in case of plain FRP sheet by 26.31%. The value of angle of internal friction for plain FRP sheet was 10.72°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =7.9°

4.11 Direct shear test between sand-rubber mixture and steel sheet with grating perpendicular to the shearing plane

Rubber content = 12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

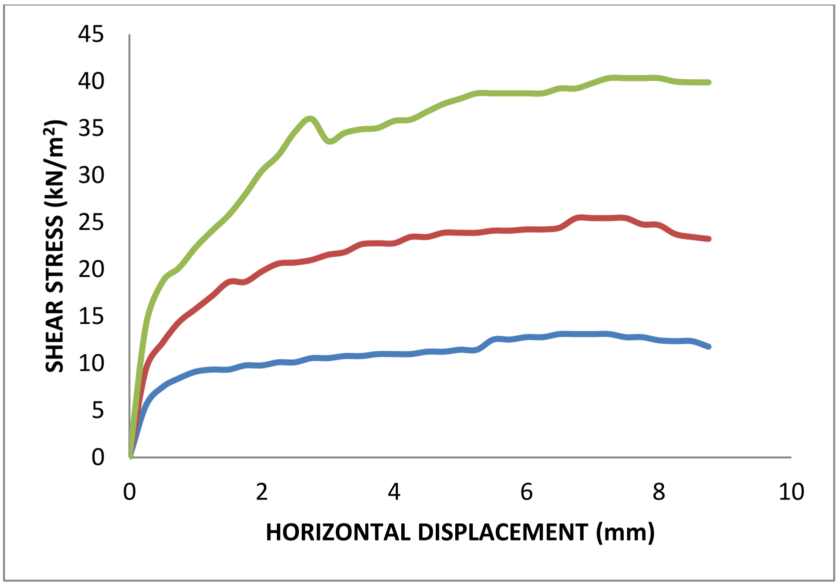


Figure 4.19 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 13.22 kN/m^2 at a horizontal displacement of 6.5 mm, for a normal load of 1 kg/cm^2 the sample failed at a shear load of 25.55 kN/m^2 at a horizontal displacement of 7.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 40.23 kN/m^2 at a horizontal displacement of 3 mm.

Table 4.11 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	13.22	25.55	40.23

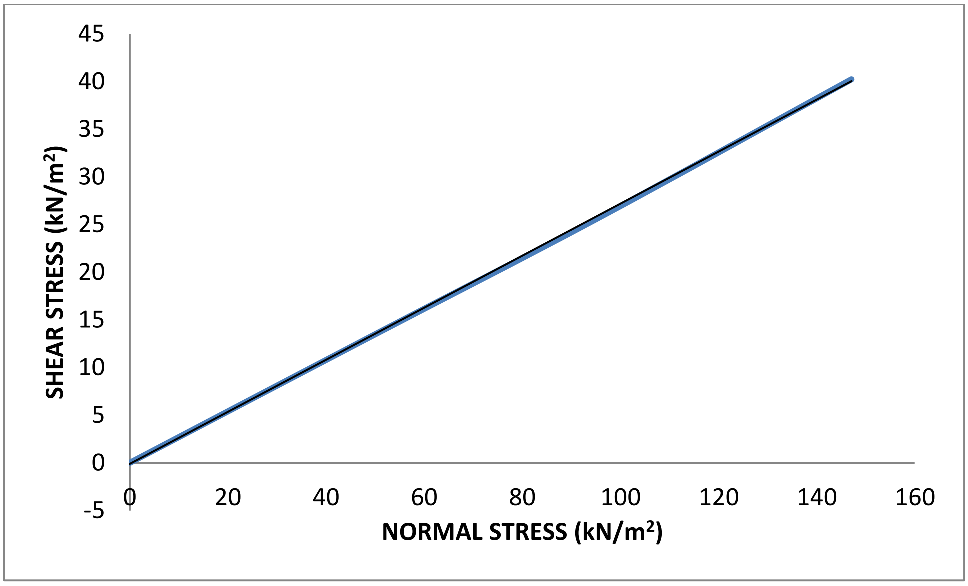


Figure 4.20 Variation of shear stress with normal load

Sample failed at a shear stress of 13.22 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 23.55 kN/m^2 of and for a normal load 147.15 kN/m^2 the sample failed at a shear stress of 40.23 kN/m^2. Angle of internal friction for the sample was found to be 15.27°. This value increased by 7.37° (93.29%) from the condition when there were no gratings on FRP sheet (7.9°). Value of angle of internal friction in this case is less than the value of internal friction in case of FRP sheet with perpendicular grating to the shearing plane by 2.11° (12.14%). Hence the presence of gratings increased the value of angle of internal friction. This value is less than the value of angle of internal friction in case of sand and crumb rubber interface which was 18.28°. But the value was more than sand – sand interface where the value of angle of internal friction was found to be 17.3°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =15.27°

4.12 Direct shear test between sand-rubber mixture and steel sheet with grating parallel to shear plane.

Rubber content = 12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

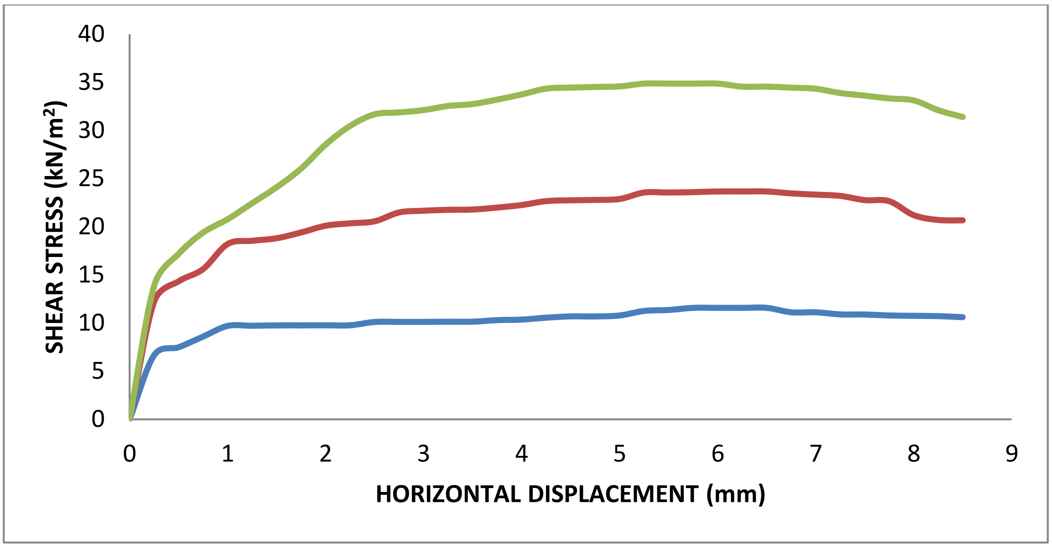


Figure 4.21 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 11.57 kN/m^2 at a horizontal displacement of 8 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 23.66 kN/m^2 at a horizontal displacement of 8 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 34.862 kN/m^2 at a horizontal displacement of 8 mm.

Table 4.12 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	11.57	23.66	34.862

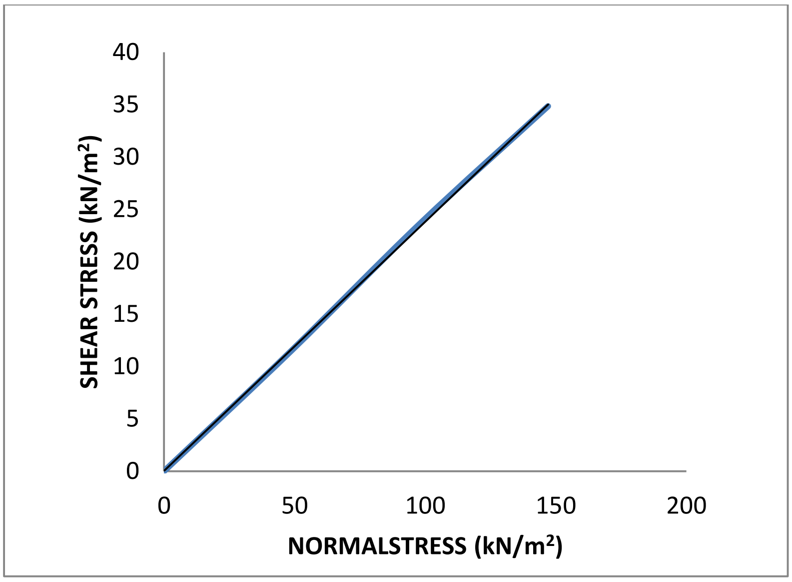


Figure 4.22 Variation of shear stress with normal load

Sample failed at a shear stress of 11.57 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 23.66 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 34.862 kN/m^2.Value of angle of internal friction for the sample was found to be 13.36°. This value decreased by 1.91° (12.51%) from the condition where the gratings were parallel to shear plane (15.27°). Value of angle of internal friction in this case is less than the value of internal friction in case of FRP sheet with parallel grating to the shearing plane by .73° (5.18%).This value is also less than the value of angle of internal friction in case of sand – sand interface where the value of this angle was found to be 17.3° and also less than the sand and crumb rubber interface where the value was found to be 18.28°.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =13.36°

4.13 Direct shear test between sand-rubber mixture and steel sheet with square grating

Rubber content=12.5% by weight of sample.

Grating spacing centre to centre = 0.75 cm

Depth and width of each grating = 2 mm

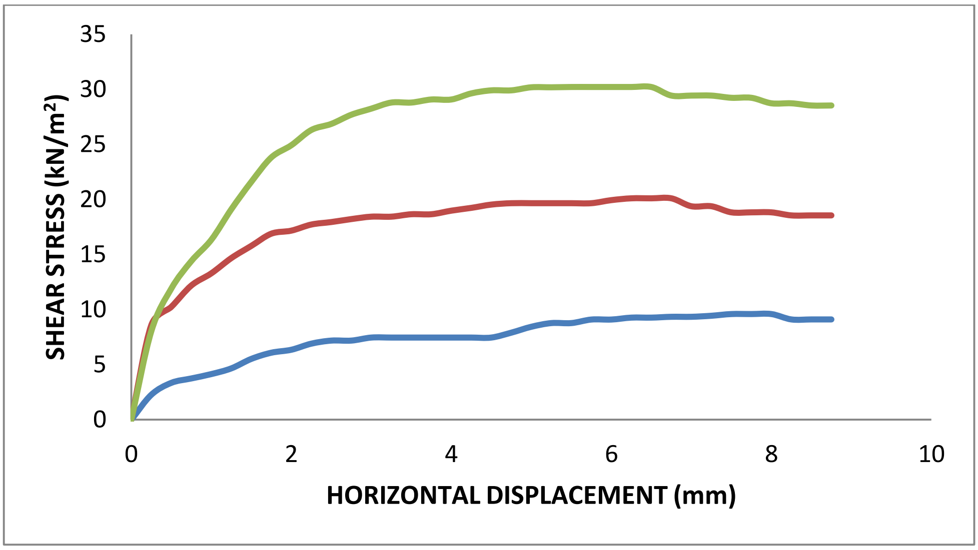


Figure 4.23 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 9.6 kN/m^2 at a horizontal displacement of 8 mm, for a normal load of 1 kg/cm^2,the sample failed at a shear load of 20.11 kN/m^2 at a horizontal displacement of 6.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 30.22 kN/m^2 at a horizontal displacement of 6.5 mm.

Table 4.13 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	9.6	20.11	30.22

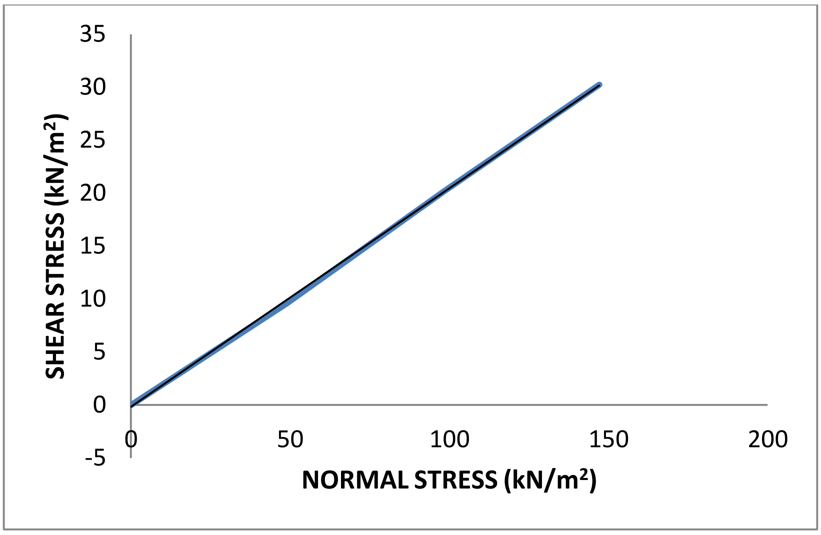


Figure 4.24 Variation of shear stress with normal load

Sample failed at a shear stress of 9.6 kN/m^2 for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 20.11 kN/m^2 of and for a normal load 147.1 kN/m^2 of the sample failed at a shear stress of 30.22 kN/m^2 .Value of angle of internal friction was found to be 11.5°. This value was found to be less than the value of angle of internal friction in case of gratings parallel to shear plane by 13.92% and gratings perpendicular to shear plane by 24.69% where the values were found to be 13.36° and 15.27° respectively. This value was found to be 45.57% more than the value of angle of internal friction in case there were no gratings present on the FRP sheet where the value was 7.9°. Also value of angle of internal friction in this case is less than the value of internal friction in case of FRP sheet with square grating to the shearing plane by 1.4° (10.85%).

Cohesion (c) = 0 kN/m^2

Angle of internal friction =11.5°

4.14 Direct shear test between sand-rubber mixture and steel sheet with angled grating

Rubber content=12.5% by weight of sample.

Grating spacing centre to centre = 1.17 cm

Depth and width of each grating = 2 mm

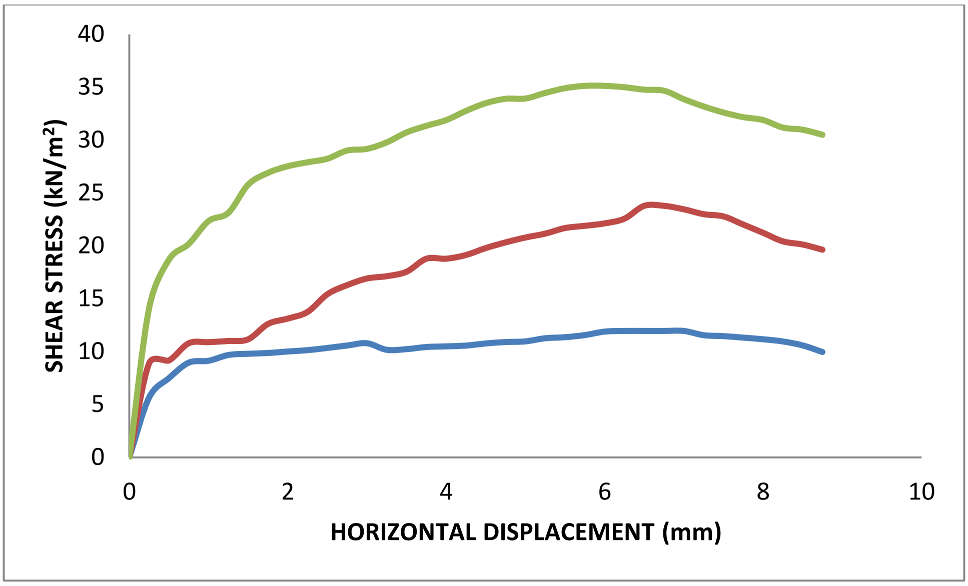


Figure 4.25 Variation of shear stress with horizontal displacement

For a normal load of 0.5 kg/cm^2 the sample failed at a shear stress of 11.94 kN/m^2 at a horizontal displacement of 7 mm, for a normal load of 1 kg/cm^2, the sample failed at a shear load of 23.54 kN/m^2 at a horizontal displacement of7.5 mm and for a normal load of 1.5 kg/cm^2 the sample failed at a shear load of 35.11 kN/m^2 at a horizontal displacement of 7 mm.

Table 4.14 Maximum shear stress and normal load

Specimen	**A**	**B**	**C**
Normal load (kN/m^2)	49.05	98.1	147.15
Maximum Shear Stress(kN/m^2)	11.94	23.54	35.11

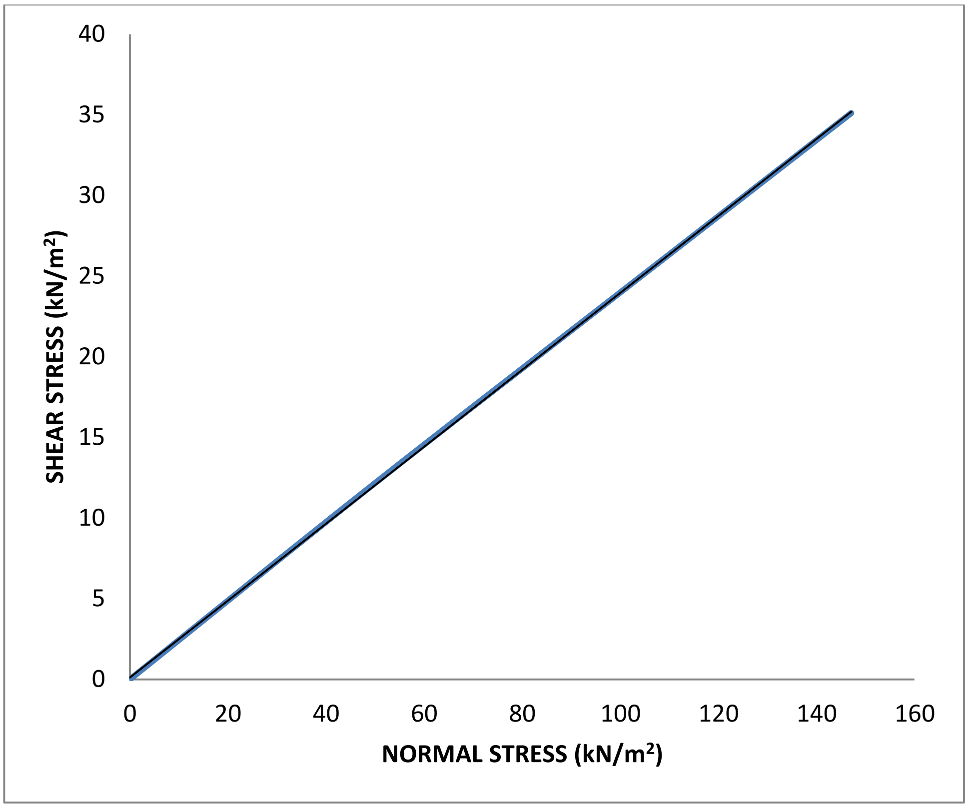


Figure 4.26 Variation of shear stress with normal load

Sample failed at a shear stress of 11.94 kN/$m^2$for a normal stress of 49.05 kN/m^2. For a normal load 98.1 kN/m^2 of the sample failed at a shear stress 23.54 kN/m^2 of and for a normal load 147.1 kN/m^2 the sample failed at a shear stress of 35.11 kN/m^2. This value was found to be greater than the value of angle of internal friction in case of plain steel sheet and that in case of sheet with square grating where the values were found to be 7.9 degrees and 11.5 degrees respectively. However, this value was les than the value of angle of internal friction in case of steel sheet with parallel grating angd grating perpendicular to shear plane where the values were 13.36 degrees and 15.27 degrees respectively.

Cohesion (c) = 0 kN/m^2

Angle of internal friction =13.414°

Table 15 Cohesion and angle of internal friction for different interface

S No.	Interface	Cohesion(c) (kN/m^2)	Angle of internal friction(°)
1.	Plain steel sheet	0	7.9
2.	Steel sheet with perpendicular grating to the shearing plane	0	15.27
3.	Steel sheet with parallel grating to the shearing plane	0	13.36
4.	Steel sheet with square grating	0	11.5
5.	Steel sheet with angled grating	0	13.414

From table no.15 it can be concluded that angle of internal friction in case of steel sheet with perpendicular grating to the shearing plane is maximum that is 15.27° which is less than angle of internal friction in case of FRP sheet with perpendicular grating to the shearing plane(17.38°).

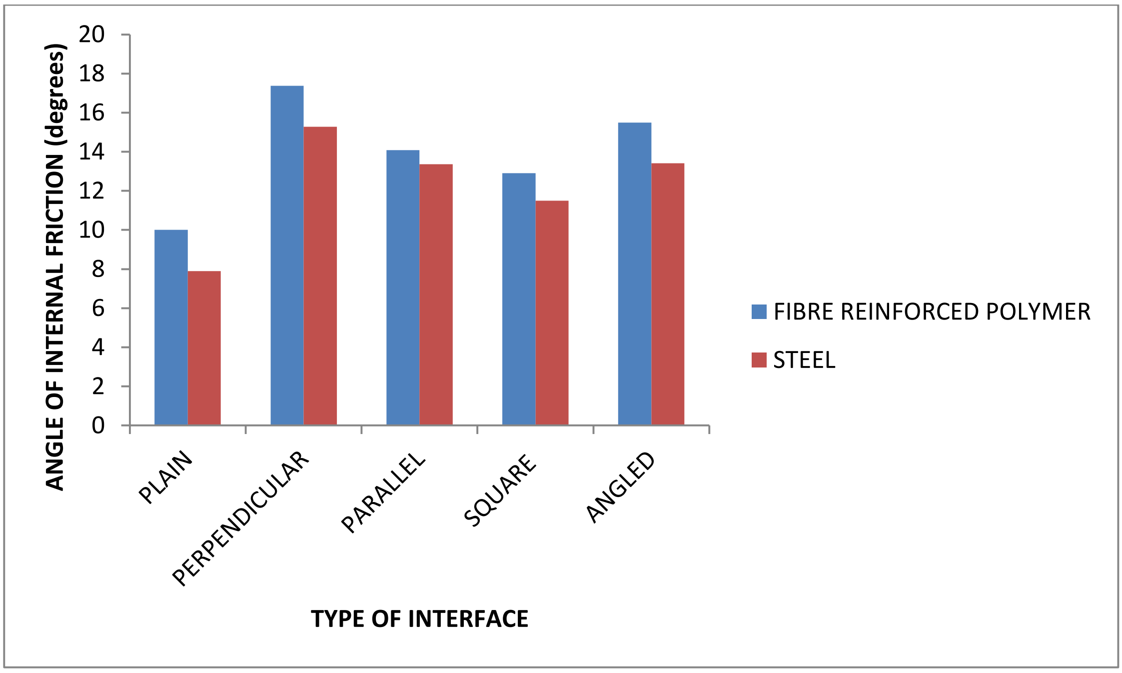


Figure 4.27 Comparison of values of angles of internal friction in case of FRP and steel

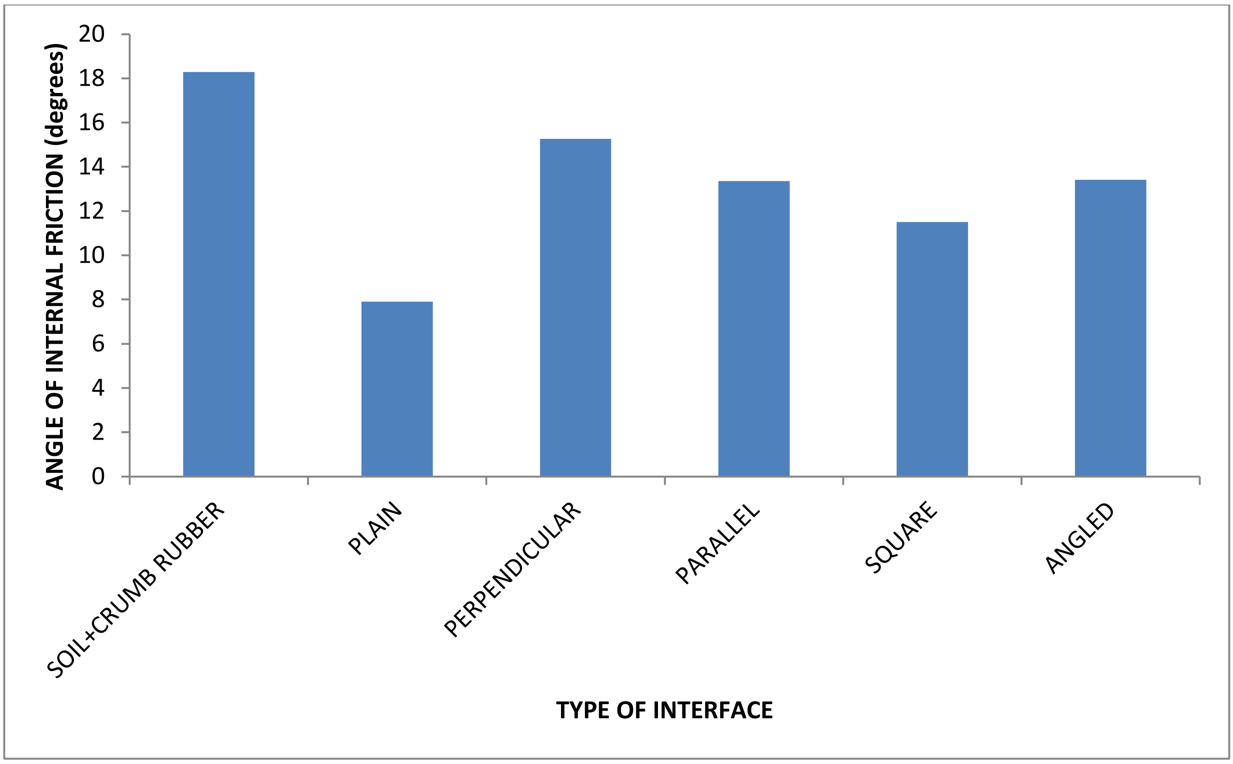


Fig 4.28 Comparison of values of angles of internal friction

CHAPTER 5

CONCLUSIONS

5.1 General

During the course of this project experimental testing of various grating patterns on FRP sheets and steel sheet which can be used as of soil reinforcement was performed. It can be inferred that the technique of soil reinforcement using mechanically stabilized earth wall has contributed to the infrastructure in terms of speed economy, aesthetics etc.

5.2 Conclusions

1. The values of the angle of internal friction during the testing were found to be 17.3° in case of sand to sand interface, 18.28 in case of sand and crumb rubber interface, 10.72° in case of sand-crumb rubber FRP interface, 17.38° in case of FRP with perpendicular grating, 14.09° in case of FRP with parallel grating, 12.90° in case of FRP with square grating. Hence it can be concluded that the value of angle of internal friction mainly depends on the type of interface and the orientation of grating patterns with respect to shear plane.
2. In case of steel sheets values of angle of internal friction were found to be 7.9° in case of plain steel and sand crumb rubber sand interface.13.36° in case of sand crumb rubber and steel sheet with parallel grating pattern. 15.27° in case of steel sheet with perpendicular grating. 11.5° in case of steel sheet with square grating. 13.414° in case of steel sheet with angled grating.
3. The value of angle of internal friction was found to be maximum in case of FRP sheet with perpendicular grating to the shearing plane that is 17.38° which is greater than that of steel sheet with perpendicular grating to shear plane by 2.11 ° (13.817%).

5.3 SCOPE OF FUTURE WORK

Numerical modelling of the results of the various Direct Shear Tests to validate the results.

Application of the results in real world applications and mass construction work.

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