Sand-Geogrid Interface Passive Resistance in Direct Shear Mode

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Abstract - *Series of large scale direct shear tests were carried out to appraise the contribution of passive resistance bestowed at the interface of the soil- transverse ribs of a geogrid .Soil samples used are with varying proportions of Sand, 6mm aggregates and 12mm aggregates at different densities. The study results revealed that the transverse ribs contribute 17% of the total interface resistance for soil samples tested with the geogrid. From the test results it is observed that the shear strength at sand – geogrid interface mobilized under direct shear mode is depending on the density, size of the particles and thickness of ribs. Moreover, it is observed that the 21 % of passive resistance contributed by transverse ribs with respect to the total shear resistance found decreasing with increase of normal load at constant density and the passive resistance found decreasing with decreasing of density.*

Key Words: combined shear resistance; interface shear ;geogrid-soil; passive resistance;shear mode; soil gradation; transverse ribs.

1. INTRODUCTION

The geosynthetics are an accepted construction material widely used in the construction of retaining walls, roads, embankments, and foundation soil improvements to resist the forces in the soil mass by reinforcing the soil. The soil geosynthetic interaction is very multifaceted depends upon the a).physical and mechanical properties of geomaterials like grain size and shape, density, grain size distribution, water content, tensile strength, shape , geometrical distinctiveness of the geosynthetic and interaction mechanism between geomaterials and geosynthetics under different loading conditions Lopez (2002).The geotextile – soil interface is mainly governed by the skin friction between them and penetration of soil particles in to the geotextile under loading. Different types of laboratory tests and analytical work have been developed, in order to improve the understanding of the soil geosynthetic interaction mechanism. The discrete interaction between the transverse members of the geogrid and the surrounding soil has been made visible by performed photo-elastic studiesDyer (1985).Different failure mechanisms occurring in specific zones due to different interactions between the backfill material and the reinforcement were indicated by Lackner et al.(2013).

Generally, the complex behaviour of geomaterial and geosynthetic interface is approximated by introducing an equivalent frictional shear stress that allows evaluating an overall resistance referring to the whole reinforcement surface. Different large direct shear test apparatus has been used very widely and literature evidences have showed a large degree of differences in published data due to the usage of different apparatuses. The studies by Nicola Moraciet al.(2014)has observed the major factors affecting the results of a large direct shear test apparatus as the shear box size, boundary conditions of the top box, the opening size gap between the two halves of the shear box, soil specimen support whether rigid base or soil, type of test like constant or reduced area etc.

The influence of passive resistance in a geogrid-soil interface under direct shear mode is a controversy. It is observed in a study by Lopez (2002) that the contribution of passive shear resistance offered is not at all significant under direct shear mode where as in a study by Bergardo et al.(1993) geogrid-geometerial properties impart much contribution to passive resistance in a direct mode shear test using a HDPE geogrid.

The shear strength parameters, such as interface friction angle and adhesion, for unreinforced, reinforced with soft geogrid, and reinforced with stiff geogrid were studied by Seo et al.(2009). In the case of unreinforced, when the particle diameter increases, the internal friction angle also increases but the internal friction angle in the case of geogrid reinforced soil turned out to be lesser than that in the case of unreinforced soil. The tendency of decrease in the interface friction angle due to reinforcing with geogrid is similar to the results in his previous research. The influence of soil particle size on soil-geosynthetic interaction is important, but its significance depends on several factors. With geogrids, it is the relative sizes of soil particles and geogrid apertures, and the thickness of the geogrid bearing members and soil-geogrid interface shear resistance. Tests on geogrids in which the bearing members had been cut, show a significant decrease in soil-geogrid interface shear resistance.

The correlation between certain physical properties of granular material such as the friction angle and the grain size distribution were studied by Esma Mostefa Karaet al.(2013). Even though the contribution of transverse ribs to the soil-geogrids interaction under pull-out mode has been documented, the contribution of transverse ribs to the soil-geogrids interaction under the direct shear mode was not so clear. However, studies were conducted and found that transverse ribs of the geogrid provide approximately 10% of the interface shear resistance Chia-Nan Liuet al.(2009). It was observed that much attention was given to overall interface shear strength on soil-geogrid studies, but less emphasis on the credentials of different mechanisms causative to the interface shear resistance.

As the geogrid consists of longitudinal and transverse ribs with opening in the aperture area, the following mechanism is working during a shear test at the interface between soil and geogrid:(1) internal soil to soil resistance at the openings in the aperture area;(2) shear resistance between soil and surface of the geogrid ribs;(3) passive resistance offered by the transverse ribs. As schematic illustration of the mechanism is shown in Fig.1 by Wrigley [9], the soil reinforcement interaction is controlled by friction between the soil and the reinforcement, the friction between soil and soil, and the bearing resistance of the soil on the transverse member of grid. The soil particle with smaller size than the aperture is locked in the openings of the geogrid and is touching the ribs. Both longitudinal ribs (LR) and transversal ribs (TR) take role to contribute to the shear strength of geogrids. The authors Chia-Nan Liu et al.(2009) ;Liu et al.(2009) observed that at smaller displacements the shear resistant components are fully mobilized and the shear resistant by the way of bearing resistance is involved at larger displacements.

The combined interface friction force of soil and geogrid F_{s+g} can be explained by

$F_{s+g} = F_{ss} + F_{sg} + F_{pr}$ .... (1)

where

F_{ss} = soil to soil direct shear frictional force

F_{sg} = soil –geogrid interface friction force

F_{pr} =transverse rib passive resistance force.

In this study, a series of large scale direct shear tests was conducted with a same geogrid but with four samples of sand soil at different densities at different normal loads. The purpose of this paper is to investigate the role of interface frictional resistance offered by soil-soil, soil-geogrid and soil-transverse ribs interfaces to the total interface shear resistance by carrying out a series of shear tests with same geogrid and different soil samples

The largescale direct shear test apparatus used for this study of shear strength on sand –geogrid interface is a shear box of dimensions 300 x 300 x 200 mm shown in Figure .4. The photograph of the equipment is shown in Figure .5. The shear box is made of MS plates having a thickness of 4mm.The whole set up is mounted on a MS testing bench with facilities to apply vertical and horizontal loads. Also, the horizontal force applied is measured through a 2 KN proving ring. The horizontal displacement is measured using a dial gauge of 0.01 mm sensitivity.

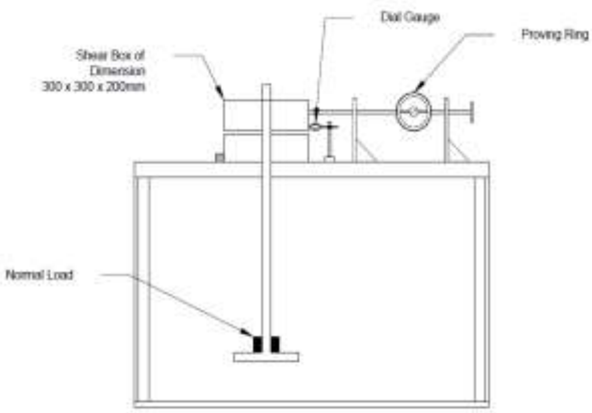

FIGURE 1: SHEAR BOX OF SIZE 300 X 300 X 200 MM

TABLE 1.PROPERTIES OF GEOGRID

Property	Value
Color	Black
Type	Biaxial
Tensile Strength (kN/m)	13
Aperture Size (mm)	26x20
Mass per Unit Area (g/m2)	225
Thickness of ribs mm	1.0

TABLE 2.SOIL PROPERTIES

Soil samples	Density kg/cu.m	Internal Friction Angle φss
S1D1	1643	35.75
S1D2	1612	33.66
S1D3	1587	32.6
S1D4	1531	31.8
S2D1	1710	38.34
S2D2	1664	34
S2D3	1613	32.6
S2D4	1575	31.1

2. MATERIALS USED

The soil samples used for this study were a mix of 12 mm aggregate, 6mm aggregate and Sand. The three different samples were mixed in different proportions and each case the sieve analysis was carried out. Total such four sand samples were prepared for the experiment study. The details of soil used are presented in Table 1 and Table 2. The properties of geogrid used are given in Table 3.The shear area is 0.09 sq.m and the total area of soil to soil contact is 0.061965sq.m and the soil to geogrid contact area is 0.028035 sq.m.of soil used are presented in Table 1 and Table 2. The properties of geogrid used are given in Table 3.The shear area is 0.09 sq.m and the total area of soil to soil contact is 0.061965sq.m and the soil to geogrid contact area is 0.028035 sq.m.

3. TEST PROCEDURE

The soil samples were prepared for each mix ratios. The samples containing 12 mm aggregate, 6mm aggregate and Sand were well mixed and the sieve analysis was carried out to determine the gradation. For testing the soil samples alone, the lower half box is placed on the platform and the plate at its bottom base. Then the upper half box is placed over the bottom box and the two screws are inserted in the holes to arrest the movements of the two boxes. The soil sample is filled in the in the box lower and upper box in equal layers of 5 cm and each layer was compacted using a 1 Kg weight rod by tamping the surface. The weight of the soil is measured. The rigid bearing plate is horizontally placed on the surface of the soil and the shear test was conducted at normal loads of 50,100 and 150 N. The horizontal load was applied by rotating the wheel which is exerting load on the upper half box at a speed of 10mm per minute. The vertical load is applied through the vertical rod touching the top plate placed over the top of upper box. The horizontal loading was stopped when the peak shear stress is obtained or till the shear strain reaches 5%.The horizontal load is read from the proving ring and the shear strain from the dial gauge at each 5 division on the PR. After completion of the test soil is fully taken out from the box and is weighed.

The shear test with geogrid is carried out the same way, but first the bottom half box is filled with soil in layers with proper compaction in layers of 5cm.Then the geogrid of size 290 x 290 mm is placed over the top of the soil without touching the sides of the box.Then the upper half box is placed oer the lower one and the screws are tightening to avoid movement of the boxes. The geogrid was very properly placed over the soil top surface and the upper portion is started filling as done before. Then the test is carried out as before and the weight measured to calculate the density of soil sample. All the four soil samples at different densities were tested with and without the geogrid.The details are given Table.

The sand –Geogrid interface under direct shear mode may include following mechanisms. (1) Soil and ribs of geogridshear resistance (2) internal soil shear resistance in the openingarea of geogrid (3) passive resistance of the transverse ribs of geogrid..An expression for this had been proposed to predict the shear strength mobilized in sand – Geogrid interface under the direct shear mode was proposed by Bergado ,D.T [5].

$\tau_{sand\text{-}Geogrid} = \sigma_n \, [(1-\rho) \tan\phi_{sg} + \rho \tan\phi_s]$…………….(2)

where σ_n is the normal stress, ρ is the per cent of open area of geogrid .$\phi_{sg}$is the interface friction angle between sand and the geogrid and ϕ_s is the soil angle of internal friction.

4. SOIL GEOGRID INTERFACE MODELING

The large scale direct shear test was carried out with four nos sand sample, each at four different densities without the geogrid.

The shear strength of the all 16 nos samples were obtained from the test at normal loads of 50, 100 and 150N. The normal stress against the shear stress was plotted and the angle of internal friction between soil to soil was obtained. This data was used for determining the soil to soil shear strength in the contact area of aperture of the geogrid.

The interface frictional force between soil to soil F_{ss} in soil-soil contact areas can be described in equation below.

$F_{ss} = A_{ss} . F_{ss} = A_{ss} .\sigma_n.\tan\varphi_{ss}$-------------(3)

where:

A_{ss} = total shear area of the box

F_{ss}=soil shear strength τ

σ_n= normal stress applied on the soil sample

φ_{ss} = soil interface friction angle

Then the tests were repeated with same nos of samples with geogrid in position. The force measured during the shear test without geogrid was the only the shear force experienced at interface of the soil to soil. When the test is done with geogrid, the shear force is experienced at soil to soil interface in the opening of the geogrid,soil to geogrid surface and the passive resistance offered by the transvers ribs of the geogrid. The normal stress against the shear stress was plotted and the combined angle of internal friction φ_{s+g}between soil to soil and soil to geogrid with transverse ribs was obtained.In this test, the total area A is 900sq.cm, area of aperture is 68.85% and that of geogrid surface is 31.15% of the total shear area.

$F_{s+g} = A.\sigma_n.\tan\varphi$………………………(4)

During the shear test usinggeogrid,the shear resistance offered by soil to geogrid interface of geogrid can be analysed by

$F_{sg} = A_{sg}. F_{sg} = A_{sg}. \sigma_n.\tan\varphi_{sg}$. ------------------(5)

where:

A_{sg} = area of geogrid in contact with soil

F_{sg} = soil to geogrid interface shear strength φsg=soil to geogrid interface frictiona angle.

The soil to geogrid interface friction Fsg including the passive resistance imparted by ribs can be obtained by deducting the soil –soil shears strength of the interface in the geogrid openings and wherever soil to soil contacts are there in the total shear area from the combined interface shear strength Fs+g.

Fsg + Fpr = Fs+g–Fss……………………..(6)

The total soil gergrid interface friction strength sg will be obtained by dividing the Fsg +Fb by the geogrid area of contact with soil.

Fsg = Fsg +Fpr/ Asg……………..(7)

On plotting the applied normal stresses against the interface peak shear stresses Fsg of the soil gegrid interfaces, the interface friction angle Φsg will be obtained .Using this, the shear strength resistance offered by soil-geogrid surface can explained using Eqn(5). The φs+gφsg and φss obtained are given in Table.5 below and Table2.

TABLE.3, INTERFACE FRICTION ANGLES

Soil samples	φs+g	φsg
S1D1	32.57	24.7
S1D2	32.21	28.9
S1D3	30.7	26.4
S1D4	29.5	24.2
S2D1	36.4	32
S2D2	32.9	35.6
S2D3	31.1	27.65
S2D4	29.9	27.34

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

TABLE.4.DETAILS OF TEST RESULTS AND CALCULATED DATA OF SOIL SAMPLES S1 AND S2

Soil Samples	σn N	F s+gN	F ssN	Fsg+Fpr N	Fsg N	Fpr N	% Fss	%Fgg	%Fpr
S1D1	50	43.2	24.98	18.22	7.24	10.98	57.83	16.75	25.41
	100	75.6	49.52	26.08	14.35	11.73	65.51	18.98	15.52
	150	107.1	74.51	32.59	21.58	11.01	69.57	20.15	10.28
S1D2	50	42.3	23.11	19.19	8.67	10.52	54.63	20.49	24.88
	100	74.7	45.81	28.89	17.18	11.71	61.32	23.00	15.68
	150	105.3	68.92	36.38	25.84	10.54	65.45	24.54	10.01
S1D3	50	42.3	22.17	20.13	7.79	12.34	52.42	18.41	29.17
	100	73.8	43.95	29.85	15.43	14.41	59.55	20.91	19.53
	150	101.7	66.12	35.58	23.22	12.35	65.02	22.83	12.15
S1D4	50	40.5	21.55	18.95	7.05	11.90	53.21	17.41	29.39
	100	70.2	42.71	27.49	13.97	13.51	60.84	19.90	19.25
	150	97.2	64.26	32.94	21.02	11.92	66.11	21.63	12.26
S2D1	50	43.2	27.41	15.79	9.80	5.99	63.46	22.68	13.87
	100	84.6	54.34	30.26	19.42	10.84	64.23	22.95	12.82
	150	117	81.75	35.25	29.21	6.03	69.87	24.97	5.16
S2D2	50	41.4	23.39	18.01	9.28	8.73	56.49	22.41	21.10
	100	81.9	46.36	35.54	18.39	17.15	56.60	22.46	20.94
	150	106.2	69.75	36.45	27.67	8.78	65.67	26.05	8.27
S2D3	50	42.3	22.17	20.13	8.23	11.90	52.42	19.45	28.13
	100	79.2	43.95	35.25	16.31	18.94	55.49	20.59	23.92
	150	102.6	66.12	36.48	24.53	11.94	64.45	23.91	11.64
S2D4	50	40.5	20.92	19.58	8.12	11.46	51.67	20.04	28.29
	100	73.8	41.48	32.32	16.09	16.24	56.20	21.80	22.00
	150	98.1	62.40	35.70	24.21	11.50	63.61	24.67	11.72

5. RESULT AND DISCUSSION

The Fs+g is the combined interface friction force obtained from the shear test with geogrid,Fss is the interface friction force of the opening area of the geogrid calculated using Eqn (2) with the angle of internal friction obtained from the shear test carried out without geogrid and Fsg is the interface friction force soil to grid contact area including passive resistance of ribs, obtained using Eqn (5) .Here the interface shear strength of sand-geogrid is taken from the graph drawn between the normal stresses against the Fsg+ Fpr .i.e.Fs+g– Fss. UsingΦsg obtained from the failure envelope, Eqn (3) and (5), were used to predict Fsg.Here only the shear resistance between the soil to geogrid surface is considered. The passive resistance is obtained by deducting Fsg from the Fsg + Fpr. The details are given in the tabled below for the 16 nos soil samples. It is reported Chia-Nan Liu et al.(2009) that there exists a difference always between the measured and predicted shear strengths using Eqn(1) and does not compare well them approximately17% on an average of the total combined shear resistance obtained from shear test with geogrid at different densities.

6. PASSIVE RESISTANCE AND NORMAL LOAD

The contribution of passive resistance offered by ribs of the geogrid under the test conditions is approximately 17% on an average of the total combined shear resistance obtained from shear test with geogrid at different densities. The contribution of soil geogrid interface shear resistance is seen 21 % on an average under the test conditions. It can be seen from the Figure.3 and Figure.4 , for all soil samples of S1 and S2,the passive resistance is seen reducing with increase of normal load applied. Table.6.cleary shows that the frictional resistance at soil to soil interface increases with increases of normal load at same density and is decreasing with decrease of density at same normal load.

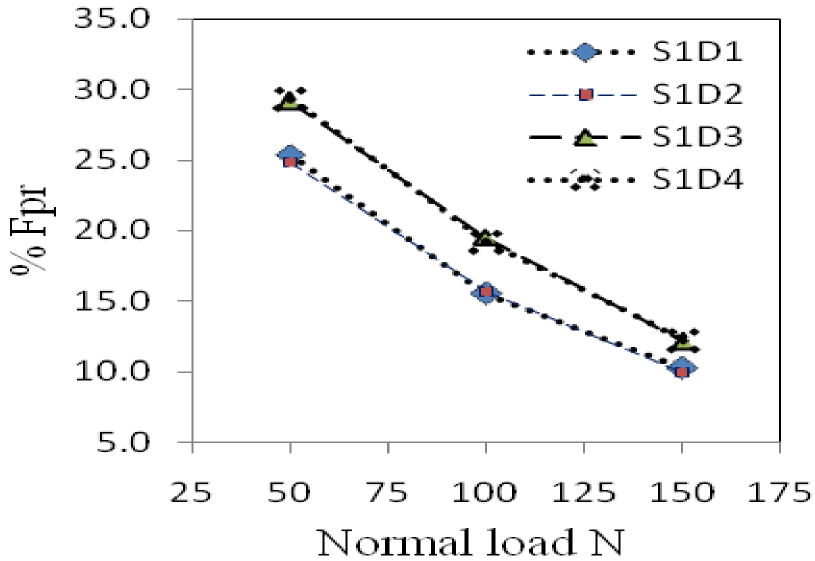

Figure 3 : % Fpr - Normal load

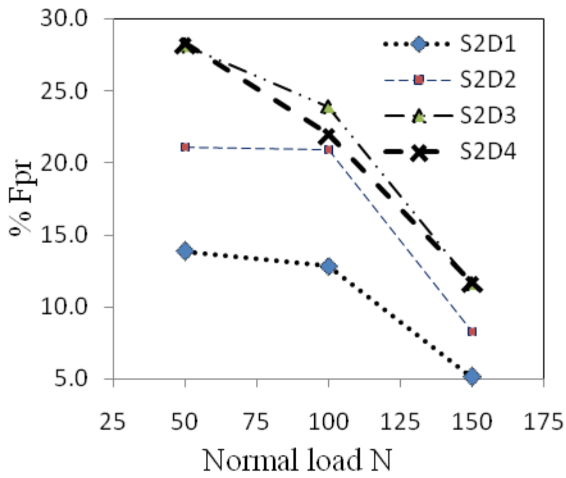

Figure 4 : % Fpr - Normal load

The interface resistance offered by soil geogrid surface is seen increasing with increase of normal load for the same densities and is decreasing with increase of densities at same normal loads. Chia-Nan Liu et al.(2009) has reported that the passive resistance contribution is more significant at low normal stress levels. The authors Nicola Moraci.et al (2014) have observed in their studies that the passive resistance contribution was very diminutive for geogrids without the transverse ribs subjected to shear test. From the Figure 3 and Figure 4 ,observed that therate of increase of % Fpr is more to less density soil samples. The soil samples S1D1and SD2 have higher densities than S1D3 and S1D4.At low normal loads the passive resistance more than the higher normal loads substantiating theories of Nicola Moraci.et al (2014).The range of passive resistance of four soil samples of S1D1 is from 25 to 30% at normal load of 50 N where as that of S2 samples are between 14 to 28% at normal load of 50N.

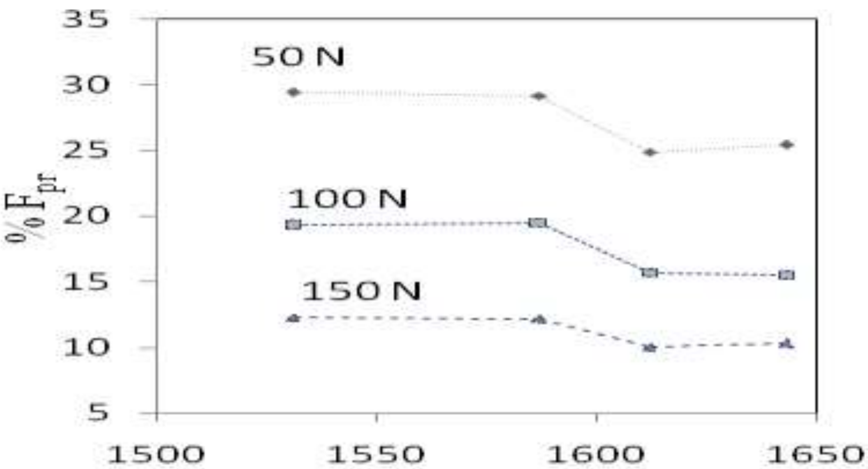

Figure.5,S1 % F_{pr} - Density

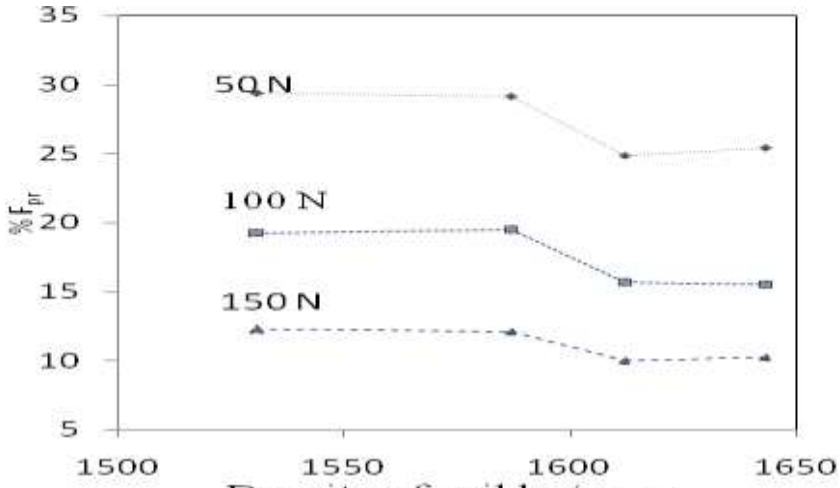

Figure.6,S2 % F_{pr} - Density

The geogrid placed in the test box is surrounded by soil subjected to the shear resistance force, buckling like a small degree bending would occur to the ribs at the same direction of the applied shear load. So the applied load is taken care by the transverse ribs, the soil-geogrid contact surfaces and soil to soil contact area in the open area of the geogrid. When the applied load is increased, the frictional force shares outs non –uniformly with maximum load at the starting point of the load application and transmits progressively to the other free end. At this stage, the relative displacement of soil and geogrid is taken place and the soil-geogrid static friction changes to dynamic condition; rearrangement of soil particles happen leading to the interlocking of soil particles with geogrid at its surfaces and on the transverse ribs. When the normal overlaying load is comparatively diminutive, the soil particles can easily get reorganised by movement and interlocking occurs, and finally, the interface friction is reached to a greatest level .When the applied is load is increased further, only static friction between soil and geogrid is demonstrated dominantly.

When load is applied on the upper half box of the shear box, subsequently the ribs will be exerting force on the soil particles in the direction of force in contact with it. As the force is increasing gradually, the geogrid ribs will be yielding to touch the particles in front of it and it buckles, the soil particles behind ribs will be moved towards the ribs touching the ribs and exerting load on it.So ribs are exerting passive load on the soil particles in front of it and soil particles behind the ribs are in contact with ribs. The soil particles are mobilised at the low vertical loads and interlocking of particles occur around the ribsalso. The soil particles willbein contact with the ribs at both front and back side of it in the direction of the applied force such that the movement of ribs are arrested further,under the constant vertical load.As the soilparticles are in a state of interlocked condition between themselves and with the geogridsurface and when the vertical load is increased further gradually, the particles on the soil-soil interface and soil-geogrid interface are subjected further rearrangements and interlocks ,thefriction load bearing by these interfaces are increased ,but the ribs are in a state of loaded condition by the passive forces by the soil particles in contact with it front side under the constant vertical load .So additional force is taken by soil –soil and soil - geogrid interfaces and hence the load taken by the ribs are reduced, at a constant normal force and density of soil.

When the normal load is increased keeping same density, the particles will have more adhesion among themselves and with geogrid. The rearrangement tendency of soil particles will be reduced because of the high vertical load as compared to a low vertical load. The passive loadings on the ribs will be reduced because of it as compared to a low vertical load. This tendency will be further reduced as the vertical loads are increased further. So the passive resistance force taken care by ribs will be reduced as the vertical loads are increased whereas friction resistance will be more at interfaces between soil to soil and soil geogrid areas.

7. PASSIVE AND COMBINED RESISTANCE

The tests were carried with and without geogrid at different densities and the results are shown in the Table xxx .During the testing at different densities also, all the mechanisms described above take place and shear parameters get changed due to the change of density. When the density of the soil is increased, the more contact area between particles themselves and soil geogrid interface will be available and the frictional resistance will be increased. By this the shear resistance at interface of soil to soil, soil to geogrid increases. The interface shear resistance increases with increase of normal also.

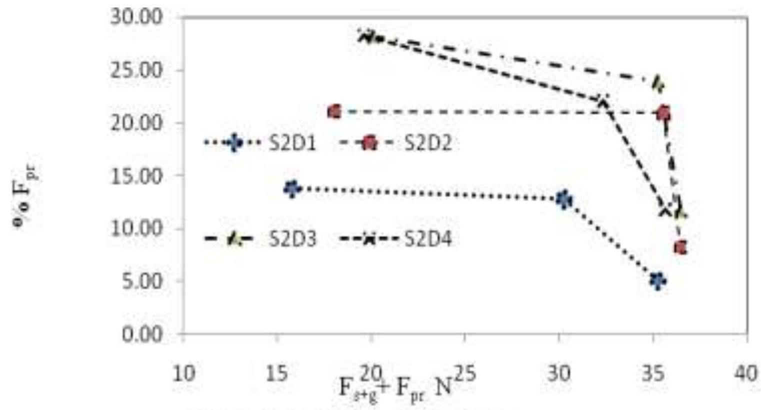

Figure.8,S2 % F_{pr} .. Fs+g + Fpr

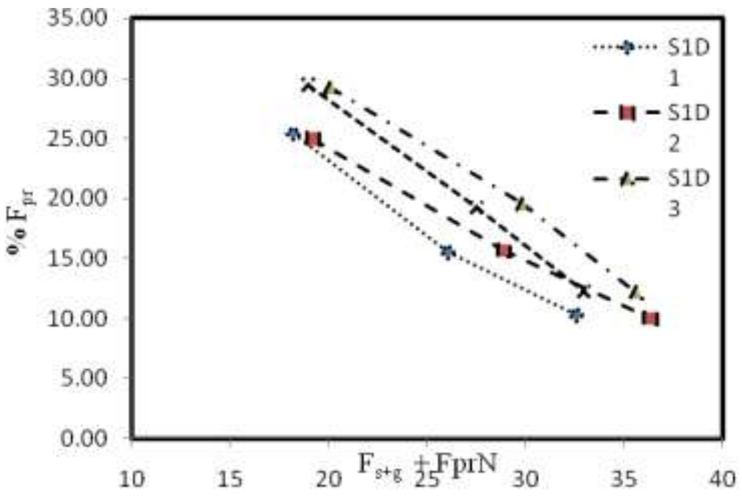

Figure.8,S2 % F_{pr} .. Fs+g + Fpr

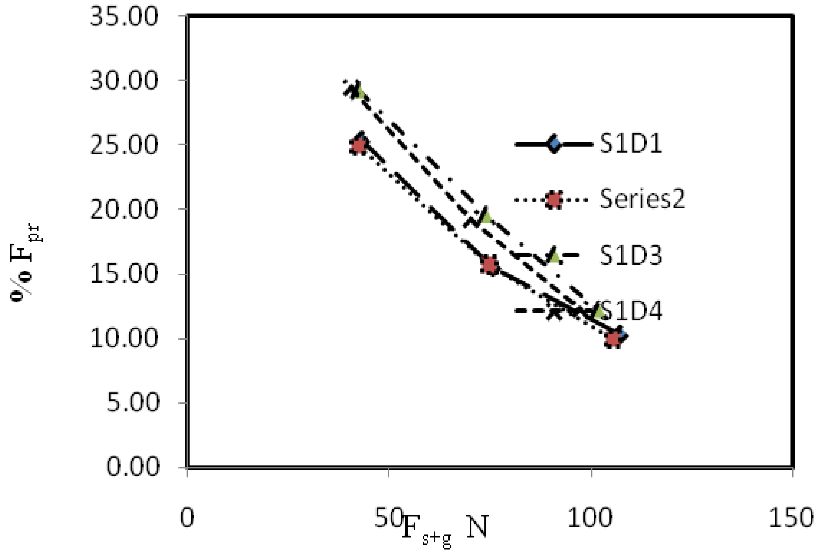

Figure.9, S1 % F_{pr} .. Fs+g

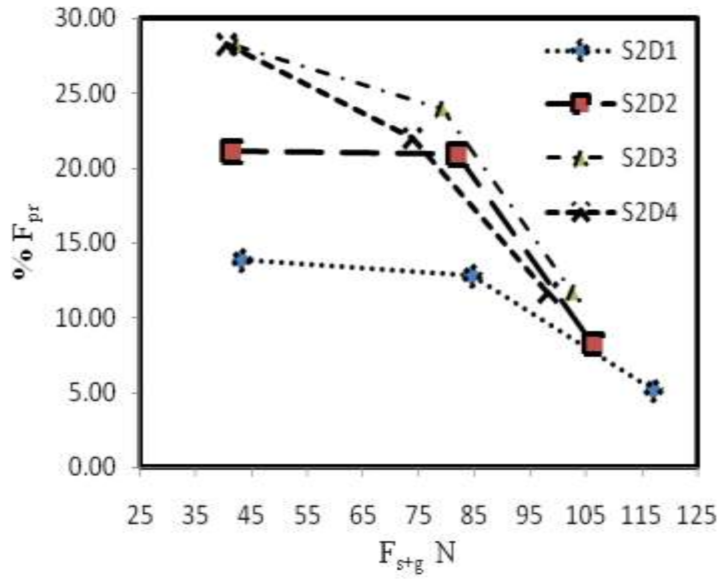

Figure.10, S2 % F_{pr} .. Fs+g

CONCLUSIONS

A sequence of large scale direct shear tests was carried out to study the influence of density and soil gradation on the shear strength parameters at geogrid and soil interface. The contribution of passive resistance of the ribs to the total combined shear strength resistance of soil geogrid interface was given due importance in this study.The following were concluded from the tests.

1. The soil-geogrid interface shear resistance is depended on the normal load, opening of the geogrid, particle gradation and thickness of transverse rib of the geogrid.
2. The passive resistance contributed by ribs found decreasing with increase of normal load. It is observed that the shear strength in sand – geogrid interface mobilized under direct shear mode is related to the particle size at percentage finer 10, 30, 50, and 60.

3. The contribution of passive resistance offered by ribs of the geogrid under the test conditions is approximately 17% on an average of the total combined shear resistance obtained from shear test with geogrid at different densities.
4. The contribution of soil geogrid interface shear resistance is seen 21 % on an average under the test conditions.
5. The presence of higher size particles in the soil samples imparts the increase of the passive resistance and the influence of D50 particles are more than D60 particles to contribute more to passive resistance.
6. When the D30, D50, and D60 are increasing the passive resistance is also increasing, but increase of passive resistance with increase of D50 is less compared to D30 at constant normal load.
7. The frictional resistance at soil to soil interface increases with increases of normal load at same density and is decreasing with decrease of density at same normal load.
8. The interface resistance offered by soil geogrid surface is seen increasing with increase of normal load for the same densities and is decreasing with increase of densities at same normal loads.

REFERENCES

[1].Lopez,M.L (2002).''Soil geosynthetic interaction," Geosynthetic and their applications,ThomasTelford,London.

[2].Dyer, M.R.,. "Observation of the stress distribution in crushed glass with applications to soil reinforcement. Ph.D. thesis, University of Oxford, UK1985.

[3].C.Lackner, D.T. Bergadob, S. Semprich,"Prestressed reinforced soil by geosynthetics e Concept and experimental investigations," Journal ofGeotextiles and Geomembranes 2013

[4].NicolaMoraci.,Giuseppe Cardile.,Domenico Gioffre.,Maria ClorindaMandaglio.,Lidia Sarah Calvarano.,and Laura Carbone,(2014),"Soil Geosynthetic Interaction :Design Parameters from E."xperimental and Theoretical analysis,"Transp.Infrastruct.Geotech.1:165-227

[5].Bergado ,D.T.,Chai,J.C.,Abiera,H.O.,afaro,M.C.,andBalasubramanian.A-.S,(1993),"Interaction between cohesive –frictional soil and various grid reinforcements."Geotext.geomember.,12(4),327-349

[6].Seo, M.; Kim, B.; Ha, I.," A comparison of coarse grained soils using large direct shear test and large triaxial shear test," Korean J. Geoenviron. Eng. 2009, 10, 25–34.

[7].EsmaMostefa Kara, MouradMeghachou , Nabil Aboubekr Contribution of Particles Size Ranges to Sand Friction,"ETASR - Engineering, Technology & Applied Science Research Vol. 3, No. 4, 2013, 497-501

[8].Chia-Nan Liu,JorgeG.ZornbergM.ASCE,Tsong-Chia Chen,Yu-Hsien Ho and Bo-Hung Lin,"Behavior of Geogrid-Sand Interface in Direct Shear mode,"Journal of geotechnical and Geoenvironmental Engineering @ ASCE/DECEMBER 2009.

[9].Wrigley, N. E. (1989), "The Durability and Aging of Geogrids," Proc. GRI-2, Durability and Aging of Geosynthetics, Publ. by Elsevier Appl. Sci., London and New York, pp. 110-134

[10].Liu,C.-N.,Ho,Y.-H.,Huang,J.-W.:Large scale direct shear tests of soil /PET-yarn geogrid interfaces.Geotext.Geomember,27,19-30(2009)

[11]. Jewell, R.A., Milligan, G.W.E., Sarsby, R.W., Dubois, D.: Interaction between soil and geogrids Telford, T. (ed.) Prooceedings of the Conference on Polymer Grid Reinforcement in Civil Engineering. 1984, pp. 18–30

[12].Kousik Deb and SankuKonai, "Bearing capacity of geotextile – reinforced sand with varying fine fraction,"Geomechanics and Engineering, vol.6,No.1(2014) 33-45.

[13].Daehyeon Kim and Sung woo Ha, "Effects of Particle Size on the Shear Behavior of Coarse Grained Soils Reinforced with Geogrid,"Materials, 2014.

[14].Ennio Marques Palmeira ,"Soil–geosynthetic interaction: Modeling and analysis"Journal of Geotextiles and Geomembranes 2009

[15].C. Lackner, D.T. Bergadob, S. Semprich,"Prestressed reinforced soil by geosynthetics e Concept and experimental investigations," Journal ofGeotextiles and Geomembranes 2013

[16].Seo, M.; Kim, B.; Ha, I.," A comparison of coarse grained soils using large direct shear test and large triaxial shear test," Korean J. Geoenviron. Eng. 2009, 10, 25–34.

[17].M.J. Lopes and M.L. Lopes," soil-geosynthetic interaction – influence of soil particle size and geosynthetic structure,"Geosynthetics international s 1999, vol. 6, no. 4.

[18].Ennio Marques Palmeira,“ Bearing force mobilization in pullout tests on geogrids, ”Geotextiles and Geomembranes,22 (2004) 481–509

[19].EsmaMostefa Kara, MouradMeghachou , Nabil Aboubekr Contribution of Particles Size Ranges to Sand Friction,”ETASR - Engineering, Technology & Applied Science Research Vol. 3, No. 4, 2013, 497-501

[20].Danda Shi and Fei Wang. Pull-out Test on the Interface Characteristics between Geogrid and soils, ”EJGE, vol.18, Bund.W, 2013.

[21].Bergado,D.T,Chai,J.C.,Abiera,H.O,Alfaro,M.C.,Balasubramaniam,A.S.,1993,Interactin between cohesive – frictional soil and various grid reinforcements,” Geotextiles and Geomembranes 12(4) 327-349.

[22]M.R.Abdi,A.Sadrnejadand M.A.Arjomand,“strength enhancemnent of clay by encapsulating geogrids in thin layers of sand,”Geotextiles and Geomembranes 27(2009) 447-455