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RESEARCH ARTICLE

GEOGRID – SAND INTERFACE FRICTIONAL PROPERTIES IN DIRECT SHEAR MODE

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Abstract

This paper presents the results of a series of large scale direct shear tests carried out using sand and geogrid to appraise the contribution of shear resistance at interfaces between soil-soil, soil-geogrid and the soil- transverse ribs of a geogrid during the test. 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 passive resistance contributed by ribs found decreasing with increase of normal load and the passive resistance found decreasing with decreasing of density

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Introduction: -

At present, 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 [1]. The geotextile – soil interface is mainly governed by the skin friction between them and penetration of soil particles into 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 studies Dyer, M.R [2]. Different failure mechanisms occurring in specific zones due to different interactions between the backfill material and the reinforcement were indicated by C. Lackner [3].

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 have 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 Moraci [4] 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.

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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 [1] 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.[5] geogrid-geometrial properties impart much contribution to passive resistance in a direct mode shear test using a HDPE geogrid - soil interface.

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, M [6]. In the case of unreinforced, as the maximum 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 Esmamostefa Kara [7]. 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 Liu [8]. It was observed by Chia-Nan Liu [8], 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 the geogrid.

The Fig.1 shows the mechanism of interlock in geogrid with soil samples. The soil particles having lesser size than the aperture is locked in the openings of the geogrid and touching the ribs. Both longitudinal ribs (LR) and transversal ribs (TR) take role to contribute to the shear strength of geogrids. Fig. 2 is showing a typical view of geogrid with longitudinal and transverse ribs with opening of the aperture. The direction of shear force and the that of shear resistant direction along the ribs also marked. The total area of geogrid shall be calculated with the dimensions of it to calculate shear resistance by the geogrid soil interface.

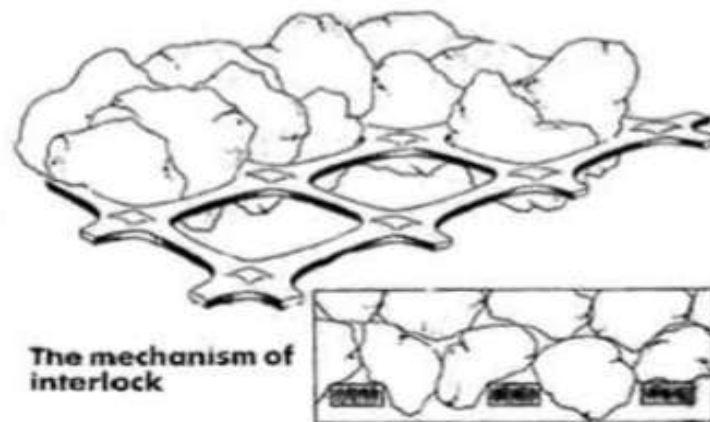


Figure 1. The mechanism of interlock (Wrigley, 1989)

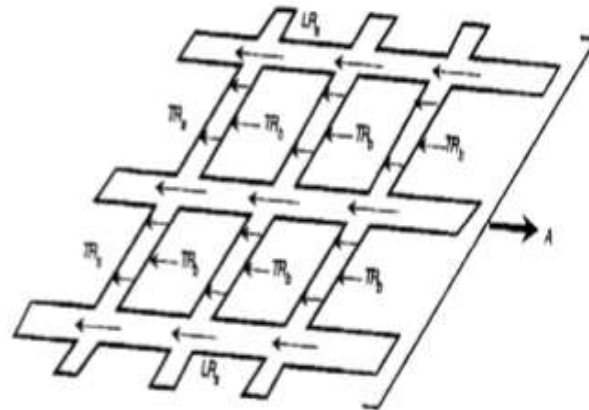


Figure 2: Interaction mechanisms on geogrids (Bergado et al, 1993)

The authors [8, 10] 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. It can be seen from the results of a direct shear test, Fig. 3 that the quantity of shear resistance component developed due to friction between soil to soil is greater than the resistance offered from soil to geogrid interfaces.

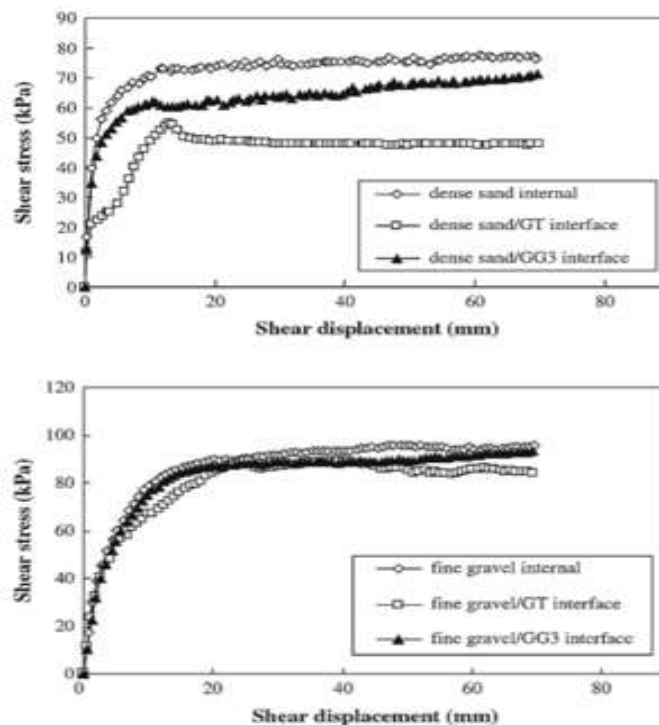


Fig. 3. Stress–strain behavior of different soil–soil, soil–GT, and soil–GG interfaces under the same normal pressure

Jewell et al. [11] conducted the first theoretical study on soil geosynthetic interaction at direct shear mode. He suggested the basic equation to calculate the shear strength in a sand geogrid interface mobilized under direct shear mode as follows.

$$\tau_{\text{sand-geogrid}} = \sigma_n \cdot [(1 - \alpha_{ds}) \cdot \tan \delta + \alpha_{ds} \tan \phi'_{ds}]$$

where α_{ds} =percentage open area of geogrid,, δ = interface friction angle between soil and geogrid,, ϕ'_{ds} = internal friction angle of sand from direct shear test

Therefore, the total direct shear force can be given as:

$$F_{s+g} = F_{ss} + F_{sg}$$

Where

F_{s+g} = Total direct shear resistance force

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

F_{sg} = soil to geogrid direct shear frictional 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

Test Apparatus:

The large scale 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.

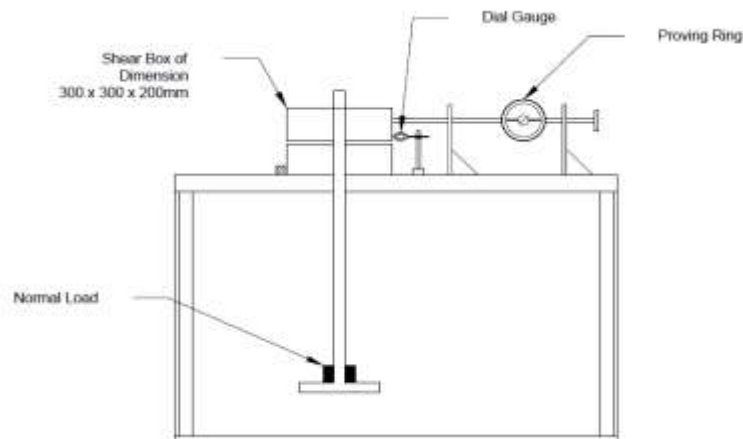


Fig 4:- Shear Box of size 300 x 300 x 200 mm.



Fig 5:- Photograph of test set up.

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.

Table 1:- Soil samples sieve analysis report.

Sand samples	D10 mm	D30 mm	D50 mm	D60 mm	Cu	Cc
S1	0.25	1.45	5	7.4	29.6	1.14
S2	0.3	1.9	6.5	8.5	28.3	1.42
S3	0.31	2.5	10.1	10.2	32.9	1.98
S4	0.19	0.31	2.3	5	26.3	0.1

Table 2:- Properties of soil samples.

Soil	Density kg/cu.m	Soil samples	Internal Friction Angle Dgrees ϕ_{ss}
S1	1643	S1D1	35.75
	1612	S1D2	33.66
	1587	S1D3	32.6
	1531	S1D4	31.8
S2	1710	S2D1	38.34
	1664	S2D2	34
	1613	S2D3	32.6
	1575	S2D4	31.1
S3	1729	S3D1	39.35
	1695	S3D2	36.43
	1612	S3D3	35
	1595	S3D4	32.9
S4	1672	S4D1	37.7
	1613	S4D2	34.7
	1598	S4D3	33.7
	1546	S4D4	32.6

Table 3:- Properties of geogrid.

Property	Value
Color	Black
Type	Biaxial
Tensile Strength (kN/m)	13
Aperture Size (mm)	26x20
Mass per Unit Area (g/m ²)	225
Thickness of ribs mm	1.0

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 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 10 mm 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 5 cm. 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 over the lower one and the screws are tightened 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 soil samples are tested without the geogrid and with geogrid at four densities of each soil samples. The details are given Table.4

The interface shear stress τ_p of the modified shear test can be defined as
 $\tau_p = T_p / A_p$

Where A_p is the area of geogrid buried in the soil sample and T_p is the horizontal force applied [10]

The sand – Geogrid interface under direct shear mode may include following mechanisms. (1) Soil and ribs of geogrid shear resistance (2) internal soil shear resistance in the opening area 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]
 $\tau_{sand-Geogrid} = \sigma_n [(1-\rho) \tan \phi_{sg} + \rho \tan \phi_s]$(1)

Where σ_n is the normal stress, ρ is the per cent of open area of geogrid. ϕ_{sg} is the interface friction angle between sand and the geogrid and ϕ_{ss} the soil angle of internal friction.

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 150 N. 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 shear test with geogrid.

The interface frictional force between soil to soil F_{ss} in soil-soil contact areas can be described in equation below.
 $F_{ss} = A_{ss} \cdot \tau_{ss} = A_{ss} \cdot \sigma_n \cdot \tan \phi_{ss}$(2)

where:

A_{ss} = total shear area of the box

τ_{ss} = soil shear strength

σ_n = normal stress applied on the soil sample

ϕ_{ss} = soil interface friction angle

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 transverse ribs of the geogrid. The normal stress against the shear stress was plotted and the combined angle of internal friction $\phi_{sg} + \phi_{ss}$ 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.

$$F_{s+g} = A \cdot \sigma_n \cdot \tan \phi_{s+g} \dots \dots \dots (3)$$

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

$$F_{s+g} = F_{ss} + F_{sg} + F_{pr} \dots \dots \dots (4)$$

Where

F_{sg} = soil –geogrid interface friction force

F_{pr} =transverse rib passive resistance force.

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

$$F_{sg} = A_{sg} \cdot \sigma_{sg} = A_{sg} \cdot \sigma_n \cdot \tan \phi_{sg} \dots \dots \dots (5)$$

Where:

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

σ_{sg} = soil to geogrid interface shear strength

ϕ_{sg} =soil to geogrid interface friction angle.

The soil to geogrid interface friction F_{sg} 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 F_{s+g} .

$$F_{sg} + F_{pr} = F_{s+g} - F_{ss} \dots \dots \dots (6)$$

The total soil geogrid interface friction strength σ_{sg} will be obtained by dividing the $F_{sg} + F_{pr}$ by the geogrid area of contact with soil.

$$\sigma_{sg} = (F_{sg} + F_{pr}) / A_{sg} \dots \dots \dots (7)$$

On plotting the applied normal stresses against the interface peak shear stresses σ_{sg} of the soil geogrid interfaces, the interface friction angle Φ_{sg} will be obtained. Using this, the shear strength resistance offered by soil-geogrid surface can explained using Eqn(5). The ϕ_{s+g} and ϕ_{sg} obtained are given in Table.5 below and Table2.

Table 5:- Interface friction angles.

Soil samples	Φ_{s+g}^0	Φ_{sg}^0
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
S3D1	33.74	33.94
S3D2	34.37	29.5
S3D3	32.94	27.9
S3D4	30.33	24
S4D1	34	24.56
S4D2	33.7	33.82
S4D3	31.5	26.24
S4D4	29.9	23.61

Result and Discussion:-

The F_{s+g} is the combined interface friction force obtained from the shear test with geogrid, F_{ss} is the interface friction force of the opening area of the geogrid calculated using Equation (2) with the angle of internal friction obtained from the shear test carried out without geogrid and F_{sg} is the interface friction force soil to grid contact area including passive resistance of ribs, obtained using Equation (5). Here the interface shear strength of sand-geogrid is taken from the graph drawn between the normal stresses against the $F_{sg} + F_{pr}$.i.e. $F_{s+g} - F_{ss}$. Using Φ_{sg} obtained from the failure envelope, Equations (3) and (5), were used to predict F_{sg} . Here only the shear resistance of between the soil to geogrid surface is considered. The passive resistance is obtained by deducting F_{sg} from calculated from the $F_{sg} + F_{pr}$. The details are given in the table below for the 16 nos soil samples. It is reported Chia-Nan Liu [8] that there

exists a difference always between the measured and predicted shear strengths using Equation (1) and does not compare well them.

Table. 6:- Details of test results and calculated data of soil samples S1 and S2.

SAMPLES	σ_n N	F_{s+g} N	F_{ss} N	$F_{sg}+F_{pr}$ N	F_{sg} N	F_{pr} N	% F_{ss}	% F_{gg}	% F_{pr}
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

It is seen that in most of the cases the magnitude of predicted shear strength is smaller than the measured value by shear test. Using a geosynthetic textile for a shear test with sand, the shear strength at interface between soil and geotextile ϕ_{sg} is used for predicting F_{sg} , it is observed that peak shear strength of the interface between geotextile and sand develops at smaller displacements than the that of sand-geogrid interface. The test results and calculated data are given Table. 6 for soil samples S1 and S2. Table .7 shows the details for soil samples S3 and S4

SAMPLES	σ_n N	F_{s+g} N	F_{ss} N	$F_{sg}+F_{pr}$ N	F_{sg} (predicted)	F_{pr} N	% F_{ss}	% F_{gg} predicted	% F_{pr}
S3D1	50	44.1	28.45	15.65	10.57	5.08	64.52	23.96	11.52
	100	88.2	56.40	31.80	20.94	10.86	63.95	23.74	12.31
	150	121.5	84.85	36.65	31.51	5.14	69.84	25.93	4.23
S3D2	50	43.2	25.61	17.59	8.87	8.72	59.28	20.53	20.19
	100	84.6	50.76	33.84	17.58	16.26	60.00	20.78	19.22
	150	111.6	76.37	35.23	26.45	8.78	68.43	23.70	7.87
S3D3	50	42.3	24.36	17.94	8.31	9.64	57.59	19.63	22.78
	100	81	48.28	32.72	16.46	16.25	59.61	20.32	20.07
	150	107.1	72.64	34.46	24.77	9.69	67.83	23.13	9.05
S3D4	50	41.4	22.49	18.91	7.00	11.91	54.31	16.91	28.77
	100	77.4	44.57	32.83	13.88	18.95	57.58	17.93	24.48
	150	99.9	67.06	32.84	20.88	11.96	67.12	20.90	11.97
S4D1	50	45	26.86	18.14	7.17	10.97	59.68	15.94	24.37
	100	83.7	53.24	30.46	14.22	16.24	63.60	16.99	19.41
	150	112.5	80.09	32.41	21.40	11.01	71.20	19.02	9.79

S4D2	50	42.3	24.05	18.25	9.53	8.72	56.85	22.53	20.62
	100	81	47.67	33.33	18.89	14.45	58.85	23.32	17.83
	150	108.9	71.71	37.19	28.42	8.77	65.85	26.10	8.05
S4D3	50	42.3	23.11	19.19	7.74	11.45	54.63	18.30	27.07
	100	76.5	45.81	30.69	15.34	15.35	59.88	20.05	20.07
	150	103.5	68.92	34.58	23.08	11.50	66.59	22.30	11.11
S4D4	50	39.6	22.17	17.43	6.86	10.57	55.99	17.33	26.68
	100	72.9	43.95	28.95	13.60	15.35	60.29	18.65	21.06
	150	97.2	66.12	31.08	20.46	10.62	68.03	21.05	10.92

Table.7:- Detailsof test results and calculated data of soil samples S3 and S4.

Variation of Passive Resistance With Densities:

The variation of Passive resistance at different densities and normal loads were studied from the results of the test. The test conducted using four soil samples each at four different densities with a same geogrid at normal loads of 50N,100N and 150N.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 Fig.5 to Fig.8, for all soil samples of S1,S2,S3 and S4,the passive resistance is seen reduced with increase of density of soil for the same normal stress. The passive resistance is reducing with increase of normal stress for soils with same densities in all the cases of soil samples tested. 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. 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 [8] has reported that the passive resistance contribution is more significant at low normal stress levels. The authors [4] have observed in their studies that the passive resistance contribution was very diminutive for geogrids without the transverse ribs subjected to shear test.

When the geogrid is placed in position in the test box, it 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 shearload. 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 out 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 happens 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 reorganise and adjust 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, 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 in 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 the ribs. The soil particles are mobilised at the low vertical loads and interlocking of particles occur around the ribs also. The soil particles will be in 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 soil particles are in a state of interlocked 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 ,the friction 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 ribs from both sides 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 at the constant same density, the particles will have more contact area with the themselves and geogrid.Therearrangement tendency of soil particles will be reduced because of the high vertical load

as compared to a low vertical load. The active and 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 where as friction resistance will be more at interfaces between soil to soil and soil geogrid areas. Similarly, when the density of the soil is increased, the more contact area between particles and the geogrid will be available and the frictional resistance will also be increased.

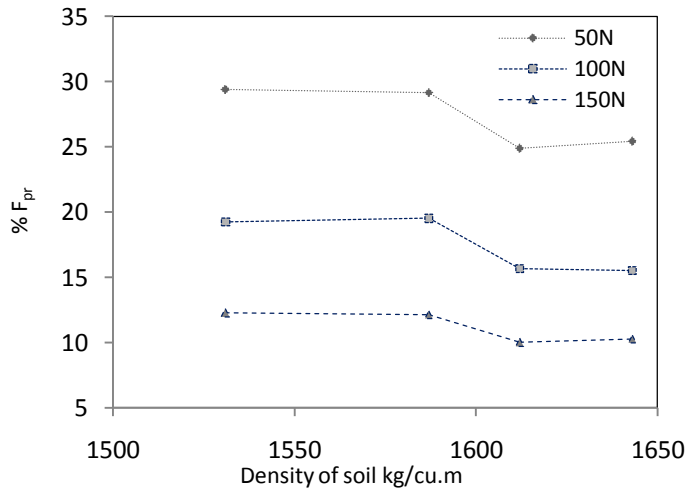


Fig.5,S1,Density against % Passive resistance

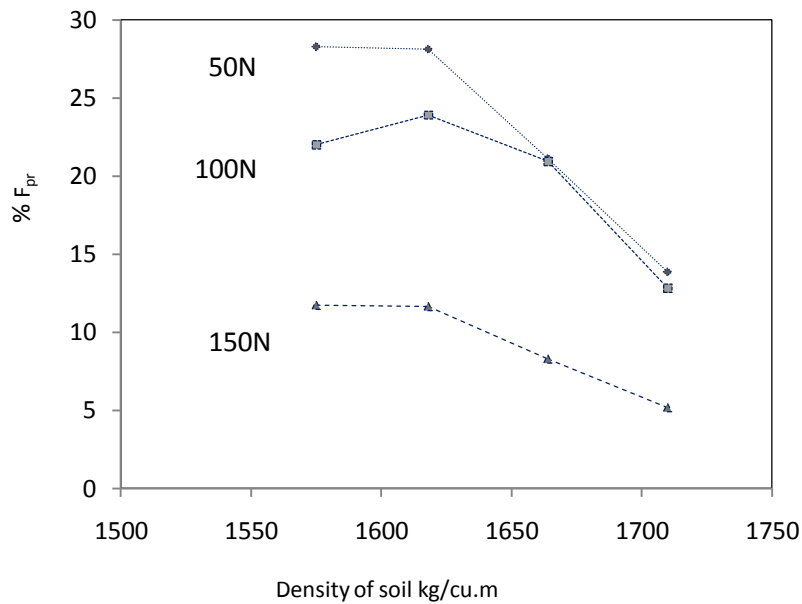


Fig.6,S2,%Passive resistance against Density

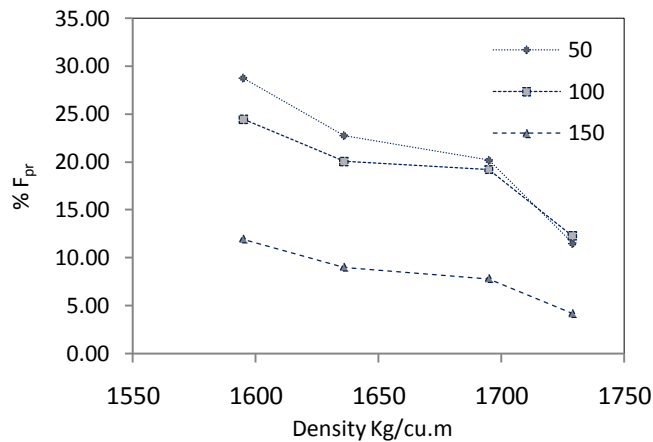


Fig.7,S3,Density against % passive resistance

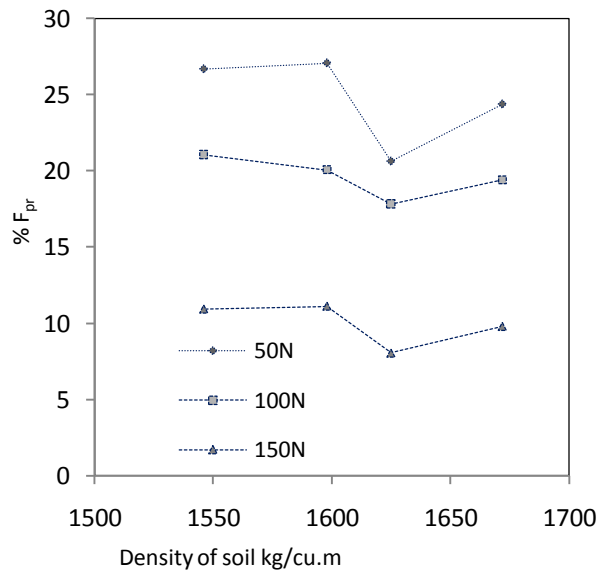


Fig.8,S4,% Passive Resistance against Density

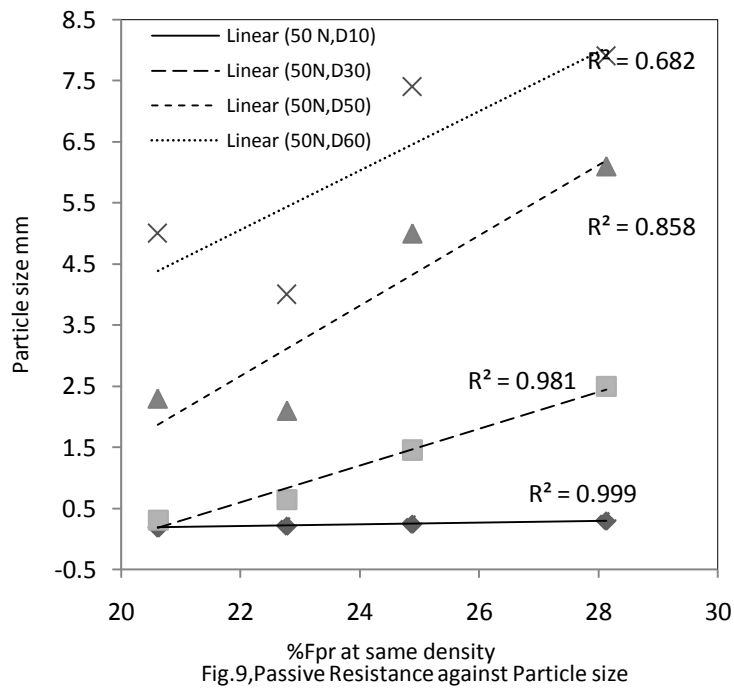
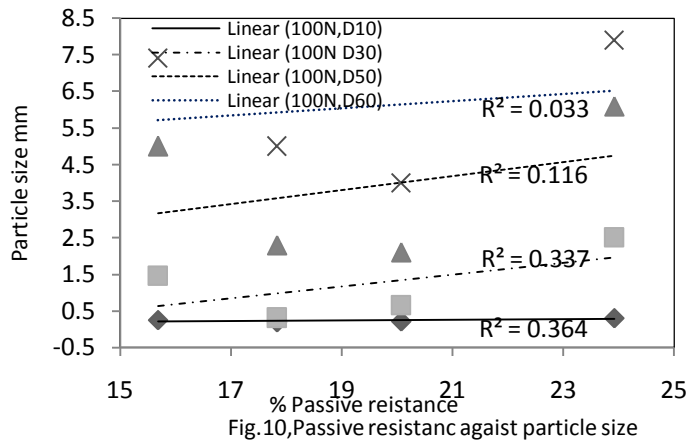
Variation of Passive resistance with particle size:

From the Table.6 and Table 7, it can be seen that soil samples S1D2, S2D3, S3D3 and S4D2 have almost the same densities.

Table.1 gives the details of particles size distribution of all the four soils taken from the sieve analysis report of the samples.

The variation of D₁₀, D₃₀, D₅₀, and D₆₀ with % passive resistance contribution of soil samples S1D2, S2D3, S3D3 and S4D2 from Table.6 and Table 7 is analysed at normal loads of 50N, 100N and 150N at same density soils. Fig.9 to Fig.11 shows the variation of passive resistance with respect to the particle sizes of D₁₀, D₃₀, D₅₀, and D₆₀ at same density of four soil samples tested at constant normal stress. The figures show that at 50N normal load, when the D₃₀, D₅₀, and D₆₀ are increasing the passive resistance is also increasing, but the increase of passive resistance with increase of D₅₀ is less compared to D₃₀ and D₆₀. Similar is the case when the normal load is 100N and 150N. Also, the passive resistance is increasing without much increase of D₁₀ particles. In all soil samples, the presence of D₅₀ and D₆₀ soil particles has a big range of sizes than D₁₀ and D₃₀ varying from size 6mm to 2.1mm for D₅₀ and 4mm to 7.9mm for D₆₀. The presence of higher size particles in the soil samples imparts the increase of the passive resistance. The thickness of the transverse rib is only 1mm and the particles having size greater than 1mm would be more effective to interlock the ribs with soil particles than particles having size less than 1mm. D₅₀ particles have less sizes than

D60 group of particles. The influence of D50 particles are more effective than D60 particles to impart the increase of passive resistance.



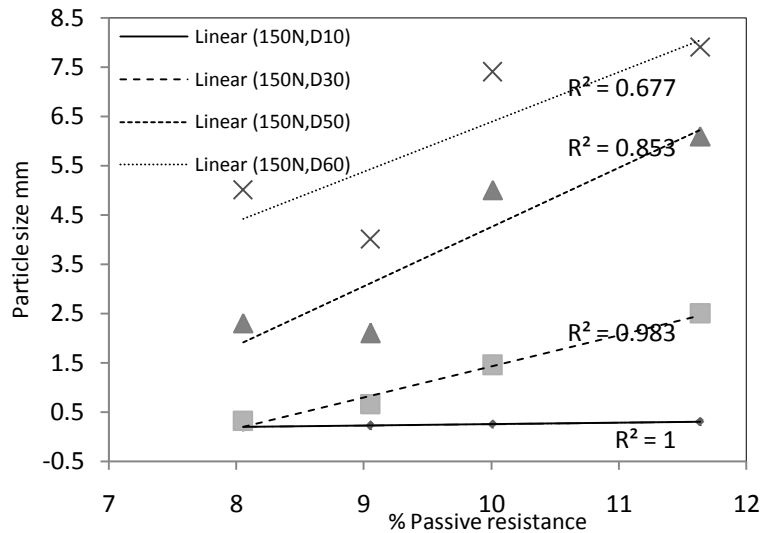


Fig.11,Passive Resistance against particle size

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 D_{50} particles are more than D_{60} particles to contribute more to passive resistance.
6. When the D_{30} , D_{50} , and D_{60} are increasing the passive resistance is also increasing, but increase of passive resistance with increase of D_{50} is less compared to D_{30} 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

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