IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified ⁜ Impact Factor 7.105 ⁜ Vol. 9, Issue 8, August 2022

DOI: 10.17148/IARJSET.2022.9820

Influence of Soil Properties on Shear Resistance at Sand-Geogrid Interface in Direct Shear Mode

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Abstract: The properties of soil in contact with the geogrid in soil-geogrid interface in shear mode is having major role in resisting the shear force. In the shear failure mode, the particles in contact with each other in aperture area and particles in touch with geogrid are effectively resisting shear force during the shear test. The particles in contact with each other or with geogrid are contributing the resistance. The particle size and their associated voids play an important role in the dissipation of energy under the loading of granular materials. A correlation was formulated by this author considering the actual area of contacts with dry density as variable for the shear resistance at the interface. Based on this formulation, the variation of shear resistance with soil properties is studied in this paper.

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

I. INTRODUCTION

In a direct shear mode failure, the movement of the soil particles on the one side of the geogrid reinforcement take place with respect to soil particles on the other side of the geogrid reinforcement. This sort of movement is invariable along the reinforcement surfaces take place. The load transformation mechanism of the granular mass depends on the individual soil grains as load transfer particle to particle and the macroscopic response of granular mass is the resultant of the individual response of the particles. In direct shear mode test using sand and geogrid, the shear strength of sand-geogrid interface is usually attributed to shear resistance of sand - geogrid interface areas and shear resistance mobilized at soil-soil interface in the geogrid openings.

II. SOIL GEOGRID INTERFACE RESISTANCE MODELLING

Jewell et al. (1986) suggested the basic equation to calculate the shear strength in a sand geogrid interface mobilized under direct shear mode as follows. The first theoretical study on soil geosynthetic interaction at direct shear mode was conducted by him.

$$\tau_{\text{sand-geogrid}} = \sigma_n.[(1-\alpha_{ds}) \cdot \tan\delta + \alpha_{ds} \tan\phi_{ds}] \qquad (4.1)$$

The interaction mechanisms between soil and geogrid at interface is composed of shear resistance between soil and surface of geogrid ribs, internal shear resistance of soil in the openings of geogrids and passive resistance of transverse ribs is depicted in Figure 4.1.

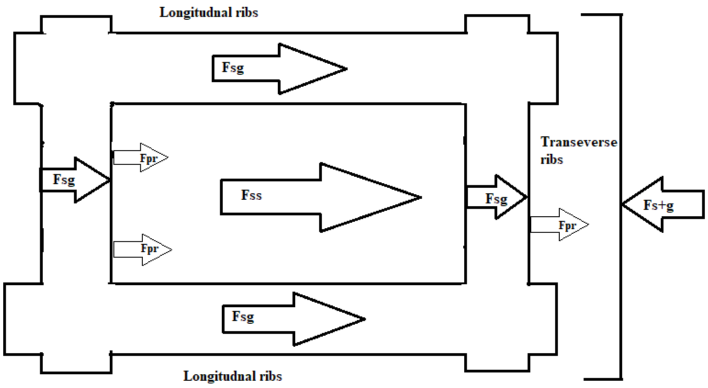

Figure 4.1 **Shear resistance forces acting on a geogrid interface in shear test interaction**

Chia-Nan Liu et al. (2015) have carried out large scale shear tests in modified shear box using sand. The test results of direct shear tests were used with above equation which predicts the shear strength of sand-geogrid interface. The equation accounts only shear resistance between sand - geogrid interface and sand-sand interface at aperture area. The team found difference between measured and predicted shear strength which indicates that the passive resistance induced by transverse ribs provides additional sand-geogrid interface shear strength under direct shear mode.

The combined interface friction force obtained in direct shear tests is explained by the following equation.

$$F_{s+g} = F_{ss} + F_{sg} + F_{pr} \quad (4.2).$$

III.CORRELATION OF SHEAR RESISTANCE WITH SOIL PROPERTIES

A.L.Mannissery.(2022) has formulated an equation connecting the shear resistance force at interface of sand-Geogrid in a shear mode The combined interface friction force (F_{s+g}) in a soil geogrid interface is the sum of soil to geogrid interface friction force (F_{sg}), soil to soil interface friction force (F_{ss}) in aperture and the passive bearing resistance F_{pr}.

$$F_{s+g} = \sigma.\ A_{sc}.\tan \phi_{s+g} \quad (4.11)$$

$$F_{ss} = \sigma.\ A_{ssc}.\tan \phi_{ss} \quad (4.12)$$

$$F_{sg} = \sigma.\ A_{sgc}.\tan \phi_{sg} \quad (4.13)$$

Replacing A_{sc}, A_{ssc} and A_{sgc} with

$$A_{sgc} = \frac{Asg}{1+e}\ ,\ A_{ssc} = \frac{Ass}{1+e}\ ,\ A_{sc} = \frac{A}{1+e}$$

the above Equations becomes as

$$F_{s+g}= \frac{1}{1+e}\sigma.A.\tan\varphi_{s+g} \quad (4.14)$$

$$F_{ss}= \frac{1}{1+e}\sigma.A_{ss}.\tan\varphi_{ss} \quad (4.15)$$

$$F_{sg}= \frac{1}{1+e}\sigma.A_{sg}.\tan\varphi_{sg} \quad (4.16)$$

On substituting the dry density relationship with void ratio, the above equations become as below

$$F_{s+g}= \frac{\rho_d}{G_s.\gamma_w}\sigma.A.\tan\varphi_{s+g} \quad (4.17)$$

$$F_{ss}= \frac{\rho_d}{G_s.\gamma_w}\sigma.A_{ss}.\tan\varphi_{ss} \quad (4.18)$$

$$F_{sg}= \frac{\rho_d}{G_s.\gamma_w}\sigma.A_{sg}.\tan\varphi_{sg} \quad (4.19)$$

Where φ_{sg} = Interface friction angle between soil and Geogrid

φ_{ss} = Interface friction angle between soil and soil

σ_n = Normal stress

ρ_d = dry density

Gs = specific gravity

γ_w = unit weight of water

A_{sgc} = Total area of contact between soil particles and geogrid at interface

A_{sgv} = Total area of voids between soil particles and geogrid at interface

A_{ssc} = Total area of contact between soil - soil in the aperture area at interface

A_{ssv} = Area of voids between soil particles in the aperture area

A_{sc} = Total area of soil contact with soil-soil and soil- geogrid surface

A_v = total area of voids at the interface failure plane.

The equation (4.2) is arranged as below, applying the concept of effective area of friction contact between the soil particles at the plane of the interface failure the passive bearing resistance provided by transverse ribs is deduced as below. The combined interface friction force (F_{s+g}) in a soil geogrid interface is measured value from direct shear tests.

$$F_{pr}=\frac{\rho_d}{Gs.\gamma_w}\sigma.\left(A.\tan\varphi_{s+g} - \left(A_{ss}.\tan\varphi_{ss} + A_{sg}.\tan\varphi_{sg}\right)\right) \quad (4.20)$$

$$F_{pr}=\frac{\rho_d}{Gs.\gamma_w}\left(F_{s+g} - \sigma\left(A_{ss}.\tan\varphi_{ss} + A_{sg}.\tan\varphi_{sg}\right)\right) \quad (4.21)$$

IV.PASSIVE BEARING RESISTANCE VARIATION WITH DRY DENSITY

The variation of passive bearing resistance and dry density of soil sample is studied at two background, one at constant dry density varying normal stress and second is variable dry density constant normal stress.

ISO 3297:2007 Certified ⁜ Impact Factor 7.105 ⁜ Vol. 9, Issue 8, August 2022

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In all cases of soil geogrid with transverse ribs interface subjected to a shear force, the statement below is all ways holds true.

$F_{s+g} > F_{ss} > F_{sg} > F_{pr}$
Also, the following statement is hold true always at constant dry density.
$\phi_{ss} > \phi_{s+g} > \phi_{sg}$

$$F_{pr}=\frac{\rho_d}{G_S.\gamma_w}\left(F_{s+g}-\sigma\left(A_{ss}.\tan\varphi_{ss}+A_{sg}.\tan\varphi_{sg}\right)\right) \qquad (4.21)$$

Figure 4.1 shows the F_{pr}, F_{s+g}, F_{ss} and F_{sg} .
At variable dry density and constant normal stress conditions considering Equation (4.20) above, it can be observed that when ρ_d increases at constant normal stress, φ_{s+g}, φ_{ss} and φ_{sg} increases. σ_n, A_{ss}, A_{sg} and A are also constants. The φ_{ss} is more than φ_{s+g} and φ_{sg} , and the F_{s+g} is the measured value from the shear tests. The rate increase of F_{s+g} with increase of dry density is only minimum whereas the rate of increase of Fss is more compared to F_{s+g} and F_{sg}.Hence the value of (F_{s+g}- σ_n (A_{ss}.tanφ_{ss} + A_{sg} . tanφ_{sg})) reduces with increase of dry density at constant normal stress σ. In case when the normal stress increases, the same happens and F_{pr} reduces. F_{pr} reduces with increase of dry density ρ_d for constant normal stress.

Considering Equation (4.21) at constant dry density and variable normal stress conditions, it can be observed that when ρ_d is constant, φ_{s+g}, φ_{ss}, φ_{sg}, A_{ss}, A_{sg} and A are constants. Only normal stress is increasing. As φ_{ss} is more than φ_{s+g} and φ_{sg}, and the F_{s+g} is the measured value from the shear tests. The rate of increase of F_{s+g} with increase of normal stress is very significant. The factor (A_{ss}. tanφ_{ss} + A_{sg}. tanφ_{sg}) in the equation is constant and normal stress goes on increasing and hence this factor is getting increased very much. Hence the value of (F_{s+g} - σ_n. (A_{ss}. tanφ_{ss} + A_{sg}. tanφ_{sg})) reduces with increase of normal stress at constant dry density. F_{pr} reduces with increase of normal stress at constant dry density ρ_d.

V.PASSIVE BEARING RESISTANCE VARIATION WITH PERCENTAGE FINER AT PARTICLE SIZE D_{10}, D_{30}, D_{50}, AND D_{60}

The size of particles D_{10}, D_{30}, D_{50}, and D_{60} increases with increase of percentage finer particle at D_{10}, D_{30}, D_{50}, and D_{60} in each soil mass. If it is required to increase the particle size at any percentage finer in the soil mass, particles having size higher than the particle size in consideration have to be removed from the soil mass, in case of field applications and add equivalent quantity of soil particles having the same size in consideration to increase. When the higher particles removed, smaller size particles up to the level of the larger sized particles. Then the quantity of smaller sized particles will be more in the soil sample. The soil with small particles will have more voids which reduces the density. The increase of size of D_{10}, D_{30}, D_{50}, and D_{60} particles will reduce density of soil.

$$F_{pr}=\frac{\rho_d}{G_S.\gamma_w}\left(F_{s+g}-\sigma\left(A_{ss}.\tan\varphi_{ss}+A_{sg}.\tan\varphi_{sg}\right)\right) \qquad (4.21)$$

Considering Equation (4.21) above, it can be observed that when ρ_d decreases at constant normal stress, φ_{s+g},φ_{ss} and φ_{sg} also reduces. σ_n, A_{ss}, A_{sg} and A are also constants. The φ_{ss} is more than φ_{s+g} and φ_{sg} , and the F_{s+g} is a measured value from the shear tests. The rate decrease of F_{s+g} with decrease of dry density is only minimum whereas the rate of decrease of F_{ss} is less compared to F_{s+g} and F_{sg}.Hence the value of (F_{s+g} - σ_n. (A_{ss}. tanφ_{ss} + A_{sg}. tanφ_{sg})) increases with decrease of dry density at constant normal stress σ. F_{pr} increases with increase of percentage finer particle D_{10}, D_{30}, D_{50}, and D_{60}.

VI.PASSIVE BEARING RESISTANCE VARIATION WITH PERCENTAGE PRESENCE OF CS, MS, AND FS

The friction resistances mobilized under direct shear mode at the soil-geogrid interface is the sum of the passive bearing resistance provided by the transverse ribs, the soil to geogrid interface frictional resistance and soil to soil interface frictional resistance in geogrid aperture area and particle size have an effect on this. When the particle size increases, the percentage presence of CS, MS, and FS also increases and these have an effect on the total friction resistance mobilized at the soil-geogrid interface.

As per the IS :1498 - 1970 Classification of soils, particle sizes range 0.075 mm – 0.425 mm is Fine Sand (FS), 0.425 mm to 2 mm is Medium Sand (MS), 2 mm to 4.75mm is coarse sand (CS) and above 4.75 mm is gravel category. Particle size less than .075 mm comes under silt and clay.

In well graded soil, the percentage presence of CS, MS, and FS will be in the ascending order in general whereas in poorly graded it is different. When the particles having size between .075mm to 4.75mm increases, the percentage presence of CS, MS and FS will also increase. When the particle D_{10} increases, the percentage presence of CS also increases for all well graded soil samples. When the soil particle size increases, the percentage presence of CS, MS and FS increases, and density also will increase.

DOI: 10.17148/IARJSET.2022.9820

$$F_{pr}=\frac{\rho_d}{G_S.\gamma_w}\left(F_{s+g}-\sigma\left(A_{ss}.\tan\varphi_{ss}+A_{sg}.\tan\varphi_{sg}\right)\right) \qquad (4.21)$$

At variable dry density and constant normal stress conditions as per Equation (4.21) above, it can be observed that when ρ_{dry} increases at constant normal stress, φ_{s+g}, φ_{ss} and φ_{sg} increases. σ_n, A_{ss}, A_{sg} and A are also constants. The φ_{ss} is more than φ_{s+g} and φ_{sg}, and the F_{s+g} is the measured value from the shear tests. The rate increase of F_{s+g} with increase of dry density is only minimum whereas the rate of increase of F_{ss} is more compared to F_{s+g} and F_{sg}. Hence the value of (F_{s+g}- σ_n. (A_{ss}. tanφ_{ss} + A_{sg}. tanφ_{sg})) reduces with increase of dry density at constant normal stress σ. In case when the normal stress increases, F_{pr} reduces. F_{pr} reduces with increase of percentage CS, MS and FS.

VII.PASSIVE BEARING RESISTANCE VARIATION WITH CU AND CC

The friction resistances mobilized under direct shear mode at the soil-geogrid interface have effect on the particles sizes of soil and hence it affects the values of Cu and Cc. Similarly, the percentage presence of CS, MS and FS are also based on the particle sizes of the soil sample. The total friction resistance is the sum of the passive bearing resistance provided by the transverse ribs, the soil to geogrid interface frictional resistance and soil to soil interface frictional resistance in geogrid aperture area. The passive resistance contribution with increasing aperture and increases with number of ribs.

The Coefficient Uniformity Cu is obtained by the ratio D_{60}/D_{10} and Coefficient of Curvature Cc is obtained by the expression ($D_{30}.D_{30}$)/(D_{60}) (D_{10}) for a soil mass. The Cu and Cc are increased when the effective size D_{10} and D_{30} are increased in a soil mass.is reduced and D_{60} is increased. If it is required to increase the particle size at D_{10} and D_{30} percentage finer in the soil mass, particles having size higher than the D_{10} and D_{30} particle size have to be removed from the soil mass and add equivalent quantity of soil particles having the size in consideration to increase. When the higher particles removed, smaller size particles up to the level of the larger sized particle and smaller particles will be more in the given soil mass. The smaller particle sized soil will have more voids which reduces the density. So the increase of Cu and Cc will reduce the density of the soil mass.

$$F_{pr}=\frac{\rho_d}{G_S.\gamma_w}\left(F_{s+g}-\sigma\left(A_{ss}.\tan\varphi_{ss}+A_{sg}.\tan\varphi_{sg}\right)\right) \qquad (4.21)$$

Considering Equation (4.21) above, it can be observed that when ρ_{dry} decreases at constant normal stress, φ_{s+g}, φ_{ss} and φ_{sg} reduces. σ_n, A_{ss}, A_{sg} and A are constants. The φ_{ss} is more than φ_{s+g} and φ_{sg}, and the F_{s+g} is the measured value from the shear tests. The rate decrease of Fs_{+g} with decrease of dry density is only minimum whereas the rate of decrease of F_{ss} is less compared to F_{s+g} and F_{sg}. Hence the value of (F_{s+g} - σ_n. (A_{ss}. tanφ_{ss} + A_{sg}. tanφ_{sg})) increases with decrease of dry density at constant normal stress σ. F_{pr} increases with increase of Cu and Cc.

VIII.VARIATION OF COMBINED SHEAR STRESS AND ANGLE OF INTERFACE FRICTION WITH SOIL PROPERTIES

When the dry density of soil samples increases, it can be observed from the following Equations (4.17) (4.18) and (4.19) that F_{s+g}, F_{ss} and F_{sg} will increase with increase of density along with angle of interface friction.

$$F_{s+g}=\frac{\rho_d}{G_s.\gamma_w}\sigma.A.\tan\varphi_{s+g} \qquad (4.17)$$

$$F_{ss}=\frac{\rho_d}{G_s.\gamma_w}\sigma.A_{ss}.\tan\varphi_{ss} \qquad (4.18)$$

$$F_{sg}=\frac{\rho_d}{G_s.\gamma_w}\sigma.A_{sg}.\tan\varphi_{sg} \qquad (4.19)$$

The increase of percentage presence of CS, MS, and FS decreases density; increase of Cu and Cc decreases density and increase of particle size at percentage finer D_{10}, D_{30}, D_{50}, and D_{60} decreases density of soil mass. The following can be observed from the above Equations.

1. The increase of percentage presence of CS, MS, and FS increases F_{s+g} and combined angle of interface friction
2. Increase of Cu and Cc reduces combined shear stress and combined angle of interface friction
3. Increase of percentage finer at particle size D_{10}, D_{30}, D_{50}, and D_{60} reduces combined shear stress and combined angle of interface friction

The Equations are applicable to the shear mode for unreinforced and reinforced with geogrid interfaces having transverse ribs and without it.

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CONCLUSIONS

The formulation clearly correlates the variation of shear strength resistance at soil-geogrid interface with dry density of soil. The dry density is related to particles sizes, void ratio, Cu, Cc ,% finer particles D_{10}, D_{30}, D_{50} and D_{60} and percentage presences of CS, MS and FS.

The conclusions are:

1. Formulated theoretical equations linking soil properties to passive bearing resistance, combined shear resistances, soil-soil and soil-geogrid friction resistances at interfaces mobilised under shear mode based on the concept of actual contact area between soil particles and geogrid area is evaluated.
2. The analysis of interface friction resistance equations and its correlations to soil properties gives better indicators on selection of soil type for a geogrid based projects.
3. The study found that passive bearing resistance in a soil geogrid interface mobilized under direct shear mode increases with increase of Cu, Cc, % finer particles D_{10}, D_{30}, D_{50} and D_{60}, and combined angle of friction; the passive resistance decreases with increase of dry density, percentage presences of %CS, %MS and %FS , shear resistance force at soil-soil and soil geogrid interfaces and Combined angle of internal friction .

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