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Shear Resistance at Sand-Geogrid Interface in Direct Shear Mode

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Abstract: 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 void area at the interface is not offering any resistance, only 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. Numerous laboratory, numerical and analytical tests has been performed by many researchers to determine the influence of particle size and void ratio on the shear interface mechanism. An equation is formulated considering the actual area of contacts with dry density as variable for the shear resistance at the interface.

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

I.INTRODUCTION

The research work carried out in this study is to evaluate and analyze the friction resistance forces at the soil-geogrid interface which is very important for the design of reinforced soil structures and are studied in this study using large scale shear box tests in direct shear mode. 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.CONCEPT OF ACTUAL AREA OF CONTACT AT SOIL GEOGRID INTERFACE AND MODELLING

Jewell et al. (1986) 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.

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

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.

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.

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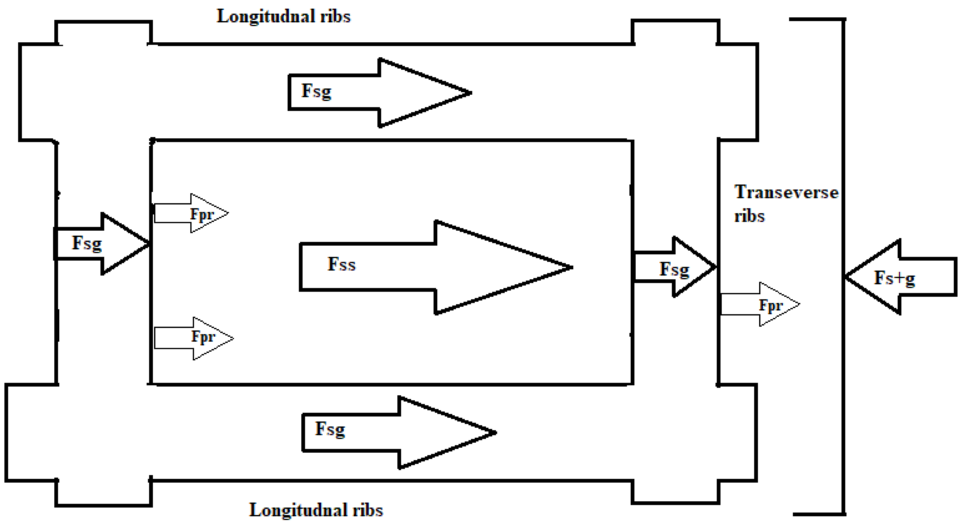

Figure 4.1 Shear resistance forces acting on a geogrid interface in shear test interaction

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

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

This can be expressed as below.
$F_{s+g} = A_{ss}. Ꞇ_{ss} + A_{sg}. Ꞇ_{sg} + F_{pr}$
Arranging the above Equation as below
$F_{s+g} = A_{ss}. \sigma_n. \tan \varphi_{ss} + A_{sg}. \sigma_n. \tan \varphi_{sg} + F_{pr}$ (4.3)

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 void area at the interface is not offering any resistance, only particles in contact with each other or with geogrid are offering resistance. During the testing, the particles move positions by rolling and interlocking, the void area formed by the movement of particles are filled up by particles moving in the direction of the shear force applied. The void ratio remains the same during the test till failure stage at the failure plane. Hence the actual area of contact is considered for the effective shear resistance. The vertical sides of the ribs in the opposite direction of applied force offer resistance at the interface with soil, and are the passive bearing resistance offered by the ribs at the interface.

III.INTERFACE SHEAR RESISTANCE FORMULATION

The interface friction area between soil and geogrid A_{sg} consists contact area of soil particles in contact with geogrid surfaces and soil particles not touching the geogrid surface in the void area at the plane of the interface failure. Similarly, A_{ss}, the area of soil to soil in the aperture area of geogrid, this area consists of soil to soil particles in contact and particles not touching each other forming voids in between the soil particles at the plane of the interface failure. The void ratio will be the same throughout in any plane in the soil mass. The total area A of interface of soil-soil and soil-geogrid is the sum of total area of contact soil particle with themselves (A_{ssc}) and with geogrid (A_{sgc}) plus the total area of voids between soil particle with themselves (A_{ssv}) and with geogrid (A_{sgv}) in any plane parallel to the pre-arranged failure plane in the shear mode. The total area of contact between soil-soil in the aperture area at interface (A_{ss}) considered consists of area of contact of soil-soil particles and the cross sectional area of soil particles positioned along the shear failure plane as some of the soil particles will be positioned in the aperture area of geogrid in zigzag position such that failure plane passes through the body of the soil particles.

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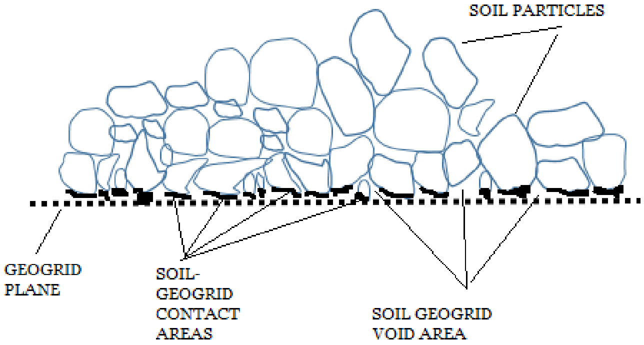

Figure 4.2 Concept of soil - geogrid interface particle contact

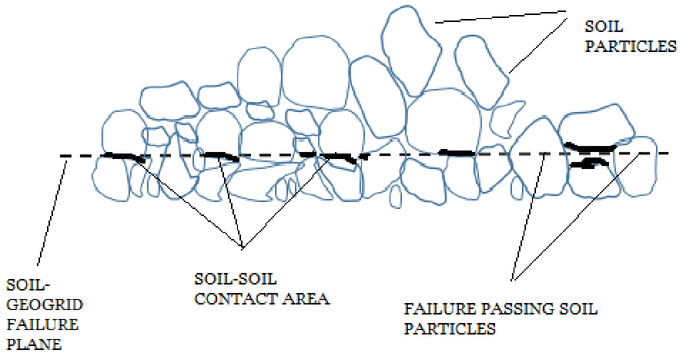

Figure 4.3 Concept of soil - soil interface particle contact

$A_{sg} = A_{sgc} + A_{sgv}$ (4.4)

$A_{ss} = A_{ssc} + A_{ssv}$ (4.5)

$A = (A_{sgc} + A_{ssc}) + (A_{ssv} + A_{sgv})$ (4.6)

$A = A_{sc} + A_v$ (4.7)

where

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.

Multiple particle sizes of soil system with areas of contact soils and geogrid A1 > A2 > A3 > A4……>An where n≥1, the total area of contact is obtained is as below.

$$A_{sgc} = \sum_{i=1}^{n} A_{sgi}$$

$$A_{ssc} = \sum_{i=1}^{n} A_{ssi}$$

The equation (4.3), $A_{sg} = A_{sgc} + A_{sgv}$ is rearranged as below by dividing A_{sgc}.

$$A_{sg}/ A_{sgc} = A_{sgc} / A_{sgc} + A_{sgv}/ A_{sgc} = 1 + V_v/ V_s = 1+ e$$

$A_{sgc} = \frac{A_{sg}}{1+e}$ (4.8)

Similarly

$A_{ssc} = \frac{A_{ss}}{1+e}$ (4.9)

Adding Equations (4.8) and (4.9)

Therefore

$Asc = A_{sgc} + A_{ssc} = A/(1+ e)$ (4.10)

Where

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V_v = volume of voids, V_s = volume of solids, e = void ratio = $\frac{Vv}{Vs}$

It is assumed that the soil particles in contact with other soil particles are resisting the shear force applied at the plane of the interface failure. The total area of interface failure plane A is composed of void area and actual contact area.

The combined shear strength of soil and geogrid interface in shear mode is resisted by particles in contact with soil themselves and geogrid at the plane of failure. The effective area of particles in contact at interface only are considered and not the entire cross-sectional area of the failure plane. The shear force is resisted by the friction developed at the interface of soil-soil and soil-geogrid. The transverse ribs resist the shear force by the way of the passive bearing resistance, no shear stress phenomenon is happening here. The normal stress is applied throughout the cross-sectional area of the interface plane through particle contact points or area and the hence normal stress is applied at the full cross sectional area A.

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}.

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

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

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

Replacing A_{sc}, A_{ssc} and A_{sgc} with equations (4.8), (4.9) and (4.10)

$A_{sgc} = \frac{A_{sg}}{1+e}$, $A_{ssc} = \frac{A_{ss}}{1+e}$, $A_{sc} = \frac{A}{1+e}$

the above Equations becomes as

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

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

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

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

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

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

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

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.

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

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

IV.CONCLUSION

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. The theoretical equations formulated at the soil-geogrid interface interaction mechanism for shear resistance mobilised under shear mode in terms of soil properties as variables.

2.Formulated theoretical equations linking soil properties is useful to evaluate 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

3. 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.

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