THE MESOSCOPIC SOIL GEOGRID INTERACTION OF REINFORCED SOIL UTILIZING DEM

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ABSTRACT

In this paper, investigations on reinforced soil utilizing Discrete Element Method (DEM) modelling are presented. A three dimensional (3D) Discrete Element model is constituted to evaluate displacements and contact forces between discrete particles in the reinforced soil structure. The granular soil particles and the discrete geogrid reinforcement have been modelled “Computer Aided Designed” (CAD). The mesoscopic load transfer mechanism of the reinforced (RE) soil element has been evaluated. Arching effects have occurred randomly between the granular soil particles and the discrete geogrid. Those arching effects have led to local stress concentrations between the particles and to high tensile forces in the geogrid at certain places. Moreover, three soil geogrid interaction effects have been determined. When the discrete clumps have entered the gaps of the discrete geogrid, the longitudinal and transverse members of the reinforcement have been pushed side wards. This effect has been classified as interlocking effect. While loading the soil element, grains have entered between the single strings of the longitudinal and transverse members of the reinforcement. This effect has been defined as single string interaction effect. In longitudinal but also in transverse direction the geogrid has aligned to the surrounding granular particles. This so called alignment effect has led to a permanent contact between geogrid and soil particles resulting in interfriction effects.

Keywords: geogrid, discrete, clump, mesoscopic

INTRODUCTION

The discrete soil geogrid interaction has been investigated by several researchers in the last years.

Three dimensional discrete element simulations have been utilized to model numerical triaxial tests on soil elements reinforced with one to three layers of a geometrically detailed modelled geogrid. Konietzky et al. (2004) conclude that the performed DEM simulations of triaxial reinforced soil element tests have given a valuable insight into the soil geogrid interaction mechanism.

Discrete element method (DEM) simulations have been used to model the interaction between ballast material and a geogrid by simulating pull-out tests and comparing their results with experimental data by McDowel et al. (2006). The DEM simulations predict precisely the peak mobilised resistance and the displacement necessary to mobilise a peak pull-out force. In addition, the effect of the ratio of the geogrid aperture size to ballast particle diameter on the pull-out resistance has been investigated. McDowel et al. (2006) found that a value of 1.4 is the ideal ratio between the opening size of the geogrid and the diameter of the grain.

Zhang et al. (2007) performed discrete simulations of pullout tests to investigate the effect of compaction of the reinforced soil body on the pullout force during the tests. The results of the discrete modelling have correlated with the tests results gained from laboratory studies.

Bhandari & Han (2010) have utilized two dimensional Discrete Element modelling to investigate the soil geotextile interaction under a cyclic vertical load. The DEM results show that the geotextile prevents the particles from vertical movement. At the same time the geotextile anticipates the horizontal movement of the granular, spherical particles. This is due to the lower frictional resistance of the soil particles, rolling and sliding on the surface of the geotextile. Bhandari & Han (2010) state that the benefit of the geotextile in minimizing the vertical deformation depends on the vertical position of the geotextile.

Tutumluer et al. (2009) conducted a detailed discrete element study on direct shear tests including two different shapes (angular and triangular) of discrete geogrids. Out of the utilized numerical simulations but also as a result of conducted direct shear tests in the laboratory, Tutumluer et al. (2009) found out that the soil geogrid interaction coefficients becomes higher than 1.0 in case of reinforcing the soil element in the shear box. This is due to the interlocking effects between the discrete particles and the gaps of the geogrid reinforcement. Tutumluer et al. (2009) concludes that both geogrid geometries have provided significant stiffening effects.

OVERVIEW ON THE NUMERICAL MODEL

A three dimensional Discrete Element model has been utilized to investigate the mesoscopic load transfer and soil geogrid interaction mechanism. The three dimensional Discrete Element Method code, "Particle Flow Code (PFC3D)" provided by Itasca (Version 4.00-191 64-bit), has been employed (Itasca Consulting Group 2005).

A cubical model (a = 0.1 m) with geometrically detailed modelled grains and geogrid has been set up. The granular soil particles and the discrete geogrid reinforcement have been modelled "Computer Aided Designed" (CAD). The granular soil particles have been mesoscopically investigated in detail and generated as clumps in PFC3D (Itasca Consulting Group 2005).

NUMERICAL SETUP AND CALCULATION PROCESS

The Itasca Consulting Group (2005) provides the fundamental principles on Discrete Element Modelling with the Particle Flow Code in three dimensions (PFC3D).

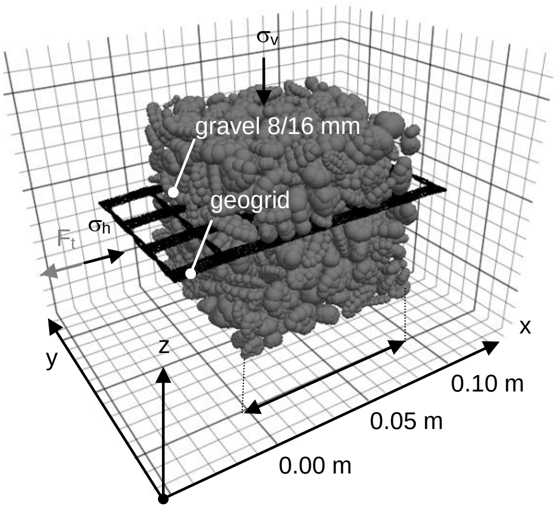

Fig. 1 Schematic sketch of the 3D overview on the Discrete Element model.

The basic geometry information of the numerical model is presented in Figure 1. The three dimensional model is generated by utilizing CAD designed clumps, representing the granular soil particles and a CAD designed discrete geogrid reinforcement.

NUMERICAL MATERIAL PARAMETERS

The mesoscopic investigated gravelly material has been numerically modelled in detail. The shape of the grains has been modelled by so called clumps (Itasca Consulting Group, 2005).

The surface of a predefined grain has been modelled by utilizing the software Blender (Version 2.4). Blender (Version 2.4) is an open source software for 3D creation. Once the surface is generated the volume inside the surface is filled with spheres. Only spheres may be added to the generated volume. This is due to the limitations of PFC3D. The software merely generates spherical particles (Itasca Consulting Group 2005).

Finally, the clump is generated. In order to implement the generated clump into the PFC^{3D} code, the position (x, y, z) and the radius of each sphere has to be defined. Additionally, the volume of the generated clump has to be analyzed. Thereafter the generated spheres are implemented in AutoCAD (Version 2006) to calculate the volume of the clumps. Four typical grain shapes have been selected to categorise and consecutively model the shape of the grains numerically by clumps.

Table 1 DEM soil parameters for granular backfill material.

parameter	unit	value
density	[kg/m³]	2.64E+03
shear modulus	[N]	3.00E+10
Poisson's ratio	[N]	0.2
normal stiffness	[N/m]	3.90E+06
shear stiffness	[N/m]	9.00E+05
friction coefficient	[-]	0.8
local/viscous damping	[-]	0.90/0.00
(normal/shear)	[-]	0.00/0.97

To evaluate the numerical microscopic parameters a detailed numerical calibration has been performed. The numerical input parameters for the granular backfill material called "Murschotter" are given in Table 1. The discrete geogrid reinforcement has been numerically modelled in detail. The shape of the geogrid has been designed computer aided. The longitudinal and transverse members of the reinforcement material have been modelled in detail by bonding single spheres to each other. The plan view and the side views on the longitudinal and transverse members of the PET woven geogrid are presented in Figure 2

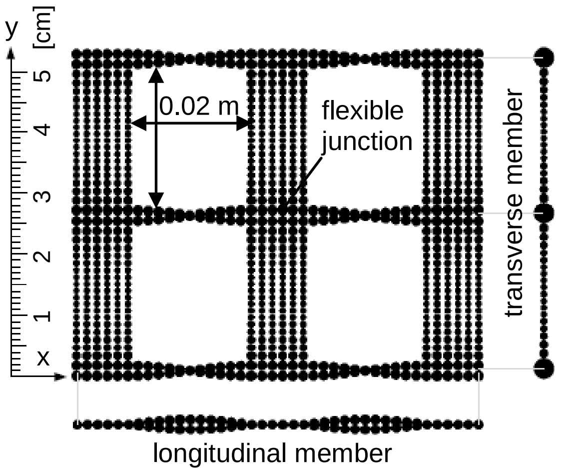

Fig. 2 Schematic sketch of plan view and side view of the longitudinal and transverse members of the PET woven geogrid.

Table 2 provides the numerical microscopic parameters of the geogrid. The geogrid is modelled with a linear elastic soft-contact model. It has to be stated that the back analyzed microscopic parameters for the geogrid reinforcement are numerical ones. It is possible to fit the macroscopic properties of the reinforcement with a different microscopic, numerical parameter set.

Table 2 DEM soil parameters for geogrid reinforcement material.

parameter geogrid		value	
		detailled	standard
density	[kg/m³]	1.03^{E+03}	2.06^{E+03}
normal stiffness	[N/m]	4.00^{E+06}	1.62^{E+07}
shear stiffness	[N/m]	8.50^{E+05}	6.00^{E+04}
contact bond normal strength	[N]	5.00^{E+05}	5.00^{E+05}
contact bond shear strength	[N]	5.00^{E+05}	5.00^{E+05}
radius multiplier	[-]	0.29	0.175
parallel bond normal stiffness	[Pa/m]	2.80^{E+12}	1.25^{E+13}
parallel bond shear stiffness	[Pa/m]	1.80^{E+12}	3.00^{E+11}
parallel bond normal strength	[Pa]	8.00^{E+14}	8.00^{E+14}
parallel bond shear strength	[Pa]	8.00^{E+14}	8.00^{E+14}
friction coefficient	[-]	0.5	0.5

The higher the amounts of differently performed calibration tests, the more realistic are the input parameters. Especially for models with high numbers of particles and large deformations, calculation times increase exponentially.

NUMERICAL RESULTS AND DISCUSSION

Figure 3 shows the DEM model of the reinforced soil element to evaluate the mesoscopic load transfer mechanism. Figure 3 presents the side view (y-z) of the soil element. The results include the contact forces (grey) between the granular particles and tensile force distribution (black) along the geogrid.

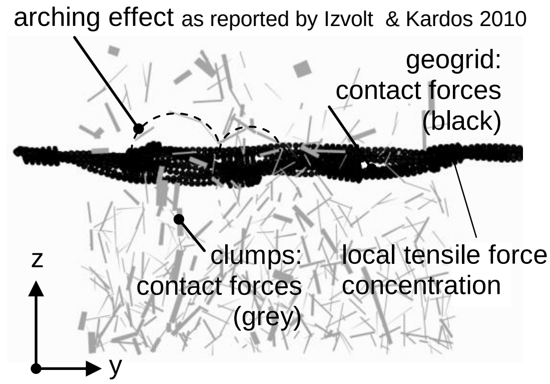

Fig. 3 Load transfer mechanism of reinforced soil.

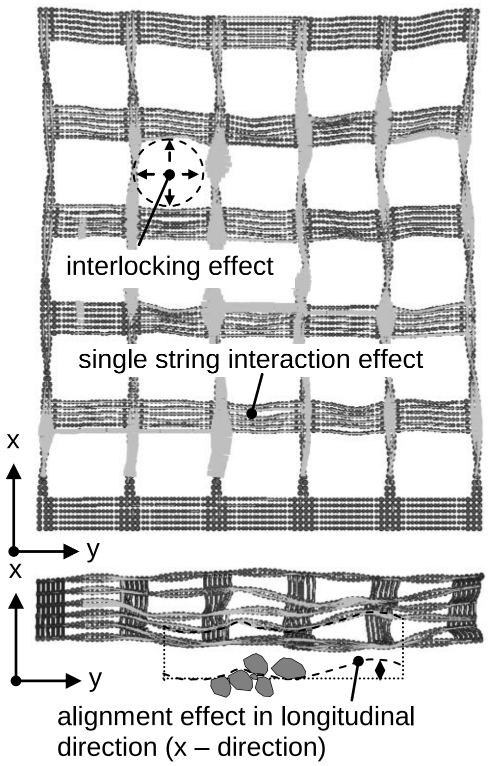

Fig. 4 Soil geogrid interaction mechanism of reinforced soil.

Arching effects, as reported by Izvolt & Kardos (2010), occur randomly between the granular soil particles and the discrete geogrid. Those arching effects lead to local stress concentrations between the particles and to high tensile forces in the geogrid at certain places.

Figure 4 shows the mesoscopic DEM model of the reinforced (RE) soil element to evaluate the mesoscopic deformation of the geogrid reinforcement. Three different soil geogrid interaction effects have been determined by analysing the discrete deformation behaviour of the reinforcement under loading.

When the discrete clumps enter the gaps of the discrete geogrid, the longitudinal and transverse members of the reinforcement are pushed sideward. This effect is called interlocking effect

While loading the soil element, clumps get in between the single strings of the longitudinal and transverse members of the reinforcement. This effect is defined as single string interaction effect.

In the longitudinal and in the transverse direction the geogrid aligns to the surrounding granular particles. This effect is called alignment effect.

CONCLUSIONS

The reinforced soil elements have represented well the mesoscopic interaction behaviour between the reinforcement and the surrounding soil structure.

The mesoscopic load transfer mechanism of the reinforced soil element has been evaluated:

- Arching effects have occurred randomly between the granular soil particles and the discrete geogrid. Those arching effects have led to local stress concentrations between the particles and to high tensile forces in the geogrid at certain places.

Three different soil geogrid interaction effects have been determined:

- Once the discrete CAD clumps have entered the gaps of the discrete geogrid, the longitudinal and transverse members of the reinforcement have been pushed apart from each other. This effect has been classified as interlocking effect.

- While loading the soil element, CAD clumps have entered between the single strings of the longitudinal and transverse members of the reinforcement. This effect has been defined as single string interaction effect.

- The geogrid has aligned onto the surrounding granular particles in the longitudinal and in transverse direction. This so called alignment effect has resulted in a permanent contact between geogrid and soil particles.

ACKNOWLEDGEMENTS

The first author would like to acknowledge and thank the School of Engineering and Technology at the Asian Institute of Technology, Bangkok, Thailand.

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