The Coefficient of Interaction for Geogrids in a Non-Cohesive Soil

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ABSTRACT: **The objective of the research presented in this paper, is to verify the applicability of the coefficient of interaction (COI) for geogrids. Research performed at the Otto Graf Institute (OGI) in Germany in 1990, has revealed that the behaviour of the COI is inconsistent. The test program performed with the pull out box developed at Delft University of Technology (DUT), is based on this former research to allow for a comparison of the results. A finite element program is used to study the impacts of the testing device. The data analysis reveals the distribution of shear stress along the geogrid. Dilatancy and arching of the non-cohesive soil lead to a local large increase in confining pressure, concentrated just in front of the point of mobilisation. After mobilisation, a large part of the geogrid does not contribute to the pull out resistance for no residual shear stress remains. The COI is not an appropriate parameter to determine from the current test method.**

1. Introduction

The pull out resistance of a geogrid is determined by three basic mechanisms of interaction; friction along the total surface area of longitudinal and transversal ribs, passive resistance of the transverse ribs and interlocking. These three interaction mechanisms form the so-called bond capacity of the geogrid that can only be measured in a pull out test. The bond capacity governs the minimum required anchor length to mobilise the allowable reinforcement force. The results of pull out tests are often expressed in the coefficient of interaction (COI), or the efficiency factor, as the ratio between the average shear stress on the interface geogrid-soil and the shear strength of the soil. For a non-cohesive soil this is expressed as in equation 1:

$$COI = \frac{< \tau_{int} >}{\tau_{soil}} = \frac{F_{pullout}}{2 \cdot B \cdot L_a \cdot \sigma_v' \cdot \tan\phi} \qquad (1)$$

$< \tau_{int} >$	= Average shear stress interface (kN/m²)
τ_{soil}	= Shear strength soil (kN/m²)
$F_{pullout}$	= Pull out force (kN)
B	= Width of geogrid (m)
L_a	= Mobilised anchor length (m)
σ_v'	= Normal vertical stress (kN/m²)
ϕ	= Soil friction angle (°)

Theoretically the coefficient of interaction, calculated from pull out test results, can take any value below 1. Differences in test procedure and test device lead to differences in the distribution of shear stress along the geogrid and thus to basically different values for the coefficient of interaction.

The results of a pull out research program, performed with extensible geogrids at the Otto Graf Institute (OGI) in Germany in 1990, have revealed that the behaviour of the coefficient of interaction for an extensible geogrid is inconsistent [Wichter, 1990].

This comprises three effects:

1. The coefficient of interaction is dependent on the normal stress.
2. The coefficient of interaction can take values larger than 1, especially at low normal stresses and short mobilised anchor lengths.
3. At a constant normal stress the coefficient of interaction is not linear related to the mobilised anchor length.

The first and the second effect have been confirmed as well by other research programs. The third effect has not been analysed yet. The aim of the research presented in this paper is to investigate and analyse the effects as described above. The influence of the mobilised anchor length on the coefficient of interaction is emphasised.

2. Fundamental aspects of geogrids in non-cohesive soil

The main factors of influence on the shear stress distribution are the unconfined load-strain relation of the geogrid, the failure mechanism, dilatancy of the non-cohesive soil and the rigid boundaries of the pull out box, like the side and front walls.

The load-strain relation of the geogrid determines the distribution of strain along the geogrid for a constant tensile force. The maximum strain level, at the loaded end, decreases towards the loose end of the geogrid with a non-linear relation. This leads to a non uniform distribution of the shear stress along the geogrid. In order to compare the influence of the stiffness on the coefficient of interaction, a situation of equal vertical stress, soil conditions and exerted pull out force is considered. A relatively extensible geogrid leads to a relatively smaller mobilised anchor length. In order to obtain the applied pull out force, the average shear stress along the geogrid has to be comparatively larger. This results in a larger coefficient of interaction.

The two failure mechanisms of the pull out test are the mobilisation of the total geogrid area and reaching the ultimate tensile strength of the geogrid. The first mechanism leads to a constant shear displacement along the total area of the geogrid at an approximately constant strain level. In the second case the pull out force reaches the ultimate tensile strength of the geogrid at a large relative amount of strain in the geogrid. The coefficient of interaction is based on the average shear stress along the geogrid and consequently influenced by the failure mechanism. The second failure mechanism represents the majority of field situations; the applied length of the geogrid is sufficiently long to prevent total pull out.

In case shear stresses are mobilised on the interface soil-geogrid in a dense non-cohesive soil under a moderate confining pressure, the soil has a tendency to dilate. Supposing that the dilatancy is restrained by the surrounding soil, the normal stress at the interface will increase. This results in a increase of shear stress along the interface. The effect of dilatancy is influenced by the boundaries of the testing device.

The shear stress distribution of a geogrid is influenced by the front wall. As the geogrid is extracted from the pull out box, lateral pressures develop in front of the rigid wall. These lateral pressures influence the local confining pressure, and consequently the shear stress distribution and pull out resistance. Hornbeck, 1982, recorded a larger pull out resistance using a rigid front wall. However, Johnston, 1985, recorded a smaller pull out resistance using a rigid front wall. These contradictory results are described by Juran et al., 1992. Sleeves transfer the pull out load inside the pull out box and can reduce the influence of the rigid front wall.

3. Test apparatus and instrumentation

The dimensions of the developed pull out box are designed to overcome the influences of the rigid boundaries on the interface soil-geogrid condition. The inner dimensions of the testing device are 3 m long, 1.30 m wide and 1 m deep. The maximum length and width of the geogrid sample are 2 by 1 m. The soil thickness, above as well as below the geogrid, and the sleeve length are 0.5 meter. The normal pressure is applied to the soil by means of a flexible airbag in order to create a homogeneous stress distribution and to allow for volume changes of the soil. Normal pressures up to 200 kN/m² can be applied. The pull out load is applied by means of a hydraulic jack, capable to execute the desired displacement or loading path. The pull out load is transmitted to the geogrid by means of a clamping system. A top view of the pull out box is shown schematically in Fig. 1.

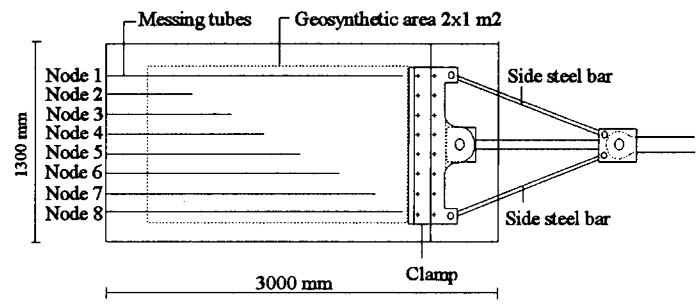

Figure 1. Top view of pull out box

The steel side bars prevent horizontal rotation of the clamp and thus provide an uniform distribution of normal stress in the geogrid. A steel tube at the back of the clamp and leather sheets are used to achieve minimum slippage and an optimal tensile strength. The clamp is situated inside the soil in order to preserve a constant frictional area between the soil and the geogrid. During the pull out test the displacement and the force of the hydraulic jack are continuously recorded. Non-extensible steel wires, so-called tell tales, pass through small messing pipes and connect the nodal points, located along the geogrid, to potential displacement recorders outside the pull out box.

4. Test procedure and test program

In order to determine the influence of the mobilised anchor length on the coefficient of interaction, it is necessary to gain insight in the distribution of shear stress along the geogrid. A finite element program, Plaxis, is used to determine the influence of the rigid boundaries on the shear stress distribution.

The pull out tests are performed with a non-extensible steel grid and an extensible mechanically bonded polyester geogrid, Fortrac 80/30-20. The unconfined load-strain relation of each geogrid is shown in Fig. 2.

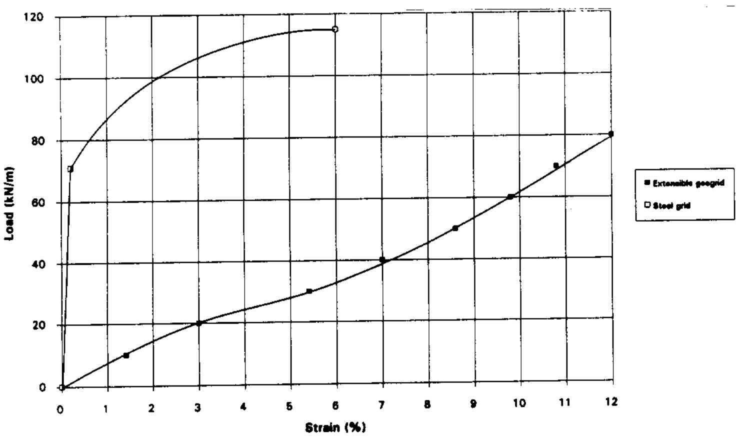

Figure 2. Unconfined load-strain relation

Both types of geogrid have equal aperture size, rib width and thickness of respectively 20·20 mm², 5 mm and 1.5 mm. The length of the extensible geogrid is sufficiently long to provoke failure by reaching the ultimate tensile strength of the geogrid. The failure mechanism for the steel grid is total pull out. The soil properties, shown in Table 1, are determined from triaxial tests.

Table 1. Soil properties

Uniformly graded Maaszand ®	
d_{50}	= 0.46 mm
d_{60}/d_{10}	= 2.7
ϕ'	= 37°
c	= 0 kN/m²
γ_d	= 17.64 kN/m³
w	= 1.6 %

The pull out tests are performed at four different normal stresses ranging up from 35 kN/m² to 110 kN/m². The displacement rate of 6 mm/min lies within the acceptable range of relative amounts that do not influence the pull out response [Farrag et al., 1993].

The pull out box with sleeves and extensible geogrid are simulated in the finite element computer program. The geometry represented in the mesh generation is equal to the pull out box geometry. The geogrid and the rigid boundaries are surrounded by interface elements in order to study the interfacial behaviour. The Mohr-Coulomb soil model is utilised to model the behaviour of the soil and interface elements. The Youngs modulus and the Poisson's rate of the soil, needed for the computer program, are obtained from the triaxial tests. The finite element program uses an advanced ultimate level loading system; the pull out load is raised in additional load steps, until the desired ultimate load is reached. The ultimate load is prescribed by the ultimate tensile strength of the geogrid.

5. **Data analysis and results**

The experimental data, obtained from the steel grid pull out tests, are presented directly in an interfacial shear stress - relative displacement relation, as shown in Fig. 3.

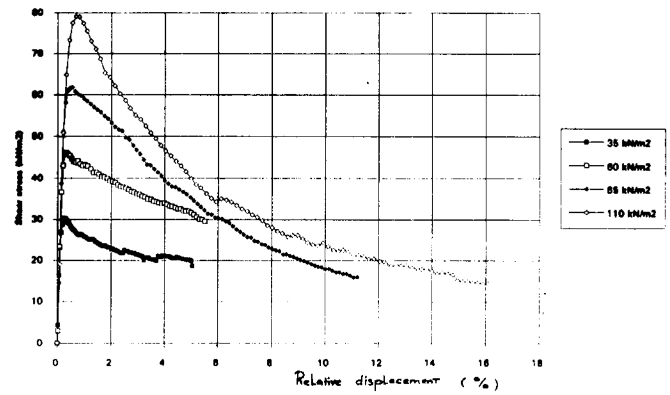

Figure 3. Shear stress - relative displacement relation

This relative displacement, the absolute displacement of the grid divided by the length of the steel grid, represents the interfacial shear displacement; the average strain in the steel grid can be neglected. The coefficient of interaction is based on the peak pull out force and the total length of the steel grid. The length is adapted to the applied normal stress. The results are presented in Table 2.

Table 2. COI for steel grid

σ'_v (kN/m²)	Length (mm)	COI
35	1720	1.15 - 1.22*
60	1005	1.02
85	765	0.97
110	535	0.95

* Validation test

In order to determine the distribution of the shear stress along the extensible geogrid, an appropriate analysis is employed. The application of the data analysis is illustrated by interpretation of the test data obtained at a confining pressure of 35 kN/m². Fig. 4 shows the pull out force at the displacement of the jack.

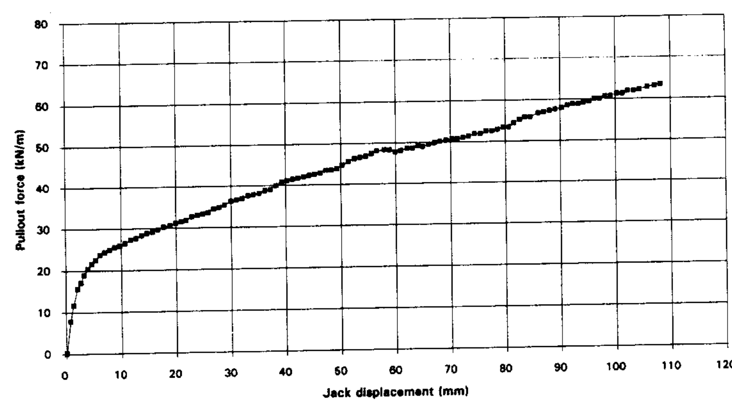

Figure 4. Pull out force - jack displacement

The recorded displacement of each nodal point at the applied hydraulic jack displacement is shown in Fig. 5.

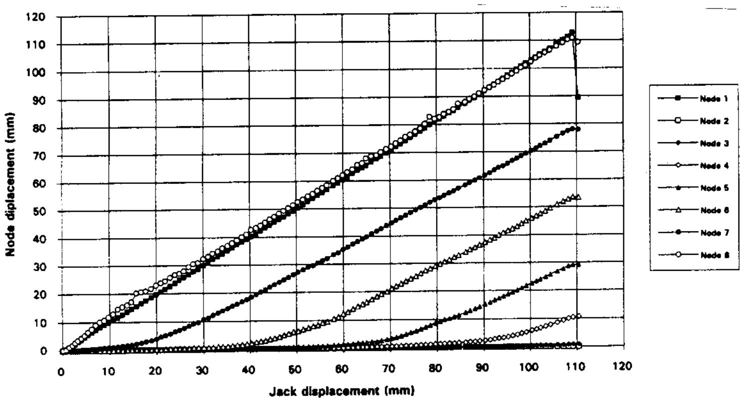

Figure 5. Nodal point displacement - jack displacement

The nodal points along the geogrid are indicated as (i) and the length, Δx, between two successive nodal points is indicated as element (I). Fig. 6 shows the distribution of the displacement (δ) of each nodal point (i), located along the geogrid, at a constant pull out force. The average strain in each element (I) is calculated by equation 2:

$$\varepsilon_I = \frac{\delta_{i+1} - \delta_i}{\Delta x} \qquad (2)$$

The unconfined stress-strain relation of the geogrid is used to determine the average tensile force in each element along the geogrid. In order to transmit the average values to a realistic curved distribution, a polynom curve fitting program is utilised. Fig. 7 shows the strain distribution in the geogrid for a constant pull out force. Fig. 8 shows the belonging tensile force distribution in the geogrid for a constant pull out force. The shear stress is determined by the slope of the tangent at each point of the tensile force curve as defined in equation 3:

$$\tau_{int} = \frac{1}{2} \cdot \frac{dF}{dx} \qquad (3)$$

The distribution of shear stress along the geogrid for a constant pull out force is shown in Fig. 9. The interfacial shear stress - displacement relation for each nodal point is obtained through combination of Fig. 9 and Fig. 6. This is shown in Fig. 10.

(Note: The interfacial displacement is a combination of the elongation and the shear displacement. These two contributions can be separated to obtain the shear stress - shear displacement of the interface soil-geogrid.)

The finite element program is solely used to study the influences of the rigid boundaries on the interface soil-geogrid condition. The results obtained at an applied normal stress of 35 kN/m² are shown, in order to compare these results to the experimental results. The stress conditions and incremental displacements are presented for four load stages during the pull out test. Load step 1 represents the situation after the vertical load has been applied, just before the start of the pull out test. Load step 15 and 30 are successive stages during the pull out test. Load step 60 represents the situation when the ultimate tensile strength of the geogrid is reached. In this manner , the progress in stresses and displacements during the test can be observed. Fig. 11 shows the condition of the effective principal stresses in the pull out box. Fig. 12 presents the condition of effective normal stresses at the interface soil-geogrid. Fig. 13 indicates the situation of the incremental displacement field. The incremental displacements denote the behaviour of the soil body during the pull out test.

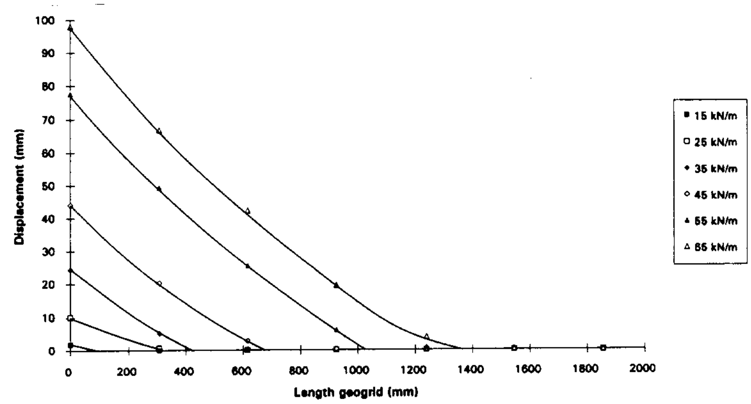

Figure 6. Displacement distribution nodal points

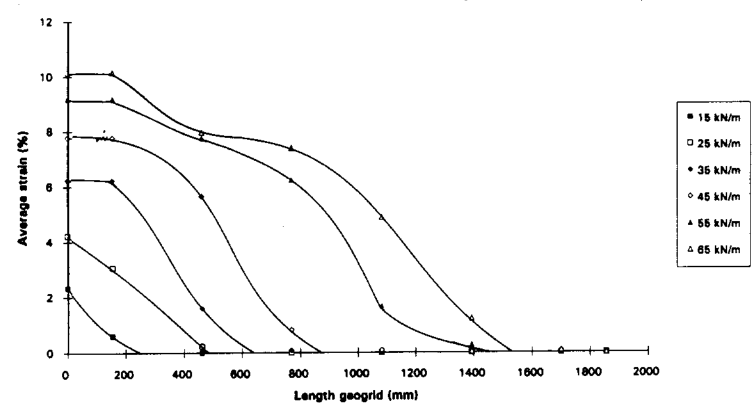

Figure 7. Strain distribution in geogrid

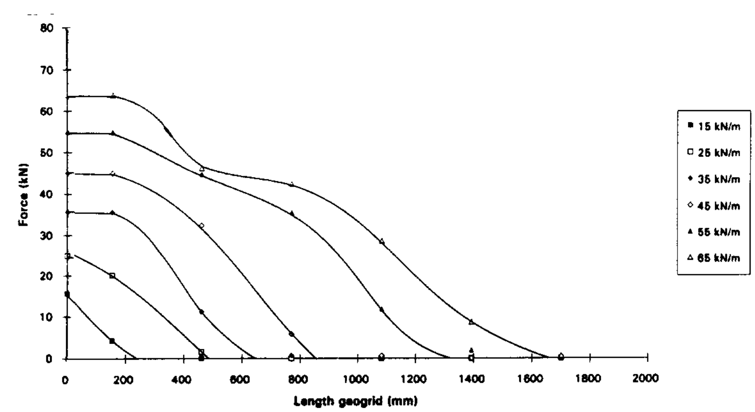

Figure 8. Tensile force distribution in geogrid

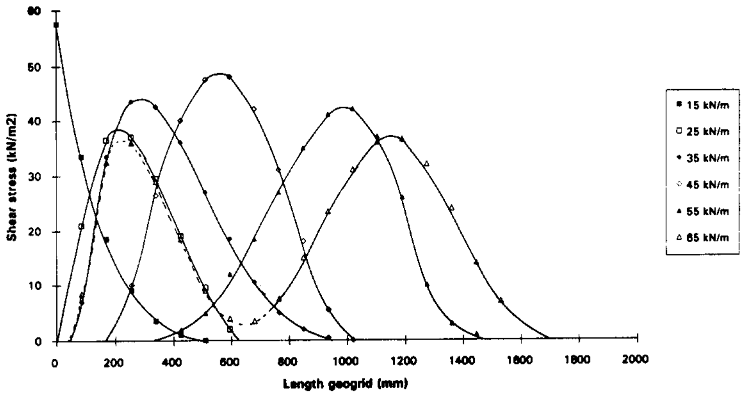

Figure 9. Shear stress distribution along geogrid

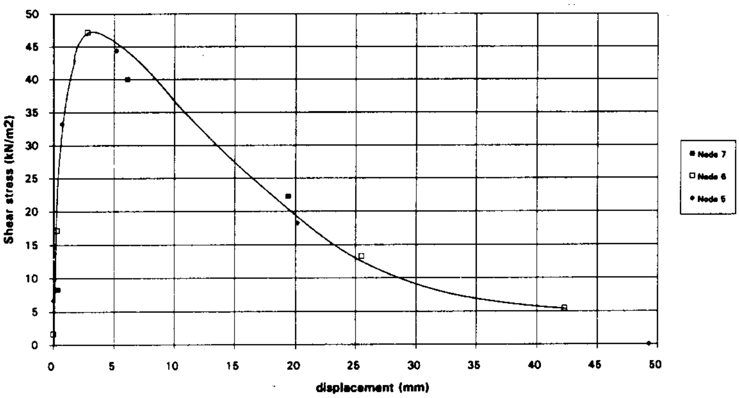

Figure 10. Shear stress - displacement relation

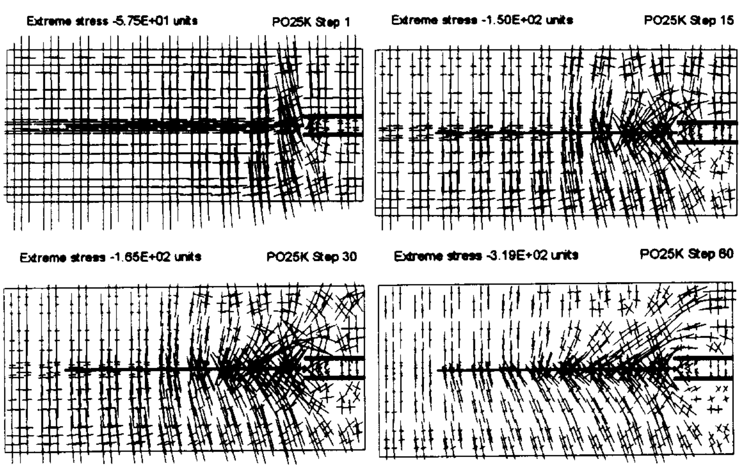

Figure 11. Effective principal stresses

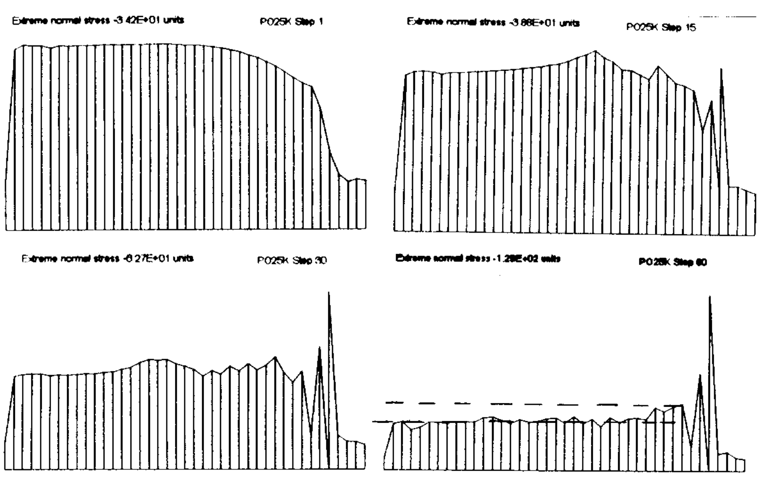

Figure 12. Effective normal stresses interface soil-geogrid

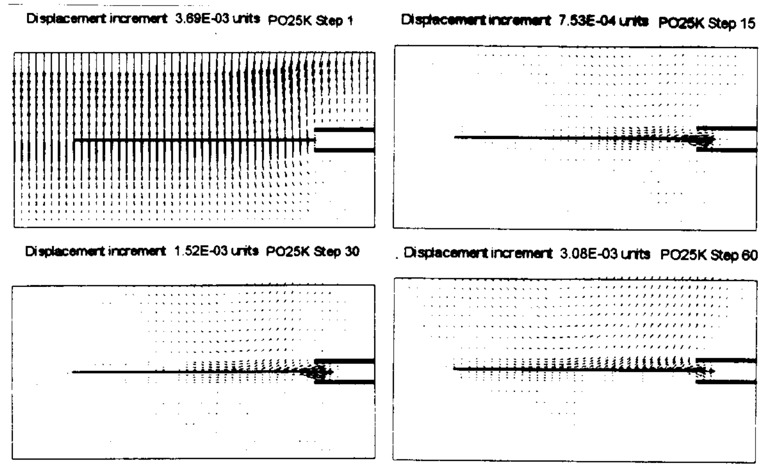

Figure 13. Incremental displacement field

6. Comparison and analysis of the results

The experimental results are compared to the effects that occurred in the research program at OGI in 1990. The examination of the results is focused on the relation between the mobilised anchor length and the coefficient of interaction. An interpretation is made of the influences of the rigid boundaries on the shear stress distribution.

1. The COI is dependant on the normal stress.

The results of different research programs have been gathered by Farrag et al., 1993. Generally, a decrease of the coefficient of interaction at an increase of the applied normal stress has been observed. Most of the tests were performed in dense sand with extensible geogrids. The elongation of the reinforcement as well as the testing device will have influenced the shear stress distribution. The results are supported by the results of the steel grid as shown in Table 2. The pull out behaviour for steel grids, however, is not influenced by the elongation of the reinforcement. Therefor, a reasonable explanation is found in the tendency of the dense, non-cohesive, soil to dilate if submitted to a shear stress. At a small normal stress the attribution of the increase in confining stress, to the obtaining stress situation is relatively large. As the normal stress increases, this attribution in stress becomes relatively smaller.

2. The COI can have values larger than 1.

This effect is supported as well by the results of the steel grid. Theoretically, the coefficient of interaction can approximately become equal to 1, if the effect of interlocking is significant. The effect of interlocking increases if the ratio between the thickness of the transversal ribs and the average grain size diameter of the soil decreases below 3 [Sarsby, 1985]. The actual ratio is equal to 3.2 for both types of geogrid. Hence, the effect of interlocking is expected to occur. As soon as interlocking as well as dilatancy occurs, values larger than 1 can be expected. The increase of confining pressure, due to

dilatancy, is determined from the results of the finite element program. The effective normal stress on the interface, Fig. 12 step 60, shows that the increase in normal stress on the interface is at most 20 %.
The value for the coefficient of interaction at the same normal stress ranges from 1.15 to 1.22; approximately 20 % above the expected value of 1. The amount of increase in confining pressure due to dilatancy leads to the same amount of increase of the coefficient of interaction.

3. A non-linear relation in mobilised anchor length and the coefficient of interaction at a constant normal stress.

The results of the OGI and the DUT for extensible geogrids are shown in Fig. 14

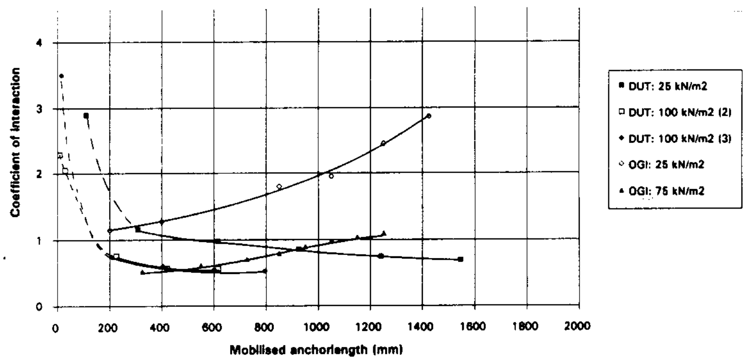

Figure 14. Results of the OGI and DUT

The coefficient of interaction is indeed not linear related to the mobilised anchor length, but the tendencies of the curves do not match. A different test method clearly yields basically different results. The soil and material properties for both research programs were approximately identical. The pull out box at OGI did not incorporate sleeves; dilantancy probably has influenced the results of OGI as well. The different tendency in curves might be explained by the difference in the test procedure; the pull out tests at OGI have been performed with a prescribed load path.

The shear stress distribution, as shown in fig. 9, at a constant pull out force is concentrated at a small part of the mobilised anchor length, situated directly in front of the point of mobilisation. As the pull out force increases, the shear stress resembles a wave progressing along with the progression of the mobilised anchor length. In the calculation of the coefficient of interaction, the shear stress is equally spread along the total mobilised area. The area enclosed by the curve of the shear stress and the geogrid is approximately constant for each pull out force. As the total mobilised anchor length increases at an increasing pull out force, the tendency of the curve for the coefficient of interaction declines, as shown in Fig. 14. for the DUT results. These results render the applicability of the equation for the COI for extensible geogrids questionable. If the shear stress is averaged along the actual part of the geogrid where shear stresses occur, the coefficient will be approximately constant.

The shear stress exceeds the theoretically maximum shear strength of the soil, Fig. 9. This is explained as follows. The introduced pull out force leads to an increase in lateral stress because of the high density of the soil. As the pull out force increases, the lateral stress increases, as well as the influenced area round the geogrid. Arching of the soil over the interface soil-geogrid, starts at the surface of the sleeves. As the pull out force increases, the arch progresses and embraces the former arch, and finally connects the front wall. At the location where the arch crosses the geogrid, the initiation of dilatancy is expected as well. This leads to a large increase in confining pressure and thus to an increase of the maximum shear stress.

7. General conclusions

In spite of the large inner dimensions of the pull out box, the influences of dilatancy and arching are considerable. For the steel grid this is indicated through a rapid decrease of the residual shear stress, once the steel grid is fully mobilised, Fig. 3. For the extensible geogrids, Fig. 9 indicates that along a large part of the mobilised anchor length no residual shears stress remains. The normal stress is diminished below the stress arch leading to an decrease in shear stress beneath the arch. Therefor, the pull out box does not successfully represent the practical situation. In practice, a residual shear stress will remain along the mobilised geogrid and will contribute to the overall pull out resistance of the geogrid. Therefor, the coefficient of interaction is not a reasonable parameter to determine for extensible geogrids from tests performed with the actual pull out method. In the near future efforts will be made to improve the developed testing device. Among other things, the effect of an air bag placed in front of the rigid wall to diminish the arching of the soil will be investigated.

REFERENCES

Farrag, K., Acar, Y.B. and Juran, I. (1993) Pull-out Resistance of Geogrid Reinforcements, *International Journal of GT and GM*, 2: 133-159.

Juran, I., Knochenmus, G., Acar, Y.B. and Arman, A. (1992) Pull-out Response of Geotextiles and Geogrids, *Geosynthetics for Soil Improvement,* Louisiana.

Sarsby, R.W. (1985) The Influence of Aperture Size/Particle Size on the Efficiency of Grid Reinforcement, *Proceedings of 2nd Canadian Symposium on GT and GM*: 7-12, Alberta Canada.

Wichter, L. (1990) Ausziehversuche am Gittergewebe in Keis, Sand und Ton-Sand gemisch, *Report IV 45/48039/48056 Otto Graf Institut*, Baden Württemberg.