Non-linearity on pull-out test of cohesive soil using low tensile strengths of geogrids

Slamet Widodo, Abdelazim M. Ibrahim
Tanjungpura University, Engineering Faculty, Pontianak, Indonesia
Jl. Prof. H. Hadari Nawawi, Pontianak 78124
slamet@engineer.com
Al Neelain University, Kartoum, Sudan
abdelazimi@yahoo.com

Influence of geosynthetics inserted into cohesive granular soil was obviously investigated using geosynthetics-soil-interaction-testing device (ITD). Observations were already made during undertaking pull-out test, and then the results revealed that a correlation between shear stress and normal stress exhibits non-linear behaviour. In this paper, three approaches of trend-lines namely linear, logarithmic, and polynomial were compared. From analysis, polynomial trend line gave the best correlation among others. The final equation is very important part when estimating more accurate values of cohesion and friction angle design purpose.

Key words: pull-out test, tensile strength, geogrid, ITD, non-linear

Introduction

Geosynthetics has already been applied worldwide in geotechnical engineering. Particularly geogrid, it is already used such as basally reinforcement of embankments, retaining walls and many other applications. For instance, application of pull-out test can be used in case of inclusion of geosynthetics with several layers for reinforcing a structure of retaining wall.

Main aim of this paper is to determine an accurate method when taking a coefficient of friction λ and coefficient of cohesion λ_C, when undertaking pull-out test. Then, the second purpose is to introduce a simple mathematical method to obtain them. The last one is to compare several approaches used for analysing them in order to obtain more accurate values.

Methodology and testing device

In these tests, six geogrids with tensile strengths ranging from 30 to 40 kN/m are applied. These geogrids are moderate tensile strength which raw materials are mainly PET (Polyester).

Interaction-behaviour of geosynthetics and soil is an important thing to be investigated for a reinforced structure. In recent years extensive studies have been done in Geotechnical Institute at Freiberg of Mining and Technology to bridge the gap of knowledge in geosynthetics soil interaction [1,2,7].

Geosynthetics-soil-interaction-testing device (ITD) in Geotechnical Institute of Technical University Bergakademie Freiberg is a large shear frame device as described in Figure 1. Not only for shear test, this device is also possible to do other tests as for friction test and pull-out test. Dimension and range of performance are shown in Table 1.

The shear box encompasses a lower and upper shear frame which each box has a volume of 250 cm³. Generally, shear box can be filled a compacted soil ranging from 60 to 80 kg depending on kind of soil, water content, and degree of compaction. Compaction of soil sample can be done with a compactor after mixing it up homogeneously using a mixing device.

Table 1. Characteristic of ITD

Size of shear box	L=437;W=437;H=200mm
Range of normal stress	0-600 kN/m²
Range of shear stress	0-600 kN/m²
Maximal force	125 kN
Maximal shear displacement	160 mm
Maximal pull-out displacement	400 mm
Shear velocity	0,000001-12,5 mm/min

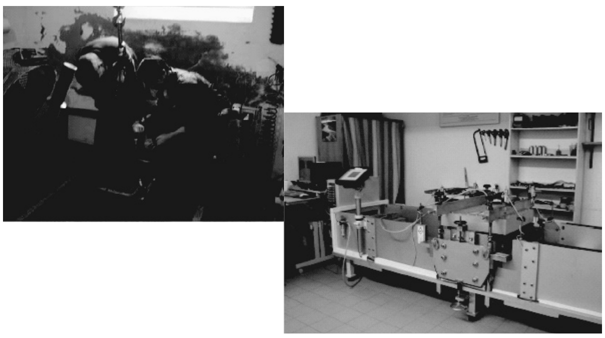

Figure 1. Installation of sample and overview of ITD

Table 2. Characteristic of compound soil for the testing

Properties	Symbols	Units	Values
Density	ρ_s	[kg/m³]	2.600
Plastic limit	w_P	[1]	0,135
Liquid limit	w_L	[1]	0,176
Plasticity index	I_p	[1]	0,0406
Optimal Water content	w_{opt}	[1]	0,113
Proctor max. density	ρ_{Pr}	[kg/m³]	1946

Geogrids used in tests

Geogrids used for pull-out test comprise six kinds of uniaxial geogrids within range of medium tensile strength as shown in Table 3.

Name of the test described in Table 3 can be explained as follows: take an example for IPV-01-CS5-V7-112 that IPV is the name of pull-out test, 01 means number of geogrid used, CS5 means Canitz soil by adding 50 percent of fine sand, V7 means seventh number of test, 114 means water content of 11.4%.

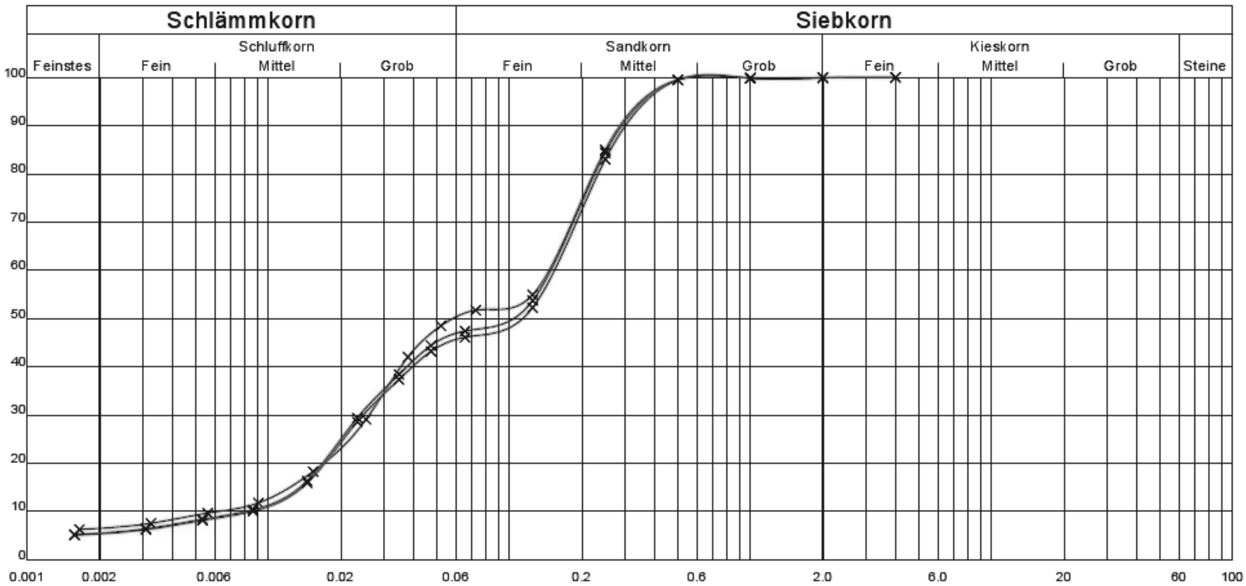

Figure 2. Grains distribution of CS5

Table 3. Tensile strengths of geogrids and names of pull-out test

No.	Names of test	Tensile strengths	Units
1	IPV-01-CS5-V7-114	30/30	[kN/m]
2	IPV-03-CS5-V1-112	40/40	[kN/m]
3	IPV-05-CS5-V7-116	35/35	[kN/m]
4	IPV-07-CS5-V1-112	40/40	[kN/m]
5	IPV-09-CS5-V2-113	40/40	[kN/m]
6	IPV-11-CS5-V3-113	40/-	[kN/m]

Preparation of cohessive soil

Soil used in this research is a mixing of Canitz clay and fine sand. In this compound soil, sand was added to Canitz clay amount of 50% by weight. Characteristics of compound soil used in the tests are shown in Table 2.

In order to get a maximum density by using Proctor compaction, great effort is really needed to determine certain water content in the soil. This was done by trial and error approach and then plotting it to a planar surface of paper, we obtain the maximum density which it is on a peak of hyperbolic curve. Maximum density for the soil is obtained when water content is around 11.3%. Grains distribution of the soil used in the test is shown in Figure 2.

Shear behaviour of soil

There is a familiar equation used in estimating a shear stress based on normal stress, cohesion, and friction angle. This equation is so-called Mohr-Coulomb [3, 5], as shown in Equation 1.

$$\tau = \sigma' \cdot \tan \varphi' + c' \tag{1}$$

where τ is shear stress, σ' is effective normal stress, φ' is friction angle, and c' is cohesion.

For pull-out test, an equation is used to predict a force on geogrid that is embedded in the soil as shown in Equation 2.

$$F = \tau \cdot 2 \cdot A \tag{2}$$

where F is a force on geogrid, τ is shear stress; A is surface area of geogrid.

In German guideline for design and analysis of earth structure using geosynthetics reinforcement, it was the familiar guideline so-called EBGEO (2010) [6], influence of geosynthetics due to friction is expressed in Equation 3.

$$f_{sg,k} = \lambda \cdot \tan \varphi_k \tag{3}$$

where

λ	Composite coefficient of friction $\lambda = \tan \delta / \tan \varphi$
$\tan \varphi$	Composite coefficient of the soil (measured)
$\tan \delta$	Composite coefficient of the geosynthetics/soil (measured)
$\tan \varphi_k$	Characteristic of friction coefficient of the soil

Influence of geosynthetics due to cohesion is exhibited in Equation 4.

$$f_{scg,k} = \lambda_c \cdot c_k \tag{4}$$

where

λ_c	Composite coefficient of cohesion $\lambda_c = a / c$
a	Adhesion of geosynthetics/the soil (measured)
c	Cohesion of the soil (measured)
c_k	Characteristic of cohesion coefficient of the soil

Analysis and results

To analyze a number of pull-out tests from laboratory, simple way was applied. By using simple method of linear regression with excel worksheet, three kinds of trend lines are simply used to describe scatter patterns of laboratory plotting data, namely linear, logarithmic, and polynomial [4].

In this analysis, we plots scatter pattern of correlation between shear stress and normal stress to get friction angle and cohesion, and then finally the closest trend line should be chosen as the best trend line. Figure 3 shows distribution of shear stress over normal stress from pull-out test namely IPV-03-CS5-V1-112.

Figure 3 shows the correlation between shear stress and normal stress resulted from laboratory pull-out test revealing non-linearity. Polynomial trend line between shear stress and normal stress presents the closest correlation among others with coefficient of correlation R= 0.9985.

Furthermore, Table 4 presents the correlation between shear stress and normal stress for all types of geogrids used in these tests. It is clear that inclusion of geogrids for all of pull-out tests with six different geogrids shows that polynomial trend line gives the highest coefficient of correlation R^2.

Appropriate trend line is important thing when we will predict value of cohesion, particularly in pull-out test. As we know well that cohesion is important parameter of cohesive soil and influences behaviour cohesive soil. It will have an effect on behaviour of composite material during the test.

Distribution of coefficient of correlation R^2 for three equations can be seen in Figure 4. From the figure, the coefficients of correlation of linear and logarithmic are not stable (fluctuated) compared with polynomial which polynomial trend-line has R^2 at least 0.9544.

It is important to understand that behaviour of composite soil by inclusion of geogrid on pull-out test is not linear but non-linear as findings resulted from six pull-out tests.

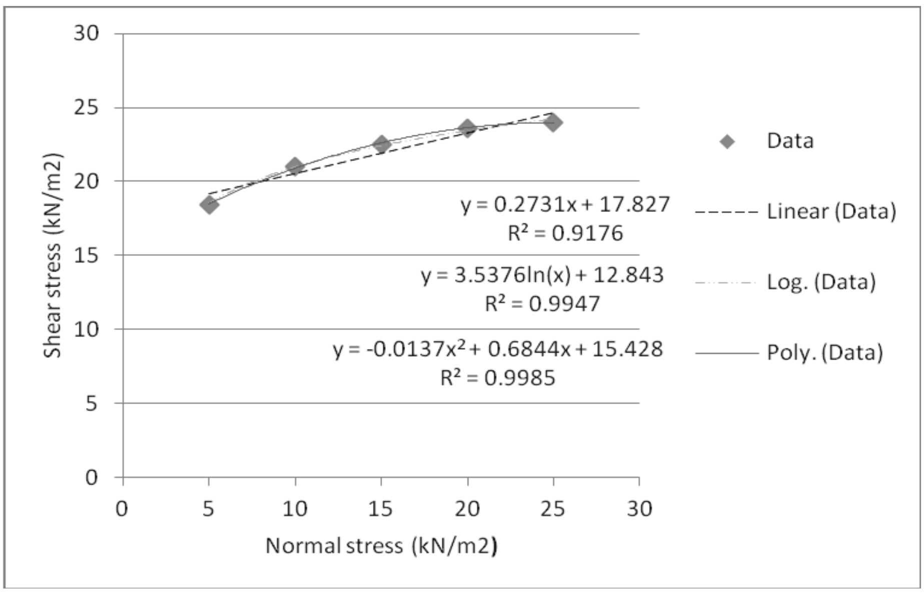

Figure 3: Plotting of shear stress vs. normal stress and trend lines

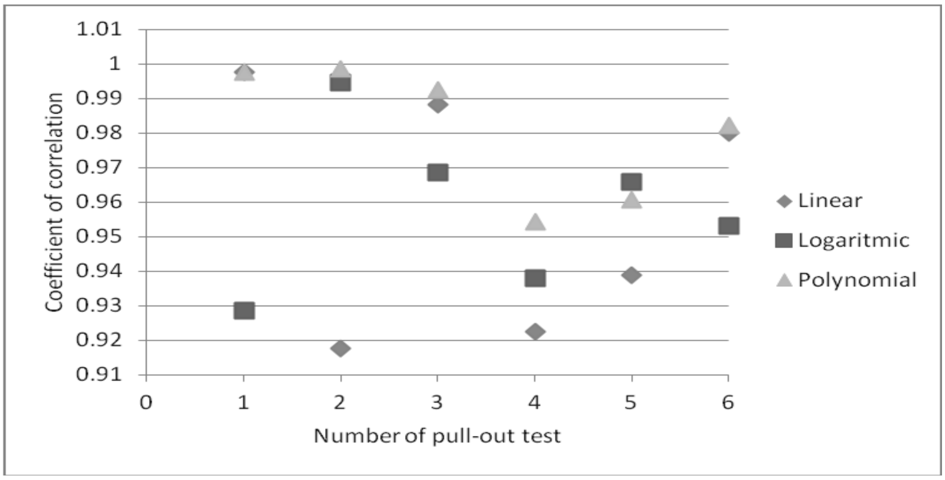

Figure 3: Plotting of shear stress vs. normal stress and trend lines

Table 3. Tensile strengths of geogrids and names of pull-out test

No.	Names of test	Equations	Trend line, R^2
1	IPV-01-CS5-V7-114	y = 0.4056 x + 18.928 y = 5.0723 ln(x) + 12.09 y = - 0.00007x^2 + 0.4078 x + 18.914	Linear, 0.9977 Log., 0.9285 Poly., 0.9977
2	IPV-03-CS5-V1-112	y = 0.2731 x + 17.827 y = 3.5376 ln(x) + 12.843 y = - 0.0137 x^2 + 0.6844 x + 15.428	Linear, 0.9176 Log., 0.9947 Poly., 0.9985
3	IPV-05-CS5-V7-116	y = 0.7366 x + 11.442 y = 7.827 ln(x) + 1.8328 y = - 0.0107 x^2 + 1.004 x + 10.101	Linear, 0.9883 Log., 0.9680 Poly., 0.9925
4	IPV-07-CS5-V1-112	y = 0.4707 x + 10.624 y = 5.0968 ln(x) + 4.2563 y = - 0.0196 x^2 + 0.9611 x + 8.1726	Linear, 0.9224 Log., 0.9379 Poly., 0.9544
5	IPV-09-CS5-V2-113	y = 0.6934 x + 11.927 y = 16.617 ln(x) - 23.509 y = - 0.0178 x^2 + 1.585 x + 1.6741	Linear, 0.9388 Log., 0.9659 Poly., 0.9605
6	IPV-11-CS5-V3-113	y = 0.424 x + 10.87 y = 9.8756 ln(x) - 9.8934 y = - 0.0029 x^2 + 0.2798 x + 12.528	Linear, 0.9800 Log., 0.9530 Poly., 0.9821

Discussion

There are three mathematical equations used in the analysis, namely linear, logarithmic, and polynomial trend-lines. In mathematical point of view, we can estimate that a prediction will be accurate if trend-line between a distribution of data and a prediction is close to a certain level or significant level. Here, coefficient of correlation R^2 is used to predict them. The more higher the value means the prediction is closer to data of measurement.

From six tests, they show that the coefficients of correlation R^2 of polynomial equation provide the highest values.

In an equation, a coefficient of cohesion λ_c is intercept or constant of the equations. Meanwhile, a coefficient of friction λ is slope or gradient of the equation.

For simplicity, a linear equation is simpler but it will provide different values for λ and λ_c. Besides that, using non-linear approach will show that slope as the designated coefficient of friction λ is changing at a normal stress.

Conclusion

Behaviour of composite soil with inclusion of geogrid on pull-out test has already been presented using simple regression analysis. Non-linearity of pull-out test, here, is observed using of three equations namely linear, logarithmic, and polynomial trend-line. Based on analysis, polynomial give the best equation which coefficient of correlation R^2 are the highest among other equations.

Acknowledgment

Special thanks is addressed to Prof. H. Klapperich, Dr. Nandor Tamaskovics, and Dipl.-Ing Sebastian Althoff.

Literature

[1] Althoff S (2011): Beitrag zum Verbundverhalten von Geokunststoffen in bindigen Böden mit Bindemittelverbesserung. Geotechnics Seminar 2011: TU-Bergakademie Freiberg.

[2] Aydogmus T., Klapperich H. (2011): Beitrag zum Interaktionsverhalten von Geokunststoff und Lockergestain. Dissertaion, TU-Bergakademie Freiberg.

[3] Andrzej S (2000): Mechanics of Reinforced Soil, A.A. Balkemia, Rotterdam.

[4] Ang H S& Tang W H (1975): Probability Concepts in Engineering Planning and Design, Volume I-basic Principles. John Wiley&Sohn, New York.

[5] Das B M (1985): Principles of Geotechnical Engineering. University Texas at El Paso, USA.

[6] EBGEO ENTWURF (2010): Empfehlung für den Entwurf und die Berechnung von Erdköpern mit Bewehrung aus Geokunststoffen. Deutsche Gesellschaft für Geotechnik e. V.

[7] Tamáskovics N., Klapperich H. (2010): Verbundverhalten von Geokunststoffen in bindigem Boden. 9. Sächsisches Bautextilien-Symposium BAUTEX 2010 Bauen mit Geokunststoffen, Chemnitz.