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Pullout Tests of Geogrids Embedded in Non-cohesive Soil

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Abstract

A source of essential information regarding the behaviour of the soil-reinforcement system can be laboratory pullout tests. In this paper, basic aspects of such testing concerning the equipment used (designed and constructed in the Geotechnical Laboratory of Gdańsk University of Technology) and procedures applied are described. The pullout tests carried out for biaxial polypropylene geogrids embedded in coarse sand are presented. Finally basing on the test results the interpretation procedure for the estimation of elasto-plastic interaction between geogrid and soil is proposed. The method proposed enables determining soil-geogrid interface: stiffness modulus responsible for elastic behaviour of the system in the range of permissible loads, as well as maximum pullout resistance corresponding to limit state.

Key words: pullout, geogrid, laboratory research, testing

1. Introduction

Correct assessment of the adherence factor of the soil-geogrid interface in the designing process enables the effective use of the geosynthetics. For that purpose it is proper to perform pullout tests for the geosynthetic and the soil to be applied in the construction. It is of particular importance for huge construction sites where the costs of detailed testing are much less than those resulting from the assumption of too high safety coefficients.

The draft of European Standard prEN 13738 *Geotextiles and related products – Determination of pullout resistance in soil* focuses only on the selection of adequate testing equipment and methodology of pullout tests without giving the principles regarding the interpretation of test results for designing purposes.

This paper presents a proposal for the interpretation of pullout tests for geogrids based on two parameters characterising soil-reinforcement interaction. The first parameter, the stiffness coefficient of soil-reinforcement interface, describes the elastic response of the material for permissible stresses, whereas the second one corresponds to the maximum pullout resistance of the geosynthetic, which is equivalent to the plastic state.

2. Test Apparatus

The tests have been performed in a large pullout apparatus (Duszyńska 2002), the basic elements of which are the following (Fig. 1):

- rectangular steel box with internal dimensions 1.60 × 0.60 × 0.36 m (length × width × height) and steel sleeves 0.20 m long reducing the influence of the front wall;
- pneumatic system of loading (200 kPa maximum) with reinforced rubber air bag to apply confining pressure;
- mechanical pullout force loading device (providing constant rate of displacement up to 10 mm/min) consisting of a frequency inverter, worm gear unit, electric engine, a load cell (of 50 kN capacity) and a special clamping system. The device enables uniform distribution of pulling force over the entire width of the specimen, its horizontal position during loading, and protection against sliding, as well as failure of the material between clamps;
- electronic displacement transducers to measure displacement of the geomaterial at the clamp and selected points located along its embedded length;
- data acquisition system for continuous recording of pulling force and displacements of chosen measuring points.

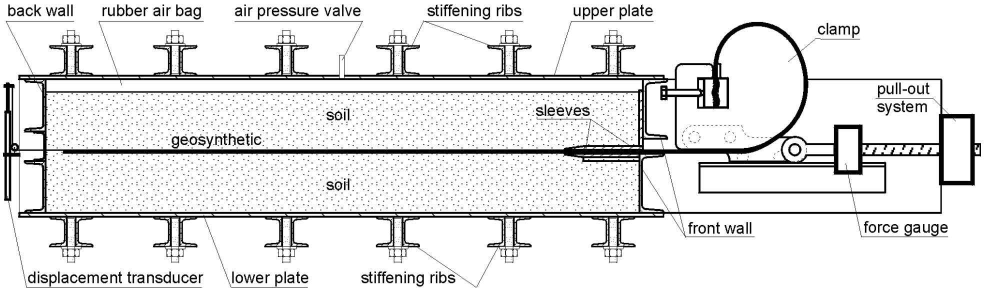

Fig. 1. Pullout testing device

3. Materials Applied

Tests have been carried out for Rybaki 2 non-cohesive soil, which is one of the model sands used in the Geotechnical Laboratory of Gdańsk University of Technology. The soil is uniform coarse quartz sand with small admixtures of other minerals. The main parameters of the soil used are presented in Table 1.

Tests have been performed for biaxial polypropylene geogrid cut out in the machine direction. The determined parameters of the material used in the tests are presented in Tables 2 and 3.

Table 1. Geotechnical parameters of the Rybaki 2 sand

Parameter	Symbol	Unit	Value
Mean particle size	d_{50}	[mm]	1.19
Effective particle size	d_{10}	[mm]	0.61
Uniformity coefficient	C_u	[–]	2.19
Mean moisture content	w_n	[%]	0.11
Poisson's ratio	ν	[–]	0.31
Density index	I_D	[–]	0.381
Dry density	ρ_d	[t/m^3]	1.668
Angle of internal friction	ϕ	[°]	35.8

Table 2. Parameters of the geogrid

Parameter	Symbol	Unit	Value
Aperture size	$S1 \times S2$	[mm]	32÷33 × 32÷33
Mass/unit area	μ_A	[g/m^2]	630
Thickness under loads:			
2 kPa	B	[mm]	9.5
20 kPa			6.5
200 kPa			6.3

Tensile strength and deformability of the geogrid have been determined by testing wide-width specimens (according to EN ISO 10319) for both geogrid directions, i.e. in machine and cross machine directions, at a pulling rate of 20 mm/min. For machine direction specimens the tests were also made for rates of 2 mm/min and 5 mm/min (the rates applied in pullout tests). Considerable scatter of tensile test results was observed. Some exemplary plots are shown in Figure 2.

Table 3. Results of geogrid tensile tests

Testing mode	Tensile strength	Load at 2% strain	Load at 5% strain
	$T_{\max}$	$T_{\max}$ (ε = 2%)	$T_{\max}$ (ε = 5%)
	[kN/m]	[kN/m]	[kN/m]
cross machine direction – $v = 20$ mm/min	25.9	14.4	23.8
machine direction – $v = 20$ mm/min	29.6	12.6	24.8
machine direction – $v = 2$ mm/min	30.2	10.9	21.7
machine direction – $v = 5$ mm/min	27.3	9.8	20.0

The pullout tests were carried out on the specimens 0.40 m wide, embedded 1.50 m lengthwise in the soil compacted to the density Index $I_D = 0.38$, at the displacement rate of clamping device $v = 2.0$ mm/min.

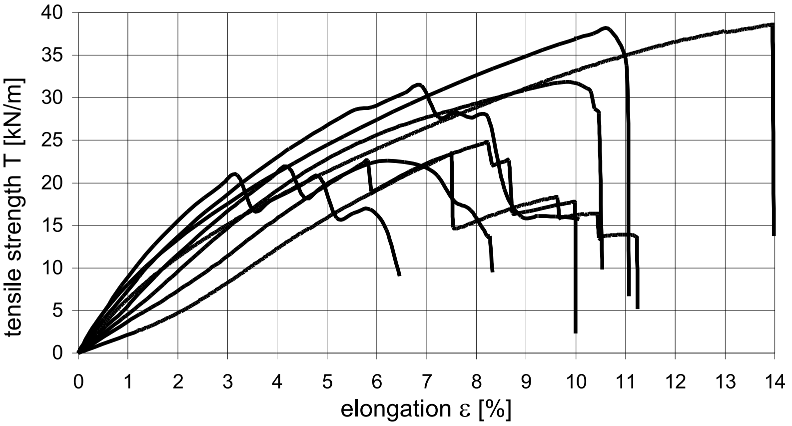

Fig. 2. Exemplary results of tensile tests

4. Testing Procedure

The first step in the testing procedure was to fill the bottom half of the pullout box with sand, which was placed in 0.05 m layers. Each layer was levelled and compacted by tamping to the required density. When the sleeve level was reached the geogrid specimen was placed over the compacted and thoroughly levelled soil surface. Next the specimen was equipped with the in-soil displacement measured devices. The arrangement of the measuring points is shown in Figure 3.

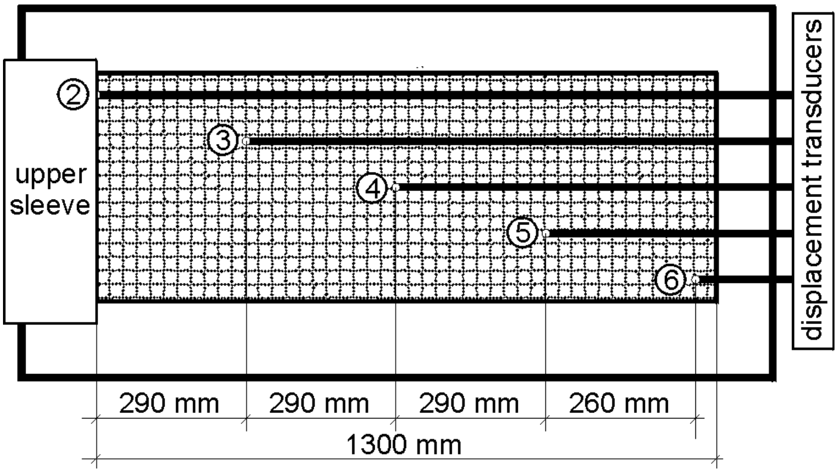

Fig. 3. Localisation of displacement measuring points

The free end of the specimen was then placed between sleeves and clamped in the clamping device equipped with additional displacement gauge and connected to a pulling system.

Next, upper sand backfill was formed using the same placement and compaction method as used in the bottom half of the test box. Finally, the rubber air bag was placed on top of the soil and the box was closed by the upper plate.

After applying confining pressures in the range of σ = 10, 15, 25, 50 and 100 kPa, the geogrid was pulled out at a constant rate of clamp displacement of 2 mm/min. During the test the displacements of chosen points and pulling force were recorded (every 1 s).

The tests were continued until pullout occurred or the specimen was broken in tension. After the test the device was dismantled and the soil-geogrid interface was inspected with regard to the uniformity of deformation and if the sleeves had not prevented specimen pullout or induced premature failure.

In all twenty five tests were conducted – five tests for every series of the tests (vary in applied confining pressures).

5. Test Results

According to prEN 13738 the pullout resistance P of geogrid was calculated as follows:

$$P = \frac{F\,n_g}{N_g}, \tag{1}$$

where:

P – pullout resistance [kN/m],

F – pullout force measured in the test [kN],

n_g – number of ribs per unit width of the geogrid in the direction of the pullout force,

N_g – number of ribs of geogrid test specimens in the direction of the pullout force.

Basing on the value of pullout force measured in the tests performed and material parameters, the adherence factor characterising the soil-geogrid interaction α_b was determined as follows:

$$\alpha_b = \frac{F}{2A\sigma_n \tan\phi}, \tag{2}$$

where:

F – pullout force [kN],

A – in-soil area of geogrid [m^2],

ϕ – angle of internal friction of the soil [°],
σ_n – total normal stress acting on the geogrid surface [kN/m^2],

$$\sigma_n = \sigma_s + \sigma, \tag{3}$$

σ_s – normal stress due to soil above the specimen,
σ – normal stress due to the confining pressure applied.

The elongation of particular geogrid sections ε_i was calculated using the values of the displacements measured at chosen points:

$$\varepsilon_i = \frac{p_{i+1} - p_i}{\Delta x}, \tag{4}$$

where:

p – measured displacement [mm],
Δx – section length [mm].

Maximum values of geogrid pullout resistance $P_{\max}$ and adherence factors of soil-geogrid interface α_b are collated in Table 4. Analysing tests results it was found that the confining pressure an the essential influence on the geogrid displacements and the behaviour of soil-geogrid interface, as shown in Figures 4 ÷ 7.

Table 4. Pullout test results

No.	Test parameters	Resistance [kN/m]	Adherence factor
		$P_{\max}$	α_b
1	$L = 1.50$ m, $W = 0.40$ m, $\sigma = 10$ kPa, $I_D = 0.38$, $v = 2.0$ mm/min	21.06	0.88
2	$L = 1.50$ m, $W = 0.40$ m, $\sigma = 15$ kPa, $I_D = 0.38$, $v = 2.0$ mm/min	27.76	0.83
3	$L = 1.50$ m, $W = 0.40$ m, $\sigma = 25$ kPa, $I_D = 0.38$, $v = 2.0$ mm/min	38.55	0.74
4	$L = 1.50$ m, $W = 0.40$ m, $\sigma = 50$ kPa, $I_D = 0.38$, $v = 2.0$ mm/min	41.91*	0.42*
5	$L = 1.50$ m, $W = 0.40$ m, $\sigma = 100$ kPa, $I_D = 0.38$, $v = 2.0$ mm/min	42.04*	0.22*

* – break of the material.

The pullout resistance of geogrid versus displacement of the clamps for various confining pressures is plotted in Figure 4. It can be seen that the force required for pulling the geogrid out of the soil increases with the increase of confining pressure.

For high values of confining pressures applied (50 and 100 kPa), failure of the geogrid was observed. Breaking of the specimen occurred at the free section

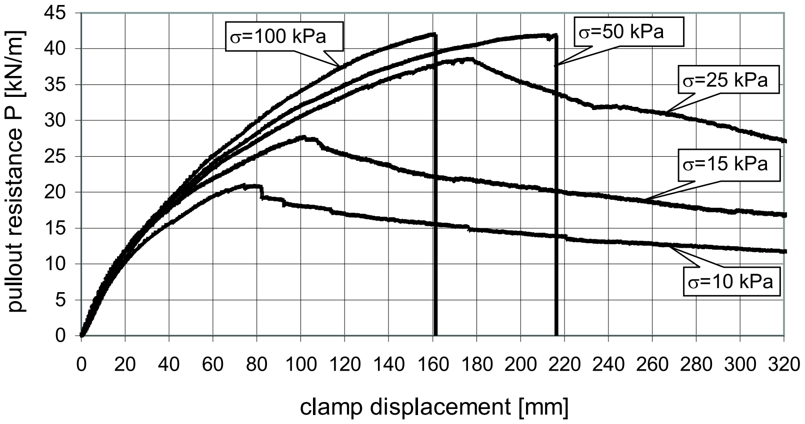

Fig. 4. The influence of the confinement pressure on the pullout resistance

outside the apparatus, when the geomaterial is decompressed. When the specimen was broken the strength of soil-geogrid interface was determined by the tensile strength of the geogrid as opposed to the shear strength of soil in the case when specimen failure did not occur. In such cases (high confining pressures), in order to mobilise pullout resistance equal to tensile strength, only a small length of the reinforcement is required.

It was found that considerable increment of pullout force occurred for confining pressures less than 25 kPa and that for pressures higher than 50 kPa the maximum pullout resistance was reached (Fig. 5).

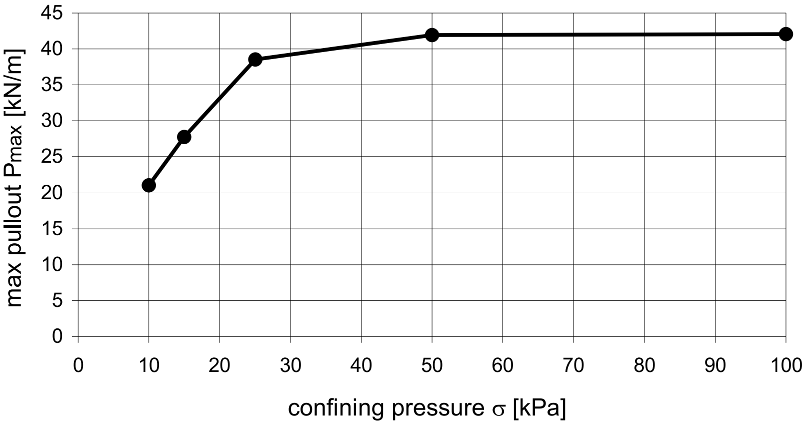

Fig. 5. The distribution of maximum pullout resistance versus normal stress

It was also found that the increase of confining pressure causes a shift of the displacements towards the point of application of pullout force, significant decrease of the displacements of the embedded part of geogrid, and for high values of confining pressures (50 kPa and 100 kPa) rigid fixing zone at the end of the specimen (see Fig. 6).

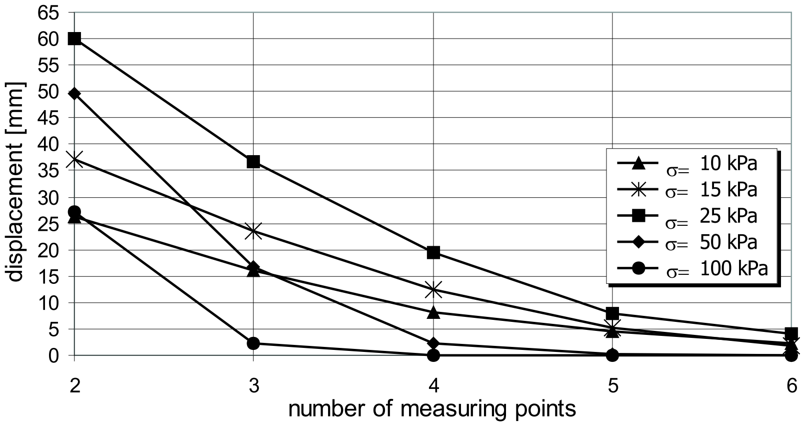

Fig. 6. Displacement distribution at $P_{\max}$ for various confining pressures

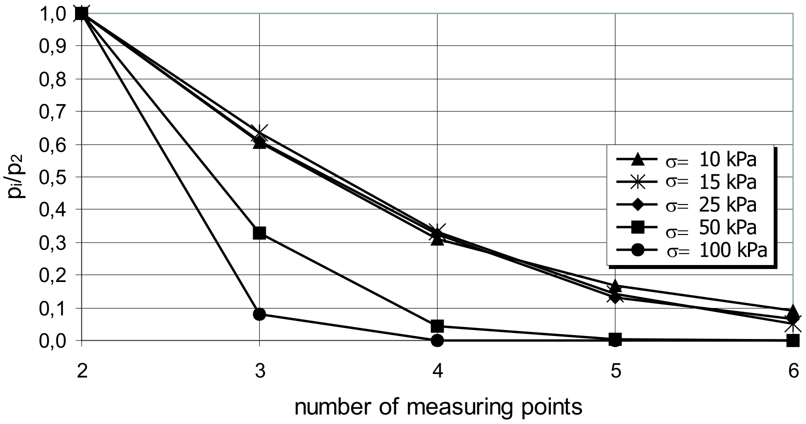

Fig. 7. Influence of confining pressure on the displacement ratio p_i/p_2 for $P_{\max}$

The influence of the confining pressure on the ratio of displacements of the in-soil part of geogrid p_i/p_2 recorded for maximum pullout resistance $P_{\max}$ is shown in Figure 7. For small values of pressure (10 ÷ 25 kPa) almost the same displacement ratio for all three test series, in which the pulling of the material occurred, is observed. An increase of the non-linear behaviour of the displacement increments along the anchored part of the geogrid for higher confining pressures indicates less uniform mobilisation of shear stress on the specimen surface.

An increase of confining pressure causes a decrease of the adherence factor (Table 4) of from $\alpha_b = 0.88$ for $\sigma = 10$ kPa up to $\alpha_b = 0.74$ for $\sigma = 25$ kPa (for higher pressures failure of the geogrid occurred).

6. Assessment of Soil-Geogrid Interface Parameters from Pullout Test

The results of standard tests carried out according to the prEN 13738 code are the dependence of maximum geogrid pullout resistance as a function of confining pressure and the displacements of particular sections of the specimen within the pullout box. There are no recommendations regarding the interpretation of the pullout test results, which may be used for design purposes.

The load-displacement curve obtained from the pullout test according to prEN 13738, determined for 6 measuring points (at the clamp and five points located in the embedded part of the geogrid), can also be used for assessment of other parameters (besides the maximum pullout resistance) describing the behaviour of the soil-reinforcement interface.

The soil-geosynthetic interaction should be related to the stress state on the material surface (Duszyńska 2002). Assuming to describe the load-elongation relationship by elasto-plastic model enables incorporation of two basic parameters characterising this interaction:

- pullout stiffness coefficient of soil-geosynthetic interface,
- maximum pullout resistance of geosynthetic.

While the determination of maximum geosynthetics resistance is unique, the determination of stiffness coefficient is not so straightforward, as at different points of the material we have to deal with various strain values resulting from the decay of tensile stresses. It requires the assessment of construction safety and selection of the criterion for approximation of the parameter. It should be pointed out that in various applications, various values of permissible strains corresponding to the serviceability limit state are assumed. This means that the most adequate parameter determining the stiffness of the soil-reinforcement system is the secant modulus assumed for the given value of strain.

The analysis of elasto-plastic soil-geogrid interaction was performed on the basis of load-elongation curve (Fig. 8), which was obtained for the following conditions:

- all pullout curves for different confining pressures have been collated,
- the analysis of geogrid elongation was limited to the first section only (section 2–3 according to Figure 3) – this is part of the specimen embedded in the soil, for which maximum strains occur,
- a representative tensile curve was assumed as an average curve for all curves obtained from unconfined tensile tests according to EN ISO 10319.

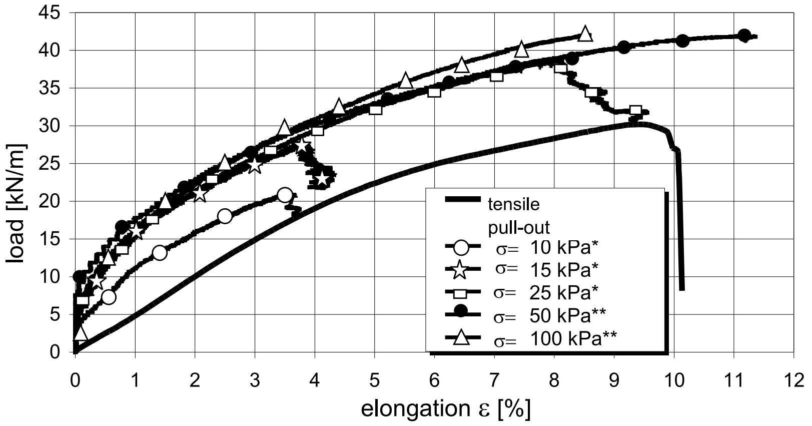

Fig. 8. Load-elongation dependence for section 2–3, *pulling out, **failure of the material

6.1. Elastic Response of the System

Elastic response of the soil-deformable reinforcement interface can be described by stiffness coefficient.

The character of the load-elongation curves at various stress states is similar for almost all curves. Only the those for 10 kPa confining pressure corresponds rather to the unconfined test conditions.

To assess soil-geogrid interaction in the elastic range the averaged pullout curve was elaborated (Fig. 9). The curve is valid for confining pressures $\sigma >$ 10 kPa.

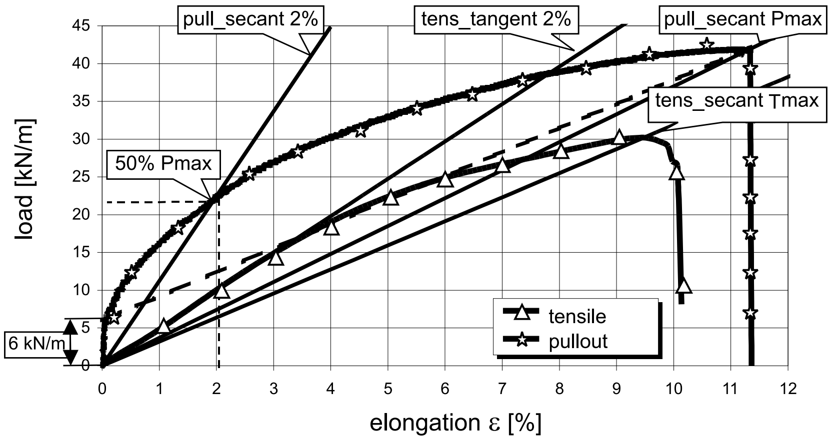

Fig. 9. Assessment of elastic parameters of soil-reinforcement interface

Comparison of tensile and pullout curves shows essential advantages resulting from the interaction between the soil and geogrid. At the beginning of the pullout process rapid increase of the pullout resistance to approximately 6 kN/m is observed. This value corresponds to almost 14% of maximum pullout resistance of geogrid and 20% of its maximum tensile resistance. Shifting of the secant to the tensile curve for maximum load by the initial value of 6 kN/m causes its intersection with the secant to pullout curve at maximum elongation of the geogrid.

For design purposes the value of secant modulus at relative elongation of 2% or 5% based on unconfined tensile test carried out according to EN ISO 10319 is assumed.

For geogrid tested the mean value of secant modulus (tangent one in this case) of tensile curve at the elongation of 2% was assumed to be:

$$J_{(grid)} = J_{(\varepsilon=2\%)} \approx 500\ \mathrm{kN/m}. \tag{5}$$

In the case of the pullout curve (for soil-geogrid system) the secant for 2% elongation coincides with the secant corresponding to 50% of maximum load:

$$J_{(system)} = J_{(\varepsilon=2\%)} = J_{(50\%P\,\mathrm{max})} \approx 1100\ \mathrm{kN/m}. \tag{6}$$

This value is equal to 220% of the modulus value determined for the geogrid from unconfined tensile test at 2% elongation:

$$J_{(system)} = 2.2 \times J_{(grid)}. \tag{7}$$

Both secants of pullout curve, for 2% elongation and 50% of maximum load enable safe assumption of the soil-reinforcement interface stiffness coefficient to be substantially higher than the value of the secant modulus determined from standard unconfined tensile test according to EN ISO 10319.

Assumption of the stiffness modulus as the secant and the recommendation of its applicability range within the tensile strength range in confined conditions seems to be safe for stress states in which the pressures acting onto the geogrid surface exceed 10 kPa what corresponds to a soil layer 0.5 ÷ 0.7 m thick.

Only in the case of small stress values $\sigma \leq 10$ kPa, the modulus values determined by unconfined test carried out according to EN ISO 10319 should be taken for calculation purposes. These values, for loads acting on a geogrid surface corresponding to a soil thickness layer > 0.5 m will always be safe.

6.2. Plastic State

The plastic part of the soil-geogrid interaction can be described by maximum pullout resistance or the adherence factor, often used in the designing process.

Pullout resistance is strictly related to the confining pressure at the level of geogrid surface, thus it depends on the soil, i.e., its state and stress level. Maximum pullout resistance of the geogrid tested in coarse sand ranged from $P = 21.0$ kN/m

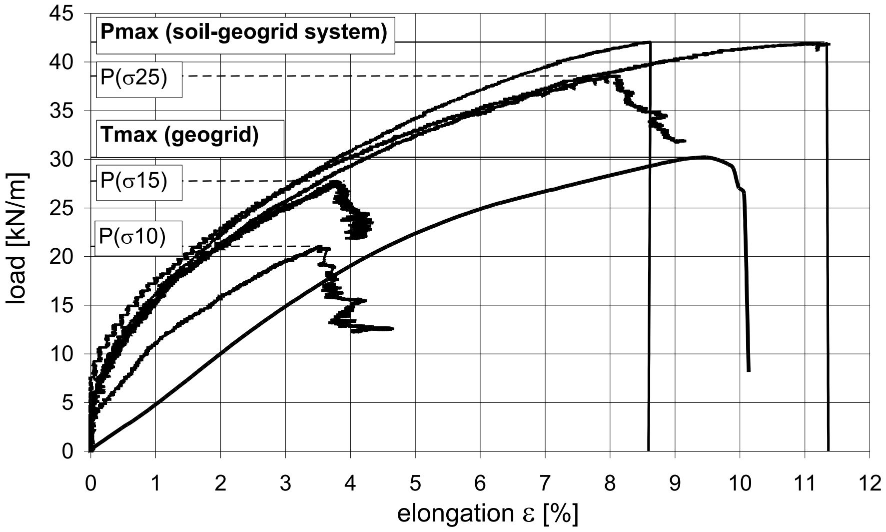

Fig. 10. Assessment of plastic parameters of soil-geogrid interface

for $\sigma = 10$ kPa up to a maximum strength of the material attained at a stress of $\sigma \geq 50$ kPa (Fig. 10).

Failure of the geogrid in the pullout tests (tests in confined conditions) occurred at a load exceeding 40 kN/m (maximum P = 42.04 kN/m), whereas average machine direction strength of the material in unconfined tensile tests on wide specimens was 30.2 kN/m. It means that the failure in pullout tests occurred at 40% higher loads than in the case of unconfined tensile test.

$$P_{\max(system)} = 1.4 \times T_{\max(grid)}. \tag{8}$$

This suggests that after placing the material in the soil construction its response is better than assumed in the designing process, where maximum tensile strength and secant modulus corresponding to 2% or 5% elongation are assumed.

7. Summary

In the case of real reinforced soil constructions its behaviour should be assessed and described, based on tests in which designed materials and soil taken from the construction site are used.

Pullout tests require considerable experience and careful performance of the test, as well as interpretation of the test results. Existing codes do not include the procedures for such interpretation. The interpretation method presented, elaborated on the basis of pullout test series carried out on the geogrid and non-cohesive soil, enables determination of the soil-geogrid interface stiffness modulus responsible for elastic behaviour of the system in the range of permissible loads, as well as the maximum pullout resistance corresponding to the limit state.

For geogrids and other products characterized by a similar structure, only detailed analysis of the products behaviour during pulling out from soil characteristic for the construction site and in the range of designing loads and deformations, makes it possible to estimate real design values of an interaction coefficient.

The analysis made shows that the testing method of geosynthetics being pulled out from the soil together with the interpretation of test results, enable the determination of factual values of the parameters and safety margins resulting from the traditional approach.

The test results presented applied to geogrids characterized by low deformability so analyses conducting for other products could call for defining other elongation criteria, which should be connected with characteristic curves obtain from the tensile tests.

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