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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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GEOGRIDS – WHAT IS IMPORTANT

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Abstract

Geogrids are frequently used for stabilisation and reinforcement of the unbound courses in transportation engineering. Benefits of their use are well known, but many times poorly understood in terms of mechanisms that govern their performance. Their performance is based on interaction with granular soil surrounding it. Paper deals with the importance of geogrid structure, geometry, junctions and mechanical properties of geogrid in relation to granular material in which they are intended to be installed. Some basic important facts on interaction between geogrid and soil are presented through experimental results and some theoretical aspects of mechanical behaviour are discussed. Current and future trends of research in this filed are highlighted.

Keywords: geogrids, reinforcement, stabilization, performance, mechanisms

1 Introduction

The use of geosynthetics in transportation engineering projects is inevitable today, due to their good and proven performance, simple and reliable technology of application, long durability and variety of solutions they can offer. Among them geogrids are most efficient in reinforcing soil. In transportation engineering geogrids are mainly used for reinforcement of soil structures, which means improvement of bearing capacity and decrease in deformability. Recently term “stabilization” was officially introduced in use in geosynthetic engineering. This term is welcomed and helps to distinguish the situation of restricting lateral (and vertical) deformations from the situation were tensile force assures force balance (reinforcement). The definitions of reinforcement and stabilization are as follows:

- Reinforcement = use of the stress-strain behaviour of a geosynthetic material to improve the mechanical properties of soil or other construction materials [1].
- Stabilization = improvement of the mechanical properties of an unbound granular material by including one or more geosynthetic layers such that the deformation under applied loads is reduced by minimizing soil particle movement (accepted but not yet published definition by ISO TC 221 Geosynthetics).

Reinforcement can be of benefit to the structure without improving soil properties, for instance in case of geotextile as a reinforcement that transfers forces. Fig. 1. shows three principal applications of geogrids: stabilization, reinforcement and earth retaining structures. The purpose of this article is to highlight important geogrid characteristics that control its performance.

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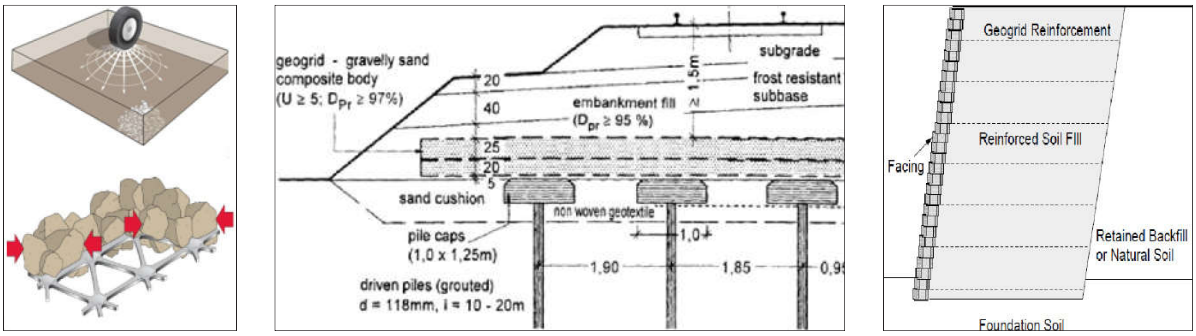

Figure 1 Typical applications of geogrids in transportation engineering: a) stabilization of soil grains under the pressure from tire by restricting lateral movements (left) [2], b) reinforcement – piled embankment platforms(middle) [3], c) earth retaining structures (right) [4]

2 Geogrids and their performance

Geogrids are by definition [5]: “planar polymeric structures consisting of regular open networks of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, used in contact with soil/ rock/ and/or any other geotechnical material in civil engineering applications”. Materials from which they are manufactured are polyethylene (PET), high density polyethylene (HDPE), polypropylene (PP), aramid (AR) and polyvinyl alcohol PVA.
Research results and experience suggest that manufacturing process is crucial for the mechanical properties of the geogrids. We distinguish main ribs (MD-machine direction) and transversal ribs (CMD- cross machine direction). They can form different forms of openings: square, rectangular, triangular (hexagonal). Manufacturing process can be adopted so that geogrids take loads (tensile forces) dominantly in one direction (uniaxial geogrids) or in two perpendicular directions (biaxial geogrids). Load distribution on bearing layers in roads and railways is radial (see Fig. 1. left) and therefore multidirectional tensile resistance and stiffness of geogrid openings is of interest. Polymers and manufacturing process control their tensile capacity and stiffness (Table 1). It would be wrong to conclude that highest tensile strength denotes best geogrid. Geogrid ribs in transportation structures are not subjected only to tension but also to bending in their plane and compression in and out of their plane. Geogrid quality criteria therefore should be based mainly on performance of geogrid in real stress-strain conditions, for which model and trial testing is of highest importance.
Stresses from the soil are transferred to geogrids (and vice versa) through the mechanism of interaction. The simplest kind of it is friction (for instance soil-geotextile contact, or uniaxial geogrids in cohesive soils). However, the nature of interaction of geogrids and unbound materials is very complex and friction is only a part of it. That complexity is reason that we today do not have generally accepted numerical design of reinforced unbound layers for transportation structures.
Numerous research projects and tremendous efforts are oriented to better understanding of this problem. Meanwhile designers rely on performance evidence based on model and/or trial field testing that are used to advocate thickness reduction of reinforced unbound soil bearing layers compared to unreinforced soil layers (Fig. 2).
Geogrid-unbound soil interaction is largely related to interlocking of particles in geogrid openings, governed more by the stiffness of the geogrid openings then by geogrid tensile strength. This interaction depends on geogrid openings geometry, tensile and flexural stiffness and thickness of ribs, radial stiffness of geogrid openings (stability of opening geometry), junction strength and ratio of the soil grain size to the geogrid opening size.
When relative displacement of soil and geogrid occurs (for instance in pullout of geogrid from soil) three mechanisms take place: 1) friction on soil-geogrid contact, 2) friction between soil grains (inside geogrid openings), and 3) passive resistance in front of the transversal rib.

Friction on soil geogrid contact is usually modelled as a part of soil shear strength multiplied by friction coefficient (usually 0.5-1.0). Friction between soil grains can be taken as shear strength of soil. Third component, the passive resistance, is very important and it has significant values. It depends on geometry and thickness of the geogrid transversal rib, junction strength, and soil gradation.

Table 1 Typical short term strengths of geogrids (adapted from [6])

Raw material	Geogrid type	Typical short-term strengths [kN/m]			Typical elongations at failure [%]	
		from	to	max.	from	to
Aramid (AR)	Woven and raschel-knit	40	1200	2200	2	4
Polyethilene (PE)	Woven and raschel-knit	20	150	300	15	20
	Extruded	40	150	200	10	15
Polyester (PET)	Woven and raschel-knit	20	800	1200	8	15
	Bonded	20	400	500	6	10
Polypropyle-ne (PP)	Woven and raschel-knit	20	200	500	8	15
	Bonded	20	200	400	8	15
	Extruded	20	50		8	20
Polyvinyl alcohol (PVA)	Woven and raschel-knit	30	1000	1600	4	5

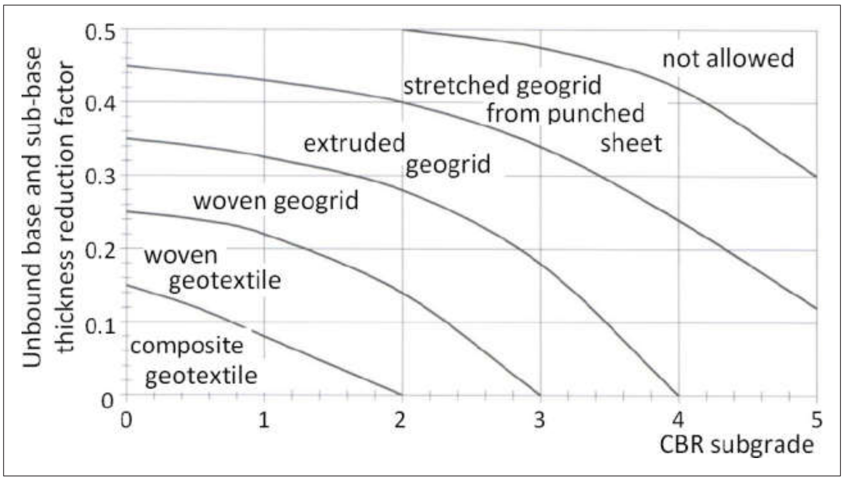

Figure 2 Diagram for thickness reduction of bearing an sub-bearing layers depending on soil type and geogrid type [7]

The experimental results suggest that, in case of good soil-geogrid interaction, soil in and around geogrid openings has higher internal friction angle compared to internal friction angle of soil alone. This ratio can have values much higher than one (1.1-1.7), especially for crushed aggregate [8-9], although in designs values <1 are regularly used.

3 Experimental and model testing results

Design engineers use available knowledge, experience and model test results in order to correctly predict and achieve required performance of geodrids in unbound materials. They have to consider three questions: 1) what is the geogrid purpose, 2) how to choose suitable geogrid for chosen soil (or vice versa) and what are the basic reasons for it, and 3) how to define technical requirements for the geogrid in order to protect design solution.
First step is to detect purpose of the geogrid: stabilization or reinforcement. For base and sub-base layers in roads and railways one should choose stabilization performance and for

retaining walls where anchor effects are expected (pullout model) it is geogrid tensile strength that matters (do not forget interlocking). There is always need to consider the pattern transferring loads between geogrid and soil. It is important to stress that performance of a geogrid in sand is very different to performance of the same geogrid in gravel. Very little research until recently was dedicated to testing geogrid-gravel interaction, and very few design engineers would treat geogrid in sand and geogrid in gravel in different way. Principal reason for different performance of geogrid in sand and in gravel comes from different geogrid-soil interaction, dominantly controlled by the grain size – geogrid opening ratio.
Stabilization performance (see Fig. 3.) depends on geogrid type and relation of grain size of soil and opening size of the geogrid. In sand, with particles up to 2 mm, most of geogrids (even very different) will have similar effects since interaction does not cause interlocking effect, due to huge difference between distance of geogrid ribs compared to soil grain size. With the increase of soil grain size stabilization and interaction effects are increasing, interlocking is increasing and difference in performance of different geogrids is evident. Having the higher stiffness of geogrid opening, there will be higher pullout resistance for proper soil gradation [10].

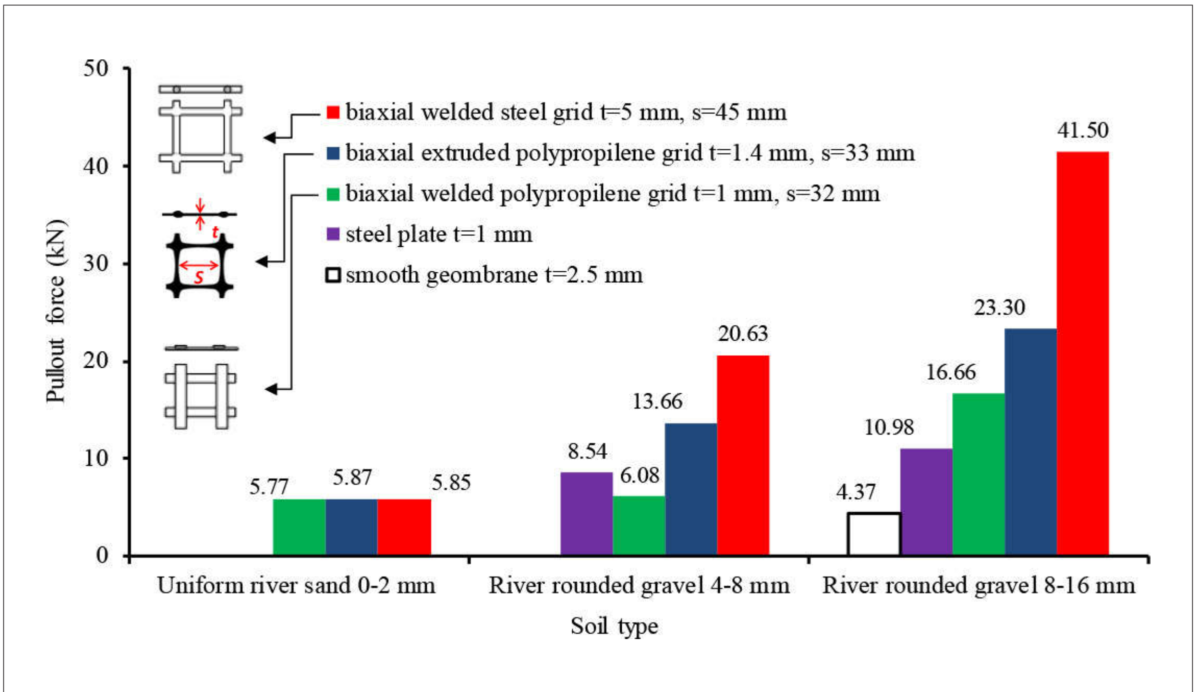

Figure 3 Pullout resistance of different reinforcement in sands and gravels [10]

Fig. 4. shows that this increase comes from transversal ribs more than from friction, since grains are locked in geogrid openings, which in turn means higher demands on junction strength. Authors believe that suitable ratio between soil grain size and geogrid opening dimension, together with stiffness of the geogrid opening, improve soil strength (friction angle) around geogrid, due to interlocking effect coming from restraining and dilatancy in shearing. Some researchers like [11-13] studied this ratio effect, but most of the published results of testing are referring mainly to sands and rarely to coarser materials. Authors of this paper conducted research utilizing big pullout testing device, showing that highest interaction (expressed as maximum pullout resistance) develops when ratio of geogrid opening size (S) and medium soil grain size (D_{50}) has value of around 2-2.3 [10], as shown at Fig. 4 (right).
Interlocking of soil grains in geogrid opening increases interaction adding much more to soil resistance than friction. Tests on real reinforced earth walls show that strain of geogrid ribs in real structures is about 0.2-0.3 % as reported in [14]. This shows how small part of tensile strength is needed, and how conservative the designs are.

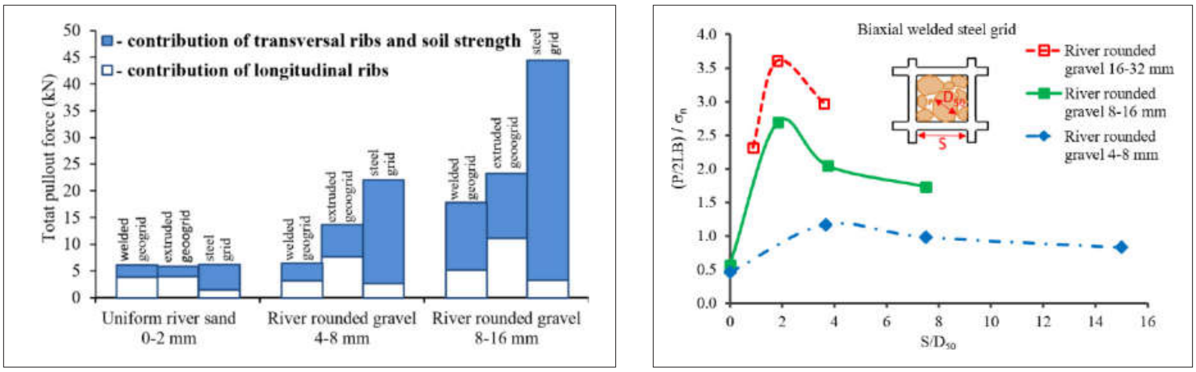

Figure 4 Participation of friction in total pullout force for different soils and different geogrids (left), pullout resistance to S/D_{50} relation (right) [8]

Very important property of a geogrid (as is of every geosynthetic) is resistance to mechanical damage – its ability to sustain mechanical actions during transportation, installation and compaction of soil above geogrid that could destroy geogrid locally and decrease its mechanical properties. Sometimes trial sections are constructed in order to examine rib and/or junction failure. There are model tests for measuring possible effect of soil compaction over geogrid which are standardized. This is very important since damage can be progressive: failure of junction results in loss of confinement of soil grains, and redistribution of stresses in soil can further damage junctions and allow deformations.

As a summary of described factors influencing soil-geogrid interaction a qualitative diagram was created (Fig. 5), showing influence of type and geometry of geogrid and grain size of the soil. Friction is a minor portion of resistance, and highest effects come from stiffness of geogrid opening in combination with thickness of ribs, their shape and junction strength. They produce effects only at proper ratio s/D_{50}.

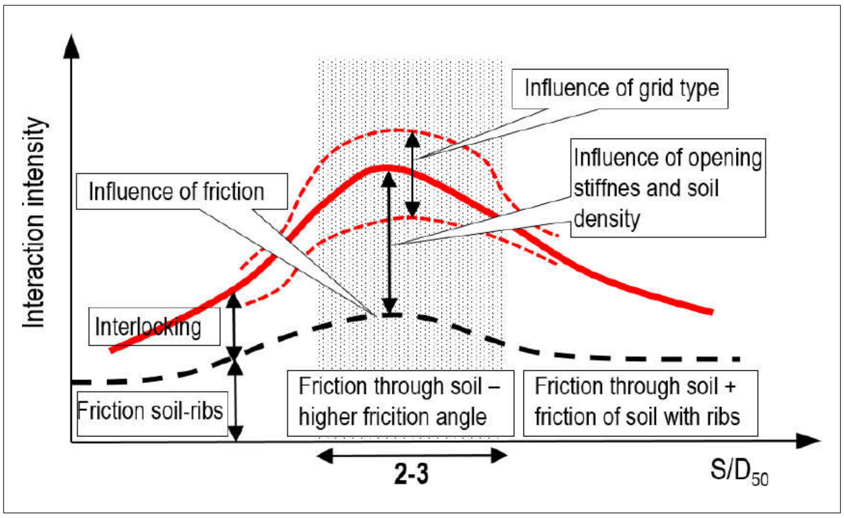

Figure 5 Tentative diagram showing relative influence of geogrid type and soil type on their interaction

3.1 Norms – testing and application

Norms define methods of testing of geogrid properties. Properties to be tested and reported for any geogrid include: tensile strength, deformation at tensile strength, tensile strength at 1, 2 and 5 % elongation, junction strength, structural stability, modulus derived from tensile test, UV resistance, resistance to chemical degradation, weathering, oxidation, installation damage. Form of rib cross section is sometimes reported (thin strip, rectangular etc.), as is

radial stiffness, coefficient of uniformity of radial stiffness (especially important for stabilization). Junction strength is usually required to be more than 90% of the tensile geogrid strength. There are geogrids without real junction since longitudinal and perpendicular ribs can freely move one through/over another, which means that their opening can get any form depending on grain movements. In that case soil grains are not laterally constrained and their pullout resistance relies to friction in one rib direction only. Since these ribs can wrinkle during soil placement and compaction, geogrid of this form can be sometimes obstacle for inter granular friction and have negative effect to soil stiffness and strength.
There are some cases were norms are a “matter of misunderstanding” between engineers and investors, engineers and suppliers, coming from misinterpretation of norms and lack of understanding of engineering behaviour of materials in reinforced structure. Norm [15] in its table 1. (related to use of geotextile and geotextile related products in railways) doesn’t specify junction strength (they name it “seems” and “joints”) as obligatory but “relevant for specific conditions in use”. Reading only this table one could think that junction strength is not important for geogrids. But, in section 4.3.2. the same norm describes “data on tensile strength of seems and joints are necessary for all functions if … load is transferred across the seams and joints”. Therefore, for geogrids it is necessary to report junction tensile strength. Designers (should) know that, so let them decide what they need in design solution. We are aware that norms do not cover all the important aspects of mechanical behaviour of geogrid in soil. Sometimes that can be bridged by technical approval for specific use, or effects which are expected from geogrids. Good example is [16] document for specific, unique hexagonal geogrids.

3.2 Comments and discussion

In this paper the results of research show that stabilization and reinforcement of soil provided by geogrids are controlled by parameters that come from geogrid type, soil type and their interaction. Engineers (designers, supervisors, contractors) should be able to understand this interaction in order to correctly use geogrids in soil reinforcement and stabilization when designing, choosing, approving or installing geogrids. There are several very basic questions related to the use of geogrids in soils:

1) is every geogrid good for any geogrid function and any kind of soils (can we choose geogrid regardless of soil type and geogrid type)? – NO;
2) how to choose right geogrid for right soil?
3) does the choice of geogrid depends of geogrid role – stabilization or reinforcement? – YES;
4) can we choose right geogrid for available soil, or choose soil for available geogrid? – YES;
5) can we adopt technical specification to protect design solution? – YES.

One almost constantly missing specification that should be included in design specification is geometrical characteristics is that geogrid opening should be related to grain size of soil, so that opening of geogrid should be 2-3 times bigger than D_{50} of soil. Model testing of different kind can improve our knowledge, and we expect more of it in future.

4 Conclusion

The paper has underlined some important aspects of interaction between soil and geogrids in function of reinforcement and stabilization. It was stressed out that geogrid type (specific stiffness of geogrid opening, junction strength, tensile strength) and ratio of geogrid opening and grain size govern the interaction and beneficial effects that are expected from geogrid in reinforcing soil. Stabilization function (leads to soil improvement) and reinforcement function (leads to transfer of tensile forces) should be distinguished as two different mechanisms.

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