# Investigation of the geogrid-granular soil combination layer with laboratory multi-level shear box test

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ABSTRACT: The paper discusses a research and development work related to investigation of the geogrid-granular soil interaction in transportation applications such as road or railways at the Department of Transport Infrastructure of Széchenyi István University (Gyor, Hungary). Utilizing special laboratory multi-level shear box tests different geogrids and geocomposites with various kinds of nonwovens and connection types will be analyzed with different soil types (different soil types for road subbase & different ballast and sub-ballast types). The authors will investigate the internal shear resistance of the different soils with and without geogrid reinforcement in the same circumstances, which shows the efficiency of the interlock effect and the effective zone of influence of the grid at regular intervals away from the grid/soil layer. Previous results from the same equipment have been prepared for a wide range of geogrids (raw material, aperture size, type of production processes, etc.) which will help the authors fully understand the complex soil/grid interaction and interlock effects.

*Keywords: Railway, roadway, geogrid, basal reinforcement, ballast reinforcement*

## 1 INTRODUCTION

Geogrid/soil interaction is key to creating a composite geosynthetic/granular fill mattress capable of increasing the bearing capacity of a given thickness of sub-grade and rail ballast (Nimbalkar et al., 2014; Nimbalkar and Indraratna, 2016; Fischer et al., 2012; Fischer, 2015). The interaction consists of both friction and tensile forces at the granular/grid contact points but also interlock of the granular particles within the grid which can serve to restrain lateral movement of the soil.

Geogrid products with a variety of different production methods, raw materials, aperture size and junction structure have been used successfully over the world for decades in road and railway basal reinforcement applications.

The interlock between the geogrid and the crushed stone or granular fill combined layer functions well provided:

- the geogrid absorbs tension with small deformations;
- the aperture size of the geogrid is compatible with the grading of the crushed stone or granular soil;
- the geogrid is able to bear the axial loads in the long term;

- the geogrid sufficiently resists the installation damage along with any environmental degradation;

The selection of the type of material to use varies widely between countries, often based on availability and familiarity rather than engineering judgement, the authors try to demonstrate that provided the four above mentioned criteria are met; the reinforcement product will work.

## 2 MULTI-LEVEL SHEAR BOX AND THE MEASURING PRINCIPLES

### 2.1 *The shear box*

The area of the shear box is 1.0 m x 1.0 m, it consists of 10 independent frames. The frames are made of steel U profiles and are fixed to each other by M12 screws, except at the plane of shearing. The structuring of the box is such that the position of the shearing plane can be fixed at different depths within the box. The box part under the shearing plane can move on cylindrical rollers on the flooring of laboratory, when the horizontal pushing force is applied. On the opposite side of the box, over the shearing plane the counter force is applied, this force keeps the upper part of the box stationary (Figure 1a and 1b).

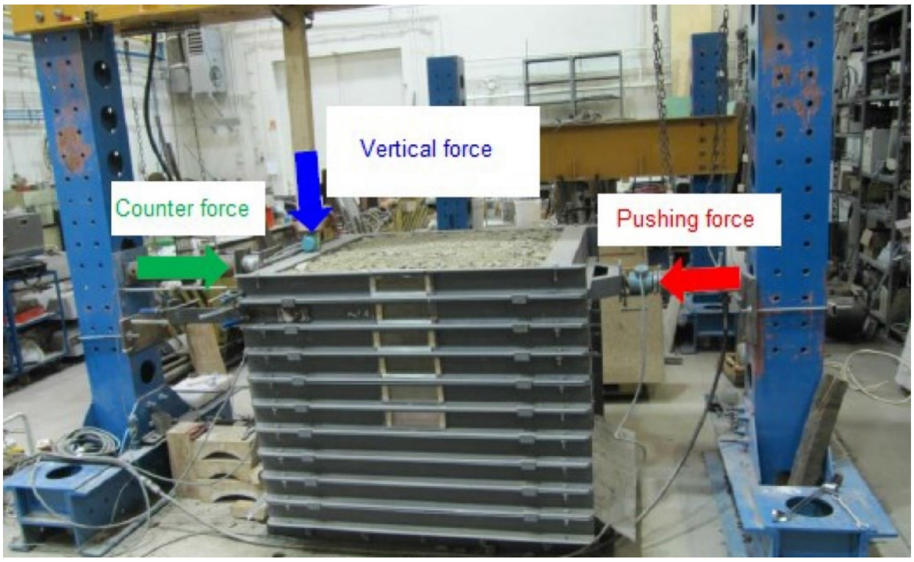

Figure 1a: The measuring principle of multi-level shear box [photo: Dr. Ferenc HORVÁT]

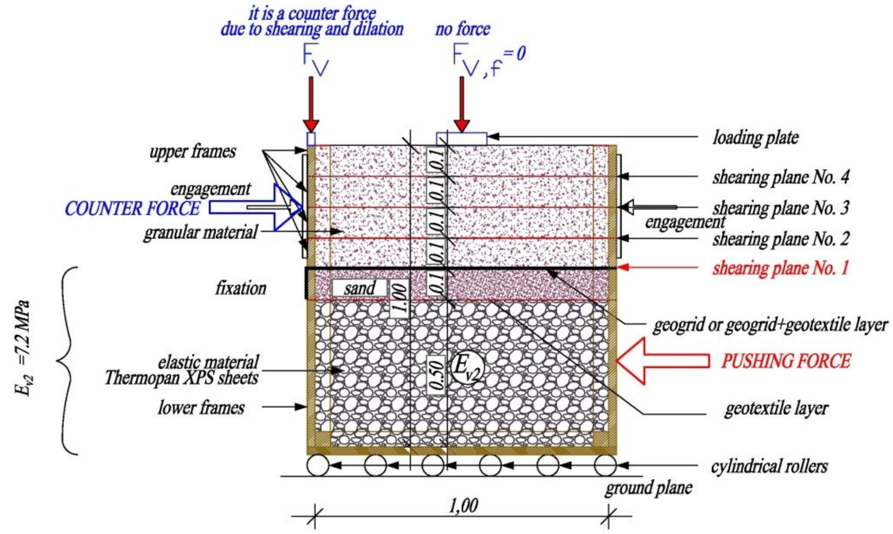

Figure 1b: The measuring principle of multi-level shear box and the set-up of layer structure

## 2.2 *Shearing principles*

During the tests counter and pushing force are recorded simultaneously. These two forces should be the same, because the movement of the lower part of the box has to be normal. If the difference between counter and pushing force is more than 10%, the measurement has to be repeated. The test starts at the shearing plane No. 4 (top), and after that follow the shearing plane No. 3, 2, and 1 (Figure 2 and Figure 1b). The speed of the shearing is 1.5 mm/s. The maximal displacement of the frames is 80 mm, and it doesn't influence the particles' position in the planes below the shearing plane. On both sides of the box (which are parallel to shearing direction) in upper five frames there are windows with 200×60 mm dimensions. Through these windows the possible movement of crushed stone particles can be monitored during shearing tests. It can be determined, whether there is any particle movement and/or rotation of particles over and/or under the shearing plane. Because of the shearing (mainly in case of shearing in the shearing plane No. 4) the particles rise up the upper frame, in this way a vertical force is needed onto the upper frame. This force doesn't influence the inner shear resistance because it doesn't act onto and into the granular material. Before the tests the friction resistance values between the frames were measured.

Figure 2: Shearing planes

To model a typical soft subsoil the lower part of the box (under the shearing plane) is filled with an elastic material with low load bearing capacity. The $E_{v2}$ modulus of this layer should be determined with static load plate test. The elasticity of the elastic supporting layer can be modified by adjusting the thickness of the elastic layer the very low value of load bearing capacity required ($E_{v2}$ modulus between 5&15 MPa) was achieved by using expanded polystyrene (XPS) sheets 40 cm thick. The measured and calculated (acc. to the MSZ (1989)) bearing capacity before the test was $E_{v2}$ = 7.2 MPa, similar to a very weak subsoil. The XPS layer was covered with a nonwoven geotextile and a 10cm depth of compacted sand. The sand layer allows the crushed stone particles to penetrate into the apertures of the geogrid whilst protecting the XPS from damage caused by the penetration of the stone. On the top of the sand layer one layer of geogrid of geocomposite is laid. In each cases the granular materials were compacted in two layers of 20 cm depth.

### 2.3 *Constant parameters*

One test series consists of altogether four shears, on the shearing plane No. 4, No. 3, No. 2 and No. 1. The constant parameters were as follows:

- $E_{v2}$ modulus of the support layer under the geogrid: 7.2 MPa (acc. to MSZ (1989));
- thickness of sand layer: 10 cm;
- one layer geogrid or geocomposite;
- compaction on two layers: on the shearing plane No. 2 and No. 4;
- there is no vertical pressure on the soil materials.

Obviously in a real situation, e.g. under a railway track the vertical pressure is higher than in this test set-up (Kurhan, 2015; Kurhan, 2016; Major, 2015a; Major, 2015b; D'Angelo, et al., 2016a; D'Angelo, et al., 2016b). In previous tests additional vertical load was applied ($F_{V,f}$ in Figure 1b), but the loaded plate on the tested material prevented the incidental displacements of the stone surface what led to more unrealistic measurements and results. For that reason we decided to neglect the additional vertical pressure during the tests.

The test series enables us to determine inner shear resistance curves in function of the distance from the No. 1 shearing plane.

## 3 MATERIALS APPLIED DURING THE SHEAR BOX TESTS

The series were conducted in the laboratories of the Széchenyi István University (Gyor, Hungary), where granular subbase or sub-ballast ("0/56 crushed gravel" and "KG1 acc. to Ril.836"(DB AG, 2008)) as well as railway ballast ("31.5/63") were investigated with different geogrid and/or geosynthetic products. In every case three-three or four-four measurements were conducted for each set-up to be able to characterize the inner shear resistance. This paper on the one hand evaluates the test results from the research work in 2016, but also involves and evaluates previous results (the first multi-level shear box test are published by Szabolcs Fischer in 2012 (Fischer, 2012)) when the test equipment, conditions and procedure were the same. It follows that the soil materials were not fully the same in every time, but their grain size distribution curves fitted to the curves of figure 3 (the typical curves related to quarry Szob of Colas Északkő Kft.).

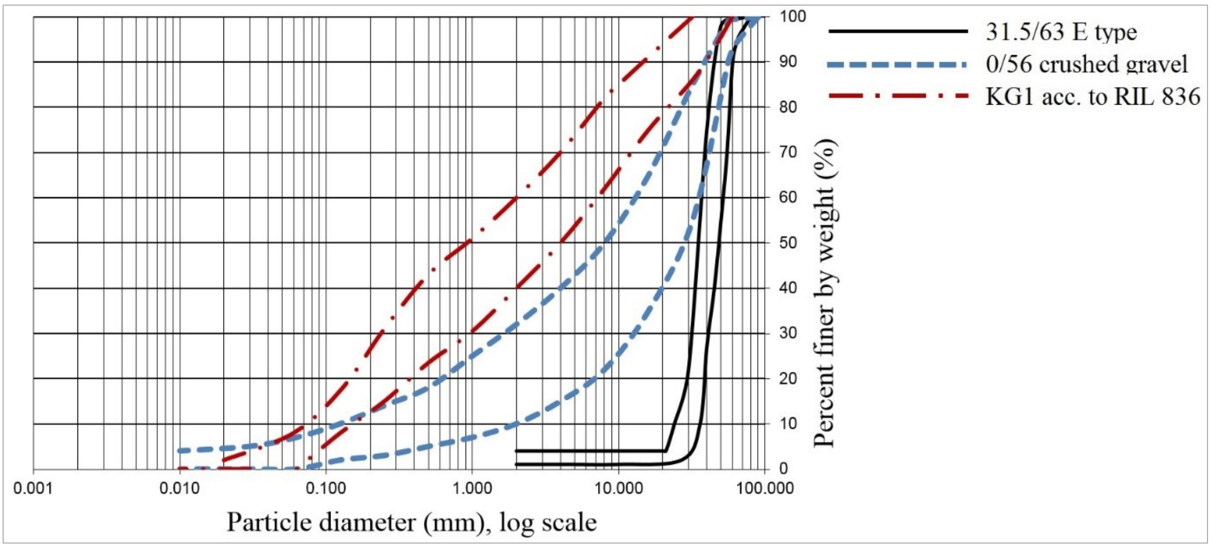

Figure 3: Grain size distribution curves (border lines)

Geosynthetic materials were chosen for the test series according to the fact that their short-term tensile strength at small elongations (0.5%...2.0%) will be in the same range, in this way the can be compared:

- GG1: Biaxial geogrids which is produced from stiff, preloaded, extruded PP strips, in both direction with the same strength, with an average aperture size (~40 mm);
- GG2: Biaxial geogrid which is produced from stiff, preloaded, extruded PP strips, in both direction with the same strength, with large aperture size (>70 mm);
- GG3: Biaxial woven geogrid which is produced from high tenacity PET yarns with PVC coating, with small aperture size (~35 mm);
- GG4: Biaxial extruded geogrid manufactured by stretching the punched sheet of PP in two orthogonal direction, with an average aperture size (~40mm);
- GG5: Hexagonal geogrid which is manufactured from an extruded PP sheet, which is punched and oriented in three directions, with and average aperture size (~40mm);
- GG6: Hexagonal geogrid which is manufactured from an extruded PP sheet, which is punched and oriented in three directions, with large aperture size (~60mm);
- GG7: Hexagonal geogrid which is manufactured from an extruded PP sheet, which is punched and oriented in three directions, with small aperture size (~30mm);
- COMP: GG1 geogrid with 160 g/m$^2$ mass PP nonwoven geotextile.

## 4 RESULTS OF LABORATORY MULTI-LEVEL SHEAR BOX TESTS

### 4.1 *Method of analysis of test results*

The inner shear resistance parameters were calculated for each cases as the tangent of the linear regression function related to the measured data between 5mm and 40 mm frame displacement. The reason is the fact that geosynthetic layers built-in granular materials as railway ballast and granular subbase or sub-ballast layers do not have significant movements larger than 40 mm. The order of magnitude is only some millimeters or centimeters. In this way reinforcing geosynthetics are characterized by the force values related to 0.5 to 2.0% strain (or maximum 5.0% elongation), hence the so called “working zone” of the geogrid and granular material can be defined in this region. Deriving from the horizontal size of the shear box, and also analyzing the inner shear resistance curves, the 5 to 40 mm zone is chosen for the survey.

After that inner shear resistance expression is applied for characterization of the shear resistance of each shearing planes. Naturally absolutely accurate inner shear resistance values for granular materials cannot be measured consistently in laboratory due to irregular, sharp-edged particles of railway ballast, as well as additional fine particles of “0/56 crushed gravel” and “KG1” subbase or sub-ballast layers. Because of that fact there always will be a determined standard deviation in the values of inner shear resistance due to the random distribution of irregular shaped particles. Inner shear resistance values were determined by averaging of the tangent values of linear regression (three-three of four-four measurements for each cases) for every layer structure with and without geosynthetic reinforcements. In cases where the difference between counter and pushing force is more than 10%, the test was repeated, so in this way these data are not in the final data base. Pushing forces recorded during shearing were not corrected by the friction values between frames. This approximation was applied because the friction resistance was much lower than the pushing forces, but at the analysis it has to be noted that the influence on the results is minor and can be neglected.

### 4.2 *Main goal of the laboratory measurements*

Although geogrids are proven to work as an effective way for providing local stabilization through aggregate interlock, industry opinions are divided as to what are the important properties for the interaction between the soil and the geosynthetic layer. Experimental studies on geogrid-reinforced aggregates suggest that an optimum aperture size of geogrid exist for a given size of soil to maximize the effectiveness of the reinforcement system. Of course the important properties may include rib or junction strength, aperture shape, rib thickness or shape. The main goal of the laboratory tests to determine the important properties for the interaction (interlocking effect), with analyzing geogrids and geocomposites produced by different methods

### 4.3 *Results of laboratory measurements*

Inner shear resistance curves as function of the distance from the geogrid plane (shearing plane No. 1) were determined for the materials (“31.5/63” E type railway ballast, “0/56 crushed gravel” and “KG1” sub-ballast layer) in case of using geosynthetic reinforcement, and without geosynthetics. According to the laboratory test results it can unequivocally be stated that multi-level shear box is adequate for determining inner shear resistance (defined points of the function) of granular aggregates, e.g. crushed stone railway ballast (31.5/63) and granular subbase and sub-ballast layers (0/56 crushed gravel and KG1). Using this data and considering boundary conditions regression functions of inner shear resistance can be determined as a function of distance from geosynthetic layer. It should be noticed that values of these functions are approximate but reliable within the height of the shearing planes.

#### 4.3.1 *Results with 31.5/63 E type railway ballast material*

In Figure 4 the tangent ratio values can be seen related to railway ballast material in the shearing plane No. 1, No. 2 and No. 3. After the shearing plane No. 3 the effect of geosynthetic materials can be neglected.

According to different research studies we learned the geogrid aperture size has a profound influence on the shear strength of the ballast-geogrid interfaces. In this respect, the aperture size based on the variation of interface shear strength can be categorized into three zones:

- feeble interlock effect when the aperture size smaller than $D_{50}\times0.95$;
- optimum interlock effect when the aperture size between $D_{50}\times0.95$ and $D_{50}\times1.20$;
- diminishing interlock zone when the aperture size larger than $D_{50}\times1.20$.

The minimum size of aperture is to ensure that the particles effectively interlock, while the maximum limit on aperture size is required to ensure that there are not too many particles in any one aperture, because their free movement does not offer much resistance to shearing. An optimum aperture size of 1.40×$D_{50}$ was reported in the past by Brown et al. (2007), but it was based on the settlements behavior of the ballast with different geogrids and not the inner shear resistance. Based on another study, S. K. K. Hussaini (2013), we can state that the optimum geogrid aperture size to reach the maximum inner shear resistance is between 1.20 and 1.30×$D_{50}$.

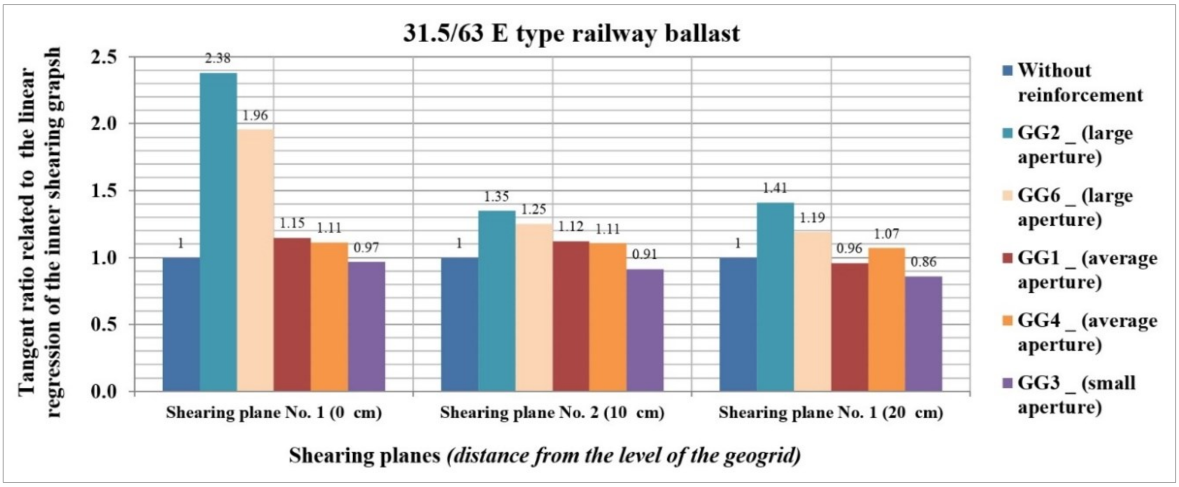

Figure 4: Tangent of the linear regression function related to the measured data between 5…40 mm frame displacement in case of 31.5/63 E type railway ballast material in different shearing planes.

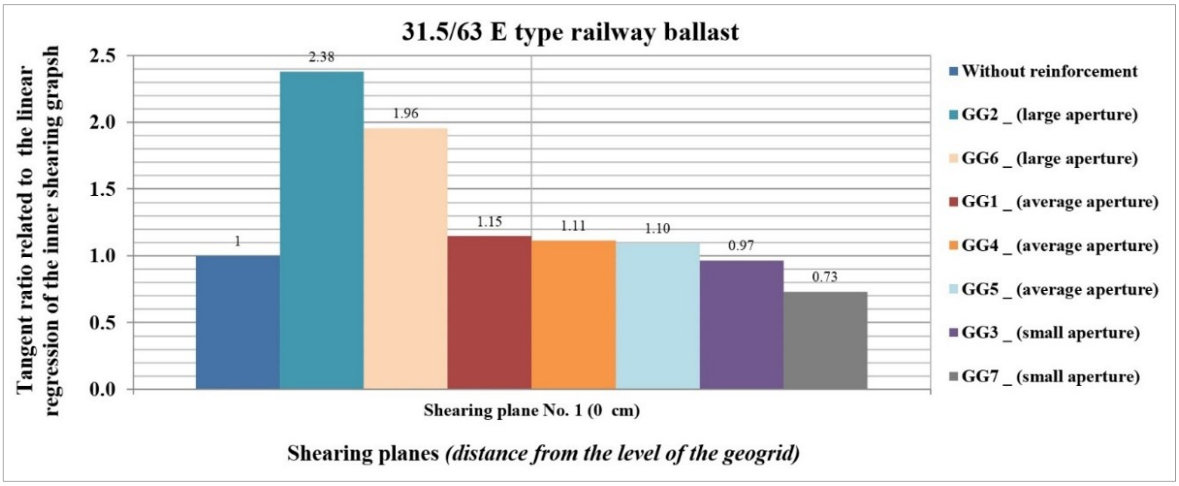

Figure 5: Tangent of the linear regression function related to the measured data between 5…40 mm frame displacement in case of 31.5/63 E type railway ballast material in the level of the geogrid.

It can be stated according to the Figure 4 that the optimal geogrid size in case of railway ballast is definitely more than the average 35-45 mm, it is more like 70-80 mm, which is 1.45 to 2.2×$D_{50}$ or in other way 1.10 to 1.25×$D_{max}$. Furthermore in Figure 5 it can be seen that the performance are not determined by the manufacturing technology (biaxial or triaxial) or the junction form, but the adequate aperture size is one of the most significant indicators of the performance.

### 4.3.2 *Results with 0/56 crushed gravel & KG1 subbase and sub-ballast materials*

The difference between the railway ballast material and the two other subbase and sub-ballast materials is not just the maximum and average particle size, but also the fact that the ballast material is a true poorly graded soil (with grains of same size) however the rest of the analyzed soils are well graded (wide range of grain sizes present) sandy gravels. From this distinction it can be concluded that with 0/56 crushed gravel and KG1 materials the optimal aperture size categories differ significantly from those stated in the chapter 4.3.1.

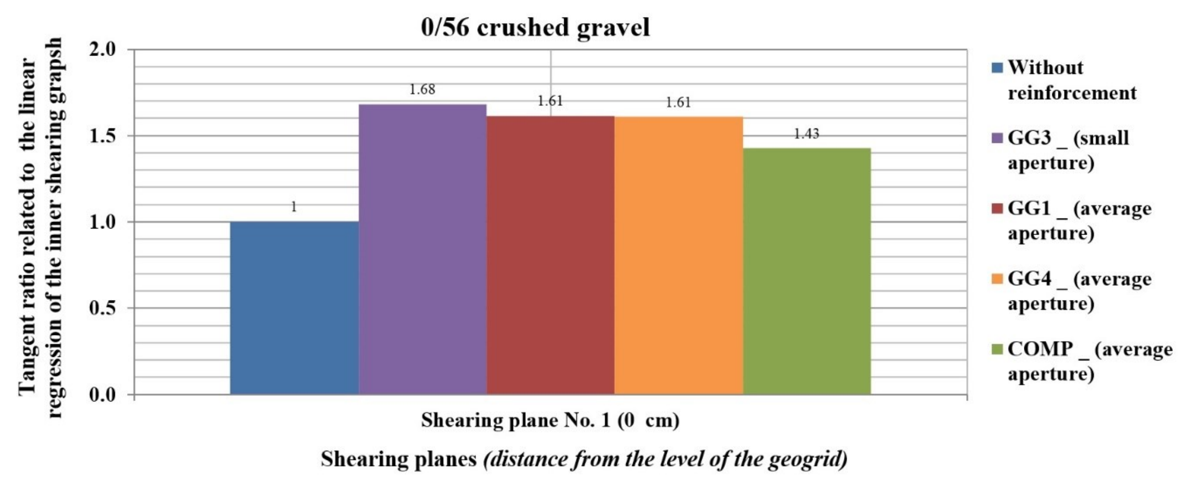

Figure 6: Tangent of the linear regression function related to the measured data between 5…40 mm frame displacement in case of 0/56 crushed gravel material.

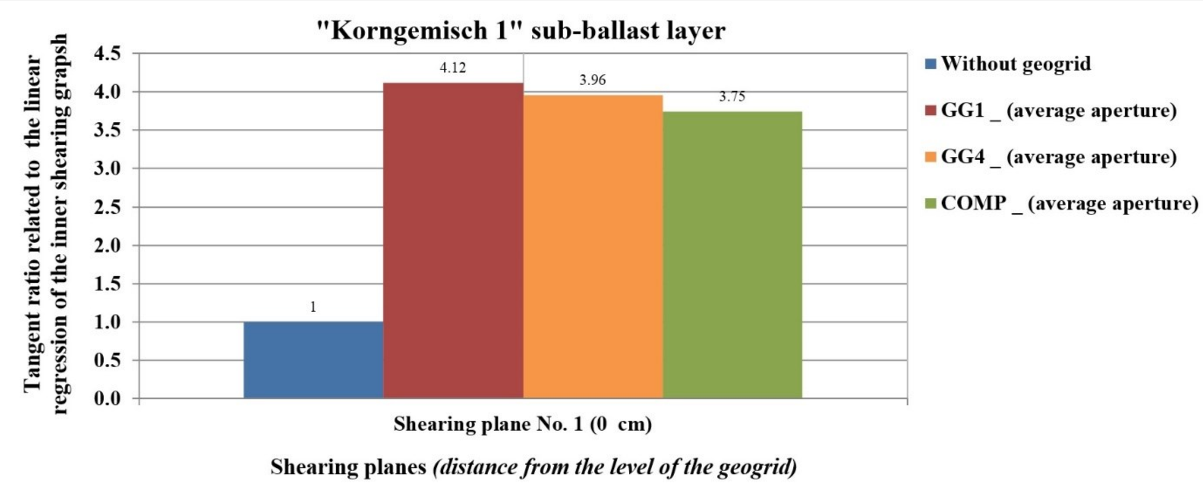

Figure 7: Tangent of the linear regression function related to the measured data between 5…40 mm frame displacement in case of KG1 material.

An investigation of the influence of the aperture size versus the particle size of well graded soils on the frictional efficiency of a number of geogrids is available from Sarsby. He finds that the optimum transfer of shear stress occurs when the minimum aperture size of the geogrid is $3.5\times D_{50}$. Based on other discussions, the interval of the optimum aperture size in the case of well graded soils is much wider than with e.g. the railway ballast material. Different researches indicate that an aperture size between 25 mm and 45 mm performs most effectively with the majority road and rail base aggregate/soil combinations.

Regarding to Figure 6 and Figure 7 it can be stated that all of the analyzed geosynthetic layers can provide real positive effect with well graded soils. In the case of “0/56 crushed gravel” material the tangent ratio value was between 1.61 and 1.68 in the case of geogrids, and the value was decreased by 11% when we combined the GG1 geogrid with a geotextile layer. In the case of “KG1” sub-ballast material the tangent ratio value was between 3.96 and 4.12 in the case of geogrids, and the value was decreased by 9% when we combined the GG1 geogrid with the geotextile layer.

## 5 CONCLUSION

Summarily it can be stated according to the test results that in case of geosynthetic reinforcement their performance are not determined by the manufacturing technology (hexagonal or biaxial) or the junction form, but the sufficient interaction (interlock) with the surrounding soil – thanks to the adequate aperture size – and the tensile strength at low deformations are the most significant indicators of their effectiveness.

Furthermore based on the results of the presented multi-level shear box tests it can be seen that a geogrid with a correct aperture size can radically increase the inner shear resistance of the soil mass with an influence even 20cm from the level of the reinforcement layer due to the effective interlocking effect.

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