Evaluation of railway track geometry stabilisation effect of geogrid layers under ballast on the basis of laboratory multi-level shear box tests

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Abstract: In this article authors investigated the railway track geometry stabilisation effect of geogrid layers under ballast with a specific laboratory multi-level shear box. During the laboratory tests four different types of geogrid layer (in two cases combined with geotextiles) were analysed when railway ballast was uncompacted and compacted. Two types from these (geogrid type 2 and geocomposite type 2) have not utilised for railway track geometry stabilisation yet. The authors determined inner shear resistance of railway ballast in case of without and with geogrid reinforcement, as well as five multiplication factors were defined which are adequate for determining inner shear resistance of reinforced and unreinforced railway ballast in consideration of different parameters.

Keywords: railway, track faults, geogrid-reinforced ballast

1. Introduction

1.1. General introduction remarks

Environment protection and awareness will be more and more important, therefore technologies should be used in all area of life which can conform considerably to this goal. It has to be noted that all the industrial and all transportation sector use fossil energy source, therefore quantity of CO_2 and other harmful materials increase in the atmosphere [9]. People of future should think about decreasing high rate of personal vehicle (automobile) transport in modal split or using more environmental-friendly energy sources because of their subsistence and ensuring of healthy life. Reversing of modal split to the adequate direction can be simply achieved with popularization of public transport, but service standard and high fares should be normalized. Against the road transport environmental friendly electric hauling railway transport has to be preferred which should be greater and greater part of continental traffic in case of passenger and freight transport too.

Rapid reaching of these aims significant financial support (foreign supports as well as national fund) has to be available, from which construction and reconstruction of high standard of railway infrastructure and investments of modern railway vehicles can be financed. If the author's scenario is fulfilled, economic execution of construction and rehabilitation reconstruction as well as decreasing of number of maintenance works will be important. In the author's opinion utilizing of modern building material and technologies will be indispensable.

1.2. Motivation and aims

It has to be noted that this paper only deals with conventional ballasted railway tracks and their more permanent geometry stabilisation. The reason of this fact that

- in the world 98.8% of railway lines is ballasted railway tracks (approximately 1.1 million km), only 1.2% is high speed railway slab tracks and maglevs [20],
- in Hungary there are slab track only on bridges and in tunnels,
- at maintenance works of slab tracks emphasis is totally different. In the consideration of speed of deterioration process of ballasted tracks, mainly respect to track geometry, they grant more disadvantageous solution.

In reference to railway infrastructure developments mentioned in Section 1.1 phrasing of more worry seems to be topical. In the past two decades[1] the Hungarian governments in power didn't pay enough money for the railway maintenance works, which would have been necessary. However, infrastructural developments were done from ISPA, KÖZOP, EU, EIB, PHARE, etc. funds, but their whole length to the Hungarian railway network is very low. Money, which can be spent for railway maintenance works, is very scant, so this is the reason of the fact that all the track faults can't be eliminated.

The extant track faults will be deteriorated forward due to the cancelled (or delayed) maintenance, and other new faults can be evolved[2] [6, 16]. If the size of the track fault exceeds the prescribed value contained the maintenance regulations related to railway tracks [10] speed restrictions have to be introduced [5], i.e. a reduced speed is allowed in this section. At the end of this kind of sections additional acceleration energy demand comes forward as compared to state if the train can be driven with constant speed.

Keep on this train of thought, it has to be mentioned that deterioration process of railway track is a natural physical procedure that is unstoppable and irreversible, with in time executed and professional maintenance work can only be slowed down. There should be an initial track fault and destructive effects for the deterioration process. There is track fault as a dimensional deviation, because engineering structures can't be constructed and maintained without any dimensional deviation. The destructive effect means primarily traffic, but environmental effects (e.g. weathering) can't be forgotten. Deterioration process of railway track can be divided in two different parts: geometrical deterioration period and structural destruction period [19]. Primarily geometrical

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[1] Until 1992 adequate maintenance was ensured, early in 1993 approximately 1600 km speed restrictions should be introduced because of the drastically decreased financial supports.

[2] There are a lot of speed restriction segments in Hungarian railway lines, all one increases energy consumption of trains, as well as journey time is also heightened which worsens service standard of railway traffic and transport. **Appropriate technical-political verdicts should be returned.**

deterioration period has to be dealt with, in which distortion of railway track is evolved firstly as dimensional deviation, secondly as dimensional faults. If the speed of deterioration process should be slowed down, regulation work (e.g. tamping) is not enough, but structural change has to be made. This kind of change is e.g. using heavier rails, sleepers, more modern flexible and higher clamping force ensured rail fastening; reinforcement of superstructure with ballast gluing, or using of geosynthetics; substructure reinforcement, etc. In this way track faults can be evolved more slowly as well as time interval between regulation works can be lengthened, which has great financially importance of course[3]. In case of any track fault is there, introduction of speed restriction is unnecessary, therefore costs of additional acceleration energy due to speed restriction don't debit the operator of railway vehicles [5].

From the above mentioned structural changes the authors chose the geogrid layers under railway ballast, because this technology is used for a few years with little practical experience and appreciating analysis for railway track geometry stabilisation[4]. Figure 1 and 2 show interlocking effect of geogrids. The essence of increasing of inner shear resistance and strength of layer structure means acting together of geogrid layer and crushed granular material. The particles of crushed granular material are wedged into the aperture of geogrid and interlocked with the geogrid ribs. In this manner a quasi-strong and relatively skidproof layer will be guaranteed for other particles lying above and interlocked into these particles which effect is favourable in the consideration of increasing of inner shear resistance. Underneath there is a geogrid-crushed stone composite layer which hinders vertical and horizontal re-arrangement of particles. Geogrid creates a so-called clamped "quilt" in which there is determined and in forced manner materialized acting together of granular material particles.

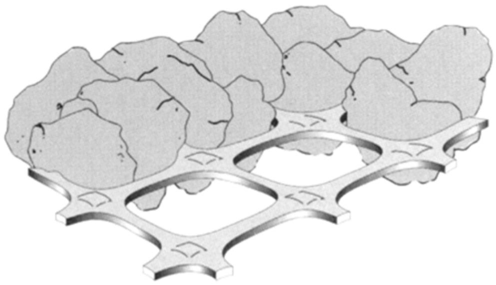

Figure 1. Crushed stone particles are wedged into the aperture of geogrid [15]

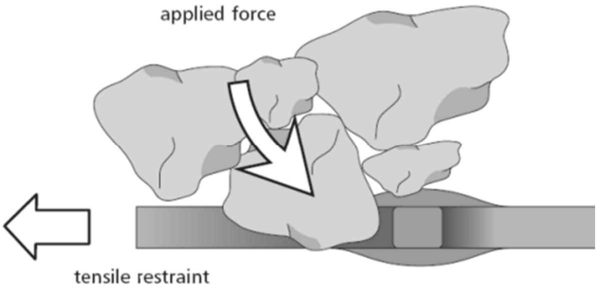

Figure 2. Interlocking effect [15]

In this way in the ballast floating, dynamic loaded railway track will geometrically be more stable and more resistant against evolving of settlement faults. Stresses arise in the ribs and junctions of the geogrid due to vehicle load, the geogrid can offer resistance against these stresses with tensile strength and low strain. Tensile strength should be adequate high, but failure strain should be acceptable low, because of the load bearing with small strain. The latter property is important because the geogrid should bear

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[3] More precisely analysis of this field exceeds the frames of this paper, but it is a significantly important research topic.

[4] Naturally geogrid-reinforced railway ballast can't help abolish all the speed restriction sections, because some of them has reasons for that's abolishment this kind of stabilisation alone is inadequate.

adequate magnitude load, i.e. it can't keep out of loads way. For example non-woven geotextile can't reinforce granular material because of elongation [4].

It was a specific formulated assumption from MÁV (Hungarian Railways) as railway line operator and geogrid/geocomposite manufacturers that geogrids as well as geocomposites under railway ballast solve geometrical stabilisation of railway tracks and with this method is low-cost and adequate for simply abolishment of local track faults (e.g. water pockets). This paper deals with only the evaluation of the railway track geometry stabilisation effect of geogrid layers under ballast on the basis of laboratory tests.

2. Summary of the results of international publications

It has been mentioned that in the papers [12, 13] reduced scale assemblies were used for the laboratory tests, however the results of these measurements are queriable, it has to be highlighted that they didn't use crushed stone and geogrids/geocomposites which adequate for real railway construction. The scale of different structural elements was not the same in their laboratory tests (M 1:12 for crushed stone ballast particles, M 1:10 for geogrid thickness, M 1:3 for geogrid aperture size, M 1:36…M 1:9 for load plate size compared to a real sleeper' loading face, etc.) With these comparison and laboratory tests can't be achieved realistic behaviour of specimens, because there is unknown distortion (it would be much better than using e.g. M 1:10 scale for all elements). The most unbelievable result is that the most effective reinforcement was measured close to the loading plate (at a very small depth) [13]. This setting is impossible because of the technology; in other respects it is true that the interlocking effect has the largest value on the plane of a geogrid layer, but for this enough soil covering depth is needed. In the authors's view there were not enough soil depths in the measurements of the papers [12, 13].

The measurements and its results described in [14] showed that the largest reduction of settlements could be obtained with three geogrid/geocomposite layers (one would be between the subbase and the subgrade soil; one would be in the subbase, and one would be under the subballast). It has to be mentioned that this kind of ballast reinforcement can only be used for construction works of new railway tracks because of the very short allowed time of hold-up of the track. Local track faults can be exception[5][6]. The most effective solution for geometry stabilisation of railway track with geogrid layers under ballast is using only one layer geogrid between railway ballast and protective layer or subgrade for longer sections during ballast cleaning works or full ballast change.

On the basis of [7, 8] it is worth considering results which show that plastic deformation of ballast layer in horizontal and vertical planes too can be achieved with geogrid/geocomposite reinforcement. It is queriable that using with only geotextile layer better settlement reduction can be obtained than with only geogrid layer, because of the elongation of geotextiles.

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[5] In this case it has to be considered that reason of track faults is related to sub- or superstructure because in case of track faults due to substructure defect, only using more geogrid layers can't help.

[6] The newest foreign experiences show that only one geogrid layer under railway ballast is effective, because the first compacted crushed stone layer above the bottom geogrid layer hinders the wedge of other particles into the upper laid down geogrid's aperture.

No one of the cited publications mentioned how many times they repeated the measurements for the published results, in the author's view it is an important deficiency.

Summarizing results of laboratory test of the international publications it can unequivocally be stated that geogrid/geocomposite-reinforced ballast is an effective solution for geometry stabilisation of railway track, but no one determined the property of this kind of reinforcements that how geogrid/geocomposite layers can change inner shear resistance of the original unreinforced ballast material as a function of vertical distance from geosynthetic layer. A great "hole" was left in the research of this topic, because no one can surely certify how much the increasing factor of inner shear resistance of railway ballast in case of using geogrids/geocomposites and how much the depth of the active reinforcement. For this investigation a multi-level shear box with minimum 1.0x1.0x1.0 m dimensions should be utilized which is from 10 cm high, on each other movable-slippable frames. Using this multi-level shear box inner shear resistance of ballast material with and without geogrid/geocomposite can be determined[7].

3. Laboratory tests

3.1. Aims of laboratory tests

In the author's view as well as on the basis of international publications geogrid layer under railway ballast can stabilise geometry of railway track and reinforce the load-carrying layer structure. For this there should be interlocking effect (Figure 1 and 2). Into geogrid's aperture wedged crushed stone and the upper others wedged into them increase significantly the inner shear resistance of railway ballast, the layer structure can resist better against outer loads. The acting together of crushed stone and geogrid is not totally known in the geogrid's plane. There is no information and results of laboratory test how the effect of geogrid decreases in the ballast material and where the border of effective acting together is.

The aim of the author's laboratory tests is to determine forces needed to push frames in several shearing planes in case of different parameters (e.g. type of geogrid, depth of railway ballast, sharpness of crushed stone particles, compaction level of ballast, elasticity (strength) of lower layers.

On the basis of assumptions geogrid layer under railway ballast can

- reduces slumping of the ballast bed's shoulder due to the vibrating effect of the railway load, in this way it holds better ballast resistance in cross direction,
- increases the inner shear resistance and load-carrying capacity of railway ballast.

Dimensional faults (direction, settlement, twist) will be decreased due to above effects. Because of less track faults less regulation works will be needed, in this way it has significant national economic result. If the behaviour of geogrid/geocomposite-reinforced ballast material is better known, its needed depth can be more precisely determined, it is an economic task too.

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[7] For the present the authors did measurements in the plane of geogrid and in ballast material above geogrid.

3.2. Interlocking effect

Interlocking effect as a function of the distance from the geogrid layer is not known. It can probably be stated that the greater is the distance from geogrid layer the less is this effect. It is an adequate approximation that three zones are supposed (Figure 3).

The furthest zone from the geogrid layer is ZONE NC, here the effect of interlocking is the minimal. Behaviour of ballast particles is influenced by their interaction. The second zone is the transition zone (ZONE TC), here predominates the interlocking effect but the nearer to the upper plane of the ballast the smaller its value. The supposed function is non-linear (Figure 4). The third zone (ZONE FC) is located next to geogrid/geocomposite layer. Here the interlocking effect is the maximal.

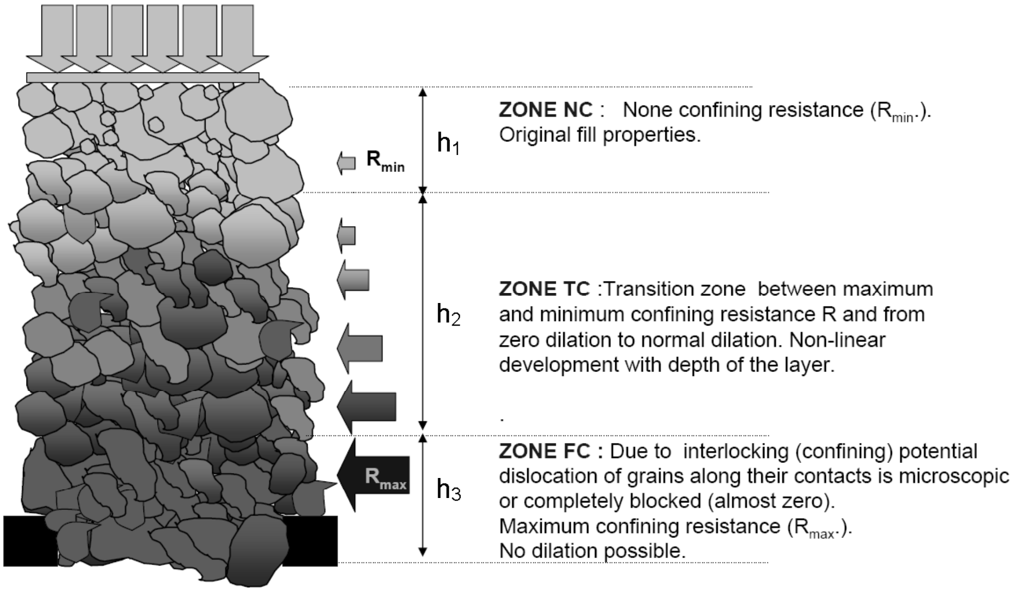

Figure 3. Hypothetical zones of confining resistance (interlocking effect) [11]

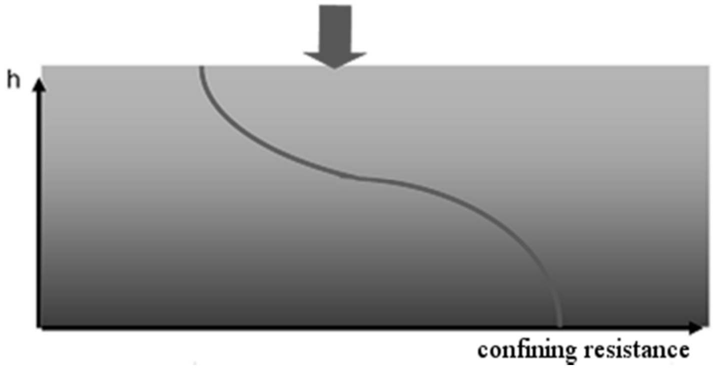

Figure 4. Supposed shape of confining resistance as a function of distance from geogrid layer [17]

3.3. Required tests determined in standards

Prescriptions of two valid standards [2, 3] have to be used, however only certain regulations from these can be utilized because of the planned special tests (multi-level shear box tests).

3.4. Method and apparatus of the laboratory tests

There should be such shear box tests to determine confining resistance as a function of distance from geogrid layer, which can give results (shear resistance) in sections of several heights of railway ballast. From this fact a special multi-level shear box had to be developed. The results are influenced by several parameters, in this way a number of measurements should be done. It is very important to ensure quasi same circumstances in the same measurement series. It means that at an identical measurement series all the parameters are the same, only the plane of shear changes (Figure 5).

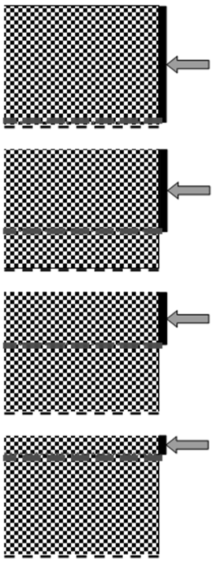

Figure 5. Shear tests in different shear planes [17]

The variables of the tests are the follows:

- elasticity (strength) of below support layer,
- type of geogrid (most important properties: aperture, elongation modulus),
- properties of ballast (grain-size distribution, shape of particles, fresh or recycled material),
- depth of ballast layer,
- compaction level of ballast material,
- loading on the top of layer structure.

The conventional two-frame shear box isn't adequate apparatus, because it always works in the same plane. For the author's task special multi-level shear box is needed, which is divided more frames vertically. The shear box consists of a lower frame and nine upper storey frames (Figure 6).

The area of shear box is 1.0x1.0 m, and its height is 1.0 m. Figure 7 shows one kind of layer structure set-up.

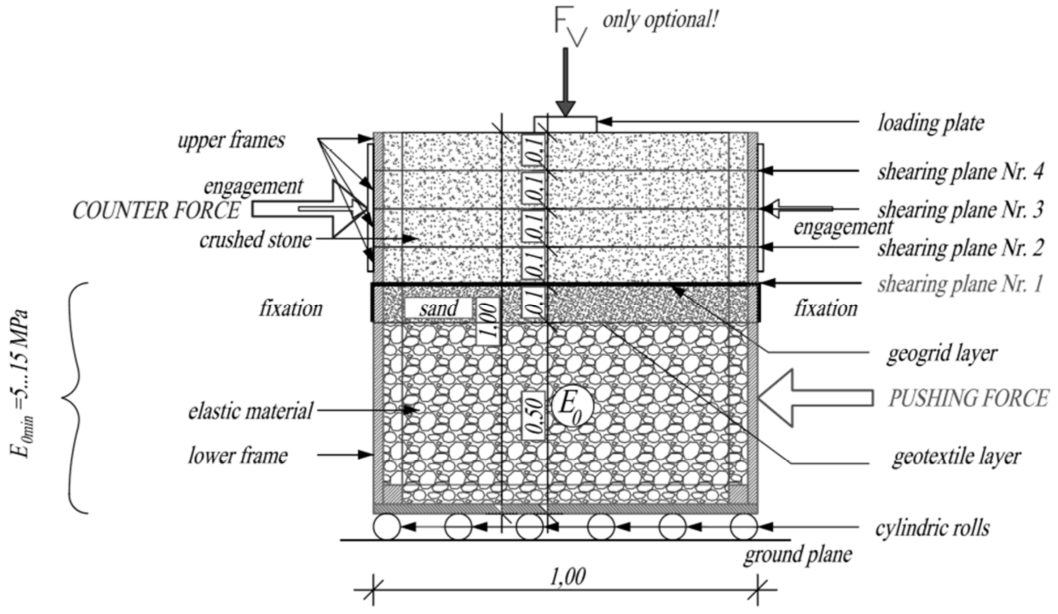

Figure 6. Principle plan of multi-level shear box, shearing in shearing plane Nr. 1 [6]

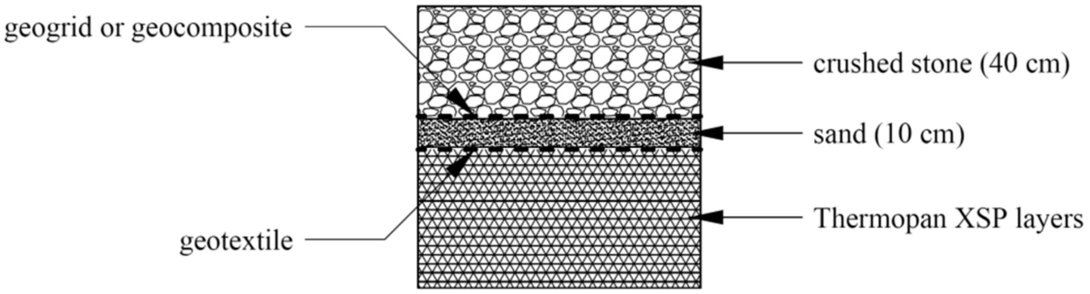

Figure 7. One kind of layer structure set-up [6]

In the lower frame there should be elastic material with low load-carrying capacity. It can be e.g. Thermopan XSP plates. The E_2 modulus of this layer should be determined with load plate test. The elasticity of the layer from Thermopan XSP plates changes if its height is changed (the concrete floor of the laboratory and steel plates used in the bottom of lower frame don't influence this value because of their approximately infinity elasticity). The very low E_2=5…15 MPa modulus can be achieved by using 40…50 cm height Thermopan XSP sheets.

The second layer from the bottom is sand with 10 cm height laid on geotextile layer. This layer helps the crushed stone particles penetrate into the aperture of geogrid and protects Thermopan XSP sheets against sharp edges of crushed stone. On the top of sand layer one layer of geogrid or geocomposite (geotextile+geogrid) is laid. It is the plane until the upper layer structure should be disassembled and from the new layer structure should be reconstructed. As the moving rear edge[8] of the simple geogrid layer or the geogrid in geocomposite has to be fixed to the outer wall of shear box. It symbolises that geogrid is the clamped into railway ballast in real situations. Plane of

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[8] In the author's laboratory tests both edge of geogrids/geocomposites perpendicular to shearing's direction were fixed.

geogrid is the shearing plane Nr. 1. Below the lower frame there are cylindrical rolls, on which the lower frame can be pushed by horizontal force.

Upon the geogrid/geocomposite crushed stone ballast of 40 cm height is laid down. Crushed stone ballast is bordered by four frames of 10 cm height. Over the plane of geogrid/geocomposite layer every plane of frame meet is shearing plane. Over and below of the chosen shearing plane frames should be engaged together because of their simultaneous moving. For example if the shearing plane Nr. 2 is chosen the lower seven frames are engaged together as well as the upper three frames in the same way, etc.

It is very important to ensure quasi same circumstances in the same measurement series. It means that in every test series the compaction level of ballast is the same, but there isn't such apparatus with which measures the density of ballast material in the shear box. In this way below things have to be done:

- always the same compaction apparatus should be used,
- always the same number of compaction passes should be utilized.

In each shear test parameters should be known or measured as follows:

- E_2 modulus of below support layer,
- grain-size distribution and shape of ballast particles,
- depth of ballast,
- value of static loading on the upper plane of ballast (if there is),
- value of horizontal force need to move the frames below the actual shearing plane (pushing force),
- value of horizontal force needed to strut the frames above the actual shearing plane (counter force),
- movement of the frames below the actual shearing plane,
- value of vertical force needed to counterforce the frame lift due to ballast dilation[9].

Figure 8 shows the planned and manufactured shear box.

Figure 8. For the tests prepared multi-level shear box [17]

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[9] Forces were recorded but the set-up of shear box doesn't influence the inner shear resistance of ballast, because this vertical force stays frame on the original shearing planes, in this way it was neglected.

On both sides (which are parallel to shearing direction) of upper five frames there are windows made of plexi with 200x60 mm dimensions. Through these windows the movement of crushed stone particles and sand can be monitored during shearing tests and it can be determined whether particle movement and rotation influences particle layers in below shearing planes. Setting frames on each other steel L-profiles ensure. Frames laid on each other can be fixed by M12 screws with vertical axes. Those two frames between them there is shearing plane aren't naturally clamped together.

The authors considered:

- compaction level with two values (uncompacted, compacted),
- two types of geogrid and two types of geocomposite (geogrid+geotextile) (namely geogrid type 1 and 2, as well as geocomposite type 1 and 2),
- ballast layer with E_2 modulus of 7.2 MPa,
- fresh ballast material (with sharp edges),
- constant ballast depth of 40 cm,
- zero vertical static loading,
- four shearing planes

during up to now completed laboratory tests.

3.5. Laboratory tests and their results

Respect to above written the following tests were done:

- grain-size distribution test and shape test of ballast particles,
- measure bedding property of support layer structure,
- measure friction resistance between empty box frames during shearing,
- inner shear resistance without vertical static loading,
  - uncompacted ballast , without geogrid,
  - uncompacted ballast, with geocomposite type 1,
  - compacted ballast without geogrid,
  - compacted ballast with four types of geogrid/geocomposite.

Three measurements were done in case of each assembly for the four shearing planes to characterize the inner shear resistance.

Crushed stone ballast material was given by mine of KŐKA Kő- és Kavicsbányászati Kft. from Komló (Hungary). Ballast material complies with the requirements of standard [1]. Because of limited space detailed tests can't be published in this paper.

3.5.1. Bedding property of support layer structure

Bedding of support layer structure was obtained by Thermopan XSP sheets of 50 cm height. Strength (E_2 modulus) of this structure was measured by static load plate test. Two measurements were done, and in the second loading cycle average settlement s_2=9.4 mm, therefore $E_2=67.5/s_2=7.2$ MPa. In each assembly E_2=7.2 MPa modulus was used.

3.5.2. Friction resistance between empty box frames during shearing

There is friction resistance in shearing planes of box between frames. Their values were determined by measurements with two repeats:

- shearing plane Nr. 4: 0.265 kN,
- shearing plane Nr. 3: 0.462 kN,
- shearing plane Nr. 2: 0.664 kN,
- shearing plane Nr. 1: 0.865 kN.

3.5.3. Investigations of different layer structure

During all laboratory tests vertical static loading was zero, E_2 modulus of below support layer was 7.2 MPa, depth of ballast layer was 40 cm, depth of sand layer below the ballast was 10 cm, the geotextile between sand layer and Thermopan sheets was Secutex 151 GRK 3.

3.5.3.1. Properties of geogrids/geocomposites used in laboratory tests

Four types of geosynthetics were used in the laboratory tests:

- geogrid type 1,
- geocomposite type 1 (geogrid type 1 + geotextile),
- geogrid type 2,
- geocomposite type 2 (geogrid type 2 + geotextile).

Geogrid type 1 and geogrid in geocomposite type 1 are extruded, geogrid type 2 and geogrid in geocomposite type 2 are welded. Geometric properties of geogrids/geocomposites can be seen in Figure 9 and in Table 1, mechanic properties of them are consisted Table 2 and 3.

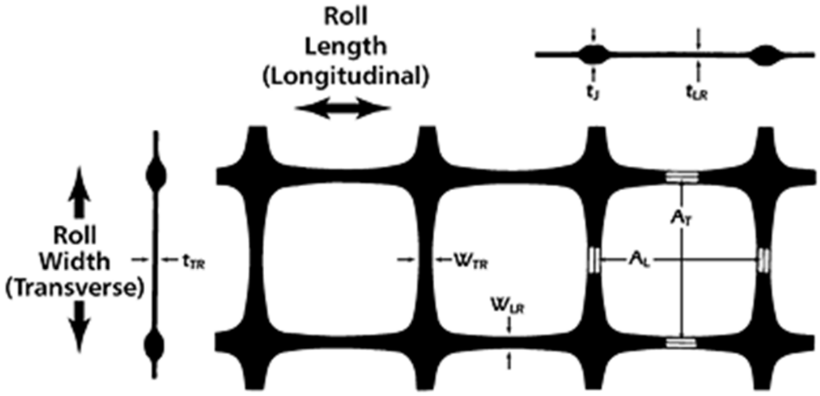

Figure 9. Definition of geometric properties of geogrids [17]

Table 1. Geometric properties of geogrids [6]

Geogrid/geo-composite type	**A_L (mm)**	**A_T (mm)**	**W_{LR} (mm)**	**W_{TR} (mm)**	**t_J (mm)**	**t_{LR} (mm)**	**t_{TR} (mm)**
Geogrid type 1	65.0	65.0	4.0	4.0	7.0	1.7	1.5
Geocomposite type 1	65.0	65.0	4.0	4.0	7.0	1.7	1.5
Geogrid type 2	80.0	80.0	8.8	8.2	2.1	1.4	1.4
Geocomposite type 2	80.0	80.0	8.8	8.2	2.1	1.4	1.4

Table 2. Mechanical properties of geogrids 1. [6]

Geogrid type	**Material**	**Uniaxial/ Biaxial**	**Ultimate strength**		**Strength at 2 % elongation**		**Ultimate elongation**	
			MD (kN/m)	**XMD (kN/m)**	**MD (kN/m)**	**XMD (kN/m)**	**MD (kN/m)**	**XMD (kN/m)**
Geogrid type 1	PP	Biaxial	30	30	11	12	N.A.	N.A.
Geocomposite type 1	PP	Biaxial	30	30	11	12	N.A.	N.A.
Geogrid type 2	PP	Biaxial	30	30	12	12	N.A.	N.A.
Geocomposite type 2	PP	Biaxial	30	30	12	12	N.A.	N.A.

Table 3. Mechanical properties of geogrids 2. [6]

Geotextiles and geotextiles in geocomposites	**Puncture resistance (N)**	**Ultimate strength**		**Ultimate elongation**		**Permeability (m/s)**	**Permeability (l/sm^2)**	**Unit weight (kg/m^2)**	**Effective opening size (mm)**
		MD (kN/m)	**XMD (kN/m)**	**MD (%)**	**XMD (%)**				
Geocomposite type 1	>1500	N.A.	N.A.	N.A.	N.A.	0.135	135	0.16	0.125
Geocomposite type 2	1670	6	11	60	40	0.11	110	0.15	0.13
Naue Secutex 150 GRK 3	1670	6	11	50	30	0.09	90	0.15	0.08

3.5.3.2. Execution of laboratory tests

3.5.3.2.1. Uncompacted layer structure without geogrid

In this series ballast was uncompacted. Shearing test was started in shearing plane Nr. 4, and then followed Nr. 3, 2 and 1. In each shearing frame moving was approximately 30…80 mm. This was generally enough to occur stationary pushing force, which shouldn't be increased to slip frames permanently. This frame moving of 30… 80 mm didn't change position of crushed stone particles in the lower layers[10].

Pushing force was increased with speed of 20 kN/min. In each shearing plane three measurements were done. After each series ballast material had been removed from the box, and then it was reconstructed[11].

3.5.3.2.2. Compacted layer structure without geogrid

Tests were done introduced in Section 3.5.3.2.1. Ballast material was compacted in 20 cm height layers by an L-2/C vibrator (68 kg, 1.1 kW power, 3000 1/min nominal vibration frequency, 500x500 mm vibration plane). Achieving same density (compaction level) always the same number of compaction passes should be utilized (on two lanes with three passes).

Figures 10-13 illustrate results of measurements related to compacted layer structure without geogrid.

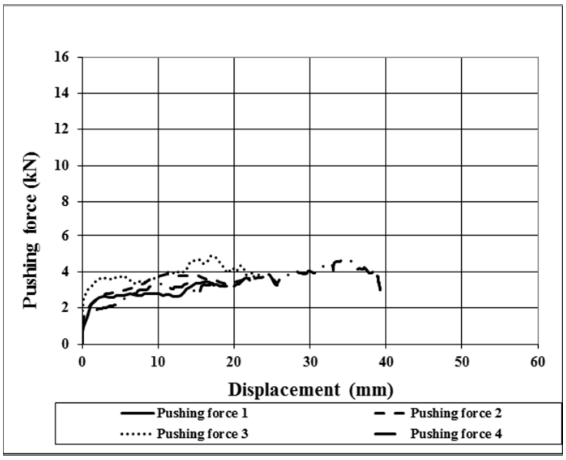

Figure 10. Pushing force-displacement diagram, compacted layer structure without geogrid, shearing plane Nr. 4. [17]

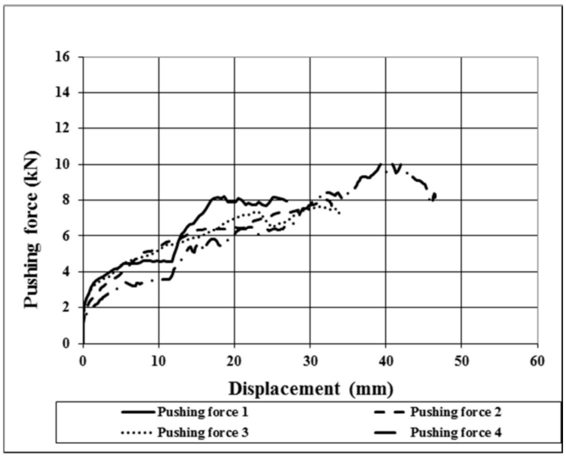

Figure 11. Pushing force-displacement diagram, compacted layer structure without geogrid, shearing plane Nr. 3. [17]

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[10] It was monitored through plexi windows.

[11] If geogrid/geocomposite-reinforced layer structure was investigated, after each series new geogrid/geocomposite was built-in.

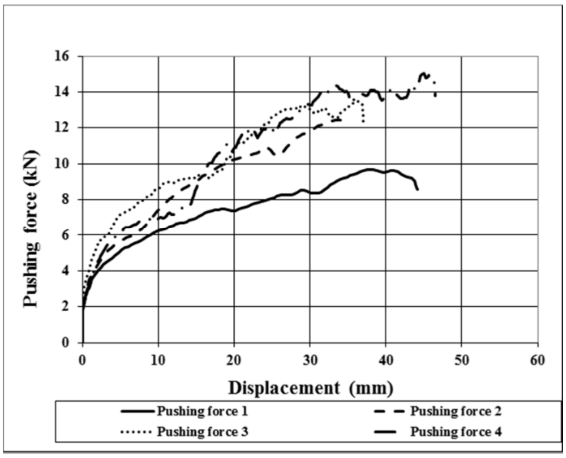

Figure 12. Pushing force-displacement diagram, compacted layer structure without geogrid, shearing plane Nr. 2. [17]

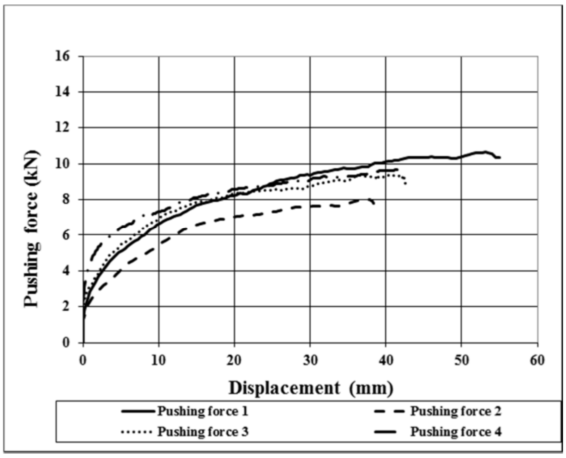

Figure 13. Pushing force-displacement diagram, compacted layer structure without geogrid, shearing plane Nr. 1. [17]

3.5.3.2.3. Uncompacted and compacted layer structures with geogrid/geocomposite

Geogrids and geocomposites were set in shear box as written in Section 3.4. In this paper only diagram related to geocomposite type 1 are shown in Figure 14-17.

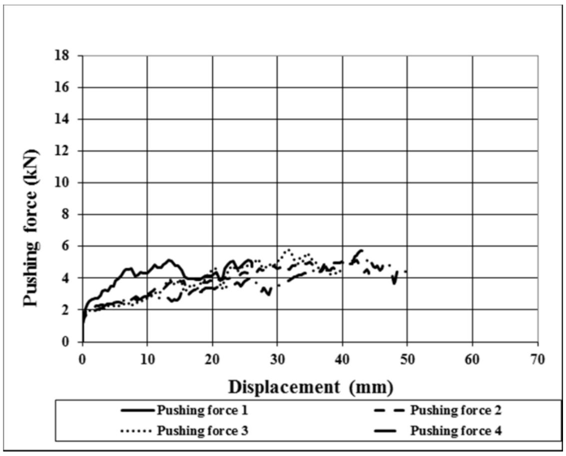

Figure 14. Pushing force-displacement diagram, compacted layer structure with geocomposite type 1, shearing plane Nr. 4. [17]

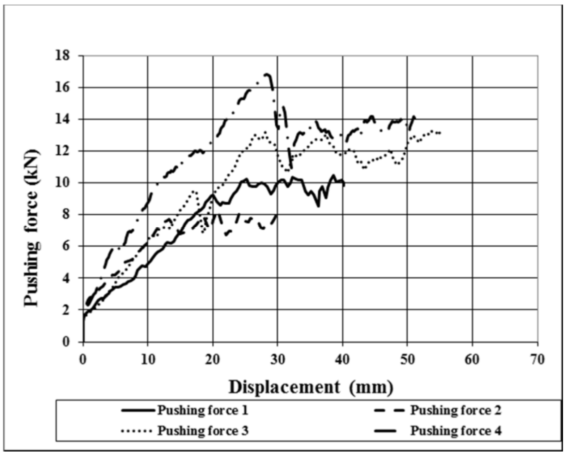

Figure 15. Pushing force-displacement diagram, compacted layer structure with geocomposite type 1, shearing plane Nr. 3. [17]

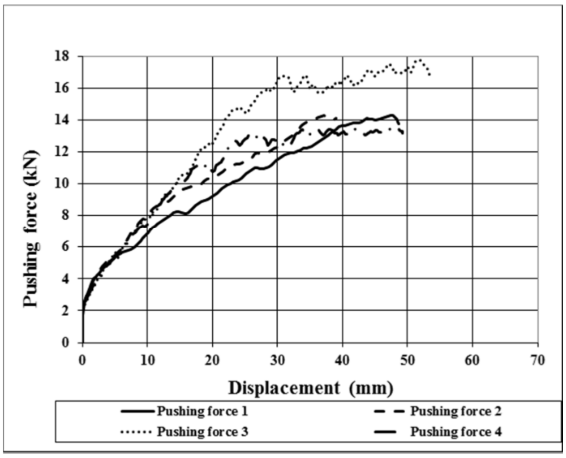

Figure 16. Pushing force-displacement diagram, compacted layer structure with geocomposite type 1, shearing plane Nr. 2. [17]

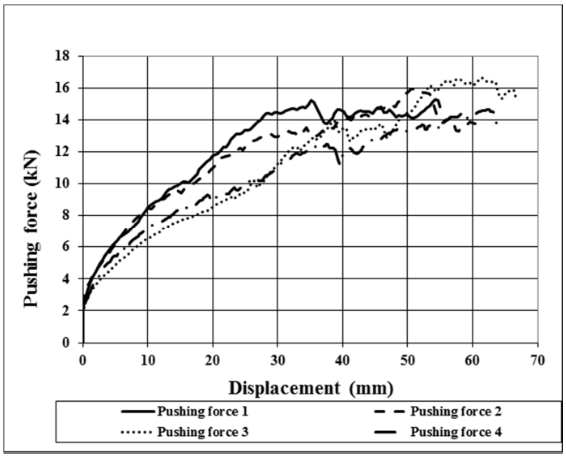

Figure 17. Pushing force-displacement diagram, compacted layer structure with geocomposite type 1, shearing plane Nr. 1. [17]

Because of limited space other diagrams can’t be published in this paper. Results of all laboratory tests are consisted in Section 3.5.3.3.2.

3.5.3.3. Methods of measured data’s process and results of laboratory tests

3.5.3.3.1. Methods of measured data’s process

In a pushing force-displacement diagram it can be seen that they show bounded above graphs. This boundedness characterizes the particle-mechanical behaviour that relates to inner shear resistance of railway ballast. It is obvious that aggregates like railway ballast (crushed stone with sharp edged particle) can’t represent exact inner shear resistance neither in laboratory. Measured data have some deviation because of random distribution of irregular shaped particles. Pushing force-displacement diagram related to shearing in a certain shearing plane can be evaluated by mathematical statistic methods which gives inner shear resistance of ballast in the certain height. These values can be calculated by determination of average of stationary pushing forces[12] related to different cases (uncompacted, compacted, with or without geogrid, etc.).

In the case of pushing force and related counter force (Figure 6) differed than 15 %, measurements should be repeated, therefore these values aren’t contained in Section 3.5.3.3.2.

Recorded pushing forces weren’t corrected by friction resistance shown in Section 3.5.2. This neglection can be used because friction resistance values are very low correlated to measured inner shear resistance values.

3.5.3.3.2. Result of laboratory tests

Inner shear resistance functions of crushed stone railway ballast were determined by using multi-level shear box tests in case of uncompacted and compacted

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[12] It means interval in which additional pushing force shouldn’t be to increase displacement.

(Section 3.5.3.2.2.) aggregates without or with geogrid/geocomposite reinforcement. Table 4 summarizes all measured data.

Table 4. Measured pushing forces [kN] related to inner shear resistance values of railway ballast as a function of distance from geogrid/geocomposite layer [6]

Distance from geogrid/geocomposite layer (cm)	No. of measurement	Uncompacted		Compacted				
		Without geogrid	With geocomposite type 1	Without geogrid	With geocomposite type 1	With geogrid type 1	With geogrid type 2	With geocomposite type 2
0	1	7.37	16.39	10.38	14.54	16.74	15.27	15.28
	2	8.52	7.45	7.64	14.16	17.93	14.36	14.32
	3	-	11.31	9.03	16.11	18.49	15.86	13.50
	4	-	10.36	9.38	13.86	-	-	-
	Min.	7.37	7.45	7.64	13.86	16.74	14.36	13.50
	Max.	8.52	16.39	10.38	16.11	18.49	15.86	15.28
	Avg.	**7.95**	**11.38**	**9.11**	**14.67**	**17.72**	**15.16**	**14.36**
	Dev.	0.81	3.72	1.13	1.00	0.89	0.76	0.89
10	1	6.72	6.59	9.61	14.08	16.02	18.43	17.90
	2	6.05	6.40	12.27	14.12	15.51	16.19	16.20
	3	-	8.99	12.76	16.67	15.62	16.64	16.43
	4	-	9.54	14.02	13.23	-	-	-
	Min.	6.05	6.40	9.61	13.23	15.51	16.19	16.20
	Max.	6.72	9.54	14.02	16.67	16.02	18.43	17.90
	Avg.	**6.39**	**7.88**	**12.17**	**14.53**	**15.72**	**17.09**	**16.84**
	Dev.	0.47	1.62	1.86	1.49	0.27	1.19	0.92
20	1	3.28	3.32	7.92	9.84	9.91	13.89	10.63
	2	3.79	3.52	7.79	7.57	9.74	10.09	11.73
	3	-	6.18	7.49	12.16	11.79	16.86	12.07
	4	-	6.83	9.74	13.19	-	-	-
	Min.	3.28	3.32	7.49	7.57	9.74	10.09	10.63
	Max.	3.79	6.83	9.74	13.19	11.79	16.86	12.07
	Avg.	**3.54**	**4.96**	**8.24**	**10.69**	**10.48**	**13.61**	**11.47**
	Dev.	0.36	1.80	1.02	2.51	1.14	3.39	0.75
30	1	1.67	2.64	3.28	4.86	3.35	4.93	4.15
	2	1.76	1.83	3.62	4.82	5.53	4.31	4.94
	3	-	3.52	4.27	5.15	3.15	4.16	6.02
	4	-	2.58	3.93	4.81	-	-	-
	Min.	1.67	1.83	3.28	4.81	3.15	4.16	4.15
	Max.	1.76	3.52	4.27	5.15	5.53	4.93	6.02
	Avg.	**1.72**	**2.64**	**3.78**	**4.91**	**4.01**	**4.47**	**5.04**
	Dev.	0.06	0.69	0.42	0.16	1.32	0.41	0.94

Averages of pushing forces are shown in Figure 18. Polynomial regression functions were utilized to evaluate the results, their equations and R^2 values are given in Table 5 and 6. Boundary condition was considered that on the upper surface of ballast (40 cm distance from geogrid layer) shearing can't be interpreted.

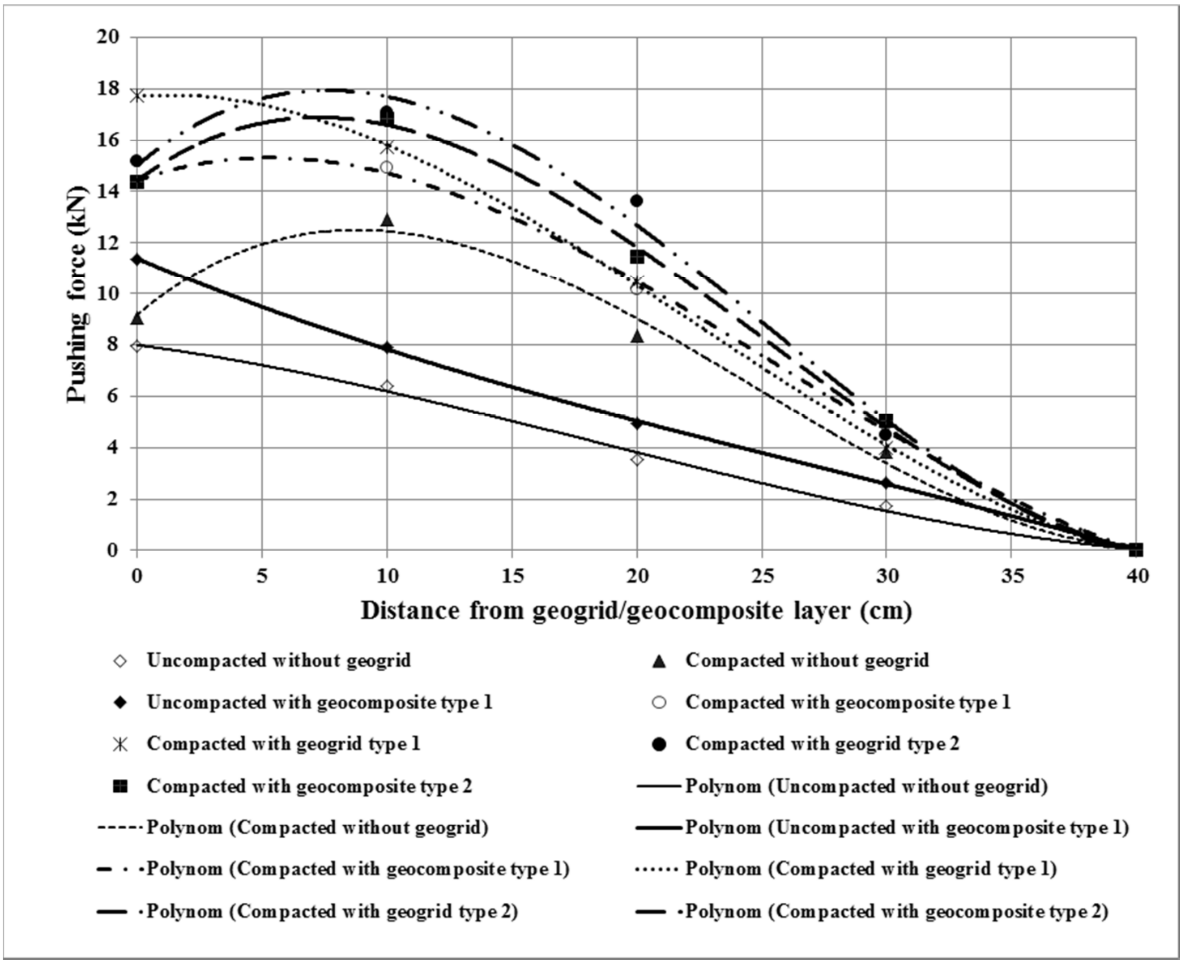

Figure 18. Averages of measured pushing forces as a function of distance from geogrid/geocomposite layer [6]

Table 5. Factors and R^2 values of cubic polynomial regression functions 1 [6]

	Uncompacted without geogrid	Compacted without geogrid	Uncompacted with geocomposite type 1	Compacted with geocomposite type 1
const.	7.991357	9.153036	11.390893	14.426460
x	–0.126196	0.820080	–0.410533	0.349165
x^2	–0.006461	–0.056529	0.006161	–0.036846
x^3	0.000116	0.000759	–0.000075	0.000478
R^2	0.9965	0.9915	0.9998	0.9985

Table 6. Factors and R^2 values of cubic polynomial regression functions 2 [6]

	Compacted with geogrid type 1	**Compacted with geogrid type 2**	**Compacted with geocomposite type 2**
const.	17.693390	15.008614	14.426210
x	0.086873	0.820204	0.716988
x^2	–0.032234	–0.063581	–0.057716
x^3	0.000475	0.000840	0.000770
R^2	0.9998	0.9927	0.9986

Conclusions can be derived from results are written in Section 3.6.

After removing layer structure from shear box significant failures can be seen on geogrid type 1 and geogrid type 2. Geogrids with welded junctions (geogrid type 2) don't ensure adequate solution because of their vulnerability[13]. In case of extruded geogrid (geogrid type 2) only smaller cracks can be observed.

Rotational resistance in geogrid plane was investigated in case of geogrid type 1 and geogrid type 2. They are characterized by rotations (degrees) due to moments of 1.0 Nm[14]:

$$\varphi_{geogrid\_type\_1.,1\_Nm} = 1{,}38°, \tag{1}$$

$$\varphi_{geogrid\_type\_2.,1\_Nm} = 19{,}02°, \tag{2}$$

Increasing factors as a function of distance from geogrid layer were defined by using polynomial regression functions of pushing forces (inner shear resistance), their mechanical meaning are the following:

- increasing factor "A": inner shear resistance related to geogrid/geocomposite-reinforced compacted ballast divided by inner shear resistance related to unreinforced compacted ballast (effect of geogrid/geocomposite reinforcement in compacted ballast),
- increasing factor "B": inner shear resistance related to geogrid/geocomposite-reinforced compacted ballast divided by inner shear resistance related to geogrid/geocomposite-reinforced uncompacted ballast (effect of compaction using geogrid/geocomposite reinforcement),
- increasing factor "C": inner shear resistance related to geocomposite-reinforced compacted ballast divided by inner shear resistance related to geogrid-reinforced uncompacted ballast (effect of geotextile using geogrid/geocomposite reinforcement in compacted ballast),
- increasing factor "D inner shear resistance related to geogrid/geocomposite-reinforced uncompacted ballast divided by inner shear resistance related to

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[13] Geogrid type 2 and geocomposite type 2 were investigated only as a probe because they are not used for geometry stabilisation of ballasted railway track.

[14] These results are from FEM modelling with AxisVM 11 software. This kind of tests was not done by authors.

unreinforced uncompacted ballast (effect of geogrid/geocomposite reinforcement in uncompacted ballast),

- increasing factor "E": inner shear resistance related to unreinforced compacted ballast divided by inner shear resistance related to unreinforced uncompacted ballast (effect of compaction in unreinforced ballast).

Increasing factors "A" to "E" as a function of distance (0…30 cm[15]) from geogrid/geocomposite layer are shown in Figure 19-23. The ordinates of graphs were calculated by ratio of specific equations. Because of limited space factors and R^2 values of regression functions can't be published in this paper, but it should be noticed that all R^2 values are higher than 0.97.

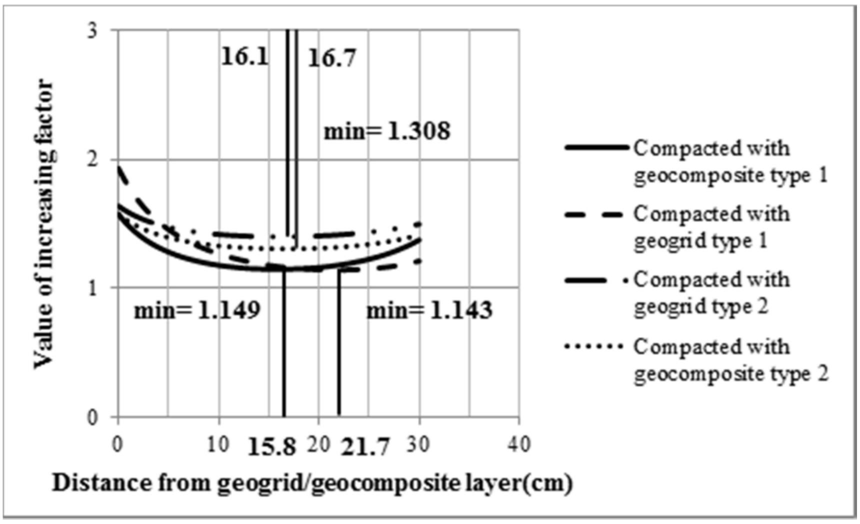

Figure 19. Value of increasing factor "A" [6]

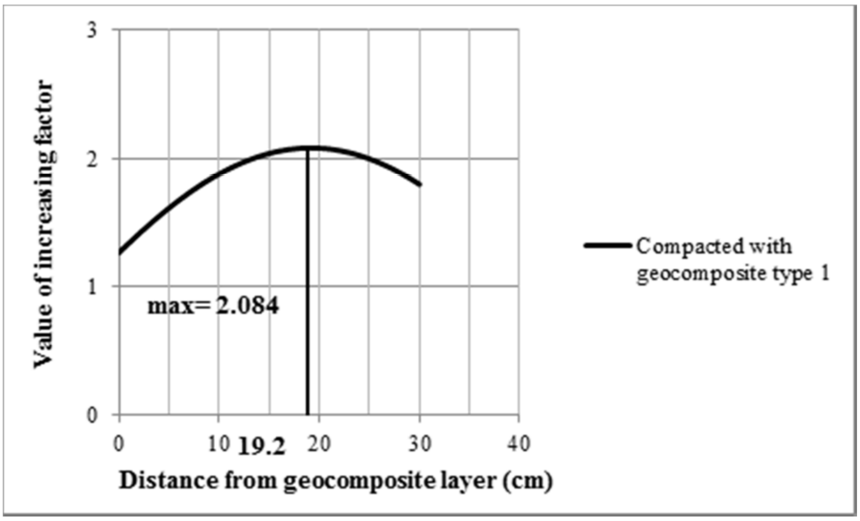

Figure 20. Value of increasing factor "B" [6]

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[15] In planes which are 30…40 cm from geogrid/geocomposite layer there are no measured data. Referred to Section 3.5.3.3.2. all increasing factors can be set to 1.0 in plane 40 cm from geogrid/geocomposite layer.

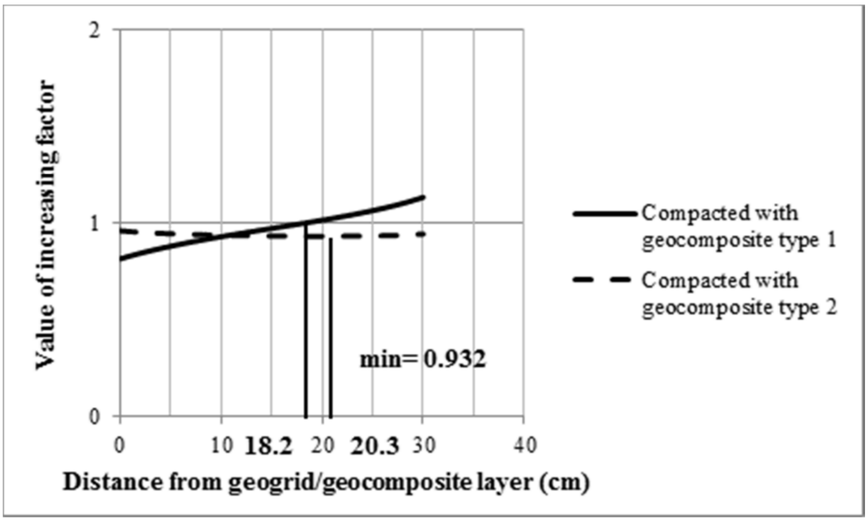

Figure 21. Value of increasing factor "C" [6]

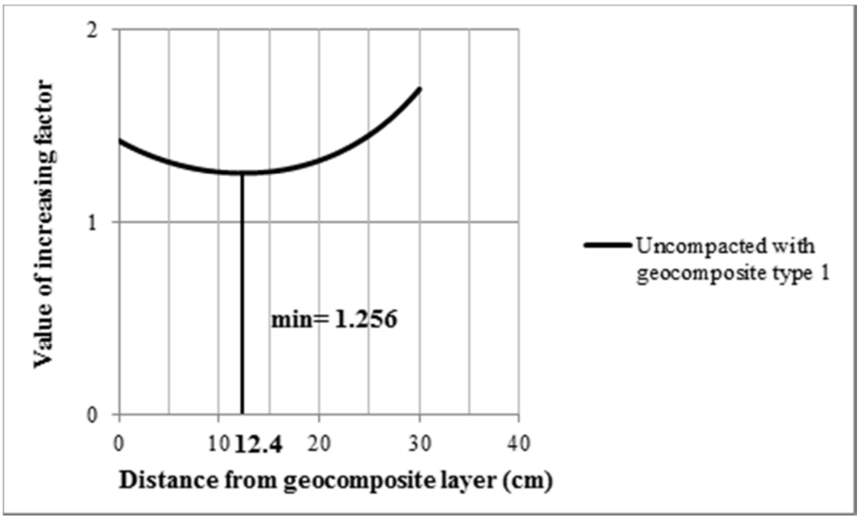

Figure 22. Value of increasing factor "D" [6]

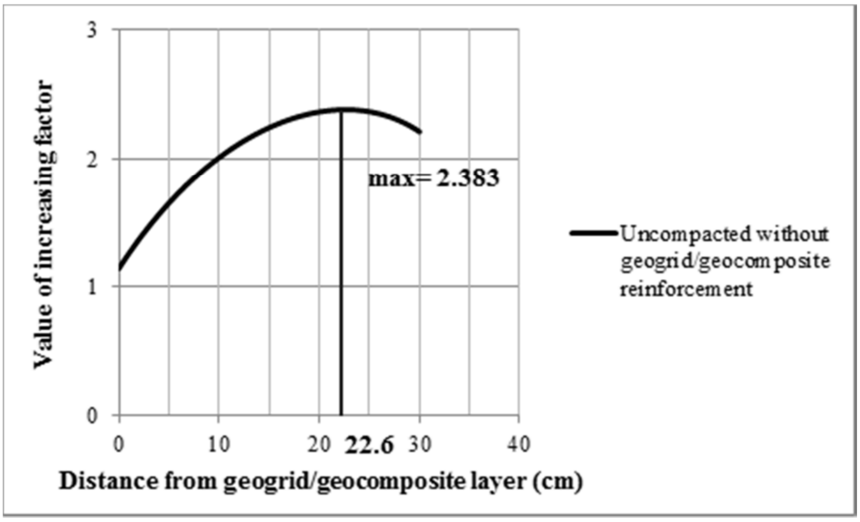

Figure 23. Value of increasing factor "E" [6]

3.6. Conclusions derived from results of laboratory tests

It can unequivocally be stated on the basis of results written in Section 3.5.3.3.2 that multi-level shear box is adequate for determining inner shear resistance of granular aggregates, e.g. crushed stone railway ballast. Using this data and considering boundary conditions regression functions of inner shear resistance can be determined as a function of distance from geogrid/geocomposite layer. It should be noticed that values of these functions are approximate but reliable only in the height of shearing planes.

In the consideration of measured data of multi-level shear box tests it can also unequivocally be stated that adequate type of geogrid/geocomposite under ballast can increase inner shear resistance of railway ballast aggregate in the following ways:

- maximum value of inner shear resistance function is not in the plane of geogrid/geocomposite (except geogrid type 1), but 0...10 cm above this plane,
- in case of geocomposite type 1 and geocomposite type 2 inner shear resistance is decreased (correlated only to same manufactured product) by glued geotextile layer because it significantly hinders ballast particle's wedging into aperture of geogrids (in case of geocomposite type 1 in the 0...18 cm zone, in case of geocomposite type 2 in the whole 0...40 cm zone),
- the reason of smaller measured pushing forces in case of geogrid type 2 was the notable observed failure because of its weakness.

Increasing factors were determined, which show the following results:

- effect of geogrid/geocomposite reinforcement in compacted ballast is minimal in the 15...22 cm zone. Maximal increasing is observed in case of geogrid type 1 (1.904). In the plane of geogrid/geocomposite the most effective are geogrids without geotextile (geogrid type 2 has this advantage in the whole 0...40 cm zone correlated to its geocomposite pair). In the zone of 10...30 cm increasing factor "A" can be considered as constant.
- Compaction increases inner shear resistance of compacted layer structure constructed by geocomposite type 1 in the whole 0...30 cm zone. Maximal increasing is observed in the height of 19.2 cm (2.084). In any other heights smaller increasing can be obtained.
- Evaluate the effect of geotextile using geogrid/geocomposite reinforcement in compacted ballast increasing can only be received by using geocomposite type 1 in the zone of 18.2...30 cm. In case of geocomposite type 2 can't be achieved increasing correlated to geogrid type 2.
- In uncompacted ballast the investigated geocomposite type reinforces railway ballast aggregate in the whole 0...30 cm zone. Maximal increasing can be observed in the maximum distance from geocomposite layer. Minimal increasing is in the height of 12.4 cm (1.255), in any other heights greater increasing can be obtained.
- Compaction significantly increases inner shear resistance of uncompacted layer structure. Its maximum value is 2.380 in the height of 22.6 cm. In any other heights smaller increasing can be obtained.

It can be stated that optimal depth of compacted railway ballast is 23 cm below from the lower face of sleeper. In case of geogrid/geocomposite-reinforced compacted ballast optimal depth would be 0…15 cm, but in the heights more far from 15 cm reinforce effect can be also obtained. In the consideration of separation of ballast and protective layer or subgrade, as well as drainage, geocomposite layer should be used – from the investigated types geocomposite type 1 is recommended –, but in this case reinforcement using geocomposite is smaller than using geogrid in the height of 0…18 cm zone. It should be noted that ballast cleaning and tamping works needed minimum 22…33 cm ballast depth between the lower face of sleeper and geogrid/geocomposite reinforcement, therefore these minimal values should be considered at design phase.

Turning-moment of unit in the plane of geogrids causes 13.78 times greater rotation of junction in case of geogrid type 1 and geocomposite type 1 than in case of geogrid type 2 and geocomposite type 2. Modulus of elasticity of geogrid type 1's material is also approximately 15 times greater than geogrid type 2's. In the consideration of these facts geogrid type 2 and geocomposite type 2 are unadequate for geometry stabilisation of ballasted railway track as reinforcement layer under ballast bed.

4. Summary and future research possibilities

This article investigated the railway track geometry stabilisation effect of geogrid layers under ballast with a specific laboratory multi-level shear box. During the laboratory tests different types of geogrid and geocomposite layers were analysed when railway ballast was uncompacted and compacted. Two types from these have not utilised for railway track geometry stabilisation yet. Inner shear resistance of railway ballast was determined in case of unreinforced and geogrid-reinforced assemblies, as well as five multiplication factors were defined which are adequate for determining inner shear resistance of reinforced and unreinforced railway ballast in consideration of different parameters.

Taking into account other parameters can help evaluation of railway track geometry stabilisation effect more precisely:

- using not only fresh, but recycled crushed stone railway ballast,
- using not only dry, but wet and oily crushed stone railway ballast,
- using different elasticity support layer,
- using different ballast depths,
- using other different geogrids/geocomposites,
- considering vertical static load on the upper surface of ballast,
- considering dynamic loads.

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References

[1] MSZ EN 13450:2003: *"Kőanyaghalmazok vasúti ágyazathoz"* in Hungarian, CEN, 2003

[2] ISO 12957-1:2005: *"Geoszintetikák. A súrlódási jellemzők meghatározása. 1. rész: Közvetlen nyíróvizsgálat"* in Hungarian, CEN, 2005

[3] MSZ EN ISO 13738:2005: *"Geotextíliák és rokon termékeik. A talajból való kihúzással szembeni ellenállás meghatározása"* in Hungarian, CEN, 2005

[4] FISCHER, SZ.: *"Georácsos vasúti felépítménystabilizáció hatékonysága"* in Hungarian, XV. Nemzetközi Építéstudományi Konferencia (EMT), Csíksomlyó, Románia, 2011. június 2-5., pp. 137-144

[5] FISCHER, SZ: *"Lassújel miatti többletköltségek, és a megszüntetés költségeinek összehasonlítása"* in Hungarian, Sínek Világa, Vol. LIII (2011), No. 5, pp. 21-29

[6] FISCHER, SZ.: *"A vasúti zúzottkő ágyazat alá beépített georácsok vágánygeometriát stabilizáló hatásának vizsgálata"* in Hungarian, Ph.D. thesis, Széchenyi István Egyetem Műszaki Tudományi Kar, 2012, 148 p.

[7] INDRARATNA, B., SHAHIN, M., RUIJIKIATKAMJORN, C., CHRISTIE, D.: *Stabilisation of ballasted rail tracks and underlying soft formation soils with geosynthetic grids and drains*, ASCE Special Geotechnical Publication No. 152, Proceedings of Geo-Shanghai 2006, Shanghai, China, 2-4 June 2006, pp. 143-152

[8] INDRARATNA, B., SHAHIN, M. A., SALIM, W.: *Stabilisation of granular media and formation soil using geosynthetics* with special reference to railway engineering, Journal of Ground Improvement, Vol. 11 (2007), No. 1, pp. 27-44

[9] www.kti.hu – *"Grafikus adatbázisok, Trendek, Dugófigyelő"* in Hungarian – Közlekedéstudományi Intézet Nonprofit Kft. - http://www.kti.hu/index.php/szolgaltatasok/trendek-grafikus-adatbazis/trendek---grafikus-adatbazis [read: 12.09.2011]

[10] *"D.54 sz. Építési és pályafenntartási műszaki adatok, előírások"* in Hungarian, Part I., KÖZDOK, 1987, Budapest, 325 p.

[11] RAKOWSKI, Z., KAWALEC, J.: *Mechanically stabilized layers in roadconstruction*, not published printed conference presentation, XXVII. International Baltic Road Conference, August 2009, Riga (Latvia)

[12] RAYMOND, G. P.: *Reinforced ballast bahaviour subjected to repeated load*, Geotextiles and Geomembranes, Vol. 20 (2002), pp. 39-61

[13] RAYMOND, G., ISMAIL, I.: *The effect of geogrid reinforcement on unbound aggregates*, Geotextiles and Geomembranes, Vol. 21 (2003), pp. 355-380

[14] SHIN, E. C., KIM, D. H., DAS, B. M.: *Geogrid-reinforced railroad bed settlement due to cyclic load*, Geotechnical and Geological Engineering, Vol. 20 (2002), pp. 261-271

[15] TENSAR INTERNATIONAL LTD.: *Railways. Mechanical Stabilisation Track Ballast and Sub-ballast*, marketing issue, 2010, Blackburn, 11 p.

[16] TÖMPE, I.: *"A pályavasúti üzletág jelene és jövője"* in Hungarian, not published printed conference presentation, Új technológiák és anyagok a pályaépítésben és fenntartásban szakmai továbbképzés", 31th August – 2nd September 2011, Békéscsaba (Hungary)

[17] UNIVERSITAS-GYŐR NONPROFIT KFT.: *"Georácsok alkalmazása a vasúti zúzottkőágyazat stabilizálására"* in Hungarian, research report (written by F. Horvát, Sz. Fischer), Győr, 30th November 2010, 139 p.

[18] STAHL, M.: Interaktion Geogitter-Boden: *"Numerische Simulation und experimentelle Analyse"* in German, Ph.D. thesis, Technischen Universität Bergakademie Freiberg, 2011, 166 p.

[19] VASZARY, P.: *"A pályaromlás elmélete"*, in I. MEZEI és Id. F. HORVÁTH (eds.) Vasútépítés és pályafenntartás Part II., Magyar Államvasutak Rt., Budapest, 1999, pp. 157-160

[20] WEINREICH, Z.: *"Nagysebességű vasutak pályafenntartási kitűzése"* in Hungarian, Sínek Világa, Vol. LIII (2011), No. 6, pp. 27-31