ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського
національного університету залізничного транспорту, 2015, № 5 (59)

UDC 625.141:624.138

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INVESTIGATION OF INNER SHEAR RESISTANCE OF GEOGRIDS BUILT UNDER GRANULAR PROTECTION LAYERS AND RAILWAY BALLAST

Purpose. Using adequate granular materials and layer structures in the railway super- and substructure is able to stabilise railway track geometry. For this purpose special behaviour of above materials has to be determined, e.g. inner shear resistance. Inner shear resistance of granular media with and without geogrid reinforcement in different depths is not known yet. **Methodology.** The author developed a special laboratory method to measure and define inner shear resistance of granular materials, it is called «multi-level shear box test». This method is adequate to determine inner shear resistance (pushing force) vs. depth (distance from the «zero» surface). Two different granular materials: andesite railway ballast (31.5/63 mm) and andesite railway protection layer material (0/56 mm), and seven different types of geogrids (GG1…GG7) were used during the tests. **Findings.** Values of inner shear resistance functions of andesite railway ballast without geogrid reinforcement and reinforced with different types of geogrids and andesite granular protection layer in function of the vertical distance from the geogrid plane were determined with multi-layer shear box tests when the material aggregation is uncompacted and compacted. Only the compacted sample was tested in case of the 0/56 mm protection layer. Cubic polynomial regression functions fitted on the mean values of the measurements are described graphically. Determination coefficients with values of $R^2>0.97$ were resulted in all the cases of regression functions. Based on the polynomial regression functions fitted on the mean values of the test results, three increasing factors were determined in function of the distance measured from the geogrid. Increasing factor «A», «B» and «D». **Originality.** Multi-level shear box test, developed by the author, is certified unequivocally adequate for determining inner shear resistance of reinforced and unreinforced granular materials, e.g. railway ballast, protection layer. **Practical value.** The paper formulated the requirements of using geogrid-reinforced railway ballast and protection layer material to stabilise railway track geometry, e.g. dewatering, draining, separation, minimum ballast depth, and suggested geogrid types from investigated ones.

Keywords: railway ballast; geogrid reinforcement; granular protection layers; multi-level shear box tests; inner shear resistance

Introduction

The self-financed R&D work of MÁV (Hungarian Railways) titled ’Application of geogrids to stabilize railway ballast’ was carried out in the period between 2009-2014, the entrepreneur was Universitas-Győr Nonprofit Ltd., topic supervisors were F. Horvát and Sz. Fischer. Research included examination of test sections built in rail tracks (analysation of geodetical measurements and railway track geometry measuring-recording car graphs), discrete element modelling of railway ballast (only between 2009 and 2011), and examination of laboratory multi-layer shear box tests. In the following part of this article only research results of the latter part between 2012 and 2014 will be presented in details. Not only railway ballast but granular protection layers were also aimed at in this 2014 research work so a more complex picture was given of inner shear resistance of geogrid-reinforced granular layers and its increasing effect. The author notes that the laboratory test series presented in this article is not enough to evaluate the behaviour of the examined geogrids in rail tracks, by all means new test sections will need to be created and their continuous diagnoses is necessary.

Purpose

Using adequate granular materials and layer structures in the railway super- and substructure is able to stabilize railway track geometry [5, 9, 10, 11, 12, 13, 14, 15]. (The better the railway track geometry the higher train speed can be reach [6, 7, 8].) For this purpose special behavior of above materials has to be determined, e.g. inner shear resistance. Inner shear resistance of granular media

doi : 10.15802/stp2015/53169

with and without geogrid reinforcement in different depths is not known yet.

Methodology

The theoretical background of the behaviour of geogrid-reinforced ballast and its increasing effect on inner shear resistance can be understood in details from the author's Ph.D. thesis [1]. Due to content limit the execution of laboratory multi-layer shear box tests will not be discussed here, they are found in bibliography [4] and [3] in details. In the following part of this article these sources will not be referred to, but the knowledge of them is inevitable to understand the tests discussed hereinafter.

The origins of materials used for our multi-level shear box tests:

- 31,5/63 mm andesite railway ballast: KŐKA Kő- és Kavicsbányászati Ltd.,
- 0/56 mm andesite granular protection layer Colas Északkő Ltd., Szob quarry,
- geogrids: Tensar International s.r.o.

Tests before measurements:

- ballast particle distribution and particle shape examination,
- particle size distribution test of granular protection layer (provided by Colas Északkő Ltd.),
- determination of resistance evolving on each shear plane between the frame elements of the empty shear box.

Laboratory measurements of inner shear resistance in case of differently formed layer structures:

- determination of inner shear resistance of railway ballast material (31.5/63 mm) without operating vertical load with compacted and uncompacted ballast material, with different types of geogrids and without geogrid
- determination of inner shear resistance of granular protective layer (0/56 mm) without operating vertical load with compacted granular protective layer without geogrid and compacted ballast material with two different types of geogrids:
- compacted granular protection layer with material, at layer structure created without geogrid,
- compacted ballast material, at layer structures created with seven different types of geogrids.

To describe inner shear resistance 3-3 measurements were performed for each arrangement and each shear plane.

During the tests the elasticity modulus of the base layer was $E_2 = 7.2$ MPa. The thickness of the ballast material and the granular protection layer was 40 cm, the ballast material and the thickness of the compacted sand layer laid under these layers was 10 cm. One layer of Naue Secutex 151 GRK 3 type geotextile was laid between the sand layer and the Austrotherm Thermopan plates (geometrical and mechanical parameters of the geotextile are in the referred literature).

Characteristics of geogrids applied in laboratory tests

Seven different types of geosynthetics were applied during the laboratory tests:

- GG1, GG2, GG3: (examined with railway ballast and granular protection layer),
- GG4, GG5, GG6, GG7 (examined only with granular protection layer).

With the exception of GG5 all geogrids are extruded, whereas GG5 was with welded junctions.

Geogrids and their geometrical characteristics are recorded in Table 1 and Figures 1-4.

Table 1

Geometrical characteristics of geogrids

Type of geogrid/ geometrical characteristics [mm]	GG1	GG2	GG3	GG4	GG5	GG6	GG7
A	38.0	47.0	70.0	–	–	–	–
A_L	–	–	–	39.0	32.0	47.0	–
A_T	–	–	–	39.0	32.0	31.50	–
A_1	–	–	–	–	–	–	42.0
A_2	3.20	3.90	–	–	–	–	44.0
A_3	–	–	–	–	–	–	60.0
W_R	0.80	1.10	2.10	–	–	–	–
W_L	–	–	–	2.30	8.00	–	–
W_T	–	–	–	–	–	8.00	–
W_{LR}	–	–	–	–	–	2.50	–
W_{TR}	–	–	–	2.87	–	6.00	–
W_{R1}	–	–	–	–	–	–	1.9
W_{R2}	–	–	–	–	–	–	1.9

doi : 10.15802/stp2015/53169

End of table 1

Type of geogrid/ geometrical characteristics [mm]	GG1	GG2	GG3	GG4	GG5	GG6	GG7
W_{R3}	–	–	–	–	–	–	1.5
t_J	–	–	5.70	5.0	1.20	4.20	–
t_L	–	–	–	–	0.80	–	–
t_R	1.20	1.50	1.80	–	–	–	–
t_T	–	–	–	–	0.80	–	–
t_{LR}	–	–	–	2.20	–	2.20	1.3
t_{TR}	–	–	–	1.30	–	1.60	1.4

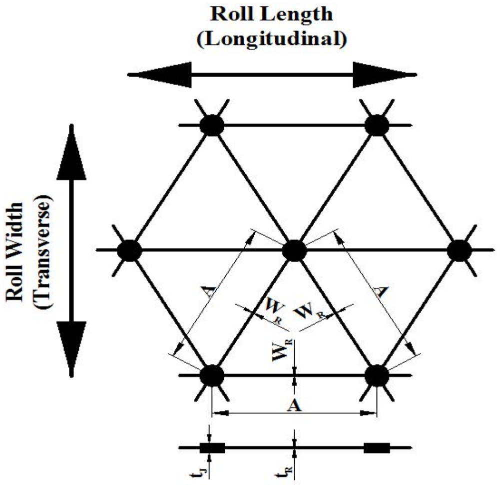

Fig. 1. Meanings of geometrical characteristics of GG1, GG2 and GG3 geogrids

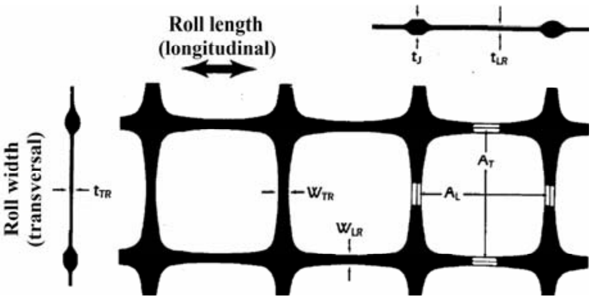

Fig. 2. Meanings of geometrical characteristics of GG4 and GG6 geogrids

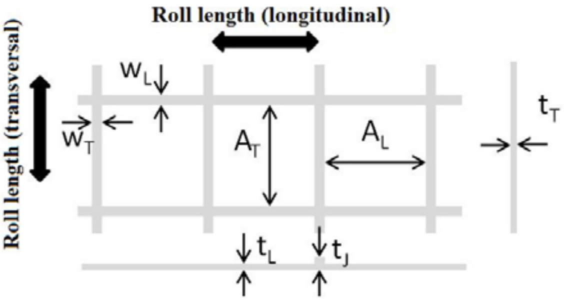

Fig. 3. Meanings of geometrical characteristics of GG5 geogrid

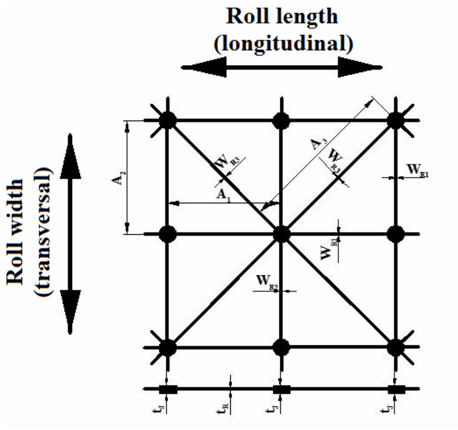

Fig. 4. Meanings of geometrical characteristics of GG7 geogrid

Particle size distribution of railway ballast and granular protection layer used in the test series

Particle distribution of railway ballast applied in the multi-layer shear box test is contained in (1), granular protective layer consists of 30% 31.5/63 mm E-type ballast stone, 40% 0/32 mm and 30% 0/5 mm fractions, its particle size distribution graph is described in Figure 5.

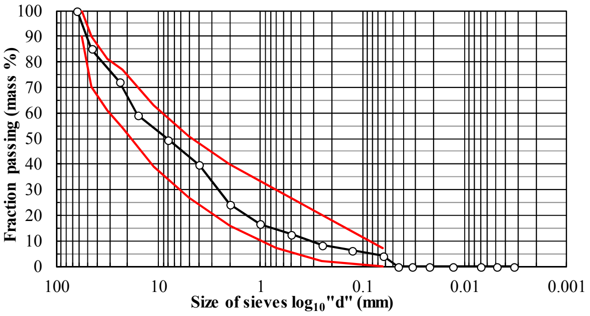

Fig. 5. Particle size distribution of granular railway protection layer material [Source: Colas Északkő Ltd.]

doi : 10.15802/stp2015/53169

Findings

Values of inner shear resistance functions of andesite railway ballast without geogrid reinforcement and reinforced with different types of geogrids and andesite granular protection layer in function of the vertical distance from the geogrid plane were determined with multi-layer shear box tests when the material aggregation is uncompacted or compacted with the method described in the referred literature (only the compacted sample was examined in case of the 0/56 mm protection layer.) Due to content limit the summarized results – the cubic polynomial regression functions fitted on the mean values of the measurements – will only be described graphically in Figures 6-7.

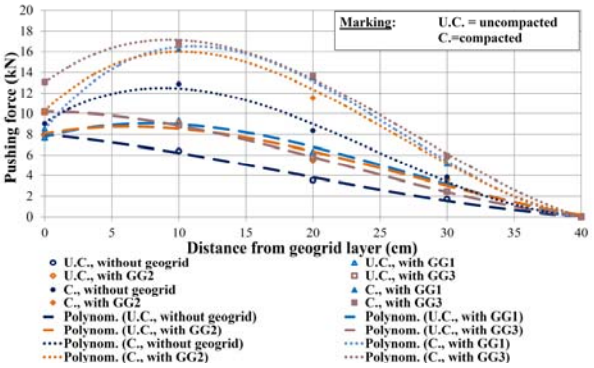

Fig. 6. Mean values of pushing force values and cubic polynomial regression functions fitted on the mean values of the measurements in case of railway ballast material (31.5/63 mm)

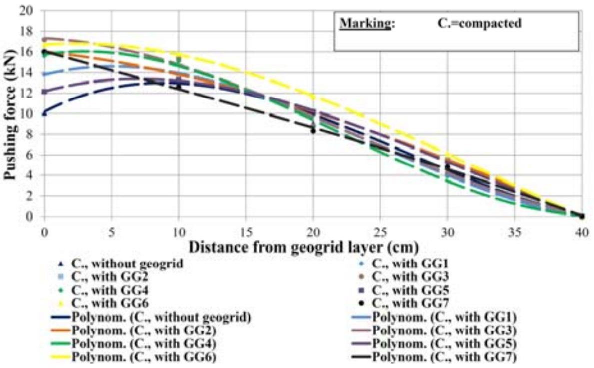

Fig. 7. Mean values of pushing force values and cubic polynomial regression functions fitted on the mean values of the measurements in case of granular railway protection layer material (0/56 mm)

A compressive force of 0 kN was taken on the 40 cm distance measured from the geogrid plane as a boundary condition, because on the upper plane the shear phenomenon can not be interpreted. Determination coefficients with values of $R^2>0.97$ were resulted in all the cases of regression functions.

When geogrids were released after the shear tests, no significant deterioration was experienced in the cases of any types. However, some cases of minor geogrid rib breakage were noticed but their operational behaviour is not influenced by them.

Based on the polynomial regression functions fitted on the mean values of the test results, increasing factors were determined in function of the distance measured from the geogrid, which have the following mechanical meaning (the meanings of all the five increasing factors are found in literature (1), in the present case only 3 of them were needed):

− increasing factor «A»: improving effect of built-in geogrid in compacted layer (increasing inner shear resistance)

− increasing factor «B»: effect of compaction in geogrid-reinforced layer

− increasing factor «D»: improving effect of built-in geogrid (increasing inner shear resistance) in uncompacted layer.

In Figures 8-11, three different increasing factors were given for railway ballast (31.5/63 mm) and granular protection layer (0/56 mm), and seven types of geogrids in the function of the distance were measured from geogrid plane.

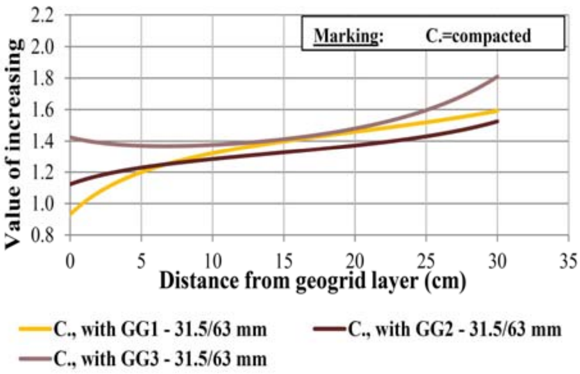

Fig. 8. Increasing factor «A» in case of railway ballast material (31.5/63 mm)

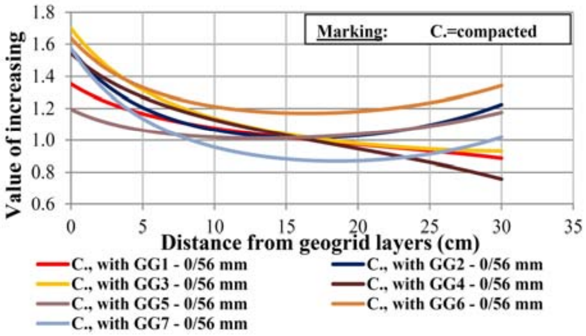

Fig. 9. Increasing factor «A» in case
of granular railway protection
layer material (0/56 mm)

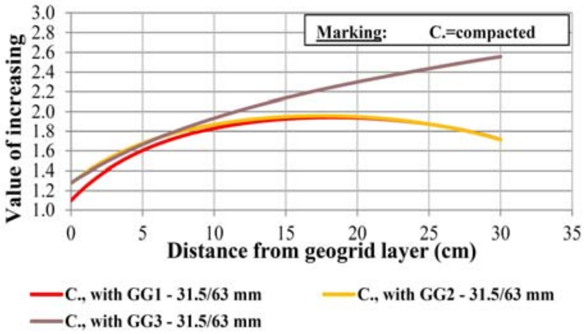

Fig. 10. Increasing factor «B» in case
of railway ballast material (31.5/63 mm)

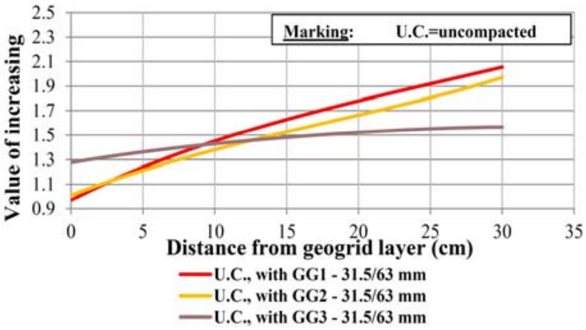

Fig. 11. Increasing factor «D» in case
of railway ballast material (31.5/63 mm)

Originality and practical value

Based on the test results introduced in details it can unequivocally be stated that the multi-layer shear box test is suitable to determine certain high coordinated points of inner shear resistance functions typical of horizontal planes in granular material aggrevations – in the present case in railway ballast and 0/56-mm protective layers. With these points and the application of 0 kN compressive force taken as boundary condition on the upper plane of granular material aggrevations, the inner shear resistance function typical of horizontal planes can be approximated with regression functions, but the fact must be acknowledged that these regression functions only provide approximate but reliable results in heights of measurement.

Based on the results of laboratory multi-layer shear box tests, it can unequivocally be stated that inner shear resistance in both uncompacted ballast and compacted granular protection layer is increased with the adequate type of geogrid layer built under the granular material aggregation in the following way:

- in railway ballast:
- Uncompacted layer without geogrid and in case of GG3 reinforcement in 0-cm height, while in case of GG1 and GG2 reinforcement the maximum of inner shear resistance functions is in the 5…10 cm zone above the geogrid, out of which GG3 had the highest one, because with GG1 and GG2 reinforcement the 38.0 mm and 47.00-mm-sidelength regular triangle apertures were too small compared to the 31.5/63 mm railway ballast particles, therefore the ’interlocking’ effect could not fully evolve and take effect.
- Compacted layer both without geogrid reinforcement and with GG1, GG2 and GG3 reinforcement the maximum of inner shear resistance functions were in about 10 cm- height above the geogrid plane, in case of GG3 was the highest value, in case of GG1 (application) weakening in the geogrid plane, while in case of GG2 (application) only little reinforcement could be determined, they refer to the effects of smaller geogrid apertures in compacted railway ballast. Reinforcement in case of GG3 geogrid is 1.4…1.8 times higher than in the case without geogrid.
- Diverging from the geogrid plane the effect of reinforcement prevails more and more with all the three types of geogrids both in uncompacted and compacted railway ballast. It is interesting that the highest amount of reinforcement can be experienced with GG1 geogrid in case of uncompacted ballast in 30 cm height measured from the geogrid plane, the lowest is with GG3 geogrid (Figure 11) – its reason is not clarified yet on the contrary, in compacted ballast (which reflects real-life operating rail tracks better) the optimum in the whole layer thickness is gained with GG3 reinforcement/application containing bigger apertures.

− In compacted granular protection layer:

− the maximum of inner shear resistance functions is in the 5…10 cm height in cases without geogrid and with GG1 and GG5 reinforcement, whereas in the cases of other geogrid types it is in the geogrid plane. Reinforcement was achieved with all the geogrid types in the geogrid plane, the highest with GG3, the lowest with GG5, on the contrary, in the whole layer thickness in 10/15…30 cm height GG1, GG3, GG4 and GG7 types do not even reach the value of the inner shear resistance measurable without geogrid, so in this interval slight weakening can be measured. It is an interesting phenomenon that the minimum of reinforcement is in the 15…20 cm zone with GG2, GG5, GG6 and GG7 types. GG6 type is able to reinforce the granular protection layer in the biggest interval, if achieving the highest reinforcement in the geogrid plane is the aim, applying GG3 type is not recommended, because it is only able to ensure 90…95% of the inner shear resistance of the original granular material in the 20….30 cm height.

− Inner shear resistance (Fig. 10) is significantly increased by compaction in geogrid-reinforced railway ballast, the effect is the highest in case of GG3 (2.6 times in the 30 cm height), reinforcement has a maximum in the 15…20 cm height with the application of GG1 and GG2, where 1.9 times higher value can be measured than the inner shear resistance of uncompacted but identical geogrid-reinforced railway ballast.

Based on the results above further observations are made:

− The separation of ballast and protective-reinforcing layer or the material of substructure earth works, the application of geocomposite are highly recommended considering the viewpoints of adequate dewatering and draining, or in such a case the interlocking of ballast particles into the geogrid apertures must be generated (geotextile bonded on geogrid or geotextile laid on the geogrid without bonding are suitable for this purpose, but with welded geogrids (e.g. GG5) the factory geotextile geocomposite, which laid between the geogrid ribs during the welding is not suitable [1, 3, 4].

− A minimum of 23-33-cm ballast thickness is needed for ballast cleaning and tamping in railway ballast under the bottom plane of the sleeper, so this technological limit must be considered when planning.

− The application of GG3 geogrid is recommended with railway ballast.

− Principally the application of GG2, GG5 and GG6 types is recommended with 0/56 mm granular protection layers when the aim is reinforcement in the whole layer thickness, if the reinforcement in the geogrid plane is necessary, GG3 is recommended.

Conclusions

In the article the inner shear resistance of geogrids built under the railway ballast and the 0/56 mm granular protection layer were investigated with a multi-layer shear box specifically developed and manufactured for this purpose. During my examinations uncompacted and compacted railway ballast, and seven different types of geogrids in case of compacted granular protection layer were studied. Inner shear resistance of the railway ballast and the granular protective layer was determined for cases without geogrid and reinforced with different types of geogrids in compacted and uncompacted condition, moreover, reinforcing effects were described with three kinds of increasing factors at each variant.

During laboratory multi-level shear box tests a more widespread analysis of the effects of geogrids built under the railway ballast for track geometry stabilization can be improved in the future with:

− application of used railway ballast that is sharp-edged, i.e. in new condition and consisting of rounded particles,

− usage of dry, wet and oily railway ballast,

− examination of layer structures built on different substructural strength modulus bases (perhaps bonded ballast base [2, 16],

− application of different ballast thicknesses

− usage of other, different types of geogrids/geocomposites,

− tests performed under vertical load,

− perform of dynamic tests,

Further research possibilities with geogrid-reinforced layers are the following:

− examination of layer structures built on different substructural strength bases,

− usage of different layer thicknesses,

− application of several geogrids simultaneously in the layer structure (e.g. in 0 cm and 20 cm height),

− usage of different types of geogrids/geocomposites,

doi : 10.15802/stp2015/53169

- tests performed under vertical load,
- execution of dynamic tests.

Acknowledgements

The mentioned R&D work was supported by MÁV in the framework of R&D contract, for which the author and his colleagues express their thanks this way, too. Furthermore, the author and his colleagues thank Tensar International s.r.o., KŐKA Kő- és Kavicsbányászati Ltd., and Colas Északkő Ltd. for providing the necessary material for our laboratory measurements.

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ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського
національного університету залізничного транспорту, 2015, № 5 (59)

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ИССЛЕДОВАНИЕ ВНУТРЕННЕГО СОПРОТИВЛЕНИЯ СДВИГУ ГЕОРЕШЕТОК, УЛОЖЕННЫХ ПОД БАЛЛАСТНЫЙ СЛОЙ ДЛЯ ЕГО ЗАЩИТЫ

Цель. Использование соответствующих сыпучих материалов и многослойных структур на макро- и микроуровне конструкции железнодорожного пути способно стабилизировать геометрию железной дороги. Для реализации этой цели должны быть определены соответствующие характеристики применяемых материалов, в т.ч. внутреннее сопротивление сдвигу. Внутреннее сопротивление сдвигу сыпучих материалов с армированием георешеткой и без него – на разных глубинах пока не изучено. **Методика.** Автором разработан специальный лабораторный метод измерения и определения внутреннего сопротивления сдвигу зернистых материалов, который называется «многоуровневый бокс тестирования на сдвиг». Этот метод является адекватным для определения внутреннего сопротивления сдвигу (сдвигающая сила) в зависимости от глубины (расстояние от «нулевой» поверхности). Во время испытаний было рассмотрено два различных сыпучих материала: балласт (31.5/63 мм) и слой защитного материала (0/56 мм), а также семь различных типов георешеток (GG1…GG7). **Результаты.** Испытаниями, проводимыми с использованием многоуровневого бокса тестирования на сдвиг, определены значения внутреннего сопротивления сдвигу балласта, как без использования армирования, так и с использованием укрепления различными типами георешеток. Они представлены в виде функции от глубины в вертикальном направлении для уплотненного и неуплотненного состояния материала. При исследовании защитного слоя 0/56 мм рассматривались только уплотненные образцы. Установленные средние значения функции регрессии в виде кубического полинома представлены в графическом виде. Для всех вариантов получены значения коэффициентов детерминации функции регрессии $R^2>0.97$. Используя полиноминальные функции регрессии, полученные по средним значениям результатов испытаний, установлены три основных параметра в зависимости от расстояний, измеренных от георешетки, – «A», «B» и «D». **Научная новизна.** Разработанный автором многоуровневый бокс тестирования на сдвиг сертифицирован как адекватный для определения внутреннего сопротивления сдвигу армированных и неармированных сыпучих материалов, в том числе балласта и его защитного слоя. **Практическая значимость.** В статье сформулированы требования и даны рекомендации по выбору типов георешеток для усиления и защиты балласта с целью стабилизации геометрии положения рельсов, а также для случаев дегидрирования, дренирования, сепарирования и неполноты балластного слоя.

Ключевые слова: балласт; армирование георешеткой; гранулированные защитные слои; многоуровневый бокс тестирования на сдвиг; внутреннее сопротивление сдвигу

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ДОСЛІДЖЕННЯ ВНУТРІШНЬОГО ОПОРУ ЗСУВУ ГЕОРЕШІТОК, ЯКІ ВКЛАДЕНІ ПІД БАЛАСТНИЙ ШАР ДЛЯ ЙОГО ЗАХИСТУ

Мета. Використання відповідних сипучих матеріалів і багатошарових структур на макро- та мікрорівні конструкції залізничної колії здатне стабілізувати геометрію залізниці. Для реалізації цієї мети повинні бути визначені відповідні характеристики матеріалів, що використовуються, у т.ч. внутрішній опір зсуву. Внутрішній опір зсуву сипучих матеріалів із армуванням георешіткою та без нього – на різних глибинах поки що не вивчено. **Методика.** Автором розроблено спеціальний лабораторний метод вимірювання та

doi : 10.15802/stp2015/53169

визначення внутрішнього опору зсуву зернистих матеріалів, який має назву «багаторівневий бокс тестування на зсув». Цей метод є адекватним для визначення внутрішнього опору зсуву (сила зсуву) в залежності від глибини (відстань від «нульової» поверхні). Під час випробувань було розглянуто два різних сипучих матеріали: баласт (31.5/63 мм) і шар захисного матеріалу (0/56 мм), а також сім різних типів георешіток (GG1…GG7). **Результати.** В результаті випробувань, які проводились із використанням багаторівневого боксу тестування на зсув, встановлені значення внутрішнього опору зсуву баласту, як без застосування армування, так і з використанням укріплення різними типами георешіток. Вони представлені у вигляді функції від глибини у вертикальному напрямку для ущільненого та неущільненого стану речовини. При дослідженні захисного шару 0/56 мм були розглянуті тільки ущільнені зразки. Середні значення функції регресії у вигляді кубічного поліному, що були визначені, представлені в графічному вигляді. Для всіх варіантів були отримані значення коефіцієнтів детермінації функції регресії $R^2 > 0.97$. Використовуючи поліномінальні функції регресії, що отримано за середніми значеннями результатів випробувань, встановлені три основні параметри відносно відстані від георешітки, – «A», «B» і «D». **Наукова новизна.** Багаторівневий бокс тестування на зсув, що був розроблений автором, сертифікований як адекватний для визначення внутрішнього опору зсуву армованих і неармованих сипучих матеріалів, у тому числі баласту та його захисного шару. **Практична значимість.** У статті сформульовані вимоги та надані рекомендації щодо вибору типів георешіток для посилення й захисту баласту з метою стабілізації геометрії положення рейок, а також стосовно випадків дегідрування, дренування, сепарування та неповноти баластного шару.

Ключові слова: баласт; армування георешіткою; гранульовані захисні шари; багаторівневий бокс тестування на зсув; внутрішній опір зсуву

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doi : 10.15802/stp2015/53169

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Received: Aug. 12, 2015
Accepted: Oct. 13, 2015

doi : 10.15802/stp2015/53169