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# Behavior of geogrid reinforced ballast in triaxial shear strength tests

## La géogrille renforcé de ballast comportement en cisaillement triaxial des tests de résistance

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**ABSTRACT:** This paper studies the effects of reinforcement on strength improvement of geosynthetic-reinforced ballast through triaxial compression tests. The effects of geosynthetic layers on the compression strength of samples as well as the stress-strain behavior were investigated. The laboratory experiments were made, which were used to evaluate the effect of the confining pressure on the friction resistance of railway ballast, reinforced by geogrid. The researches has been studied in a series of monotonic triaxial shearing tests using a large-scale triaxial apparatus. Although several researchers have investigated the crushed stone that was reinforced by geosynthetics the behavior of several geogrid layers in ballast needs to be clarified. The effectiveness of the reinforcement is more significant at low confining pressure.

**RÉSUMÉ:** Cet article étudie les effets du renforcement sur l'amélioration de la résistance du ballast renforcé géosynthétiquement par des essais de compression triaxiale. Les effets des couches géosynthétiques sur la force de compression des échantillons ainsi que sur le comportement contrainte-déformation ont été étudiés. Les expériences en laboratoire ont été réalisées, qui ont été utilisées pour évaluer l'effet de la pression de confinement sur la résistance au frottement du ballast de la voie, renforcée par des géogrilles. Les recherches ont été étudiées dans une série d'essais triaxiaux monotones utilisant un appareil triaxial à grande échelle. Bien que plusieurs chercheurs aient étudié la pierre concassée qui a été renforcée par des géosynthétiques, le comportement de plusieurs couches de géogrilles dans le ballast doit être clarifié. L'efficacité du renfort est plus significative à basse pression de confinement.

**Keywords:** Ballast; geogrid; triaxial; railway

## 1 INTRODUCTION

The analysis of the conducted ballast material researches shows the increasingly important role of accurate strength and deformation characteristics materials determination under conditions of three-axis compression. These parameters are used in a number of modern application software packages for calculating and modeling substructure behavior as input data (Liu et al., 2015, Ngamkhanong et al., 2017).

A more accurate account of these parameters at the design stage, which were obtained with the modeling of the required operating conditions, will allow to predict the long - term behavior of the railway track, to develop reasonable requirements for the characteristics of the initial materials and to determine procedures to improve the reliability of the track as a whole.

Large-scale modeling of ballast behavior was carried out at different confining pressure. The use of a three-axis compression device is one of the most common methods of laboratory studies of strength and deformation characteristics of soils (De Bono, 2018, Ishikawa et al., 2016,Quian et al., 2015). Despite its wide acceptance as the main method in laboratory soil studies, it is almost impossible to carry out shear tests on a ballast specimen in a conventional triaxial compression device, due to the large grain size.

According to Russian standards, ballast particles can have a maximum size of up to 63.0 mm, while the diameters of usual samples for triaxial tests are 40-60 mm.

Therefore, the maximum diameter of the ballast particles is reduced for testing on conventional three-axis devices or a large test apparatus are used.

Many researchers point out that the ballast strength and deformation characteristics depends on the particle size (Brown et al., 2007, Indraratna et al., 2013). Due to the ballast particle size forced reduction in a conventional three-axis compression devices, the obtained strength and deformation characteristics may be inaccurate.

The large-scale three-dimensional ballast tests were carried out with natural particle size distribution to overcome this problem.

## 2 TRIAXIAL TEST DEVICE

The STX-600 system and its accessories allow to carry out at a high technical level studies of physical and mechanical properties of ballast prism materials with maximum imitation of real operating conditions.

Large-scale triaxial apparatus takes into account the heterogeneity of the sample material (ballast) by using a sample with a diameter of 300 mm and a height of 700 mm.. with a maximum particle size of up to 63mm.

The main elements of the device are:

- cylindrical chamber
- axial loading device,
- chamber pressure control unit
- chamber pressure measurement system,
- devices for measuring axial and volumetric strain

The pressure control system in the stabilometer chamber prevents its change during the test.

## 3 BALLAST MATERIAL AND GEOGRID

Magmatic and sedimentary rocks are used as a source of ballast materials in various countries because they tend to have high hardness and compressive strength and resistance to weathering.

The tested ballast in this study is a sharp angular coarse particles of volcanic granites crushing. The grain size distribution of fresh ballast is shown in figure 1. The selected particle size distribution, which are used in laboratory tests, is typical for Railways of JSC "Russian Railways".

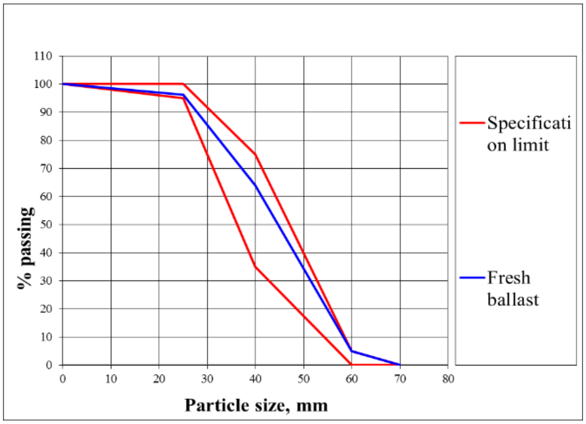

*Figure 1. Particle size distribution of tested ballast*

Tensar type SS30 geogrid with rectangular apertures was used to stabilize the ballast.

## 4 PREPARATION OF BALLAST SPECIMENS AND TEST PROCEDURE

The lower plate is installed on the base of the stabilometer using a portal crane.

The LVDT sensors are connected to PC to control the axial and volumetric deformation, the sealing is installed and lubricated with silicone grease into the groove of the bottom plate. The membrane is put on the lower plate and fixed on it with the help of clamps (Fig 2).

A detachable mold is assembled and installed on the base plate by means of tension bands and pins. The membrane was evenly stretched on the top of the temporary steel mold and was bended on it. A vacuum tube was connected to the channel of the base for a tight fit of the membrane to the walls of the mold.

The ballast was carefully sifted using standard sieves, and then different particle size proportions were mixed together according to the selected particle size distribution. The mixed ballast was then placed inside the rubber membrane and compacted by hand rammer into five layers, each approximately 130 mm thick. The bulk unit weights of the samples were 15.4-15.8 kN/m3, according the typical ballast density in the field.

The upper plate was placed on the sample with the help of a crane and 2 eyebolts, a membrane was put on it and fixed with a clamps. After connecting the necessary hoses, a vacuum was applied to the sample and kept until the readings stabilized for 5 minutes. The mold is disassembled and removed from the bottom plate. The sample retains its shape under the action of vacuum.

A built-in device for measuring lateral (diametral) deformations and embedded LVDN sensors are installed on the sample.

The stabilometer dome and its cover with a loading rod are installed using a portal crane and slings. The stabilometer was installed in the working position on the table of the power frame by means of an air cushion under the base (figure 3).

A pre-comprehensive pressure was created in the stabilometer after filling the chamber with water, the vacuum in the sample was created to hold its shape is discharged and the sample preload was set through the vertical loading rod. The load rod was connected to the force sensor by tightening the coupling nut. Pressure sensors, LVDT and load control were connected to a PC and their readings were processed using WIN-CATS-ADV software. After this operation, the STX-600 system was ready for testing.

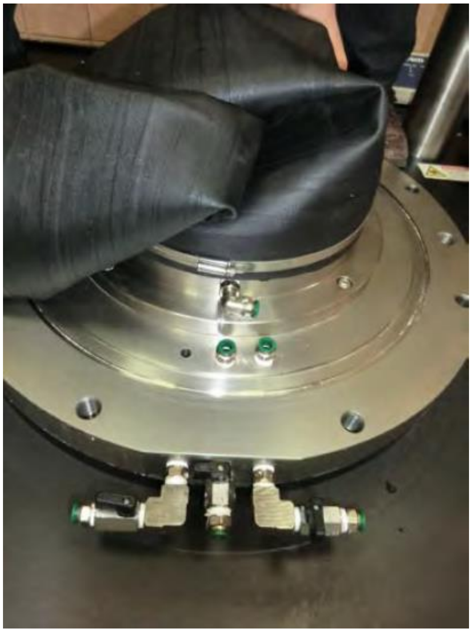

*Figure 2. Bottom plate with membrane*

*Figure 3. Triaxial shear strength test setup*

## 5 TESTING PROCEDURE

The crushed stone samples were pre-compacted with a comprehensive pressure of 20 to 80 kPa to investigate the effect of the confining pressure on the strength and deformation of the ballast.

Shear tests were carried out at a loading rate of 1 mm per second, which allowed the pressure concentration on the soil particles to dissipate completely and it was continued to a vertical deformation of about 15%.

After the test, ballast samples were sieved to separate the fine fraction and weighed.

## 6 DISCUSSION

The increase in the volume of tested ballast samples during their destruction (dilatancy) is associated with the formation of microcracks in them. When the sample is destroyed, a macroscopic plane of the cut is formed. The plane of the cut is an uneven surface, which is an alternation of micro-steps and depressions, so any movement of adjacent surfaces relative to each other leads to a decrease in the area of contact between them and an increase in dilatancy. Thus, the dilatancy of rocks during their destruction is due to two reasons: the formation of microscopic cracks and the movement of adjacent surfaces relative to each other. Crushing particals leads to an increase in the number of contacts, therefore, to the distribution and reduction of the load acting on them.

Stress-strain behavior of fresh ballast with 40 kPa confining pressure is shown at Fig.4. At lower confining pressure, smaller splash amplitude of the stress deviator were observed, which are accompanied by stress redistribution. After reinforcing, these splashes are approximately two times smaller in absolute value, which indicates the role of the geogrid in the ballast stabilization. As the reinforcement layers increase, the splashes become smaller (Figure 5).

The elastic part of the stress-strain graph is observed up to a relative vertical strain of about 0.25% for the stabilized specimen and 0.5% for the non-stabilized.

An increase in the confining pressure leads to an increase in the stress deviator with the same vertical deformations and to an increase in the peak deviator stress corresponding to the limiting state of the ballast.

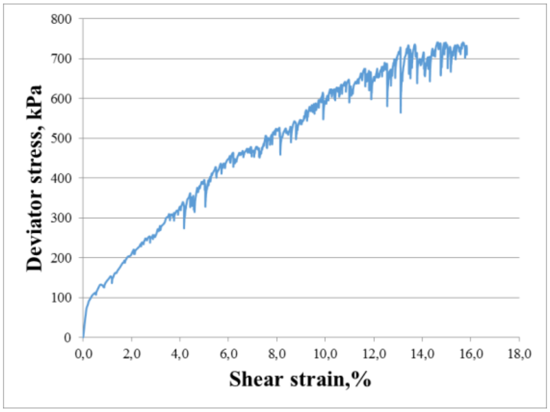

*Figure 4. Stress-strains responcse of fresh ballast*

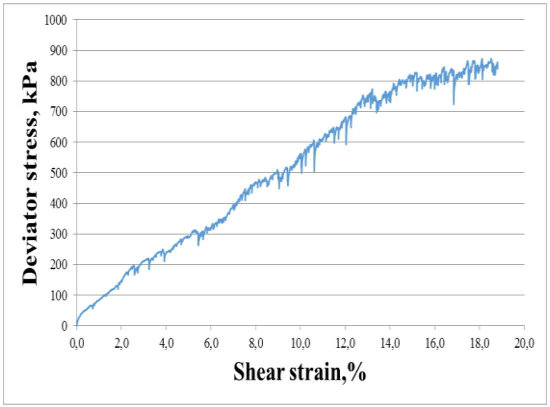

*Figure 5. Stress-strains responcse of stabilized ballast by 3 geogrid layers*

One of the objectives of the study was to determine the effective thickness of the ballast particles interlocking layer with geogrid. The researchers note that with increasing distance between the geosynthetic material layers, the ballast stabilization efficiency decreases (Ziegler, 2017). The stress-strain behavior of stabilized by geogrids ballast during a triaxial test is similar to the ballast without reinforcement, and the values of the peak deviator stress of stabilized ballast are higher. Comparison of reinforced and unreinforced ballast with the same limiting pressure is presented in Figure 6.

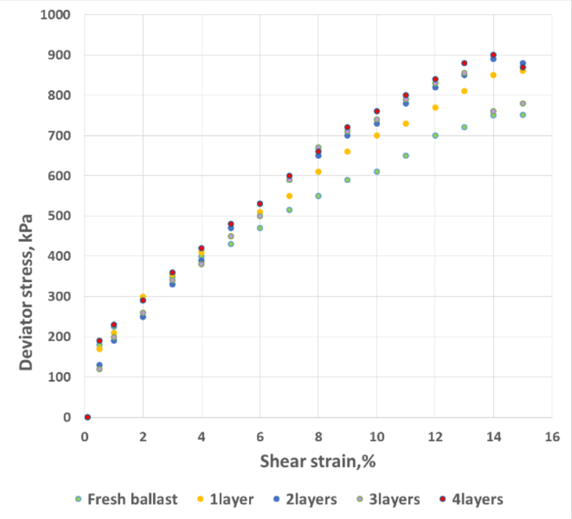

*Figure 6. Stress-strains responcse of stabilized and fresh ballast*

These results clearly show that the axial deformation decreases with increasing number of geogrid layers, reaching its maximum at three layers. Adding a fourth layer does not lead to a significant reduction in vertical deformation. It can be concluded that the effective geogrid influence zone in the ballast is 12cm. from every side.

## 7 CONCLUSIONS

This paper present results of large-scale triaxial shear strength test with geogrid stabilized ballast. The axial deformation of ballast decreases with increasing number of geogrid layers. The effective geogrid influence zone was reach at 12 cm. on both sides.

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