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Laboratory and Field Investigation of Railway Ballast, Stabilized by Geosynthetics

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Abstract. The paper presents research result of geosynthetics applications in railway structure with focus on ballast and subballast stabilization. Previous investigations have indicated the influence of geosynthetics on ballast bearing capacity and its deformation behavior, but comparison of field and laboratory results needs to be made. Also the interaction between large size aggregate particles and geosynthetics that leads to improvement track structure have not clearly indicated. In this study the monotonic triaxial shear strength test and in field investigations under axial load were conducted on both the ballast and ballast that was stabilized by geosynthetics

Keywords. Railway, geogrid, ballast.

1. Introduction

The intensity and magnitude of residual deformations of the ballast layer and subgrade depends on many factors. These include: constant compaction of ballast and the subgrade soil due to the particle repacking under the influence of train vibration load; different loading on the ballast of nearby sleepers and from each tie in its different sections, a different combination of loads which are transmitted to the ballast layer, etc. The nature of compaction depends on the initial voidness, the grain composition and the shape of the ballast grains, on the strength and other physical and mechanical properties of the rock.

The residual deformations are accumulated in the ballast layer with an increase in the passing tonnage under dynamic effects of rolling stock, which leads to the formation of rail track various deviations from the design position in the form of one or two-sided drawdowns and distortions. It is known that the best ballast is a ballast, which works for a long time without the appearance of the listed deviations in the track structure or with the formation of them in insignificant quantity. However, any ballast works with the accumulation of residual deformations in the vertical plane for the period between repairs of the railway track.

Previous laboratory studies and numerical simulation results have highlighted the benefits of geosynthetics stabilization [1,2]. These studies, as well as field investigations [3-7] have identified the conditions of geogrid layers influence on the subgrade and cell dimensions effect on the geogrid performance. Previous studies have mostly focused on the deformation characteristics of soils, stabilized by geosynthetics. However, to determine their influence on the bearing capacity of ballast and subgrade it

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is necessary to know the substructure stress state under moving load.Many researchers point out that the ballast strength and deformation characteristics depends on the particle size [8, 9]. Due to the ballast particle size forced reduction in 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. Geosynthetics properties and their laying

The experimental study were conducted on the Oktyabrskaya railway to identify the stresses in the subgrade soils during passage of heavy trains and to assess the effect of reinforcement on the superstructure deformability. Some geosynthetics were placed on the top of subgrade on the depth of 40cm. from the sleeper bottom during the track repair (Table 1).

Table 1. Tested geosynthetics.

Material characteristics	Type 1	Type 2	Type 3	Type 4	Type 5
Structure	Geocells	Bi-oriented geogrid	Bi-oriented geogrid	Bi-oriented geogrid	Sheet
Polymer type	Polyethylene	Polypropylene	Polypropylene	Polyester	XPS
Aperture size MD/TD, mm	200/200	39/39	35/45	50/50	-
Strength at 5% strain MD/TD, kN/m		21/21	28/30	28/28	-
Peak tensile strength MD/TD, kN/m	29/29	30/30	40/40	80/80	-
Yield point elongation MD/TD,%	25/25	12	10/10	13/13	-
Compressive strength at 10% deformation, MPa	-	-	-	--	0.5
Density, kN/m^3	-	-	-	-	0.38

The ballast was cleaned to the required depth under sleeper bed with laying geogrid or XPS plates at 4 m width. Work is performed without removing the track by machines RM-80 or SCHU-800-600. Cleaned ballast was laid directly on XPS plates or on the geogrid, which is unwound from a roll assigned to the machine pit chain (Figure 1). Roll length is 30 - 50 m, the overlap of next rolls must not be less than 0.5 m.

Figure 1. Laying of geocells and two geogrid layers.

3. Substructure stress state under moving load

On the sections with geosynthetics data analysis shows that in all cases, the highest stresses level was recorded at the under rail section, and the smallest ones were at track centre. Stresses at sleeper end have an intermediate position. Vertical stresses distribution under passing trains, which is shown on Figure 2, is different for different types of geosynthetics.

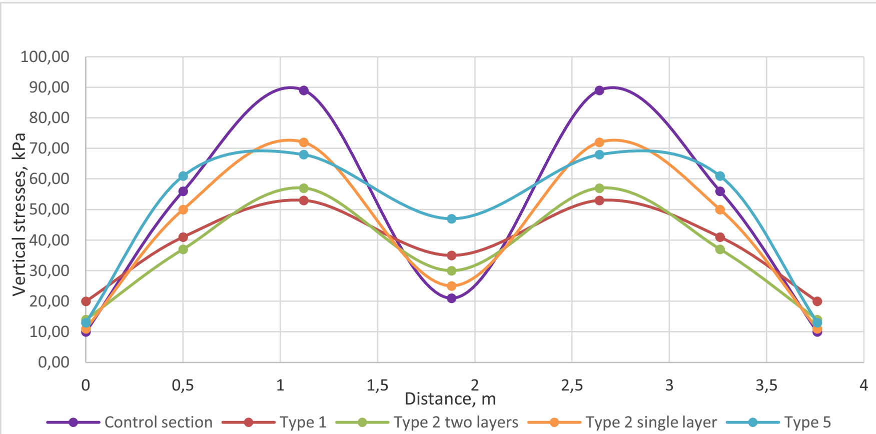


Figure 2. Vertical stresses distribution on the subballast under freight train at speed 40 km/h.

On the track section, where ballast was stabilized by Type 1 geosynthetic, vertical stresses in the under rail cross-section were reduced by 1.5 - 1.8 times. For the 50 km/h speed of freight train, the stress on control section (without reinforcement) at the under-rail section was 93 kPa, for the section with Type 1 geosynthetic the stress was 57 kPa, which is 1.6 times lower. At 60 km/h speed, these values were respectively 110 kPa and 64 kPa, which is 1.7 times lower. Similar results were obtained for 20, 30, 40 km/h train speeds. In addition, stresses lowered at sleeper end compared to the control plot, but it was not as obvious, as at the under-rail cross section. At this section stresses decreased by 10-20%. At the cross-section under track center, the vertical stresses were decreased by 1.5-1.8 times.

Geogrids stresses in under-rail cross section was reduced by 30-37% on the section with two layers of Type 2 or Type 3. In this case, stresses at sleeper end cross section were also reduced. This reduction was by 20% to 43% and the speed changing was from 20 to 60 km/h. At the same time stress values along track center increased in comparison with the control section. In this case, increase did not exceed 30 %.

One layer of Type 2, 3, 4 geogrids does not significantly reduce stresses in comparison with the control section. In this case, stresses at under rail section reduced by 5 to 25 % on average. Vertical stresses were fixed equal 72 kPa at section with one layer of Type 1 geogrid, and corresponding result at control cross section was 89 kPa, which is by 24% less. The stress values were respectively equal to 75 kPa and 74 kPa for Type 2 and 3 geogrids that is by 16% and 17% less compared with the control section with the same train speed.

Stresses decreased slightly compared to the control section at the sleeper end cross section. Stress values were up to 62 kPa under the sleeper end at section with Type 2 geogrid and 40 km/h train speed. At control section, stresses were 56 kPa, which is 10% lower. Similar dependences was observed at track center cross section.

Vertical stresses, which was caused on top of subgrade, were reduced from 89 kPa to 68 kPa (1.3 - 1.4 times) in terms of 40 km/h train speed at section with Type 5 geosynthetics. In contrast to all of the foresaid cases, vertical stress increase by 5-10% was observed at sleeper end cross section. Stresses at track center increased significantly. In this section, they were respectively equal 37 kPa, 40 kPa, 46 kPa and 48 kPa at speeds of 20, 30, 40, 50, 60 km/h, which is 2.0-2. 2 times more than at the control section.

Of course, from the point of view of subgrade stability, the best way of loading subgrade top is uniform stress distribution. However, this is impossible to achieve, but the less the difference between stresses value at under-rail cross section, at sleeper end and at track center, the more stable railway track. Stress redistribution will reduce probability of local zones formation with plastic deformations on the subgrade top, especially in the under rail section. Plastic deformation zones formation lead to defects, which may in the further lead to the strength loss and stability of subgrade. Thus, the smoother the curve of stress distribution on the top of subgrade, the better the conditions be for stable operation of railway track.

4. Stress response analyses

The laboratory of engineering-geological surveys (LIGO) is designed for the most reliable subgrade and rail track deformation characteristics determination by means of direct experiment. Special loading device, which is presented on Figure 3, creates a calibrated load on the rail track and the measuring complex fixes the rail track deformation and calculate the results.

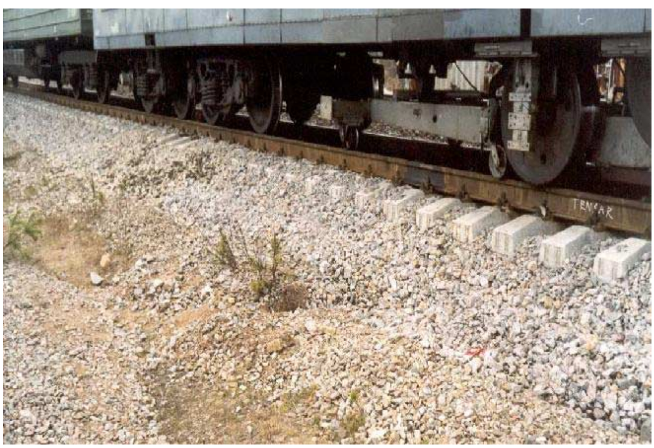
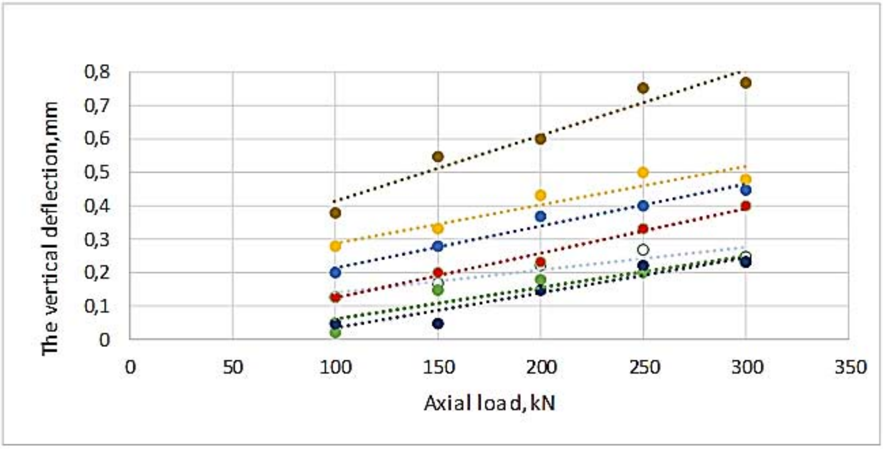


Figure 3. The laboratory of engineering-geological surveys (LIGO).

The loading of individual sections of the railway track in static mode was carried out to determine the components of elastic railway track deformation. The field and onboard measurement tools, forming part of the LIGO laboratory, were used for these purposes. The results are shown on the Figure 4.

Comparative analysis of loading results in the cross-sections with reinforced and not reinforced ballast layer allowed to obtain a correlative coefficient of ballast deformation, which is defined as the ratio of the average elastic deformation of crushed stone layer under load of 300 kN to the same value for the section with geosynthetics. The measurements characterize the initial stage, when there are stabilization processes after laying the reinforcing materials and substructure deformation parameters are changed.

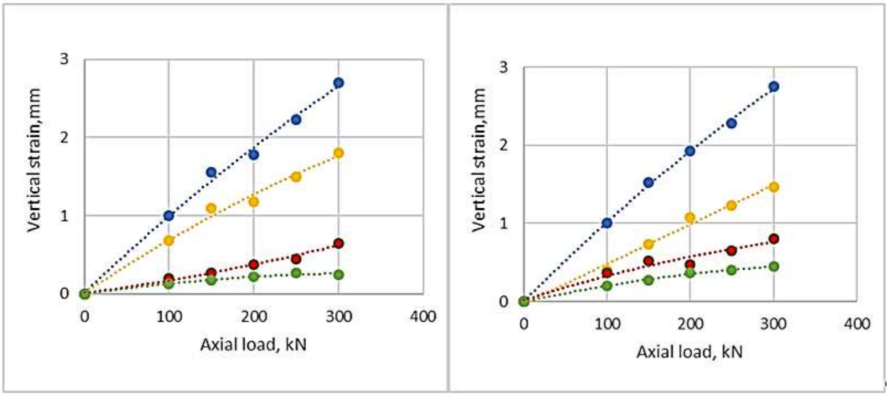


•- ballast; •- Type 5; • -Type 4; • -Type 3; •-Type 1 one layer;•-Type 1 two layers; •- Type 2 one layer.

Figure 4. Dependency of ballast vertical deflection on axis load.

The smallest deformation of the ballast layer is observed at section with double layers Type 1, and the highest deformability on a section Type 5. Received correlative coefficients of ballast deformation are in good agreement with the results of stamping tests [6].

Figure 5 shows the load test results with rail track elements deformation determination.



•- top of subgrade; •- fastening; •- rail; •- ballast

Figure 5. Dependency of vertical deflection on axis load on the section with one single layer geosystemic type 1 and non-reinforced section.

The displacement proportions of rail track elements in the total rails deformation for non-reinforced section are: for fastening 54%, for ballast 17%, for the top of subgrade 30%; for the area with single layer Type 1 for fastening 67%, for ballast 9% for the top of subgrade 24%.

The results show that the increase of ballast layer stiffness, reinforced with geogrid, leads to forces redistribution in elements of the railway track by means of increasing of fasteners deformability and reducing subgrade and ballast deformations.

As a practical implementation of field studies, it is possible to reduce the ballast layer thickness from 40 cm to 30 cm by means of laying geogrid on the top of subgrade and geotextile in the middle of this layer (Figure6). In this case, tree main problems have been solved: the stress reducing on the subgrade top, ballast contamination decrease and reducing of ballast deformability.

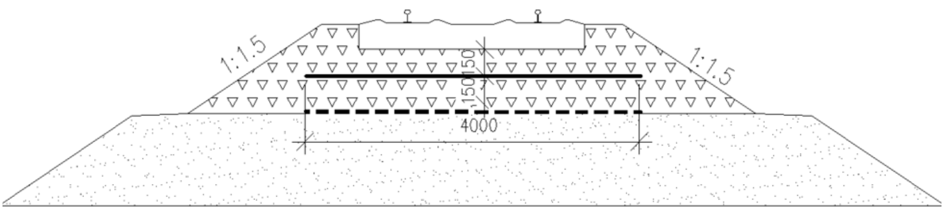


Figure 6. Ballast stabilization.

5. Tri axial test

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 (Figure 7).

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.

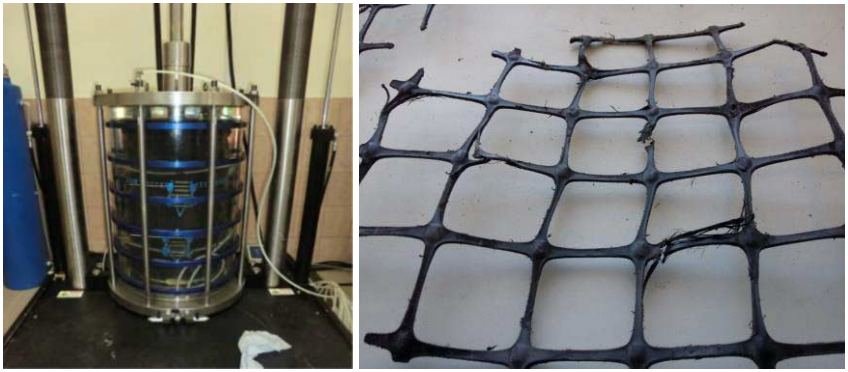


Figure 7. Triaxial shear strength test setup and geogrid after test.

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

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-convexity 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 particles leads to an increase in the number of contacts, therefore, to the distribution and reduction of the load acting on them.

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 [10].

The stress-strain behavior of ballast, stabilized by geogrids, during a triaxial test is similar to a 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 at Figure 8.

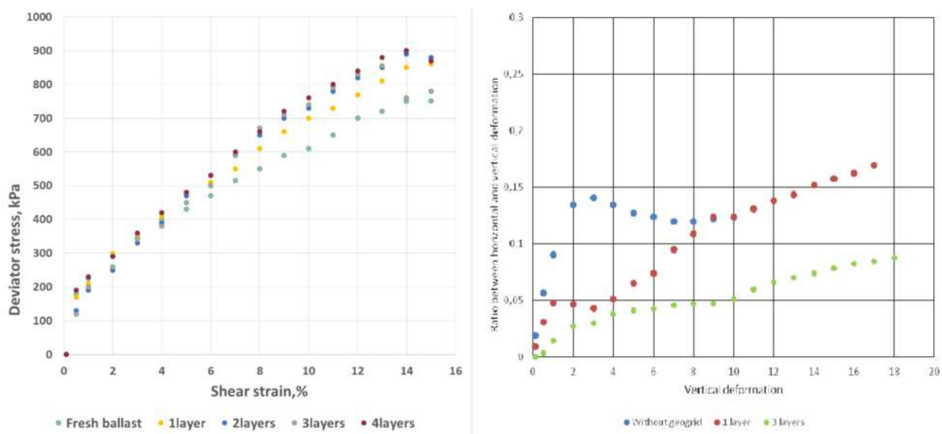


Figure 8. Stress-strains responcse of fresh ballast and the ballast stabilized ballast.

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.

Considering the sample of the geogrid after the tests (Figure 7), we see ribs integrity destructions and junctions, which are similar to fracture at break. The ultimate strain at break is 12% for the geogrid involved in testing, but the horizontal strain of the specimen at fracture is about 1% (Figure 8). Similar values of crushed stone sample horizontal deformations, which were stabilized by geogrids, were obtained in [10]. Thus, the horizontal stretching cannot cause the geogrid damage.

After a careful study of the geogrid damaged samples, it was found that the cause of the ribs and nodes destruction is the ballast particles grains vertical movement.

The geogrid prevents not only horizontal ballast deformations, but also vertical, as in the sample loading process the particles grain are rested against the geogrid nodes and ribs, which is the cause of their destruction. This circumstance may be the cause of the loading curves mismatch, obtained by calculation in mathematical modeling and in field tests.

6. Conclusions

Biaxial geogrids in ballast layer is suitable solution for increasing bearing capacity of substructure. Geocells and dual layer biaxial geogrids reinforcement are very effective for stresses redistribution on the sub ballast. The XPS plates reduce stresses on the top of subgrade and thus they demonstrate the potential performance of their usage in track. The study results allow us to recommend the geosynthetics for using as a low-cost solution to stabilize substructure.

The tests, conducted by means of load apparatus LIGO, confirm the effectiveness of geosynthetics using on the top of subgrade to reduce deformation and to improve stability of the track immediately after the renovation and for an extended period.

The stiffness of ballast, which is stabilized by geogrid, is in 1.1 – 2.6 times more than for not reinforced one.

The axial deformation of ballast decreases with increasing number of geogrid layers. The effective geogrid influence zone was reach at 12 cm. from both geogrid sides.

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