Application of geocomposite placed beneath ballast bed to improve ballast quality and track stability

Leoš Horníček¹, Petr Břešťovský¹ and Petr Jasanský²

¹ Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 7, Prague, 166 29, Czech Republic
² The Railway Infrastructure Administration, state organization, Dlazdena 7, Prague, 110 00, Czech Republic

E-mail: leos.hornicek@fsv.cvut.cz

Abstract. The article deals with the application of a stabilization hexagonal geocomposite for the improvement of poor stability of railway tracks caused by undesirable migration of fine soil particles from the subgrade into the ballast bed. The establishment of a test railway section on a single-line track situated near Domazlice and its long-term monitoring programme are described. Evaluation is aimed especially at track geometry parameters, the load-bearing capacity of the ballast bed, elastic rail deflection during train passages and the durability of geocomposite's physical properties. The data taken from the test section during five measurement campaigns are compared with both adjacent sections. In one of them, only the ballast bed renovation was carried out, whereas in the second one no intervention was performed at all. The usage of a pioneering geosynthetic product in combination with new trends in ballast bed restoration seems to be an innovative as well as effective solution to analogous problematic spots on railway tracks in the Czech Republic.

1. Introduction

Due to complex geological conditions and gradual track degradation, railway tracks in the Czech Republic with high traffic volumes suffer from the migration of fine-grained soil particles from subgrade layers into the ballast bed and from the appearance of muddy spots. The accompanying phenomenon of the above process is local reduction of the vertical track stiffness, malfunctioning ballast drainage as well as total deterioration of track geometry parameters, and often also reduced load-bearing capacity of the track formation. This situation successively requires either frequent operative repairs (ballast cleaning and tamping) or a single, costly and extensive intervention into the whole roadway. The standard procedure consisting in repairing mud spots by cleaning the ballast bed, adding missing aggregates into the ballast bed and rail tamping, however, usually does not lead to the solution of this problem, but, on the contrary, to its periodic repetition.

An alternative, longer-term solution to the above issue without the necessity of an extensive and costly intervention into the track bed is the application of suitable geogrids or geocomposites placed underneath the ballast bed or in its bottom part, based on the knowledge of the interaction of geosynthetics with granular material [1]. Efficient interlocking of the geocomposite with ballast aggregates leads to the limitation of the horizontal movement of aggregate grains around the geogrid and reduction of permanent vertical deformations of the ballast, which is favourably manifested by
increased stability of track geometry parameters, less frequent maintenance cycles and extended service life of aggregates, or reduced degradation of aggregate grains due to frequent tamping [2]. Separation or filtration geotextiles, which are part of the geocomposite, prevent the migration of fine-grained soil particles into the ballast allowing, simultaneously, water passage in both directions to enable functioning ballast drainage in the long-term. In the case of a properly taken measure, economies in material, maintenance costs and costs of traffic limitations can be reached [3].

An efficient interconnection of the geogrid and granular aggregate material via interlocking leads to mechanical stabilization of aggregates within the reinforced zone, which results in the reduction of lateral movements of aggregates and increased stiffness of the layer. In practical terms, it is necessary to place the geosynthetic in a proper depth to secure it from damage during machinery-based maintenance, even though its placement closer to the sleeper would be more efficient [4]. The effective combination of the geogrid aperture size and the aggregate grading is also very important [5].

2. Operational verification in the Czech Republic

The ballast bed stabilization with geogrids and geocomposites in the Czech Republic has been verified since 2008 [6]. Based on a stimulus from the Centre for Effective and Sustainable Transport Infrastructure (CESTI), the Czech Railway Infrastructure Administration, state enterprise, approved the extension of the operational verification, including a combination of a new type of geosynthetic and transversally inclined track formation for efficient drainage of the ballast bed.

The verified technology applies a progressive type of geosynthetic product, which is inserted between the ballast and subballast layer, or directly on the subgrade, e.g. as part of a planned ballast replacement or repair. The inserted geosynthetic – in this case a geocomposite composed of a monolithic hexagonal geogrid and a separation geotextile – should fulfil two objectives at once. One of them is to stabilize the ballast by interlocking aggregate grains with the geogrid, which limits the pushing out of ballast bed grains in the transverse direction, reduces the vertical deformation of the ballast and extends the intervals between track geometrical position adjustments. The second objective is to prevent the penetration of fine-grained soil particles from the subgrade into the ballast bed, which protects the ballast bed from undesirable contamination reducing its ability of draining water from the ballast as well as friction between individual aggregate grains.

3. Description and establishment of a test section

3.1. Test section description

The position of the test section was selected on a non-electrified, single-line track national railway line Plzeň-Jižní předměstí – Česká Kubice in the section of Domažlice-město – Havlovice. Mud spots had been found within the selected section on a long-term basis, which, however, was visibly manifested in 2014 (Figure 1).
At the same time, the quality of key track parameters, i.e. track alignment and longitudinal rail height, had significantly deteriorated between 2012 and 2015. An important precondition for choosing this section was the fact that ballast cleaning and renovation ca 30 years after its placement had been planned in this section.

The test section is situated in a straight line, with a gradient of ca 9 ‰, passing over an at-grade crossing. The line speed limit in this section is 90 km/h, a standard gauge of 1435 mm and the line is serviced by mixed traffic. The substructure does not contain any structural layers, therefore, underneath the ballast bed there is just subgrade, consisting of frost-susceptible impermeable soil.

The monitored track section is subdivided into three immediately adjoining subsections. Stabilization geocomposite was placed in a subsection 95 m in length (km 169.850-169.945). This subsection is adjoined on one side by subsection No. 1, 100 m in length (km 169.750-169.850), in which a new ballast bed was installed and tamped. On the other side, it is adjoined by subsection No. 3, 100 m in length (km 169.945-170.045), where no intervention was made, and which, therefore, serves as a reference section.

3.2. Test section establishment

The geocomposite was placed in the test section in June 2015 during ballast replacement using the conventional method of track renewal. In the test section, the track panels were first lifted by means of a truck crane, the remaining ballast bed was extracted down to the track formation level (forming, at the same time, the subgrade) and this subgrade was treated to produce a one-sided gradient of min. 3 % towards the longitudinal ditch.

Two rolls of stabilization geocomposite, 3.8 m wide, with a mutual longitudinal overlap of 50 cm were unrolled onto non-compacted subgrade. The TENSAR TriaX TX190L-GN geocomposite, which complies with the ETA 12/0531 certificate, was chosen. It is composed of a monolithic hexagonal geogrid and non-woven geotextile, both components being mutually interconnected. The geocomposite serves both for the ballast stabilization due to the interlocking of aggregate grains with geogrid apertures (geogrid aperture size corresponds to the ballast aggregate grading of 31.5/63) and for avoiding the migration of fine-grained soil particles from the subgrade into the ballast (low geotextile effective aperture size corresponds to this). The geogrid of polypropylene has a hexagon pitch of 120 mm, an isotropic stiffness ratio of 0.75 and radial stiffness at 0.5% elongation of 540 kN.m⁻¹. The effective aperture size of the non-woven polypropylene geotextile is 95 μm.

The geocomposite was placed centrically to the rail axis. A ballast layer of new coarse crushed aggregates with a grading of 31.5/63 in a min. thickness of 35 cm underneath the rail seat was successively laid (Figure 2).

![Figure 2. Ballast bed placement on stabilization geocomposite.](image-url)
The aggregates were brought by lorry and spread by wheel loaders using a so-called cascade method when the aggregates must first be spread in front of the loader in a thickness of min. 15 cm and only then can a machine move over them. The track panels were successively put back, welded and the track position was adjusted into the desired condition by a tamping machine.

4. Test section monitoring
First, initiation measurement was performed on the original state of the construction in June 2015, and, successively, after the geocomposite placement underneath the ballast bed, the 2.5-year monitoring programme was launched, including:

- periodic checking of track geometry parameters by a track geometry car,
- measurement of the load-bearing capacity of the ballast bed and the track bed by means of static and impact plate load tests,
- checks of the degradation rate of geocomposite’s utility properties via laboratory testing of geocomposite specimens sampled from trial holes,
- visual checks of the environment at the placed geocomposite level,
- measurement of rail deflection during the passage of trains,
- levelling of the rail string height.

4.1. Measurements performed in 2015 and 2016
Three measurement campaigns were carried out in the test section and both adjoining sections in 2015. The first of them (06/2015) took place on the original state of the roadway immediately before the start of repairs. This campaign covered the measurement of rail deflection during the passage of trains in 4 cross sections, 2 of which were situated in the test section and the remaining 2 in both adjoining sections. Besides, the running plane was levelled and soil specimens were sampled from trial holes made between sleepers. The second measurement campaign (06/2015) was a component part of the test section establishment. Static plate load tests in profiles showing the greatest problems with the track geometry parameters were performed on the modified track formation in the rail axis. Furthermore, impact plate load tests were performed in the rail axis with a spacing of 10 m and at a distance of 0.80 m in both directions. Soil specimens were sampled from the track formation to carry out index laboratory tests. The third measurement campaign (09/2015) took place immediately after the last necessary rail machine tamping. This campaign, as well as all successive measurement campaigns, included rail deflection measurement during the passage of trains in 4 cross sections identical to those used in the first campaign, running plane levelling in 5 cross sections 50 m apart and in the middle of the railway crossing, and impact plate load tests at the rail seat level near the rail string in 15 profiles 10 m apart from each other.

In 2016, two measurement campaigns followed, performed in spring and autumn (04/2016, 11/2016), i.e. at the time when the load-bearing capacity of the subgrade is usually lower. Both campaigns included 4 static plate load tests at the rail seat level in the test section as well as both adjoining sections. As they were performed in the rail axis, railway traffic on the respective rail had to be interrupted for the necessary time. In the fifth measurement campaign, the first sampling of two geocomposite specimens from the space between sleepers in the rail axis took place (Figure 3). The samples were successively sent to the geocomposite manufacturer’s laboratory to detect changes in its mechanical properties from the time of placement.

5. Evaluation of results
The test section, as well as both adjoining sections, are regularly monitored in terms of the development of track geometry parameters. In view of the type of track, this happens twice a year, as part of the spring and autumn measurement campaign carried out by the track geometry car’s travels. The results achieved in the form of charts (continuous time patterns of measured parameters) and section evaluations (numerical evaluation of track sections using so-called quality parameters –
mathematical recalculation of standard deviations of monitored parameters) represent an important source of data. The results of monitored geometric parameters (particularly alignment and height deviations) and their development over time allow assessing the stability and long-term behaviour of the track bed construction.

Figure 3. Excavated geocomposite specimen.

An important aspect for a serious evaluation of the development of track geometry parameters in the monitored sections was also the assessment of the development of these parameters in the period preceding the stabilization geosynthetic’s installation. Figure 4 displays the comparison of charts from the track geometry car immediately before the test section’s establishment and ca one year after its establishment. Individual monitored subsections are marked in the figure (section 1 – section with a new ballast bed; section 2 – section with a geocomposite; section 3 – section without any intervention).

The time pattern of parameters from measurement 1/2015 (June) clearly shows that it was a track section complying with operating conditions in terms of observing the track geometry parameter limits. There are no evident spots where the maximum allowable limits were exceeded, but, in a detailed analysis of mainly vertical type parameters, it cannot be labelled as optimum and because of the development of quality parameters, the section required maintenance interventions.

The lower part of Figure 4 shows the course of measurement 1/2016 (May) performed nearly one year later after the geocomposite placement. There is an evident improvement in the course of individual parameters. In the longitudinal height time pattern (labelled VL and VP in the right part of the charts), the occurrence of more significant deviations at interfaces between the monitored sections can be observed. This phenomenon can be attributed to differences in the building interventions and the composition of the track bed construction. The subject of further monitoring, including the overall assessment of the development of track geometry parameters in relation to the other monitored variables in individual sections, is whether these deviations will gradually consolidate or will further develop under operating conditions.

The results of static plate load tests (Table 1) imply that the average load-bearing capacity identified in the rail axis at the rail seat in the test section fitted with a geocomposite was 55.1 MPa in spring and 76.9 MPa in autumn. In adjoining sections, the average values identified were 31.8 MPa, or 34.5 MPa respectively. Thus, a significantly higher load-bearing capacity was measured in the test section, which, moreover, further grew by ca 40 % between both measurement campaigns. A more detailed analysis of the results from the adjoining sections reveals that the load-bearing capacity value in subsection 3 (km 169.960) has remained practically unchanged, while in subsection 1 (km 169.830) the load-bearing capacity has increased by 19.1 %. This difference is caused by the on-going consolidation of cleaned ballast in subsection 1.
Figure 4. Comparison of track geometry measurements before and after test section’s establishment.

Table 1. Results of static plate load tests.

| Stationing [km] | E₂ [MPa] 04/2016 | E₂ [MPa] 11/2016 | Change [MPa] | Change [%] |
|-----------------|-------------------|-------------------|--------------|------------|
| 169.830         | 25.0              | 29.7              | 4.8          | 19.1       |
| 169.860         | 51.9              | 76.1              | 24.1         | 46.5       |
| 169.910         | 58.3              | 77.8              | 19.5         | 33.4       |
| 169.960         | 38.7              | 39.2              | 0.6          | 1.4        |

Figure 5 displays the development of the impact modulus of deformation detected during three successive measurement campaigns at the rail seat level near the left rail string. The results imply that the average load-bearing capacity in the section fitted with a geocomposite (41.3 MPa to 44.0 MPa) was higher in all campaigns than in the adjoining sections without a geocomposite (25.8 MPa to 27.2 MPa). The chart also clearly shows a significant change in the load-bearing capacity at the interface of the test section and subsection 1 (km 169.840 vs. km 169.850).
Table 2 presents the average values of the rail string deflection during the passage of trains, identified in 4 characteristic profiles. The measurement took place in spaces between sleepers, on the right rail string for the reason of better access and higher safety during the measurement. The highest values detected after the passage of all trains within an integral time interval lasting always no less than 4 hours in both directions were included in the evaluation.

The results imply that after the geocomposite placement, or after ballast cleaning and successive tamping, a significant reduction in the average deflection in the respective profiles occurred. Since then, the deflection values in profile 1, which falls in subsection 1, have shown a rising trend, while the values in both profiles of the test section have remained at roughly the same level. A significantly lower average speed of trains in the second line of the table is related to the reduction of the line speed limit in the monitored section during the time of ballast consolidation, i.e. until the time shortly after the last tamping.

The continuous measurement of the rail string height by means of levelling allows stating that the ballast bed consolidation process is gradually coming to an end. Whereas the average rail deflection in the test section with the geocomposite measured between the measurement campaigns of September 2015 and April 2016 was 7.2 mm, the difference between April 2016 and November 2016 accounted for only 1.6 mm. Trial holes allowed visual checks of the state of geocomposite placement. It was
found in undamaged condition and no penetration of fine-grained soil from the subgrade into the ballast had been detected.

6. Conclusion
Based on the measurements performed in the monitored section to-date, the findings obtained are as follows:

- The geocomposite was successfully fitted under the ballast, or on the transversally inclined track formation. This allows efficient ballast drainage.
- The geocomposite prevented undesirable migration of fine-grained soil particles from the subgrade into the ballast.
- A significant improvement of key track geometry parameters was detected in the section with the geocomposite, deviations are evident at interfaces of sections with a different composition of the construction.
- The load-bearing capacity at the rail seat level identified in both the static and impact plate load test was significantly higher in the test section than in both adjoining subsections.
- A drop and homogenization of rail deflection values during train passages was identified in the section fitted with the geocomposite, which is accompanied by enhanced riding comfort and lower wear of the component parts of the permanent way and substructure.

The monitoring campaign of the section will continue at least by the end of 2017, and a complex evaluation of the efficiency and contributions of the used technology, including its effects on track geometry parameters, will be subsequently made.

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