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DOI: 10.35117/A_ENG_22_08_09_05

Protection of under ballast mats against damage Due to loads from railroad tracks

Abstract: The paper presents the application of geogrids with uniform radial stiffness in subgrade structures in the function of protecting under ballast mats from damage caused by the railroad superstructure. The importance of the stabilizing function as a key mechanism of cooperation between geogrid and aggregate was pointed out, affecting the increase of subgrade bearing capacity, extension of ballast life and ensuring the required operating parameters of the ballast placed on anti-vibration mats.

Keywords: Mechanical stabilization; Hexagonal geogrids; Under ballast mats; Railway trackbed

Introduction

The use of under ballast mats is becoming more and more common. There are mats available on the market made of polyurethane, mineral wool, and rubber granulate combined with a polyurethane binder. Manufacturers declare for their products effective damping of vibrations, low coefficient of dynamic stiffness, as well as increasing the durability of the surface. However, the declared advantages are closely related to the type of railroad construction. While in the case of under-slab mats there are no critical factors that may lead to damage to the mats in a short time, sub-ballast mats used in ballasted surfaces are subject to the destructive impact of the crushed stone placed on their surface.

In many research centers, works are carried out aimed at evaluating the durability of sub-ballast mats used in the construction of railway superstructures. The results of durability tests under ballast mats used in North America are presented in [8]. At the same time, research is being carried out to assess the possibility of using geosynthetics in the function of protecting sub-ballast mats against damage caused by contact with sharp edges of the ballast, which undergoes displacement as a result of loads from train traffic.

The use of geogrids in the stabilization function to protect sub-ballast mats

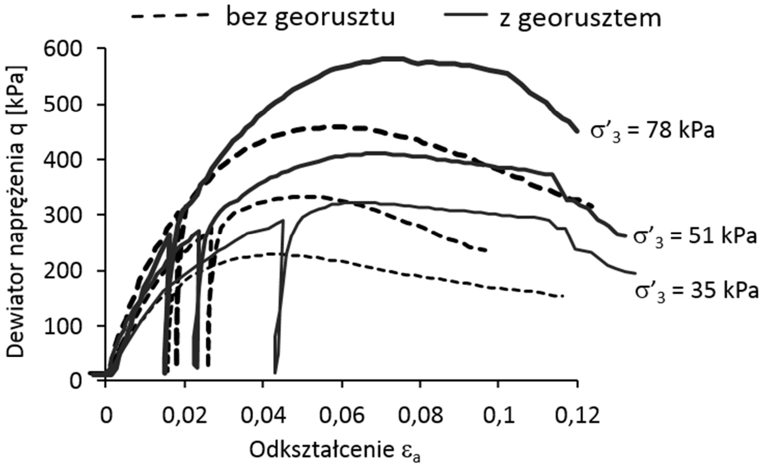
The use of geosynthetics in construction is currently common, mainly due to the significant benefits that result from the use of these materials. A wide spectrum of applications includes the following functions: drainage, filtration, anti-erosion, reinforcement, and stabilization. The stabilization function, defined in the EOTA (European Organization for Technical Approvals) report [4], means the improvement of aggregate strength parameters by limiting displacements under load [5]. The stabilization function has also been recognized by ISO (International Organization for Standardization) as one of the distinct functions of geosynthetics. The definition of stabilization with geosynthetics was introduced in the PN-EN ISO 10318 standard [10].

Due to the interlocking of the aggregate grains in the meshes of the geogrid and the wedging of subsequent grains in the constrained layer of interlocking grains, the increased load resistance is achieved and the displacement of the crushed stone layer subjected to cyclical dynamic loads from train traffic is limited. In the case of railway trackbeds, the use of geogrids with rigid nodes and uniform radial stiffness, often called hexagonal geogrids, is of particular importance in improving the load-bearing capacity of weak subsoil layers, increasing durability and limiting deformation of ballast layers, and ensuring proper performance of ballast topping placed on under ballast mats.

Aggregate stabilization with geogrid

The combination of geogrid and aggregate creates a mechanically stabilized composite layer with significantly better properties and greater load-carrying capacity compared to the aggregate layer alone.

The mechanism of cooperation of both materials was analyzed by Lees and Clausen [7] in triaxial studies, in a specially designed and built apparatus with a diameter of 50 cm and a height of 100 cm. Thanks to such dimensions, it was possible to use crushed stone in the tests, the granularity index of which was Cu=23, reliable diameters d60=8mm and d_{100}=40 mm, and the degree of compaction $I_D \geq 0{,}95$. The tests were carried out both for the aggregate itself as well as for the aggregate and triaxial geogrid placed in the middle of the sample height. The diagrams of the stress deviator q versus the mean axial strain ε_a presented in Figure **1** show the increased maximum shear strength in soil stabilized with a geogrid for each of the three values of the applied compressive stress.

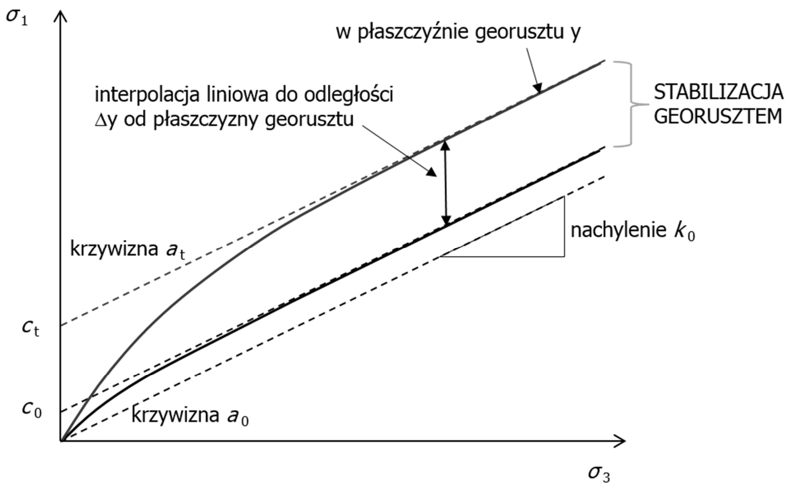


1. Mechanical stabilization effect
Source: [7]

The increase in the shear strength of the sample stabilized with geogrid results from the reduction of displacements and rotations of the aggregate grains. It is also worth noting the higher value of deformation of the stabilized aggregate, at which destruction occurs. The shearing of the aggregate-only sample occurred at approximately 4-5% strain, while a significant reduction in the shear strength of the geogrid-stabilized sample was noted at approximately 10% strain.

Since the maximum limit of aggregate displacement occurs directly in the geogrid arrangement plane and decreases with the distance from this plane, it was assumed that the failure envelope changes linearly from the maximum value in the geogrid plane to the minimum value at the distance Δy, where the destruction area is assumed as for the aggregate without stabilization (Fig. **2**).

As a result of the conducted research, Lees and Clausen developed a linearly elastic, perfectly plastic constitutive model of the geocomposite (aggregate + geogrid) used in FEM numerical analyzes in the Plaxis 2D 2018 program. The reliability of the model and the accuracy of determining the failure stresses were confirmed in the back analysis.



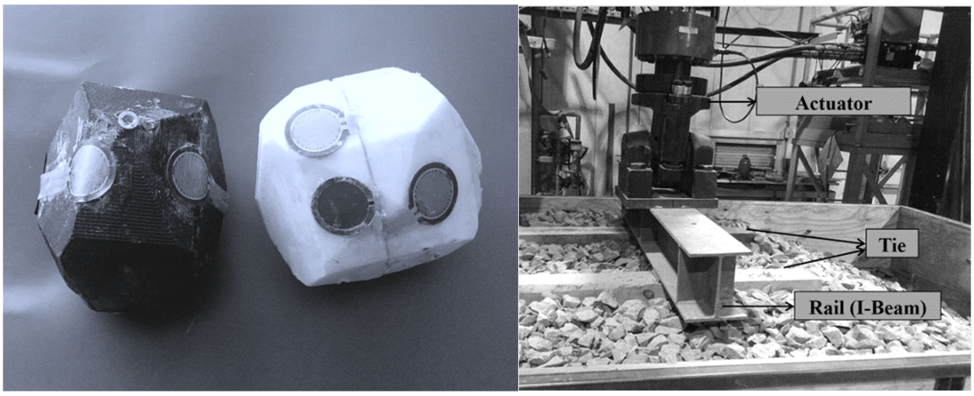
2. Envelope of failure of the aggregate stabilized with a hexagonal geogrid
Source: [7]

Research on the impact of geogrid on the aggregate properties in the railway trackbed

A research program was carried out at the University of Pennsylvania in the USA, aimed at determining the impact of geogrids on the aggregate in ballast surfaces [9]. On the model stand, the impact of cyclical dynamic loads from the passage of trains on the behavior of the aggregate without stabilization and with stabilization using a biaxial and hexagonal geogrid, placed 25 cm below the upper layer of the ballast bed, was tested.

To monitor the movement of aggregate grains, "SmartRock" (Fig. **3**) was used - lumps of aggregate formed by 3D printing, equipped with wireless sensors recording the position, rotation, and displacement of the element in space. The measured parameters were recorded with a frequency of 500 Hz.

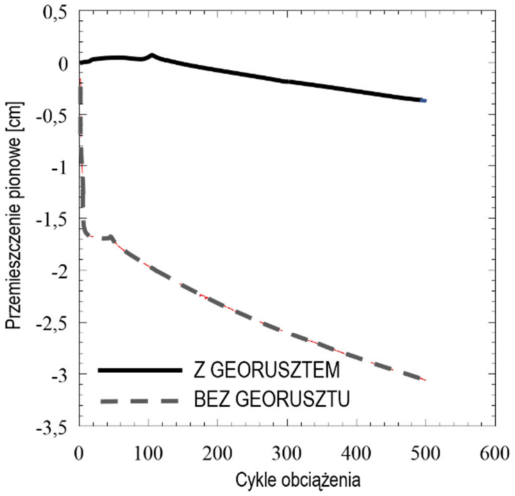
"SmartRock" was installed on a test stand in a structure simulating a railway superstructure. The structure consisting of a layer of 25 cm thick crushed stone was loaded cyclically with a frequency of 1 Hz. The tests were carried out on the control section - without the geogrid and the section reinforced with hexagonal geogrid. The geogrid was placed at the bottom of the aggregate layer, and the SmartRock at the level of 10 cm above the geogrid.



3. "SmartRock" research (SmartRock lumps on the left, research station on the right)
Source: [9]

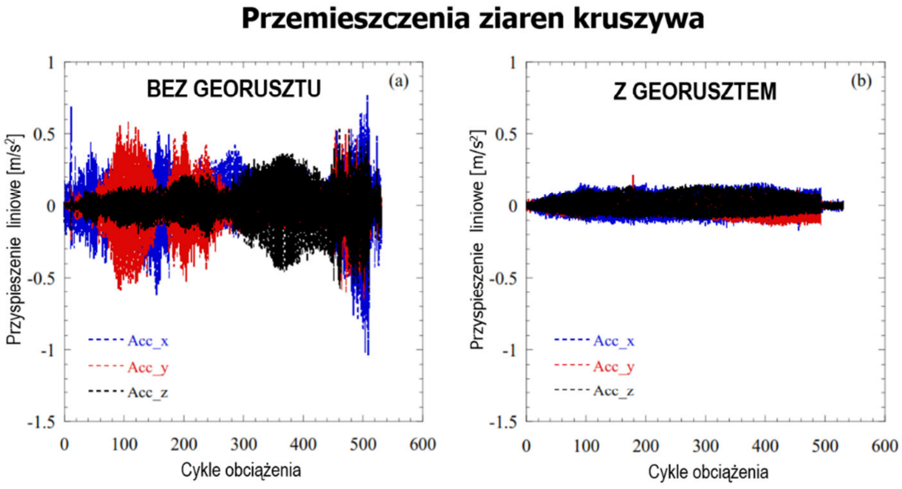
Figure **4** shows the vertical displacement of the top layer of ballast depending on the number of load cycles. In both tests, the displacement increased with the number of load cycles, however, for the test without the geogrid, the amount of vertical displacement increased rapidly in the first 10 load cycles, with a maximum measured displacement of 30 mm. In the case of the test with the geogrid, the increase in the amount of settlement was slower, and the maximum displacement was 4 mm, and after 500 load cycles it was 85% lower than the displacement measured in the test without the geogrid.

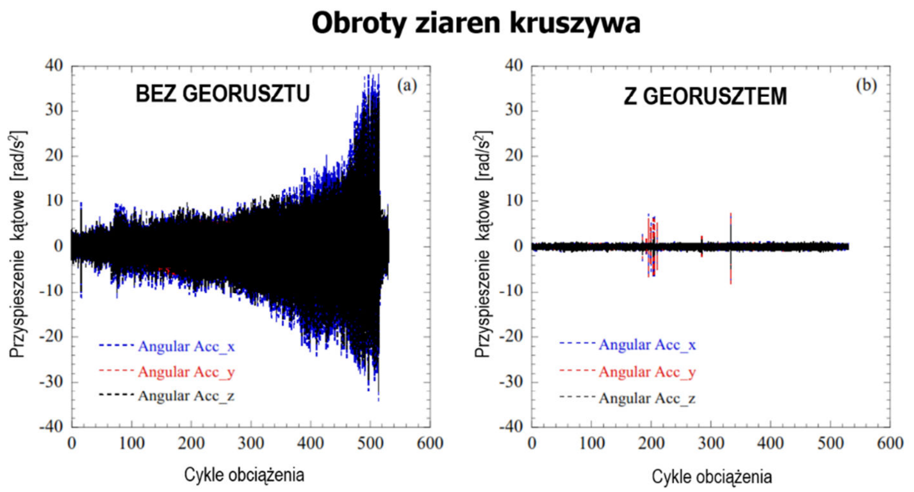
The analysis of the results confirmed the impact of mechanical stabilization with a hexagonal geogrid on a significant reduction in displacement and rotation of aggregate grains in the ballast bed layer. Figure **5** shows the size of displacements and rotations of SmartRock lumps in the test without geogrid and with triaxial geogrid. The rotation acceleration in the geogrid stabilized section was approximately 2 rad/s2 throughout the test, while in the control section where no geogrid was used, the initial value was approximately 4 rad/s^2 and increased to 30 rad/s^2 as the number of cycles increased loads.



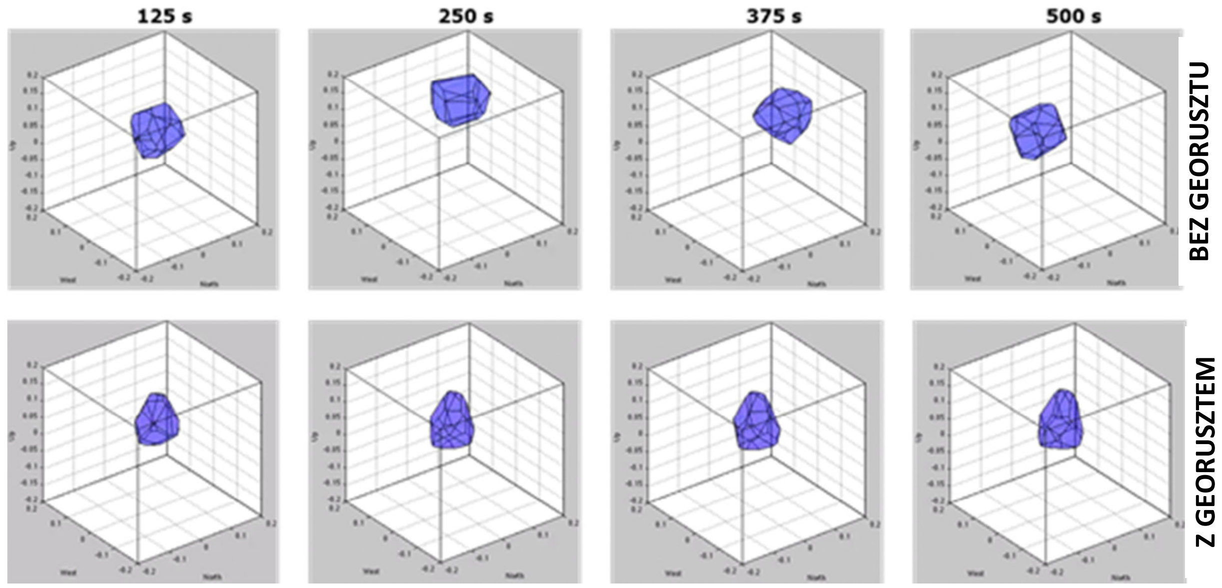
4. Vertical displacement depending on the number of load cycles
Source: [9]

Figure **6** shows the displacements of SmartRock lumps during 500 load cycles in tests without and with geogrid. It is noticeable that the observed grain moves away from the initial location with the increase in the number of load cycles, which indicates a significant loosening of the ballast layer in the section without hexagonal geogrid stabilization.





5. Displacements and rotations of SmartRock grains due to cyclic loads
Source: [9]



6. Displacements of SmartRock grains in a layer of ballast (upper without stabilization, lower with TriAx geogrid stabilization)
Source: [9]

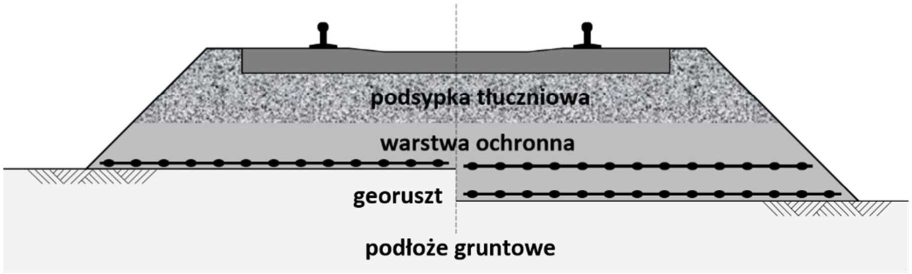
The use of geogrids for aggregate stabilization in railway engineering

Aggregate stabilization function using geogrids with uniform radial stiffness can be used in railway trackbed construction in three possible ways:

- protective layer stabilization,
- obalast stabilization,
- ballast on under ballast mats stabilization.

Stabilization of the protective layer

Stabilization of the protective layer is related to the presence of soils with unfavorable geotechnical parameters in the subgrade. The use of geogrid allows to increase the bearing capacity of the substrate under the structure or to reduce the thickness of the aggregate in relation to the thickness without geogrid while obtaining the same load-bearing parameters on top of the protective layer. The aforementioned reduction in thickness can reach up to 50%, but each time it requires individual analysis. With the very poor load-bearing capacity of soils in the subgrade, it may be necessary to use stabilization in a multi-layer system. The schematic location of the geogrid to stabilize the protective layer is shown in Figure **7**.



7. The use of geogrid to stabilize the protective layer, single layer on the left, multilayer on the right

Ballast bed stabilization

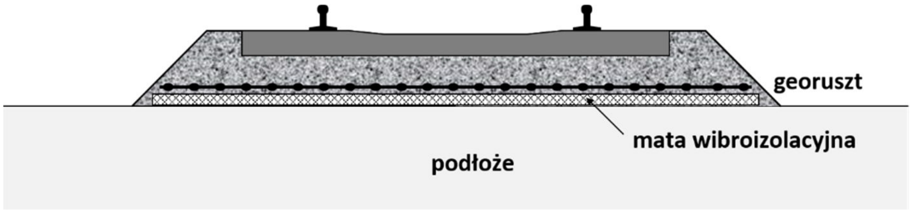
The use of geogrids to stabilize the ballast layer reduces the displacement of the aggregate and thus reduces its degradation as a result of the impact of cyclical dynamic loads. Greater stiffness of the ballast layer reduces the rate of growth of its deformation and, consequently, the reduction of deformations (plastic deformation) occurring in the protective layer. In general, this deformation is manifested by irregular subsidence of the track and deterioration of its geometry in the plan.

Research on the impact of geogrids on the reduction of subsidence and thus the necessary maintenance procedures was carried out at the University of Nottingham (Great Britain). The analysis of the results [2] shows an increase in the number of load cycles by a factor of 2.5 after the use of geogrid. An example of using a geogrid to stabilize a ballast bed is shown in Figure **8**.

8. The use of geogrid for ballast bed stabilization

Stabilization of ballast on under ballast mats

obtaining the right operating parameters for the ballast bed laid on under ballast mats. Absorption of vibrations requires the use of materials that are characterized by relatively low static and dynamic stiffness, which directly affects the cooperation with the crushed stone. The results of tests carried out by British Rail, presented, among others, in [1], indicate a significant reduction in the deformation of the ballast layer and track displacements in sections where under ballast mats were used in the subgrade.



9. The use of geogrid for ballast stabilization on under ballast mats

Examples of using geogrids for railway trackbed stabilization

The use of geogrids with uniform radial stiffness to stabilize the aggregate in the construction of railway trackbeds is often used in the construction and modernization of railway lines around the world. National experiences in this field are equally interesting. Three selected projects from Poland are discussed below.

LK E65 Gdynia Warsaw

The modernization of the E65 line was carried out in 2012-2014 [3]. Based on the geotechnical expertise in the area of LCS Gdańsk on the route Pruszcz Gdański - Gdańsk Południowy, locally unfavorable soil conditions were found in the form of peat up to 4.5 m thick in the subgrade. The existing embankment was built of sandy soils with an admixture of dust. The requirements for the protective layer assumed carrying it directly under the layer of ballast to the bearing capacity E2≥ 120 MPa, while the existing subsoil was characterized by a secondary deformation modulus E2≥ 25 MPa. As a result of the calculations, a structure with a total thickness of 50 cm was adopted, which consisted of:

- separation and filtration geotextile,
- triaxial geogrid,
- a layer of broken aggregate 0/31.5, 25 cm thick,
- triaxial geogrid,
- a layer of broken aggregate 0/31.5, 25 cm thick.

10. Laying the first layer of triaxial geogrid during the modernization of the E65 line in the area of LCS Gdańsk

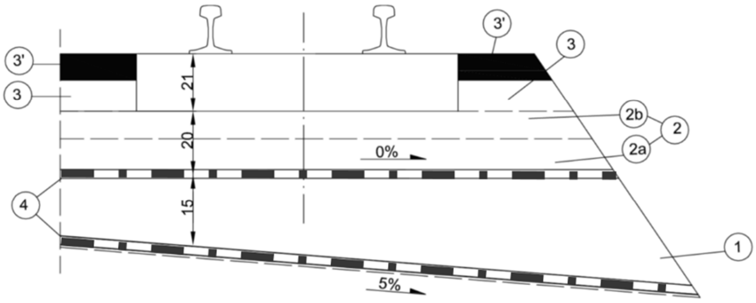
LK 273 Zielona Gora - Niedoradz

During the modernization of LK 273 on the Głogów - Zielona Gora - Rzepin - Dolna Odra section, Zielona Góra-Niedoradz section, carried out in 2017-2018, the problem was cohesive soils in the form of silty loams and loamy sands in the subgrade under the existing railway superstructure plastic and soft plastic. The use of hexagonal geogrid to stabilize the upper protective layer made of unsorted stone with a layer thickness of 35 cm allowed obtaining the required load capacity values determined by the deformation modulus E2≥ 110 MPa and density E2/E1 ≤ 2.2 [3].

11. Stabilization of the protective layer during the modernization of the LK 273 line

Central Railroad

In 2008, on the test section of the Central Railway Main Line near the town of Psary, on a section with a length of about 800 m, the pavement structure shown in Figure **12** was made. It consisted of a composite layer of crushed stone stabilized with geogrids and locally stabilized with a special binder made on the basis of polyurethane resins developed in the Department of Transport Infrastructure of the Faculty of Transport of the Warsaw University of Technology [6]). It was an innovative solution consisting in increasing the resistance to the deconsolidation of the ballast layer in areas exposed to intense vibrations. The works were carried out using the AHM machine (Fig. **13**).



12. Test surface with a composite ballast [6]
1 – lower layer of compacted crushed stone, 2 - upper layer of compacted crushed stone,
3 - compacted layer of crushed stone in which the track frame is embedded,
3′ – layer of chemically stabilized crushed stone, 4 – geogrids

13. Laying Tensar TriAx geogrid with AHM

During the test period, the track carried a load of 18.6 Tg, i.e. insignificant in relation to the load that this surface can carry over the entire period of operation. Based on the obtained results, the authors of the research concluded that the resistance of the pavement with a composite crushed stone is higher by about 30% in relation to the pavement used without the composite [6].

The tests also showed that the pavement with the ballast composite is characterized by lower synthetic track condition indicators compared to the conventional track, which is also confirmed by the results of the assessment of vertical and horizontal deformations.

Summary

More and more frequent use of under ballast mats in railway structures, especially in ballast surfaces, which are made of aggregates produced in the process of crushing hard rocks such as basalt, syenite, or dolomite, imposes additional requirements in terms of protecting the mats against the destructive action of sharp edges of crushed stone.

As a result of the action of cyclical dynamic loads, the ballast grains move and rotate, causing damage to the sub-ballast mats, which may lead to their complete degradation. The use of ballast stabilization with a multi-directional geogrid significantly reduces the displacement of the ballast, and thus extends the durability of the pavement and the under ballast mats built into it. The results of model tests and measurements on a natural scale confirmed that the use of geogrids with uniform radial stiffness in the railway trackbed structure increases the bearing capacity of the subgrade, extends the durability of the ballast, and ensures the required operational parameters of the ballast laid on under ballast mats.

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