The Technology of Multilayer Mechanical Stabilization of the Railway Ballast by Flat Polymer Geogrids

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Abstract. The problem of railway ballast degradation during service life is receiving considerable attention. The primary reason of aggregate particles cracking and abrasion is the maintenance operation of machine ballast tamping. Reduction of tamping operations frequency helps to maintain the quality of crushed stone and therefore, reduce the deformation of ballast. This may be achieved by increasing aggregate stiffness by mechanical stabilisation with flat rigid polymer geogrid. Laboratory modeling of cyclic loaded ballast shows that one layer of geogrid at the bottom of ballast reduces the settlement by 34 % while multilayer stabilisation by 3 geogrids reduces it by 67 % and possibly allows avoiding tapping during service life. As an alternative maintenance option, the authors propose bedding with pneumatic stone blowing or shallow tapping to the depth of 70 mm.

1. Introduction
In the paper, the effect of reinforcing the hard ballast of crushed stone with a flat polymer geogrid is studied.

Thereat, the reinforced ballast gains some new properties, including, among others, the formation of a composite material with new properties similar to those of a homogeneous solid mass. It lacks the macrostrains typical of granular material under dynamic loading. Instead, under dynamic loading, microstrains typical of a single rock emerge in the composite material.

2. Railway ballast service life
In Russia, the average ballast service life is 350 million gross tons passed over, which is significantly less than that of other track superstructure (TSS) elements (Fig. 1).
Such a low service life as compared to other TSS components is determined by the ballast choking and contamination, the main source of which is the fracture and abrasion of ballast granules (Fig. 2), which was formulated by E. Selig and J. Waters [1] and confirmed by the RUH (MIIT) studies in 2017 [2].

In this case, over 50% of the total ballast fracture and abrasion is formed due to leveling the track rails in the profile by machine ballast tamping under the sleepers [1]. Refuse from leveling the railway track by machine tamping of ballast granules under sleepers allows increasing the ballast section service life by 2-7 times [1].
3. Aggregate mechanical stabilization

Refuse from leveling the railway track by machine tamping of ballast is not the only way to increase its service life. Thus, since 2000, many attempts have been made to increase the service life of the under-sleeper pad by reinforcing and stabilizing the stone material with flat polymer geogrids laid under the ballast section or even in it [3] due to the widespread use of crushed stone reinforcement in road construction.

According to Kwan [3], the ballast reinforcement reduces its choking by 1.9 times; given that, according to Indraratna [4], the reinforced ballast serves better than the new unreinforced one until 40% contamination, the combination of the ballast reinforcement and non-tamping may increase its service life by up to 10 times. This is quite a serious figure, given that the overhaul of 1 kilometer of the TSS under favorable conditions requires direct costs of RUB 18 mln. or USD 270 thousand, and the renovation of ballast makes up to 25% of this amount.

The effective blocking of crushed stone in the meshes is determined, among others, by the optimum ratio of the granule and hole sizes. Kwan [3] recommends using geogrids with an internal mesh size of 60–80 mm at a rated size of ballast granules of 50 mm, while Rakovski [5] states that the granule sizes should vary within 110–140% of the mesh size in the light [6].

The bulk material + grid system works as follows: when placing and compacting the stone material over the geogrid, some granules partially penetrate the holes and adjoin the rigid edges of the geomaterial. As a result, the geogrid and granules interact with blocking a single grain in the mesh. Thus, the blocking effect is defined as limiting the horizontal movement of stone particles when applying a vertical load [5].

![Figure 3](image)

**Figure 3.** The Work of Two Ballast Particles when Deblocked by the Overlying Third Particle; a) without a Geogrid; b) with a Geogrid.

Figure 3 shows that the ballast granule is optimally blocked in the mesh in such a way that when applying a vertical load, the geogrid rib stretch resistance forces are activated. In turn, the granules in the next row are blocked, falling between the granules already blocked by the geogrid [5].

According to [5], the stiffer and higher the geogrid rib, the better, and the vertical rib shape is better than the horizontal one.

It is argued that if all the conditions are met, the macrostrains typical of granular material under a load are replaced by microstrains in the reinforced material, as in the case of a single rock [6].

A fully immobilized area in a geogrid with a square mesh may reach a thickness of 7-10 cm per a geogrid layer. In the case of a hexagonal geogrid, the maximum effect extends up to 15 cm [5].
4. Laboratory simulation of cyclic loading
In February 2018, MIIT performed a series of laboratory tests simulating the railway track ballast reinforcement with flat geogrids.

The below models have been tested:
1. 25-60 mm ballast fraction model, unreinforced,
2. 35-40 mm ballast fraction model, reinforced with three geogrid layers with a mesh size in the light of 32 mm in every 100 mm,
3. 25-60 mm ballast fraction model, reinforced with two geogrid layers with a mesh size in the light of 57 mm in every 100 mm starting from the ballast base,
4. 25-60 mm ballast fraction model, reinforced with two geogrid layers with a mesh size in the light of 32 mm in every 100 mm starting from the ballast base,
5. 25-60 mm ballast fraction model, reinforced with a single geogrid layer with a mesh size in the light of 32 mm at the ballast base.

Figure 4. Diagrams of Tested Under-Sleeper Bed Models and Suggested Ways of Their Current Maintenance.
The test results are shown in Figure 5.

![Diagram showing vertical settlement of tested models](image)

**Figure 5.** Vertical Settlement of Tested Models a) reinforced with 33 (32) mm geogrid; b) reinforced with 65 (57) mm geogrid.

According to the test results, the best stabilization was shown by models Nos. 2 & 5, and model No. 2 showed the smallest vertical settlement.

In all 5 models, the greatest deformation occurred within 0 to 100 thousand cycles (except for model No. 5, where the deformation occurred at 300 thousand cycles).

In general, reinforcement gives an undoubted positive effect, however, the problems of the current maintenance and repair of structures with geogrid layers arise.

### 5. Alternative maintenance technology

Supposed content of the reinforced ballast. In models Nos. 3 & 5, an unreinforced ballast layer with a thickness of 250 mm was used to simulate the work of the track renewal trains. However, the use of this leveling technique is extremely disadvantageous since losing particle packing may lead to a sharp uncontrolled vertical settlement at the leveling point, which violates the geometry of the overlying track panel.

What to do in this case, given the extremely uneven settlement of material such as ballast crushed stone?

First, in the armored ballast structure, leveling by tamping should be replaced with leveling by chip packing [7] or combined packing and under-sleeper padding [8].
Moreover, it should be considered that Andersen [7] recommends using ballast granules about 20 mm in size in leveling by pneumatic stone blowing to avoid penetration of the granules into the standard ballast particles.

If the ballast is reinforced with not a single but several geogrid layers, the need for recycling the contaminated ballast will inevitably arise, which would seem to exclude the maintainability of this structure.

This is an erroneous statement since modern ballast cleaning machines have virtually no restrictions on the minimum cleaning depth. I.e. using a lifting and leveling device (LLD), the machine can clean layers up to 70 mm. Such cleaning depth is not used due to the low machine performance in this case. Considering that according to [5], the blocked (immobilized) layer thickness may reach 15 cm, this cleaning technique can extend the reinforced ballast service life by at least 50%.

The second solution is using a geogrid with a lower tensile strength, e.g. not 40 but 20 kN/m, in the upper layer. For a more accurate answer to this question, an additional series of tests of the ballast base reinforced with a flat geogrid having a strength of 20 kN/m should be performed.

Since the flat geogrid strength is directly related to its thickness, the ballast cleaning machine chain will probably be able to break the geogrid into small components. In this case, the major engineering problems of maintaining the armored ballast structure will be removed. Otherwise, the technical opportunity of destructuring the geogrid before deep ballast cleaning should be found. It should be noted that the Infrastructure Design Bureau has developed a process that allows cutting the colmated geotextile when cutting out contaminated ballast [9].

6. Summary

1. Reinforcing the ballast even by a third of the height allows reducing the vertical settlement during compaction of ballast granules by almost 50%.

2. If the ballast granule size is within 110-140% of the mesh size, the armored ballast structure reinforced to the entire ballast depth works as a monolithic rock material after 300 thousand cycles.

3. The higher the flat geogrid rib profile, the stiffer it is, and the less the geogrid and ballast granule composite deformation.

4. Combining reinforcement and gentle maintenance of the reinforced ballast may increase the life cycle of the reinforced sleeper base several times.

5. Before testing the reinforced ballast structure under the trains, the techniques for the maintenance and repair of this structure should first be developed.

7. References

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