HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 39(1) pp. 101-106 (2011)

SUPERSTRUCTURE STABILIZATION OF BALLAST BEDDED RAILWAY TRACKS WITH GEOGRIDS

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The paper deals with the research and development of the authors related to investigation of geogrid railway ballast reinforcement. It summarizes the theory of the geometrical deterioration of railway tracks, as well as the advantages of the use of geogrid reinforced ballast in railway superstructure. This article summarizes the results of the field tests with five different geogrid types on a Hungarian main railway line and laboratory multi-level shear box tests. It points out to future research possibilities, for example the modelling of laboratory multi-level shear box tests with discrete element method that may certify their results.

Keywords: railway, superstructure, stabilization of track geometry, geogrid-reinforced ballast

Introduction

The geometrical deterioration process of ballasted railway tracks

Geometrically and structurally perfect railway tracks cannot be constructed because of the tolerances and quality differences of constructional elements as well as inaccuracy of geodetic alignment and technology during construction and maintenance works. However the railway tracks' geometry and quality differ from the accurate conditions, but if the tolerances and quality differences are below their permissible limits, the tracks can be opened to traffic for the speed limit in accordance with the appropriate acceptance requirements.

The train traffic and its damaging effects generate harmful changes in the railway track; this is actually the geometrical deterioration process. This geometrical deterioration takes place according to strict physical laws and it is an irreversible process. Its speed can be influenced as well as decreased by maintenance works, but it can be never stopped.

The function of the geometrical deterioration process in explicit form is the following:

$$C = C_0 \cdot e^{\alpha \cdot m \cdot v^2} \tag{1}$$

In (Eq. 1) "C" means the geometrical quality of the railway track, "C_0" is a parameter related to the initial track condition and it shows the quality of the maintenance, "m" is the through-rolled mass, "v" is the equivalent speed, and "α" is a superstructure dependent parameter.

In the exponent of "e" in (1) there is an expression related to the energy of motion [1].

Improvement (i.e. reduction of "C") can only be reached with maintenance works (e.g. tamping work). "C" value can be decreased more in a track with worse geometrical quality but the result will be characterized with more and more "C" value.

Function and deterioration of railway ballast

The railway ballast has to support the track soundly and flexibly and it has to distribute the load from the sleepers' lower faces to the substructure (embankment and supplemental layer). The ballast material should have adequate resistance in longitudinal and transversal directions which are necessary for the track's bedding and structural stability. The direction, the settlement and plane distortion values have to be ensured in respect to relative geometry.

The good quality ballast material is an aggregation of non-cohesive, graduated and cubic shaped, angular particles. In this particle aggregation the vertical load of vehicles is distributed through the 'stone-skeleton' to the lower layers, while the horizontal loads are balanced by friction between sleepers and ballast particles and by passive earth pressure. In both load-distributions the interlocking effect between particles is very important.

External effects (mainly the repetitive through-rolled axles, as well as the weather) change the behaviour of particle aggregation; therefore the actual geometry of the track will be worse and worse. The ballast particles can be pushed into lower layers especially in the case of weak embankment or supplemental layer; therefore large vertical plastic deformations (settlements) can arise.

Because of the reasons above, a structural modification seems to be practical for prevention to ensure that particles of the aggregate act together. Using geogrid reinforcement under the ballast bed can be a good solution for this problem.

Effect of geogrid reinforcement under railway ballast

Geosynthethics have been used for soil reinforcement for more decades. They can compensate some weak soil parameters: e.g. they ensure additional tensile and shear strength for soil structures. In this way soils with unsuitable geotechnical parameters can be used for construction of steep slopes, with these types of soils very quick consolidation can also be achieved on bad quality subgrade, and for example geosynthetic-reinforced soils are also suitable for construction of very good isolation and separation layers at waste-dumps by the help of decreasing of water permeability of soils [2]. Geogrids ensure additional tensile and shear strength for both granular and cohesive soils. Using this soil reinforcement, soils can bear not only pressure but tensile force too, due to the longitudinal and transversal ribs and junctions of geogrid if there is an adequate soil-geogrid interaction. This reinforced structure works similar to the reinforced concrete in which concrete bears pressure and reinforcing steel bars take up tensile forces. Geogrids can be used for counterforcing shear forces, but their use is limited because of the shear strength of geogrids.

Laboratory tests have been made related to such use of geogrids in railway constructions where not the subgrade/subsoil was reinforced but the bed-ballasted railway superstructure [3-19]. Besides the laboratory tests field tests [5, 7, 9, 13, 17, 20, 21] and FEM [22-24] as well as DEM modeling [25-31] were also carried out. These papers certify that geogrids reinforce the granular media the following way.

Interaction between the granular and angular ballast material particles and the geogrid is the basis of the increase of the internal shear resistance of the layer-structure. It is called interlocking effect of geogrids *(Fig. 1*). The particles can penetrate into the geogrid layer's apertures, and grapple on to ribs. The other particles bear up onto this composite (particle and geogrid) layer. Its face structure is advantageous for the higher internal shear resistance. The re-arrangement of particles is hindered by the composite layer in vertical and horizontal planes too. Stresses arise in the ribs and junctions of the geogrid due to vehicle load, the geogrid can offer resistance against these stresses with tensile strength and low strain. Tensile strength should be adequate high, but failure strain should be acceptable low, because of the load bearing with small strain.

The aim of the following chapters is to summarize the results of the research team at the in this research field.

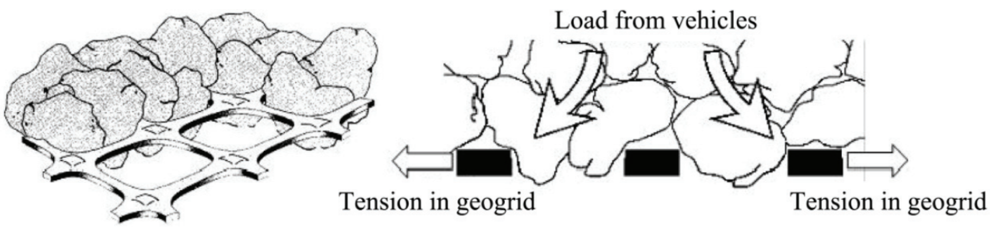

Figure 1: Interlocking effect and load bearing of a reinforced ballast (modified from Konietzky, et al., 2004)

Goal of the research work

The research team investigates the stabilization effect of geogrid layers under railway ballast using three methods:
- constructing trial field track sections where the track geometry position and its changes are regularly measured,
- setting up laboratory tests which are adequate for determining parameters related to ballast material-geogrid interaction,
- computer-aided modelling for improving and generalizing the relationships.

At the trial field track sections, geometric levelling are completed on the rail-heads, therefore the track's geometry changes can be measured and determined. If the measuring points on the rail-heads are close enough to each other and the measurements are often repeated, there will be a large database which can be processed. Values below and their changes can be determined as a function of through-rolled axle tons as well as of the elapsed time from the first tamping work after the geogrid's built-in:
- cross settlement difference between the two rail-heads,
- settlement (can be calculated with different chord lengths on one rail),
- plane distortion (twist) (can be calculated with different base lengths),
- settlement on individual sleepers.

The laboratory tests can help to better understand the behaviour of geogrid-reinforced railway ballast. A great deal of parameters influences this behaviour (e.g. geogrid type, properties and density of ballast material, depth of ballast layer, elasticity of support layer, etc.). The changing of interlocking effect in the ballast material as a function of vertical distance from geogrid layer is a key-role for the conformability of evaluation of geogrid reinforcement's use. The research team would like to get much information from the test of interlocking effect in order to evaluate the expedience geogrid-reinforced ballast.

Computer-aided modelling is needed for numerous reasons. Consideration of all variable parameters will unfeasibly extend the number of laboratory tests. If an acceptable number of tests have been implemented, models can be constructed whose behaviour can be confirmed and certified by the measured parameters. Using this model in computer-aided modelling is conformable for more detailed analysis of various parameters' effect, as well as for universalizing of statements which are needed for determining correct general laws about the behaviour of geogrid-reinforced railway ballast. This paper doesn't deal with computer-aided modelling of geogrid-reinforced railway ballast material in detail.

Tests and results

The research team had an opportunity to create a 700 m long trial field track section with uniform soil properties at a Hungarian main railway line in May, 2010. This section of railway line contains substructure faults, e.g. water pockets. Three different subsections had been constructed in this section and finally five geogrid types had been built-in during ballast cleaning:

– sections without ballast cleaning just tamped,
– sections with ballast cleaning without geogrid reinforcement then tamped,
– sections with ballast cleaning with geogrid reinforcement then tamped.

Geogrid types 1, 3 and 4 contain geotextile layers too, types 2 and 5 are single geogrids. All tested geogrid types are made of polypropylene. The geogrid and geotextile properties are contained in *Tables 1* and *2*. The last two subsections contain blocks with and without water pockets which water pockets are local faults. *Fig. 2* shows the setting in work of Geogrid type 2 during ballast cleaning technology in railway line Lebeny-Mosonszentmiklos (Hungary) on 25th of May in 2010. After the final tamping work of the construction (17th of June, 2010) several geometric leveling has been done and their data have been processed. *Figs 3* and *4* show the mean and standard deviation of plane distortion as a function of elapsed days from 17th of June, 2010. On the 124th day there was a tamping work again, before and after it geometric levelling has been accomplished.

Table 1: Properties of geogrid types used in trial field tests

Geogrid properties								
Geogrid types	Material	Uniaxial/ Biaxial	Ultimate strength		Strength at 2 % elongation		Ultimate elongation	
			MD (kN/m)	XMD (kN/m)	MD (kN/m)	XMD (kN/m)	MD (%)	XMD (%)
Geogrid type 1	PP	Biaxial	30	30	11	12	N.A.	N.A.
Geogrid type 2	PP	Biaxial	30	30	11	12	N.A.	N.A.
Geogrid type 3	PP	Biaxial	30	30	12	12	N.A.	N.A.
Geogrid type 4	PP	Biaxial	30	30	12	12	N.A.	N.A.
Geogrid type 5	PP	Biaxial	30	30	N.A.	N.A.	12±3	12±3

Table 2: Properties of geotextiles in geocomposits used in trial field tests

Geotextile properties									
Geocomposits	Puncture resistance (N)	Ultimate strength		Ultimate elongation		Perme-ability (m/s)	Perme-ability (l/sm^2)	Unit weight (kg/m^2)	Effective opening size (mm)
		MD (kN/m)	XMD (kN/m)	MD (%)	XMD (%)				
Geogrid type 2	>1500	N.A.	N.A.	N.A.	N.A.	0.135	135	0.16	0.125
Geogrid type 3	1670	6	11	60	40	0.11	110	0.15	0.13
Geogrid type 4	1670	6	11	50	30	0.09	90	0.15	0.08

Figure 2: Construction geogrid-reinforced trial railway track on line Lebeny-Mosonszentmiklos (Hungary) on 25th of May in 2010 with Geogrid type 2

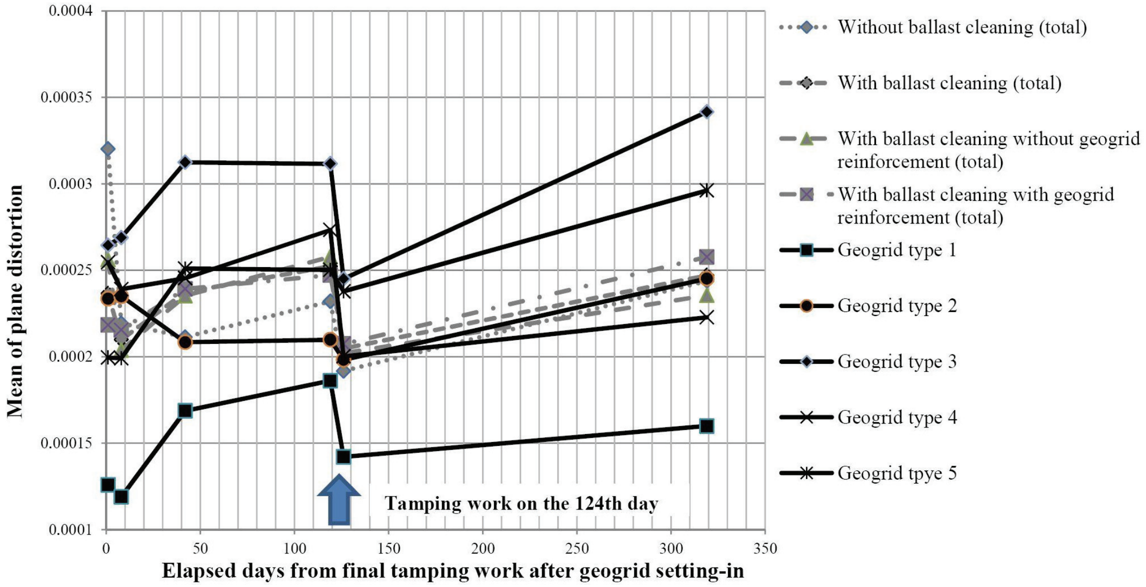

Figure 3: Mean of plane distortion (twist) (3.6 m base length) as a function of elapsed days from final tamping work after geogrid setting-in

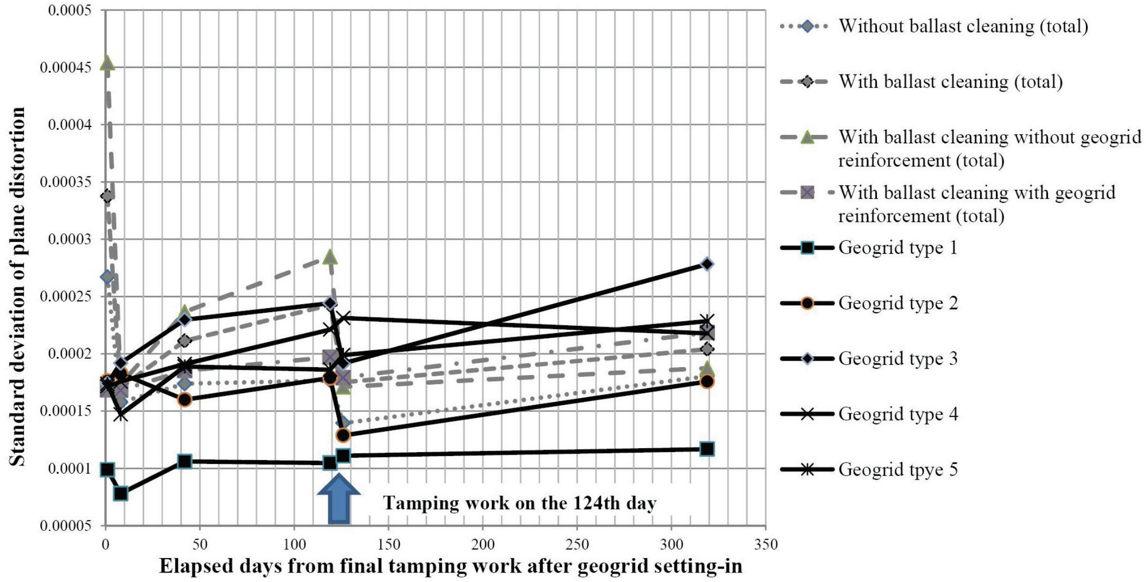

Figure 4: Standard deviation of plane distortion (twist) (3.6 m base length) as a function of elapsed days from final tamping work after geogrid setting-in

In Fig. 3 and 4 it can be seen that sections without geogrid reinforcement are characterized with higher mean and standard deviation values than several geogrid types, e.g. geogrid type 1 and 2, but other types do not improve the track's geometric stability in this controlled short time period. Sections without ballast cleaning just tamped do not show low values in the mean diagram because of the relatively dense ballast superstructure, but in the standard deviation diagram this section seems to be the worst.

The reference time before (123 days) and after (195 days) the 2nd tamping were not long enough, the results will be more precise with extended inspection time, so the measurements have to be continued in the future.

For the laboratory tests the research team planned and constructed a multi-level shear box with which the change of the interlocking effect in the railway ballast material was investigated as a function of vertical distance from the geogrid layer. This function in the above form has not been determined by anyone with lab test; international researchers reached such kind of results using of DEM modelling of geogrid pullout test (Konietzky, et al., 2004; McDowell, et al., 2006) but not with a multi-level shear box.

The 1.0×1.0×1.0 m multi-level shear box mentioned above *(Fig. 5)* contains max. ten 10 cm high horizontal frames filled with max. 50 cm high elastic layer, thereon 10 cm height sand, thereon geogrid layer with or without geotextile as well as thereon four times 10 cm height railway ballast material. Horizontal shear resistance can be measured at each frame connection. The tests up to now are related to only one geogrid type (geogrid type 2 in the field test) and to only new loose and dense ballast material. Tests were conducted with and without geogrid reinforcement too. *Fig. 6* shows the horizontal shear resistance of railway ballast aggregate.

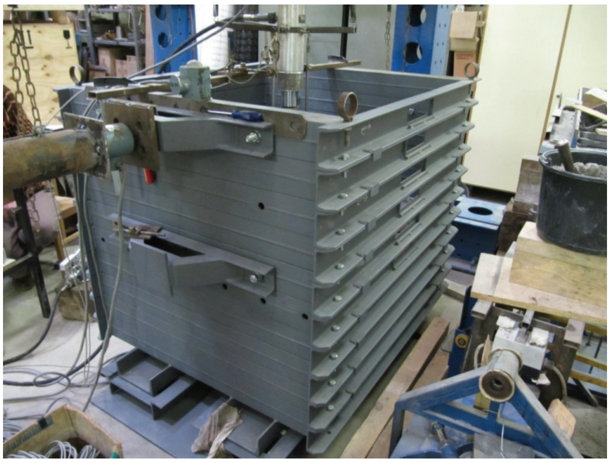

Figure 5: Multi-level shear box for laboratory tests

Dense specimens had higher shear resistance than loose ones; the geogrid reinforcement increased these values especially in the near region of geogrid layer same like in Konietzky, et al. 2004 and McDowell, et al. 2006.

Conclusion

It can be clearly stated that with adequate geogrid type the ballasted railway superstructure can be strengthened. This kind of geosynthetics can guarantee additional shear strength for ballast bed. Consequently, the settlements as well as disadvantageous cross settlements, direction faults, twist faults are less likely to occur in these tracks and the interval between maintenance works (for example tamping works) can be extended. This is very important in the aspect of maintenance costs.

Having processed the measured data, it has to be stated that more measurements are required in field trial and in laboratory tests too, and then the computer-aided modelling will be needed to check the results in laboratory multi-level shearing tests.

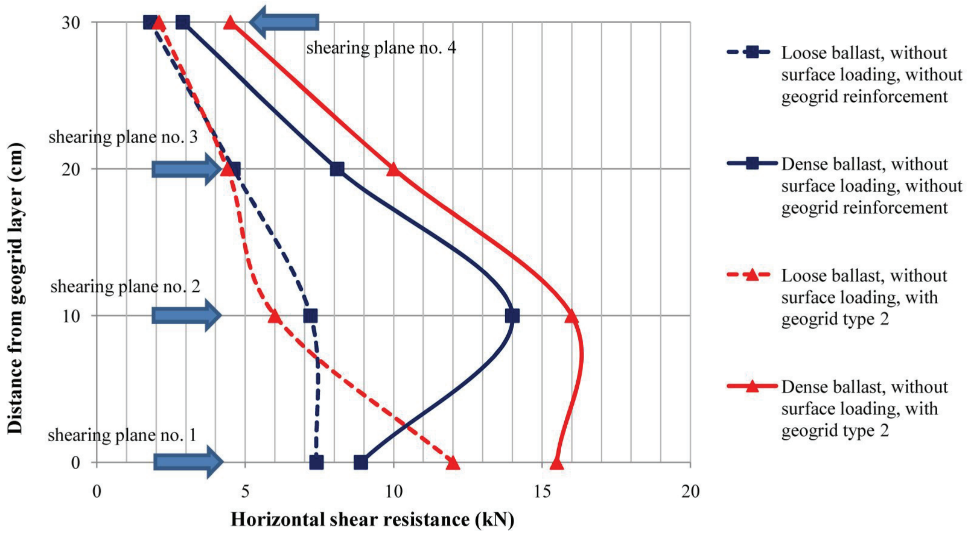

Figure 6: Horizontal shear resistance as a function of distance from geogrid layer

ACKNOWLEDGEMENTS

This paper is supported by TAMOP-4.2.1/B-09/1/KONV-2010-0003: Mobility and Environment. The Project is supported by the EU and co-financed by the European Social Fund.

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