Influence of geosynthetics on the oscillations amplitude of railway subgrade

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ABSTRACT: This paper highlights recent field studies at Emperor Alexander I St. Petersburg State Transport University, which helped to quantify the geosynthetics reinforcement performance in railway ballast. The rolling stock causes oscillations of track superstructure, which show up in the form of noise and vibration. The increase in loads and speeds of trains leads to a significant increase of dynamic vibration effects on the roadbed. Because of this exposure the intensity of uneven residual deformation accumulation of the railway track increases. It affects not only on the roadbed, but also on constructions of buildings and construction.

Technologies for subgrade top reinforcing are widely used during the lines reconstruction. They allow guaranteeing the operational reliability of subgrade working area. These works are performed in complex with track repairs by the ballast cleaning machines of a new generation. These machines allow using new specialized geosynthetics which are geogrids and geocells.

Field tests were conducted on the railway section to assess the reinforcement effect on the superstructure. Geosynthetics were placed on the top of subgrade during track repair on the depth of 40 cm below the sleeper pad.

Previous studies have mostly focused on the deformation characteristics of soils, reinforced by geosynthetics. However, it is necessary to know the vibration level under moving load to determine their influence on the bearing capacity of ballast and subgrade.

The paper describes recent research efforts in field studies, which helped to identify the geosynthetics influence on substructure vibration reduction.

Keywords: dynamic vibration impact, the attenuation of the amplitudes of oscillations, geosynthetics

1 INTRODUCTION

Introduction of heavy freight trains on the railways of common use and the tendency to increase overhaul life leads to the additional activities to improve stability of the rail track. Stability of a superstructure depends on the strength and deformation properties of ballast and subgrade soils (Stoyanovich 2005, Pupatenko et al 2008).

Change of exploitation terms requires special measures for track preparation (Kolos & Konon 2016, Konon 2017). Increasing of speed and axle load causes rise of vibrational dynamic impact on railway track. World's exploitation experience shows that axle load increasing accelerates deformations of ballasted track. Ballast redistributes stress from rolling stock and track superstructure. Ballast performance makes great influence on track performance in total.

We made research to assess rolling stock vibrational dynamic impact on railway track.

2 DISTRIBUTION OF VIBRATIONAL ACCELERATION OF BALLAST PARTICLES IN TERMS OF INCREASED AXLE LOADS

2.1 *Field tests of vibrational acceleration of ballast particles: materials and methods*

PGUPS researchers made a survey of vibrational acceleration of ballast particles in terms of increased axle loads (Konon 2018). Rolling stock on the site had axle loads from 230 to 300 kN and 70 kmph speed. Tests were held at Russian Railway Research Institute experimental track.

Vibrational accelerations were measured in vertical plane using accelerometer set. Accelerometers are able to measure accelerations from 0 to 100 g with frequency from 2 to 3000 Hz. Sensors were placed under the sleeper and in depth of ballast layer. Sensors were set at the sleeper end, underrail section, and near center line of the track and up to 55 cm under the sleeper (at the sleeper end). Sensor placement in the ballast layer and subballast is presented in the Figure 1.

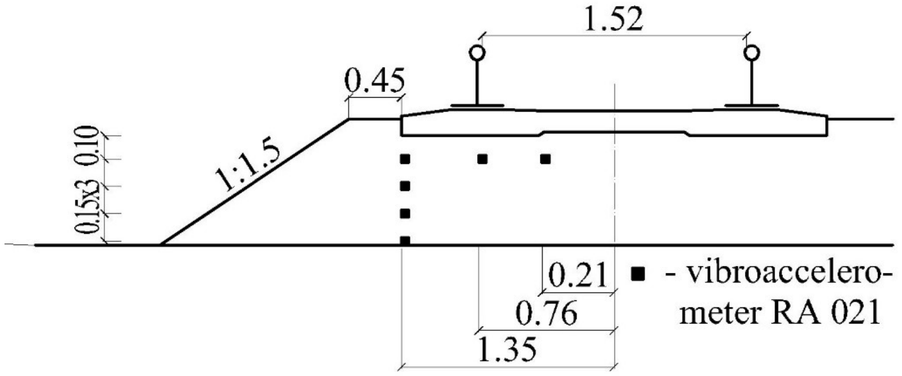

Figure 1. Sensor placement in the ballast layer and subballast (all measurements in metres).

2.2 *Field tests of vibrational acceleration of ballast particles: results and discussion*

Test results show that increasing axle load causes the rise of vibrational acceleration and stress values in the ballast layer and subballast. Vertical vibrational acceleration and stress distribution charts at levels of 10 and 55 cm under the sleeper pad are presented in Figures 2–5.

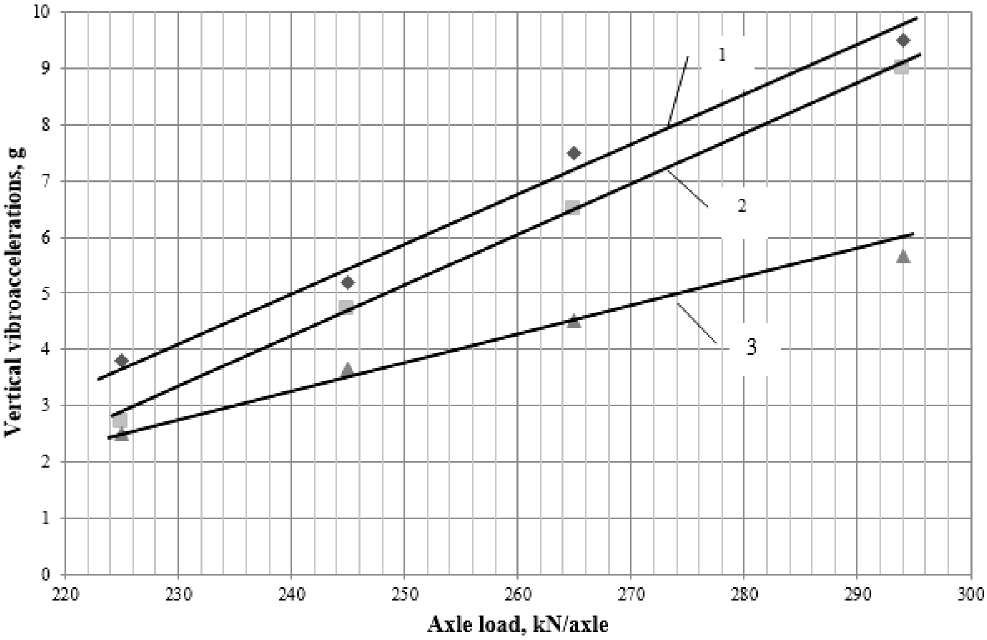

Figure 2. Vertical vibrational acceleration distribution at the level of 10 cm under the sleeper pad: 1 – at underrail section, 2 - near track center line, 3 – at the sleeper end

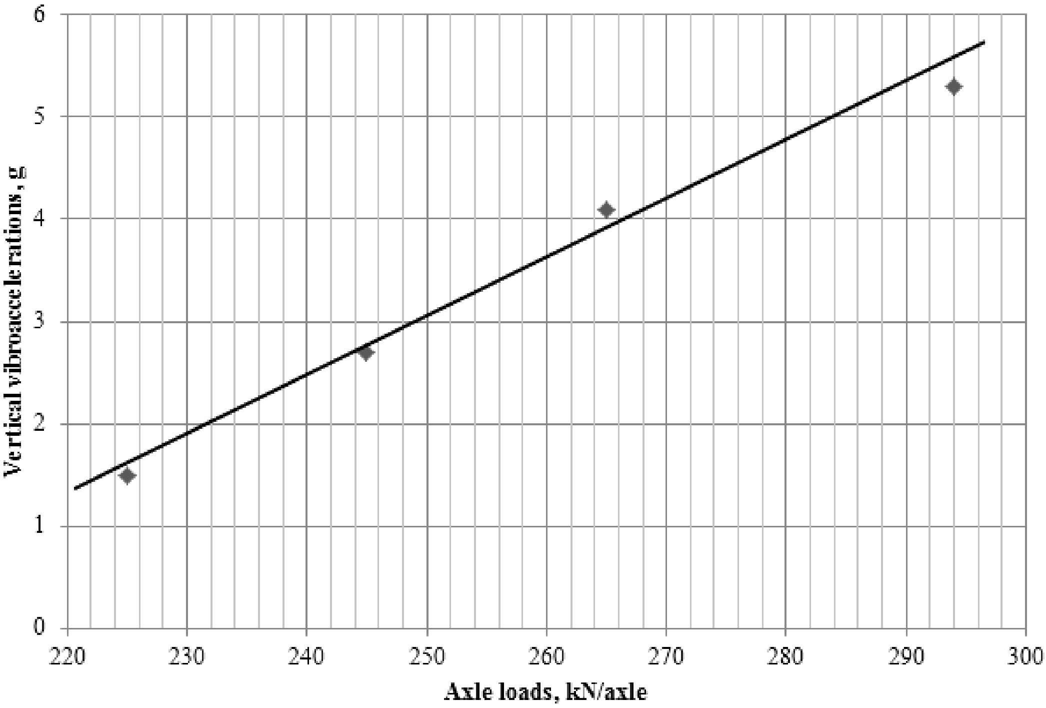

Figure 3. Vertical vibrational acceleration distribution at the level of 55 cm at the sleeper end

Analysis of test data shows that increasing of rolling stock axle loads from 225 to 294 kN/axle causes growth of vertical vibrational accelerations. Maximal values of vibrational accelerations are recorded at the underrail section, reaching from 3.8 to 9.5g and growing 2.5x. At the sleeper end vertical vibrational accelerations are about 15% lower than at the underrail section, with amounts of 2.7 to 9g for 225–294 kN axle load at a depth of 10 cm under the sleeper. The lowest values are near the track center line, which change from 2.5 to 5.7g.

Vibrational impact rises significantly due to axle load increasing. It requires solutions to keep railway track stable.

3 TESTS OF GEOSYNTHETICS REINFORCED SUBGRADE

Technologies for subgrade top reinforcing are widely used during railway lines reconstruction. They allow guaranteeing the operational reliability of subgrade working area. These works are performed in complex with track repairs by the ballast cleaning machines of a new generation. These machines allow using a new specialized geosynthetics - geogrids and geocells (see Figure 4).

Figure 4. Laying of geocells and two geogrid layers.

They are flat or three-dimensional structure that consists of regularly spaced open cells. Geogrids have stiffness, significant tensile strength, high modulus of deformation (small elongation), and high resistance to thermal, chemical, and biological effects and thus, they are characterized by a long service life.

Previous studies have shown a positive impact of geosynthetics on reducing of ballast degradation (Serebryakov et al 2017, Petryaev et al 2001 and 2003). They have revealed the effect of cell size and the material stiffness of the geogrid, the presence of moisture and contaminants of ballast, etc. on the effectiveness of the reinforcement. Most of the studies were conducted in the laboratory using mathematical modeling methods (Petryaev et al 2013, Indraratna et al 2014, Qian et al 2015, Hussaini et al 2015, Mishra et al 2014).

It is known (Stoyanovich 2005, Pupatenko et al 2008, Petriaev 2015 and 2016), that the subgrade oscillations, occurred under the influence of vibrational dynamic forces, reduce the strength characteristics of soils. Many authors carried out research in the field of the oscillatory process, however, we don’t known the studies, that have any results to determine the impact of geosynthetics on the oscillatory process of subgrade soil. We performed experimental studies to obtain quantitative data on this issue.

Research was conducted on the railway section to assess the effect of reinforcement on the substructure oscillation.

3.1 *Field investigations on geosynthetics-reinforced subgrade: materials and methods*

To determine the influence of various kinds of geosynthetics on oscillation of the roadbed under passing trains, it is necessary to carry out experimental studies to determine the values of the vibration amplitudes in the railway roadbed and to compare the results with similar data recorded without reinforcement.

Geosynthetics were placed on the top of subgrade on the depth of 40cm from the sleeper-bearing surface during the track repair (Table 1). They included geocells with 20 cm height (Type 4), a single and two layers of geogrids from different materials with 10 cm distance between layers (Types 1-3), and 5 cm thick polystyrene plates (Type 5). Experimental line section is a main double-track line with sand embankment with 1.5-2.0 m height. Supporting soil is peat up to 6 m depth. Line section is a tangent track with long-welded rails R65 and prestressed concrete sleepers.

Table 1. Tested geosynthetics

Characteristics of the material	Type 1	Type 2	Type 3	Type 4	Type 5
Structure	Bi-oriented geogrid	Bi-oriented geogrid	Bi-oriented geogrid	Geocells	Plate
Polymer type	Polypropylene	Polypropylene	Polyester	Polyethylene	XPS
Aperture size MD/TD, mm	39/39	35/45	50/50	200/200	
Strength at 5% strain MD/TD, kN/m	21/21	28/30	28/28		
Peak tensile strength MD/TD, kN/m	30/30	40/40	80/80	29/29	
Yield point elongation MD/TD,%	12	10/10	13/13	25/25	
Compressive strength at 10% deformation, MPa					0,5
Density, kN/m^3					0,38

The subgrade oscillatory process study is possible by using of quite a variety of equipment, which is confirmed by (Stoyanovich 2005).

Experience of previous oscillatory process studies in the roadbed showed that the seismic sensors of CM-3 type are the most suitable for this purpose. Their use allows to register the vibrational amplitude up to 1000 microns, with a frequency from 2 Hz to 200 Hz. These sensors practically do not register the external interferences, they have a device for temperature compensation and are characterized by the minimum mutual influence of the orthogonal vibrations.

Test set includes three sensors that allow measuring three components of vibration amplitude: vertical (along Z-axis), horizontal along track axis (X) and horizontal across the track (Y).

Registration of oscillations was carried out in three orthogonal directions during freight trains passing with locomotives 2VL-10 and 2VL-11 and passenger trains with locomotives 2CHS-6, 2CH-200 with different speed.

Subgrade oscillations were recorded only at the end of the sleepers on the depth 50 cm from their bottom, i.e. at the level of subgrade top.

Registration of oscillations was carried out by sensors, which were installed in the open pit. The possibility of conducting studies in the pits was substantiated earlier (Stoyanovich 2005). Test section was placed in the joint section due to the fact that high level of vibrational dynamic impact occurs in this area from the trains and there is more intensive accumulation of vertical and horizontal deformations of subgrade top, than in the middle of the section.

A schematic diagram of the sensor locations on each cross-section is shown in Figure 5. Preparation of test site is shown in Figure 6.

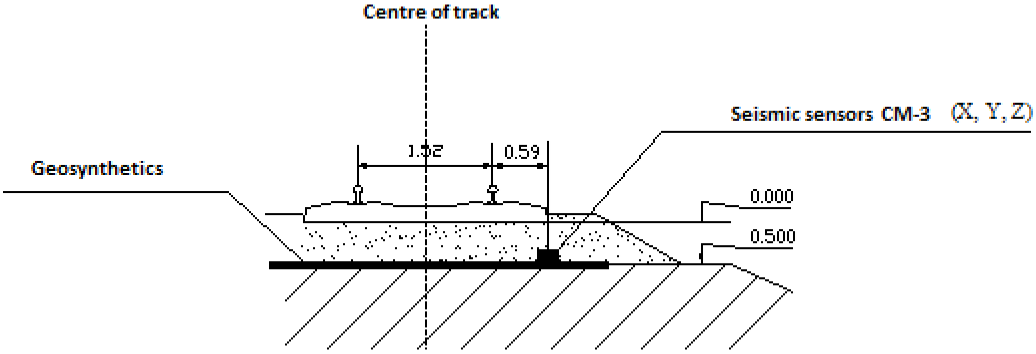

Figure 5. Layout of sensors.

Figure 6. Preparation of test site.

3.2 *Field investigations on geosynthetics-reinforced subgrade: results and discussion*

Evaluation of the oscillation amplitude can be generated through the resultant and the components of vibration amplitude: horizontal components along and across the track and the vertical component. The value of each component is defined as the sum of the amplitudes of the main and superimposed harmonics in places of maximum amplitudes. The value of each component is the sum of the amplitudes of the main and superimposed harmonics in the places of their greatest amplitudes.

Analysis of the oscillatory process nature of the soil massif was conducted on the waveforms, recorded at sites during passage of different types of passing load.

There is a significant difference between the value and shape of the oscillations. It depends not only from the speed of passing loads and layer depth, but from sensors orientation.

Analysis of waveforms shows that each component of the oscillations can be symbolically sorted into three components - low frequency (1.0 to 3.0 Hz), medium frequency (10-25 Hz), and high frequency component (more than 25 Hz). The last one was absent. With experience of previous studies it is known that this component is not registered in the embankments on the soft soil. In our case, the roadbed was built on a swamp, which determined the result.

Mid-frequency component is characterized by significant values of vibrational amplitudes. They depend on train speed and static axle load. This component occurs during bogie axis passage and it is registered in the form of sharp peaks and spikes. Amplitude of low frequency harmonics surpasses twice the amplitude of mid-frequency component. The higher the speed is the greater the difference. This harmonic is observed on all three components of the oscillations and at all tested cross-sections. It is known (Stoyanovich 2005, Pupatenko et al 2008) that this harmonic reflects total subgrade deformation under passing load.

Considering the vibrations waveforms of the subgrade top, first of all, it is necessary to note the difference in the nature of oscillation components.

The horizontal component along the track has not dependence from the axle load or train speed nearly. It has great stability and it has not abrupt surges.

The amplitude of this component is an average 32% of resultant amplitude at 40 km/h speed for cross-section without geosynthetics, 38% for reinforcement with type 4geosynthetics, 50% for the case of roadbed reinforcing with 2 layers of type 1 or 2 geosynthetics, 40% when one layer of type 1, 2 or 3 geosynthetics was used and 38% for type 5 geosynthetics. Percentage decreases with speed rising.

Vertical component amplitude of oscillation is characterized by considerable values and mostly depends on the train speed, axle load and reinforcement type. It averaged from 63 to 88% of the resulting value for all types of reinforcing.

Horizontal component aligned across the track has comparable amplitude with the horizontal component along the track for all cross-sections but its magnitude is 20-25% higher. This component does not greatly depend on the speed of the train, but the increase rate of oscillation amplitudes is slightly higher than for horizontal component along the track. Data of oscillation amplitude measurement are presented in Table 2.

Resulting oscillations and oscillation components have complex nature and differ greatly from harmonic oscillations and they are stochastic processes in general. A comparison of soil oscillations essence in different directions allows obtaining a qualitative pattern of components amplitude ratio.

When Type 4 geosynthetics had been laid on the top of subgrade, oscillation increased from 307 μm to 414 μm at 20 km/h speed, which is 26 % more. At 40 km/h speed this difference was 15 %. However, in our opinion, we should not make a hasty conclusion that this geosynthetics layer increases the amplitude. Value increasing may occur because of the ballast, which might not be sufficiently compacted in cells. It is not possible to compact it by tamping machines. Perhaps ballast in the cells will be compacted by passing trains during certain time. Therefore, it is necessary to perform further study for more precise answer to the question about the impact of Type 4 geosynthetics on oscillation process.

Two layers of Type 1 or Type 2 geosynthetics in ballast can reduce oscillation amplitude in the whole range of speed. So, for example at 50 km/h speed amplitude decreases from 633 μm to 559 μm for Type 1 and to 518 μm for Type 2 grid, which is less for 12% and 18% in comparison with the control cross-section correspondingly.

Laying under ballast of one layer Type 1, 2 or 3 geosynthetics increases oscillation amplitude of the horizontal component across the track, measured in the soil layer over geosynthetics, on average 25 – 35 % at all speeds compared to the control cross-section. This leads to increasing of resulting vibrations by 20-30 %. Since Type 1, 2, 3 geosynthetics (bi-oriented geogrid) have both longitudinal and transverse ribs, oscillations amplitude increasing is related to the fact that sensors detect the longitudinal displacement caused by the geogrid pulling from sleeper end due to geogrid deflection under passing trains.

XPS plate (Type 5 geosynthetics layer) has positive role in reducing oscillation effects on the top of subgrade soils. Here, a decrease in oscillation amplitude is 10 - 15% compared to standard cross-section.

Analysis of oscillation amplitudes growth depending on train speed was carried out for each component for different cross-sections. For all cross-sections, the vertical component of oscillation has maximum growth rate and horizontal component along the track has minimum growth rate.

Table 2. Field test results.

Geosynthetics type	Oscillation components	Oscillation amplitude, µm				
		CHS-200	2VL-10			
		60 km/h	20 km/h	30 km/h	40 km/h	50 km/h
Without reinforcement	Ax	246	69	194	215	207
	Ay	257	77	231	215	205
	Az	457	296	397	378	567
	Ares	477	307	498	440	633
Type 4	Ax	107	133	197	149	294
	Ay	211	139	190	145	184
	Az	410	373	387	472	455
	Ares	531	414	517	519	562
Type 2, two layers	Ax	241	168	153	213	232
	Ay	222	166	217	185	273
	Az	399	187	300	416	379
	Ares	491	238	367	464	559
Type 1, two layers	Ax	193	140	174	150	210
	Ay	170	170	222	163	239
	Az	276	226	296	373	468
	Ares	357	225	329	473	518
Type 1,2,3, two layers (*)	Ax	257	230	240	272	220
	Ay	272	307	326	367	327
	Az	440	388	351	456	485
	Ares	468	546	660	671	816
Type 5	Ax	194	163	138	170	179
	Ay	200	205	225	227	253
	Az	372	348	378	437	396
	Ares	410	399	431	457	530

(*) – oscillation sensors were installed on the geosynthetics

Railway track reinforcement with Type 4 or Type 5 geosynthetics leads to reducing of train speed influence on resultant amplitude. For control cross-section resulting oscillation amplitude increases with the intensity of 92 microns for every 10 km/h of speed increasing , in case of laying Type 5 geosynthetics its value was 44 µm, and in the case of geosynthetics Type 4 - 41 µm. Similar results are observed for the vertical component. Reduction was from 79 µm for the control cross-section to 33 µm for Type 4 geosynthetics and 20 µm for Type 5 geosynthetics for every 10 km/h of speed increasing.

The Type 4 geosynthetics on the top of subgrade reduces growth intensity of oscillation horizontal components across and along the track respectively from 37 µm to 15 µm and from 43 µm to 8 µm.

Laying under ballast Type 1, 2, 3 geosynthetics in a single layer and Type 1 or Type 2 geosynthetics in two layers does not significantly reduce speed influence on roadbed oscillation level. In case of placing two geogrid layers resulting oscillation amplitude increases with average intensity of 95 microns for every 10 km/h of speed increasing and in case of one layer reinforcement it was 88 microns.

Presence of Type 4 geosynthetics (geocells) in the subballast slightly increases the growth rate of the horizontal component across the track. It increased from 37 µm to 43 µm for every 10 km/h of speed increasing, however, for the horizontal component along the track it is significantly reduced from 43 µm to 9 µm. We would like to note that we had the same research result of oscillatory process of subgrade in sections with concrete reinforcing. Thus, we can predict that Type 4 geosynthetics (geocells) perform like subballast plate, which allows reducing vibration in addition to stress redistribution at the top of subgrade.

From all that has been said, it follows that XPS plates and geocells have the best damping capacity of oscillating process, while the XPS plates have the best dissipative properties.

4 CONCLUSIONS

This paper discusses results of field studies conducted at Emperor Alexander I St. Petersburg State Transport University for track performance enhancement.

Field test data show that increasing of rolling stock axle loads from 225 to 294 kN/axle causes growth of vertical vibrational acceleration. Maximal vibrational acceleration values are recorded at the underrail section. This fact highlights the problem of railway track stability in terms of axle load and speed increasing.

Oscillation process of ballast and top of subgrade with different geosynsetics types were assessed. Biaxial geogrids in ballast layer are suitable solution to reduce oscillation of the top of substructure. Geocells and two-layered biaxial geogrid reinforcement are very effective for stresses redistribution in subballast. XPS plates also reduce oscillation amplitude on the top of subgrade and thus they demonstrate potential of their use in track. Oscillation values increasing is due to difficulty of ballast compaction in the cells. Optimal particle size mixture should be put in a cell to achieve the maximum effect of reinforcement. Laying under ballast of one layer of bi-oriented geogrid increases horizontal component oscillation amplitude across the track, measured in the soil layer over geosynthetics, due to geogrid longitudinal displacement under train passing. The study results allow us to recommend geosynthetics for using as a low-cost solution to stabilize substructure.

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