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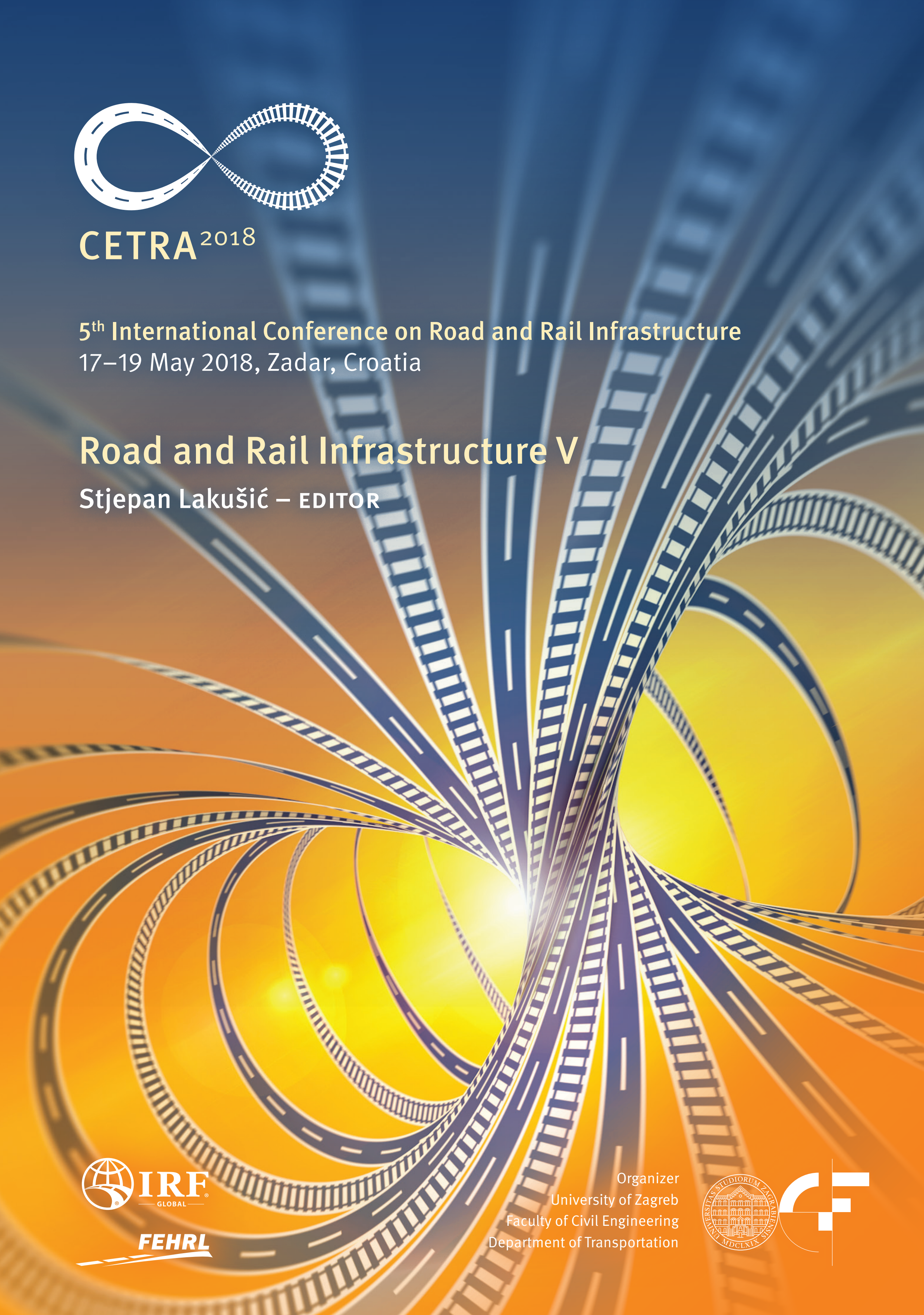
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure V

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VIBRODINAMIC IMPACT ON THE RAILWAY SUBSTRUCTURE AND METHODS OF ITS REDUCTION

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Abstract

Increase of train speeds induces increased levels of vibration and structural noise in residential areas. The railway track stability and the reducing of harmful vibration influence on the environment can be achieved by means of the rail base stiffness optimization. The experimental plots were laid with different types of under ballast mats. It is shown that the polyurethane ballast mats are 1.9 times more effective than two layers of geocomposite and 1.5 times more effective than the porous rubber mats. The advantage of this technical solution is the possibility of its implementation both on a separate local section and in conjunction with the track repair without reducing repairing speed.

Keywords: vibration, stiffness, under ballast mat, geogrids

1 Introduction

Heavy and heavy-duty trains moving leads to the problems in the condition of roadbed main plan and the ballast layer. The decisive factor that reduces the operational reliability of the track is not the length of the train, but the axial and per meter loads. Therefore, it is necessary to develop and implement the modern technology and design solutions to ensure ballast and subgrade reliability under the impact of heavy trains [1-3]. The railway track stability and the reducing of harmful vibration influence on the environment can be achieved by means of the rail base stiffness optimizations.
The under ballast reinforcement technology is widely used during the reconstruction of lines for high-speed passenger trains, which allow to ensure the operational reliability of the roadbed working area. These works are performed during railway tracks repairing in parallel with cleaning ballast by means of cleaning machines of a new generation without removing the rodding.
Increasing the stiffness of the roadbed due to the under ballast protective layers with the increase at the same time in axial loads leads to an increase in the ballast stress, to a track deterioration, reducing its service life and, consequently, to a disproportionate increase in the cost of road maintenance. The long-term behaviour of the railway track depend on the pressure on the ballast is estimated by the function with the exponent 2 and 4 [5].
The stress in the subgrade is significantly reduced and distributed more evenly after under ballast layer reinforcement. A number of researchers note the positive impact of these procedures on reducing the track deformability. So, in particular, it is noted that on the sections of the road with a less rigid sub ballast base, the economic efficiency of the protective layers will be higher, since there the deformations of the track is developed faster and, consequently, the aligning of the track is needed more often [4]. However, this conclusion is refuted in the paper [5], where the author argues that the higher the axle load and the more intensively the ballast prism is fouled, the less should be the rigidity of the railway track. This is due to the di-

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sadvantages of the modern ballast rails track with concrete sleepers, which include: rigid contact between the ballast and the sleeper, high sensitivity to the ballast base heterogeneity, a small sleeper contact area, relatively high loads on the ballast with a rigid substructure [6]. There are two ways to reduce the negative impact on the track from heavy-duty trains: by increasing the bearing capacity of the ballast and reducing the level of operating stress in it.

1.1 The Increasing of ballast bearing capacity

The first way is a full replacement of the existing ballast during repairing with the laying of a new high-quality crushed stone ballast, which is not previously used. This is a complex and painstaking work, which requires a careful control from the consumer. Angular particles provide a greater resistance to the repeated loads [7]. The strength and stiffness of the ballast layer are decreased during the minimization of particles roughness due to abrasive wearing, and as a result, the track deformations is increased [8]. The ballast with rounded particles after cleaning has strength and deformation characteristics lower than the new one, even if its grain size composition is satisfied to the standard.
The geogrids are a complex solution for the creation of a sleeper bearing with equally stiffness, which provides the track stability. The geogrid (not geocell) is laid at a depth of 45 cm from the sleeper bearing surface during working of ballast cleaning machine. Ballast particles penetrate through the geogrid mesh and they are fixed in it, creating the “blocking” effect. Due to their high rigidity, the geogrid allows the ballast to withstand heavy loads at low deformations, and thereby increases its bearing capacity by 20-40 %. In addition the stress is redistributed on the top of subgrade, which reduces the probability of plastic deformations formation in the local zones, especially in the under rail sections. Plastic deformation leads to the pumping track and depression of track, which in the future can lead to loss of bearing capacity and stability of the roadbed. The advantage of this technical solution is the possibility of its implementation both on a separate local section and in conjunction with the track repair without reducing repairing speed.

1.2 Decrease in the level of acting stresses in the ballast

It is possible to provide the track stability by means of control the track elasticity modulus. To do this, it is necessary to achieve the stiffness of the sub-rail base within the specified limits (deflection under the wheel load of 12 tons about 4 mm) [9]. Low elasticity prevents an unacceptable depression of the track during passing high-speed trains, but excessively high stiffness of the track base under heavy axis load leads to an increasing in the pressure of the rail on the sleeper and to an accelerated track lowering.
The most effective reserve for improving the track reliability is a reducing the level of vibration impact on the roadbed and ballast prism. In such cases, the optimal solution is to lay the elastic layer, which reduces vibrations and noises from the rolling stock and allows controlling the stiffness of the sub-rail base.
The elasticity modulus of the upper structure can be reduced by the use of elastic under rail pads [10], but their use requires the use of rails with wider bottom to avoid premature damage due to mechanical stress under high axial loads and limiting lateral deflection of the railhead under the action of a rolling wheel.
An alternative to this is the use of elastic under sleeper pads. In the laboratory tests it was found that due to an elastic sleeper bearing, the position of the particles of the ballast upper layer are stabilized and the displacement of the particles take place in deeper places. This ensures a uniform distribution of the contact pressure under the sleeper and leads to an increase in the particles contact area, which is inversely proportional to the base stiffness. The process of railway track stabilization is much slower on the sleepers with an elastic base, which favourably effects on it long-term stability.

The experiments which was carried out with the sleepers, on the lower surface of which an elastic material was applied, showed that a protective layer is needed here, which prevents the punching failure of the elastic material by the crushed stone particles. Together with the expected decrease in track depression and high quality of the track geometry, the undesirable bending resonant vibrations of the sleepers were found, which lead to their destruction [11], the values of which increase with the decrease in the elastic layer stiffness. In addition, the transverse shear resistance was less than expected. The disadvantages of sleepers with elastic soles include additional costs for the maintenance in particular to control the damage occurrences of the elastic layer and its repair during maintenance (during tamping and track adjusting) [6]. One of the most effective solutions to improve the elasticity of the railway track is the laying of the elastic layer in the form of under ballast mats Figure 1.

Figure 1 Under ballast mat

Such solution can reduce the vibration level in the ballast and the growth rate of residual strain of the rail track by 3-4 times, it reduces the ballast wear by 50 % and thereby reduces the track maintenance cost [12]. This solution significantly reduces the railway track vibrations resonance frequency and is devoid of the previously described methods drawbacks to increase the elasticity, as it does not reduce superstructure lateral stability, has a long service life due to the lower stresses level on the mat surface and distance from the influence zone of track machines.

2 Under ballast mat method

In order to test under ballast mats under operational conditions, the Russian Ministry of Railways requested St. Petersburg State Transport University to arrange a pilot area of the main line track of the railway between St. Petersburg and Moscow. The pilot area was prepared during the line overhaul. The pilot area consists of 4 test sections: under-ballast vibration protection materials were installed at three of those sections and the forth one was a reference section. The total length of the pilot area was about 100 m.

Under-ballast vibration protection materials included polyurethane mats (Sylomer Getzner Werkstoffe), porous rubber mats (Elapor) and two layers of geocomposite (ENKADRAIN Colbond Geosynthetics). Static stiffness of mats was 0.03 N/mm^3 and 0.06 N/m^3 correspondingly. The geocomposite material was net drainage mats of polyethylene placed between two layers of geotextile. The vibration protection materials were selected following the study of existing under ballast mats and theoretical research.

The pilot area was an embankment up to 2 m high filled of sand and the foundation of loam clay. The track superstructure has the following parameters: jointless track, the P65 rails, reinforced concrete sleepers and rail fasteners KB. The track is located in the immediate vicinity of Sablino village. Under ballast mats were laid out using a method similar to installation of a geofoam separating layer in the ballast prism. Crushed stone was removed to the depth of 40 cm from sleepers' bed and the mats were laid out across the width of 4 m. The work was

done by a ballast cleaner machine RM-80. Cleaned ballast was placed onto the mats behind a cutting bar. The thickness of each vibration protection layer made of elastic mats was 2.5 cm. Geocomposite material was placed in two layers, one above the other, with a total thickness of 2.4 cm.
Special instruments and geophones CM-3 were used for assessing the influence of installed vibration protection elements on subgrade soil oscillations within the main subgrade surface. Measurements were taken both at cross-sections of each test section with vibration protection installed and at the reference section.

3 Damping factor evaluation for under ballast mats of various materials

Experimental data was obtained for the test sections with various types of vibration protection elements laid in the foundation of the ballast section. The obtained values of oscillation amplitudes were compared with each other and with the data registered at the reference section having a standard ballast structure. The analysis of the measured data and the curves of resulting oscillation amplitudes (A_p) and their components (A_x, A_y, A_z) as a function of the train speed shows a direct relationship between all oscillation amplitudes and the train speed. Figure 2 shows the curve of soil oscillation amplitude changes (A_p) at the level of the main subgrade surface as a speed function of a train driven by a CHS-2T locomotive.

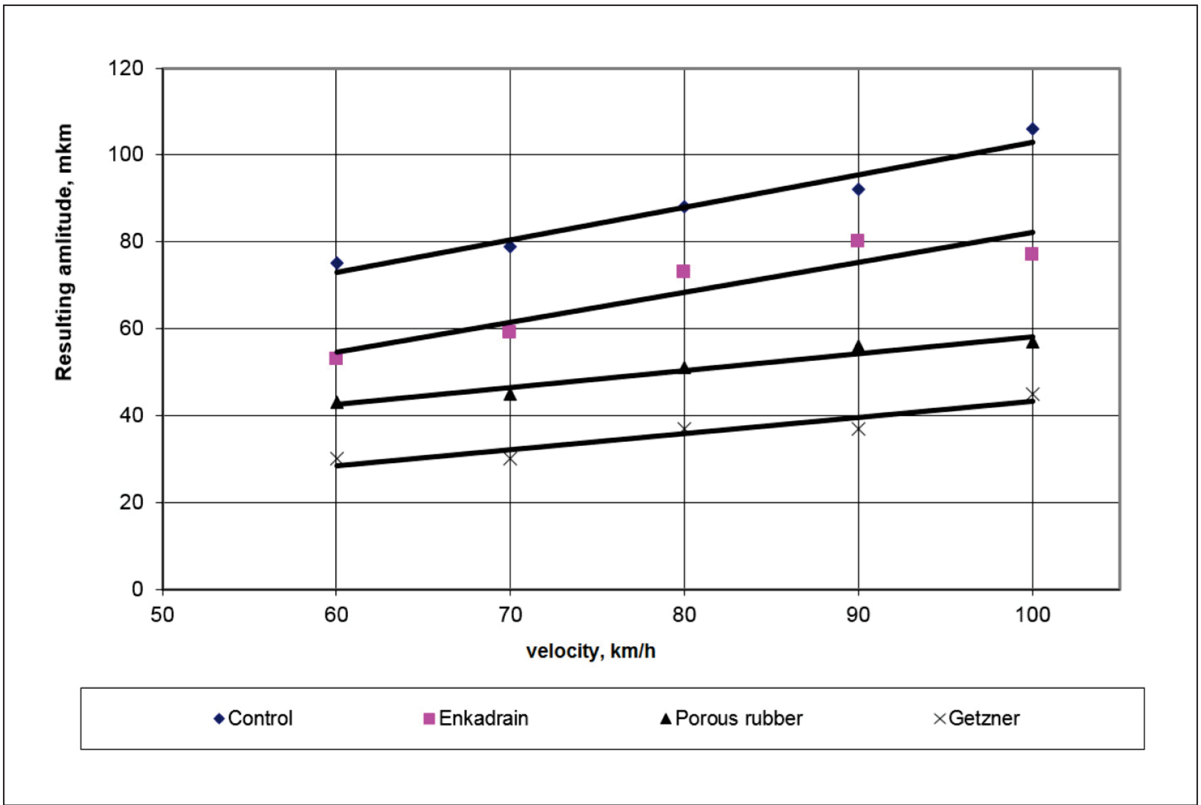

Figure 2 Relationship of resulting oscillation amplitudes as a speed function of a train driven by a CHS-2T locomotive with account of different types of vibration protection materials laid in the ballast layer

The above relationships show that the application of vibration protection layers in the railway track structure can reduce the amplitude increase rate (A_p) at increased train speeds. With application of polyurethane mats, A_p can be reduced 2 times, with porous rubber mats – 1.9 times and when 2 layers of geocomposite material are used – 1.1 times. It was also found out that in all cases the application of vibration protection layers under the ballast considerably reduces vertical oscillations (A_z).

To estimate the decrease of resulting amplitudes of soil oscillations, a damping factor was used that can be defined as:

$$K_d = \frac{A_t}{A_i}$$

Where:

At – is an oscillation amplitude at the main subgrade surface for a standard ballast structure, μm;

Ai – is an oscillation amplitude under the vibration protection material placed onto the main subgrade surface, μm.

The damping factor for each material was determined as an arithmetic mean of amplitudes at various train speeds. The analysis of the calculated damping factors shows that the applied materials have different damping capacity for oscillations that are transmitted from the track superstructure to the subgrade. The maximum decrease of the resulting oscillation amplitudes is observed where polyurethane mats are installed (Kd = 2.47) and the minimum decrease is observed when two layers of geocomposite mats are applied (Kd = 1.30), while porous rubber mats show Kd = 1.75. Comparison of damping factors of different tested materials showed that polyurethane mats are 1.9 times more effective than two layers of geocomposite material and 1.5 times more effective than porous rubber mats.

4 Estimation of vibration reduction by under ballast mats

At design stage, the reduction of vibration levels can be assessed by calculation [13]. If under ballast mats are placed directly onto the subgrade without reinforcing the sub-ballast, vibration damping due to the mat can be defined as:

$$\Delta L = 20\lg\left|1 + \frac{\beta_s \beta_\delta}{\left[\beta_s\left(1 - \left(\frac{f_0}{f}\right)^2\right) + \beta_\delta\right]\beta_M}\right|, \quad \text{dB} \tag{1}$$

Where:

β_s – subgrade soil stiffness, N/m, which is usually 1 to 3*10^8 N/m and is calculated with the formula:

$$\beta_s = \frac{nP_{ax}}{y}, \quad \text{N/m} \tag{2}$$

Where:

n – number of car axles,

P_{ax} – load from one axle to the track, N

y – vertical deformation of the main subgrade surface under train load, m,

f_0 – resonant frequency determined as:

$$f_0 \approx \frac{1}{2\pi}\sqrt{\frac{\beta_\delta}{M}}, \quad \text{Hz} \tag{3}$$

Where:

β_δ – ballast stiffness, N/m; for crushed stone ballast, $\beta\delta$ = 5*10^8(1+0,5i), N/m;

M – unspring mass of a wheelset, kg.

f – frequency for which vibration reduction is calculated, Hz. For engineering analysis, it is assumed to be 4, 8, 16, 31.5, 64, 128 and 250 Hz.

β_M – stiffness of under ballast mat which is defined as:

$$\beta_M = \beta_{Mdyn} S(1+i), \quad N/m \tag{4}$$

Where:

β_{Mdyn} – dynamic stiffness of the under ballast mat for the corresponding frequency range, N/m3, which is determined as:

$$B_{Mdyn} = \frac{E_{dyn}}{d} \tag{5}$$

Where:

d – the thickness of elastic mat;

E_{dyn} – dynamic elastic modulus;

x – the coefficient of insertion loss due to the under ballast mat, which is accepted in line with the mat specification;

S – ballast effective area, which is determined based on conical configuration of load accommodation and distribution under the sleeper, m_2. It is 1.3 m_2 for the super structure of typical design.

If the calculated vibration insertion loss due to under ballast mats placed on the subgrade is not sufficient, additional measures should be provided to increase the total foundation impedance. This can be achieved by increasing the stiffness of the under ballast bed with protection cement soil layers or compacted sand and gravel mixtures. The insertion loss ΔL is defined as:

$$\Delta L = 20\lg\left|1+\frac{\frac{\beta_\delta}{\beta_M}}{1-\left(\frac{f_0}{f}\right)^2}\right|, \quad dB \tag{6}$$

The calculations performed following the above methodology have shown that for a standard track structure with reinforced concrete sleepers, crushed stone ballast prism and non-deforming subgrade, the optimal stiffness of the under ballast mat is within the range of 0.5 – 1.0 N/m. Elastic mats with such stiffness are produced by various companies; however field and laboratory tests performed show that Sylomer D 619 under ballast mats produced by Getzner Werkstoffe GmbH satisfy the requirements in the best way.

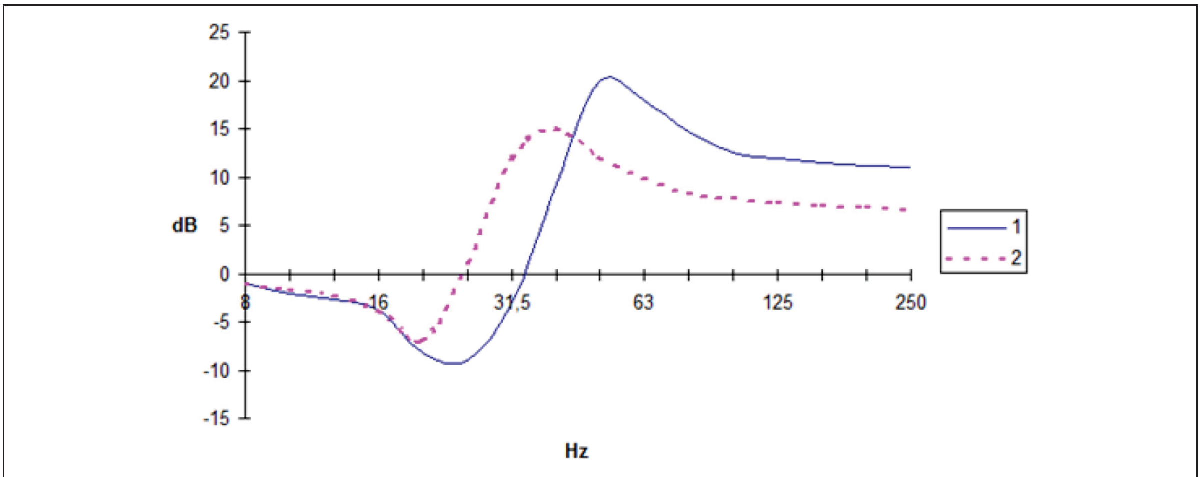

Figure 3 Vibration level reduction by under ballast mats placed on stiff foundation (1) and on the subgrade (2)

Figure 3 shows the curves of vibration reduction for the above under ballast mats placed in the track superstructure of a standard design. The analysis of the calculated data shows that the application of mats allows reducing the vibration level by 15-20 dB at frequencies over 31.5 Hz. It is estimated that the corresponding reduction of structure-borne noise will be the same.

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