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RECYTRACK Project: Elastomeric Eco-friendly Material Based on End-of-Life Tires Blended with Organic Bind Resin for Railway Applications

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Abstract: RECYTRACK is a 3.5 year project granted by the European Commission through LIFE+ 2010 program. The overall objective of the project is to demonstrate the environmental benefits and technical feasibility of the implementation of an elastomeric eco-friendly material made of end-of-life tires with resin for railway applications. Within the project, AV Ingenieros jointly with LEAM, carries out the study of the vibration behavior of the eco-friendly material, which will be applied as a mat for ballasted tracks as well as an isolated block system for slab tracks. Firstly, an analytical model capable to predict the efficiency of the eco-friendly material as a vibration mitigation measure has been developed. Subsequently, and after the implementation of the eco-friendly solutions in real railway infrastructures, its vibration behavior will be measured and validated through in situ measurements during regular service. In this paper the analytical model is defined, the elastomeric material dynamic experimental characterization is described and the under ballast mat Insertion Loss is calculated for two different soil stiffness.

Key words: Vibration, railway, modeling, isolation, eco-friendly.

1. Introduction

On the one hand, as ETRMA (European Tire & Rubber Manufacturers' Association), stated in its annual activity report 2007, during that year Europe generated more than 3.4 million ton end-of-life tires, corresponding to about 300 million units [1]. Fig. 1 shows an end-of-life tires warehouse near Madrid. On the other hand, 2008/98/EC directive about waste materials establishes that products from end-of-life tires are not considered as waste but are considered as by-product for new applications. RECYTRACK project applies this orientation and is developing a new product using technical solutions that allow end-of-life tires recycling.

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The main objective of the project is to demonstrate the environmental benefits and technical and economic feasibility of the implementation of an elastomeric eco-friendly material made of end-of-life tires blended with resin. The proposed solutions are an elastomeric UBM (under ballast mat) to be used in ballasted tracks and an elastomeric IBS (isolated block system) to be used in concrete slab tracks. Thanks to these solutions and as a planning for the future, a minimum revalorization of 1.5 million tires is foreseen for the next 10 years. In terms of economical indicators, saving of more than 5.8 M€ can be estimated considering the previous plan.

One of the expected environmental benefits to be obtained from the elastomeric solutions is the reduction of the ground-borne vibration level induced near the infrastructure. Consequently, ground-borne vibrations induced in nearby buildings will be reduced too. This

Fig. 1 View of an end-of-life tire warehouse near Madrid (Spain).

will entail a comfort improvement inside buildings located nearby the railway infrastructure and susceptible to be affected by undesired vibration levels.

This paper describes the methodology used to calculate the IL (Insertion Loss), provided by the UBM developed within the framework of RECYTRACK project. In section 2, the elastomeric products developed within RECYTRACK project are described while section 3 describes the analytical superstructure/ground model that has been developed to assess the Insertion Loss as well as the experimental mat dynamic characterization in order to get the values to feed the model. The model is based on an elementary superstructure model with no elastomeric material [2] and is conveniently modified to introduce the UBM in the case of ballasted tracks, and the IBS in the case of slab tracks. Section 4 shows the obtained results: UBM dynamic parameters experimentally obtained at LADICIM laboratory and the predicted IL that can be obtained using the UBM in two different types of soils. Finally, section 5 summarizes the conclusions of the investigation.

2. Elastomeric Solutions

The UBM is a continuous elastomeric element placed under the ballast layer while the IBS is a discrete elastomeric isolated block, placed between a concrete block acting as a sleeper and the track's concrete slab.

Both solutions provide the railway superstructure a low stiffness layer, allowing in the majority of cases to reduce the track maintenance costs as well as to increase the abatement of the vibration energy generated at the wheel-rail contact area and transmitted to the surrounding ground. Figs. 2 and 3 show a sample of UBM and IBS and their solutions' concept, respectively.

The innovative aspect in these solutions is the revalorization of a waste (as end-of-life tires) into a new product which contributes to increase the track elasticity. Furthermore, end-of-life tires are ageing resistant, which is an important characteristic for elements to be placed under a railway infrastructure because of its costly replacement.

(a)

(b)

Fig. 2 (a) A sample of the developed UBM and (b) the UBM placed in the railway superstructure.

(a)

(b)

Fig. 3 (a) A sample of the developed IBS and (b) the IBS placed in the railway superstructure.

3. Elastomeric Solutions' Vibration Design

Vibration generation in railway systems is due to the axle loads generated in the wheel/rail contact. These loads can be classified as [3]: quasi-static excitation, caused by the static component of axle loads moving along the track, and dynamic excitation, due to the spatial variation of the support stiffness along the track as well as wheel and rail roughness. Quasi-static excitation dominates track response while dynamic excitation dominates ground free field response [3, 4], when sub-Rayleigh train speed is considered. The superstructure model must take into account these excitations in order to assess the ground-borne vibration level.

The frequency range of interest to assess track response lies between 20 Hz and 1,500 Hz [5, 6] and between 20 Hz and 250 Hz to evaluate the ground borne vibration levels [7, 8]. Standards [9, 10] establish the range 1-80 Hz as the interesting frequency range to assess human exposure to vibration into buildings. Therefore, any abatement solution defined to reduce vibration levels into buildings must be effective within the aforementioned frequency range, although the range 1-20 Hz is not really meaningful when low or mid speed trains are considered.

3.1 Theoretical Background

Superstructure is modeled as a 2-layer continuously supported model where the rail is assumed to be an Euler-Bernoulli beam [6]. The dynamic coupling between rails is not taken into account because the sleepers are considered as completely rigid elements. The contact force between sleepers and soil is considered as a continuous function in the longitudinal track direction while in the transversal track direction it is considered as a rectangular function. Fig. 4 shows an outline of the superstructure model, where z_r, z_s and z_g are the rail, sleepers and soil displacements, respectively, k_f, k_b and k_{bm} are the fastening, ballast and under-ballast mat stiffnesses, c_f, c_b and c_{bm} are the fastening, ballast and under-ballast mat viscous dampings,

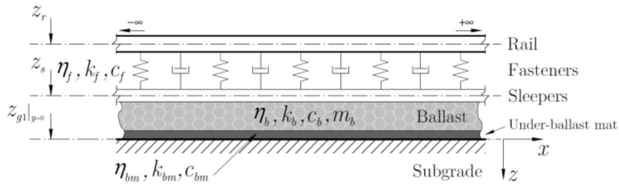

Fig. 4 Outline of the considered superstructure model, which includes the under-ballast mat.

and m_b is the ballast mass. Stiffness, damping and sleepers mass are continuously distributed parameters along the track.

Governing equation for the vertical track displacement, z_r, due to wave propagation along it is as Eq. (1) [11] shows:

$$EI\frac{\partial^4 z_r}{\partial x^4} + \rho S\frac{\partial^2 z_r}{\partial t^4} + f(x,t) = q(x,t) \tag{1}$$

where, E is the Young Modulus, I is the rail second moment of inertia, ρ is the rail density, S is the rail cross-sectional area, $f(x, t)$ is the distributed force due to the sleepers and $q(x, t)$ is the distributed force due to the train. As can be deduced from Fig. 4, the distributed force due to sleepers can be described by Eq. (2) and the sleeper motion by Eq. (3):

$$f(x,t) = k_F(z_r - z_s) + c_F(\dot{z}_r - \dot{z}_s) \tag{2}$$

$$\begin{aligned} &k_F(z_r - z_s) + c_F(\dot{z}_r - \dot{z}_s) - \\ &-k_B(z_s - z_g) - c_B(\dot{z}_s - \dot{z}_g) = m_s\ddot{Z}_s \end{aligned} \tag{3}$$

where, m_z is the sleeper mass. Sleepers apply a force onto the soil, called superstructure-soil coupling force, which can be expressed as Eq. (4)

$$f_g(x,t) = k_B(z_s - z_g) + c_B(\dot{z}_s - \dot{z}_g) \tag{4}$$

Ground is modeled as a homogeneous and viscoelastic half-space defined by Lamé constants, λ and μ, soil density, ρ, and P and S wave damping, D_P and D_S, respectively. To go into detail about ground modeling, refer to Ref. [12].

3.2 Elastomeric Mat Dynamic Characterization

Elastomeric product has to be dynamically tested between 1 Hz and 80 Hz in order to characterize its behavior within this frequency range of interest. They are assumed to be linear massless damped springs with frequency dependant and uniformly distributed parameters. These experimental tests have been performed at LADICIM (Universidad de Cantabria) laboratory.

As shown in Fig. 5, eight seismic accelerometers have been used to perform the measurements: a set of four accelerometers placed on the upper plate, where a hydraulic actuator applies a vertical force and another set of four accelerometers placed on the bank. These second group of accelerometers are used to ensure that the bank has no significant motion. If so, their vibration displacements are subtracted to the respective upper plate accelerometers displacement. The force applied by the hydraulic actuator is acquired with a load cell.

Recorded vibration accelerations were integrated to vibration displacements, allowing to the construction of the hysteretic loops. For each frequency four hysteretic loops are obtained, since there are four accelerometers on the upper plate.

3.3 Hysteretic Loop Method to Assess the UBM/IBS Dynamical Parameters

This method is based on the extraction of experimental hysteretic loops and fit them with theoretical hysteretic loops obtained from a 1 DOF system, as illustrated in Fig. 6, where k_{bm}, c_{bm} and η_{bm} are the stiffness, viscous damping and structural damping of the RECYTRACK under-ballast mat, respectively, and m is the vibrating mass. Same procedure can be applied to isolated block system.

Assuming that the dynamic load excitation is $f(t) = F{\cdot}\cos(\omega t + \varphi)$, where F is its amplitude and φ is its phase, the vibration displacement associated to this dynamic load for 1 DOF system is as stated in Eq. (5):

$$z_{up}(t) - z_{down}(t) = -\frac{F}{(k_{bm} - m\omega^2)^2 + (\eta_{bm}k_{bm} + \omega c_{bm})^2}\cos(\omega t + \varphi - \frac{\pi}{2} + \theta) \quad (5)$$

Fig. 5 Front and upper view of the experimental setup to dynamically characterize the UBM.

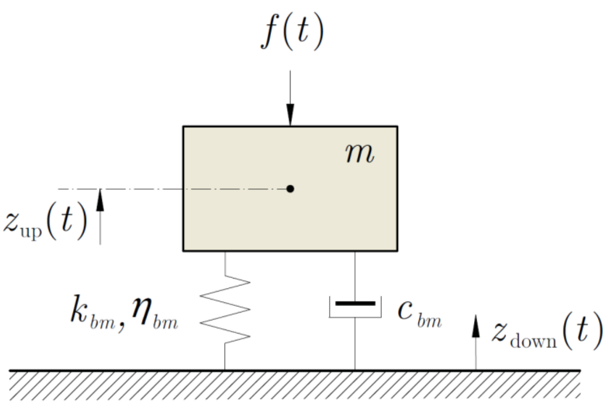

Fig. 6 Theoretical model used to fit experimental hysteretic loops and to assess material dynamical properties.

where,

$$\theta = \tan^{-1}(\frac{k_{bm} - m\omega^2}{\eta_{bm}k_{bm} + \omega c_{bm}}) + \begin{cases} 0 & \text{if } \eta_{bm}k_{bm} + \omega c_{bm} \geq 0 \\ \pi & \text{if } \eta_{bm}k_{bm} + \omega c_{bm} < 0 \end{cases},$$

$z_{up}(t)$ is the vibration displacement of an upper accelerometer and $z_{down}(t)$ is the vibration displacement of its associated lower accelerometer. The fitting of the experimental hysteretic loops with Eq. (5) gives the equivalent dynamic parameters of the mat: k_{bm}, c_{bm} and η_{bm}. Fig. 7 shows two examples of hysteretic loop fitting, where blue lines are experimental data and green line is the theoretical hysteretic loop.

3.4 IL (Insertion Loss) Calculation

The *IL* (insertion loss) is the parameter used to define the difference of vibration level in a specific location due to the insertion of an elastomeric material (UBM or IBS) in the railway superstructure.

To perform the *IL* calculation of the RECYTRACK UBM or IBS, the model outlined in Fig. 4 (isolated model) and the same model without the elastomeric layer (unisolated model) are used. Both models are fed using the dynamic parameters of the elastomeric solutions calculated as stated in previous section. The

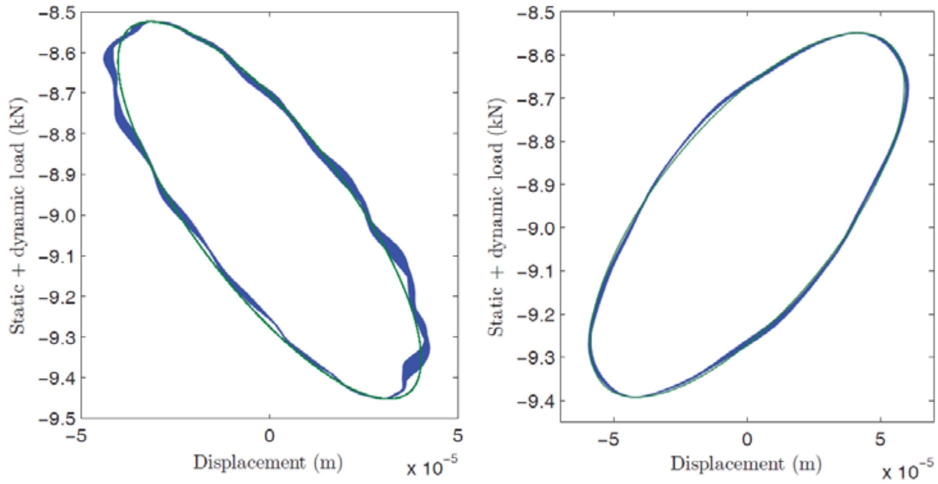

Fig. 7 Experimental and theoretical hysteretic loops at 12.5 Hz and 32.5 Hz excitation frequencies.

receptance of the ground surface at x = 0 m and y = 8 m [13] due to a vertical harmonic load applied on the railhead at x = 0 m is calculated for both unisolated and isolated cases. Each of these receptances has three components $X_{g1}(x,y,\omega)$, $Y_{g1}(x,y,\omega)$, $Z_{g1}(x,y,\omega)$, where x and y are the spatial coordinates according to Fig. 4 and ω is the frequency. These three components can be integrated in a global value by the following expressions:

$$U_{g1}^{uniso}(x,y,\omega)=\sqrt{\left|X_{g1}^{uniso}(x,y,\omega)\right|^2+\left|Y_{g1}^{uniso}(x,y,\omega)\right|^2+\left|Z_{g1}^{uniso}(x,y,\omega)\right|^2} \quad (6)$$

$$U_{g1}^{iso}(x,y,\omega)=\sqrt{\left|X_{g1}^{iso}(x,y,\omega)\right|^2+\left|Y_{g1}^{iso}(x,y,\omega)\right|^2+\left|Z_{g1}^{iso}(x,y,\omega)\right|^2} \quad (7)$$

Setting x = 0, the IL is calculated for any distance to the track y using Eq. (8):

$$IL=20\log_{10}\left(\frac{U_{g1}^{uniso}(0,y,\omega)}{U_{g1}^{iso}(0,y,\omega)}\right) \quad (8)$$

4. Results

Some of the dynamic UBM parameters, like C_{dyn} and c_{bm}, experimentally obtained using the hysteretic loop method, are shown in Figs. 8 and 9.

Insertion Loss, IL, calculation as a function of frequency in the range 1-80 Hz at different distances y from the track using the methodology previously described, are shown in Figs. 10 and 11. In order to take into account the whole range of possible soils, in this figures, the UBM IL is calculated for two types of soils: one representing a soft soil (50 MPa) and another one representing a stiff soil (300 MPa).

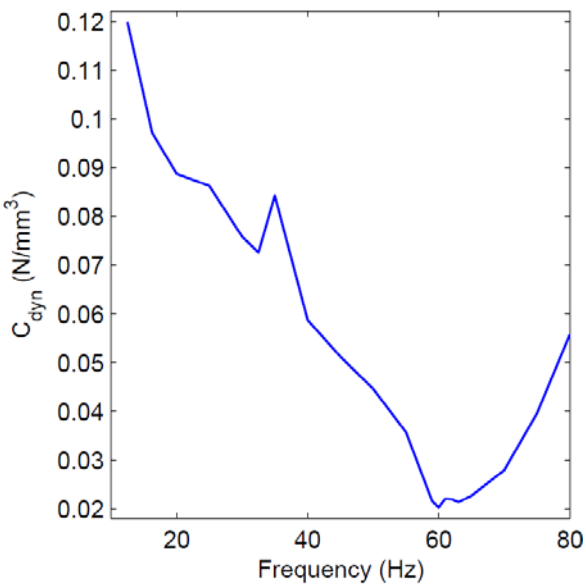

Fig. 8 Results of C_{dyn}.

5. Conclusions

An analytical prediction model to calculate the IL (Insertion Loss), provided by an elastomeric solution applied to the railway superstructure has been developed. To feed this model with accurate values, an experimental dynamic characterization of the UBM (under ballast mat) and the IBS (isolated block system)

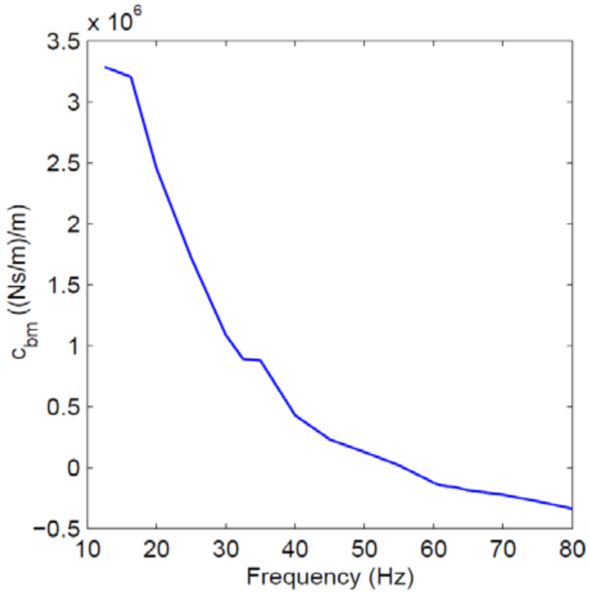

Fig. 9 Results of c_{bm}.

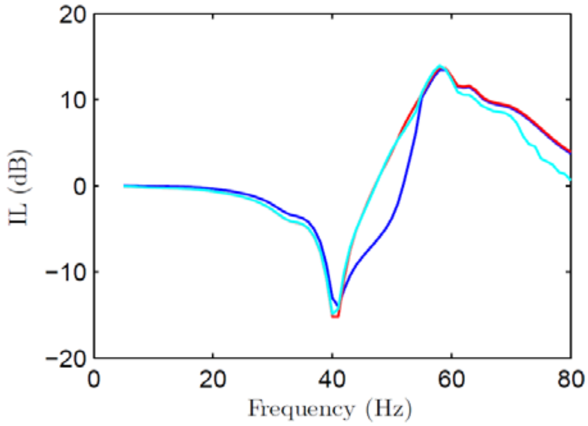

Fig. 10 Results of the *IL* prediction for the UBM at *y* = 2 m (dark blue), *y* = 8 m (red) and *y* = 15 m (light blue) on soft soil.

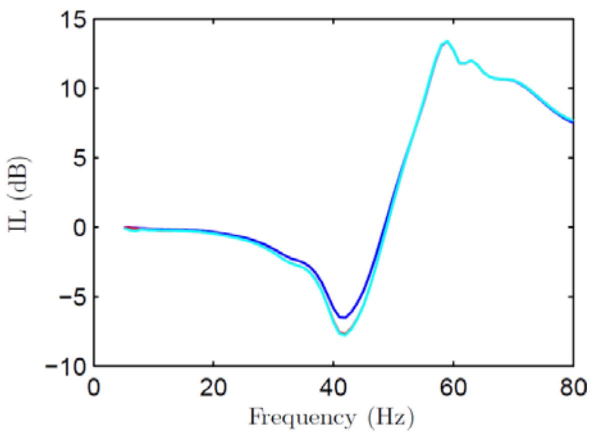

Fig. 11 Results of the *IL* prediction for the UBM at *y* = 2 m (dark blue), *y* = 8 m (red) and *y* = 15 m (light blue) on stiff soil.

has been performed at LADICIM (Universidad de Cantabria).

Experimental acceleration signals have been measured, vibration displacements have been obtained by integration of these signals and experimental hysteretic loops have been calculated. Using a 1 DOF system, experimental hysteretic loops have been fitted to theoretical hysteretic loops with high accuracy in order to obtain the UBM and IBS dynamic parameters: k_{bm}, c_{bm} and η_{bm}.

These parameters have been then used to feed the prediction model capable to calculate the IL, which has been defined as a 2-layer continuously supported model where the rail is considered as an Euler-Bernoulli beam and the soil is modeled as a homogeneous and viscoelastic half-space.

The IL has been determined at different distances to the track (y = 8 m is the reference distance according to Ref. [13]) for different soil stiffness. The IL has been calculated as a function of the frequency within the range 1-80 Hz because this is the interesting frequency range to assess human exposure to vibration into buildings.

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