24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

AN INNOVATIVE NUMERICAL APPROACH FOR RAILWAY ROLLING NOISE FORECAST

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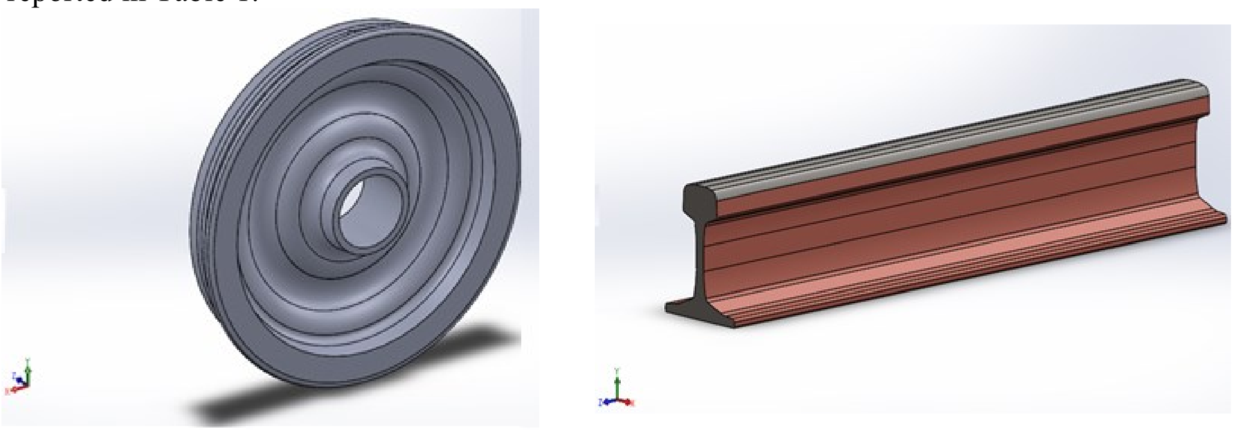
In recent years there has been a growing worldwide development of rail transport, mainly due to technological innovations both on armaments and on rail vehicles. Such technological issue focused almost parallel on two main fronts: on one hand the performance enhancement and on the other side the internal comfort. This technology advancement has been driven mainly by the need to move goods and passengers over long distances in a short time, making it the safest transportation system in the world thanks also to the latest monitoring systems, of which European Community is undoubtedly one of the major leaders. The passenger transport has introduced problems related to comfort: traveling so fast is the main goal so long as it is comfortable and safe. One of the requirements that mostly turned out to be significant and sometimes more difficult to satisfy is that regarding acoustic comfort and environmental impact. As known, the regulations become with the passage of time more and more stringent, and every company that wants to operate in this area is required to respect them. The acoustic comfort improvement implies the intervention as much as possible focused on noise sources, which in this case are constituted by: electric motor, pantograph, wheel-rail contact. In such research framework, the authors focused on determination of a simple, but at the same time reliable, method for radiated sound power assessment in the wheel-rail contact due to combined wheel-rail roughness in order to reduce the environmental impact of this type of transmission system. Targeted analysis were implemented in an efficient numerical investigation in MSC NASTRAN® and ACTRAN® environments providing the necessary vibro-acoustic parameters as input data for the further definition of the wheel-rail interaction force by a MATLAB® customized tool, once known the roughness profile.
Keywords: Finite Element, Noise, Radiated power, Roughness, Wheel-rail interaction.

1. Introduction

The most important sound radiating parts of a tracked transit system are the steel wheels of the rail vehicles [1]. Small-scale unevenness on the wheel and rail contact surfaces, referred to as roughness, induces high frequency dynamic interaction between the wheel and rail when a train runs on the track. As a result, the wheel and rail are excited, vibrate and radiate noise. It is important to know the wheel/rail interaction force for predicting track and wheel vibration, railway noise radiation as well as the formation of wheel and rail corrugation or truck damage. The combined roughness form a relative displacement input between the wheel and rail, and thus the wheel-rail interaction force depends on the dynamic properties of the wheel and rail (including the contact zone) at the contact position. The moving irregularity model has been widely used to investigate problems of wheel-rail interaction and rolling noise [2-5]. The EU Directive 2015/9961 of the European Commission defines the common methods for noise assessment in accordance with Directive 2002/49 / EC of the European Parliament [6]. The Directive 2002/49 / EC 2, in accordance with its Article 1, aims to define a common approach to avoid, prevent or reduce relying upon a prioritized basis, the harmful effects, including annoyance, due to exposure to environmental noise [7]. The present work descends from a research project aimed at designing and testing of internal soundproofing vehicle and rolling noise systems. The paper deals with the objective to investigate a method for the determination and characterization of the "rolling noise" phenomenon. The key issue is the estimation of the acoustic radiated power given by the wheel-rail contact, on which the European Union is focusing its attention in order to reduce the environmental impact of such class of transport system. Starting from the known three-dimensional models both of the wheel and the rail, the structural modal characterization has been carried out within MSC NASTRAN® environment. A careful investigation of air-structure interaction for surface radiated power forecast has been then performed in ACTRAN® in compliance with EU 2015/996 regulations, imposing once an unitary amplitude force, and another some known roughness profiles. A further development will aim to implement such outcomes in a MATLAB® routine, which allows for estimating the operative wheel-rail interaction force on a real train.

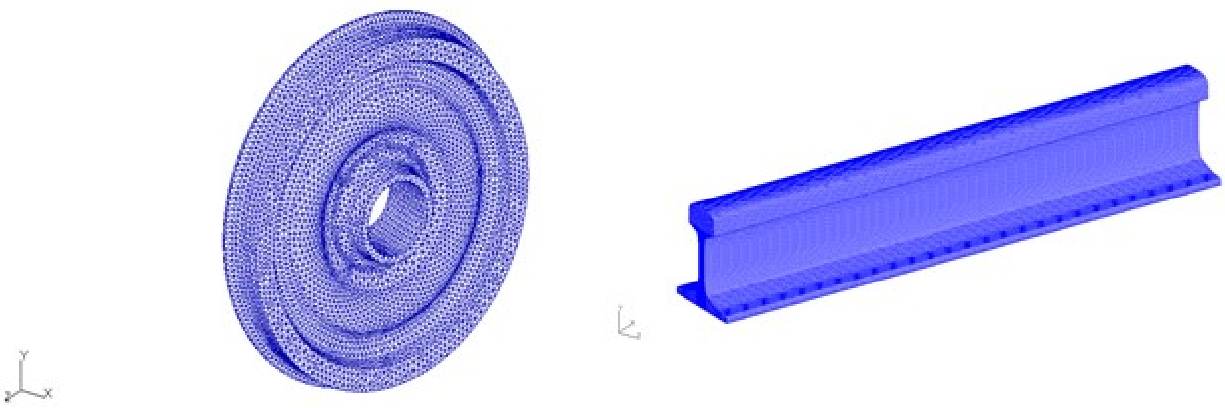
2. Numerical models

The numerical strategy is mainly based on FE (Finite Element) modelling of certificates mechanical components, Fig. 1. A 3D mesh has been performed in order to be fully representative both for the wheel (CTETRA elements) and the rail (CHEXA elements), Fig. 2 [8]. Material characteristics are reported in Table 1.



(a) Monobloc wheel S1002 (b) Rail UIC 60

Figure 1: 3D CAD reference models.



(a) Monobloc wheel S1002 (b) Rail UIC 60

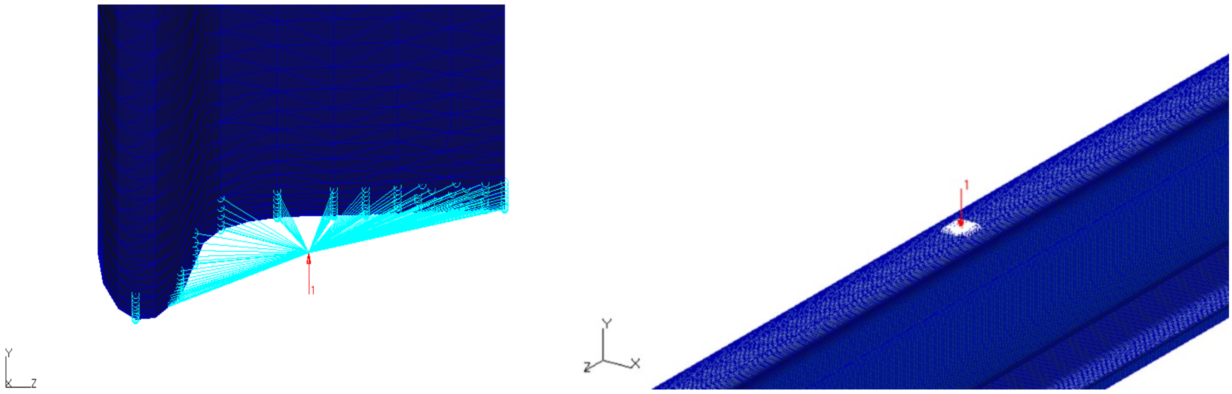
Figure 2: 3D FEM models.

Table 1: Reference materials

Steel R7T (Wheel)			Steel R260 (Rail)		
E [GPa]	ν	ρ [Kg/m^3]	E [GPa]	ν	ρ [Kg/m^3]
200	0.26	7860	210	0.3	7860

2.1 Frequency analysis

The acceleration and velocity spectra, in the hypothetical contact point by means of a rigid link RBE2, have been determined applying an unitary amplitude load in order to identify all natural frequencies in the range [0, 4000 Hz], Fig. 3; the spectrograms are shown in Figs. 4-5. The wheel is fixed in the hub while the rail at the end faces.



(a) Wheel contact region (b) Rail contact region

Figure 3: Spectral load application.

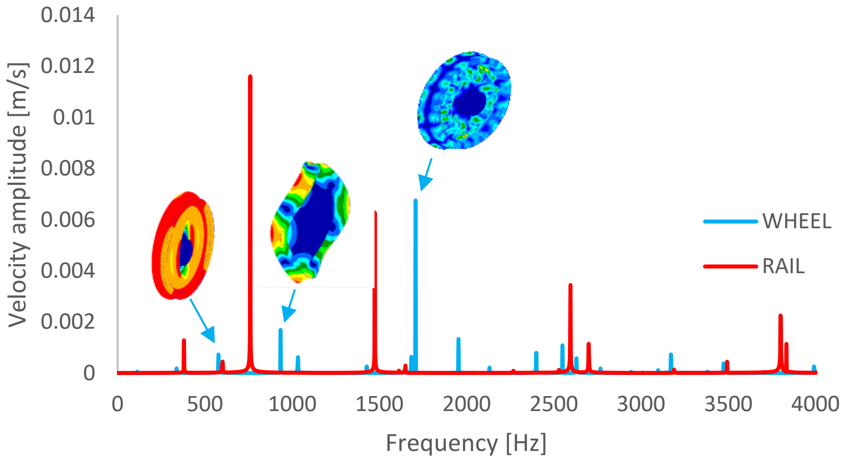


Figure 4: Velocity spectrogram, SOL 108.

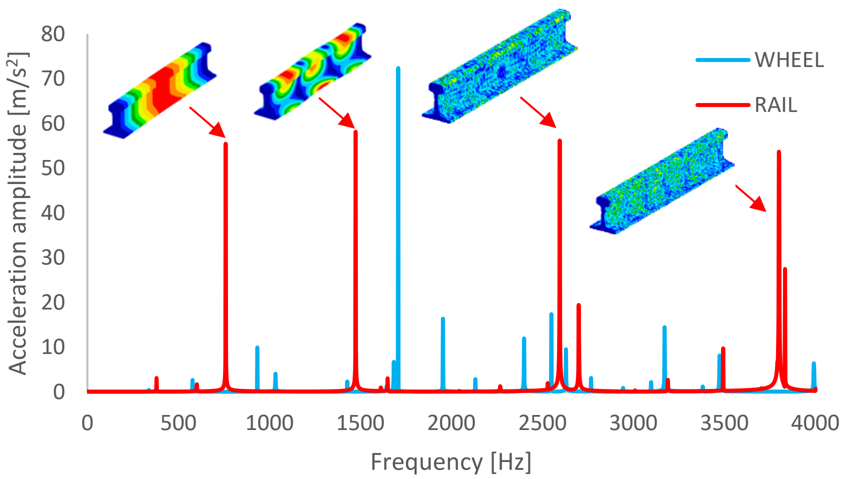
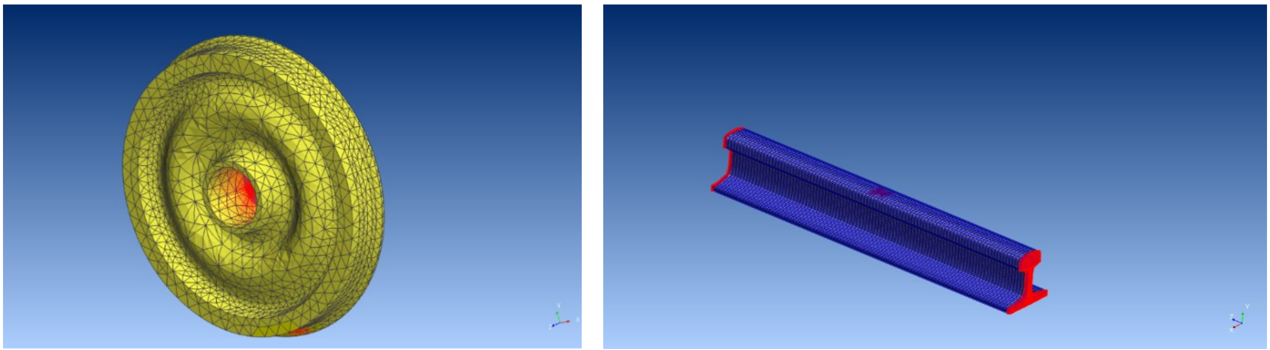


Figure 5: Acceleration spectrogram, SOL 108.

3. Noise levels determination

The acoustic analysis in free-field condition has been therefore carried out within ACTRAN® software, relying upon the FE models already developed for vibration characterization; in particular, the wheel skin has been defined as a Rayleigh radiating surface while an infinite element domain allowed for assess the radiated power when a greater number of elements is used, as for the rail model [9].



(a) Wheel – Rayleigh Surface (b) Rail – Infinite Elements

Figure 6: ACTRAN® models.

Furthermore, the Sound Pressure Level (SPL) has been determined by a virtual microphone placed at 7.5 m from the track center and a height of 1.2 m above the top of the railhead [6].

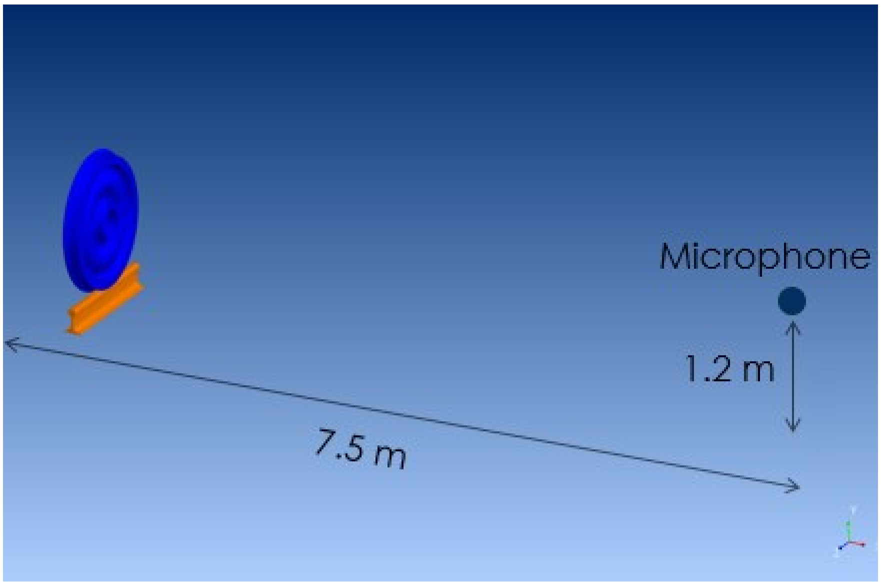


Figure 7: Rolling noise virtual acquisition.

The sound radiated power has been assessed implementing two different approaches:

- Explicit: an unitary input force has been applied in the contact region;
- Implicit: a spectral displacement allows for simulating the roughness profile.

In particular, with reference to the second case, the roughness profile, estimated experimentally in a test campaign on a real line at the speed of 60 km/h, has been assigned as boundary condition to the model, and then the outcomes have been compared successively with the reference profile according to ISO 3095 regulations [10].

3.1 Explicit approach

The acoustic radiated power magnitude, applying an input load in the contact point of each component, is represented in Fig. 8. The spectrograms show a trend, similar to what has been achieved in the frequency analysis by MSC NASTRAN®: the radiated power, being generally a function of the surface vibration velocity, exhibits the same peaks representative of the structural resonance frequencies [11-12].

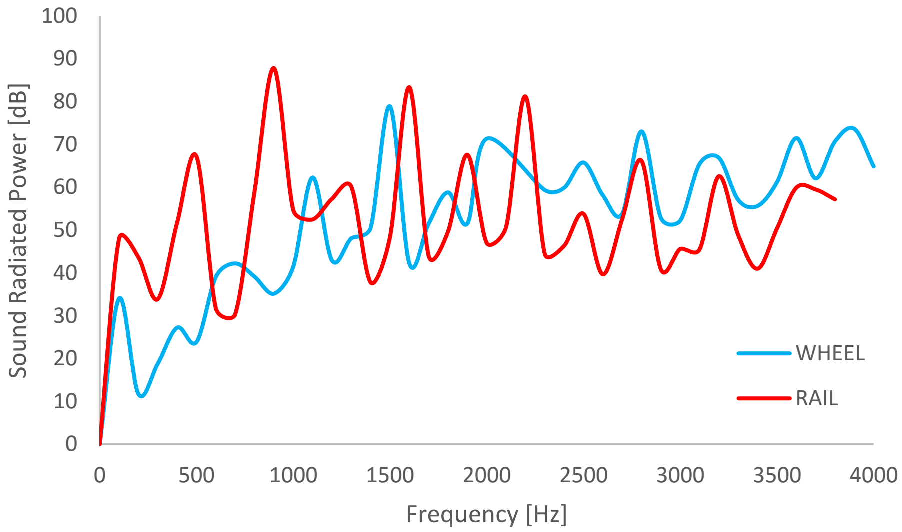


Figure 8: Acoustic radiated power, force input.

3.2 Implicit approach

The indirect analysis has been carried out, by means of two typical roughness profiles: the first one has been measured following an experimental campaign on a line while the second one is referred to the ISO 3095, Fig. 9.

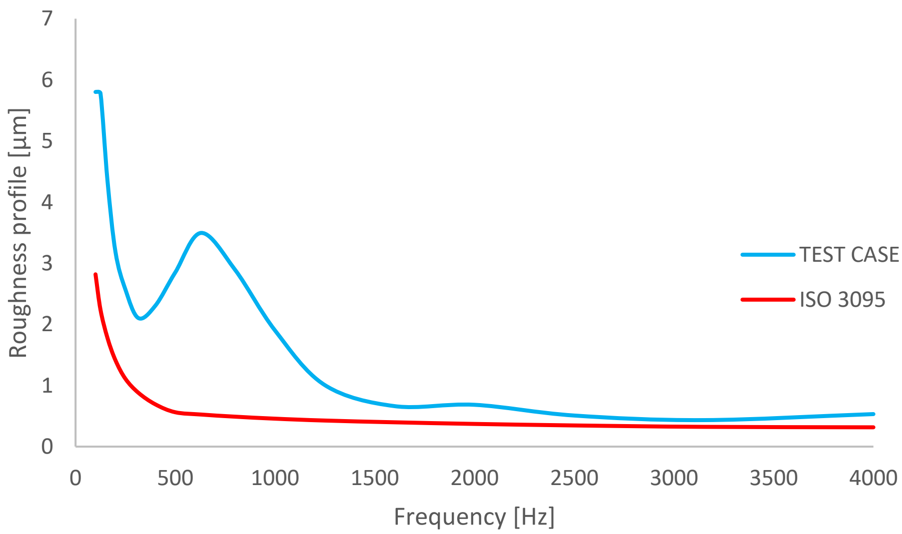


Figure 9: Roughness profiles.

The results reported below in Figs. 10-11, show, respectively, the sound radiated power in near-field condition and the SPL at 7.5 m from the track center, combining concurrently both the wheel and the rail contributions.

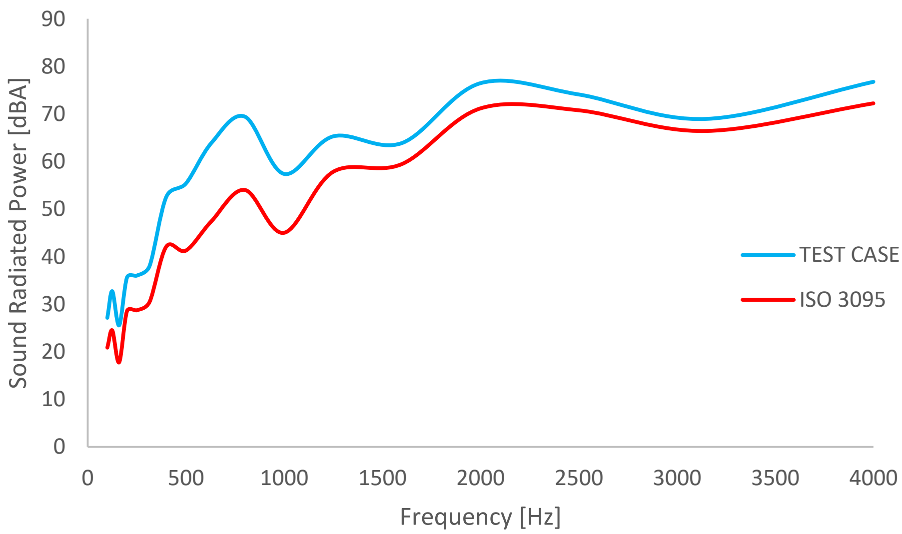


Figure 10: Acoustic radiated power, roughness profile input.

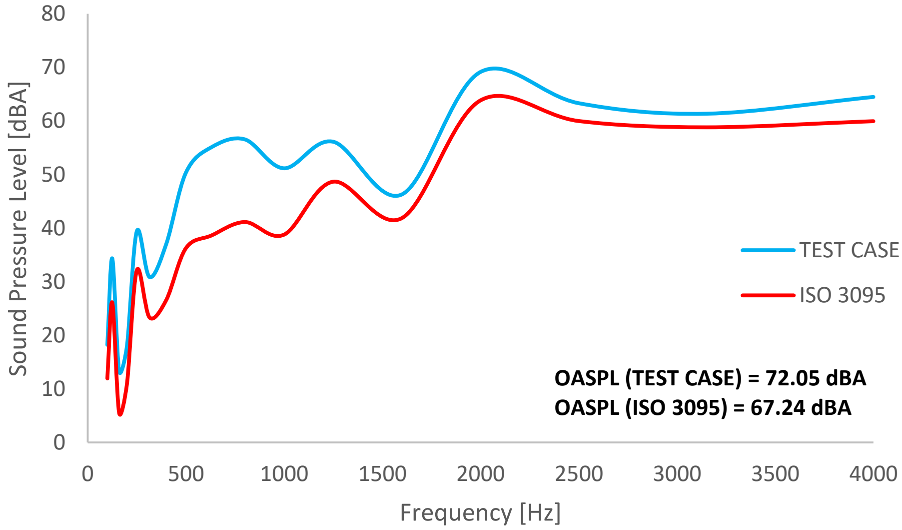


Figure 11: Sound Pressure Level, roughness profile input.

From the diagrams, it is clear as the outcomes, carried out using the surface roughness data obtained experimentally are very close to those defined by ISO 3095. In addition, considering the Overall Sound Pressure Level (OASPL), such regulation allowed to further correct the results of about 5 dB (A), in according to Eq. 1 [10]:

$$\Delta L_{r,rail}(f) = L_{r,rail}^{measured}(f) - L_{r,rail}^{corrected}(f) \tag{1}$$

where:

- $L_{r,rail}^{measured}(f)$ is the one-third octave frequency spectrum of the measured rail acoustic roughness;
- $L_{r,rail}^{corrected}(f)$ is the one-third octave frequency spectrum of the corrected rail acoustic roughness;
- $\Delta L_{r,rail}(f)$ is the one-third octave frequency correcting spectrum.

4. Conclusions and further developments

The aim of the paper has been to perform a preliminary numerical model, addressed to evaluate the problem of "rolling noise", extensively investigated by the research field [13-25]. Starting from 3D CAD models of the wheel and the rail, their mode shapes and frequency responses have been determined, up to the noise emitted characterization within ACTRAN® environment by two different approaches. The results showed that, starting from experimental data obtained in a test campaign, the numerical model is in line with the standard values in the sector, the ISO 3095, which allows to scale the SPL values of approximately 5 dBA. However, this represents a forecasting model that takes into account the surface irregularities and train speed but not the actual forces acting during the wheel-rail contact, which depend primarily on the masses involved and the stiffness suspensions. In this regard, it is already developing a MATLAB® computational tool, which integrates such mechanical characteristics too, for the real contact forces assessment.

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