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Sound radiation of a railway rail in close proximity to the ground

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ABSTRACT

The sound radiation of a railway in close to proximity to a ground (both rigid and absorptive) is predicted by the boundary element method (BEM) in two dimensions (2D). Results are given in terms of the radiation ratio for both vertical and lateral motion of the rail, when the effects of the acoustic boundary conditions due to the sleepers and ballast are taken into account in the numerical models. Allowance is made for the effect of wave propagation along the rail by applying a correction in the 2D modelling. It is shown that the 2D correction is necessary at low frequency, for both vertical and lateral motion of an unsupported rail, especially in the vicinity of the corresponding critical frequency. However, this correction is not applicable for a supported rail; for vertical motion no correction is needed to the 2D result while for lateral motion the corresponding correction would depend on the pad stiffness. Finally, the corresponding numerical predictions of the sound radiation from a rail are verified by comparison with experimental results obtained using a 1/5 scale rail model in different configurations.

1. Introduction

Railways are generally viewed as an environmentally-friendly and sustainable means of transportation. However, noise and vibration often lead to adverse reactions to both new and existing railways. The most important source of environmental noise from railways is rolling noise. It is produced by vibration of the track and wheel, which is induced by their combined surface roughness at the wheel/rail contact [1]. The relative importance of the wheel and track radiation depends on details of their design, the roughness spectra and the train speed [1]. Nonetheless, the component of noise radiated by the rail is often the highest, and dominates the important mid-frequency region between 400 and 2000 Hz. It is therefore necessary to understand the mechanisms of sound radiation by railway track in order to implement effective noise control measures.

Comprehensive analytical formulas were proposed by Remington [2] to predict wheel/rail rolling noise in urban rail transit systems based on the characterisation of the wheel/rail dynamic system developed in [3]. The results agreed well with measured wayside noise. For the sound radiation from the rail, using the model of Bender and Remington [4], the radiation efficiency was based on the uniform motion of simple cylindrical beams for both vertical and horizontal motion with an assumption that the rail was located in free field. Later, this theoretical analysis to predict wheel/rail rolling noise was expanded [5]. In particular, the noise propagation was estimated by modelling the ground as a finite impedance plane

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using the approach of Chessell [6]. Also, an extensive series of field measurements on a full scale urban rail transit vehicle was carried out [7] for comparison with the prediction of the wayside noise during a train passby by using the theoretical model in [5].

Thompson extended these engineering methods for predicting rolling noise [8] and a software package, known as Track-Wheel Interaction Noise Software (TWINS), was produced [9,10]. For the sound radiation from the rail in the TWINS model, a multiple source model based on the geometry of the rail cross-section was used to represent the vibrating rail [11]. One of the assumptions in this model, as in Bender and Remington [4], was that the rail radiation could be modelled in a free field. Similar results were obtained by using a two-dimensional boundary element model of the rail radiation in free space [12]. Comparisons with a three-dimensional model were also presented in [12] showing that a two-dimensional model gives satisfactory results in most practical cases for frequencies above about 250 Hz. Below this frequency, allowance should be made for the high decay rate of vibration along the rail which means that the radiation resembles that from a point source instead of a line source.

Nilsson et al. [13] used a combination of waveguide finite elements and wavenumber boundary elements to calculate the sound radiation from a rail including an embedded rail as well as a rail in free space. Recently, the directivity of noise radiated by a rail has also been investigated by several authors [14–16].

The TWINS model for rolling noise has been validated by means of field measurements during train passby [9,10,17]. This showed reasonably good agreement between measurements and predictions over a wide range of conditions. Particularly where the noise was predicted directly from the measured vibration the agreement was good; larger uncertainty was found in the prediction of the vibration from the surface roughness.

In practice, the rail is not located in free space but is in close proximity to the ground. This consists of ballast, which is partially absorptive, and sleepers (or cross ties) which are reflective. This is expected to influence the results at low frequency, but since the sleepers dominate the radiated noise below about 400 Hz [1], it has been neglected up to now. In the current work, the effect of the proximity of the ground on the rail radiation is studied in terms of its radiation ratio. In order to propose a more realistic model to predict the noise from the rail at low frequencies, the effects of acoustic boundary conditions due to the sleeper and ballast are taken into account. Results are presented initially for the radiation ratio of the rail in different conditions (in free space, attached to a rigid ground and above a rigid ground) by using the boundary element method (BEM) in two dimensions (2D), for both vertical and horizontal vibration. Then numerical calculations are presented which investigate the effects on the sound radiation of an absorptive ground in close proximity to the rail. Allowance is made for the effect of wave propagation along the rail by applying a wavenumber correction in the 2D modelling. Finally, the numerical results are verified by comparison with experimental results obtained using a 1/5 scale rail model in different configurations.

2. Sound radiation from the rail in two dimensions

The sound radiation from the rail is presented here in terms of the radiation ratio, or radiation efficiency, which can be written as

$$\sigma = \frac{W}{\rho_0 c_0 S \langle v^2 \rangle} \tag{1}$$

where ρ_0, c_0 are the density of the air and the speed of sound, respectively, W is the radiated sound power of the structure, S is its total surface area and $\langle v^2 \rangle$ is the surface-averaged mean-square normal velocity. The quantities σ, W and v are functions of frequency.

The geometry of a rail can be considered as two-dimensional, with the third dimension being effectively infinite. Then W becomes the power per unit length and Sbecomes the perimeter length. As the wavelength of rail vibration is generally large compared with the acoustic wavelength, the radiated sound field can be approximated as two-dimensional, allowing it to be calculated using a two-dimensional boundary element model. The validity of such an approach has been considered in Ref.

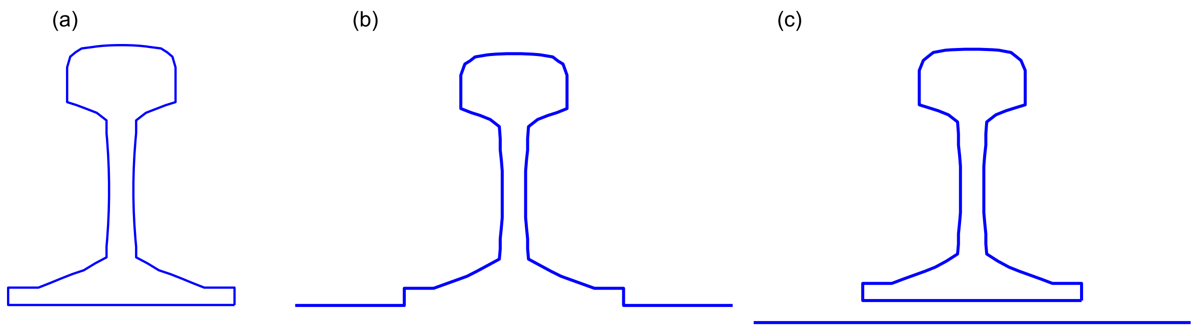

Fig. 1. Two-dimensional boundary element models of a rail.