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Sound radiation from railway sleepers

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A B S T R A C T

The sleepers supporting the rails of a railway track are an important source of noise at low frequencies. The sound radiation from the sleepers has been calculated using a three-dimensional boundary element model including the effect of both reflective and partially absorptive ground. When the sleeper flexibility and support stiffness are taken into account, it is found that the radiation ratio of the sleeper can be approximated by that of a rigid half-sleeper. When multiple sleepers are excited through the rail, their sound radiation is increased. This effect has been calculated for cases where the sleeper is embedded in a rigid or partially absorptive ground. It is shown that it is sufficient to consider only three sleepers in determining their radiation ratio when installed in track. At low frequencies the vibration of the track is localised to the three sleepers nearest the excitation point whereas at higher frequencies the distance between the sleepers is large enough for them to be treated independently. Consequently the sound radiation increases by up to 5 dB below 100 Hz compared with the result for a single sleeper whereas above 300 Hz the result can be approximated by that for a single sleeper. Measurements on a 1/5 scale model railway track are used to verify the numerical predictions with good agreement being found for all configurations.

1. Introduction

Conventional railway track consists of steel rails attached via rail pads and clips to transverse sleepers (cross ties) which are supported in ballast. In modern track the sleepers are usually made of pre-stressed concrete although timber and steel are also in use. In most situations the dominant source of noise from the railway system for conventional speeds is rolling noise. This is radiated by the wheels, the rails and, at low frequencies, also the sleepers.

In recent years numerical models have been developed that can be used to predict rolling noise and to separate the sound radiated by the various components. The first models of rolling noise were developed in the 1970s by Remington [1,2]. Analytical models were used for the wheel and rail impedances and for their radiation efficiencies but the sound radiation of the sleepers was not considered. Nevertheless, Remington's work took account of many features that are still considered to be important: the relative displacement excitation by the wheel/rail roughness, the contact filter effect, track decay rates, etc. Subsequently, Thompson [3] extended this basic model to include other features that were found to be significant. This was implemented in the TWINS (Track–Wheel Interaction Noise Software) package [3] which was validated through field tests [4,5]. It has been found the sleeper radiation is the dominant component at low frequency, the rail radiation is important between 400 and 2000 Hz and the wheel radiation is significant at high frequency. Despite its

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widespread use, there remain areas for improvement in this model, in particular at low frequencies (below 300 Hz) where the agreement with measurements is often less satisfactory. In this region it is found that the sleepers radiate most of the noise.

The sleeper acoustic power is currently predicted in TWINS by adopting a simplified formulation for its radiation efficiency [6]. Radiation efficiency is the sound power normalised by the surface area, mean square velocity and acoustic impedance of air. The model in TWINS [6] is based on an approximate relation for the radiation from a rectangular piston set in an infinite baffle. However, this is modified at low frequencies to allow for the fact that multiple sleepers are close together compared with the acoustic wavelength and therefore can be considered to form a single composite source. The increase in the radiation efficiency compared with that of a single sleeper is estimated using a heuristic approach [6]. One aim of the present work is to provide a more rigorous estimate of this effect. In addition to the sound power, to predict the sound pressure at a receiver location, information is required about the directivity. In TWINS [6] this is assumed to be omnidirectional as the source is acting as a monopole.

The sleeper radiation has been explored by some authors aiming at reducing track noise. Vincent et al. [7] used TWINS to investigate the various parameters that affect the track noise. They concluded that the sound power radiated by the sleepers could be minimised by reducing the rail pad stiffness. However, this was shown to lead to an increase in the rail noise component. Other possible approaches to reduce the sleeper noise that were identified were to increase the sleeper mass or to reduce the area of its upper side.

Acoustic optimisation of railway sleepers was investigated numerically by Nielsen [8]. He used a finite element model of the sleeper to determine its vibration due to a passing train and combined this with the radiation efficiency for a single sleeper obtained using a three-dimensional boundary element model of a sleeper on a rigid plane. He studied the effect of changing the sleeper geometry on the radiated noise, concluding that a bi-block sleeper with appropriate dimensions and sufficient mass could be 2–3 dB(A) quieter than the reference monobloc design. Based on these results a modified sleeper design was tested within the Silent Track project [9,10] in conjunction with a modified rail section. Together these gave a noise reduction of about 3 dB but the effect of the sleeper design was not quantified separately.

Some initial results for the sound radiation of a single sleeper as well as multiple sleepers, embedded in a rigid ground, are presented in [10]. These were obtained using the Rayleigh integral approach [11], which is based on the assumption that the vibrating surface is flush with a rigid ground. Apart from the above references, however, very little work has been carried out into the acoustic characteristics of the sleepers.

Attenborough et al. [12] considered the effect of replacing acoustically hard sleepers by porous concrete sleepers. They used boundary element calculations to show that the rail noise could be reduced by 1.5 dB(A) by such porous concrete sleepers. However, this work focused on the absorptive properties of the sleepers and did not take account of the sound produced by their vibration. In [13] it has been shown, using a boundary element approach, that the ground impedance can have a significant effect on the radiation from the rail. Similar effects may be expected for the radiation from the sleeper itself and will be considered here.

In this paper, calculations of the sound radiation from a single sleeper obtained by using the boundary element method in three dimensions (3D) are first presented in Section 2. Results are presented in terms of radiation efficiency; no consideration is given to the directivity. Initially, the sleeper is considered to be located in free space. The ground is then introduced, first as a rigid reflecting surface and then as a partially absorptive surface, represented by its impedance, and the effects on the sound radiation are investigated. The fact that multiple sleepers are connected by the rails can lead to a change in their radiation efficiency [10]. This effect is explored in Section 3 for sleepers in close proximity to both a rigid and an absorptive ground. Finally, in Section 4, measurements on a scale model are presented to verify the numerical predictions. The work concentrates on concrete monobloc sleepers which are the most common form used in modern ballasted track.

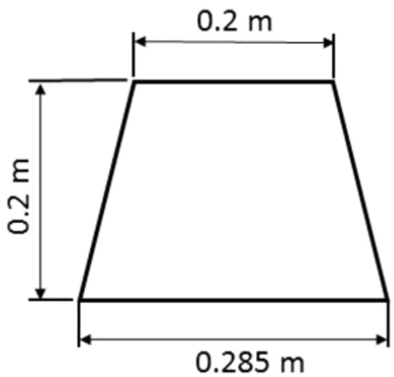

Fig. 1. Cross-section of the idealised concrete sleeper.