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PREDICTION OF RAILWAY INDUCED GROUND VIBRATION

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ABSTRACT

The wheel/rail-impedance model RIM for the prediction of railway noise has been combined with soil models to predict ground vibration. The soil calculations are based on an analytical model of a horizontally layered halfspace. The tool can be used to study the effects of the application of various mitigation measures suitable for track applications: resilient rail fastening systems, sleeper soffit pads, ballast mats and floating slabs. Furthermore the influence of the soil on the vibration levels can be investigated. The paper describes the model, and its applications. Results from the predictions are compared with those from measurements provided by DB AG also used for the ERRI project RENVIB.

1 - INTRODUCTION

Vibration and re-radiated noise are important environmental problems that have to be taken serious by the railroads, especially when building new lines. To allow for optimum solutions of mitigation measures model calculations are very useful for comparing different situations and are of great help if they are provided with reliable input parameters.

2 - MODEL**2.1 - Overview**

In the past Müller-BBM and German Railroads (DB AG) have developed the prediction model RIM for rolling noise of railroads. The model is excited by the combined tread roughnesses of wheels and rails. The basic concept is shown in Figure 1, the rail and the sleeper are modelled as Euler-Bernoulli beams, the track elements as springs including a loss factor. The validation of the model for passenger trains on ballasted track has been reported on in [1].

As the tread roughnesses are the main excitation mechanism for ground vibration as well, the model has been extended to include more detail in the base impedance below the ballast. Depending on the application different approaches are used:

- Rolling noise prediction: simple ground model
- Bridge noise estimate: simple bridge model
- Vibration prediction for complex structures: input from external source (measurement, FE-model)
- Vibration prediction in the soil: layered half space or slab on layered half space

2.2 - Modelling surface lines

The ground can be modelled as a horizontally layered infinite half space loaded by a disc load using the Hankel transform [2]. In the first step the point input impedance of the soil for the super structure and the transfer impedances to an observation point are calculated. In the next step the calculation is done from bottom to top to predict the vibration distribution on the rail in longitudinal direction and then

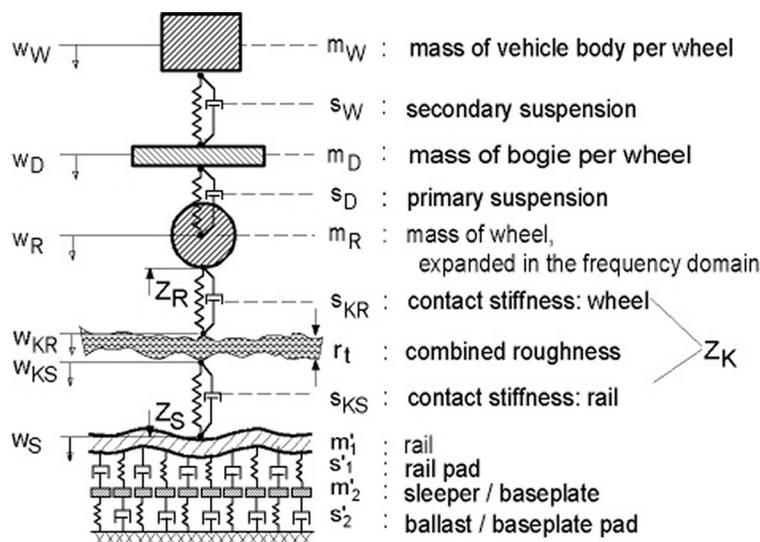


Figure 1: Diagrammatic representation of the base model which was extended for vibration prediction.

from top to bottom for the estimate of the ground vibration. The effective stress distribution on the ground caused by the train is then predicted using a superposition of equivalent disc loads. In the last step the vibration levels at the observer point are predicted. A slab introduced on the soil as a mitigation measure may be included and can be calculated as a finite plate on the ground. The stress distribution at the surface is calculated from the elastic layering effect of the loaded slab on elastic supports.

2.3 - Modelling tunnel lines

For tunnels two-dimensional FE-models of the cross section and the soil around it are used. These results are then combined with another two dimensional model of the permanent way in the tunnel. Floating slabs are thus modelled as a, possibly segmented, beam on an elastic foundation and thus taking the longitudinal effects of load distribution into account. Instead of a detailed FE-model of the tunnel cross section a simple base impedance may be used.

3 - APPLICATION PROBLEMS

3.1 - Dynamic input parameters

The main problem for the application of such dynamic soil track models is the determination of suitable model parameters. In the last years some experience has been gained determining dynamic properties for a frequency range from several Hz up to one kHz or more for elastic track elements like rail pads, baseplate pads or ballast mats using laboratory test rigs. The availability of dynamic values is of utter importance, as a ratio of dynamic to static stiffness of up to three or even more may be applicable. Concerning the soil the choice of parameters is even more complicated, as the stratification and the parameters of the layers are often not well known. On the other hand, local variations or inclusions in the soil are of minor importance as long as they are small compared to the relevant wave lengths.

3.2 - Excitation levels

As with rolling noise prediction the excitation level, the tread roughness, has to be determined with sufficient accuracy. For the wavelengths relevant for noise (depending on vehicle speed between 0,2 and 0,01m) precision instruments have been developed [3]. Using the wheel instrument (eg. RMR 1435) unroundness and its harmonics can be determined as well. For rail roughness or waviness data has either to be used from track geometry cars or by combining the high precision roughness data measured with RM1200E in longitudinal direction.

In order to include the parametric excitation caused by the sleeper passing frequency or unbalanced wheels an equivalent roughness can be determined.

4 - EXAMPLES

The UIC project RENVIB (Railway Environmental VIBration) has investigated the subject of ground borne vibrations. In phase 2 of the project a study on a comparison of measured and predicted vibration level differences for mitigation measures was undertaken. The project focussed on the level reductions

achievable by mitigation measures, as the excitation levels were unknown. Soil parameters were mostly taken from a handbook as no dynamic data was available. In this paper the results obtained for sites of DB AG are presented.

4.1 - Tunnel line

In [4] the results for tunnel sites are described. At the DB site a ballasted trough is put on discrete springs forming a mass spring system. The design Eigenfrequency is 7Hz. Fig. 2 compares measurement results and predictions. As the measurements were done at different locations the velocity level differences could not be called insertion loss.

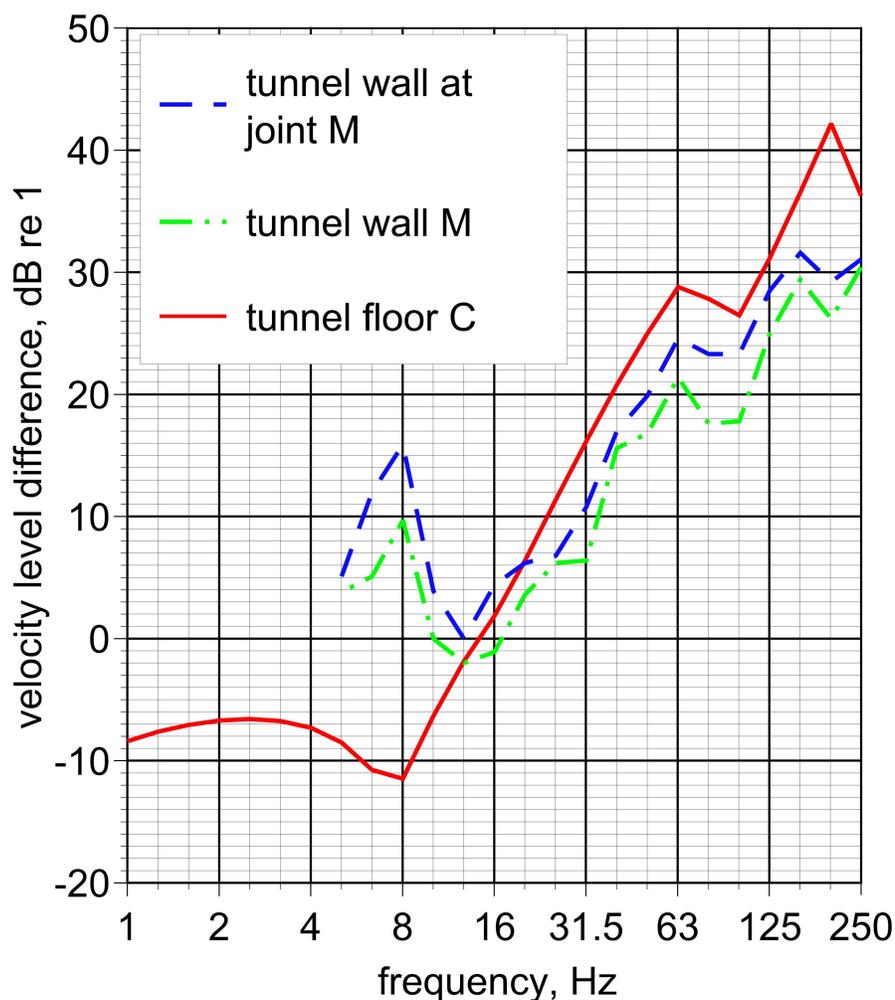


Figure 2: Comparison of predicted (C) and measured (M) vibration level differences in a tunnel with a floating ballast trough.

4.2 - Surface line

In [5] the results for surface lines are described. Fig. 3 compares prediction and measurement results of vibration level differences 8m from the track for soil improvements using concrete and lean concrete layers under the ballast.

The effect of the lean concrete and concrete slabs are overpredicted. This is due to the assumption of a low damping coefficient for the soil, which also leads to the sharp resonant peaks for the stratified soil. Another problem that could not be taken account of in the theoretical study were the differences in waviness of the rail surfaces and in soil profile for the compared measurement locations with and without mitigation measures.

5 - EXPERIENCE

The quality of vibration predictions depends highly on the precision of the available input parameters, specifically the dynamic track and soil parameters and the excitation levels.

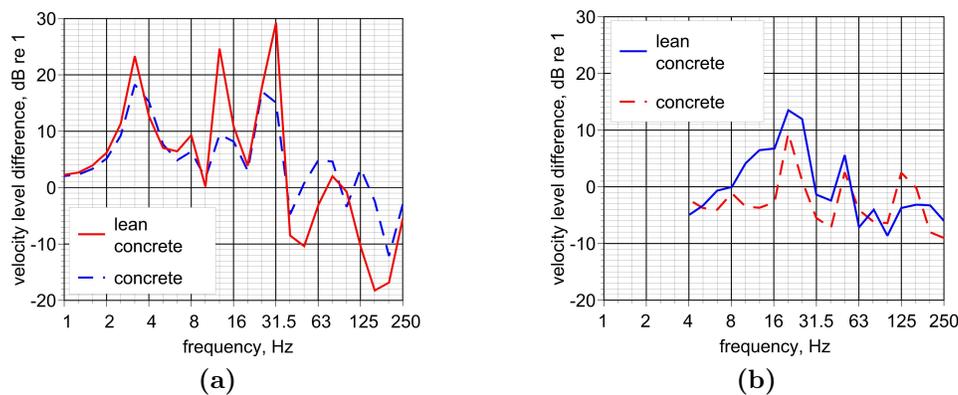


Figure 3: Comparison of predicted (a) and measured (b) vibration level differences for the insertion of soil improvement at a surface line.

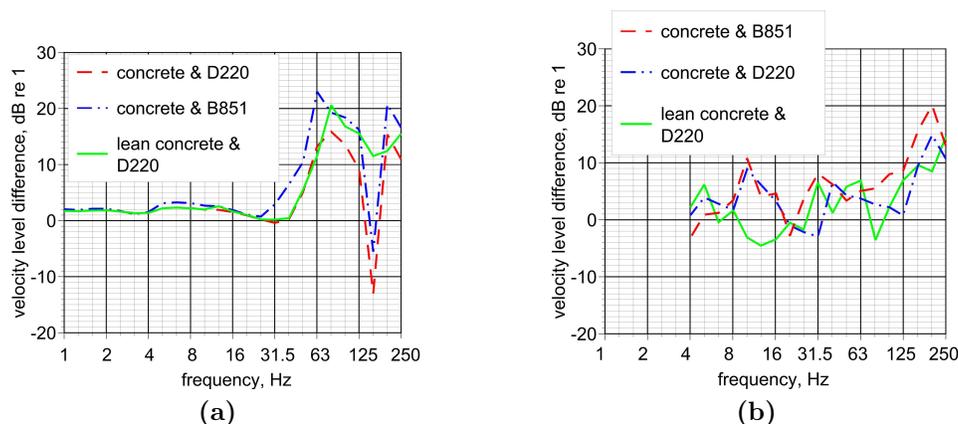


Figure 4: Comparison of predicted (left) and measured (right) vibration level differences for the insertion of ballast mats at a surface line.

Insertion losses measured in tunnels for mass spring systems are influenced by the characteristic length of the slab, due to the fact that forces are distributed over a longer length, thus leading to higher insertion losses in the tunnel than at possible distant receiver points.

It is important to be aware of the fact, that the insertion loss of the mitigation measures decreases with increasing distance from the track of the observing point, because vibrations are radiated along the track for lower contact stiffness between track and soil. This causes lower vibration amplitudes in the vicinity of the track, but on the other hand changes the source from being more or less point source type to line source type; therefore the geometric level reduction with distance from the track may be significantly reduced.

An effect that may be caused by stiffening concrete slabs on the soil surface is the change in wavelength transmitted via the contact area, leading to a change in the frequency range of the vibration being transmitted into the soil at its surface. Due to the fact, that the slabs shift the transmitted frequencies into a lower range, the effect of the mitigation measures can be reduced significantly.

In an unlayered soil compression and shear waves decrease at a higher rate so that in a larger distance mainly Rayleigh waves which propagate along the surface can be observed. The stratification of the soil may cause other important effects. When the ground is layered the other two wave types can be reflected back to the surface at the interface of the layers. Therefore vibration transmission in a wider frequency range is possible. In addition the geometric attenuation with distance is reduced, as reflected waves must be added to the surface waves at observing points at distances corresponding to the depth of the interface of the layers and the reflection angle.

6 - CONCLUSION

Vibration caused by railroads may be predicted with the extended rolling noise model. It must however be taken into account that the uncertainty of the model parameters is greater for the vibration case than for the noise case, as the excitation levels and the layering and the dynamic properties of the soil are

not as well known as their counterparts for the noise model. The uncertainty of absolute predictions is therefore higher. However the simulations are useful for parametric studies to improve the understanding of the relevant mechanisms and allow for a comparison of mitigation measures.

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