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GROUNDBORNE NOISE FROM NEW RAILWAY TUNNELS

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1. INTRODUCTION

Trains running in tunnels cause vibration to be transmitted into the surrounding soil medium. This may give rise to significant noise radiation in the frequency range 30Hz to 200Hz inside buildings from the walls and floors. At these frequencies the vibration may coincide with resonances of the building. The phenomenon is known as 'groundborne noise' or 'reradiated noise'.

Groundborne noise is an established environmental concern of metropolitan railways which run largely in tunnels in heavily built-up areas. However, as a recent survey [1] has shown, the mainline railways of Europe are increasingly concerned with the phenomenon. This is, in part, due to the increasing use of tunnels to reduce other environmental impacts including direct airborne noise. In some cases the use of very efficient airborne noise screening has led to concern over groundborne noise from surface trains.

2. THE ROLES OF THEORETICAL AND EMPIRICAL MODELS

Mathematical models are required:-

(1) to predict the level of groundborne noise in buildings on the route of a proposed new railway, and,

(2) to provide a tool to derive the specification of track, track components and, possibly, rolling stock where noise reduction is required.

Models to predict groundborne noise take two forms. The first is empirical - that is, to collect measurements of vibration from trains in existing tunnels and to fit a mathematical expression to the parameters observed using statistical regression techniques. The parameters would include the train type and speed, the track structure, tunnel depth, the tunnel structure, distance from the tunnel and the ground lithology. While the tunnel depth and distance from the tunnel would be variables in an empirical formula, the train type, track, tunnel and ground structures would be cases for which the measurement and data fitting exercise must be repeated.

The empirical method is used by a number of railway authorities and is acceptable providing the range of situations measured covers that of the prediction. In practice, difficulties arise because of differences between train types, train speeds, trackforms, tunnel structures, and the detail of the lithology. Unlike the case for airborne noise, the properties of the propagation medium are rarely alike at any two locations. This leads to the requirement for a prediction capability to be based on a very large number of carefully controlled measurements and in practice, a compromise must be reached between the precision of the prediction and the number of parameters that are to be taken into account.

Often it is necessary to go outside the range of data on which the empirical method is based. This can be done by establishing corrections, either using further, carefully controlled, measurements or using theoretical models. The empirical method, on its own, cannot provide information on the effect of new design variations.

The second approach is to use theoretical models, ie. those which model the mechanism of vibration generation or produce a mathematical solution of the elastodynamic wave-equation for the propagation of vibration. The development of these models provides an understanding of the mechanism of generation and propagation. This is important as, an empirical model relies heavily on the correct choice of mathematical function particularly if extrapolation is to be used.

However, theoretical models also have limitations:-

- assumptions have to be made as to the mechanisms involved in each stage of the vibration generation and propagation process.
- such models require a detailed knowledge of a great many parameters such as soil properties and the tunnel structure. These are difficult to determine in the detail required and may have a degree of inherent variation.
- results may be sensitive to the mathematical idealisation of the irregularly shaped domain and the randomly inhomogeneous medium.

Currently available theoretical models cannot therefore be reliably used to predict absolute levels of environmental vibration. However, they may be used to model parts of the process and particularly to provide information on the changes of vibration level due to design changes in the rolling stock, track, tunnel etc.

A model for the vibration characteristics of a tunnel, which models the tunnel structure using Finite Elements and the ground using a combination of Finite and semi-infinite elements, has been presented previously [2]. In this paper a model for predicting the effects of the vehicle and track design is presented.

3. MODEL FOR CHANGES IN VEHICLE AND TRACK DESIGN

Track designs which incorporate resilient supports to isolate vibration in the groundborne noise frequency range have been installed in railway tunnels.

In standard ballasted track it is the ballast layer that provides the resilience and this gives an isolation effect above about 60Hz. Modern lines in tunnels use slab track constructions for reasons of space, alignment stability and low maintenance. Basic designs of slab track have only the rail pad resilience which is much stiffer than a ballast layer. This leads to an increased groundborne noise level compared to ballasted track.

A number of vibration isolating track forms have been implemented to alleviate this problem. These include soft baseplates on slab track and floating slab track.

A model, called CIVET (Change In Vibration Emitted by Track), for predicting the performance of vibration isolation in track structures has been developed. It is shown diagrammatically in Figure 1.

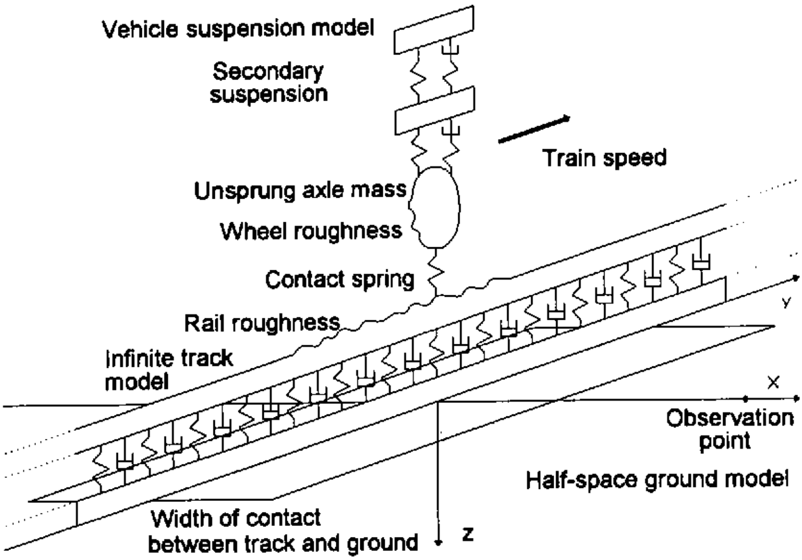

Fig. 1 Diagram of vehicle, track and ground model

The model is used to calculate the change in vibration response at an observation point on the surface of the half-space, away from the track, due to a change in the vehicle or track parameters.

The track is represented as a two-dimensional, infinite, layered beam resting on a three-dimensional half-space of ground material. The diagram shows the idealisation of a slab track. A number of alternative track structure models are implemented including ballasted track and floating slab track. All the track components are attributed properties as if continuous along the track. This is valid for the frequency range of interest as the effects of modes due to periodic rail support occur above 500Hz. The components of the track structure have been modelled with the following parameters.

- Rail: bending stiffness and mass per unit length
- Pad or baseplate: vertical stiffness but no mass
- Resiliently supported slab: bending stiffness and mass per unit length
- Slab mounts: vertical stiffness but no mass
- Base slab/tunnel invert: bending stiffness and mass per unit length
- Ballast: vertical spring stiffness with consistent mass

Hysteretic damping is included in each component using a complex stiffness property, ie. a material loss factor.

At the contact between the ground and the track, the track is assumed to exert a constant vertical pressure over the width of the track. No transverse tractions are applied to the half-space at the interface.

The unsprung mass acts at the rail via a linearized contact stiffness. The roughness is introduced as a differential displacement function across the contact spring.

The vehicle suspension is modelled as a one-dimensional system for each wheelset. The damper has been modelled by introducing a series stiffness to uncouple the viscous element at high frequency. The series stiffness represents the effects of the rubber bushes with which the damper is mounted and the complex internal behaviour of the damper.

The half-space foundation model represents the frequency-dependent support stiffness distribution under the track and provides a suitable summation of the contributions of vibration from all points along, and across the width of, the track. This summation takes account of appropriate geometric and material damping attenuations and phase (path length) relationships for a three-dimensional propagation medium.

In calculating the change in the forces at the tunnel invert and also summing their effect by using the half-space, it is assumed that a change in the response on the half-space due to a change in the parameters for the vehicle or track will be similar to the change in response for the propagation medium that surrounds the tunnel. This assumption is valid as long as the dynamic track support stiffness is high compared to the resilience in the track. Tests on the model have shown that the *difference* in response due to a change in track design does not alter significantly, either over a wide range of observation distances (3m to 100m), or for a change in ground properties from soft surface clay to those of compacted gravel.

The excitation of vibration in the groundborne noise frequency range is the roughness of the track observed at the rail head combined with the roughness of the wheel running surface. Devices have been developed to measure the wheel and rail roughness in the wavelength range from about 5mm to 2.5m. These have been used to measure roughness on tread-braked and disc-braked wheels and, on the rail, for ballasted and slab track.

4. EXAMPLE RESULTS

The predicted vibration level difference between ballasted track and slab track is shown in Figure 2 for the case where the same rail roughness is assumed for the two track types. In this case the difference does not vary with the train speed. Also shown on Figure 2, are the differences for train speeds of 50km/h, 100km/h and 140km/h which take into account the roughness spectra of the two track types. The graph confirms the known behaviour of slab track that it causes an approximately 10dB increase in groundborne noise between the 63Hz and 125Hz bands.

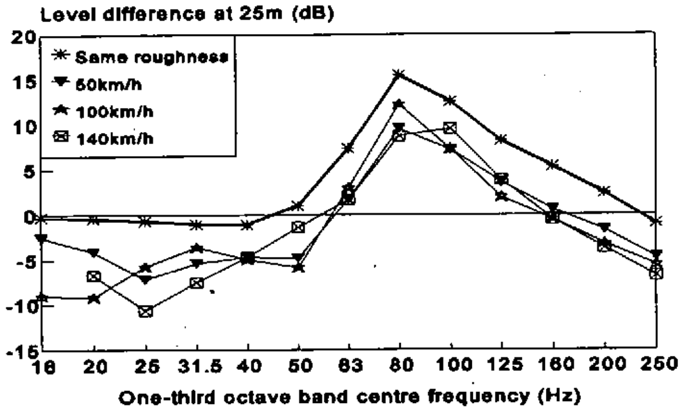

Fig. 2 Predicted change in response between ballasted and slab track

Figure 3 shows the predicted change in vibration when soft baseplates are added to slab track. Three stiffnesses have been used for the baseplates so that the effect of the baseplate stiffness is shown. The main track resonance for the standard slab track occurs in the 80Hz band. This can be seen as a peak in the difference spectrum in this band. This resonance is moved downwards in frequency by using the soft baseplates. For the three stiffnesses of baseplate (120×10^6Nm^{-2}, 60×10^6Nm^{-2} and 30×10^6Nm^{-2}) the new resonance shows as an increase (negative difference) in the 50Hz, 40Hz and 31.5Hz bands respectively. In the frequency band above each of these, and for the higher frequency bands, a reduction in vibration transmission is achieved. The softer the baseplate the greater the reduction in vibration at high frequency.

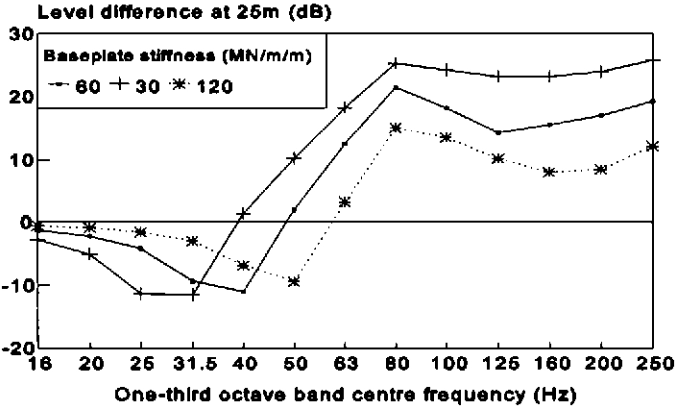

Fig. 3 Predicted effect of soft baseplates

5. CONCLUSIONS

Prediction models are used to estimate levels of groundborne noise for new railways. The most appropriate models are currently those derived empirically from existing railway situations. Theoretical models are needed to support the formulation of empirical models and to calculate changes in design outside the range of applicability of the empirical model. The use of theoretical models has been illustrated by describing in detail a model which accounts for the effects of train and track parameters. Example results from the model are shown for two tracks with different rail roughness spectra and different rail support stiffness.

6. REFERENCES

[1] A questionnaire on the concerns of European railways with respect to ground vibration phenomena. Conducted by BR Research on behalf of ERRI, November 1995.

[2] Jones, CJC, Wang, A and Dawn, TM, Modelling the propagation of vibration from railway tunnels, Computational Acoustics and its Environmental Applications, p285 - 292, Computational Mechanics Publications, Southampton, 1995.

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