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THE PiP MODEL, A SOFTWARE APPLICATION FOR CALCULATING VIBRATION FROM UNDERGROND RAILWAYS

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Abstract

Significant vibration in buildings near underground tunnels is attributed to moving trains. Vibration is generated due to irregularities of wheels and tracks and propagates to nearby buildings causing annoyance to people and malfunctioning of sensitive equipment. Modelling of vibration from underground railways is gaining more interest on account of the need for quick tools to design vibration countermeasures for both existing and newly constructed tunnels.
This paper describes a software application for calculating vibration from underground railways, called the Pipe-in-Pipe (PiP) model. The software has a user-friendly interface and is available on the internet as a freeware for engineers in charge of designing of vibration countermeasures in railway tunnels. The PiP model accounts for a train running on a floating-slab track in a tunnel embedded in the ground. The software calculates the Power Spectral Density (PSD) of the vertical displacement at any selected point in the soil for a roughness excitation of a unit value (i.e. white noise). It also calculates the Insertion Gain (IG) which is the difference in decibel between the displacement PSD after and before changing parameters of the track, tunnel or soil. The latest version of the software plots the displacement contours around the tunnel and accounts for a bedrock layer below the tunnel using the mirror-image method.
The software is computationally efficient as it calculates results accurately and quickly on a personal computer unlike other available models of vibration from underground railways which take much longer time and require huge computational resources. A full description of the current version of the software is given in this paper along with ongoing developments that will appear in future versions.

1. INTRODUCTION

Occupants of buildings in close proximity to underground tunnels can be disturbed due to vibration and reradiated noise caused by moving trains. Vibration is generated at the wheel-rail interface and propagates through the tunnel and the surrounding soil to nearby buildings.

The magnitudes and frequency content of vibration in buildings depend on the excitation mechanism at the wheel-rail interface and the dynamics of the track, the tunnel, the soil and the building and the interaction between these systems. Vibration can be isolated by using a number of vibration countermeasures such as soft railpads, floating slab tracks, barriers between tunnels and buildings and base isolation of buildings. Evaluating the performance of a vibration countermeasure before being installed or constructed is of a great importance. This is attributed to the high cost of countermeasures and the difficulty of retrospective replacement. To evaluate the performance of countermeasures, a computationally efficient model is needed especially for engineers in charge of designing of these countermeasures.

This paper reports on a software application for assessing vibration countermeasures in underground railway tunnels. The software is called the Pipe-in-Pipe (PiP) model and it is available as a freeware on the web. The main characteristic of the software is that it combines between accuracy and computational efficiency and therefore it is a valuable tool for acousticians and vibration engineers especially those in charge of designing of vibration countermeasures. The following sections of this paper describe the software, its features and limitations and the future developments.

2. THE PiP MODEL

The PiP model has been under continuous development for more ten years [1-5]. The model is based on two concentric pipes to account for a tunnel wall embedded in a full space, see Figure 1. The inner pipe represents a tunnel wall and the outer pipe, with external radius set to infinity, represents the surrounding soil. The tunnel wall is modelled as a thin cylindrical shell and the surrounding soil is modelled using the elastic continuum theory. The model is fast running on account of uniformity of the tunnel and soil in the longitudinal direction (the tunnel direction) and in the circumferential direction. A floating slab track is coupled to the model (Figure 2) by formulating the governing equations in the wavenumber-frequency domain.

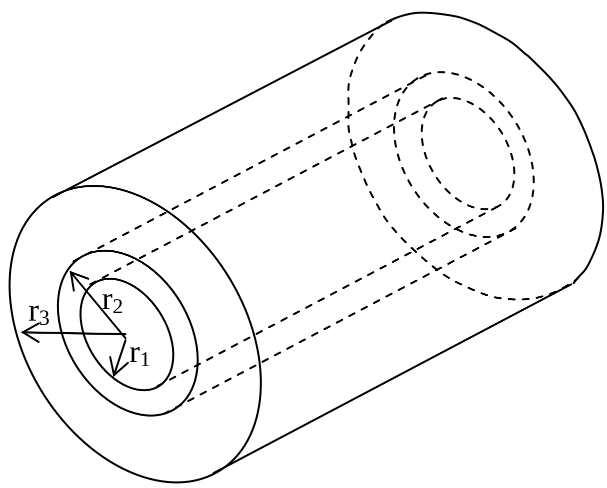

Figure 1: The PiP model consists of two concentric pipes, the internal pipe to account for the tunnel wall and the external to account for the surrounding soil.

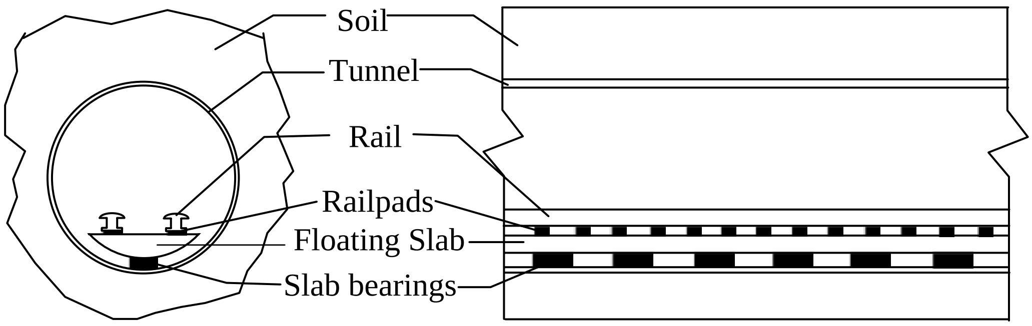

Figure 2: A floating-slab track is coupled to the tunnel wall.

An infinite number of masses are used to model the axles of an infinitely-long train and roughness is considered as the source of excitation, see Figure 3. The theory of random vibration is used to calculate the Power Spectral Density (PSD) of the displacement at a point in the soil due to dynamic forces at the wheel-rail interface. The dynamic forces are calculated due to a white-noise rail-roughness. The difference between the PSD results after and before using a vibration countermeasure gives the Insertion Gain (IG) which is a direct measure of the effectiveness of the vibration countermeasure. The current version of the PiP model has the following limitations

1. There is no account for free surface. Although this is a serious limitation when it is required to predict vibration in the free-surface or in buildings. The authors believe that this is of a little importance for calculation of IG. The PiP model has recently been developed to account for a free-surface and multi-layered ground [6-8].

2. The computed spectra are pseudo stationary, i.e. there is no assumed variation in vibration level as the train passes by. This assumption is good at distances away from the tunnel that are large compared with the axle spacing.

A detailed description of the model formulation can be found in [1-3].

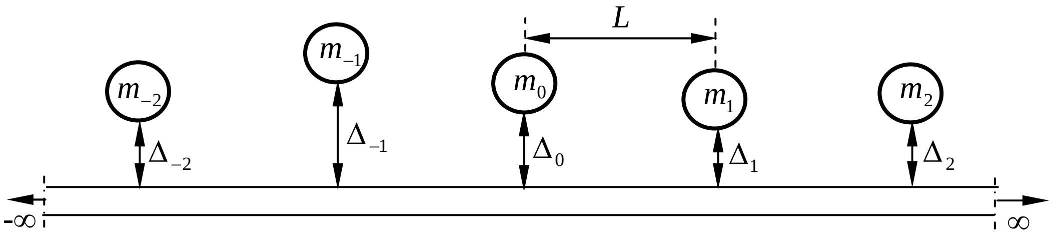

Figure 3: The input to the model is a random roughness excitation applied as displacement between the axle masses and the rails, note that the beam represents the two rails and each mass represents an axle.

3. THE SOFTWARE INTERFACE

The PiP software is available on the web as a freeware [9]. Three versions have been released so far. The software has a user-friendly interface, see Figure 4. The parameters of the model should be entered by the user and these comprise parameters of the train, the track, the tunnel and the soil. The software calculates the PSD of the displacement at a point in the soil selected by the user. It also calculates the Insertion Gain (IG) which is the difference between the PSD after and before using a vibration countermeasure. The software is self-explanatory and easy to use. It takes no longer than a couple of minutes for a user to assess the performance of a vibration countermeasure on reducing vibration from underground railways.

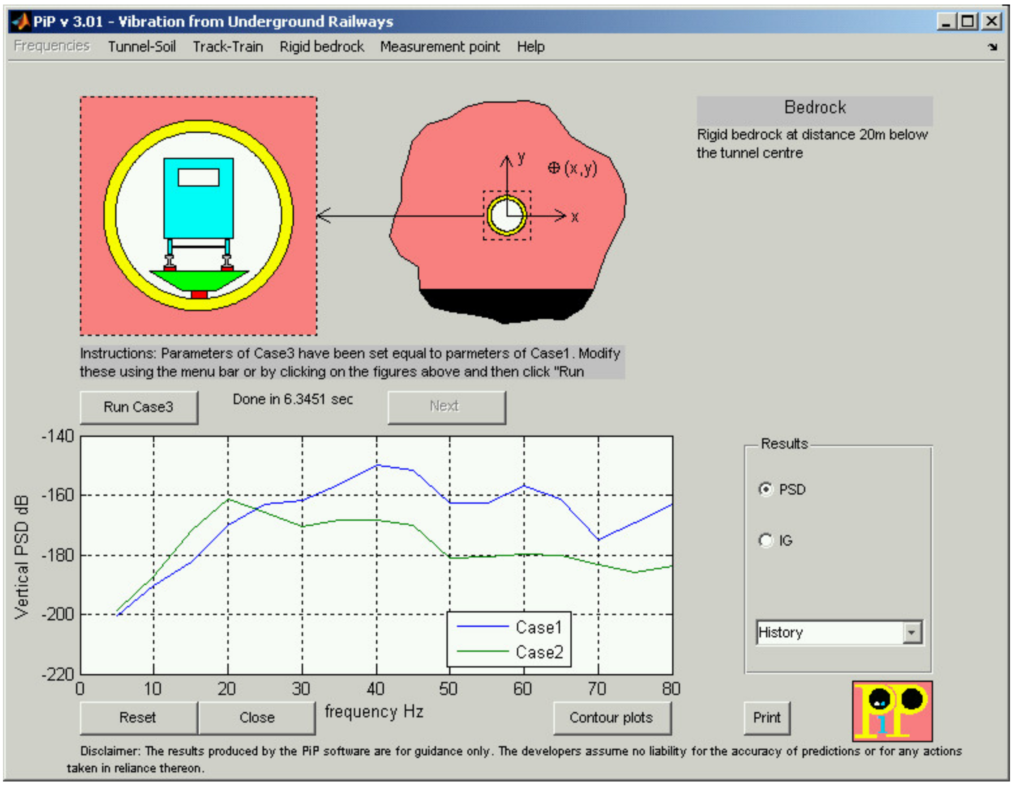

Figure 4: The interface of the PiP software.

The latest version of the software was released in August 2006 with the following new features:

1. The Contour Plot function is introduced to plot the Power Spectral density (PSD) and the Insertion Gain (IG) of the vertical displacement at a mesh of points around the tunnel for a fixed frequency, see Figure 5. Results are plotted in a 2D plane perpendicular to the tunnel longitudinal axis due to an infinitely-long train running in the tunnel at a constant frequency f. The constant frequency f corresponds to a fixed wavelength (k=v/f) of the rail roughness, where v is the train velocity. The IG Contour Plot is a direct measure of the isolation performance at a particular frequency.

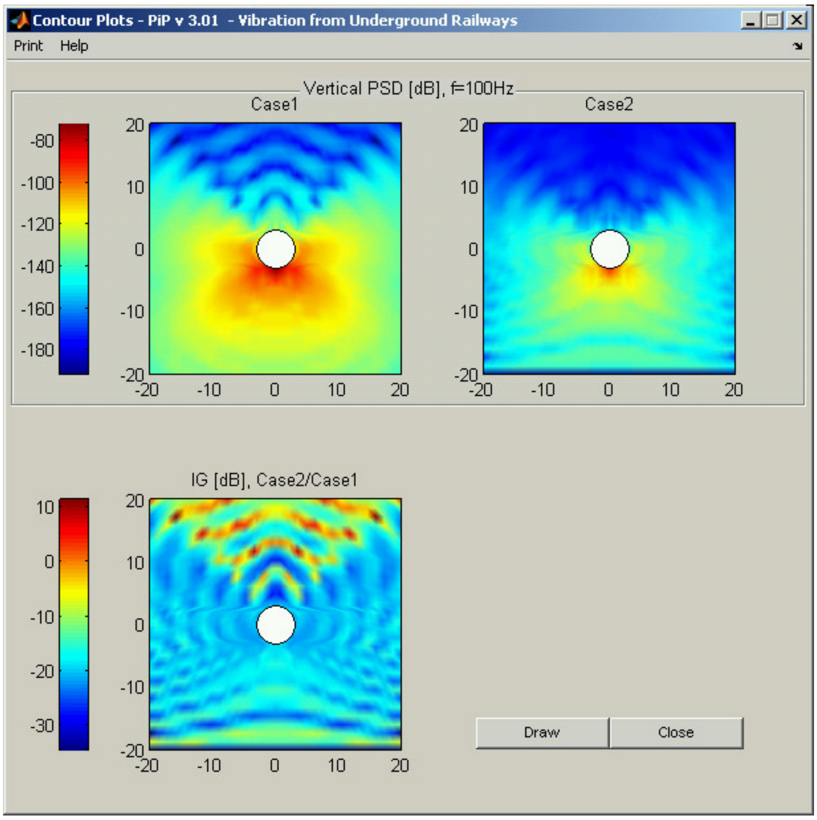

Figure 5: contour plots of the displacement PSD and the IG.

2. A computationally efficient method is used to account for rigid bedrock below the tunnel. The method is based on the mirror-image method as illustrated in Figure 6. In the case of rigid boundary as shown in Figure 6.a, vibration at the receiver is attributed to direct field from the source and reflection field from the boundary. The reflection field can be accounted for by removing the boundary and placing another source at the same distance from the removed boundary, as shown in Figure 6.b. In the case of a 3D elastic continuum, the method satisfies the vertical-displacement boundary condition at the boundary but not the horizontal and the longitudinal ones. However, it gives a good approximation with low computational requirements, see [10] for more details.

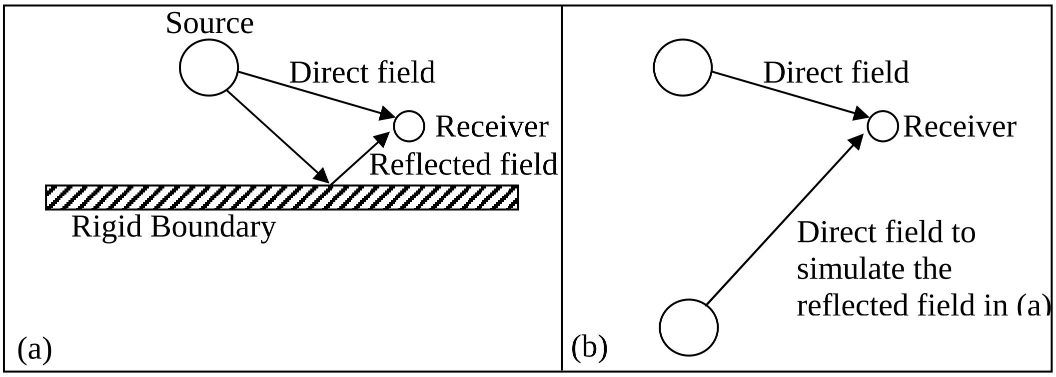

Figure 6: The mirror-image method.

5. ONGOING AND FUTURE DEVELOPMENTS

The PiP model in its current form is a valuable tool for evaluating the performance of vibration countermeasures through the IG calculations. The model has recently been developed to predict vibration from underground railways by accounting for realistic situations such as the existence of a free-surface and multi-layered ground [6-8]. Future versions of the software will incorporate these new developments.

6. SUMMARY

This paper has reported on a software application for assessing vibration countermeasures in underground railway tunnels. The software combined between accuracy and computational efficiency and is available on the web as a freeware. The current features of the software and the future developments have been presented.

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