Vibrations Nuisance due to Road and Railway Traffic

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Summary

One of the most critical problems in the design of roads and railway tracks in urban areas is the limitation of vibration hinder, and possible damage, caused by passing rail and road traffic. Apart from the traffic the main sources for vibration nuisance are related to pile driving and the vibration of sheet piles. The prediction of this vibration nuisance, and the effectiveness of measures to reduce this hinder, was the main target to develop a prediction model for vibration hinder. One of the prerequisites was the modular structure of the components which govern the problems. Modules which define the load application by pile driving or traffic loads are separated from the modules defining the transmission problems in the soil and modules defining buildings, which are subjected to the vibration hinder.

Keywords: railway track, vibrations, waves, dynamics, mitigating measures, nuisance, modelling

1. Introduction

Research data in The Netherlands indicate that about 10 % of the population experiences vibration hinder due to human activities in the neighborhood. Vibration nuisance can be associated with different phenomena such as the direct exposure to unpleasant vibrations in a building. But also the resulting effects of vibrations causing break down of equipment and damage to buildings due to fatigue can be mentioned. From a physical point these problems can be described as a classical mechanics problem dealing with responses of the building, for instance floor and wall velocities.

2. Structure of the prediction model

Under the auspices of the Center for Underground Building (COB) in The Netherlands the Committee L400 and later the Committee G106 developed the prediction model, further referred to as the L400-model. In order to limit the computational time use was made of so-called macro elements. Complex structures such as buildings, could be modeled initially with a large number of degrees of freedom. Afterwards the number of degrees of freedom could be substantially reduced via the component mode synthesis technique. In the macro element philosophy the vibration problem could be schematized to basically 3 parts:

- Source;
- Transmission medium;
- Receiver.

Figure 1 Vibration prediction model

Besides, parts of the model can be replaced by a transfer functions (impedance), calculated from measured data. The vibration source should be modeled sufficiently realistic. The model contains the following excitation sources:

- Pile and sheet driving;
- Road traffic;
- Rail traffic.

The excitation sources can be described either by a load versus time or by a load spectrum in the frequency domain. Both options are applicable.

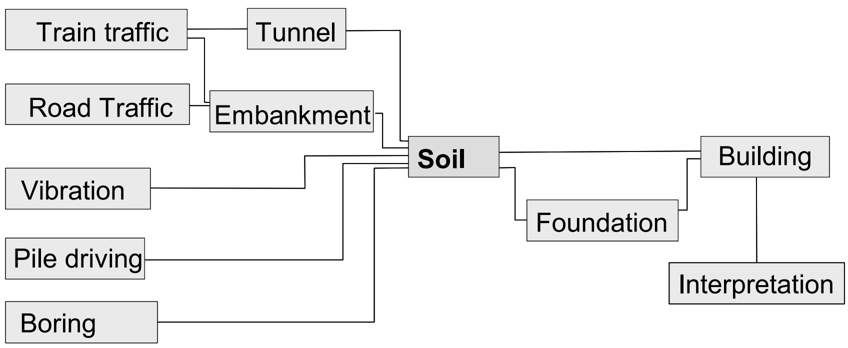

Figure 2 Structure of the prediction model

The transmission medium is composed of a number of transmission modules such as:

- Tunnel or embankment;
- Soil;
- Piled foundation;
- Building.

Calculations are made in the frequency domain in the frequency band 5 – 100 Hz.

3. Transmission models

In the chain of processes the modeling of the transmission of stress waves between load source and target is the most difficult step to realize. The apparently most common approach is to model the stratified medium by a finite element model. This approach, however, fails because of the many degrees of freedom (dofs) which are needed to obtain sufficient accuracy. To develop a method which yields sufficient accurate results with the limited power of a PC semi analytical methods were proposed. With the help of these analytical methods the large distances between a load application point (the source) and the target points (the receivers) could be overcome. A finite element model would require millions of dofs which is prohibitive for a PC. In the following sections the proposed analytical tools will be outlined.

4. The strategy of a transmission model

Homogeneous properties in the horizontal plane is one of the starting points of a stratified medium. With respect to the depth the layers are modeled by discrete changes of the properties. The basic question is to relate the loads applied in a source to the response in a receiver point. Using analytical tools we will find a relation between forces $\boldsymbol{f}_{source}$ and displacements $\boldsymbol{u}_{receiver}$ or velocities $\boldsymbol{v}_{receiver}$. Such relations are given by the admittance matrix $\boldsymbol{A}$ following

$$\boldsymbol{v}_{receiver} = \boldsymbol{A}\,\boldsymbol{f}_{source}$$

The model that we will analyze is given by an horizontal circular load area, loaded by an uniformly distributed load in x, y and z direction and a receiver point at some distance from the load area.

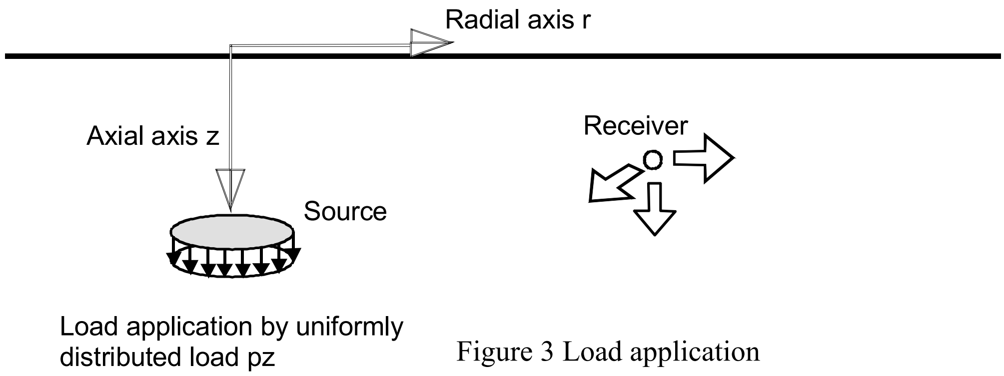

Figure 3 Load application

To employ the analytical tools the following reductions are performed:

1. We transform the equations of motion with the help of a FFT to the frequency domain. Now the differentiations with respect to time are replaced by dependency on the frequency parameter ω. We will solve the problem for a limited number of frequencies.
2. We apply a Fourier series with respect to angle θ. Actually we need only the constant and the first sine and cosine term. For our problems we have to solve two load cases, namely

$$p_x = p_y = 0. \quad p_z = \text{constant}$$

and

$$p_x = \text{constant} \quad p_y = p_z = 0.$$

For our further elaborations we will use a cylindrical reference system, thus we replace x,y and z by r,z and θ. The source is located at the axial axis z.

To employ the analytical tools we introduce displacements potential as follows

$$u_r = \frac{\partial \varphi}{\partial r} + \frac{1}{r}\frac{\partial \psi_z}{\partial \theta} - \frac{\partial \psi_\theta}{\partial z}$$

$$u_\theta = \frac{1}{r}\frac{\partial \varphi}{\partial \theta} + \frac{\partial \psi_r}{\partial z} - \frac{\partial \psi_z}{\partial r}$$

$$u_z = \frac{\partial \varphi}{\partial z} + \frac{1}{r}\frac{\partial (r\psi_\theta)}{\partial r} - \frac{1}{r}\frac{\partial \psi_r}{\partial \theta}$$

Substitution hereof into the equations of motion yields a series of uncoupled differential equations [1,2]. The displacement potentials are coupled only by the boundary and interface conditions. From this point two different solution methods will be applied, namely an approach based upon Hankel transformations and a method based upon the separation of variables (SV method). Both methods have their own merits. Briefly, the Hankel method is exact but very time consuming, the SV method is much more efficient but less accurate for low frequencies. For low frequencies the Hankel method is applied and for high frequencies the SV method.

The solution methods

In the preceding section we have reduced the equations of motion to a series of uncoupled differential equations with respect to r and z. The next step is to solve these differential equations with either the Hankel method or the SV method.

The Hankel method eliminates the differentiation with respect to the radial direction by a transformation with the use of Bessel functions following

$$\hat{f}(\xi) = \int_0^\infty r\, f(r)\, J_0(\xi r)\, dr$$

Later we will perform the back transformation following

$$f(r) = \int_0^\infty \xi\, \hat{f}(\xi)\, J_0(\xi r)\, d\xi$$

After this transformation we get very simple ordinary differential equations such as

$$\frac{d^2 \hat{f}}{dz^2} - \alpha^2 \hat{f} = 0$$

with α complex. These equations are solved easily and consecutively the back substitution process can be performed.

The SV method is based upon the separation of variables under the assumption

$$\varphi(r,z) = R(r)Z(z) \text{ etc.}$$

This assumption is not exact but satisfies very well for higher frequencies. Substitution hereof into the reduced equations of motion yields a (larger) series of uncoupled ordinary differential equations with respect to r for R(r) and z for Z(z). Again the displacement potentials are coupled by the boundary and interface conditions. These ordinary differential equations are solved easily and the back substitution process can be executed.

In this case it is not needed to perform a back transformation in the radial direction, the method is much more efficient then the Hankel method. For high frequencies this is the appropriate method.

5. Examples

In the remainder of this article two examples are presented of calculations carried out with the L400-model. In figure 4 the velocities at the surface and at 20 deep, due to a vertical load at the surface, are depicted.

The second example deals with pile driving, modeled as an impulse load at a depth of 20 m.

Homogeneous halfspace

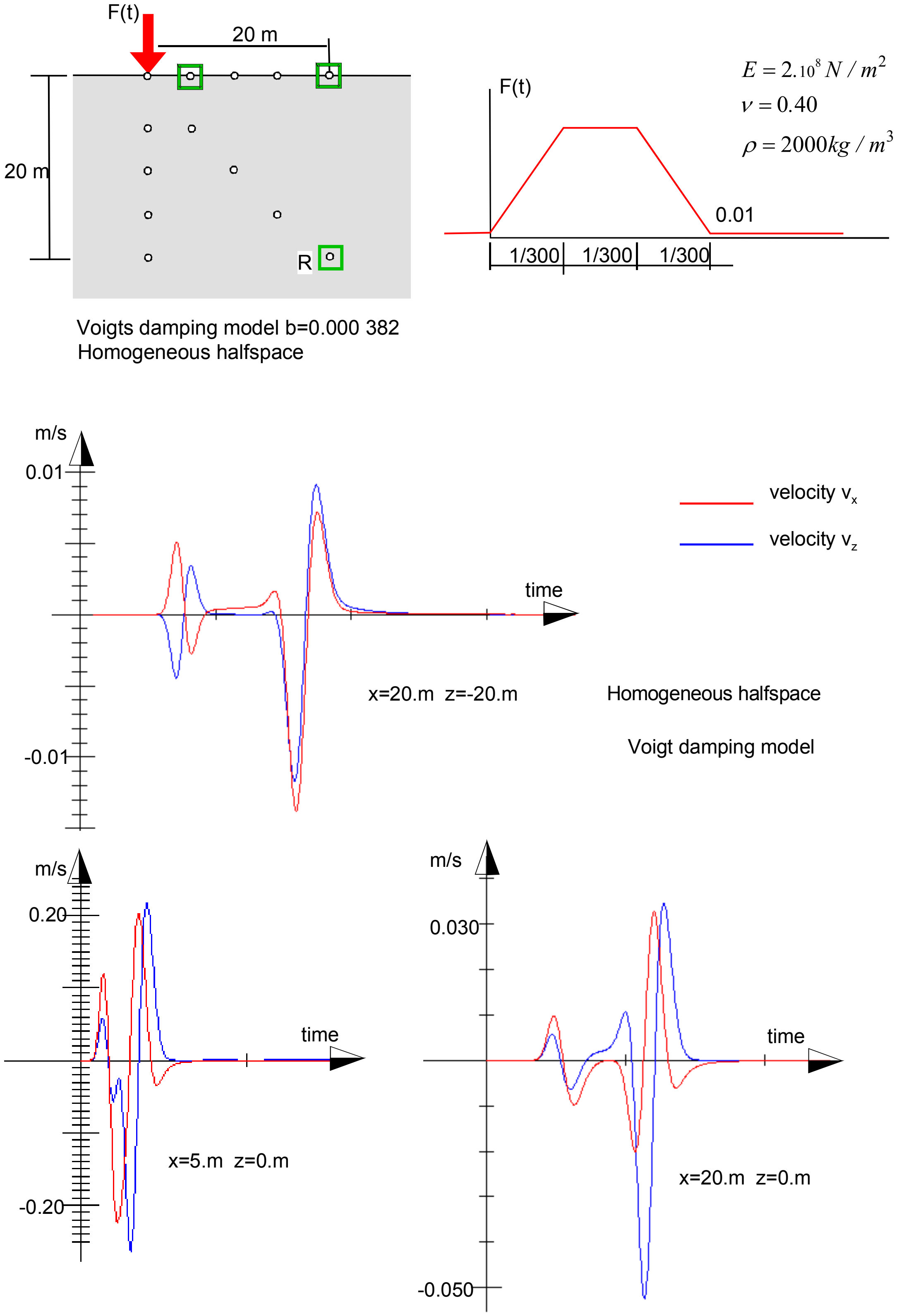

Figure 4 Load on homogeneous half space

Pile driving

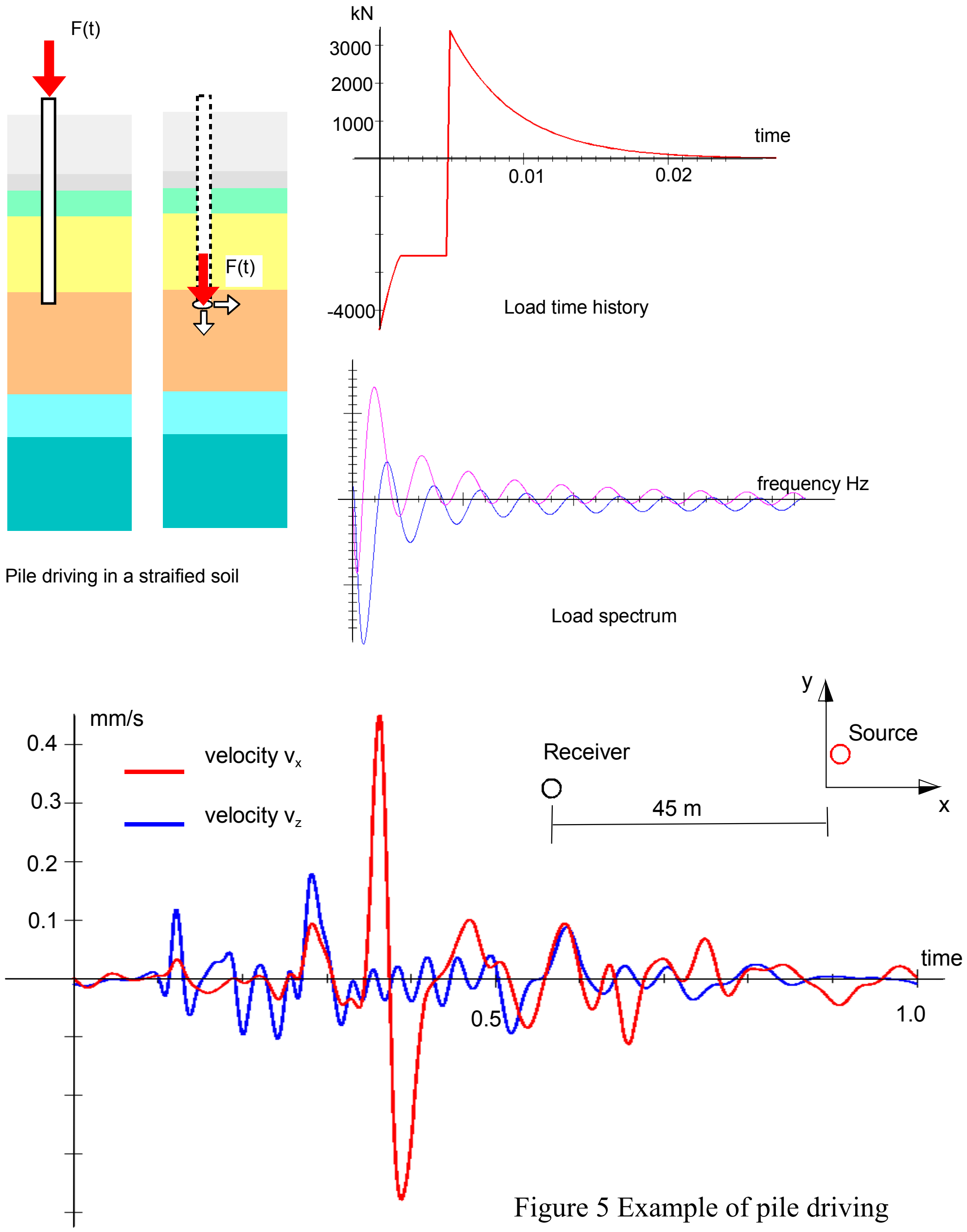

Figure 5 Example of pile driving

6. Future developments

Future development has to address the problems of interfacing between the transmission model and the finite element models of the structures. The first step will be the creation of a rigid interface between soil and buildings. This problem area is certainly not a self evident subject and will require considerable efforts.

References

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