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VIBRADYNA: A NEW VIBRATION PREDICTION MODEL

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Annoyance due to vibrations from roads and railroads is an increasing problem. A recent Dutch survey has shown that as much as 20% of the residents living within 300m from a railroad track report severe annoyance from vibrations. To increase accuracy and cost-efficiency of vibration research, Movares has developed the VibraDyna package, a vibration prediction model based on accurate empirical relations established on the analysis of hundreds of measurements along roads and railroads. The package uses (mainly) publicly available information from the vibration source (train model, speed, track type, switches and crossings, etc.), transmittant (soil type, terrain lay-out, etc.) and receiver (building properties) to make an accurate prediction of the expected vibration and ground borne noise levels. VibraDyna uses a vast database with measurements and model calculations to minimize the required field measurements. If necessary, users can also use own measurements or model relations to increase model accuracy for specific circumstances. The model has been validated in a variety of projects over the past years, showing a good resemblance between predicted and actually measured vibration levels.
Keywords: VibraDyna, vibration prediction model, empirical model, road and rail vibrations

1. Introduction

Annoyance due to vibrations from roads and railroads is an increasing problem. A recent Dutch survey has shown that as much as 20% of the residents living within 300m from a railroad track report severe annoyance from vibrations. To prevent annoyance or costly measures in new infrastructural development projects, research is needed on the prediction of vibration and ground borne noise levels in the environment. Movares has developed the VibraDyna package to predict vibration levels using empirical relations established on hundreds of measurements on ground level and in buildings. These measurements are categorized according to transmittant, source and receiver properties, e.g. soil type, terrain lay-out, train/car model, track type, track lay-out, switches, crossings and building properties. The quantitative contribution of each property on the vibration levels in the environment are determined by either direct calculation or fitting empirical models on the data. As the contribution of more properties are quantified with each added measurement to the database the VibraDyna package is able to lower the need for costly measurements to establish a good prediction of vibration levels and predict at earlier stages in the project.

This paper addresses the soil and source properties of two train models on a sandy soil and the properties for three different soil types to give a first impression on the properties used in the VibraDyna package. The used relations in the package have been validated in a variety of projects over the past years, showing a good resemblance between predicted and actually measured vibration levels. First the empirical model which is used to estimate source and soil properties is discussed. Secondly the fitted parameters of two sets of measurements are presented. Then the accuracy of the estimated parameters is discussed. In chapter 5 the estimated soil properties for three different doil types are presented followed by a conclusion on the estimation process.

2. Empirical model

To distinguish the source and soil properties the empirical relation described by the frequency dependent version of the Barkan curve is used, as shown in equation (1). The Barkan curve calculates the vibration velocity $\mathrm{v}(f)$ for each frequency at a distance r using the reference vibration velocity $\mathrm{v}_0(f)$ at reference distance r_0, geometrical spreading parameter $n(f)$ and intrinsic soil damping $\alpha(f)$. The parameters are estimated using a best fit procedure for each train passage, estimating the expected value of the parameters with a certain spreading. The spreading accounts for the variations between train passages in the model.

$$\mathrm{v}(r,f)=\mathrm{v}_0(f)\cdot\left(\frac{r_0}{r}\right)^{n(f)}\cdot e^{-\alpha(f)\cdot(r-r_0)}. \tag{1}$$

Fitting the Barkan curve on measured data has the difficulty of fitting two terms, the geometrical spreading and the intrinsic soil damping, with similar shapes. This increases the chance for local optimized fitting results, especially in the presence of noise. To prevent local optimized fitting results an assumption is made for the geometrical spreading paramter. Based on observation and a layered ground model a general shape is described for the geometrical spreading using equation (2), where the geometrical spreading is function of the frequency f and a certain eigenfrequency f_0 at which the spreading reaches a peak value of 2.

$$\mathrm{n}(f)=\left|\frac{1}{\left(f_0/f\cdot i\right)^2+0.52\cdot\left(f_0/f\cdot i\right)+1}\right| \tag{2}$$

3. Fitting parameters

The results of two measurements at adjacent locations are presented to discuss the accuracy of the fitted model. Measurements were conducted on opposite sides of the track and several hundred meters apart. Fitted parameters for both measurements (location 1 en location 2) are shown in **Figure 1**. Location 2 is approximately 30 meters further from the track than location 1 and the speed of passing trains is slightly lower at location 2 with a smaller variation.

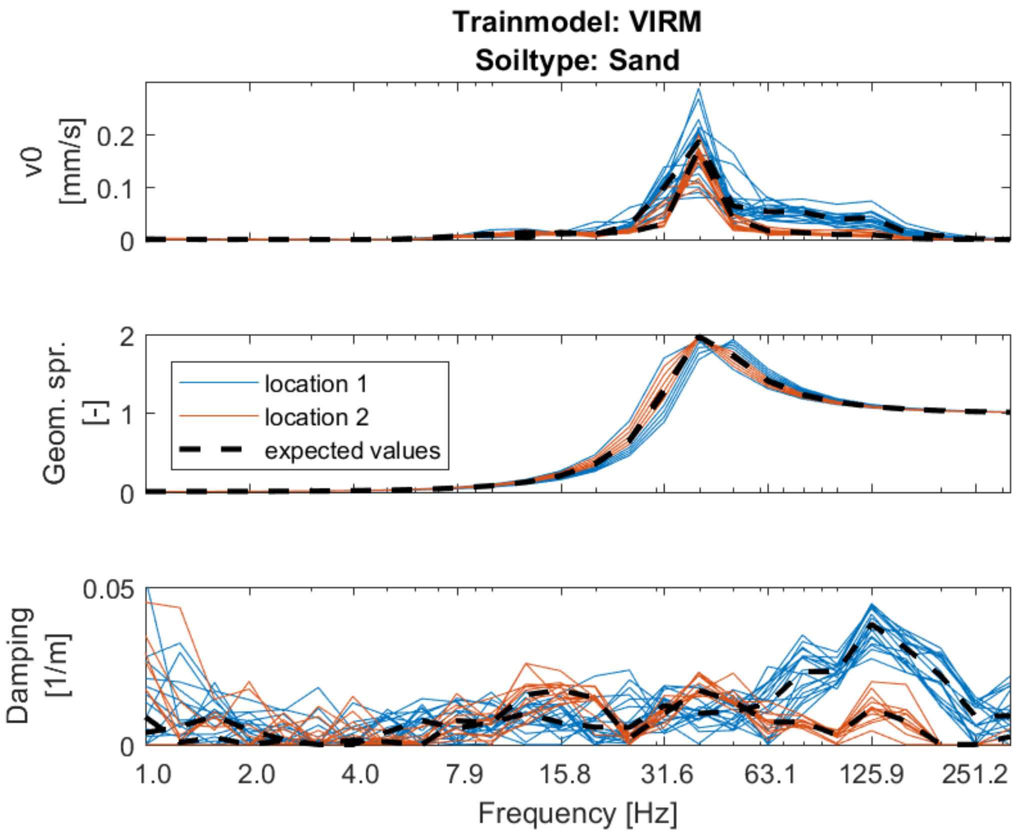

Figure 1: Fitted parameters for the empirical model of two measurement location 1 and 2, shown for each train passage (coloured) and the expected values for the locations (black striped).

Both locations show a similar eigenfrequency around 40Hz for the geometrical spreading. Between the locations and within the locations the variation of the eigenfrequency is small. The estimated intrinsic soil damping for both locations up to 63.1Hz is similar. At higher frequencies the estimated damping is higher for location 1. The reference vibration velocity is similar between both locations up to 63.1Hz, thereafter higher vibration velocities are estimated for location 1.

4. Estimation accuracy

Up to 63.1Hz both locations give very similar results for all estimated parameters, at higher frequencies both the reference vibration velocity and intrinsic soil damping are significantly higher for location 1. The signal strength decreases rapidly with distance at higher frequencies, due to relative higher damping and geometrical spreading at these frequencies. As the measurement of location 2 is placed at a larger distance from the track, the signal strength and damping effects become too weak for a good fit at higher frequencies. In order to estimate the parameters accurately the signal strength should be high enough for all examined frequencies.

5. Comparison soil types

The intrinsic soil damping is estimated for a sandy, clay and peat soil. The results are shown in Figure 2. It is clear that the intrinsic damping differs significantly between the three soil types. Sand gives the least amount of damping, followed by clay and peat has the highest damping. For frequencies above 63.1Hz the damping drops rapidly towards zero for high frequencies. This effect is also seen at location 2 in Figure 1. It is probable that both have the same cause, the distance from the track is too great for high frequencies to establish a good fit.

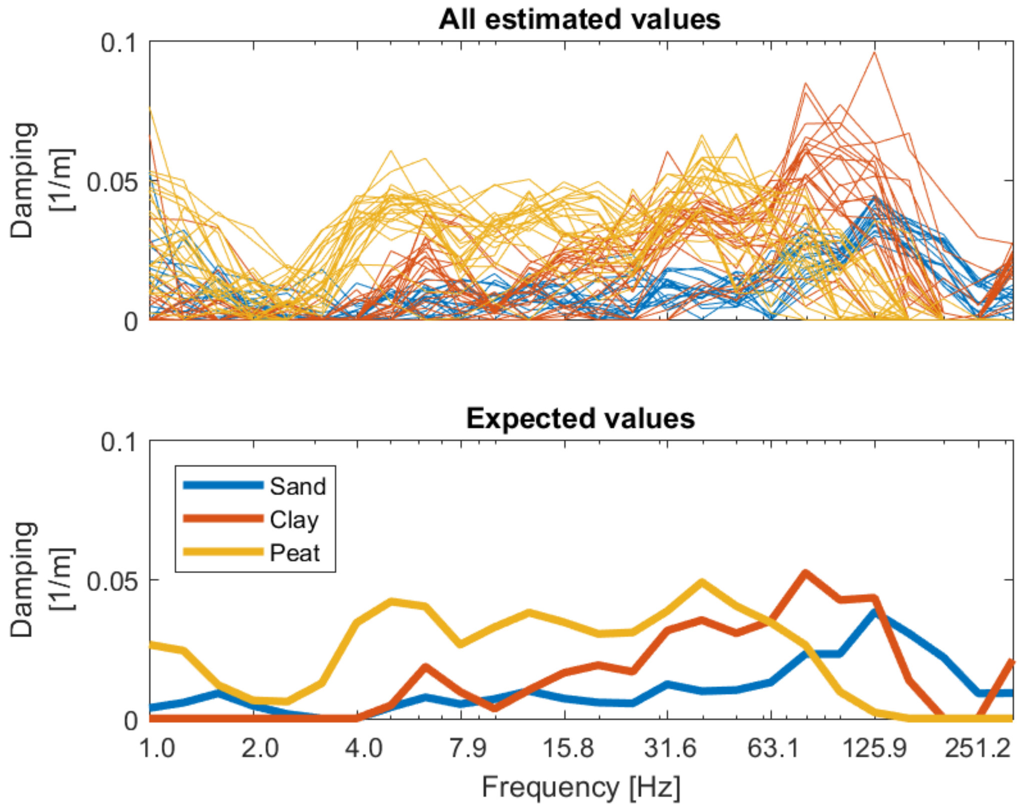

Figure 2: Estimated intrinsic damping for sandy, clay and peat soil.

6. Conclusion

The VibraDyna packages uses several relations to accurately predict vibration levels in a variety of environmental conditions. This paper describes how one of these relations, the decrease in vibration levels through the ground at a certain distance from the source, is estimated. At an adjacent location the estimated parameters show similar results for almost all frequencies. Estimation of the parameters at frequencies with low effect and signal strength compromises the accuracy. At different locations with different soil types the estimated intrinsic soil damping shows a pattern that matches the experience in the field.

A similar approach of estimating parameters using measurements is also established for the other model properties, giving a complete package of relations to accurately predict the vibration levels in a fast amount of environmental conditions. If necessary, users can also use own measurements or model relations to increase model accuracy for specific circumstances.