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Prediction of ground vibration amplitudes due to urban railway traffic using quantitative and qualitative field data

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ABSTRACT

The growth of railway transport in urban areas has lead to an increase in ground vibrations enhancing their negative environmental impact. Therefore is mandatory to predict and control ground vibrations. This work presents a methodology for the determination of prediction models of ground vibration amplitudes due to railway train circulation in urban environments. Using quantitative predictors (train speed and distance) and qualitative predictors (railway track type, dominant geology and building type), being the use of the latter predictors justified by the fact that, most frequently, quantitative parameters are very difficult to obtain in the urban environment due to their characterization. Thus, a detailed statistical study based on the proposal and validation of multiple linear regression models, is successfully applied in order to predict vibration amplitudes produced by railway train circulation, in the considered domain, as function of quantitative and qualitative predictors, easily obtained in field work. A multiple linear regression model for ground vibration prediction due to underground railway traffic has been presented for the Lisbon area.

Introduction

The problem of the environmental impact due to ground vibrations produced by railway transport in urban areas became an urgent research issue. It is known that in the last 50 years, the use of railway transportation has increased, not only in terms of density but also in terms of circulation speed in order to respond to the demands of the modern society (Connolly et al., 2014). This situation has caused an increase in ground vibrations, such that when certain levels are achieved it can be considered as having a severe environmental impact, causing damages to buildings, discomfort for the population, amongst other issues.

The standard ISO 2631, Part 2, updated in 2003, reveals that a slowdown in the restrictions imposed by older versions were disregarded, showing that new studies are necessary in order to establish suitable restrictions.

Ground vibrations are the result of the vehicle forces acting into the track, which depend on vehicles weight and irregu larities/discontinuities at the wheel/rail interface (Kouroussis et al., 2014). Therefore, the generated vibrations will propagate outwards from the track.

Vehicle type plays a significant role in vibration generation. Wilson et al. (1983) demonstrated that a proper design of the bogie suspension can significantly reduce levels of ground vibration and Nelson (1996) inferred that, in general, vehicles with soft primary suspension produce lower levels of vibration than vehicles equipped with stiff suspensions.

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According to Kouroussis et al. (2014), vibrations generated by high-speed trains are mainly dependent on quasi-static track deflection, because high-speed lines are characterized by very high quality rolling surfaces. On the other hand, light transit vehicles (which are vehicle types the considered in the present paper), are characterized by a low speed and a relatively high density of singular rail surface defects and, thus, dynamic track deflection mainly contributes to ground wave generation. The moderate speed trains present excitation mechanisms that are a combination of those experienced on both high-speed and urban railway lines. Fig. 1 shows a representation of three train types: low speed, medium speed and high-speed trains.

An accurate estimate of ground vibrations generated by railway traffic requires the knowledge of input parameters, such as the dynamic track and ground characteristics, for which in situ testing may be required. For this, the Federal Railroad Administration (FRA) and the Federal Transit Administration (FTA) of the U.S. Department of Transportation have developed a set of empirical procedures to predict vibration levels due to railway traffic (Hanson et al., 2005, 2006). Also, the standard ISO 14837-1:2005 offers guidance on prediction for a range of circumstances (e.g. to support the assessment of the effect on human occupants, considering the activities developed in the target structures, the effect on sensitive equipment and the risk of damage to building structures) and covers all forms of wheel and rail systems, from light-rail to high-speed trains and freight, circulating on grade rail systems, elevated structures and in tunnels.

Several numerical models have been developed for the prediction of ground vibrations due to surface railway traffic (Grundmann et al., 1999; Sheng et al., 1999; Picoux and Le Houédec, 2005; Lombaert et al., 2006a,b; Galvín and Domínguez, 2007) and in tunnels (Metrikine and Vrouwenvelder, 2000; Andersen and Jones, 2006; Degrande et al., 2006). Kouroussis et al. (2014) offers a good scoping of some vibration prediction models and points the particular aspects in each approach.

In the particular case of the prediction of ground vibrations due to railway traffic in urban areas, it can be highlighted the work of Verbraken et al. (2011) which established a link between numerical and empirical predictions as the FRA procedures allows for so-called hybrid predictions based on empirical data and numerical results. Connolly et al. (2014a) developed a new scoping railway vibration prediction model (so called ScopeRail), capable of predicting three international vibration metrics in the presence of layered soils, using a high accuracy 3D model to populate a database of vibration records. From this database the relationships between key railway variables were established using a machine learning approach. This model was later developed to instantly predict ground vibration levels in the presence of different train speeds and soil profiles (Connolly et al., 2014b).

In fact, the use of numerical models, for environmental vibration predictions, avoids extensive fieldwork and, occasionally, the amount of field data is not sufficient to perform detailed studies. In some cases (Kouroussis et al., 2014), namely those related to the use of boundary element numerical method for complex geometries, being the frequency domain limited to linear problems, the use of numerical models becomes inconvenient and the alternative is based on empirical approaches, which are often used during the preliminary design phase.

Field measurements are important to get direct information about structures behaviour over these dynamic events. When a suitable number of samples is obtained, data can be statistically analysed and predictive models for identical situations can be developed (Hung and Yang, 2000). As an example, it is highlighted the field tests developed under the research project CONVURT (*The Control Vibration from Underground Traffic*) (Degrande et al., 2006) to predict vibration levels inside buildings and to identify human discomfort situations. This prediction is based on different project solutions in order to minimize vibrations in permanent tracks, over distinct background conditions, layout possibilities and infrastructure typologies.

The main objective of this study is the prediction of ground vibrations amplitudes due to urban railway traffic. For data regression analysis, a detailed statistical study, made by proposal and validation of multiple linear regression model variations for vibration amplitudes prediction is performed, These models consider, as dependent variable, ground vibration amplitude and, as predictors, different quantitative and qualitative predictors, easily obtained in field works.

This paper starts with the presentation of some basic concepts about source, propagation media and vibration targets. Next, the method of qualitative predictors codification is explained. Then, the methodology for field data analysis is detailed, mainly the aspects concerning field data quality analysis and collinearities, multiple linear regression parameter estimate and model selection criteria. The case study is based on the application of the described methodology in the Lisbon

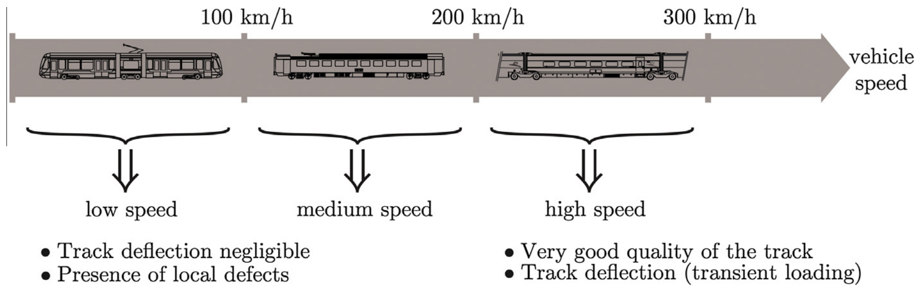

Fig. 1. Schematic representation of the parameters influencing railway-induced ground vibrations (Kouroussis et al., 2014).