Understanding Critical Velocity Effects on High Speed Railways

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1 Introduction

In many countries there is a pressure to increase speeds on existing rail networks as well as to construct new routes. As train speeds are increased, ballasted railway tracks that have previously performed acceptably may start to deteriorate more rapidly and in extreme cases may begin to experience large movements as a result of what are commonly termed critical velocity effects. These occur when the train speed approaches the speed of surface (Rayleigh) waves in the underlying ground, and can lead to substantially increased rates of track geometry degradation, poor ride quality and increased maintenance costs. Critical velocity effects are also a potential concern for new high-speed lines where they cross areas of soft ground that have traditionally been avoided. The soils involved are typically peats, organic clays and soft marine clays with shear wave velocities of 30 ms-1 or less. Modern trains running at speeds of up to 300 km/h (83 ms-1) or above are therefore increasingly likely to approach or exceed the Rayleigh wave speed of the ground and so induce critical velocity effects. It is therefore desirable to be able to model critical velocity effects. The Rayleigh wave speed is approximately equal to 90-95% of the shear wave speed of the ground, hence the shear wave speed is often the parameter of interest in any investigation.

Such effects were first noted by De Nie (1948), with theoretical work then developed by several authors, including Kenney (1954). Many authors have since incorporated layered ground geometry into their analyses, such as Krylov (1998) and Alves Costa et al., (2010). Most models tend to be 2.5D linear elastic, with some aiming to include more complex non-linear effects. Critical velocity effects have been observed in many countries, especially in locations where the running speed on the existing classic rail network has been raised. One of the most well documented and highly cited occurrences is that in Ledsgaard in Sweden, where soft organic clays caused the onset of critical velocity effects at approximately 150 km/h (42 ms-1) (Kaynia et al., 2000).

2 Focus Of This Project

To identify potentially problematic locations, and develop more cost-effective remediation solutions, an improved understanding of the cause of ground and track movements is needed. This project aims to combine field instrumentation, laboratory testing and computer modelling to gain an insight into the importance of various parameters, and the appropriate measures for determining them.

Most work within this field has focused on developing increasingly complex models to estimate ground movements more accurately. However, all of these models rely on the quality of the parameters applied they use. While some sites are easily identifiable as problem locations, owing to extremely soft soil conditions, many others are marginal. Arguably, these sites are the most important in terms of modelling predictions, as decisions will be required on what remediation will be necessary before train speeds can be raised across them. A combination of parametric studies, laboratory testing and modelling of case study sites should enable recommendations to be made as to which parameters, and from what sources, are most essential in estimating track movements on critical velocity sites.

There are several potential sites from which it is hoped to take soil samples for testing and modelling, two of which are described here. Both are on the existing UK classic network. Site A experienced displacement problems after train speeds were raised from 160 km/h to 200 km/h. Boreholes show the site to be underlain by a horizon of peat, over stiffer sands and gravels. Site B is a marginal site – it does not currently experience critical velocity problems, but owing to its location over soft clay this could change if line speeds were increased. Site monitoring techniques using geophones and MASW (Multi-Channel Analysis of Surface Waves) are also being used to measure track movements during train passages on these and other sites.

3 Modelling

Extensive modelling using a 2.5D analytical model (MOTIV) (Sheng et al., 2004) and a 2.5D finite element/ boundary element model (WANDS) (Nilsson et al., 2010) has been carried out for case study site A. A parametric study showed predicted ground movement to be most sensitive to the Young's modulus, or equivalently the shear wave speed, making these the main parameters of interest for future work. The importance of input parameter accuracy was also shown, with models using parameters sourced from a desk-study proving a poor match to the site measurements. The parameter set that provide the best fit contained Young's modulus and density values for the peat that are higher than would be expected. This is believed to be due to the analytical model being unable to reproduce the limited lateral extent of the peat layer, so that the parameters used actually represent an aggregation of the peat and the stiffer layers that surround it. The finite lateral extent of the peat layer can be studied in the FE/BE, model allowing its effect to be understood in more detail.

4 Laboratory Testing

A range of laboratory techniques are available to measure the key parameters of interest – shear wave speeds, stiffness (Young's modulus) and damping. Resonant Column and Bender Elements are non-destructive methods that can operate over similar strain ranges, and can be used on the same sample simultaneously. This allows comparison of results without additional sample disturbance. The equipment can be used to analyse the strain and stress degradation profiles of site samples, to assess the importance of non-linear behaviour during a train passage.

Conclusions and Further Work

Past work has shown the ground stiffness and shear wave speed to be essential in modelling critical velocity effects. To determine whether marginal sites will require mitigation, accurate estimation of these parameters is essential. In the future, laboratory testing on a range of site samples will be carried out, and the resulting impact on model accuracy assessed. Through a combination of case studies, laboratory testing and modelling it is intended to provide recommendations for how best to measure these parameters for use in relatively simple linear elastic models used as scoping tools.

This work is funded by the Engineering and Physical Sciences Research Council (EPSRC) through the grant Track Systems for High Speed Railways: Getting It Right (EP/K03765X) and HS2 Ltd.

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