Coupling stiffness-damping in modeling high-speed train track-embankment

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ABSTRACT

The levels of demand associated with railways for high-speed trains imply great accuracy in the definition of numerical models for the prediction of its behaviour. Therefore, it is increasingly important to account for the nonlinear behaviour of foundation soils of these railways. These soils are subject to cyclic and dynamic loadings, and so, their dynamic response is highly affected by the induced level of cycling shear strain. Several studies have been done to characterize the stiffness and damping variation with cycling shear strain. In this study, this variation is formulated using the proposal of Ishibashi e Zhang (1993) and is used to study the influence of the cycling shear strain on soil foundations in the behavior of the high-speed tracks.

The case study is, in part, based in an experience carried out in a stretch of rail track in the line of Brussels-Paris, close to the locality of Ath, 55km the South of Brussels (Degrande and Lombaert 2000). In this stretch it was carried a series of measurements of vibrations in the superstructure and the ground, at distances that vary between 4m to 72m of the track, during the passing of a Thalys HST at various speed between 160km/h and 330km/h. The results of these measurements are used in comparison to the ones obtained by the numerical simulations, making possible the calibration of the used numerical tools (Gomes Correia et al 2007).

To study the effect of the variation of stiffness and damping in the soil’s performance under high speed train tracks, a numerical model in the program DIANA (TNO 2005) was developed. This model, in plane strain, incorporates rail, interface, sleeper, ballast, sub-ballast, subgrade and the soil. In all numerical models presented the action was a dynamic loading which corresponds to the passage of a Thalys HST at 314 km/h (Marcelino 2007).

Two models were considered. One in a homogeneous soil and another in a multilayer soil foundation. The first incorporated the case study with constant stiffness and damping. The dynamic analysis in the time domain with the referred dynamic loading was done and the sleeper behavior and cycling shear train in the foundation soil were analyzed. In the multilayer soil foundation, equivalent stiffness and damping was adopted for the strain level of each layer. As a result, an iterative procedure was implemented to incorporate the non-linear behavior of the soil in linear models.

In both models the ballast behavior is very different, showing how the disregard of the non-linear properties of the soil may result in a simplification with high impact in the numerical results.
Furthermore, a parametric study was conducted for two types of homogeneous soil foundations, sand and clay. In each type, several levels of cycling shear strain were considered and the corresponding stiffness and damping were used for the dynamic analyses. The displacements and acceleration were compared in three points: at the sleeper, and in two points in the near field. The initial values considered for the sand were $E_0=100\text{MPa}$ and $\sigma'_0=30\text{kPa}$, whereas for the clay were $I_p = 50$, $\sigma'_0=30\text{kpa}$ and $E_0=35\text{Mpa}$.

The two types of soils revealed different trends in the three points in terms of displacement variation, but similar for the accelerations. For the sand, an initial increase of the damping occurs for lower strains than for the case of the clay soil. This induces a considerable initial variation of accelerations which is followed by a phase of stabilization. For the clay soil, the initial variation is not so abrupt, since the damping also changes in a more moderate way. Following this initial variation comes another one even less abrupt but it never reaches stabilization like in the case of the sand.

Concerning the displacements, they naturally tend to increase along with shear strain. However, this can be preceded by a small initial phase where there is a decrease, mainly at strains close to $1\text{E}-5$ where the stiffness is virtually $E_0$ but the damping is already considerable.

An interesting point to retain from these analyses is that both the vibrations and displacements show an alteration in their tendency at strains close to $2\text{E}-4$. So for this configuration of rail track, it would be benefic to guarantee that shear strain in the soil is close to this value as that induces low displacements and accelerations.

It is shown that the knowledge of the shear strain induced in the foundation soils of the rail tracks for high-speed trains is important. It induces a variation in the soil’s stiffness and damping that is reflected in the accelerations and displacements. The knowledge of these variations might be important to accomplish a configuration that combines lower accelerations with lower displacements on the track and soil.
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