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THE INFLUENCE OF THE SOIL STIFFNESS REDUCTION IN THE RESPONSE OF RAIL TRACKS

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Finite element method, rail track, foundation soil.

EXTENDED ABSTRACT

The development of tools and methodologies that can accurately predict the behavior of high-speed tracks when subjected to traffic loads, along with the development and study of mitigation countermeasures, has become one of the main issues of research in the past few decades. It is well established that the deformation characteristics of soils depend heavily on the level of shear strain to which soils are subjected (Ishiara, 1996). The majority of soils subject to symmetric cyclic loading present a hysteresis curve for which a secant shear modulus can be computed to relate the shear strain and the shear stress. The damping coefficient can also be determined, which is proportional to the area of the curve. The implication of this is that as the shear strain in the soil increases, so does increase the damping ratio (Figure 1) and the stiffness decreases.

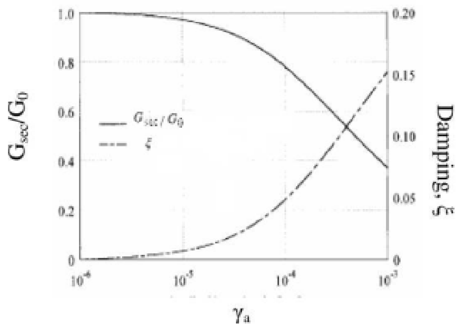

Figure 1: Variation of stiffness and damping with shear strain (adapted from Assimaki et al, 2000)

The purpose of the study is to determine the influence of the foundation soil stiffness reduction and damping increase in the response of a rail track to the passage of a moving axle load. To achieve this, the task is split in two phases: the first consists in the implementation of a cyclic non-linear model able to represent the soil stiffness reduction in a 3D FEM environment; the second consists in the choice of a case study for which the passage of a train axle load is modeled and the response is studied. In the cyclic non-linear model, the hysteresis curve is incorporated in the model's response using the Iwan equation which relies on the assumption that a hysteretic system can be constructed by a large number of elasto-plastic elements with different yield levels. The shear strain and damping variations result implicitly from the fact that the model follows the hysteretic curve. The experimental data used for the calibration of the non-linear model is obtained from the literature (Wang and Kuwano, 1999). The material model was calibrated to replicate the experimental stiffness reduction and damping increase of a clayey sand. The calibrated material model is used to simulate the foundation soil in the numerical simulation of the track response. The situation simulated is the passage of a single axle of the Thalys High Speed Train at 300 km/h. The track is modeled to accurately simulate the geometry of ballasted railway tracks: the rail is modeled as a Mindlin-Reissner beam of 3 nodes and is discretely supported by a two-node translation spring/dashpot element that connects it with the sleepers; the sleepers are modeled with solid elements and embedded in the ballast; the ballast and soil are modeled with solid elements also (Figure 2).

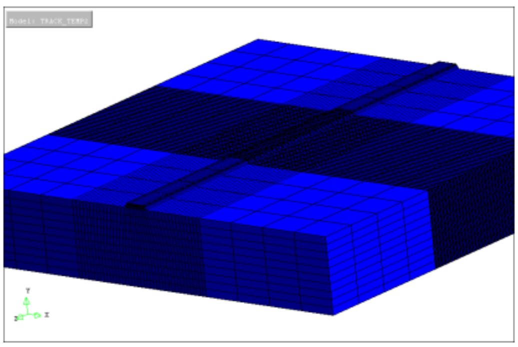

Figure 2: FE mesh of the model

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In Figure 3 the transversal soil profile is presented with the distribution of the stiffness reduction that occurs at the moment of the passage of the axle load.

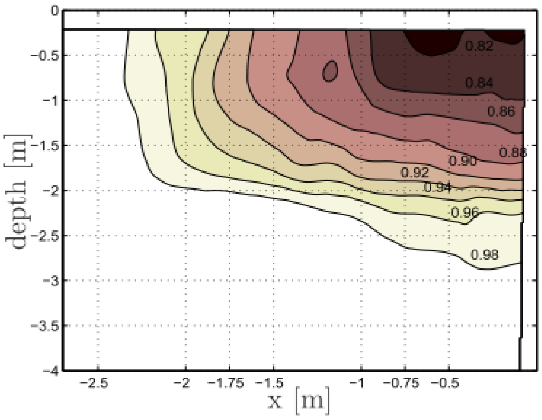

Figure 3: Tranversal distribution of the stiffness reduction (G/G0) of the soil at the moment of the passage of a Thalys HST axle load

In the track-soil interface directly below the track, the soil can reduce to slightly lower than 82% its original stiffness, which represents a considerable reduction that can change the stress distribution through the soil. Although this occurs in a very small portion of soil, there is also a considerable reduction of 10% of the original stiffness that can occur as deep as 1.7m and as far from the center of the track as at 1.7m distance. The highest values of stiffness reduction are thus very localized in space, which may lead to a small influence in the track response. Figure 4 presents the time history of the displacements, of the rail in the linear and non-linear cases.

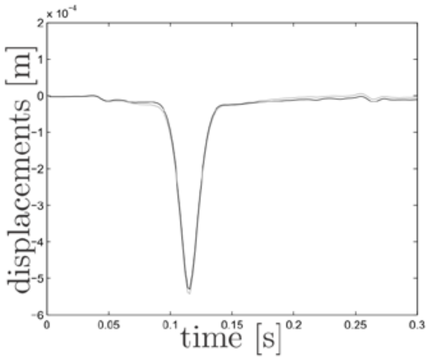

Figure 4: Rail displacement considering linear (black) and nonlinear (gray) foundation soil

The soil stiffness reduction, although reaching significant values in some areas, does not imply important changes at the track response. At the rail, only some minor changes in the peak displacement are noticeable.

The passage of a train on the track may induce shear strains in at levels that produce significant momentary stiffness reductions. These are localized at small depths and directly below the track implying that their influence in the overall behavior of the soil-structure may not be significantly affected. In the case study presented only a small variation in the rail's peak displacement was detected.

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