Degradation at transition zones in railway tracks: 1-D and 2-D model comparison

Andrei B. Fărăgău*, Andrei V. Metrikine*, Karel N. van Dalen*
**Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands*

Summary. Transition zones in railway tracks are areas with considerable variation of track properties (i.e., foundation stiffness) encountered near structures such as bridges. Due to strong amplification of the railway track's response, transition zones are prone to rapid degradation. To study this degradation, researchers and engineers have developed models ranging from simple 1-D models (e.g., beam on Winkler foundation) to complex 3-D models with accurate geometry and material behaviour. This study compares a 1-D model to a 2-D one with the aim of assessing if the degradation patterns predicted by the more simplistic model are accurate. We choose a very simple geometry for the 2-D model such that the comparison is restricted to (mainly) the influence of the soil layer (present in the 2-D model) on the predicted degradation at transition zones; incorporating the soil layer makes the response of the supporting structure frequency and wavenumber dependent as well as non-local, characteristics which are not usually incorporated in 1-D models. Preliminary results show that the degradation predicted by the 1-D model is significantly larger than the one in the 2-D model.

Introduction

Transition zones in railway tracks are areas with significant variation of track properties (e.g., stiffness, mass, etc.) encountered near man-made structures such as bridges, tunnels or culverts. These zones require more frequent maintenance than the regular parts of the railway track, leading to high costs and reduced availability of the track. A substantial part of the maintenance performed in transition zones is concerned with restoring the vertical position of the track, which changes over time due to soil and ballast settlement.

To understand the settlement mechanisms at transition zones, researchers have developed a multitude of computational models. They range from 1-D models (e.g., beam on Winkler foundation) to 3-D finite element models (FEM) models with accurate geometry of the real scenario. For predictive purposes, the models with more accurate geometry are preferred; these predictive models are important and show reasonable agreement to measurements, especially due to their accurate geometry representation and material behaviour. However, their complexity makes it difficult to investigate specific mechanisms due to the multitude of phenomena simultaneously at play. That is why, for research focusing on individual mechanisms, the simpler models (e.g., 1-D models) are preferred. Nonetheless, the simplistic models may overlook important features that can render their results incorrect.

This study compares two such models, namely a 1-D and a 2-D model, in terms of degradation (after one load passage) with the purpose of judging if the results obtained with the simplified model are trustworthy. The 1-D model is composed of a beam on nonlinear and inhomogeneous Kelvin foundation and is described in [1] while the 2-D model consists of an infinite beam and a viscoelastic-continuum layer (i.e., soil) connected through a layer of nonlinear and inhomogeneous springs and dashpots (Figure 1). The layer of springs-dashpots represents the effective contribution of all components between the rail and soil (i.e., railpads, ballast and sub-ballast). In both models, the nonlinearity and inhomogeneity are located in the layer of springs-dashpots; the nonlinear behaviour of the springs models the compaction of ballast (Figure 1), while the inhomogeneity represents the transition zone. The 2-D model has a simple geometry such that the comparison is restricted to (mainly) the influence of the soil layer on the results; incorporating the soil layer makes the response of the supporting structure frequency and wavenumber dependent as well as non-local, characteristics which are not usually incorporated in 1-D models.

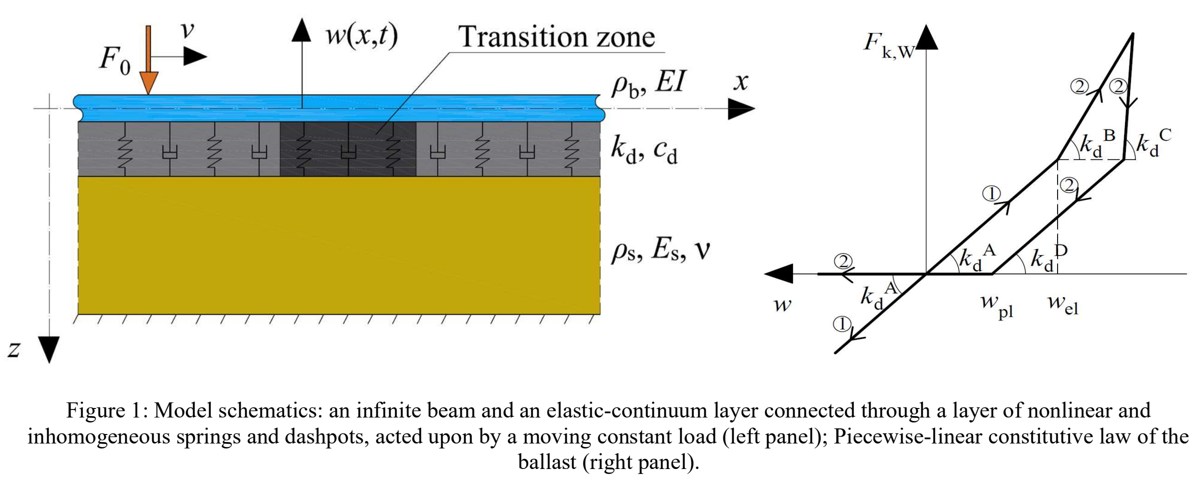

Figure 1: Model schematics: an infinite beam and an elastic-continuum layer connected through a layer of nonlinear and inhomogeneous springs and dashpots, acted upon by a moving constant load (left panel); Piecewise-linear constitutive law of the ballast (right panel).

Tuning the 1-D model

To compare the two models, the parameters of the 1-D model need to be tuned to the ones of the 2-D model. The tuning is performed for the steady-state response in each of the domains (open track and stiff zone) individually. Advanced algorithms have been developed to make the response of the 1-D model match well that of 2D/3D models (see [2]). However, this study aims to investigate if most of the models used in literature, which do not use a complex tuning technique, can predict a correct degradation pattern. Therefore, the tuning is done in a more standard manner. Firstly, the static track stiffness is matched in the two models. Secondly, the mass of the rail in the 1-D model is chosen such that the critical velocities are matched in the two models. Finally, the damping in the 1-D model is chosen based on engineering judgement; nonetheless, the damping in the 1-D model has been varied and for reasonable values it does not significantly affect the results.

Preliminary results

Figure 2 presents the degradation predicted by the two models after one load passage. For the 2-D model, there are two cases presented depending on how the nonlinear constitutive model is defined. Firstly, case A considers that the degradation is governed by the differential displacement between the beam and the top surface of the soil since the nonlinear constitutive model is only for ballast; this represents a realistic case. Secondly, case B assumes the degradation to be governed by the displacement of the beam only; this case is not representative of reality and is considered just for comparison reasons.

Preliminary results show that the degradation in the 1-D model is significantly higher than in the 2-D model (case A). The main reason is that the degradation in the 1-D model is based on the displacement of the beam, while in the 2-D model the degradation is dictated by the differential displacement between the beam and the top surface of the soil. Since the soil is considerably softer than the ballast, the differential settlement between the beam and the top surface of soil is small, leading to reduced degradation. When imposing the degradation to be dictated by the displacement of the beam only (case B), the degradation predicted by the two models becomes comparable in magnitude, although still larger in the 1-D model. This shows that the large difference in degradation (1-D vs 2-D case A) is caused by the springs in the 1-D model being fixed at the bottom while in the 2-D model (case A) the springs lay on a compliant medium.

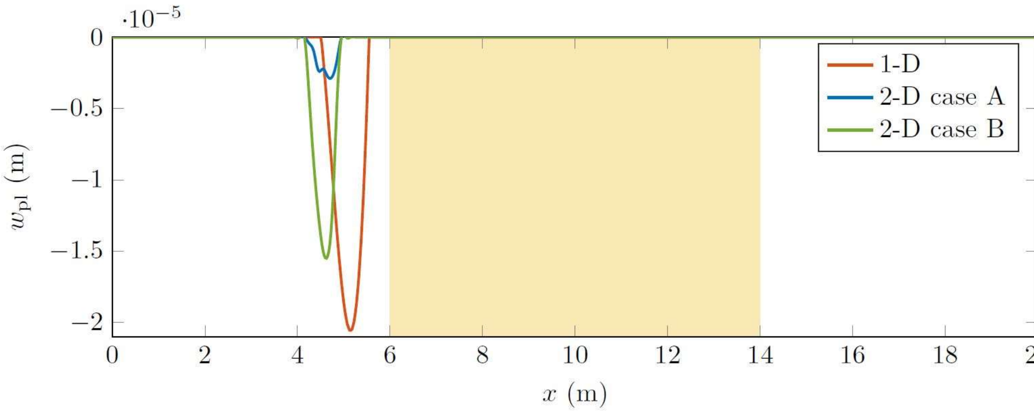

Figure 2: Degradation predicted by the two models after 1 load passage for a load velocity of 85% the critical velocity; the location of the transition zone is marked by the yellow background.

Conclusions

This study compares two models (1-D and 2-D) representative of railway tracks at transition zones, in terms of the predicted ballast degradation with the purpose of judging if the results obtained with the simplified model are trustworthy. Preliminary results show that the degradation after one load passage predicted by the 1-D model is significantly larger than the one in the 2-D model. This is mainly caused by the springs in the 1-D model being fixed at the bottom while in the 2-D model the springs lay on a compliant medium. The shortcoming of the simplified model considered here could be overcome by adopting a model with two beams connected by the nonlinear and inhomogeneous springs (representative for ballast compaction) and resting on Kelvin foundation. Finally, simplified models (beam on elastic foundation) potentially overestimate the predicted degradation at transition zones.

References

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