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Ballasted Track Lateral Resistance Estimation by Discrete Element Method Simulations

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Abstract

In this work, discrete elements methods (DEM) were used to simulate ballasted track lateral resistance problems by representing a granular material such as ballast as an assembly of rigid grains interacting through contact laws that contain micromechanical physics relevant for the material. Macro-mechanical properties, such as global resistance of the ballast bed, are then seen as a consequence of the collective dynamics of the assembly. A large number of lateral resistance tests simulations were run to find optimal value for frictional parameters so that experimentally measured values for various track configurations were satisfyingly found. The model was then used to explore the lateral track resistance of experimentally untested configurations, namely standard profiles and nonstandard ballast profile alike, for instance no shoulder, reinforced shoulder, “infinite” shoulder or walls. By varying the length and height of the shoulder, we could predict how much one can enhance the lateral resistance by adding more ballast on the side of the track, and what geometry is optimal for profile reinforcement in term of ballast quantity, while respecting security constraints toward lateral efforts due to potential rail buckling.

Keywords: Ballasted Track, Lateral Resistance, Ballast Shoulder, Simulation, Discrete Element Method, Model Calibration

1 Introduction

Due to buckling tendencies of long welded rails in times of high temperature, it is highly important to understand and control the capacity of a ballasted track to resist to such stresses so that no geometry deterioration occurs. This 'lateral' resistance is ensured by the capacity of ballast grains to rearrange under stress, to prevent any motion from sleepers. This behaviour is essentially dictated by the granular nature of ballast, a heterogeneous and frictional material, whose mechanics is difficult to model using traditional methods such as finite elements.

Discrete elements methods (DEM) have been used to approach those problems in the past, but mostly in comparative, relative ways [1] to analyse track states that are not easily experimentally accessible. Other works focus on numerical model conception and calibration by comparison with experiments on controlled states [2,3]. Model calibration and tuning is necessary to obtain predictive results useable with confidence in track design. The reason for this work is therefore to develop a tuning procedure for DEM methods based on comparison with experimental tests. This tuning can then be used to predict quantitatively lateral resistance of a ballasted track in various configurations: mono-bloc sleepers, bi-bloc sleepers, reinforced ballast shoulder, walls…

2 Methods

In order to find a satisfying numerical setting allowing the quantitative prediction of ballasted track lateral resistance, we used the following methodology:

1. Numerically investigate the response of a ballasted track section to lateral efforts in various configurations via DEM simulations (see figure 1 top).
2. Identify relevant observables (namely the lateral force-displacement curve of the track, see figure 1, bottom) and compare it with known experimental values.
3. Repeat the process, until all numerically found values for resistance are as close as possible from their experimentally known values counterparts.

DEM methods represent granular materials as an assembly of rigid grains interacting through contact laws that contain micromechanical physics relevant for the material [4]. In the case of ballast stones, grains are modeled as 3D polyhedrons interacting through dry friction with a sliding criterion on tangential forces. Non-Smooth Contact Dynamic (NSCD) type approaches are based on a non-smooth formulation of mutual exclusion and dry friction between contacting grains, and an implicit time integration of equations of motion [5].

These ideas are at the core of the LMGC90 code [6,7] we used to conduct simulations. Macro-mechanical properties, such as global resistance of the ballast bed, are then seen as a consequence of the collective dynamics of the assembly.

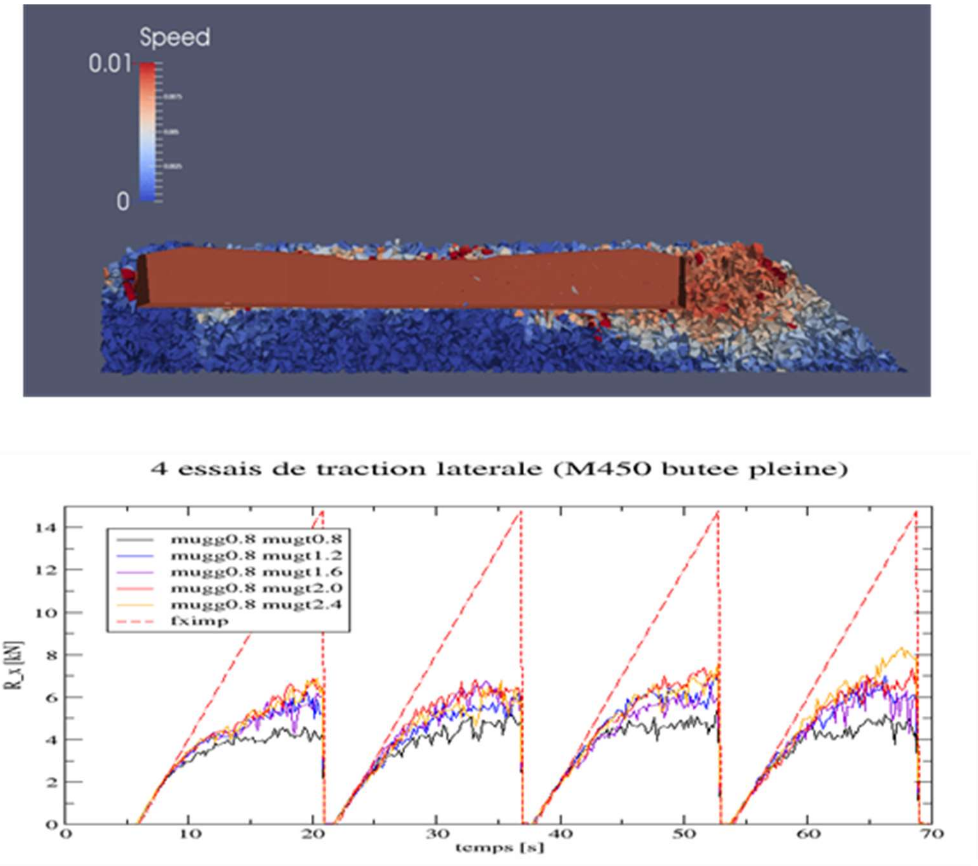

Figure 1: Top : numerical model for a ballasted track section, with apparent strain rate in the ballast shoulder. Bottom : Corresponding force-displacement curves for the sleeper for various frictional parameters.

3 Results

To provide reliable quantitative information, numerical calculations have to be compared with experimental results to validate the subjacent choices and models. Given a set of physical measurements of lateral resistance in various track configurations (varying sleepers or ballast profile geometry) we were able to tune numerical parameters of the model so that a unique set of parameters is sufficient to tackle all those different situations.

A large number of simulations were therefore run to explore the parameters space, and optimal values for simulation parameters like friction coefficients were found using regressions methods, minimizing the gap between numerical results and experimental (expected) results over all configurations at once.

We then used this model to explore the lateral track resistance of experimentally untested configurations, namely nonstandard ballast profile (see figure 2):

- No shoulder: This configuration was investigated in order to estimate a minimal boundary one could expect from a totally degraded track. It also gave us insight on the role played by the interface with the underlying ballast in the sleeper resistance ;

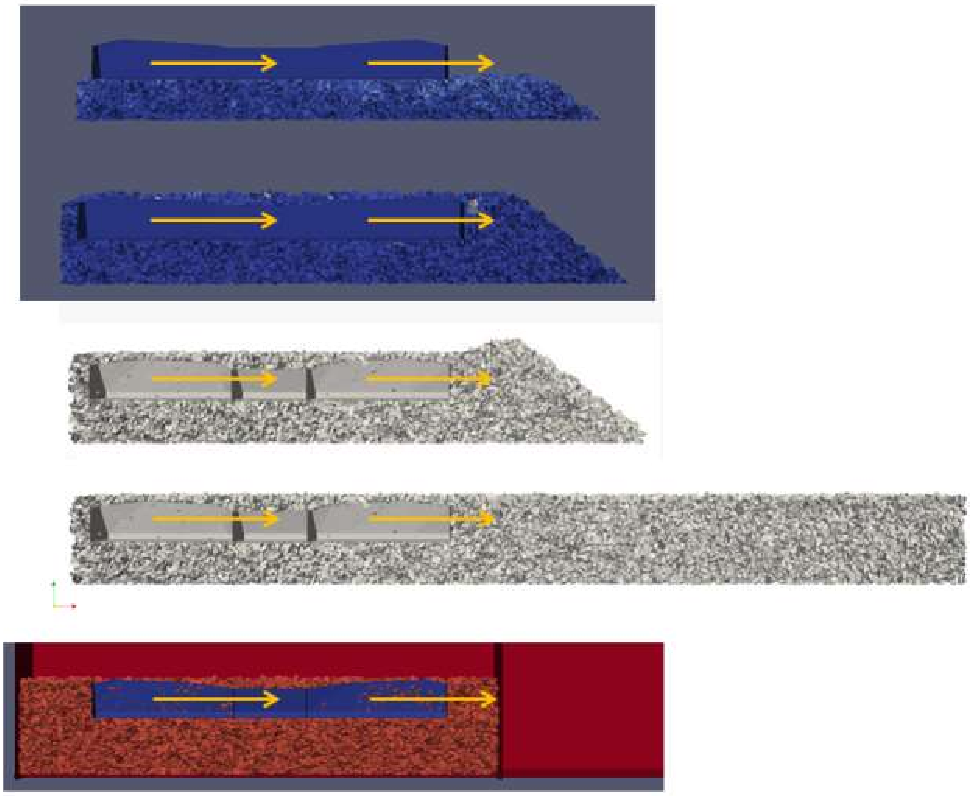

Figure 2 : Various ballasted track configuration that were investigated in regard to their lateral resistance. From top to bottom: no shoulder; standard shoulder ; reinforced shoulder ; "infinite" shoulder ; wall.

- Reinforced shoulder : This configuration corresponds to the most common way to increase lateral resistance of a standard shoulder ballasted track ;
- "Infinite shoulder" : This configuration was investigated in order to estimate a maximal boundary one could hope by simply extending the length of the shoulder ;
- Wall: This configuration is the most realistic way to mimic the "infinite" shoulder case in weak area like bridges.

4 Conclusions and Contributions

As a conclusion, by varying the length and height of the shoulder, we could predict how much one can enhance the lateral resistance by adding more ballast on the side of the track, and what geometry is optimal for profile reinforcement in term of ballast quantity, while respecting security constraints toward lateral efforts due to potential rail buckling.

This research demonstrates the possibilities offered by simulations and particularly DEM simulations in the field of track design. Optimal designs that preserve security are easier to find when one can virtually test a larger number of settings with simulations and trust the results.

It is a step forward in the direction of having new models that can be used and trusted for the production of studies in the field of track design and maintenance. The interest of such models, while not explaining the underlying mechanics, is to provide engineers a tool easier to deploy than full scale simulations when an accurate estimation of the resistance of a given track design is needed.

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