Coupled Rail-Ballast-Subgrade Analysis of Train Dynamics

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Ballast, sub-ballast, and subgrade are extremely important components of the rail system that affect train dynamics, rail component wear, and vibrations in surrounding buildings, among other areas. In this project, we develop an integrated multibody dynamics and finite element model that include wheel-rail contact and deformation of the rail, fasteners, ties, ballast, sub-ballast and subgrade. The wheel-rail interaction is governed by a floating frame of reference multibody model. A modal representation of the substructure is input into the multibody code to determine the stiffness and damping of the system. A wheel set is simulated and the deformation is examined. This phase of the research focuses on the effect of the substructure on the stiffness and damping properties of the rail and wheel.

Introduction

Support conditions greatly affect the performance rail systems, and hence the track substructure is of great importance to train dynamics. Ballast, sub-ballast, and subgrade influence the stiffness and damping of the system, which can greatly affect ride quality, wear in the rail and wheels, and vibration in surrounding structures, among other issues. Many researchers have ignored the stiffness of the subgrade or used simplified spring-damper models to account for their behavior. These models are inaccurate in some situations, including bridges approaches, inclined track sections, and areas with complex soil topographies.

While multibody dynamics has been successfully used to simulate rail-wheel contact, the finite element method is an efficient way to determine structural stiffness in bodies. In this study, a floating frame of reference (FFR) multibody code is coupled to existing finite element software to determine the stiffness and damping properties of the substructure. Modal decomposition is used to improve efficiency. These processes are coupled to examine the effects of the substructure on rail vibration.

Modeling and Example Problem

In this work, a finite element model is created that includes: rails and sleepers (beam elements), fasteners (spring elements), ballast, sub-ballast, and sub-grade (solid elements), as in Figure 1.

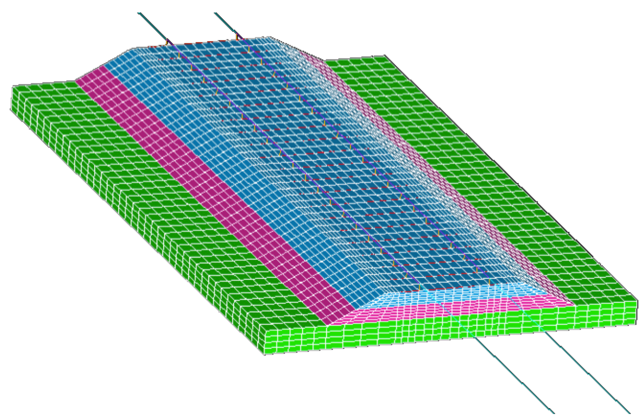

Figure 1. A 3D full FE model of the rail and substructure.

The soil properties are defined as follow:
ballast: ρ=1800 kg/m^3, E=260 Mpa, ν=0.25, sub-ballast: ρ=1850 kg/m^3, E=200 Mpa, ν=0.35, for the subgrade: ρ=1850 kg/m^3, E=200 Mpa, ν=0.3.

For the dynamic part of the analysis, a wheelset with the following properties: Mass=1578 kg, Ixx=Izz=656 kgm2, Iyy=168 kgm2, longitudinal spring stiffness= 13,500 N/m, lateral spring stiffness=25,000 N/m, damping=1000Ns/m, and the running speed is 30m/s.

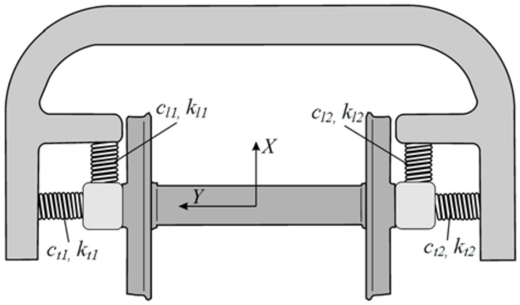

Figure 2. The dynamic analysis suspended wheelset.

Numerical Results

The model presented above was compared to the literature, to test the model ability to capture the different deformations and forces. The results showed good agreement on both displacements and forces at different points on the rails with and without missing tie support. The following figures show some of the results. Figures 3 and 4 show the normal forces between the presented model and the literature work in the case of all sleepers supported and unsupported middle sleeper, respectively.

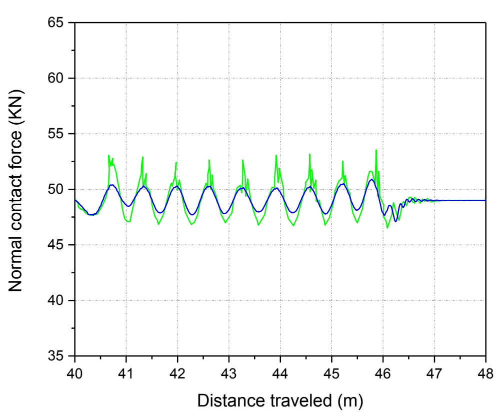

Figure 3. The contact force (Normal direction).
(FE model ——, Literature model ——)

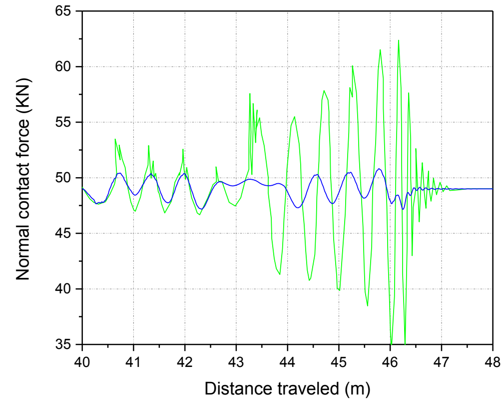

Figure 4. The contact force for unsupported tie case (Normal direction).
(FE model ——, Literature model ——)

Figures 5 and 6 show the vertical displacement at the center of the model, in the case of full model and the case of unsupported middle sleeper, respectively.

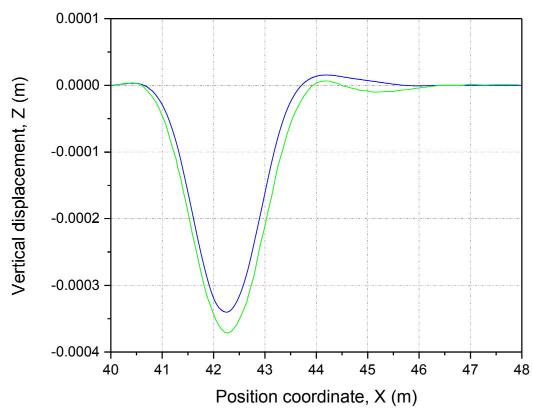

Figure 5. Vertical displacement below the unsupported sleeper.
(FE model ——, Literature model ——)

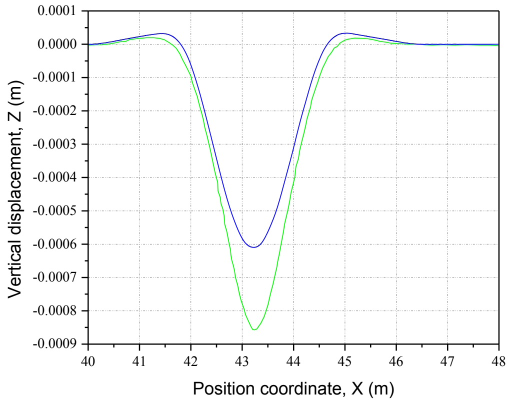

Figure 6. Vertical displacement below the unsupported sleeper.

(FE model ——— , Literature model ———)

Summary and Conclusions

In this work, a model of rail substructure was developed to account for the compliance and damping of vibration under trains. Compared to the literature, smoother results may be attained. This type of model can also be applied to bridge approaches, vibration in nearby structures, and other issues related to rail geotechnics.

References

[1] El-Ghandour, Ahmed I., Martin B. Hamper, and Craig D. Foster. "Coupled finite element and multibody system dynamics modeling of a three-dimensional railroad system." Proceedings of the Institution of Mechanical Engineers, Part F: *Journal of Rail and Rapid Transit* (2014): 0954409714539942.

[2] Recuero, A. M., J. L. Escalona, and A. A. Shabana. "Finite-element analysis of unsupported sleepers using three-dimensional wheel–rail contact formulation," Proceedings of the Institution of Mechanical Engineers, Part K: *Journal of Multi-body Dynamics* 225.2 (2011): 153-165.

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