Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 199 (2017) 2681–2686

Procedia Engineering

www.elsevier.com/locate/procedia

X International Conference on Structural Dynamics, EURODYN 2017

Effect of track defects on vibration from high speed train

Amir M. Kaynia[a,]*, Joonsang Park[a], Karin Norén-Cosgriff[a]

[a]Norwegian Geotechnical Institute, Sognsveien 72, N-0855, Oslo, Norway

Abstract

The response of railway tracks and trackside vibration are strongly governed by the quality of the track. Defects or non-homogeneities in the track/substructure/ground can remarkably increase the responses in the system, leading to further deterioration of the track. This issue is more dramatic in high-speed lines. The objective of this paper is to study the impact of two types of non-homogeneities on the track response. In the first case, the effect of hanging sleepers is studied, and in the second case, the effect of locally deteriorated substructure is investigated. Two numerical solutions are used for the simulation of track-substructure-ground response. The first is the frequency-domain solution *VibTrain* that has been developed for efficient simulation of track/ground response under moving loads using a combination of beam elements for the track/substructure and Green's functions for the layered soil medium. The second model is a FE model in COMSOL Multiphysics enhanced with the absorbing boundary PML (Perfectly Matched Layer) in the time domain. In addition to studying the effect of track defects on rail vibration, the results of the two solutions are compared and practical conclusions are drawn on the potential of using vibration data for detection of track defects.

Peer-review under responsibility of the organizing committee of EURODYN 2017.

Keywords: High speed rail, track damage, hanging sleeper, track vibration, damage detection

1. Introduction

Development of conventional and high-speed railway lines has been growing rapidly throughout the world. While high-speed lines, with train speeds typically over 250 km/h, represent special challenges and demands for track conditions, conventional lines with a trend of coming closer to residential areas and critical infrastructure pose environmental challenges related to noise and vibration and damage to other structures. Railway traffic induce

* Corresponding author. Tel.: +47-926-18-644; fax: +47-22-23-04-48.
E-mail address: amir.m.kaynia@ngi.no

1877-7058
Peer-review under responsibility of the organizing committee of EURODYN 2017.
10.1016/j.proeng.2017.09.551

vibrations by quasi-static loads and dynamic axle loads. The vibrations by the dynamic loads are due to several mechanisms such as wheel and rail unevenness, impact at rail joints and wheel flats. In the frequency range between 1 and 80 Hz, building vibration is felt as mechanical vibration, while in the frequency range 16 to 200 Hz, ground-borne vibrations can cause structure-borne noise because of vibrations in secondary elements in a structure. A great research effort has been made over the past three decades to develop empirical and rigorous analytical-numerical tools for prediction of vibration generated by railway traffic for different loading conditions and for modelling of countermeasures [1-8].

Another source of ground vibration addressed by the research community is the so-called parametric excitation that is related to the variability of the track and ground. While in some cases this excitation could lead to unacceptable vibration, a more significant impact is directly for the track and its long-term performance. It is well recognized that track variability could lead to local excessive stresses under the sleepers leading to loss of contact between the ballast and sleepers, the so-called hanging sleepers. This in turn will accelerate the track deterioration and will increase the need for maintenance. Realizing the importance of this issue in track design, researchers and railway owners have spent considerable effort on condition assessment and detection of defects in the track and substructure. There exist a few methods for continuous assessment of substructure condition (see for example [9-10]) where Ground Penetrating Radar (GPR) is one of the common methods. However, GPR can only provide information about the upper part of the substructure (ballast and embankment). Therefore, there has been a dire need for other condition monitoring methods of railway track substructures. Among relevant projects and initiatives that have addressed this issue, one could mention the EC-funded research projects *SuperTrack* [11] and *Innotrack* [12].

A key to successful identification of track non-homogeneity or possibly track defects is the ability of measuring the track behavior under railway traffic. Traditionally, the track-substructure condition is evaluated through static stiffness of the track. A study for determination of dynamic track stiffness using Track Loading Vehicle (TLV) and Rolling Stiffness Measurement Vehicle (RSMV), which is capable of measuring track stiffness for a train speed of up to 60 km/h, is presented in [13]. This reference also reviews several existing static methods.

While measurement of track stiffness is a useful tool for detection of anomalies and possibly defects in the track-substructure system, a solution that can allow processing of the vibration data, for example on the bogies, for the purpose of identifying track defects would be an ideal tool. This paper presents a first attempt by the authors to explore the possibility of such a solution. The objective is then to study the impact of two cases of track and substructure defects on track vibration. The two cases include 1) hanging sleepers, and 2) locally deteriorated substructure (mainly ballast). Two numerical solutions are used for the simulation of track-substructure-ground response. The first is the frequency-domain solution *VibTrain* [2] that has been developed for efficient simulation of track/ground response under moving loads, and the second is an FE model in COMSOL Multiphysics enhanced with the absorbing boundary PML (Perfectly Matched Layer) in the time domain.

2. Simulation of hanging sleeper by VibTrain

Figure 1(a) shows the key elements in the computational tool *VibTrain* [2]. The ground consists of visco-elastic soil layers over a half-space and the substructure and tracks are modelled as separate beams with elastic elements between them to represent rail/sleeper pad flexibility. The interaction between the substructure beam and the ground is accounted for by use of Green's functions for layered media [14]. The software was validated against field test data at the Swedish test site Ledsgaard and for Swedish train X2000. Figure 1(b) shows the bogie loads used in the simulation. While it is possible to use the axle loads in the simulations, it was decided to use the bogie loads for simplifications. Therefore, only the loads for one passenger car, i.e. 245 kN, Fig. 1(b), were used in the simulations.

Table 1 summarizes the dynamic soil parameters established for the test site at Ledsgaard using a combination of geotechnical site investigation and lab testing (see [2,15] for more information).

To investigate the impact of hanging sleepers on track response only the quasi-static load mechanism was considered in this study. VibTrain has the possibility of computing vibration from the dynamic loading of the unsprung mass of the train due to rail/track unevenness [16]. However, it was considered that an irregular dynamic load variation might mask the mechanism of track response and would require statistical analyses of numerous analyses. This will be the subject of future studies if the results of the present investigation give a clear indication of the effectiveness of the use of numerical simulations.

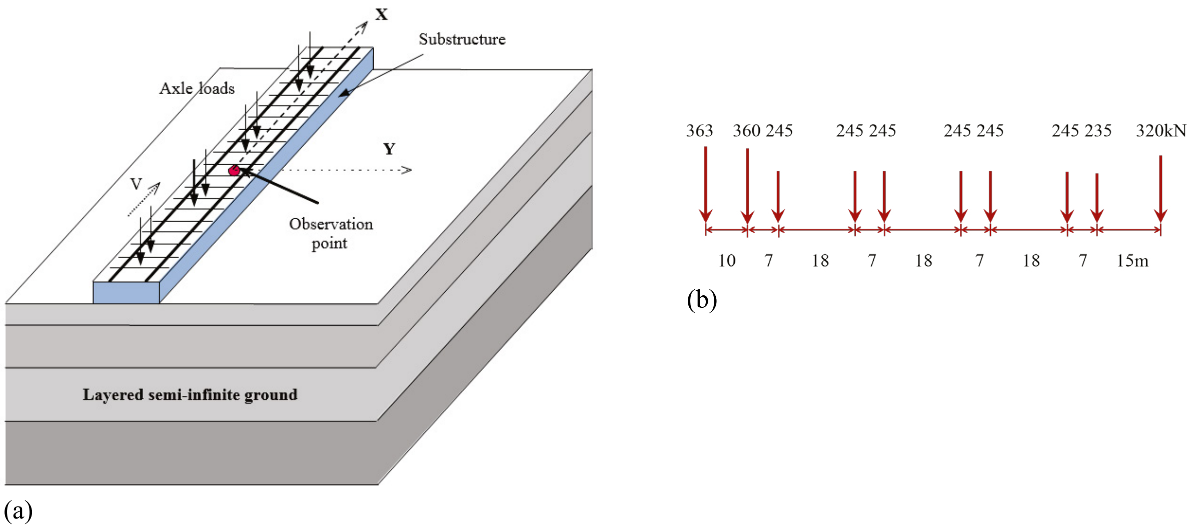


Fig. 1. (a) Key elements of computational tool VibTrain [2], (b) Bogie loads of X2000

Table 1. Soil parameters applied to the FE simulation.

Soil layer	Thickness [m]	Density [kg/m^3]	C_S [m/s]		C_P [m/s]	
			V= 70 [km/h]	V= 200 [km/h]	V= 70 [km/h]	V= 200 [km/h]
Crust	1.1	1500	72	65	500	500
Organic clay	3.0	1260	41	33	500	500
Clay	4.5	1475	65	60	1500	1500
Clay	6.0	1475	87	85	1500	1500
Half space	-	1475	100	100	1500	1500

Figure 2 presents the computed track vibrations for train speeds 100, 125 and 150 km/h for an ideal track, that is, a track with no irregularities, and for a track with three adjacent hanging sleepers. The figure displays the plots of the vertical velocities of the track at the location of the middle hanging sleeper as the train loads pass. As expected, the vibration amplitudes increase considerably. Moreover, as the train speed increases, the differences between the defected and intact (flawless) track become larger.

3. Simulation of track defect in 3D FE model

Figure 3(a) shows the model used in the commercial code COMSOL Multiphysics, and Fig. 3(b) shows a close-up of the FE mesh. COMSOL is a general-purpose FE code that suits well simulation of wave propagation in the ground due to the possibility of implementing the so-called perfectly matched layer (PML) scheme [17]. The PML scheme is applicable to both time and frequency domain analyses. The main computational domain is 100 m long in the longitudinal direction, 10 m long in the transverse direction and 14 m deep. This domain is surrounded by the PML domains of 20 m long in all three directions. In addition, due to symmetry of the problem, half of the 3D model in the railway direction was used. The soil and train loads are those used for Ledsgaard test site described above. Before introducing track defects in the FE model, its satisfactory performance was ascertained by simulating the measured track responses for low and high speeds (below and above critical speed) as reported in [2,15]. Figure 4 shows the FE model used for the assessment of hanging sleepers. The width of the sleepers is 20 cm, and their spacing is 60 cm. The numbers 1 to 4 represent both the number of hanging sleepers and their order of activation in the model. The triangle in the figure indicates the location where the track response was computed.

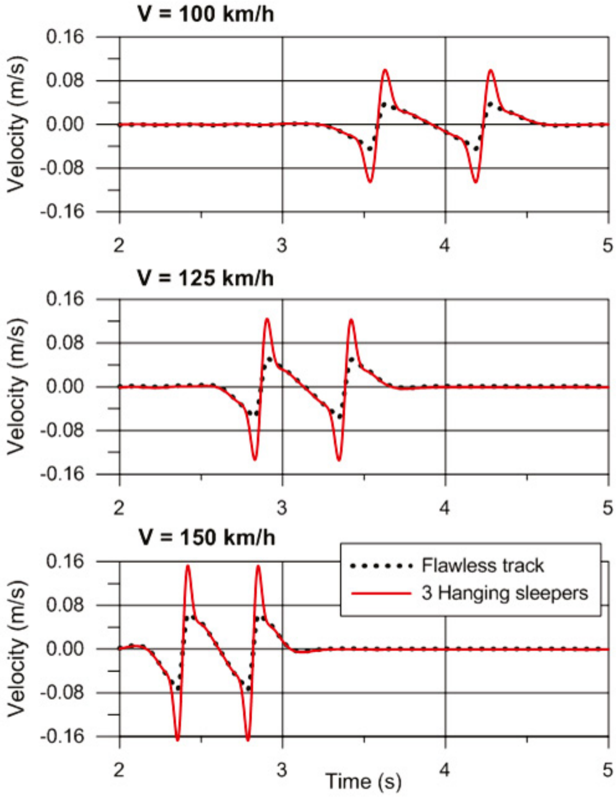


Fig. 2 Simulation of track vibration, with and without hanging sleepers

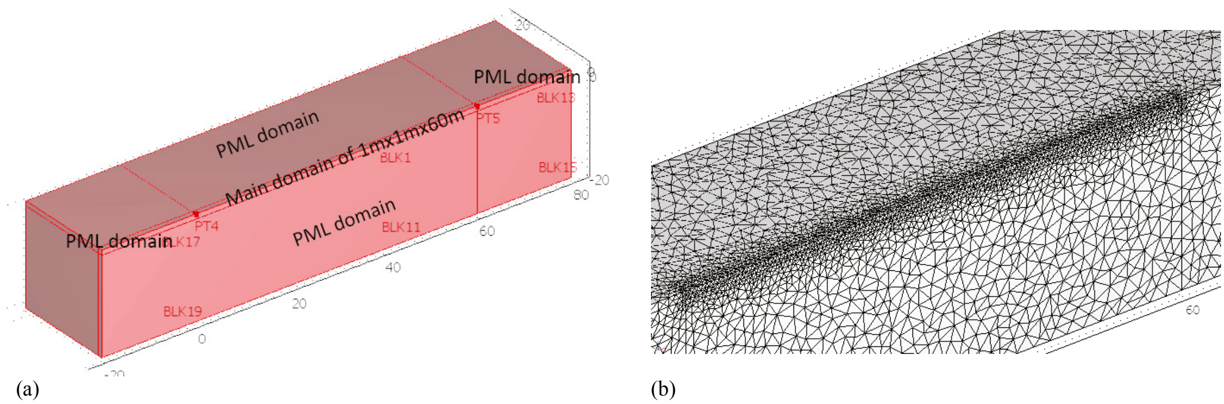


Fig. 3. FE model used for simulation of track defect: (a) geometry for whole FE model, and (b) close-up of FE mesh

Figures 5 displays the results of numerical simulations of the track response for the cases of intact track and tracks with different numbers of hanging sleepers for a train speed of 100 km/h. Figure 5(a) plots the computed vertical velocities at the observation points. The results for the intact track and track with three hanging sleepers can be compared with those in Fig. 2 for train speed 100 km/h. Despite considerable differences in the two models, the results are satisfactorily comparable. Figure 5(b) compares the corresponding results of bending strains in the rail. The figure clearly indicates the dramatic effect of increasing the number of hanging sleepers on the strains (about a factor of three for four hanging sleepers).

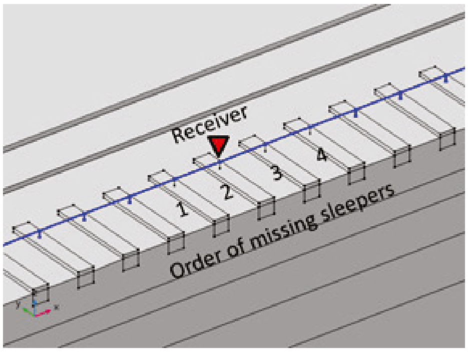
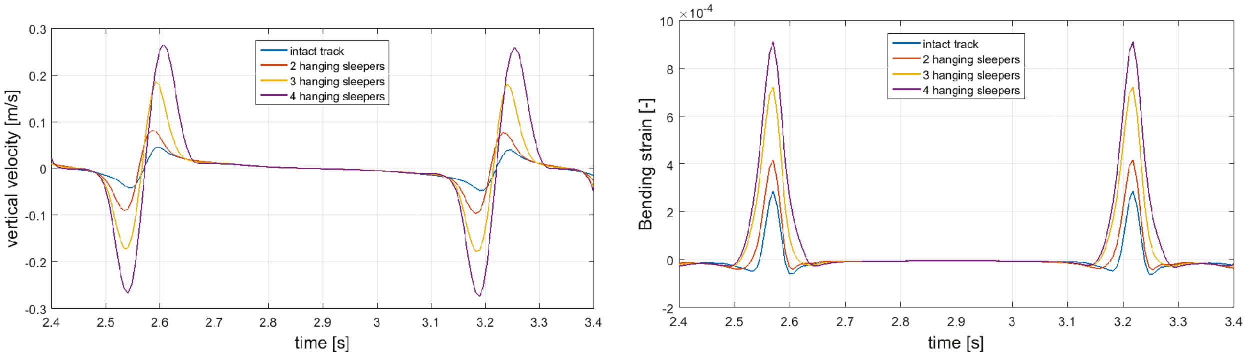


Fig. 4. Model description - reversed triangle represents receiver, numbers 1-4 show the order of introducing hanging sleepers



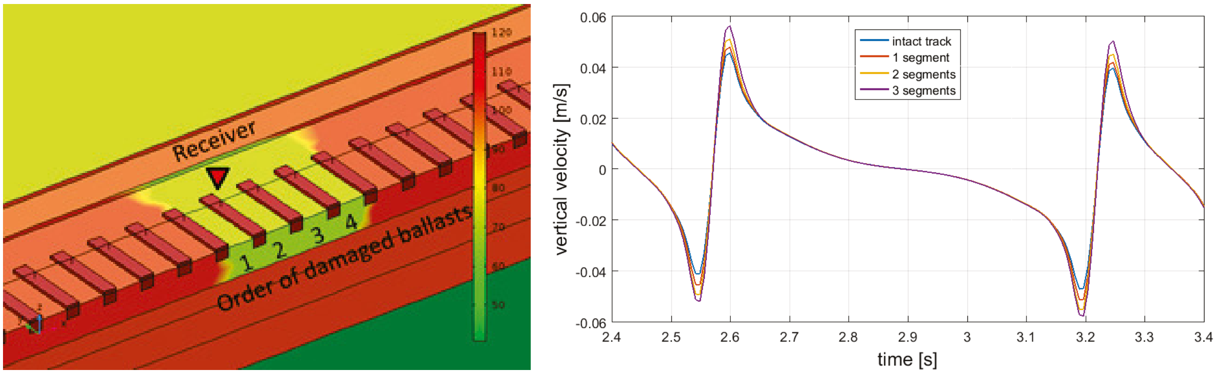
(a) (b)

Fig. 5. Simulation of effect of number of hanging sleepers, (a) vertical velocity of track, (b) bending strain in rail

Figures 6(a) considers another form of track defect in which the ballast layer is degraded. The degradation was introduced by reducing the elastic modulus of the ballast by 50%. The simulation of the track response was carried out for four spans of degraded ballast as indicated in Fig. 6(a). Figure 6(b) displays the results of numerical simulations for the intact track and for four cases of degraded tracks for a train speed of 100 km/h. The numbers 1 to 4 represent both the number of zones of deteriorated ballast and their order of activation in the model. The triangle indicates the location where the track response was computed. For the cases and range of parameters considered here, the results for this type of track defect do not show detectable differences in track vibration due to degraded ballast.

4. Summary and Conclusions

This paper has presented the results of an initial study to investigate the potential of using track vibration under normal or high-speed train passage to detect defects in the track and substructure. The cases considered were hanging sleepers and deterioration of the ballast layer. Two numerical simulation tools, *VibTrain* and COMSOL were used for this purpose. The simulations showed compatible results and indicated that hanging sleepers display clear increase in track vibration. However, the results of simulations for the deteriorated ballast did not indicate detectable changes in track vibration for the cases and the ranges considered in this study. In conclusion, these results motivate more research in this subject by considering more realistic and variable dynamic loads and by using different track/substructure/ground models.



(a) (b)

Fig. 6. Model description - reversed triangle represents receiver, numbers 1-4 show the order of introducing hanging sleepers

Acknowledgements

The authors would like to acknowledge partial support for this study by the research project DESTination Rail - Decision Support Tool for Rail Infrastructure Managers, funded by the European Commission, Grant Agreement 636285 (H2020-MG-2014-2015).

References

[1] H.A. Dieterman, A.V. Metrikine, Steady-state displacements of a beam on an elastic half-space due to a uniformly moving constant load, Eur. J. Mech., A/Solids, 16 (2), (1997) 295-306.

[2] A.M. Kaynia, C. Madshus, P. Zackrisson, Ground vibration from high speed tains: prediction and countermeasure, J. Geotech. & Geoenv. Engrg, ASCE, 126(6), (2000) 531-537.

[3] G. Lombaert, G. Degrande, J. Kogut, S. François, The experimental validation of a numerical model for the prediction of railway induced vibrations. Journal of Sound and Vibration, 297(3-5), (2006) 512–535.

[4] X. Bian, H. Jiang , C. Chang , J. Hu , Y. Chen, Track and ground vibrations generated by high-speed train running on ballastless railway with excitation of vertical track irregularities, Soil Dynamics and Earthquake Engineering 76 (2015) 29–43.

[5] G. Kouroussis, L. Van Parys, C. Conti, O. Verlinden, Using three-dimensional finite element analysis in time domain to model railway–induced ground vibrations, Advances in Engineering Software, 70, (2014) 63–76.

[6] M.A. Sayeed, M.A. Shahin, Three-dimensional numerical modelling of ballasted railway track foundations for high-speed trains with special reference to critical speed. Transportation Geotechnics, 6 (2016) 55-65.

[7] J.-Y. Shih, D.J. Thompson, A. Zervos, The effect of boundary conditions, model size and dmpaing models in the finite element modeling of moving load on a track/ground system, Soil Dyn. Earthq. Eng., vol. 89, (2016) 12–27.

[8] A. Peplow, A.M. Kaynia, Prediction and validation of traffic vibration reduction due to cement column stabilization, Soil Dynamics & Earthquake Engrg, 27, (2007) 793-802.

[9] C. Esveld, Modern Railway Track, 2nd edition, MRT-Productions, Delft, 2001.

[10] M. Silvast, A. Nurmikolu, B. Wiljanen, E. Mäkelä, Condition-based track maintenance and rehabilitation design using combined data analysis, Int. Symp Geotechnical Railway, GEORAIL 2014, Nov. 6-7, Paris.

[11] A.M. Kaynia, D. Clouteau, Improved performance of ballasted tracks. Chaper 2, Design and Construction of Pavements and Rail Tracks, (A.G. Correia, Y. Momoya and F. Tatsuoka, ed.), Taylor and Francis, London.

[12] Paulsson, H.B. INNOTRACK - innovative track system - a unique approach of infrastructure managers and competitive track supply industry for developing the innovative products of the future, Proc. IHHA Specialist Technical Session (STS), Kiruna, June 11-13 (2007).

[13] E.G. Berggren, A.M. Kaynia, B. Dehlbom, Identification of substructure properties of railway tracks by dynamic stiffness measurements and simulations, Journal of Sound and Vibration, 329, (2010) 3999 – 4016.

[14] E. Kausel, J.M. Roesset, Stiffness matrices for layered soils. Bull. Seism. Soc. Am., 71 (6), (1981) 1743-1761.

[15] C. Madshus, A.M. Kaynia, High-speed railway lines on soft ground: dynamic behaviour at critical train speed, J. Sound & Vibration, 231(3), (2000) 689-701.

[16] A.M. Kaynia, Measurement and prediction of ground vibration from railway traffic. Proc. 15th Int. Conf. Soil Mech. Geotech. Engng, Istanbul, Turkey, Aug. 27-31, (2001) vol.3, 2105-2109.

[17] J. Park, T.I. Bjørnarå, B.A. Farrelly, Absorbing boundary domain for CSEM 3D modelling, Proceedings of COMSOL conference, Paris, France, November 17-19 (2010).