56º Congresso Brasileiro do Concreto

A vehicle-structure interaction method for analyzing the train running safety

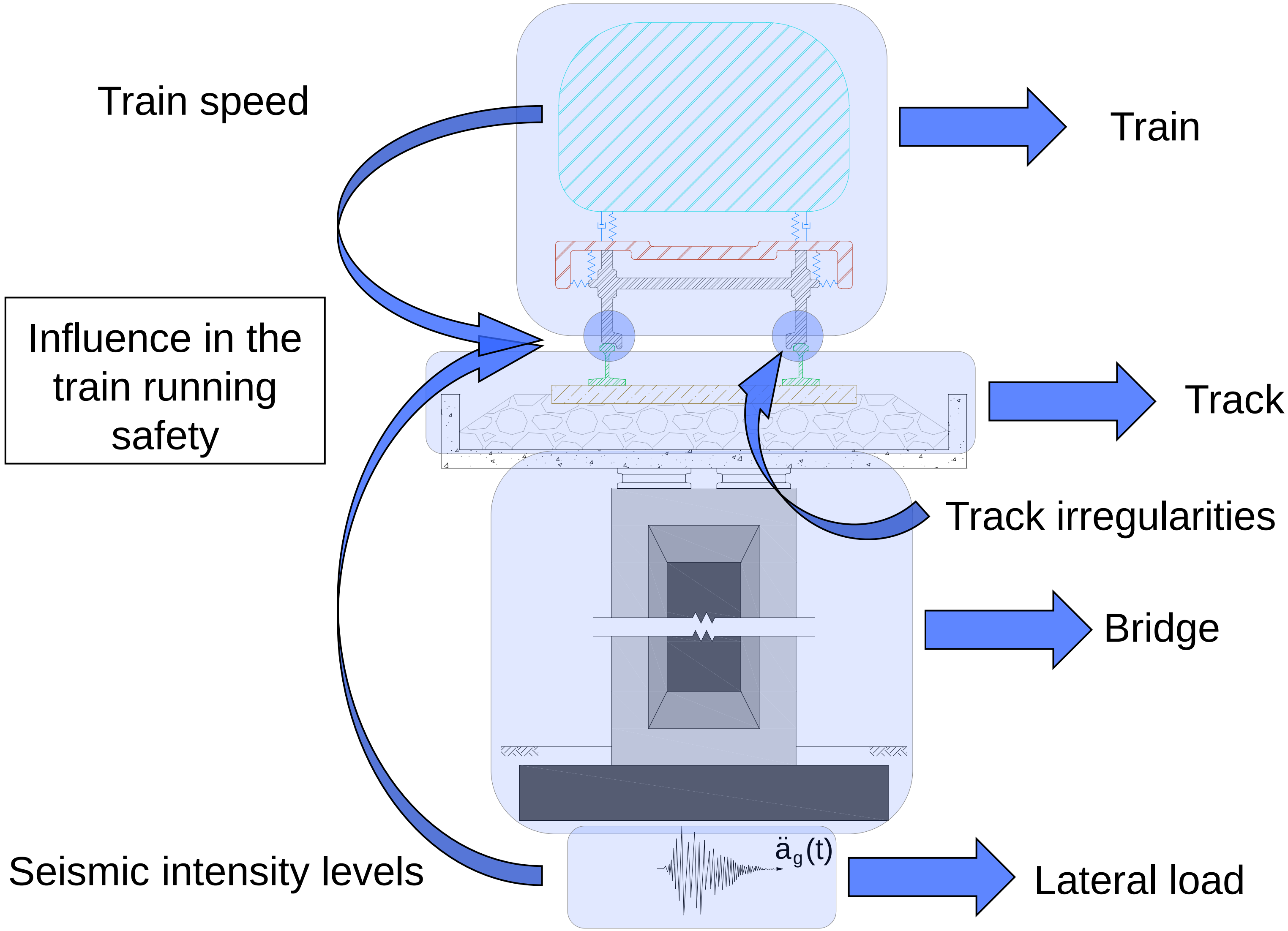
Pedro Aires Montenegro, Rui Calçada and Nelson Vila Pouca

7 – 10 October 2014 | Natal, Brazil

Contents

1. Introduction

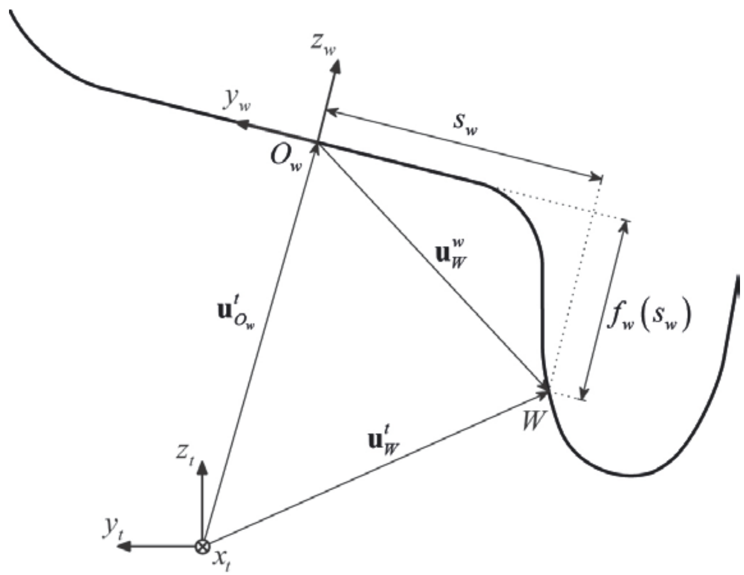
Motivation and objectives



2. Train-structure interaction method

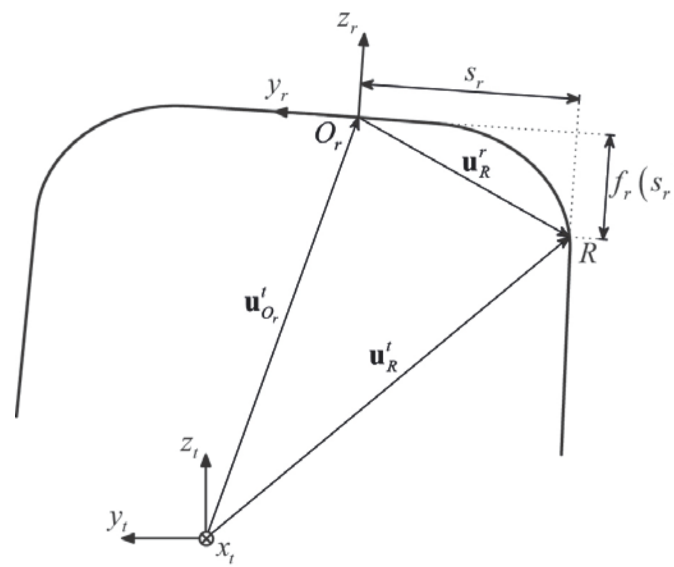
Wheel-rail contact

Wheel parameterization



$$\mathbf{u}_W^t = \mathbf{u}_{O_W}^t + \mathbf{T}^{tw^T} \mathbf{u}_W^w$$

Rail parameterization



$$\mathbf{u}_R^t = \mathbf{u}_{O_r}^t + \mathbf{T}^{tr^T} \mathbf{u}_R^r$$

The geometrical contact problem consists of solving a system of nonlinear equations to detect the position of the contact point between wheel and rail.

2. Train-structure interaction method

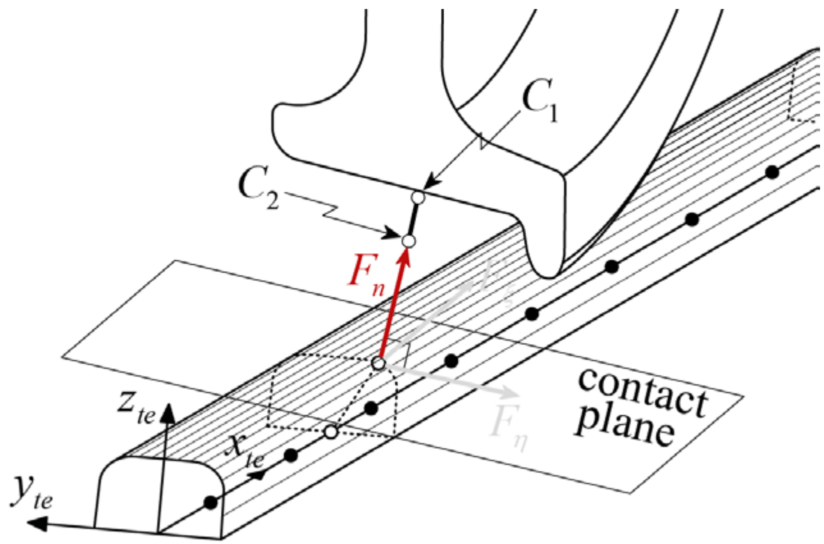
Wheel-rail contact

Nonlinear Hertz theory

The nonlinear Hertz contact theory is used to solve the normal contact problem.

$$F_n = K_h \, \delta^{3/2}$$

The normal contact force depends on the deformation between wheel and rail when they contact eachother, on the mechanical properties of the bodies in contact and on the curvatures of the bodies at the contact point.



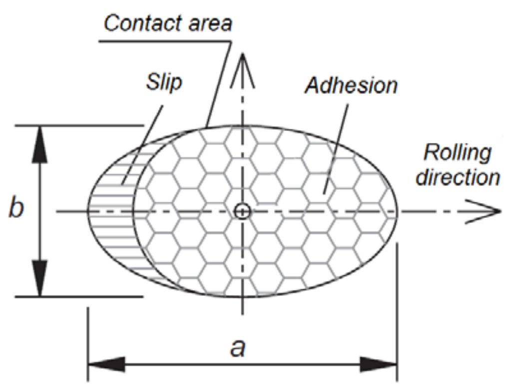
2. Train-structure interaction method

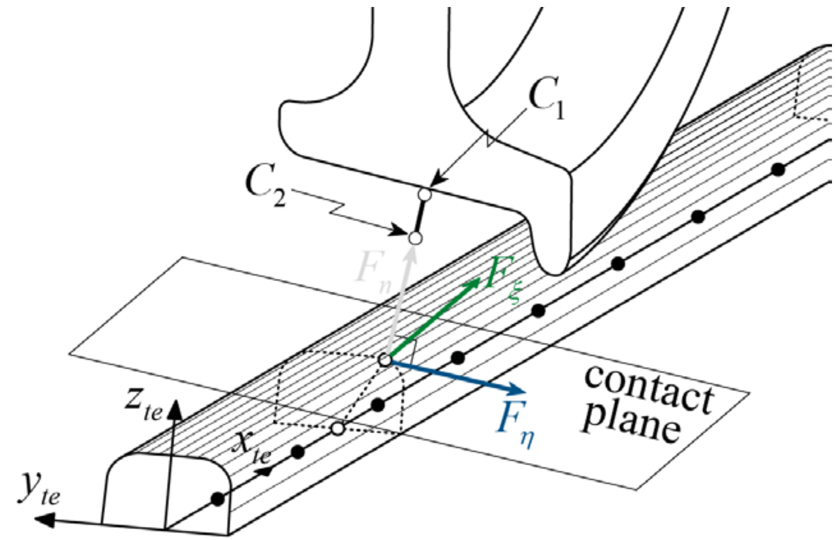
Wheel-rail contact

Kalker's rolling contact theory

The Kalker's nonlinear rolling contact theory is used to solve the tangential contact problem.

The creep forces are calculated by the USETAB routine, based on Kalker's exact three dimensional theory, and by the Kalker's linear theory for small creepages.

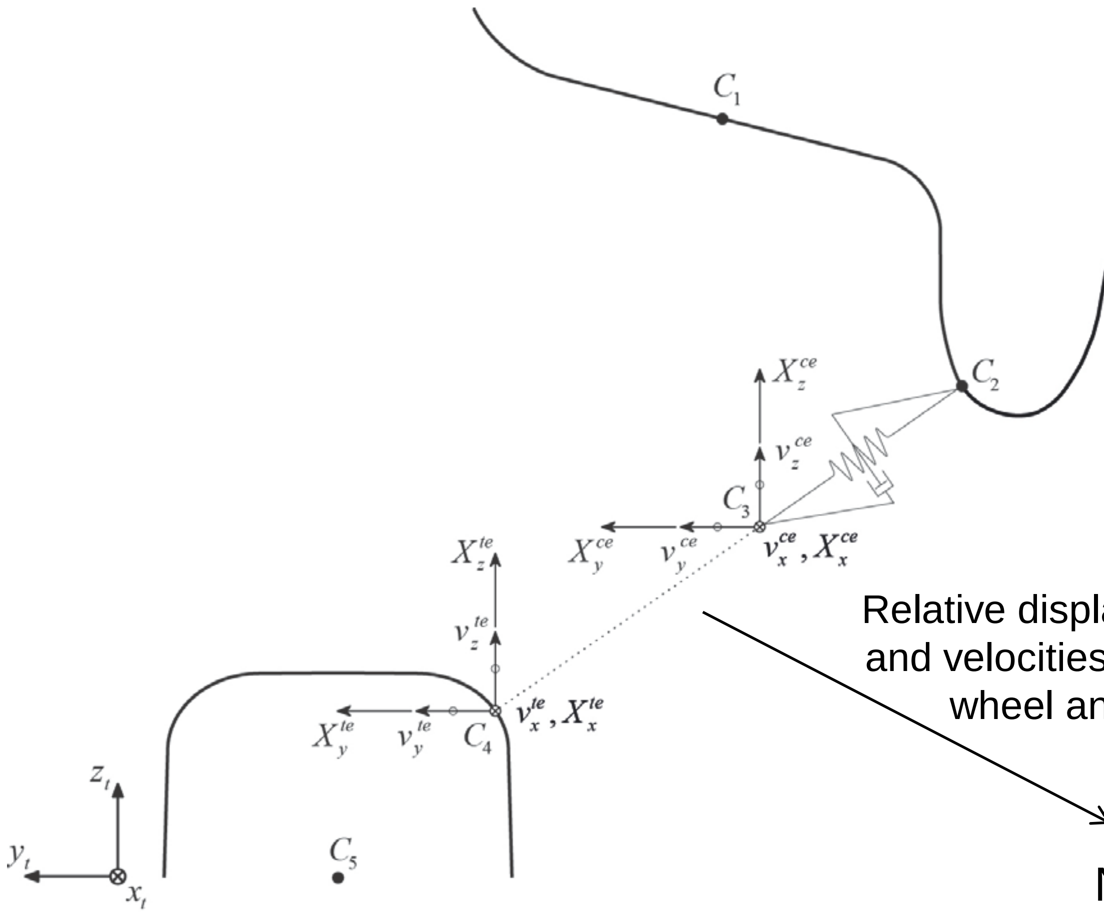




2. Train-structure interaction method

Wheel-rail contact

Target and node-to-segment contact element



Relative displacements and velocities between wheel and rail

→ Contact point position;
Normal contact behavior;
Tangential contact behavior;

2. Train-structure interaction method

Numerical solution of the interaction problem

- The direct method developed by Neves et al. 2012[a] is used to solve the interaction problem.

- The governing equilibrium equations of the vehicle and structure are complemented with additional constraint equations that relate the displacements of the contact nodes of the vehicle with the corresponding nodal displacements of the structure.

$$\begin{bmatrix} \overline{\mathbf{K}}_{FF} & \overline{\mathbf{D}}_{FX} \\ \overline{\mathbf{H}}_{XF} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \Delta \mathbf{a}_F^{i+1} \\ \Delta \mathbf{X}^{i+1} \end{bmatrix} = \begin{bmatrix} \boldsymbol{\psi}\left(\mathbf{a}_F^{c,i}, \mathbf{X}^{c,i}\right) \\ \overline{\mathbf{g}} \end{bmatrix}$$

- Neves et al. 2014[b] proposed and extension of the direct method to account the nonlinear characteristics of contact. In the present work there are three contact directions (normal and two tangential).

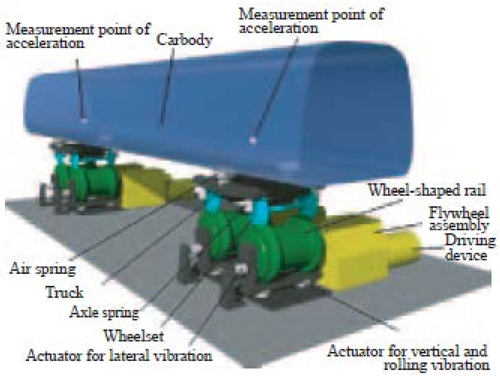
[a] S. G. M. Neves, A. F. M. Azevedo, R. Calçada, A direct method for analyzing the vertical vehicle–structure interaction, Engineering Structures, 2012.

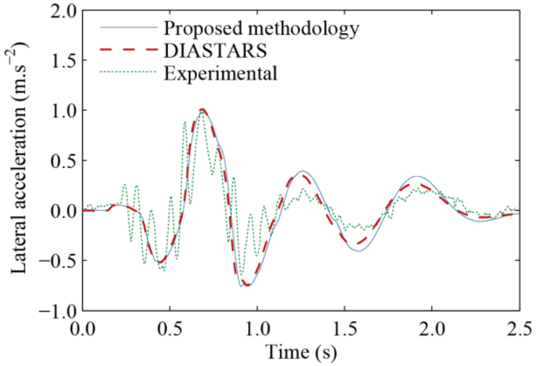
[b] S. G. M. Neves, P. A. Montenegro, A. F. M. Azevedo, R. Calçada, A direct method for analyzing the nonlinear vehicle–structure interaction, Engineering Structures (accepted).

2. Train-structure interaction method

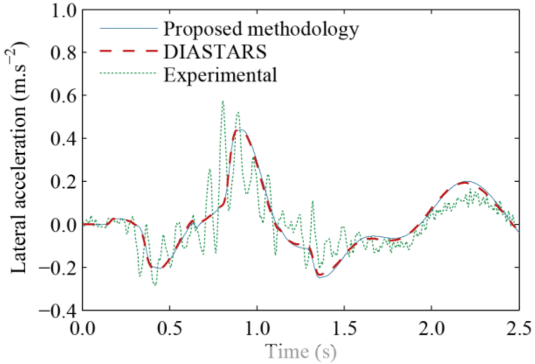
Validation using results from an experimental test developed in the RTRI

Lateral accelerations inside the carbody above the rear bogie [a]





Bending shape L=20m



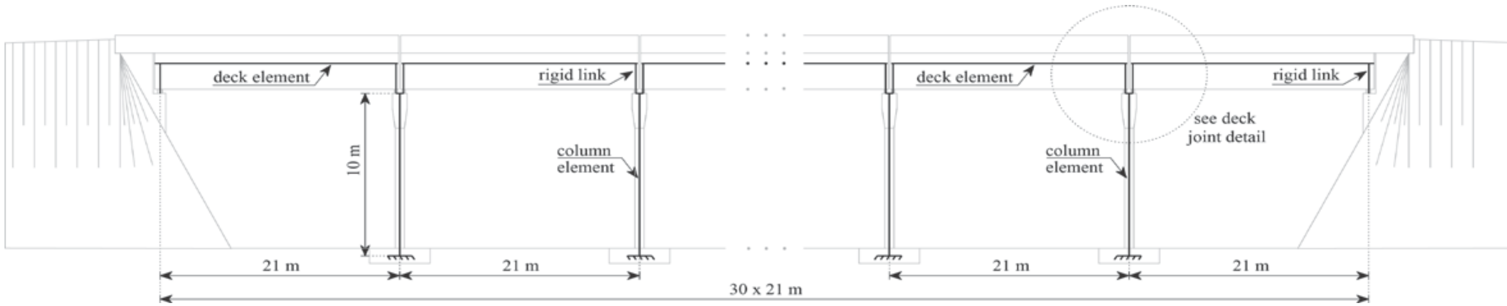
Bending shape L=40m

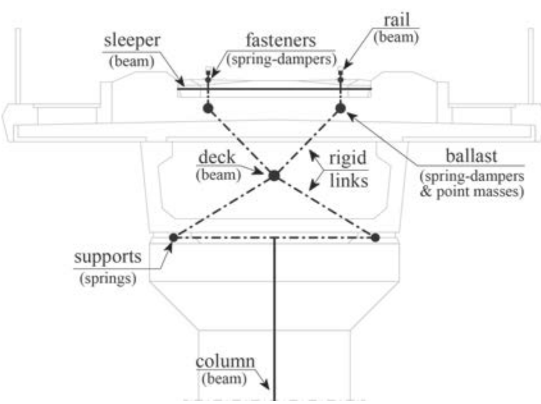
[a] P. A. Montenegro, S. G. M. Neves, R. Calçada, M. Tanabe, M. Sogabe, *Wheel-rail contact method for analyzing the lateral train-structure dynamic interaction* , Computers & Structures (under review).

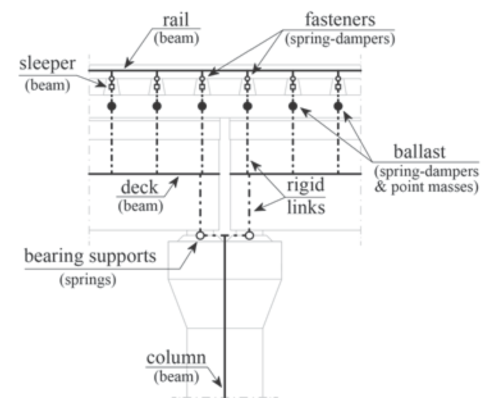
3. Finite element model of the viaduct and train

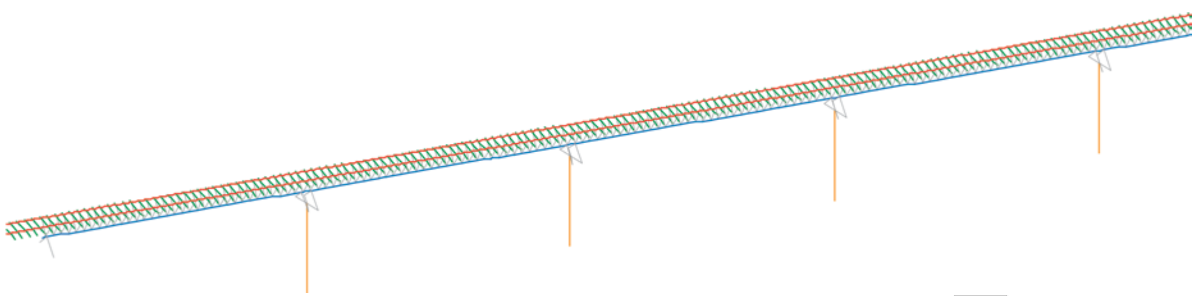
Alverca viaduct

Finite element model of the Alverca viaduct





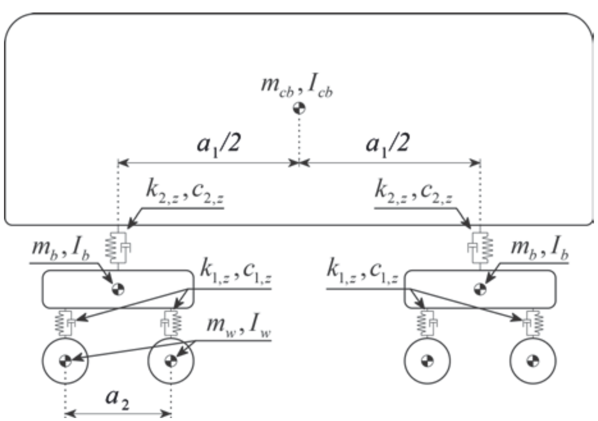


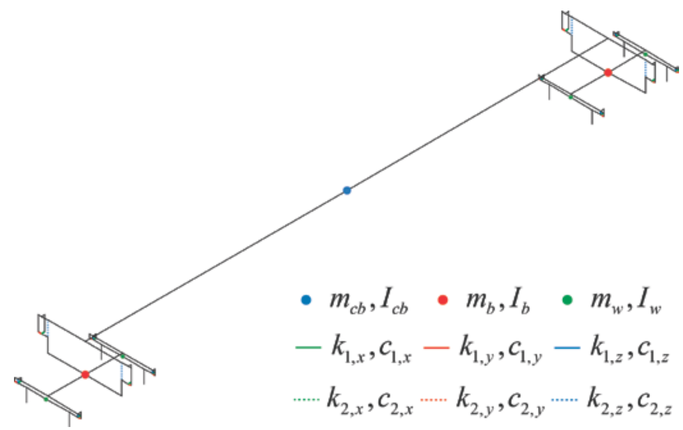


3. Finite element model of the viaduct and train

Japanese Shinkansen high-speed train

Finite element model of the Shinkansen

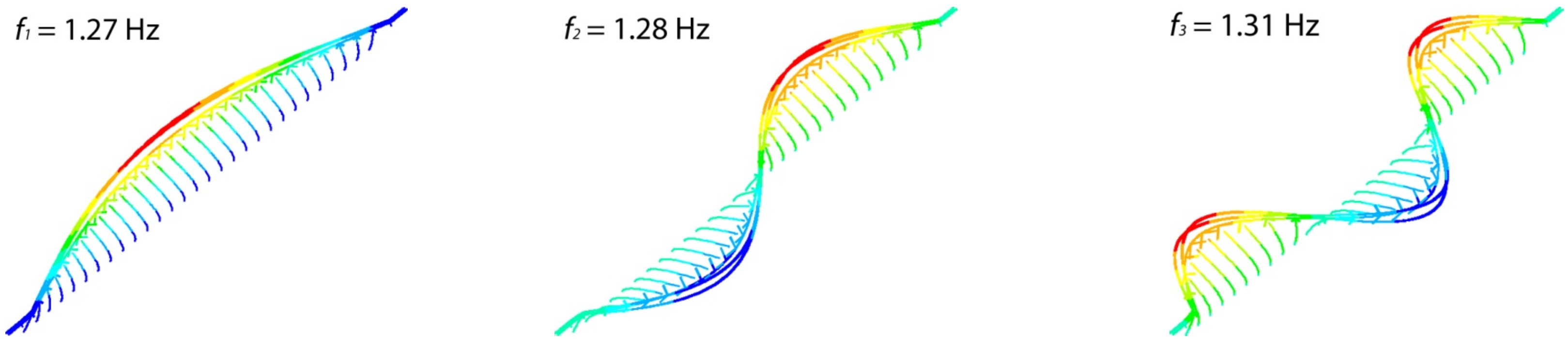




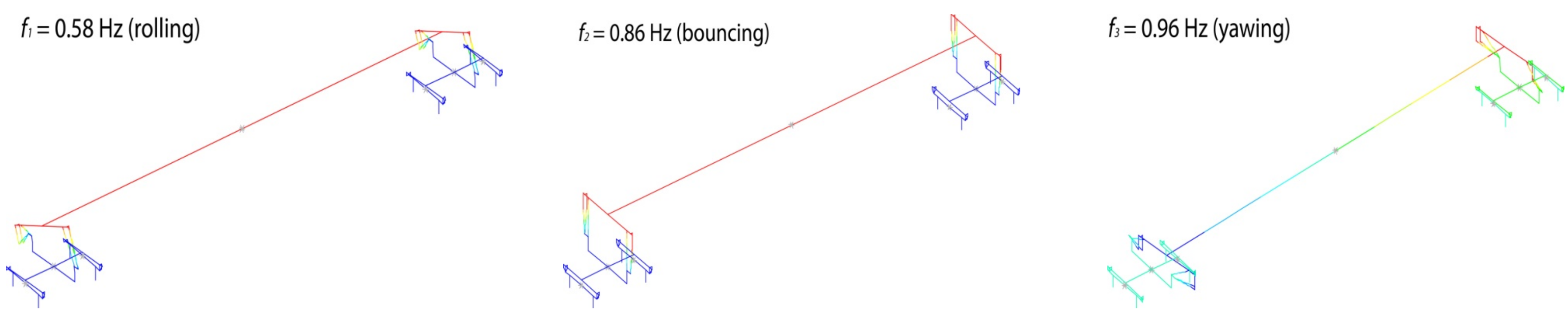
3. Finite element model of the viaduct and train

Dynamic properties of the viaduct and train

Frequencies and mode shapes of the viaduct



Frequencies and mode shapes of the vehicle



4. Running safety analysis

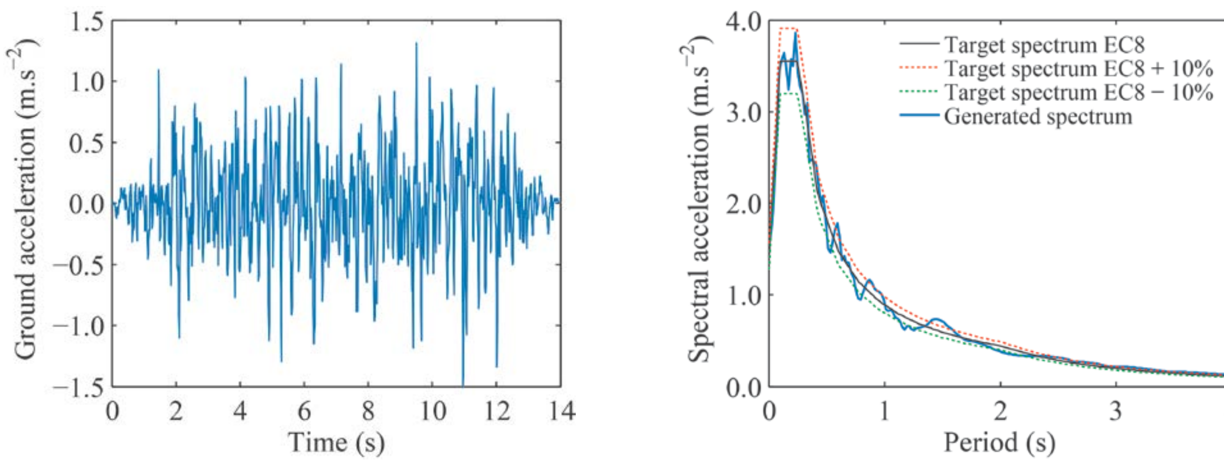
Seismic action

• Artificial accelerograms generated with the software SeismoArtif ®;

• Moderate seismic intensities with *T* = 95, 150, 225 and 310 years. These level of intensities do not cause significant damage to the structure but may jeopardize the train running safety.

• Target elastic spectra defined for the seismic zone 2.3 of the Portuguese territory, soil type A and importance factor 1.0 (NP EN 1998-1, 2009).

T = 310 years

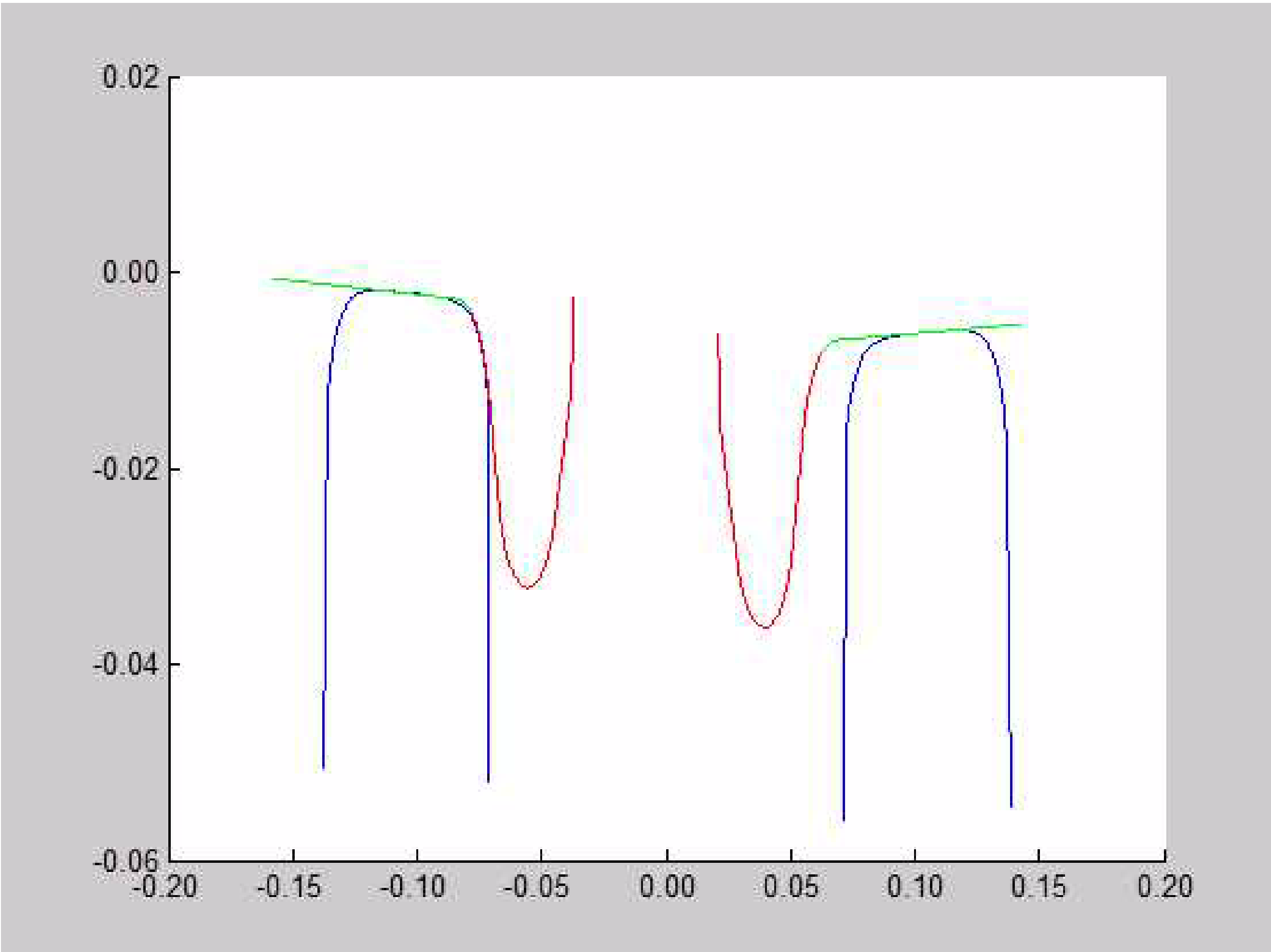


U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

CSF CENTRO DE SABER DA FERROVIA

4. Running safety analysis

Results



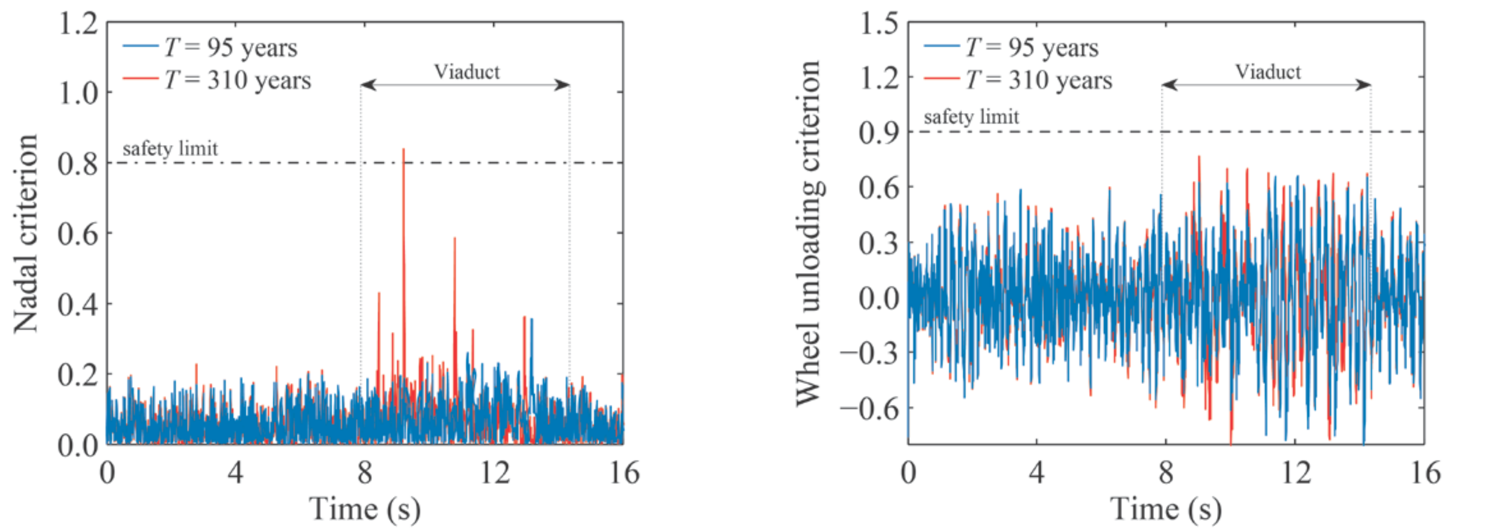
4. Running safety analysis

Influence of the seismic intensity

<u>V = 350 km/h and regular operation limit irregularities</u>

Seismic level	Nadal (0.8)	Prud'homme (1.0)	Wheel unloading (0.9)
No earthquake	0.26	0.37	0.72
T = 95 years	0.71	0.89	0.76
T = 150 years	0.70	1.17	0.82
T = 225 years	1.02	1.35	0.89
T = 310 years	1.05	1.42	0.89

Left wheel, 2nd wheelset, V = 350 km/h, regular operation limit irregularities



U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

CSF CENTRO DE SABER DA FERROVIA

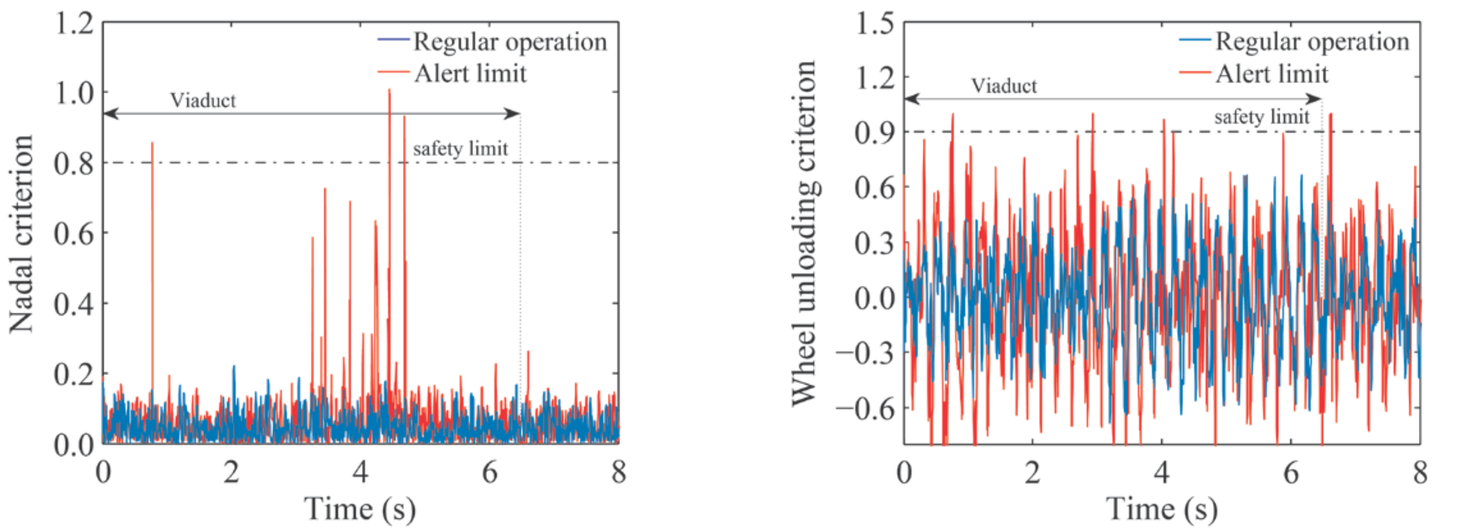
4. Running safety analysis

Influence of the track quality

V = 350 km/h and no earthquake

Track quality level	Nadal (0.8)	Prud'homme (1.0)	Wheel unloading (0.9)
Regular operation limit	0.26	0.37	0.72
Alert limit	1.45	1.68	1.00

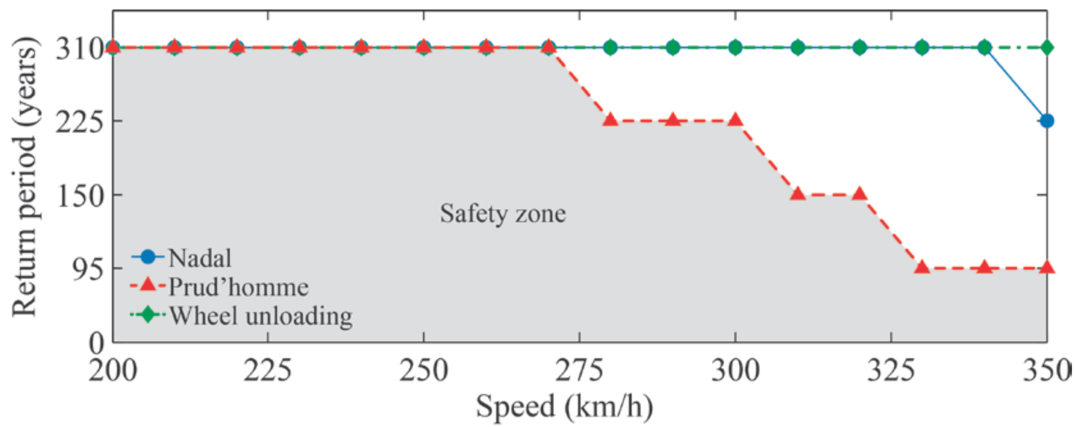
Left wheel, 1st wheelset, V = 350 km/h, no earthquake



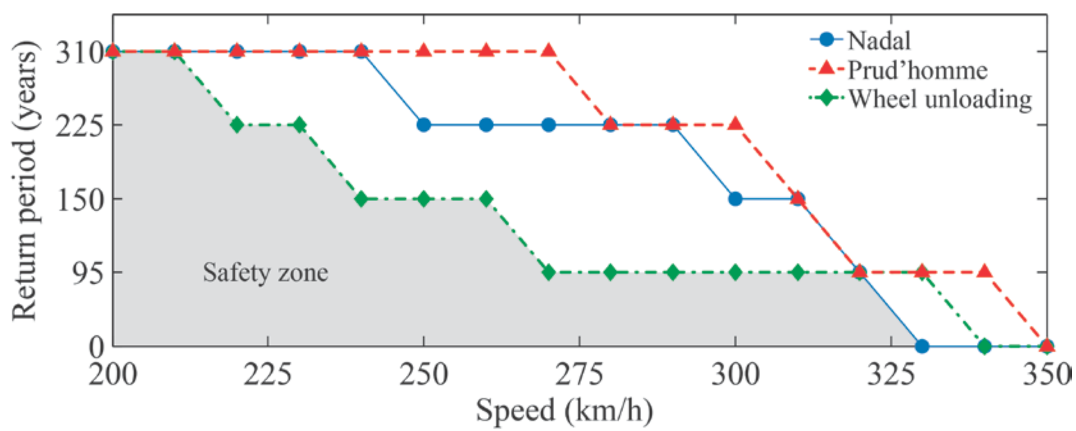
4. Running safety analysis

Running safety charts

Regular operation limit irregularities



Alert limit irregularities



P. A. Montenegro, R. Calçada, N. Vila Pouca, M. Tanabe, *Running safety assessment of trains moving over bridges subjected to moderate earthquakes* , Earthquake Engineering & Structural Dynamics (under review).

5. Conclusions

- A study about the running safety assessment of trains moving over bridges subjected to earthquakes is presented. A train-structure interaction method that takes into account the geometry of the wheel and rail, is adopted to solve the dynamic problem.

- The influence of the seismic intensity level and track quality in the running safety of a high-speed railway vehicle moving over a viaduct is discussed.

- Even considering only moderate seismic intensities, the train safety is put at risk in a considerable number of scenarios, especially due to the risks of derailment caused by wheel flange climbing.

- The results prove the importance of taking low intensity earthquakes into account in the design of railway bridges, even if they do not represent a major threat to the structure integrity.

U.PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
CSF CENTRO DE SABER DA FERROVIA

Acknowledgements

The present work has been funded by the Portuguese Foundation for Science and Technology (FCT), in the context of the doctoral grant number SFRH/BD/48320/2008.

FCT Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

Portuguese Republic   European Union — Structural Funds

CSF
CENTRO DE SABER
DA FERROVIA

Thank you for your attention

csf@fe.up.pt

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO