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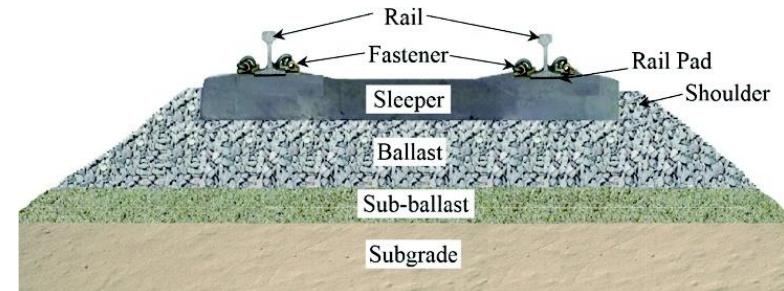
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A fast analytical model for free track dynamics

Bart Van Damme – Empa, Materials Science and Technology

Introduction

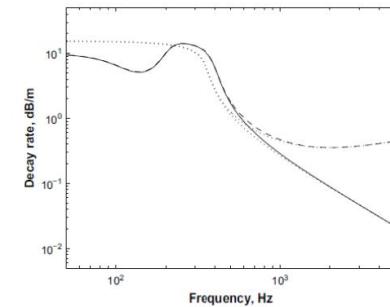
- Model-based rail pad development
 - Multiscale approach (material -> noise emission of track)
 - Properties over acoustic range (0 Hz – 5 kHz)
 - Detailed, adaptable models needed
- Goal: softer than standard pads with lower noise emission
- Fast enough track models to allow predictions for many materials and geometries



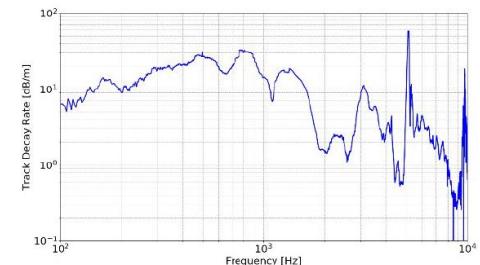
Objectives

- Predict free track dynamics (track decay rate, point mobility) within minutes
 - 200 sleeper sections, 0-3000 Hz
 - Vertical and lateral motion
 - Sufficient detail of all components (ballast, sleeper, pad, rail)
- Challenges
 - Realistic representation of viscoelastic rail pads over the entire frequency range
 - Narrow-band spectral data
 - Quantitative agreement with validation measurements

Continuously supported analytical track model

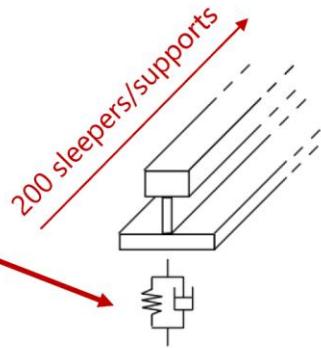
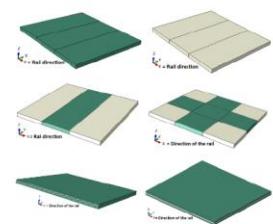


Field Measurements



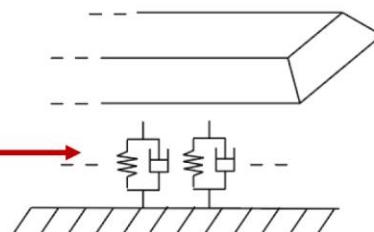
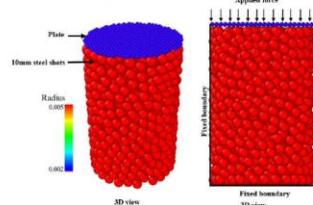
Components of the model

FEM model reduced to frequency dependant complex spring

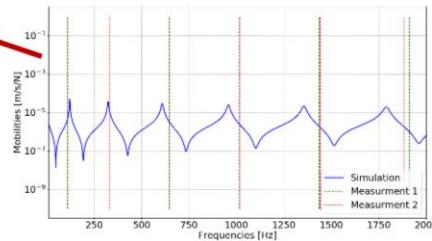


Rail: 3 Timoshenko beams
Head, Web, Foot

Continuous spring layer for ballast and USP
Ballast properties from DEM



Sleeper: finite Timoshenko beam

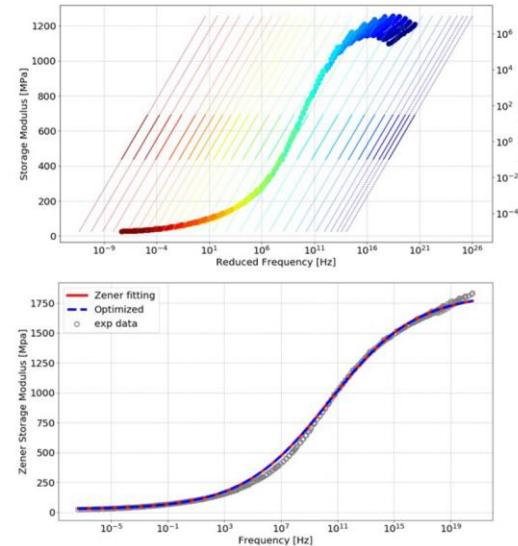


- Vertical vibrations
 - Wave numbers in free rails based on 1 Timoshenko beam
 - Discrete reaction forces from ballast + sleeper + rail pad
 - Harmonic excitation in the middle of 200 sleeper section
 - Transfer matrix method to calculate rail accelerance
 - Rail pad = vertical complex spring
- Lateral vibrations
 - Wave numbers in free rails based on **3 Timoshenko beams**
 - Reaction forces and moments from ballast + sleeper + rail pad
 - Harmonic excitation in the middle of 200 sleeper section
 - Transfer matrix method to calculate rail accelerance
 - **Rail pad = shear complex spring and 2 torsional springs**



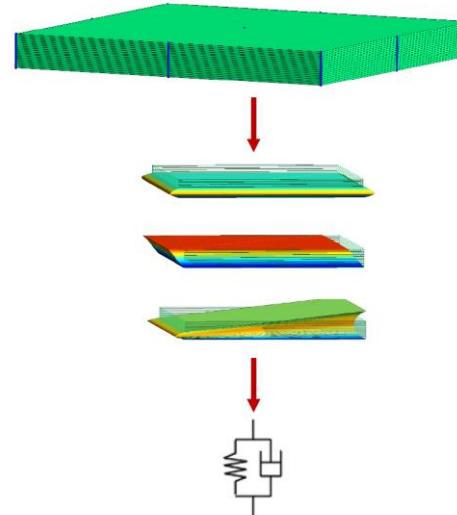
Modelling of the rail pads

- Reaction forces/momenta on the rails are the result of a complex stiffness value
$$k = k_R + ik_I$$
- Constant stiffness values give insight in basic track dynamics
- Quantitative agreement requires frequency-dependent pad/sleeper properties
 - Storage and loss modulus
 - Pad geometry (slits, thickness)
- DMA of desired material to measure moduli

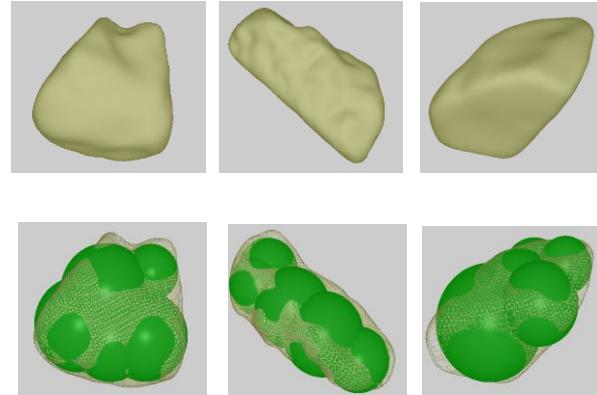
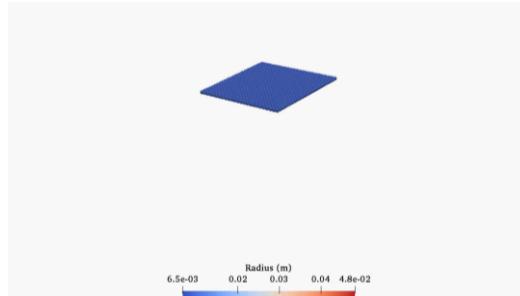


Modelling of the rail pads

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- Quantitative agreement requires frequency-dependent pad/sleeper properties
 - Storage and loss modulus
 - Pad geometry (slits, thickness)
- Model reduction of full pad geometry to 4 springs



- Discrete element model
 - Individual rocks are modelled
 - High degree of detail, long calculation time
 - Best approximation to physics of ballast

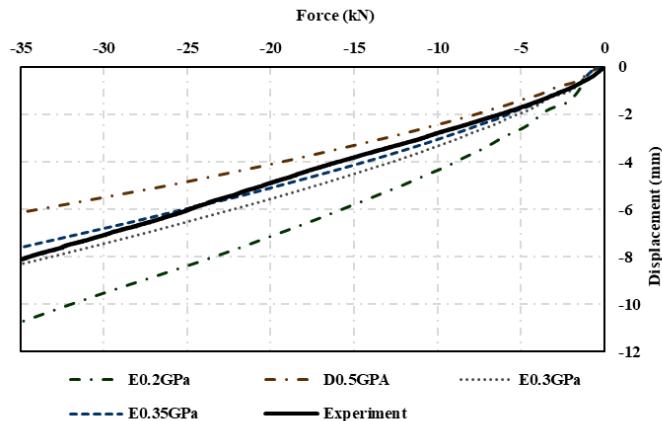


Total Particles generated : 25 ballast particle
Number of spheres limited to 5-6 to reduce computational time

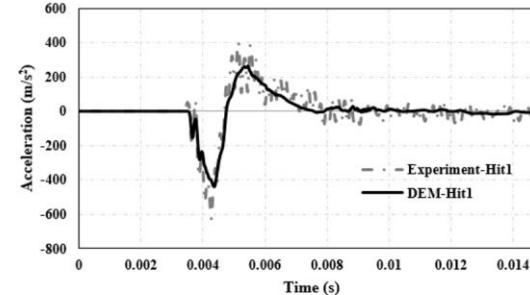


Ballast models: results

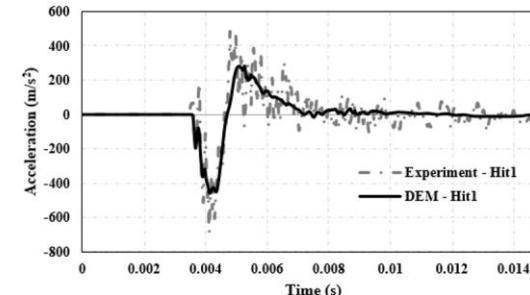
- Static stiffness
 - Define contact parameters
 - First insight in quality of model



- Dynamic stiffness
 - 0 to 1000 Hz
 - First study of this kind
 - Surprising results in experiment and model
- Three stiffness regimes
 - Low stiffness < 70 Hz
 - Power-law increase
 - High constant stiffness > 700Hz



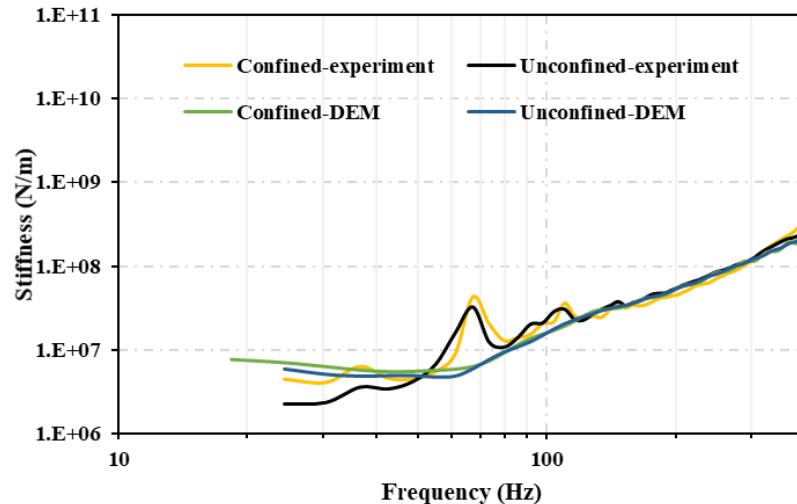
(a) Confined condition -Hit1



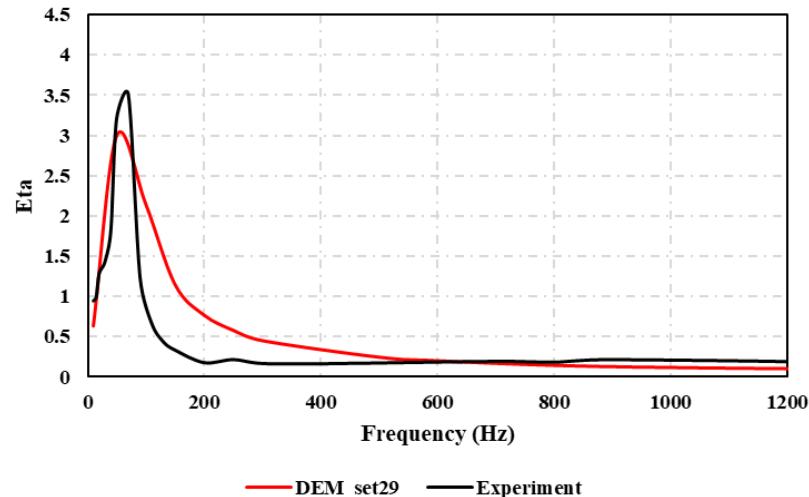
(c) Unconfined condition -Hit1



- Dynamic stiffness
 - 0 to 1000 Hz
 - First study of this kind
 - Surprising results in experiment and model
- Three stiffness regimes
 - Low stiffness < 70 Hz
 - Power-law increase
 - High constant stiffness > 700Hz

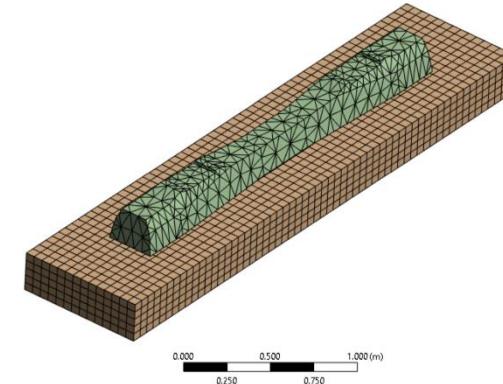


- Dynamic damping
 - Surprising experimental results
 - Peak in damping at 40 Hz
 - Might be related to fluidization
 - Very low damping at low frequencies and >100 Hz
 - Agrees with recent experimental data from TU Wien



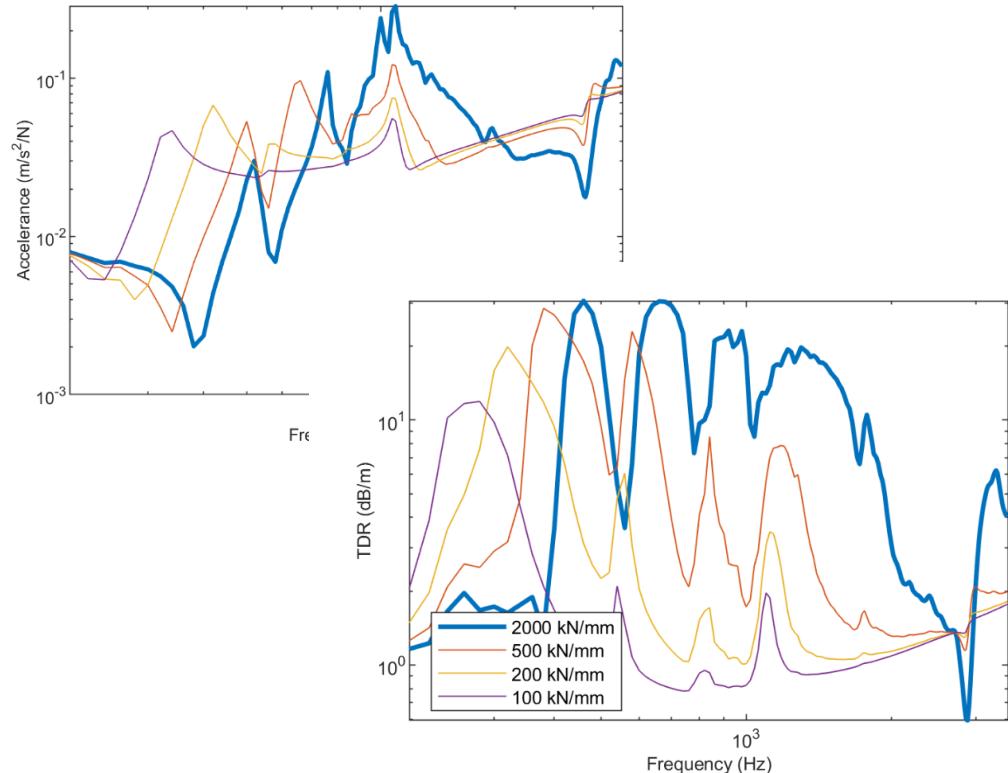
Modelling of the sleeper/ballast

- Frequency-dependent mobility (in m/N) replaces rigid-mass model
- Analytical solution for rectangular beam resting on resilient layer
- The mobility can be gathered from measurements (free sleeper in-situ) or from numerical models



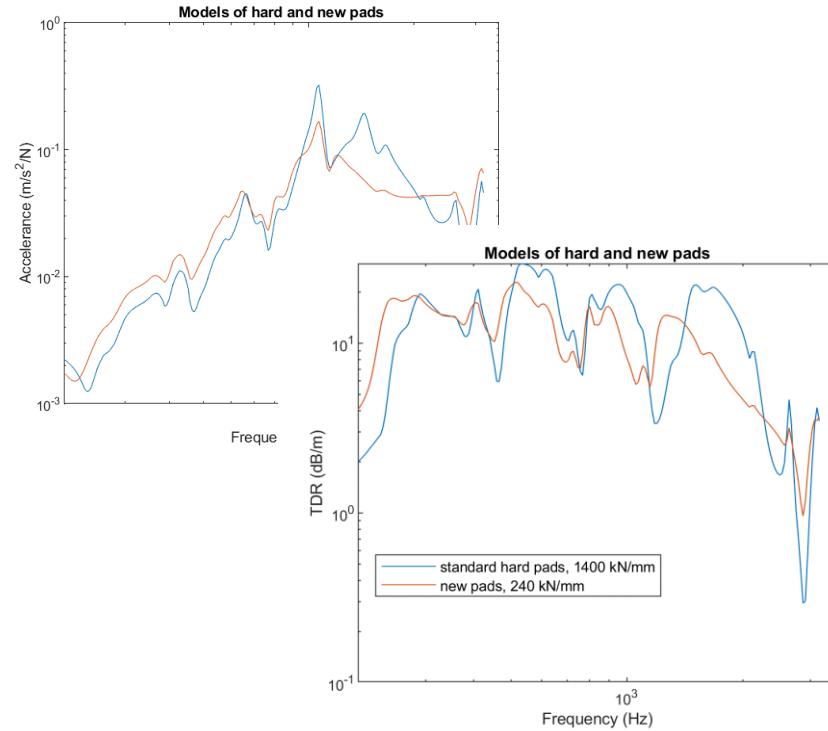
Track model: results

- Excellent tool for parameter studies
 - Railpad stiffness/damping
 - Influence of sleeper
 - Only 2-3min to get results
 - High level of detail
- Model is only as good as its components

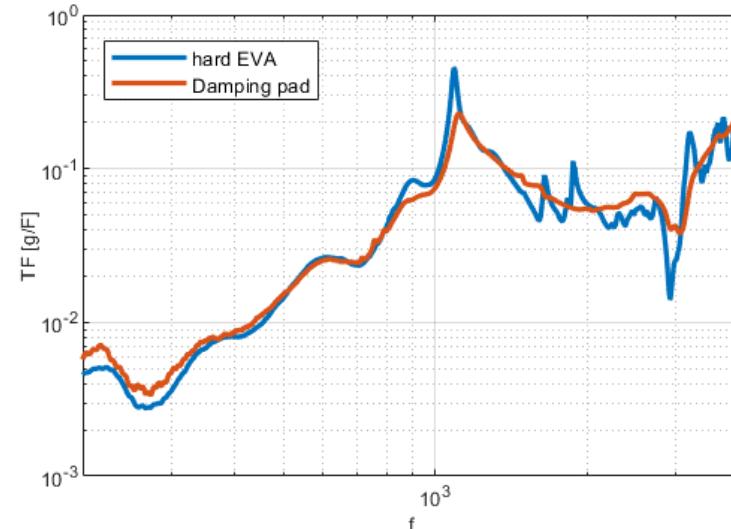
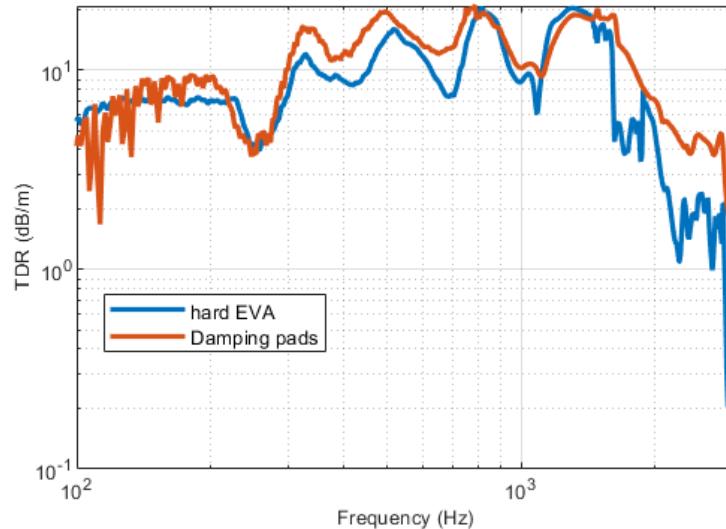


Track model: results

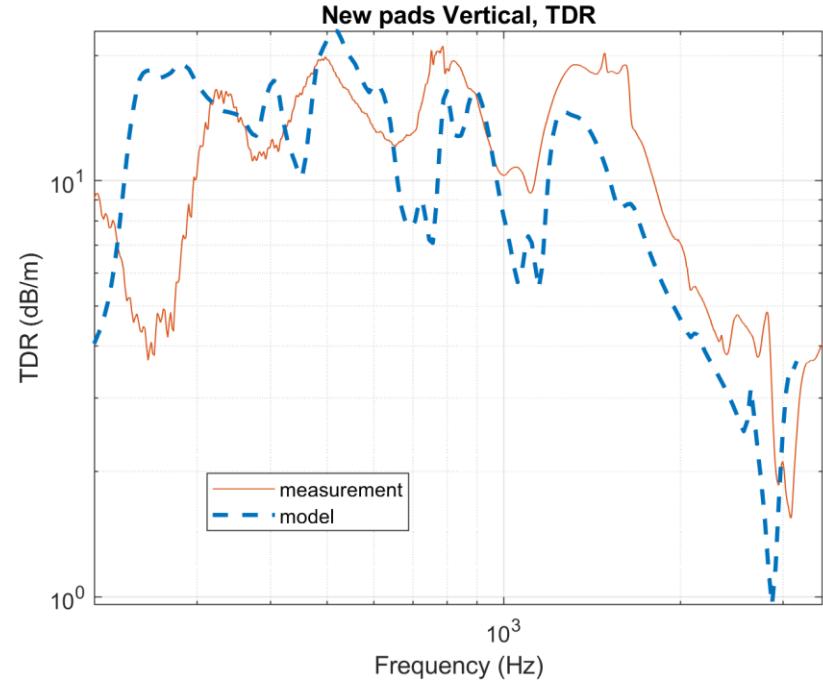
- Prediction of behaviour of new pads
 - Input from FEM for pad stiffness and damping over full frequency range
 - Constant (static) stiffness value is not sufficient
- Semperit pads
 - High dynamic stiffness
 - High damping (up to 1)



Reduction of mobility and increase of TDR



- Fast and easy-to-use model to predict the free-track dynamics
- Detailed model of dynamic stiffness/damping of ballast over full frequency range
 - Can be extended to settlement and vibration transmission
- Predictions match the real behaviour of the track





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This work was funded by the
Swiss federal government

