PREDICTION OF TRAIN-INDUCED VIBRATIONS: From track to building

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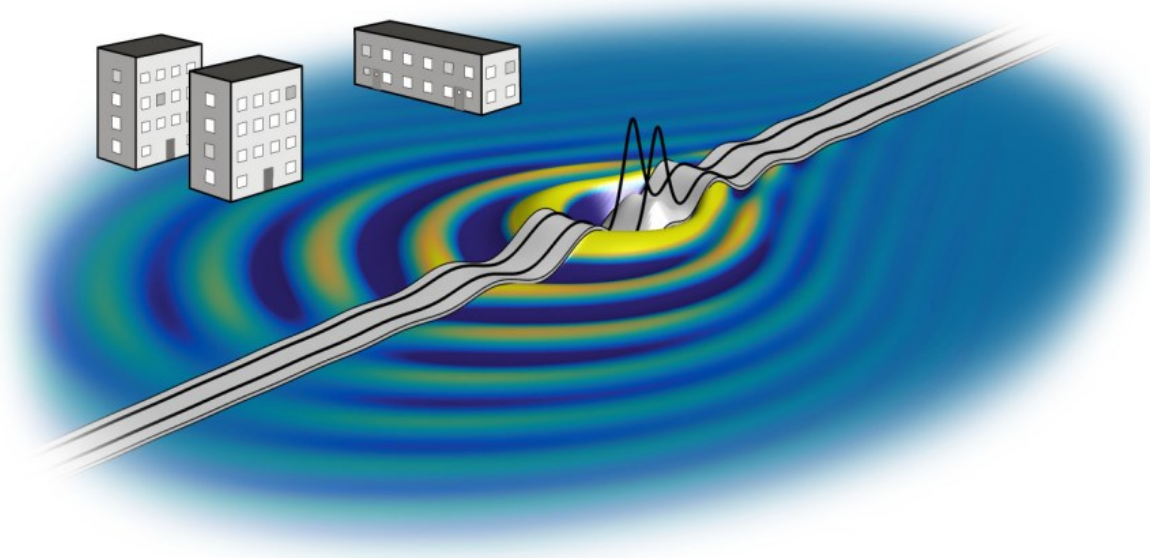
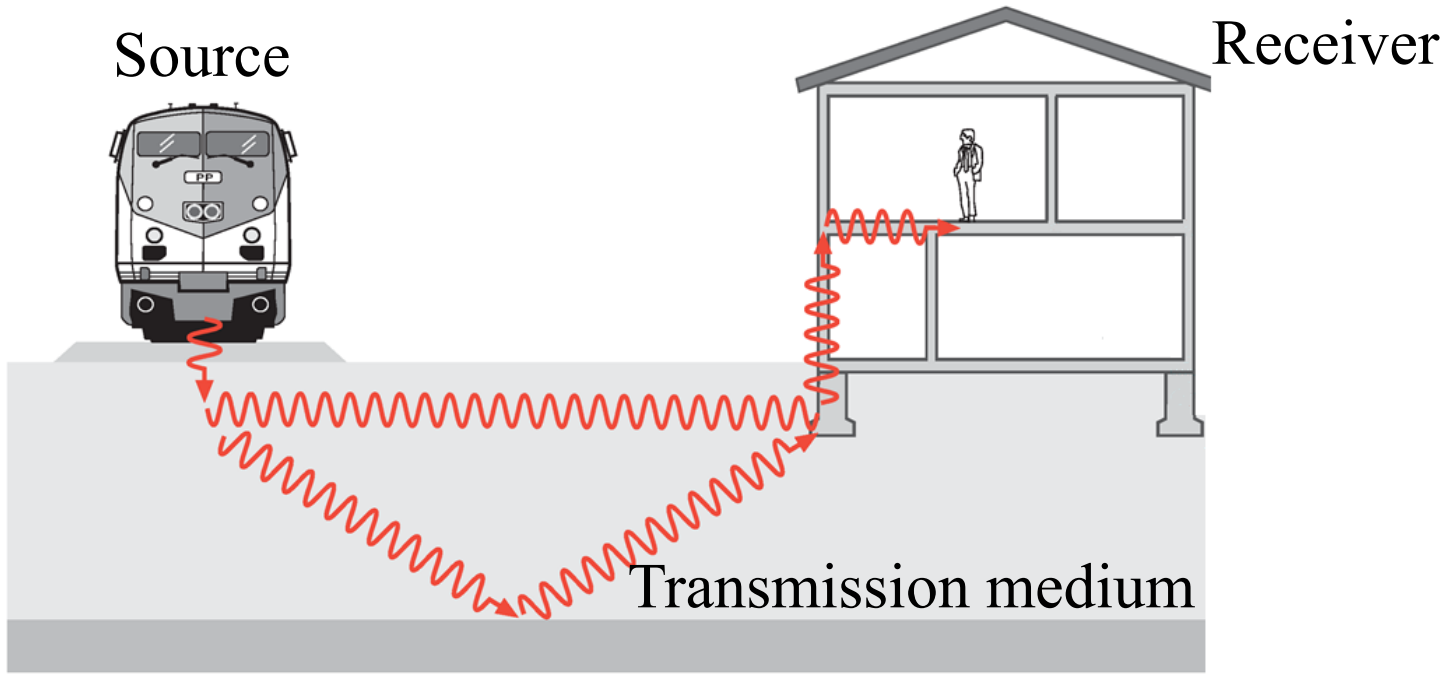


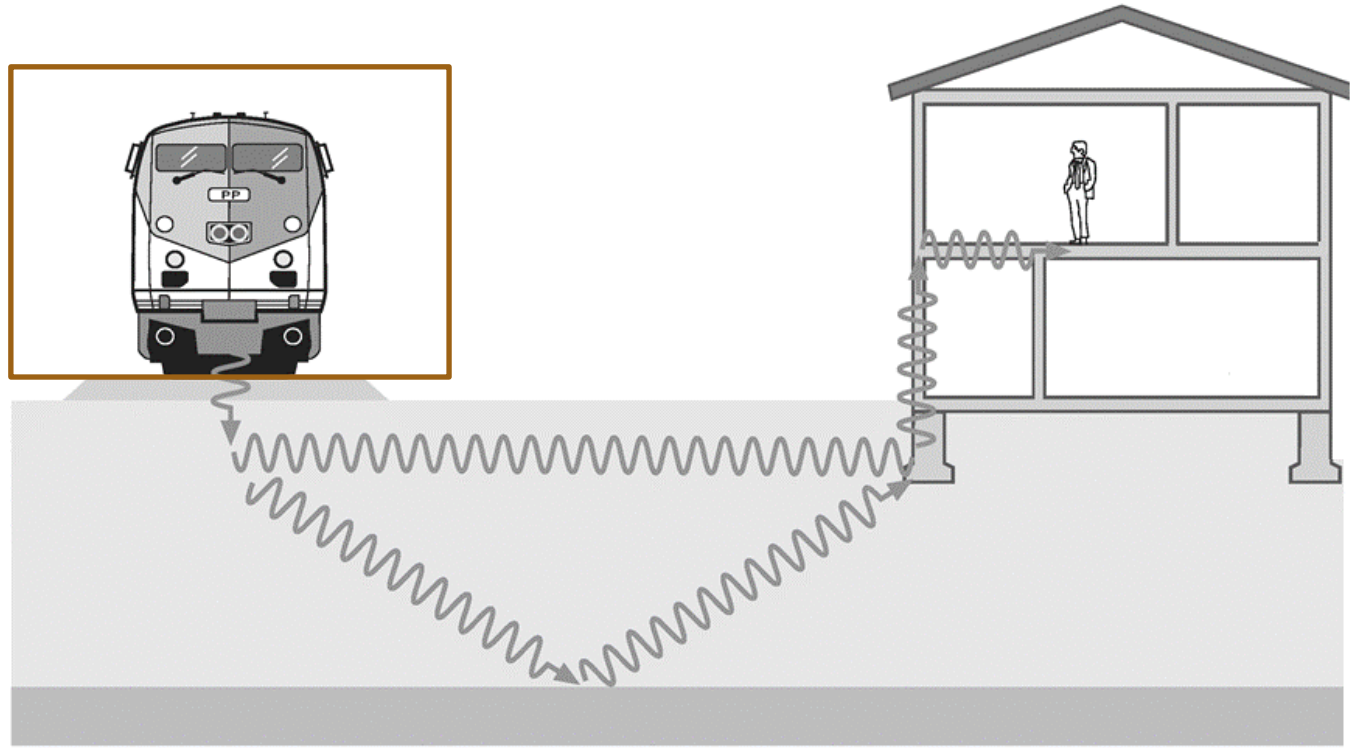
NGV 2022
5th Nordic Ground Vibration Day
24 October 2022 • Aarhus • Denmark

Research challenges

- Understand, predict and prevent vibration problems
- Numerical prediction models to enable informed design choices



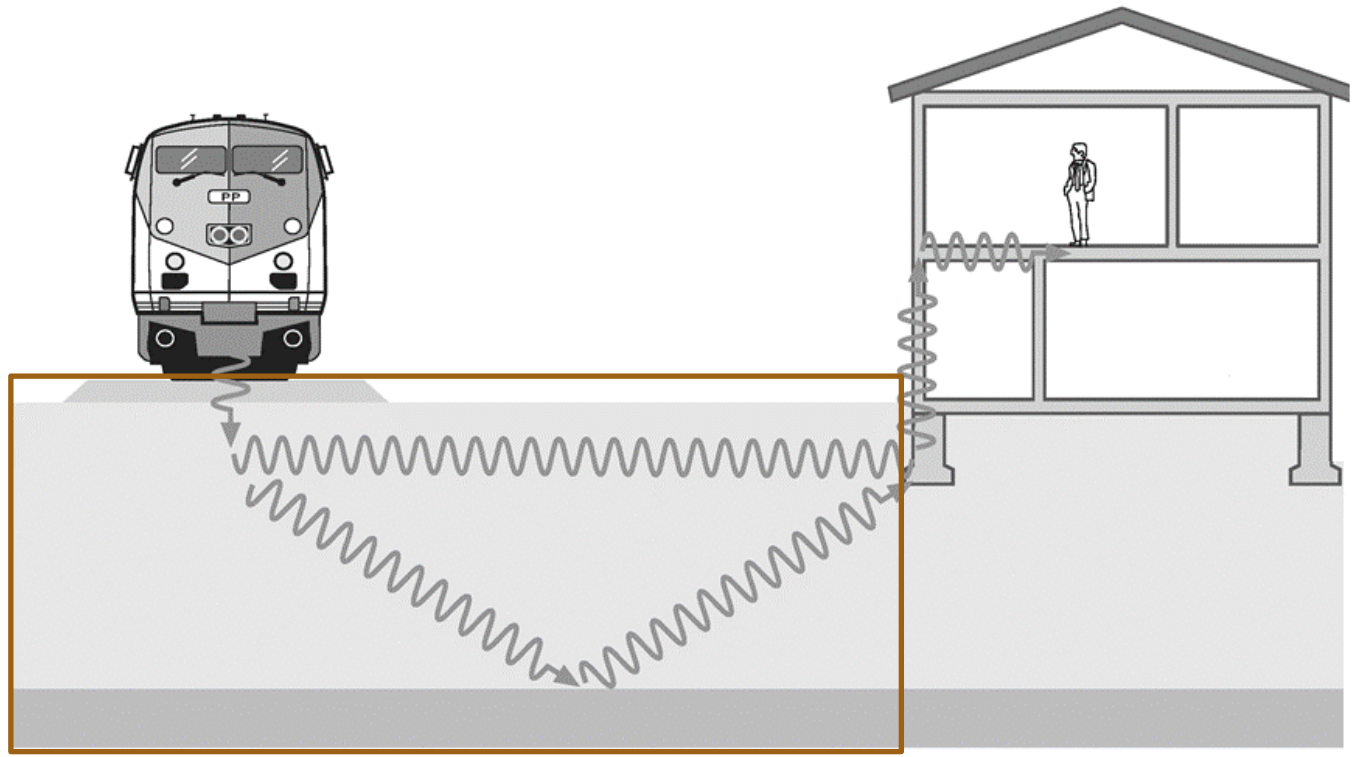
Load source: Train



Load source: Train

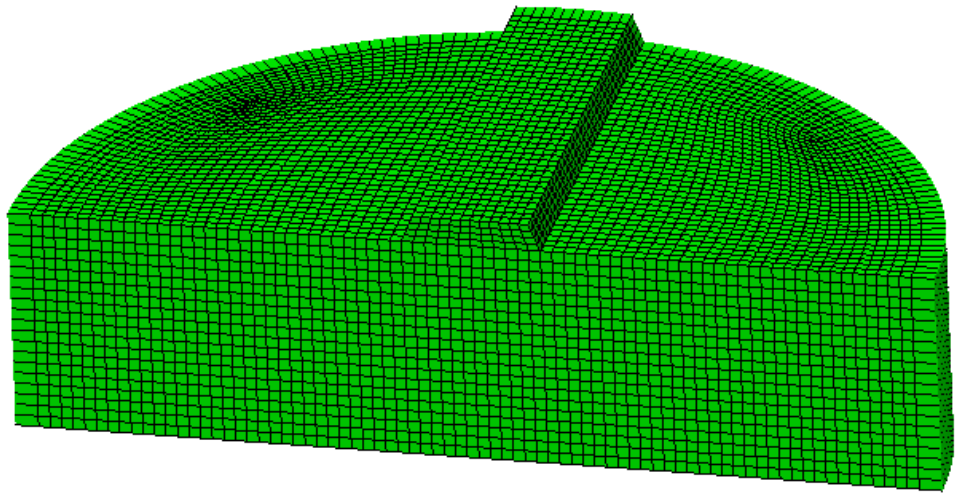
- Quasi-static load (deadweight of train)
- Dynamic load
  - Rail unevenness
  - Wheel unevenness
  - Varying track stiffness
  - Switches, intersections, etc.

Track and soil



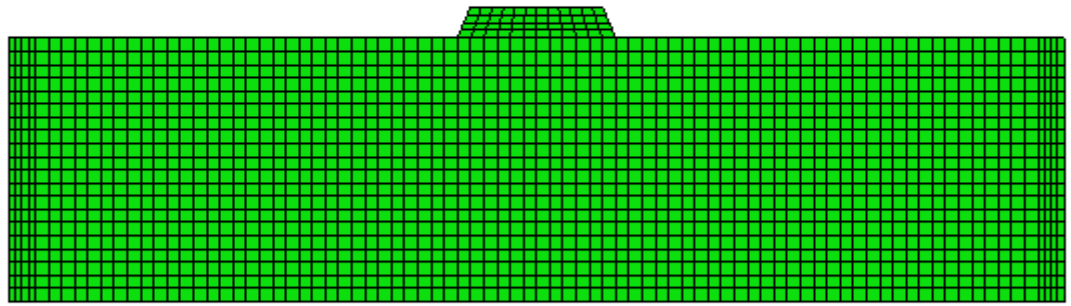
Finite element methods

- Large system of equations
- Solved once per frequency



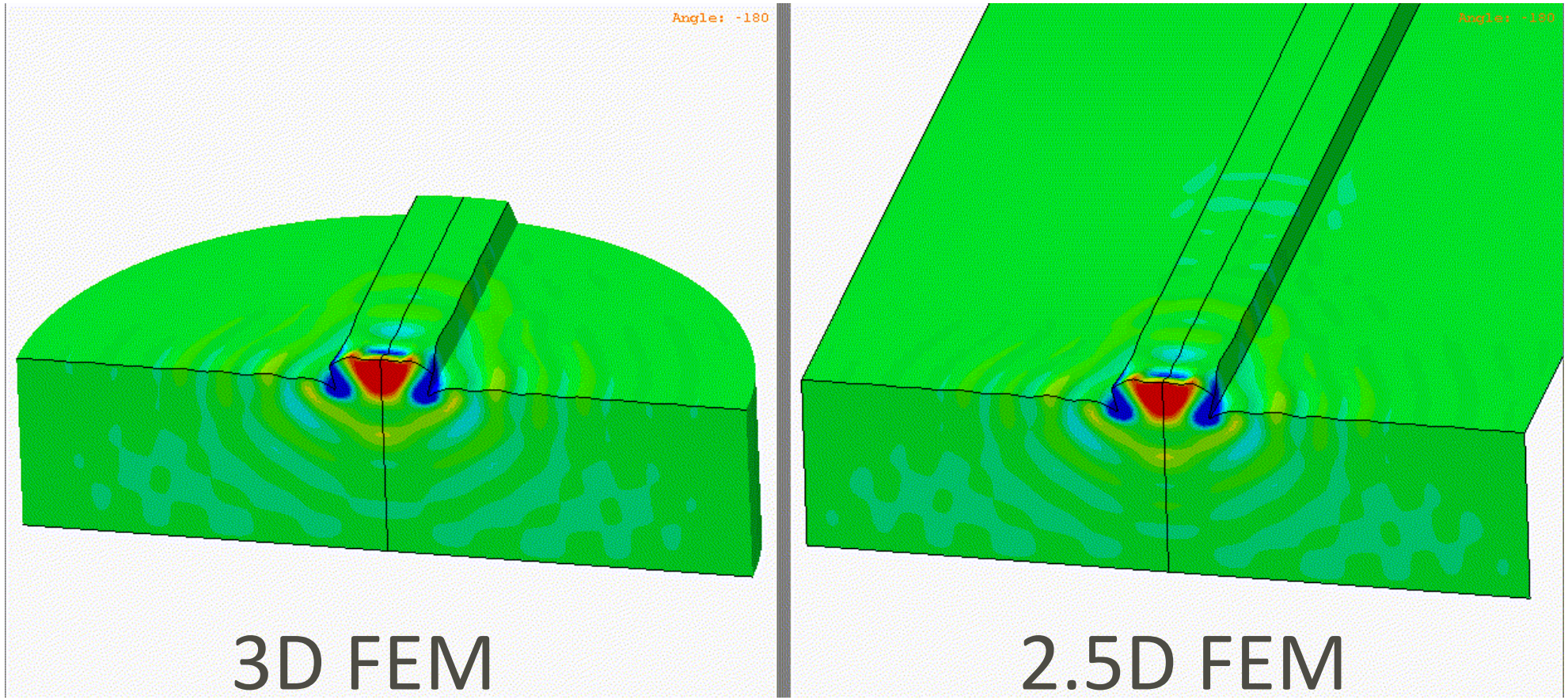
3D FEM

- Small system of equations
- Solved many times per frequency



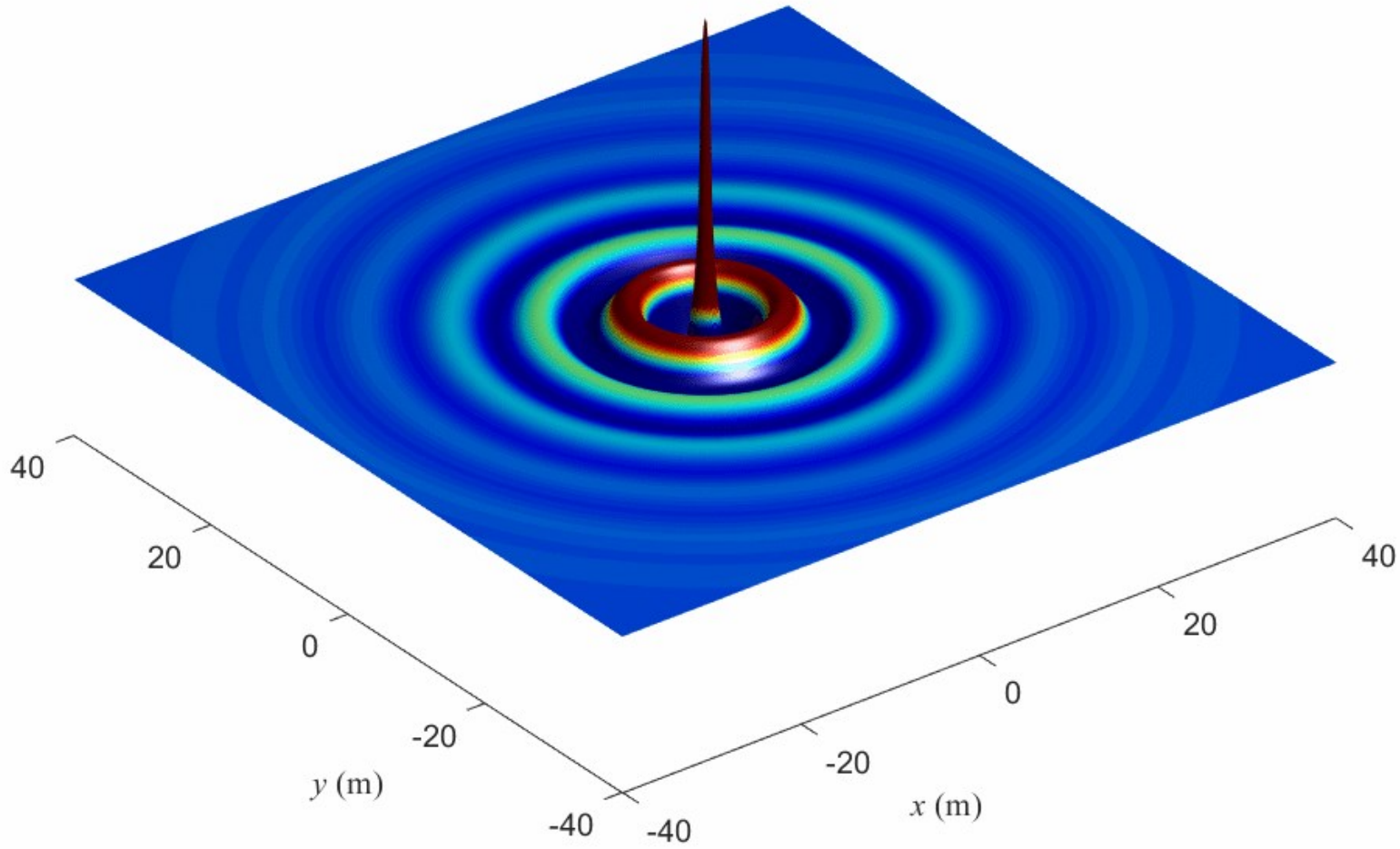
2.5D FEM

Finite element methods



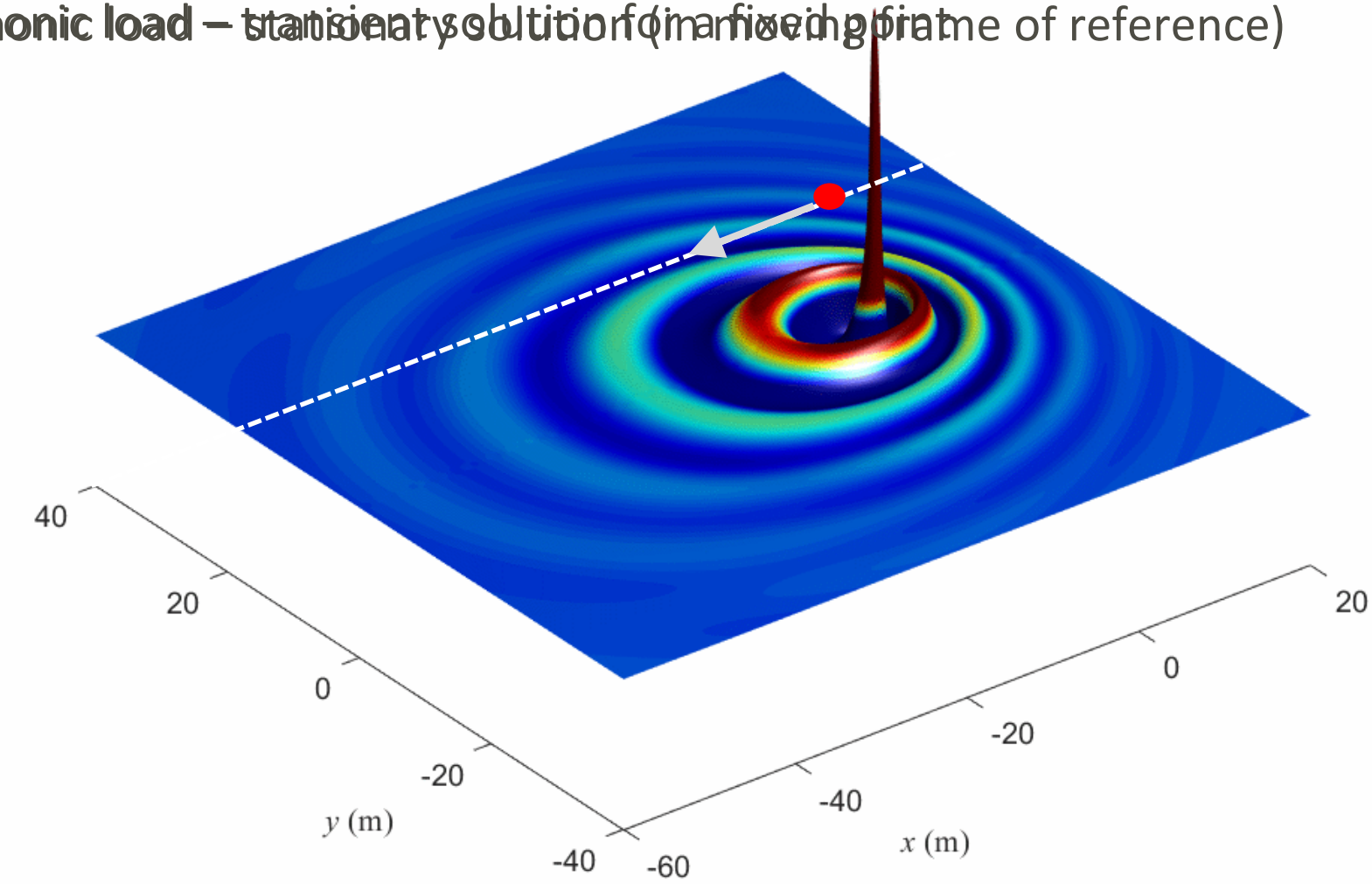
Green's function (Semi-analytical solution)

Stationary harmonic load – stationary solution



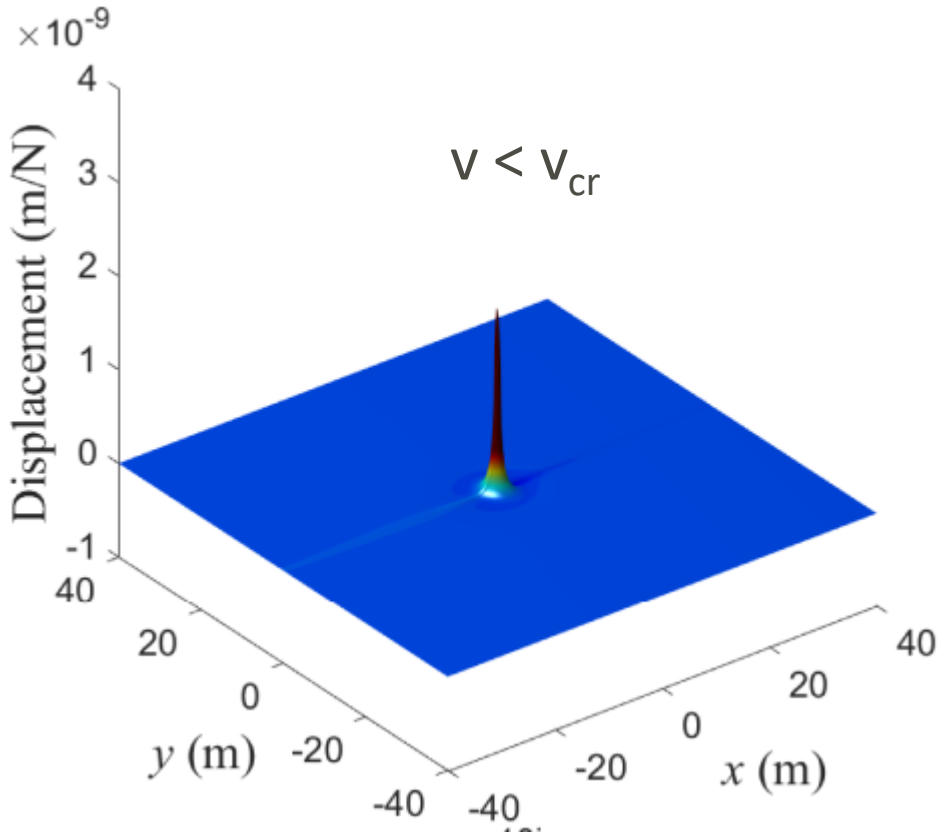
Green's function (Semi-analytical solution)

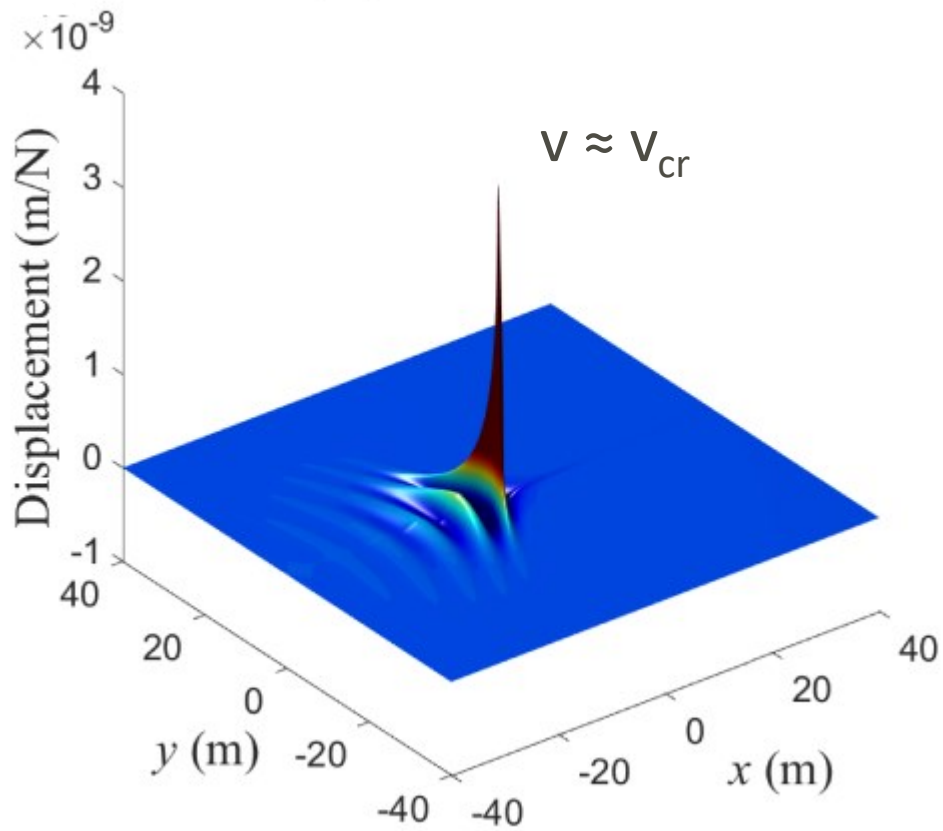
Moving harmonic load – stationary solution (in a moving frame of reference)



Green's function (Semi-analytical solution)

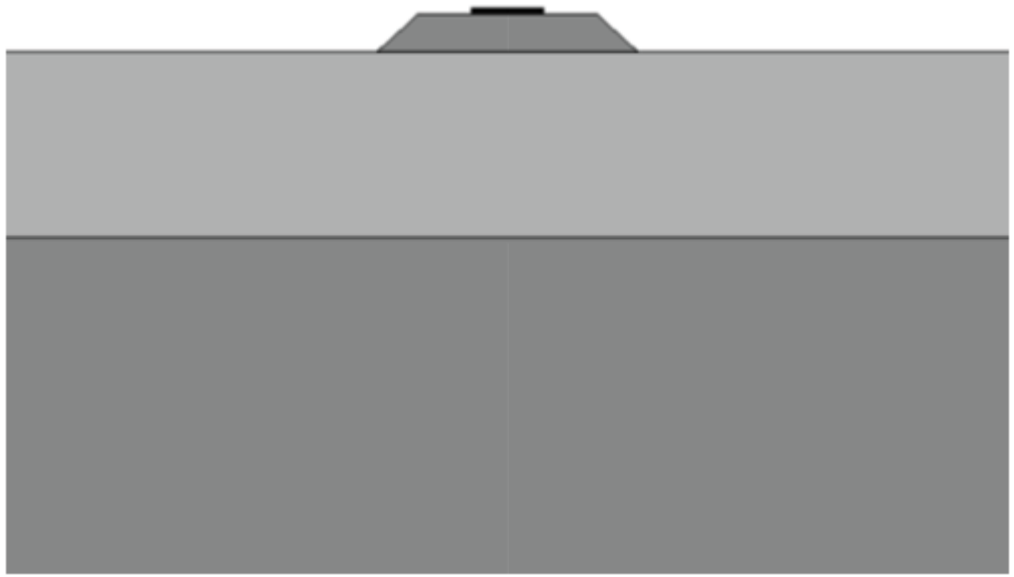
Moving quasi-static load

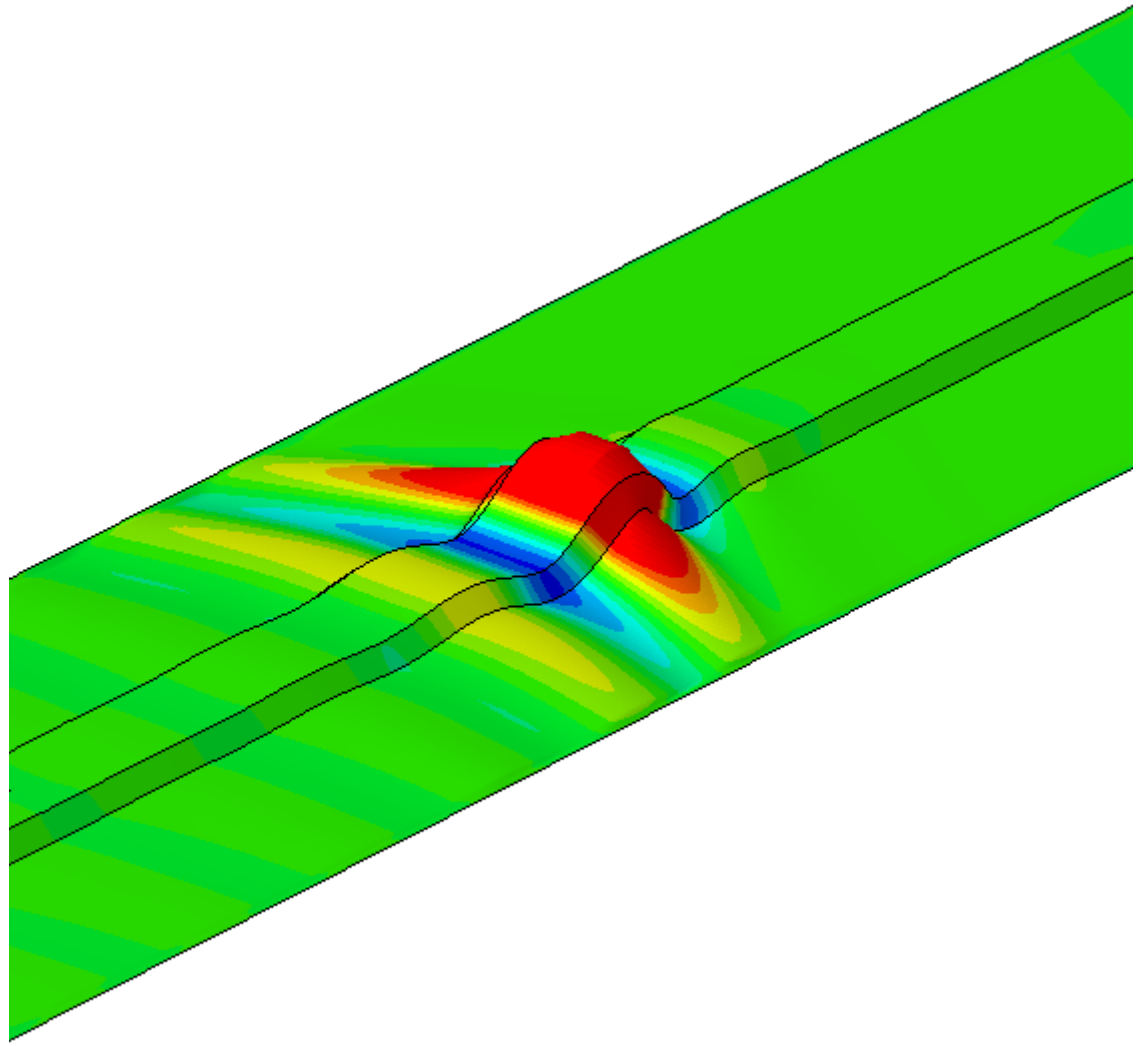




Critical speed and soil improvement (2.5D FEM)

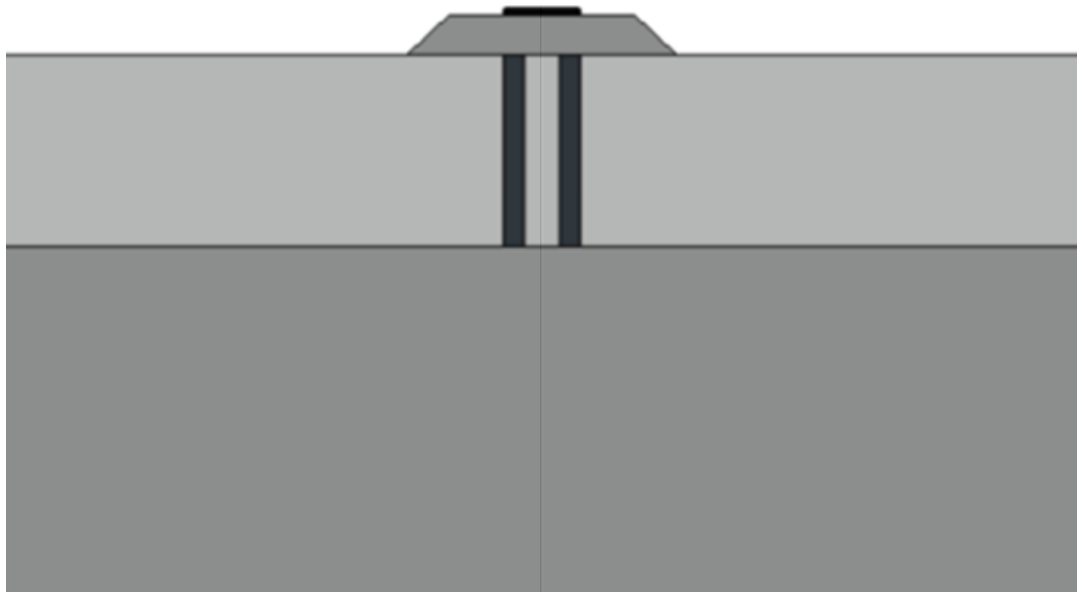
No soil improvement

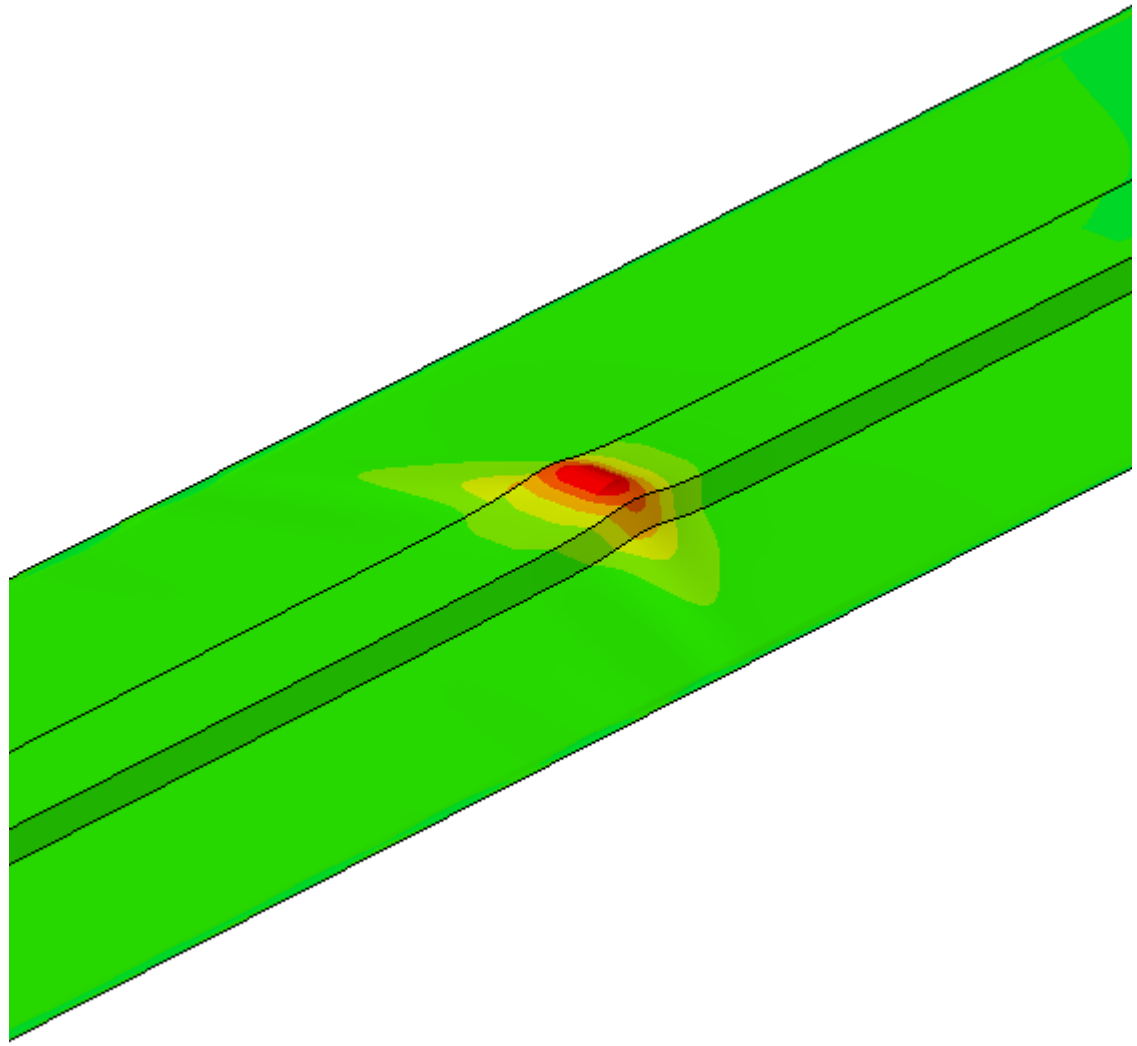




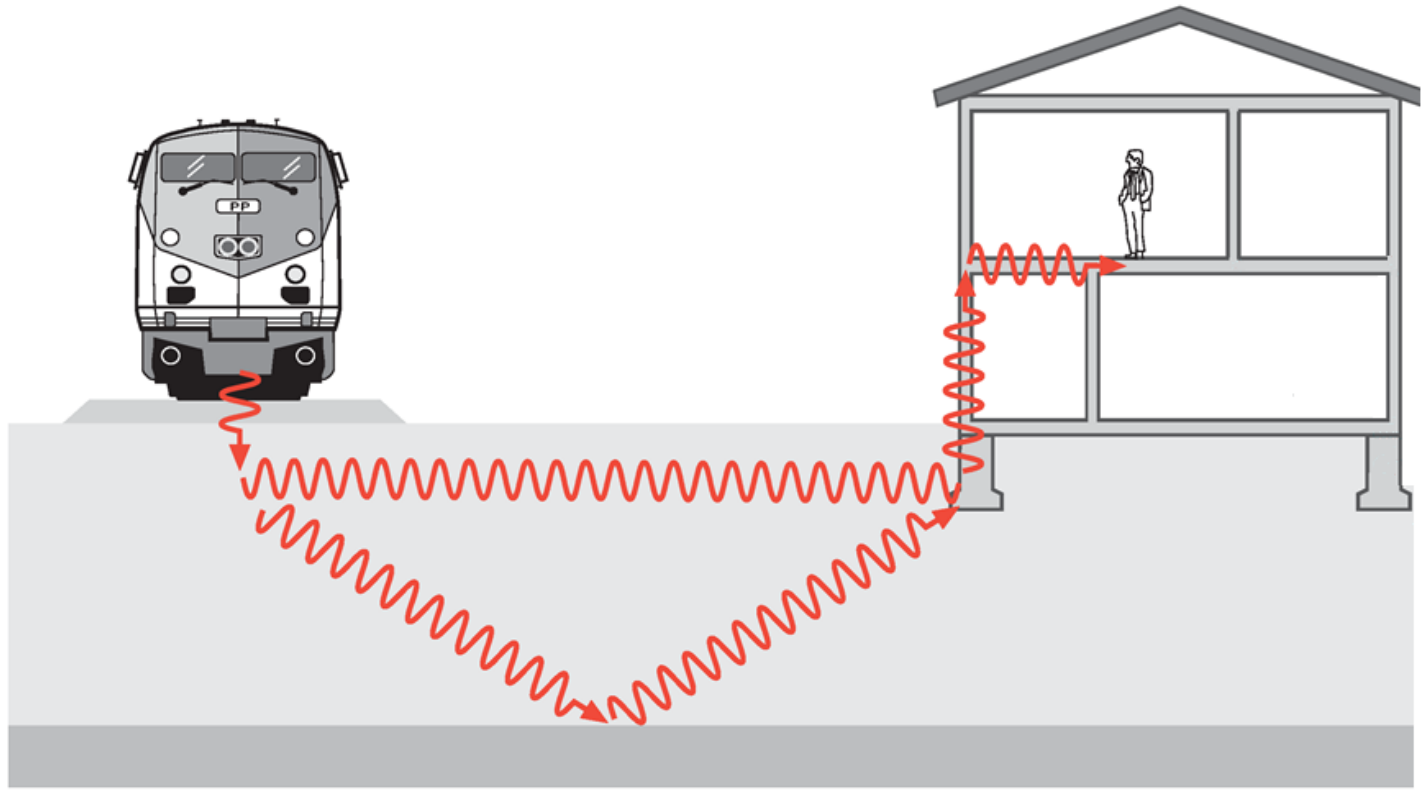
Critical speed and soil improvement (2.5D FEM)

Soil improvement: 2 panels



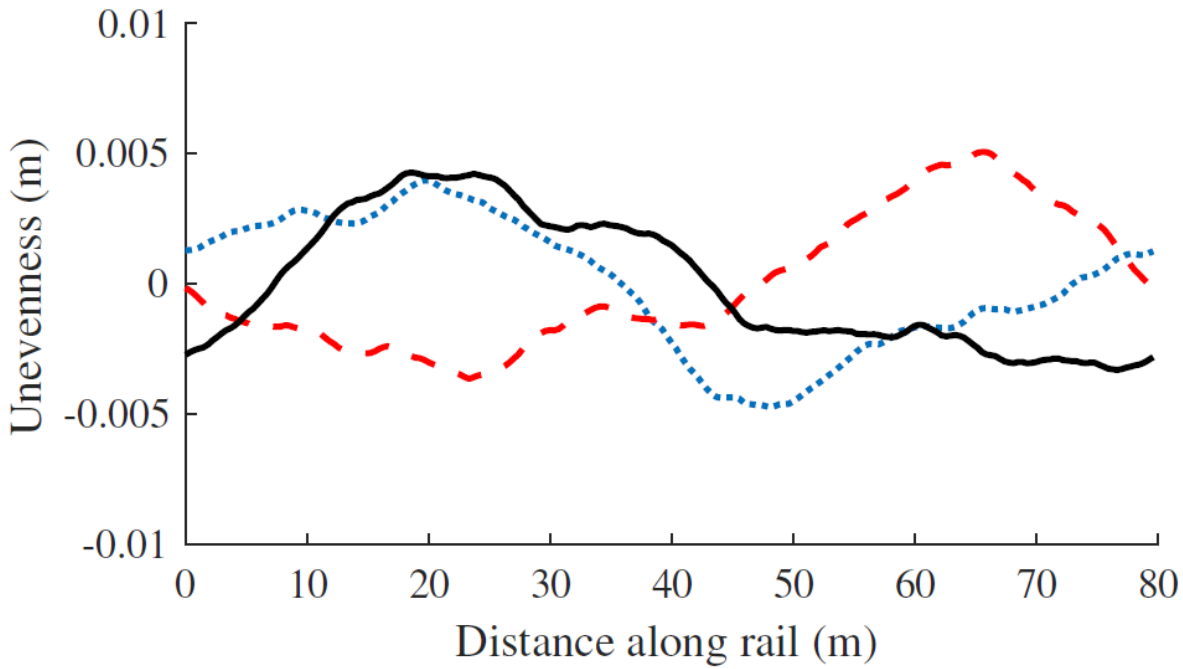


Track, soil and building

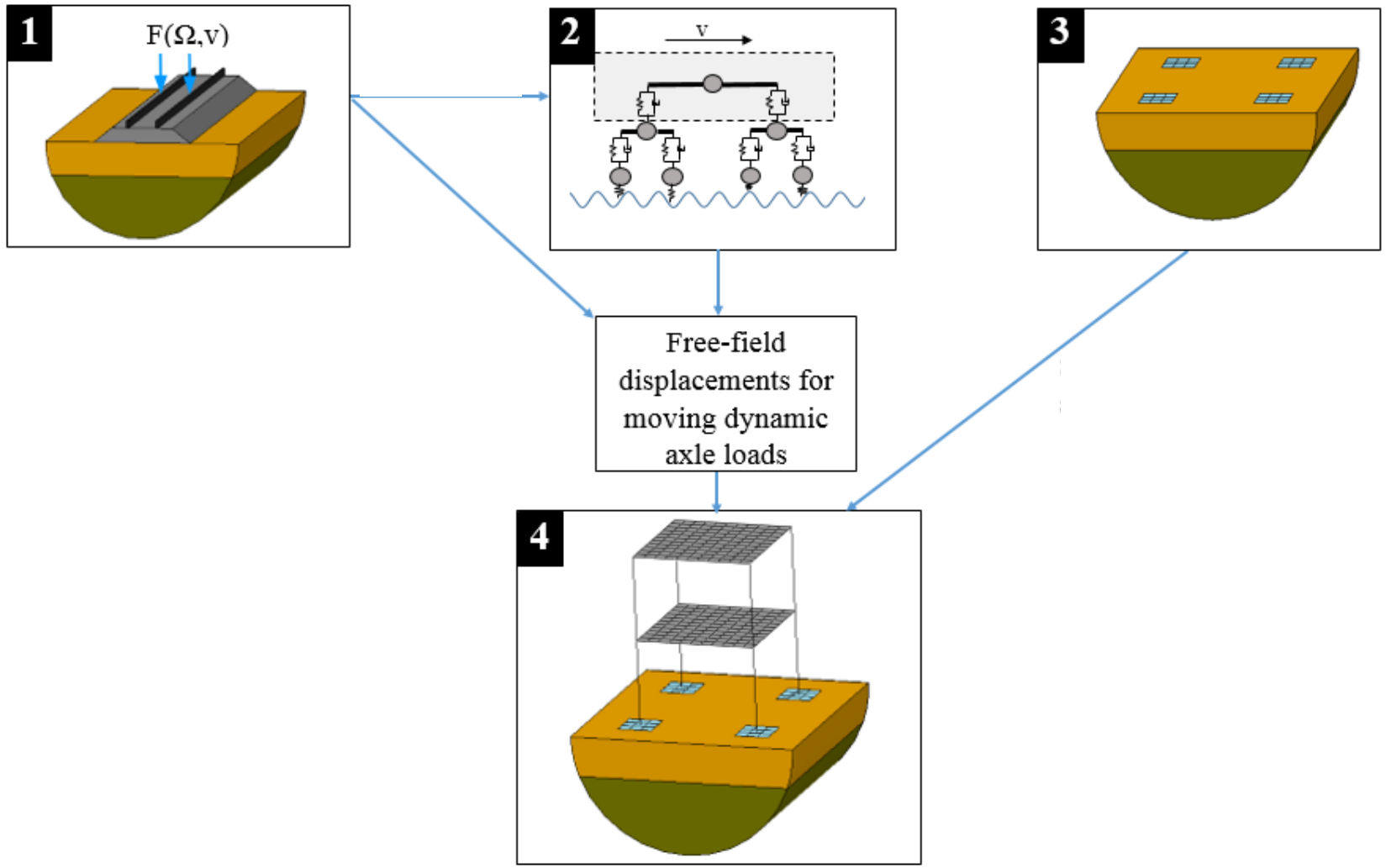


Vibrations in nearby building

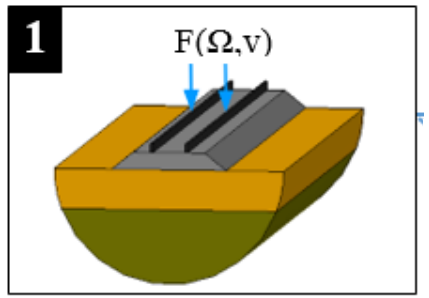
- Synthesized rail profile
- Unevenness composed of discrete wavelength components

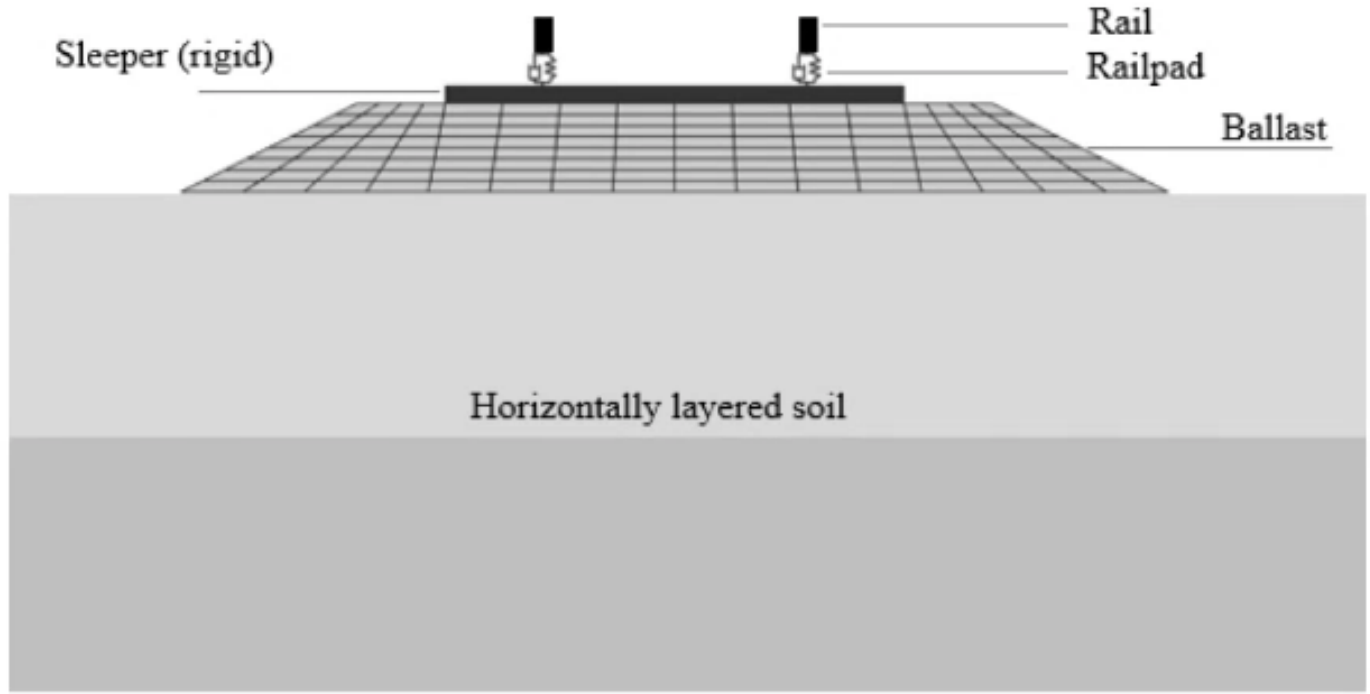


Vibrations in nearby building



Vibrations in nearby building



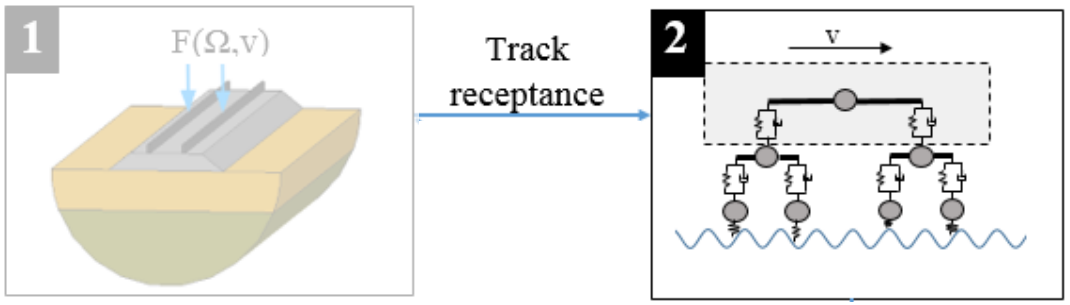


2.5D track/ground model

For frequencies 0-80 Hz:

- Calculate track and free-field ground displacements for a moving unit load

Vibrations in nearby building

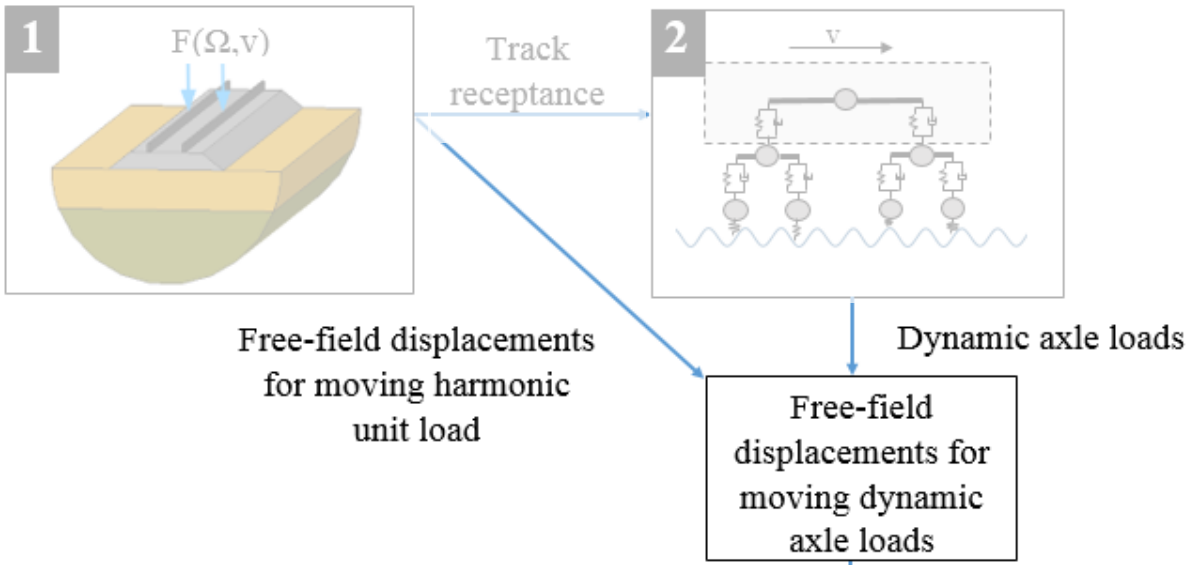


Vehicle model on track dynamic stiffness

For frequencies 0-80 Hz:

- Frequency *f* corresponds to unevenness wavelength $\lambda = v/f$
- Calculate wheel—rail contact forces

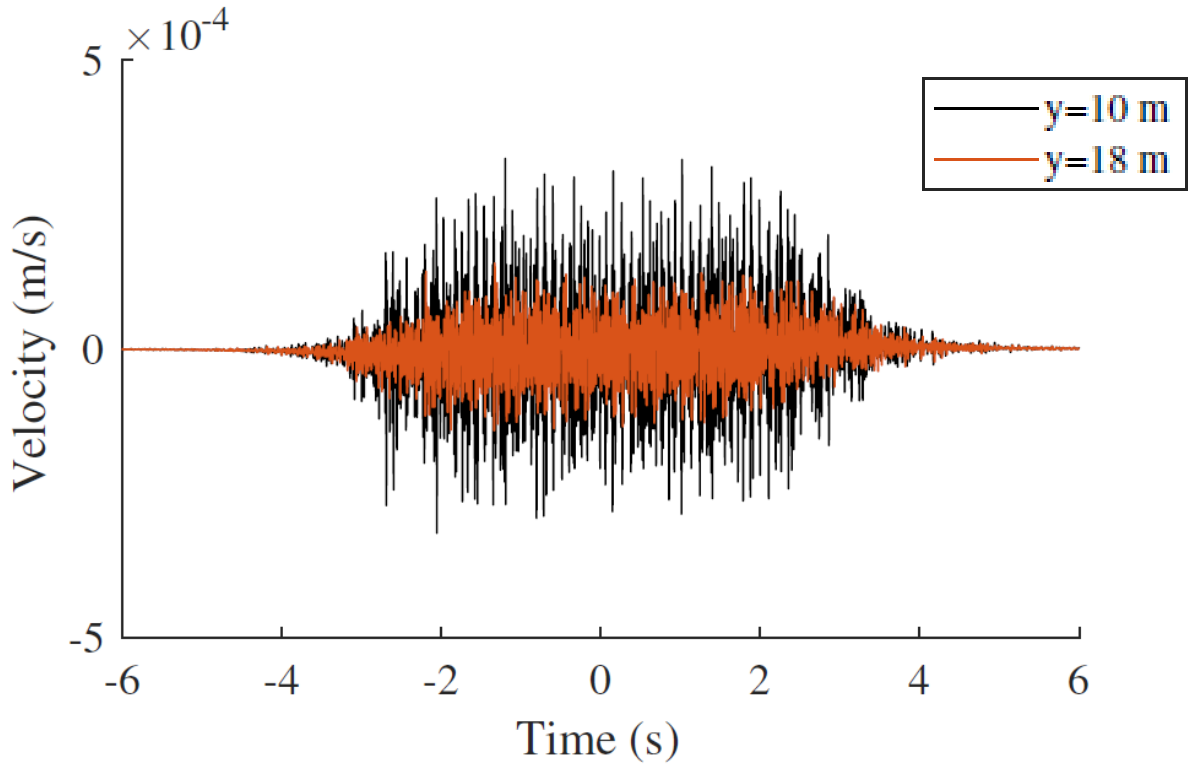
Vibrations in nearby building



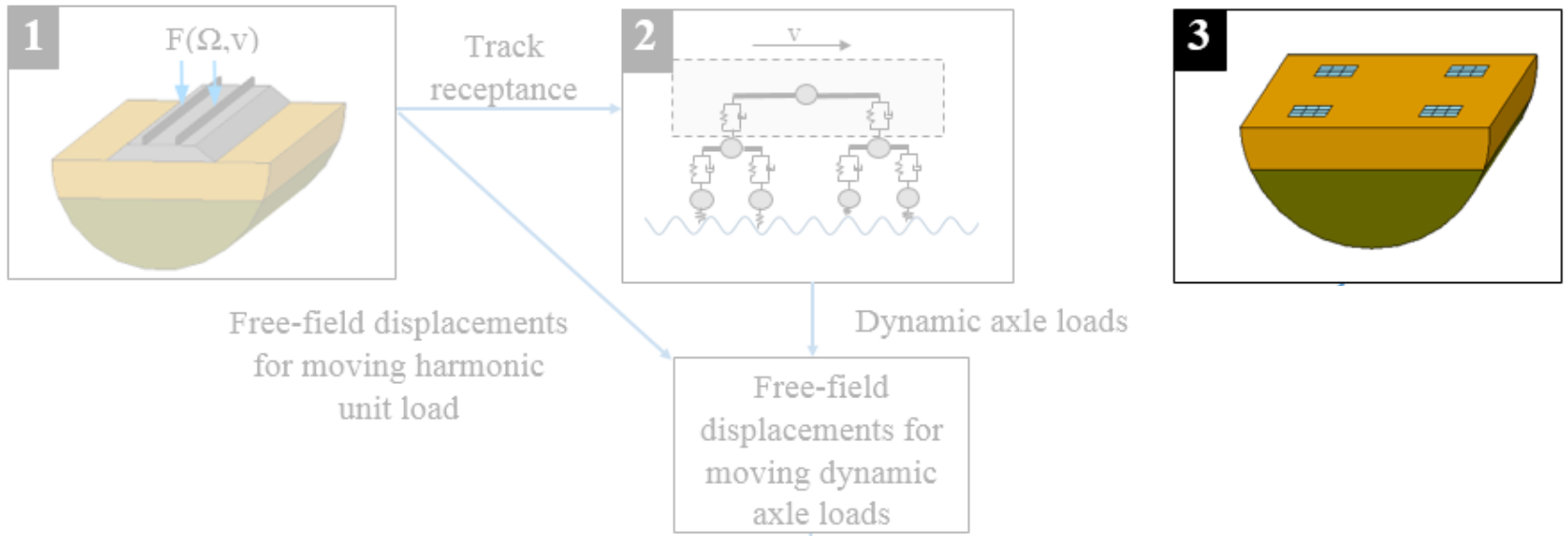
Unit load response (1) and dynamic axle loads (2) give the free-field response for the full train

Vibrations in nearby building

- Free-field ground response due to train running on uneven rail

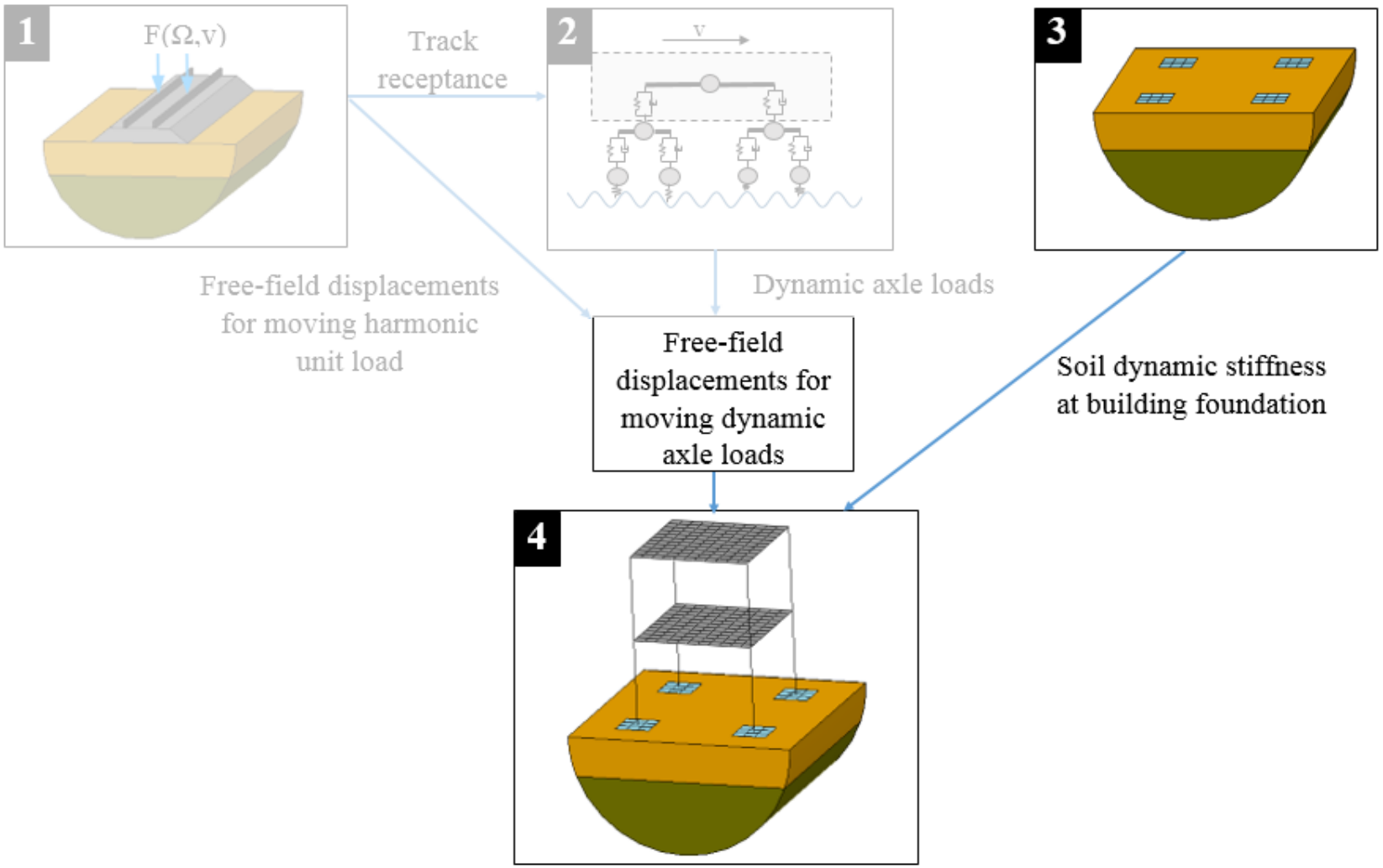


Vibrations in nearby building



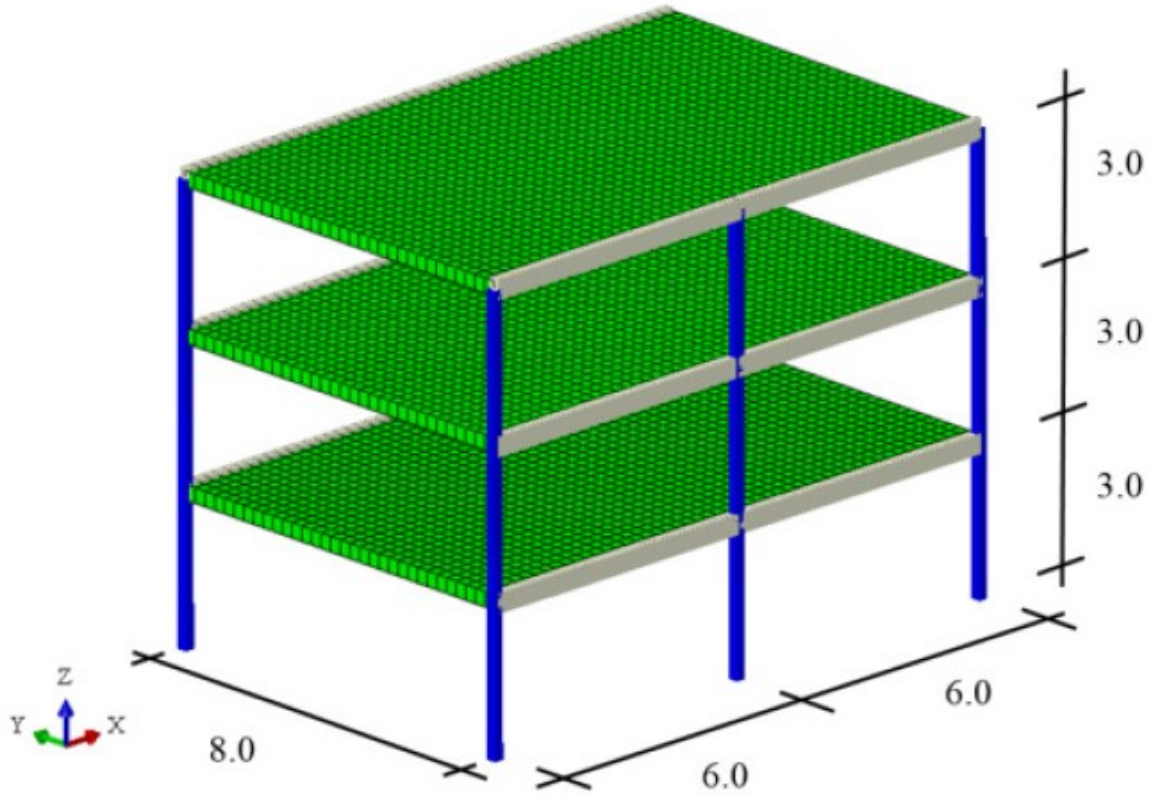
Obtain dynamic stiffness matrix of the soil at the soil–footing interface using boundary elements (Green's function for a layered half-space)

Vibrations in nearby building



Vibrations in nearby building

Free-field ground response to excite building structure

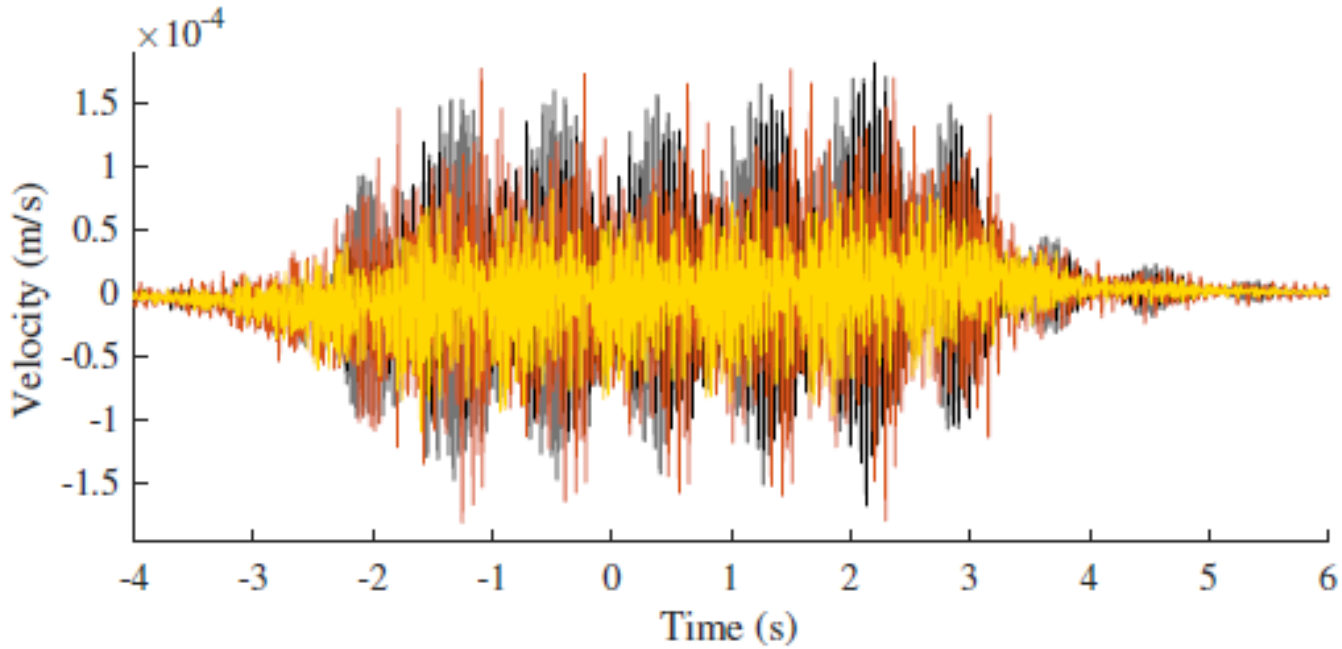


Substructure theorem[1)]

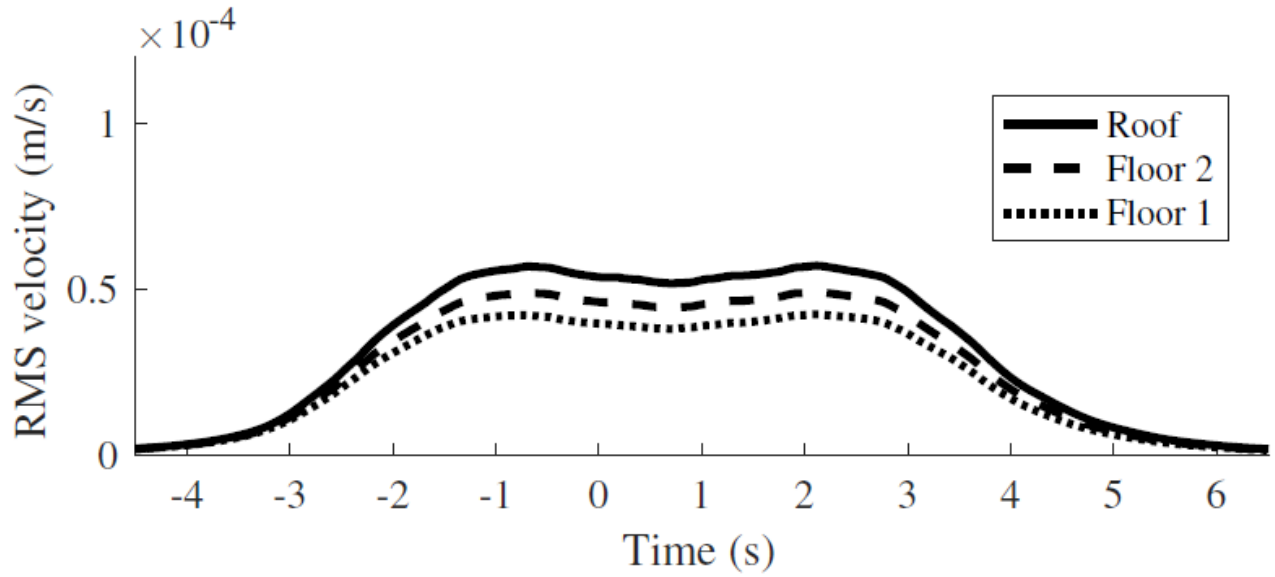
$$\begin{bmatrix} \mathbf{D}_{bb} & \mathbf{D}_{bi} \\ \mathbf{D}_{ib} & \mathbf{D}_{ii} + \mathbf{Z} \end{bmatrix} \begin{bmatrix} \mathbf{u}_b \\ \mathbf{u}_i \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{Z}\mathbf{u}_i^* + \mathbf{p}_i^* \end{bmatrix}$$

1): E. Kausel, R.V. Whitman, J.P. Morray, F. Elsabee, The spring method for embedded foundations. NuclearEngineering and Design, 48(2-3). 377–392,1972

Vibrations in nearby building



Vibrations in nearby building



Closing remarks

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Sub-structure approach to predict building vibrations

- 2.5D FEM/BEM model of track/ground
- Train – track contact forces due to rail unevenness
- BEM model of soil – footing interface
- FEM model of building
- Building vibrations due to incident wave field

Closing remarks

Conclusions, cont'd

Building vibrations:

- Lower than free-field ground response in studied case
- Increase for higher floors
- Increase for increasing train speeds
- Similar for wooden/concrete building with identical layouts
- Disregarding SSI results in over-estimated building response

Thank you for your attention

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