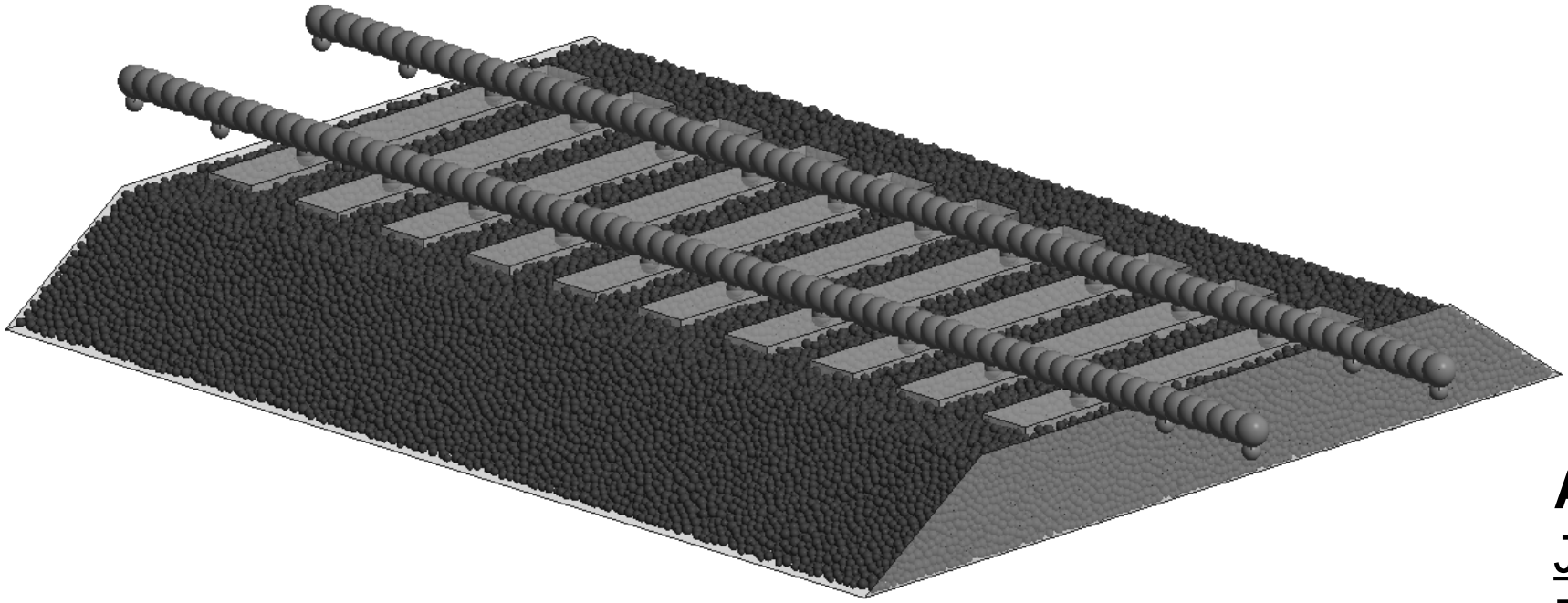
Evaluation of the performance of ballasted railway structures subjected to high-speed train loads by the Discrete Element Method

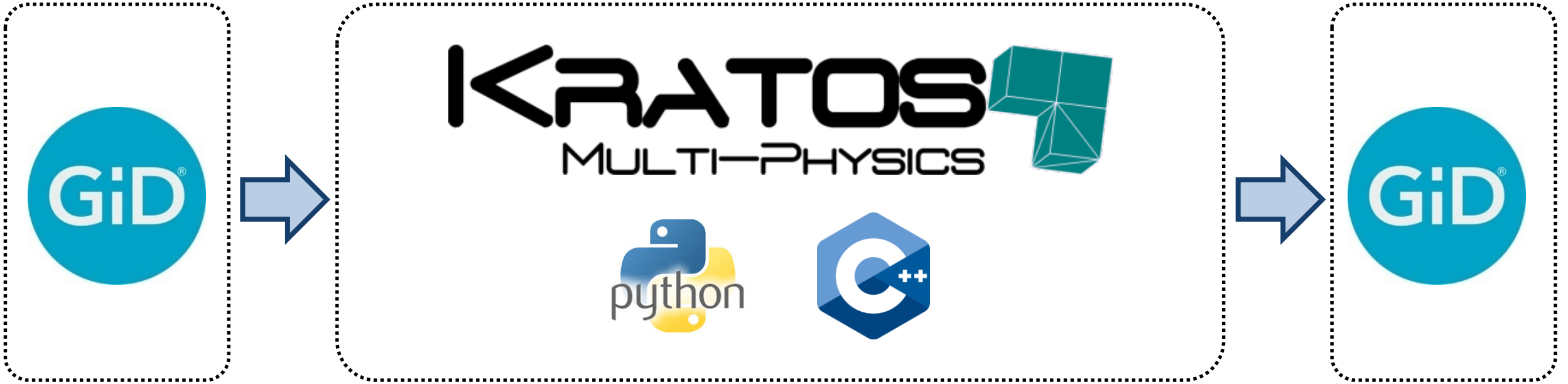


Authors:
Joaquín Irazábal
Fernando Salazar
Eugenio Oñate

Pre-process

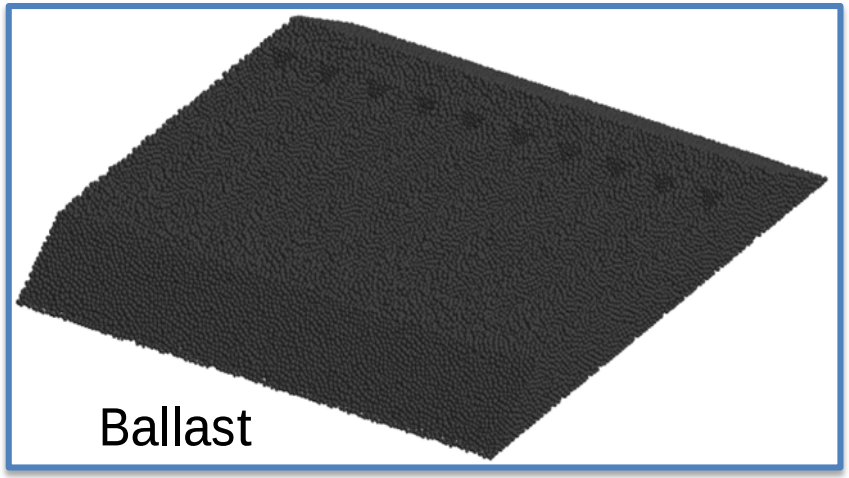
Numerical Calculation

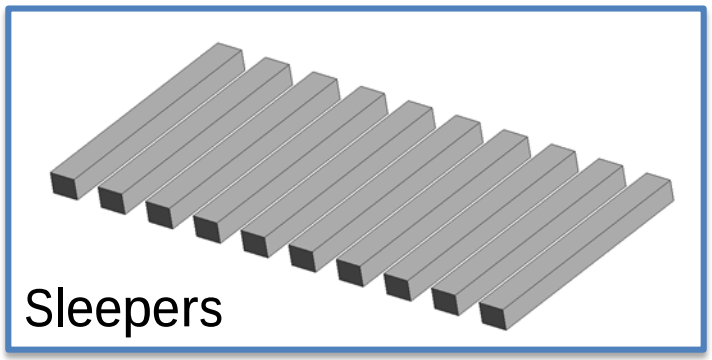
Post-process

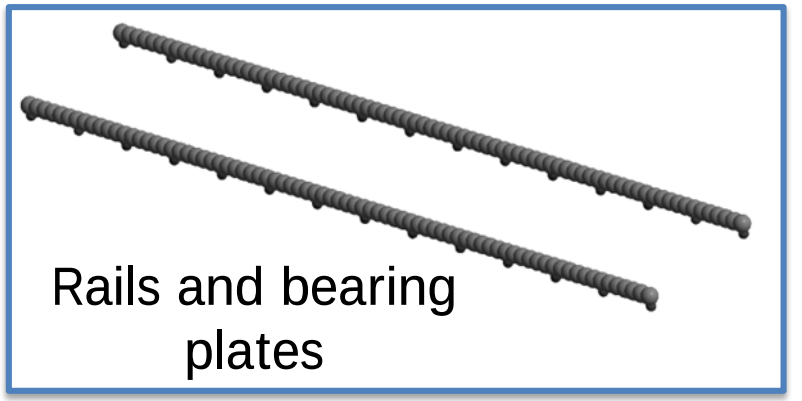


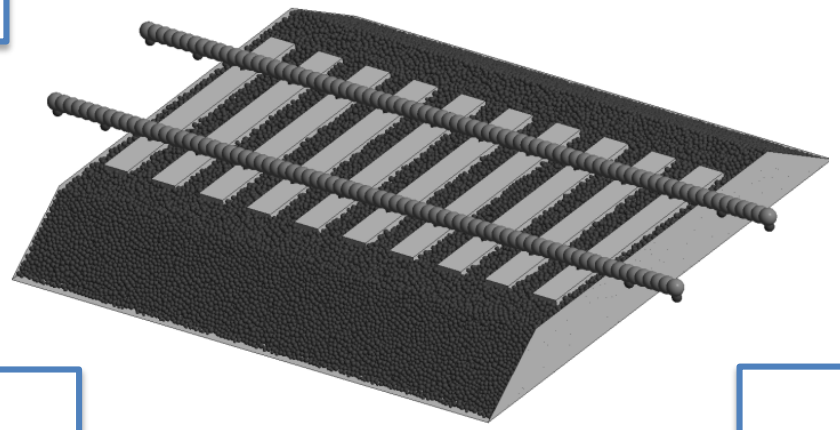
https://github.com/KratosMultiphysics/Kratos
http://gid.cimne.upc.es/

Motivation and Outline

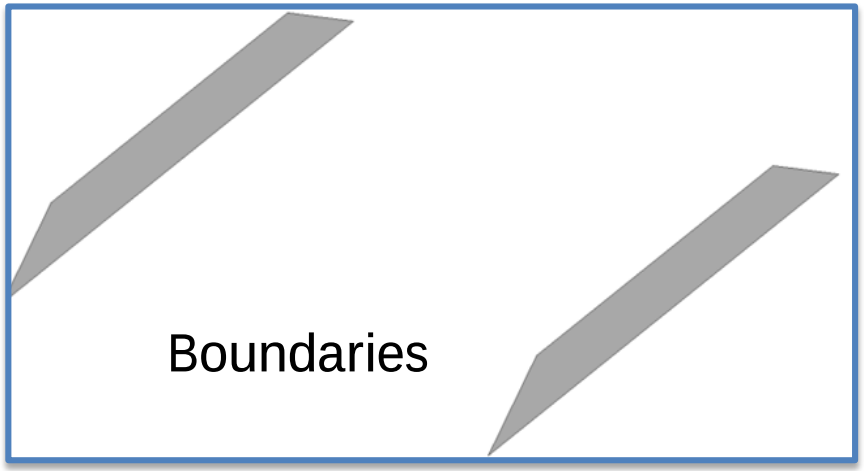


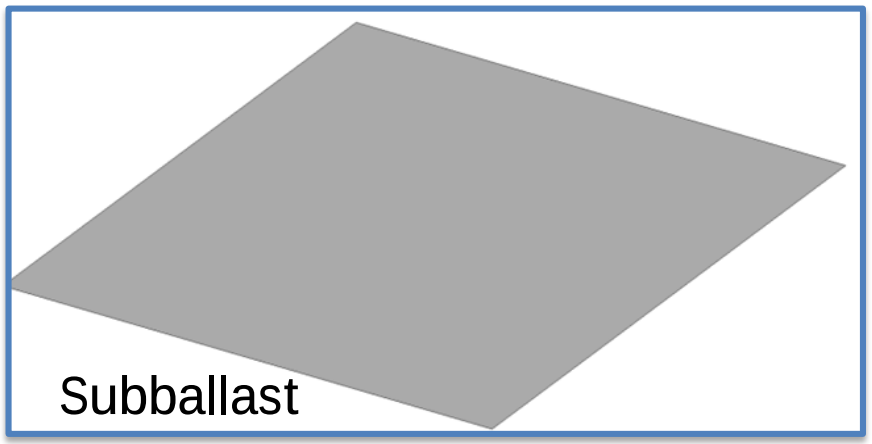




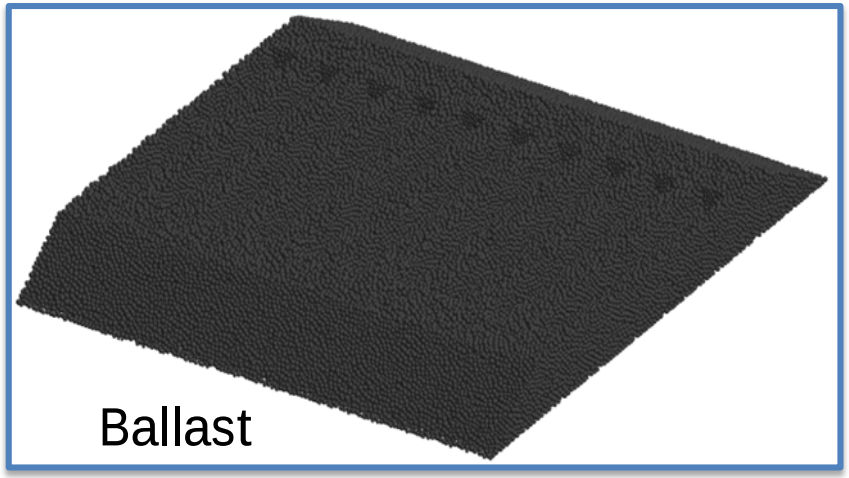


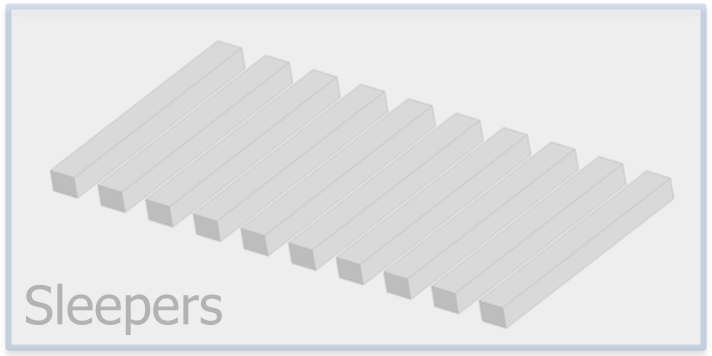
Full-scale test

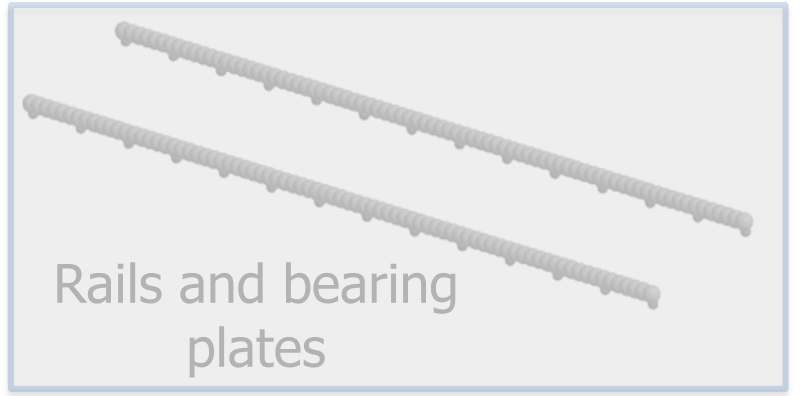


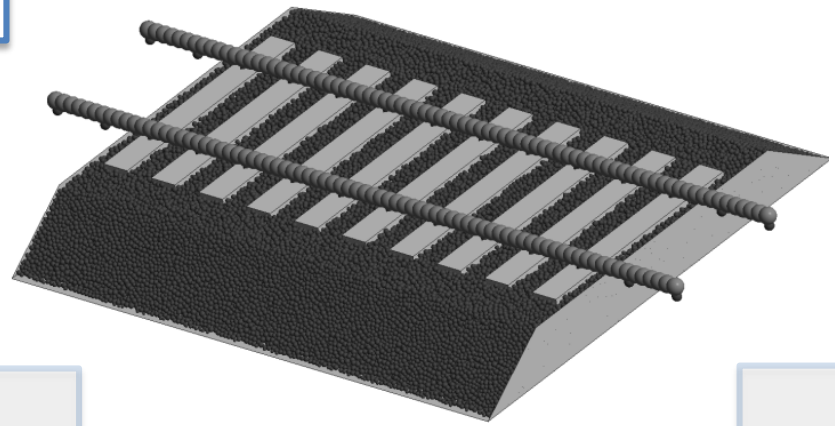


Ballast









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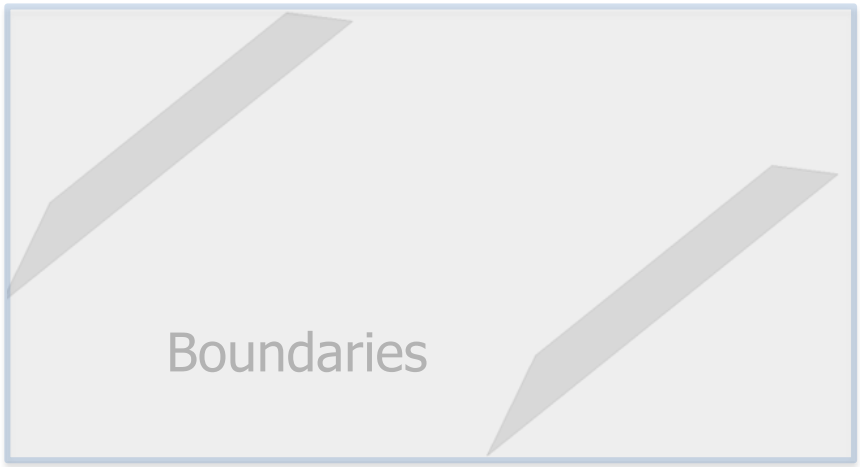
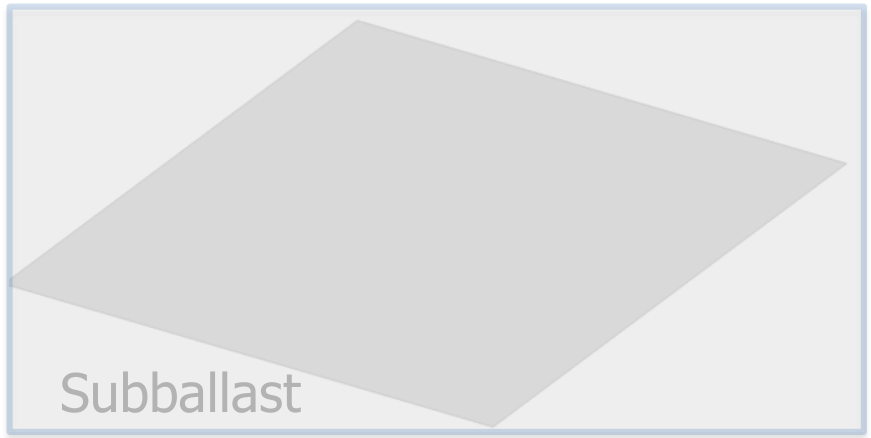
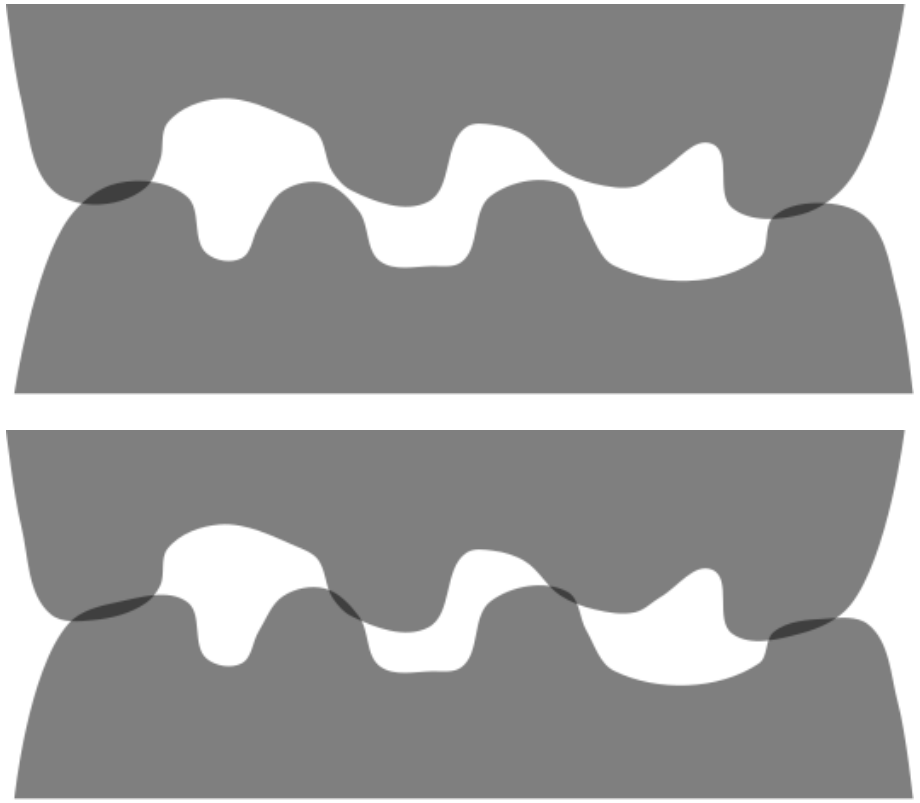


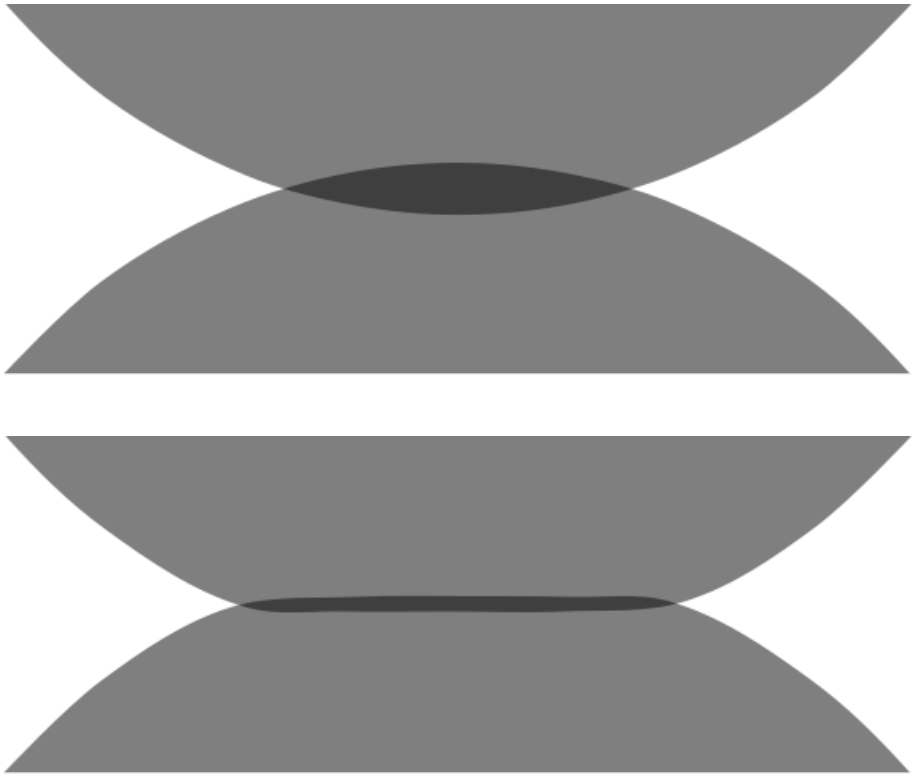


Particles geometry and contact model

- Simplest particle geometry: Spheres with rolling friction
- More sophisticated contact model than the Hertz one: Conical damage contact model



Real contact geometry



Numerical contact geometry

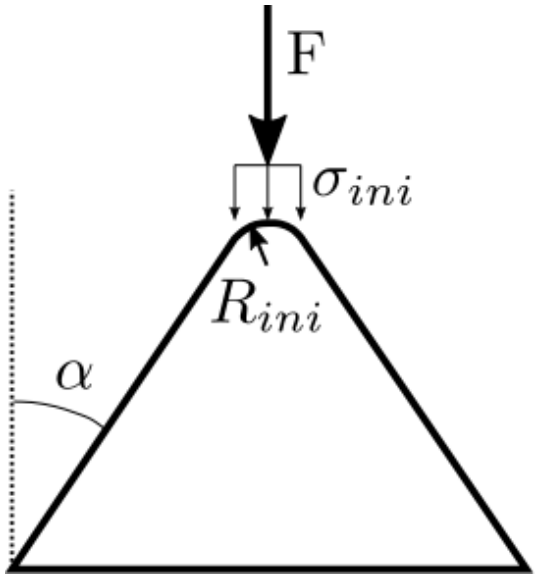
Harkness, J., Zervos, A., Le Pen, L., Aingaran, S., & Powrie, W. (2016). Discrete element simulation of railway ballast: modelling cell pressure effects in triaxial tests. Granular Matter, 18(3), 65.

Particles geometry and contact model

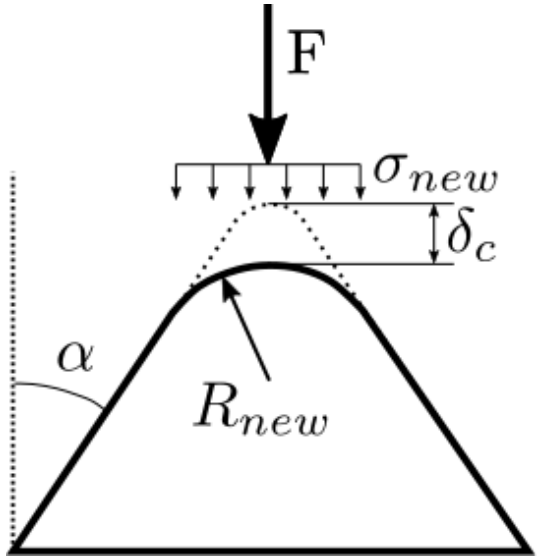
- Simplest particle geometry: Spheres with rolling friction
- More sophisticated contact model than the Hertz one: Conical damage contact model

  Accounts for edge breakage

  Two new material properties: Maximum stress and α



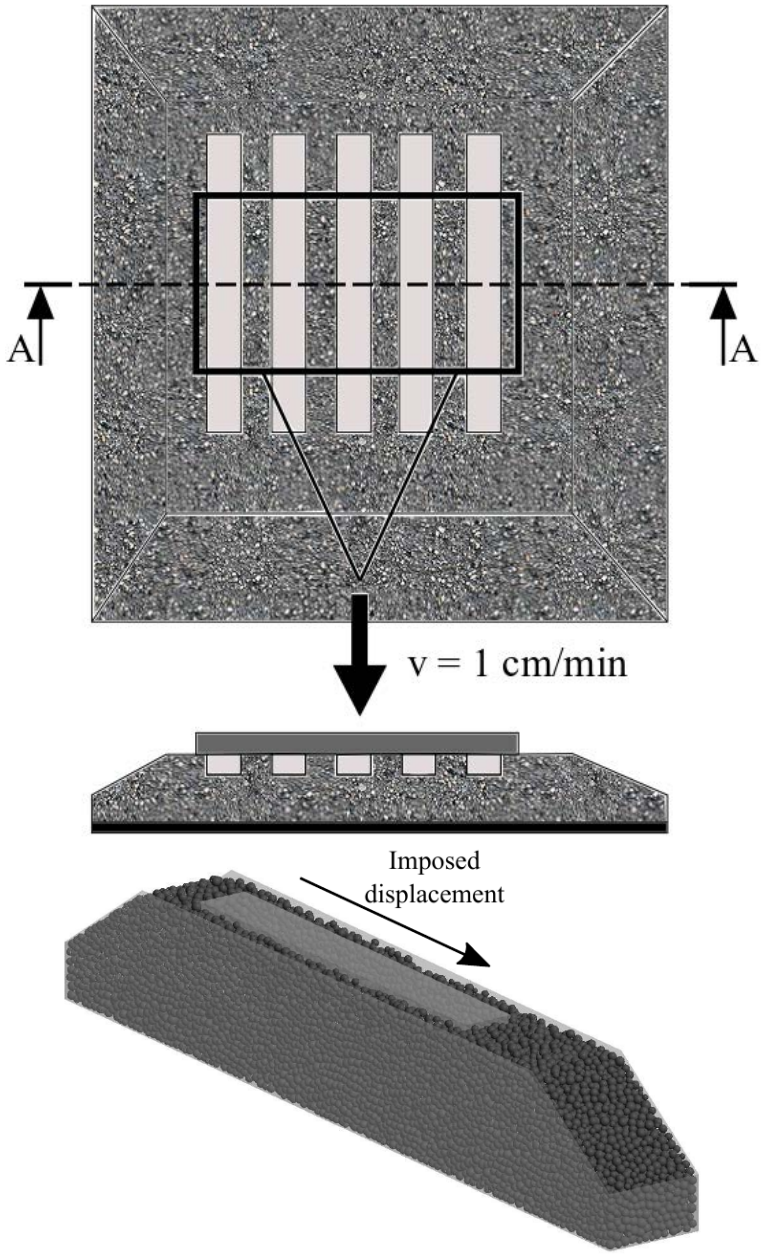
Initial radius

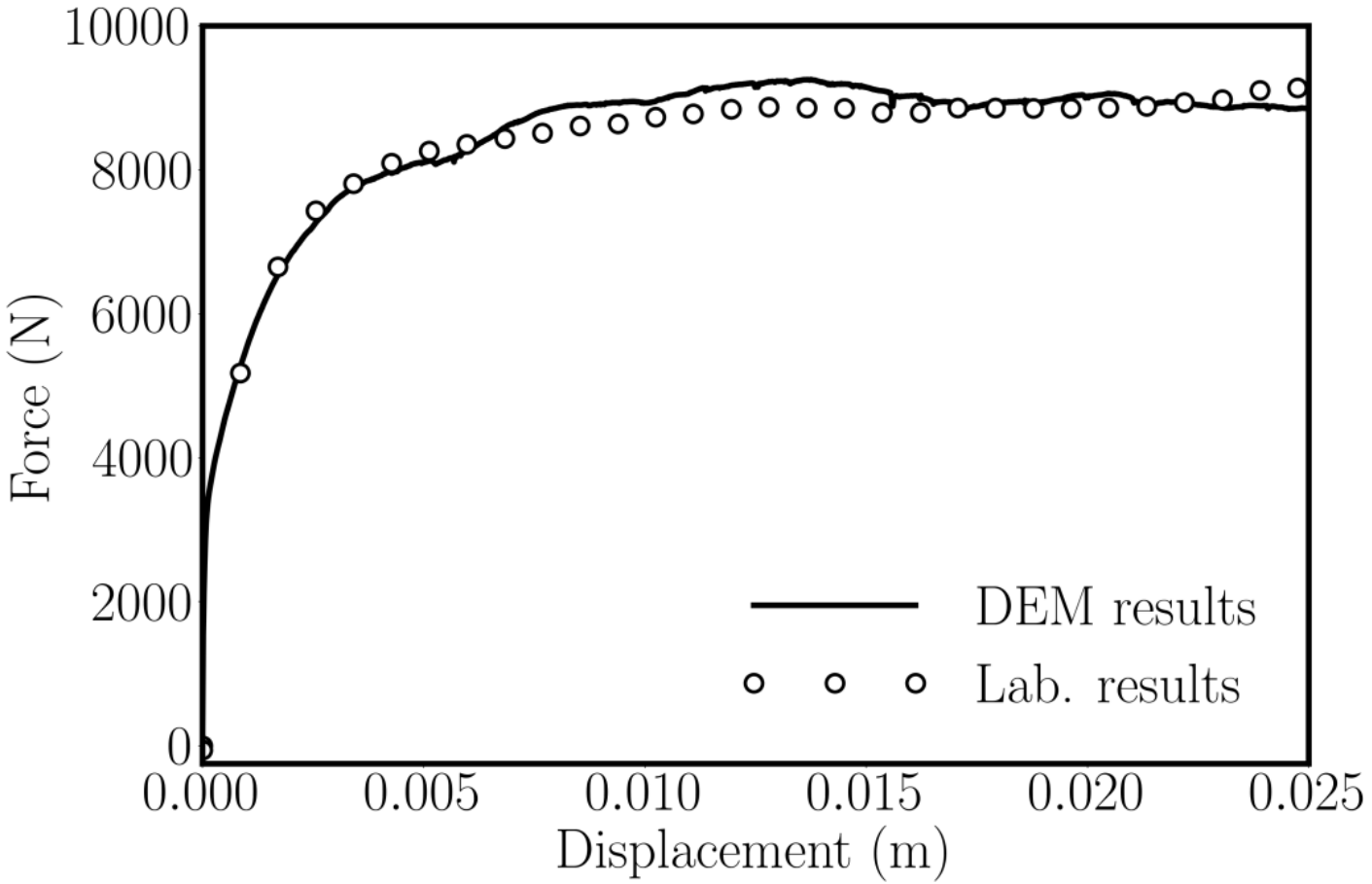


Final Radius and offset

Harkness, J., Zervos, A., Le Pen, L., Aingaran, S., & Powrie, W. (2016). Discrete element simulation of railway ballast: modelling cell pressure effects in triaxial tests. Granular Matter, 18(3), 65.

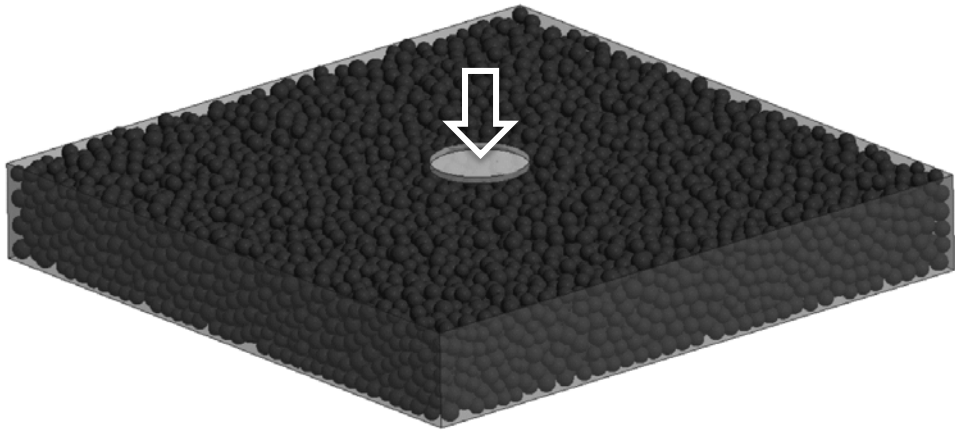
Previous calculations – Lateral resistance test

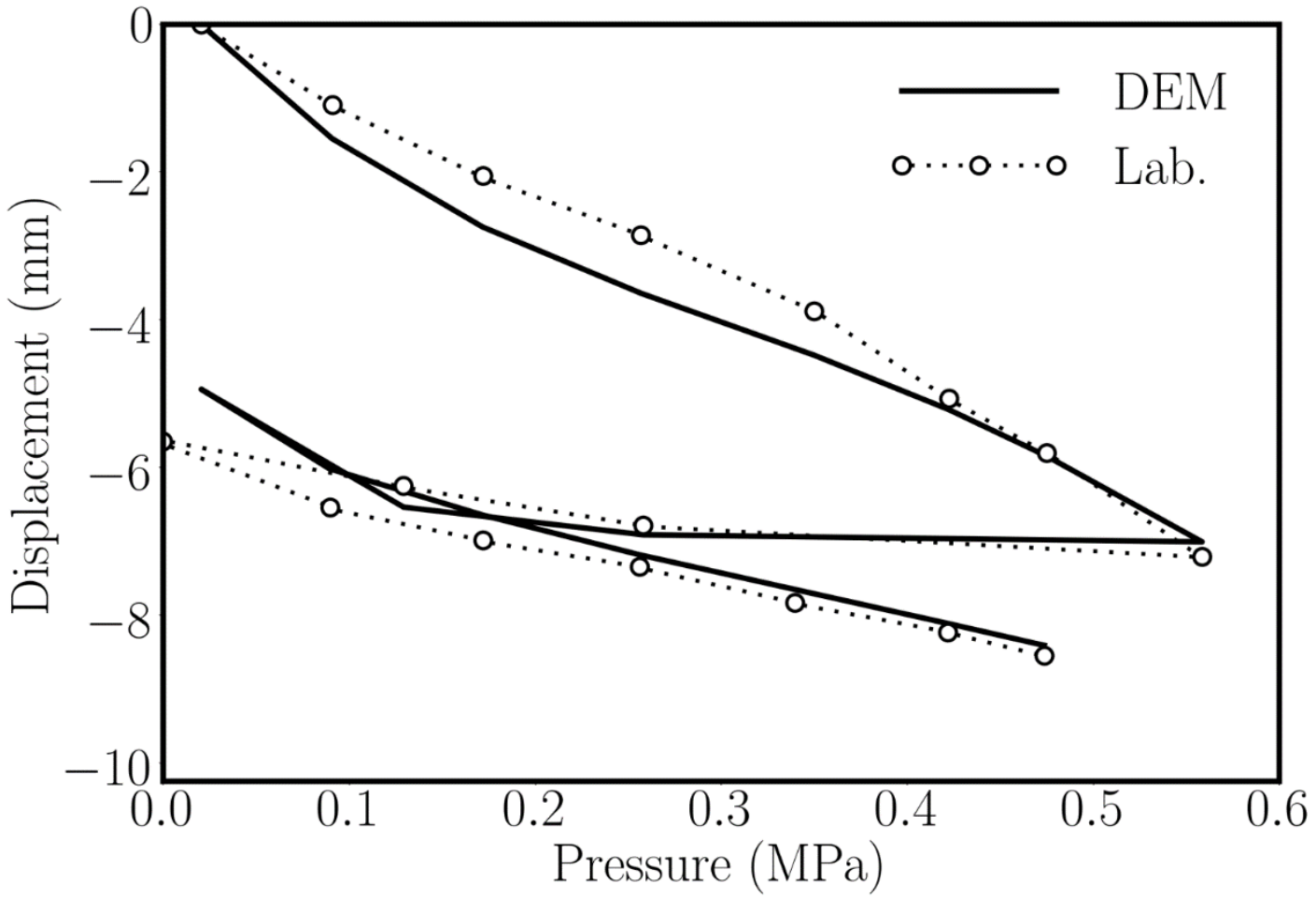




Good results with **spheres with rolling friction** and applying the **Conical Damage contact model**

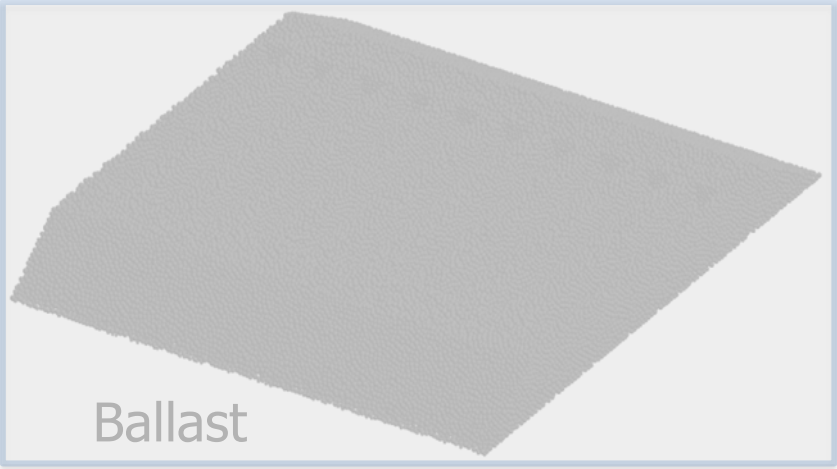
Previous calculations – Loading plate test

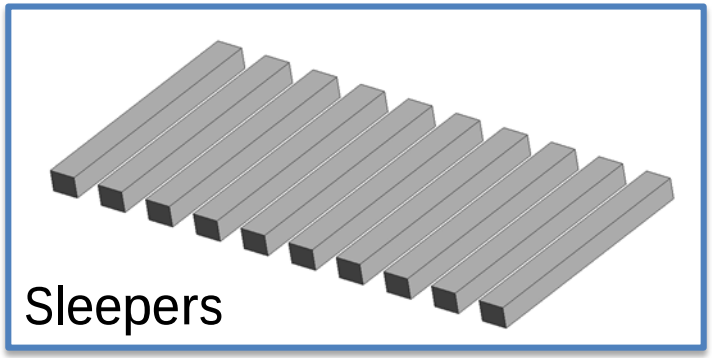


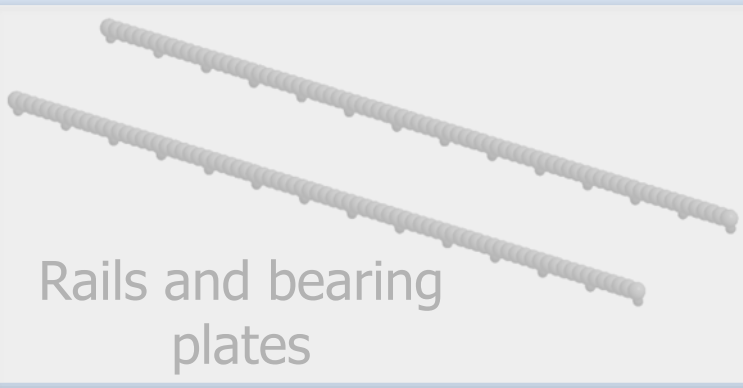


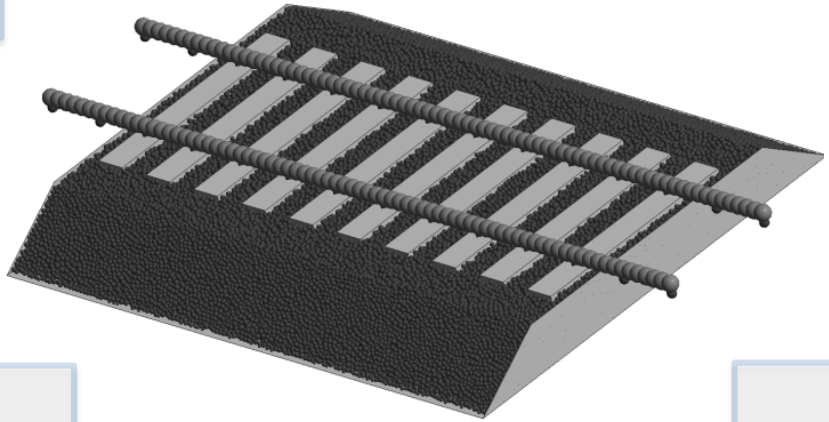
Good results with **spheres with rolling friction** and applying the **Conical Damage contact model**

Sleepers

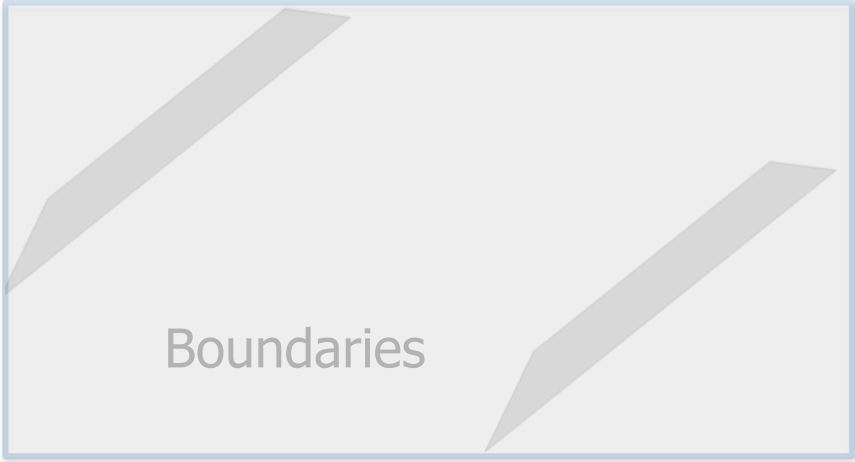


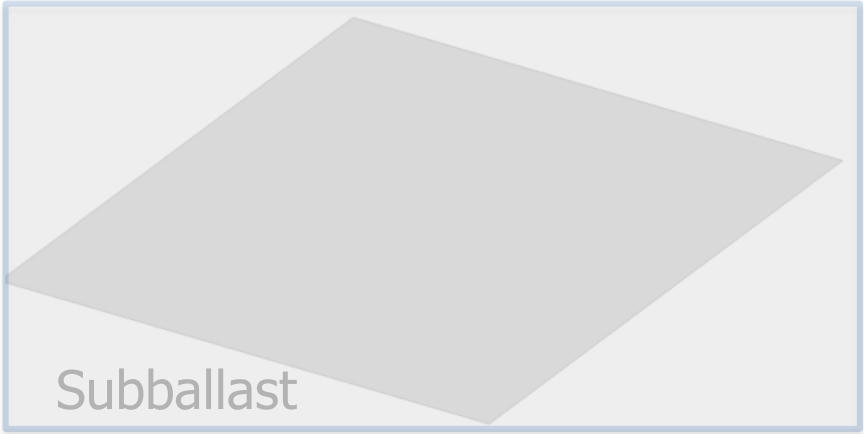


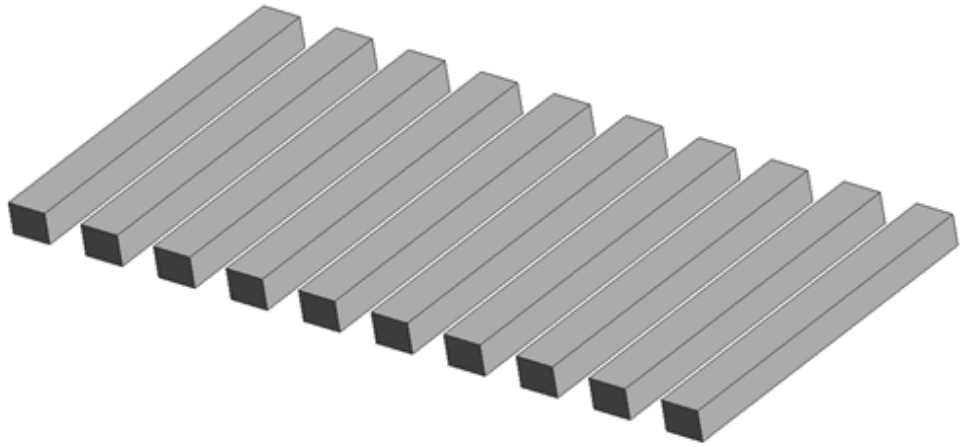




Full-scale test







Rigid bodies and simplified geometry

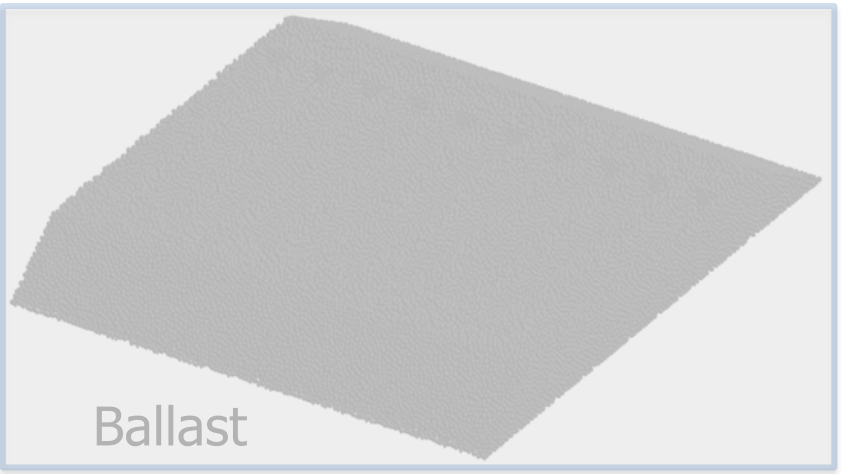
Sleepers contact parameters

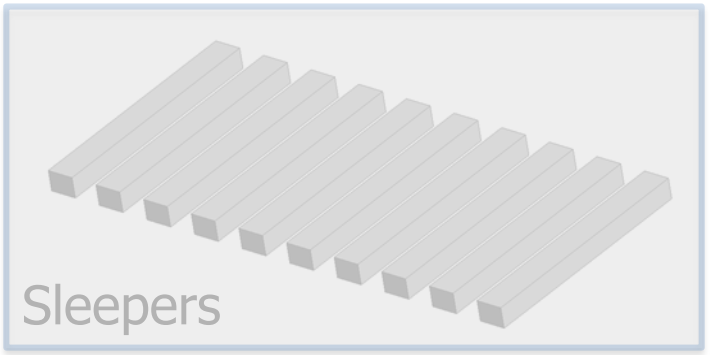
Young modulus = 30 Gpa (prestressed concrete)

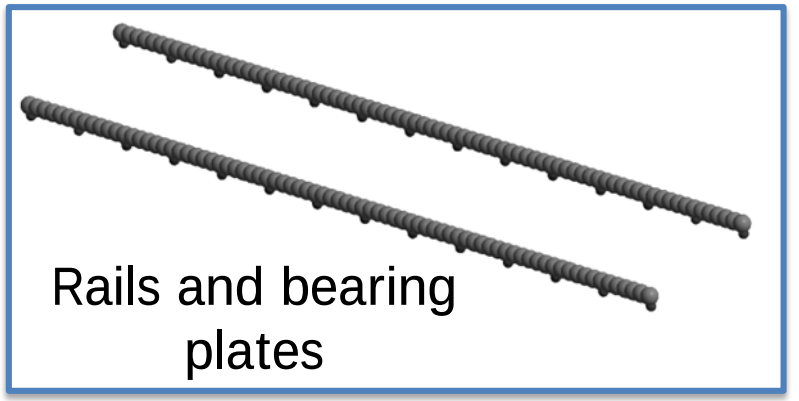
Friction coefficient = 0.7247*

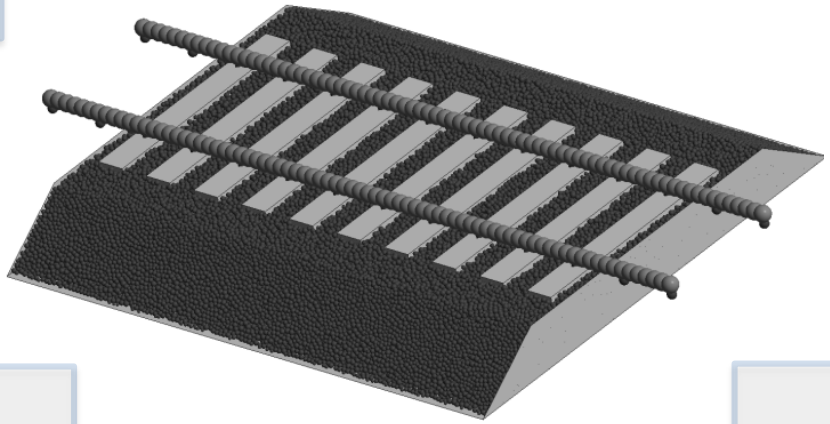
*Zand, J. van't, & Moraal, J. (1997) Roads and Railways Research Laboratory Technical University of Delft

Rails and bearing plates

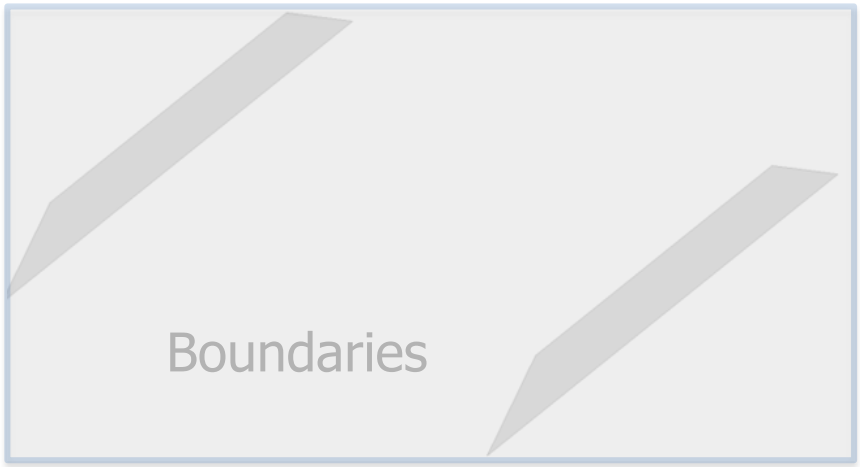


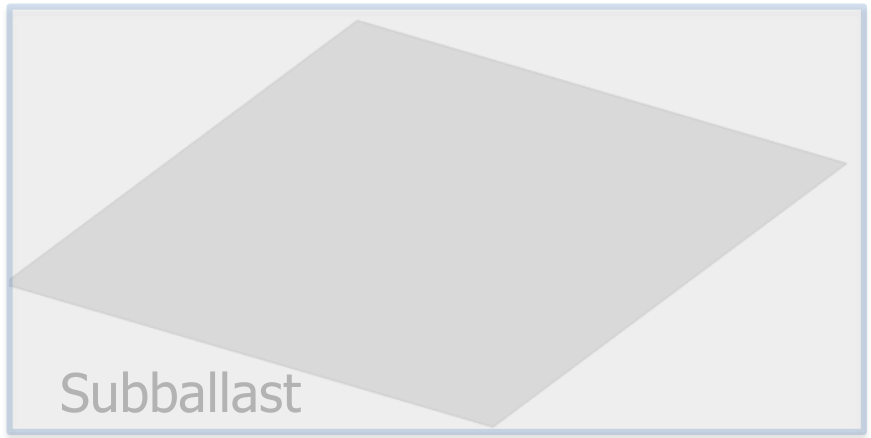




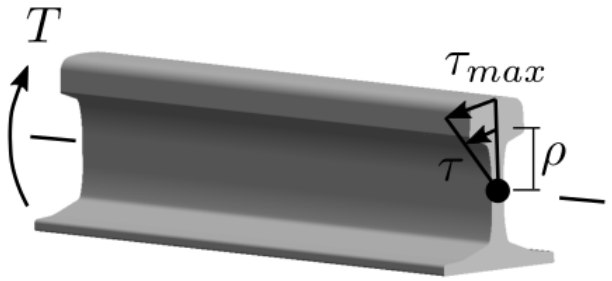


Full-scale test

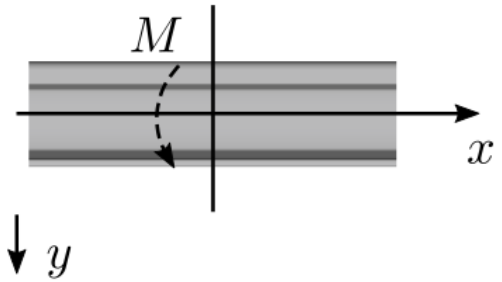




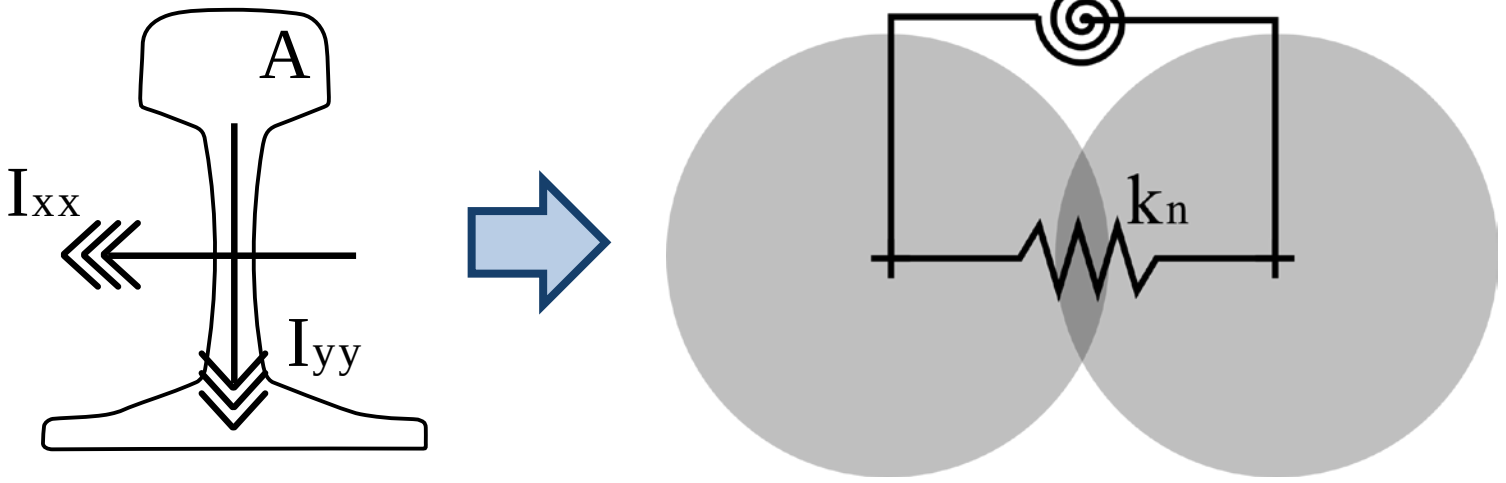
Axial loading: $\sigma_x = \frac{P}{A}$



Torsion: $\tau = \frac{T\rho}{J}$



Bending: $\sigma_x = -\frac{My}{I}$

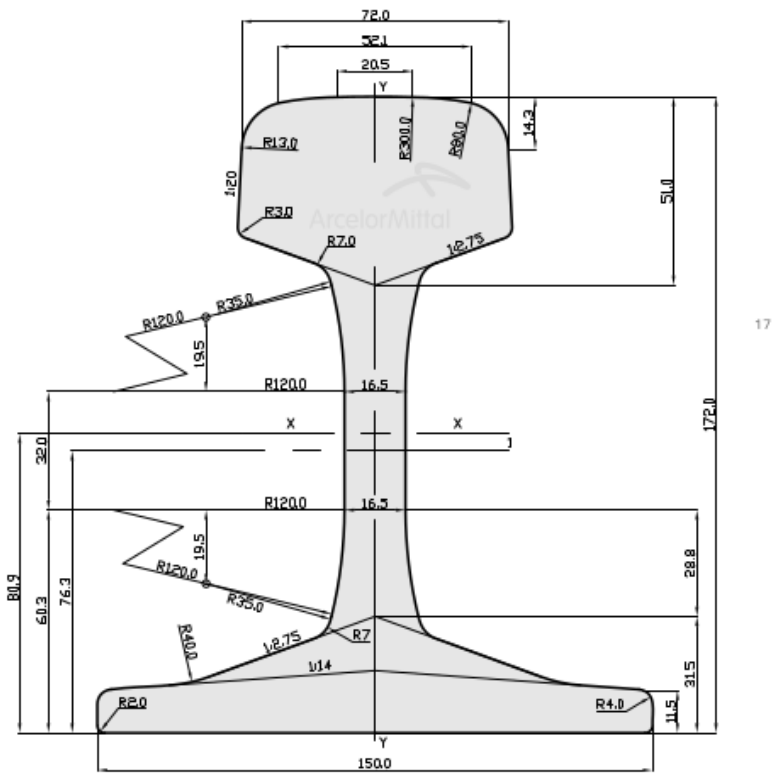


ArcelorMittal

Transport rail / Carril de transporte

European Standard / Norma Europea

60E1
(UIC60)

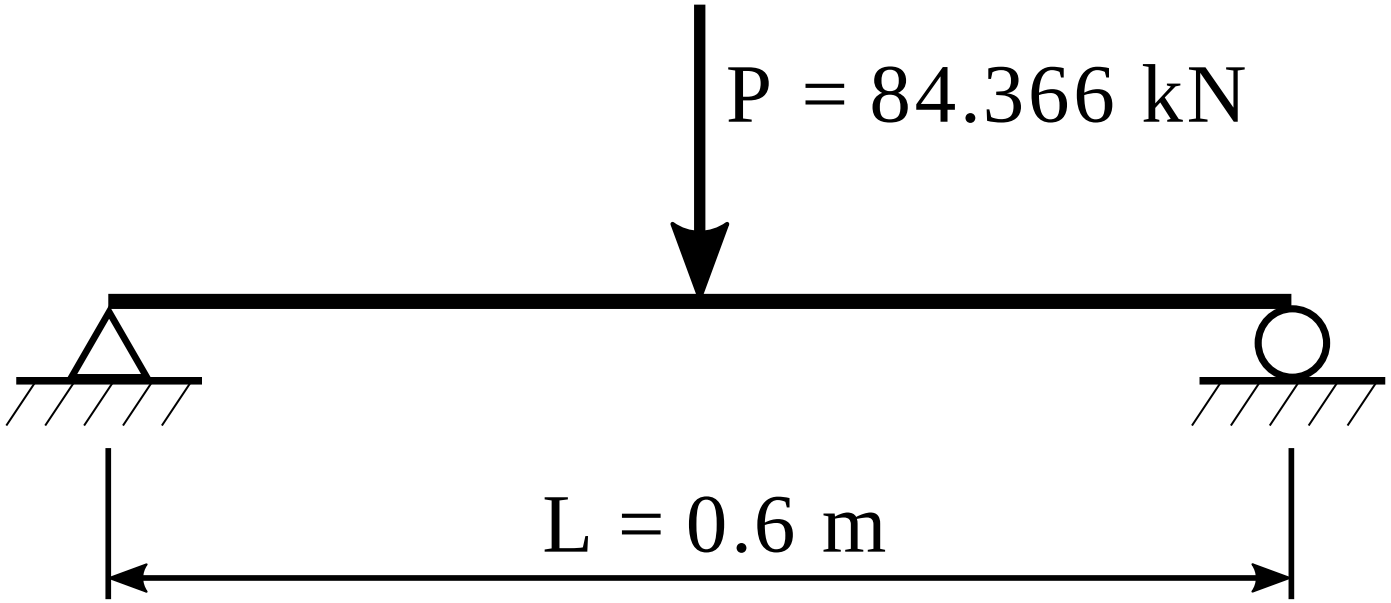


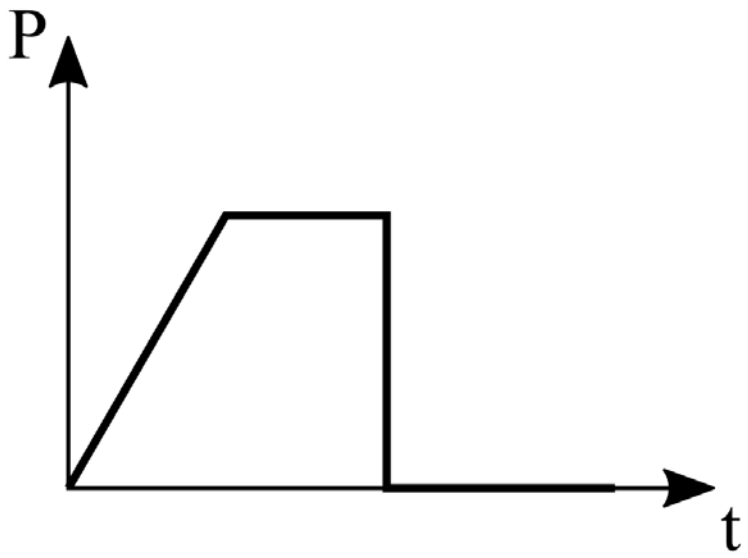
Mass / Masa		60,21 kg/m	Scale / Escala 1:1.2
Area / Área		76,70 cm²	
Moment of inertia / Momento de inercia	X-X	3038,3 cm⁴	
	Y-Y	512,3 cm⁴	
Section modulus / Módulo de sección	X-X Head / Cabeza	333,6 cm³	
	X-X Base / Pie	375,5 cm³	
	Y-Y Axis / Eje	68,3 cm³	

ArcelorMittal

60E1

Mass / Masa		60,21 kg/m
Area / Área		76,70 cm²
Moment of inertia / Momento de inercia	X-X	3038,3 cm⁴
	Y-Y	512,3 cm⁴

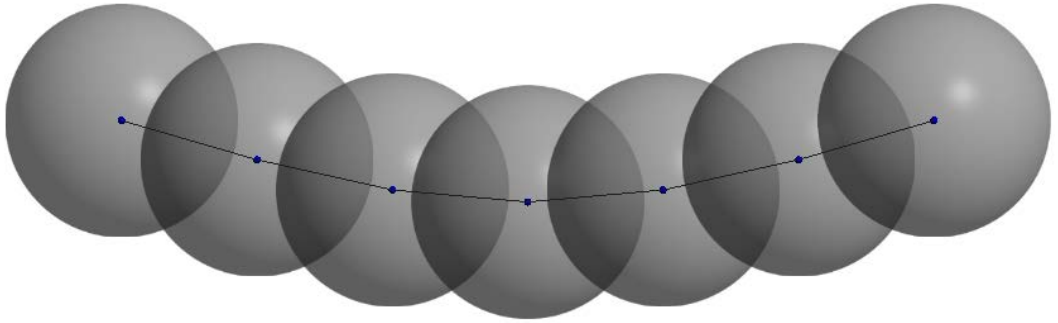


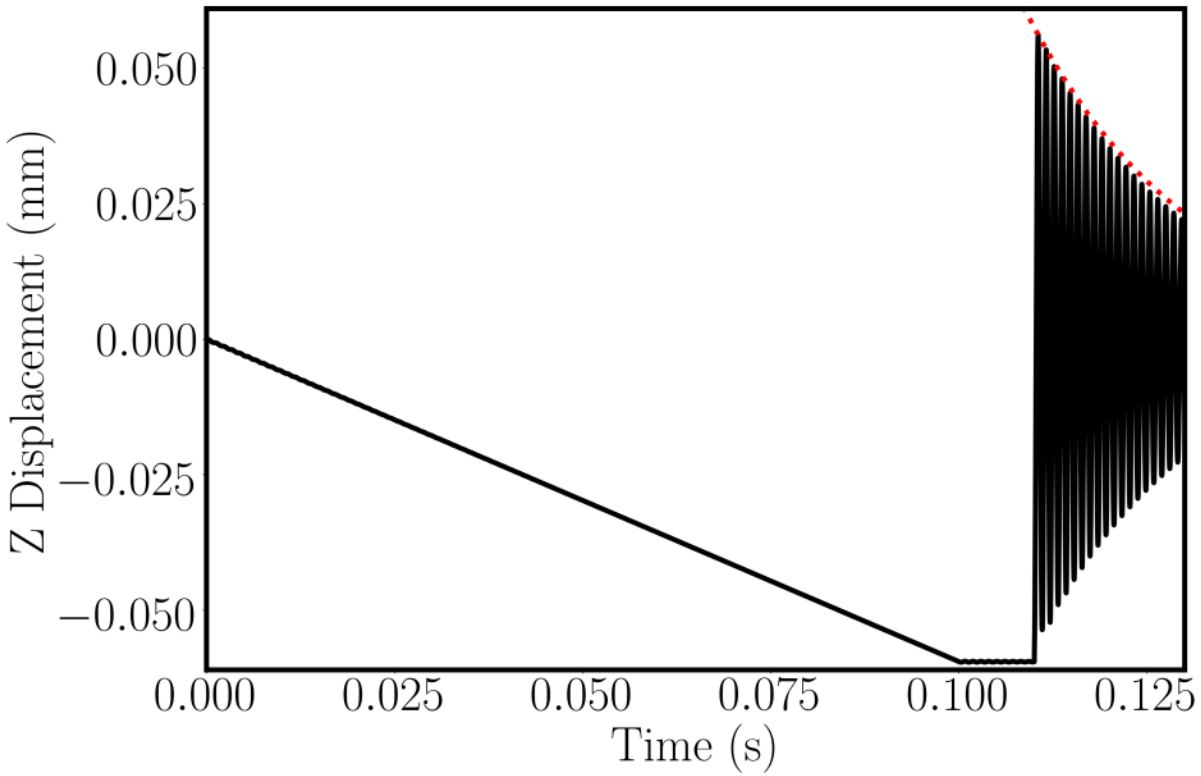


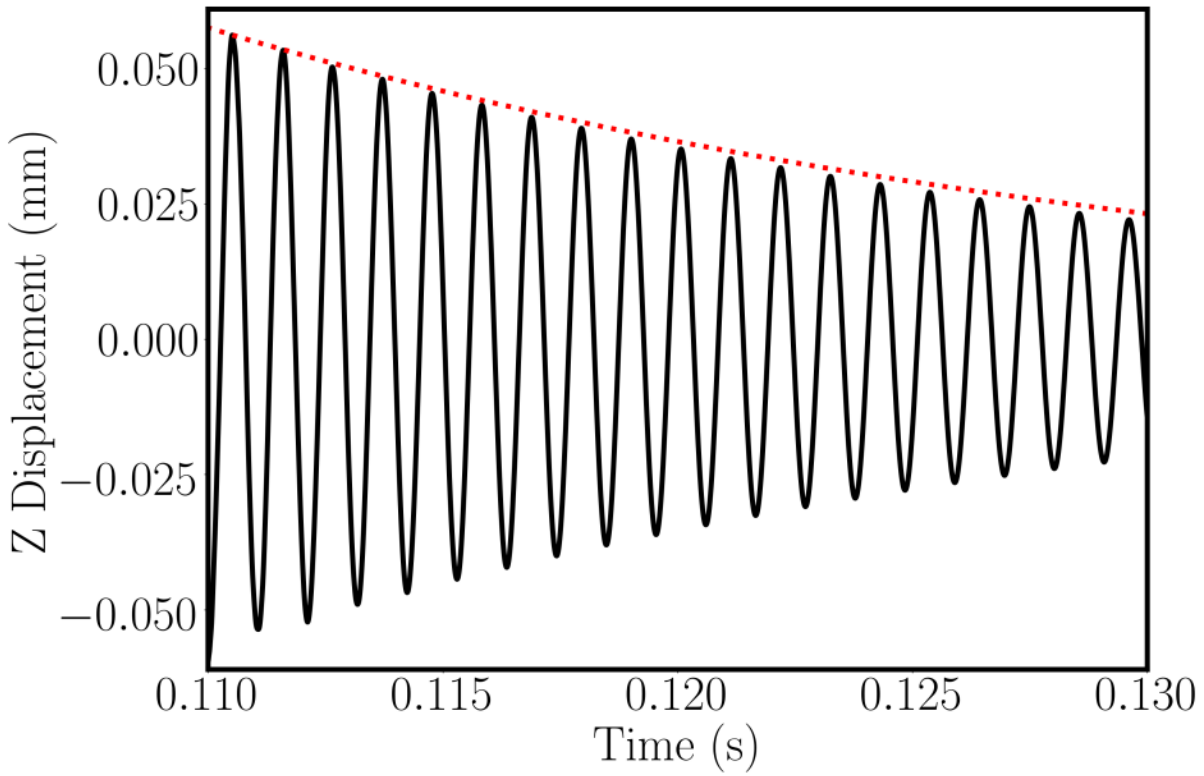
Analytical solution

Displacement: $\frac{PL^3}{48EI_{xx}}$

Frequency: $\frac{1}{2\pi L^2}\sqrt{\frac{48EI_{xx}}{\rho A}}$

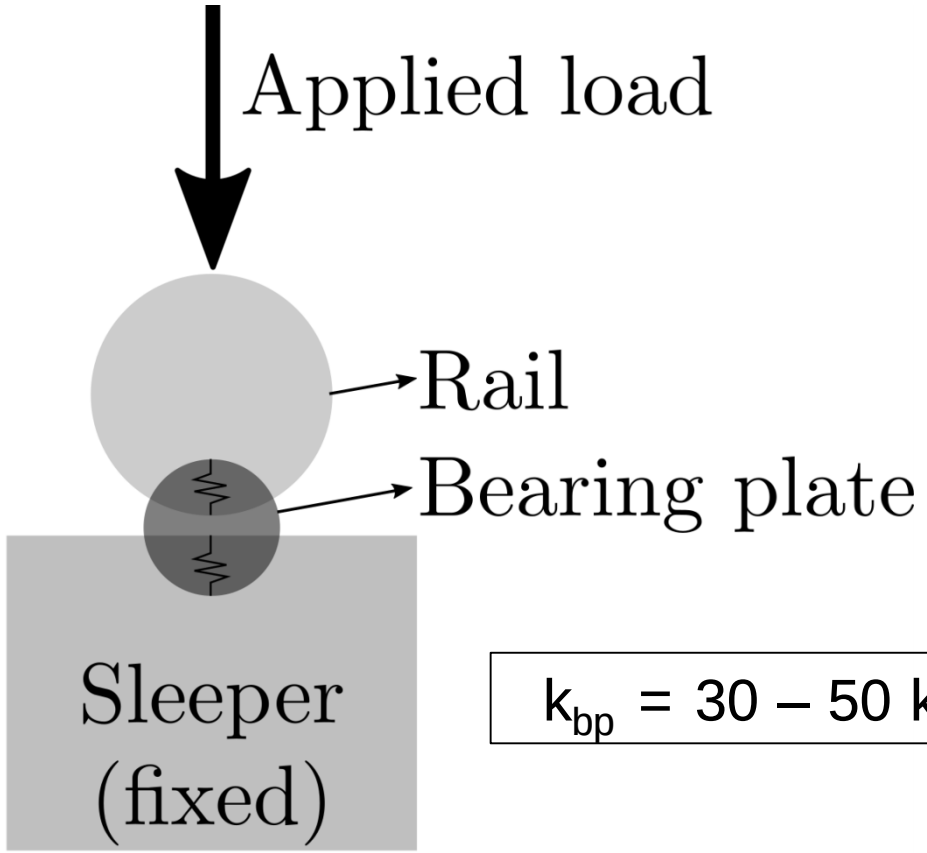




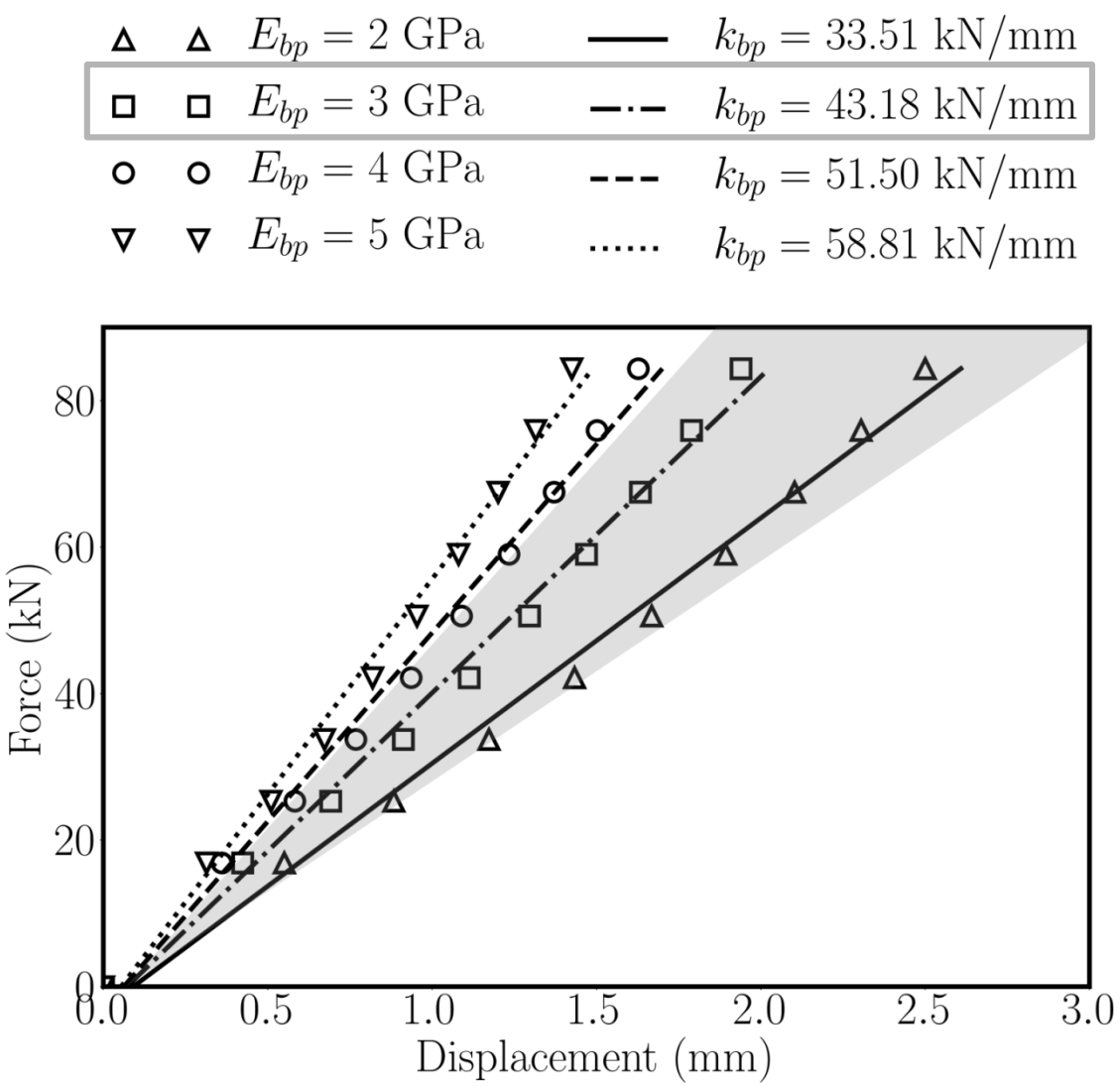


	Analytical solution	DEM solution	Error (%)
Max. Displ. (mm)	0.059502	0.059504	0.00
Frequency (Hz)	997.082	1015.35	1.83

Bearing plates

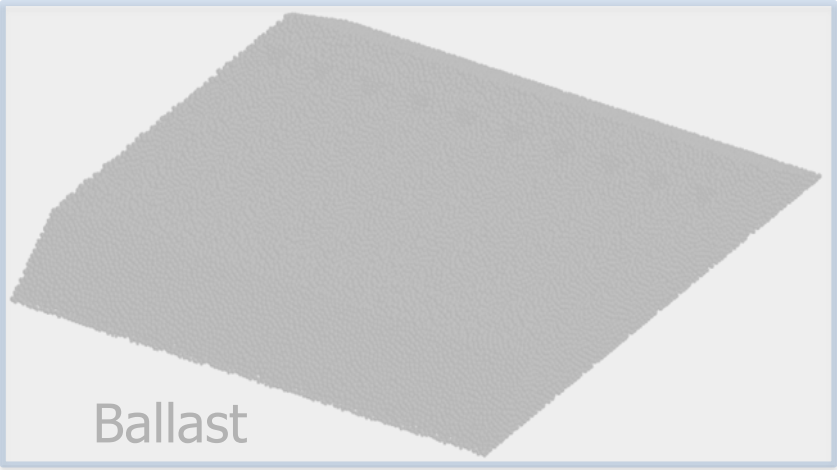


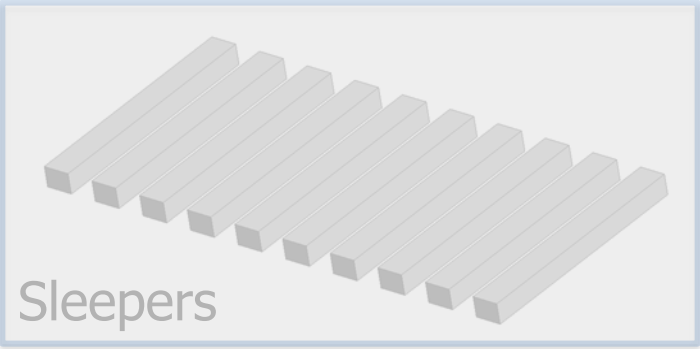
k_{bp} = 30 – 50 kN/mm

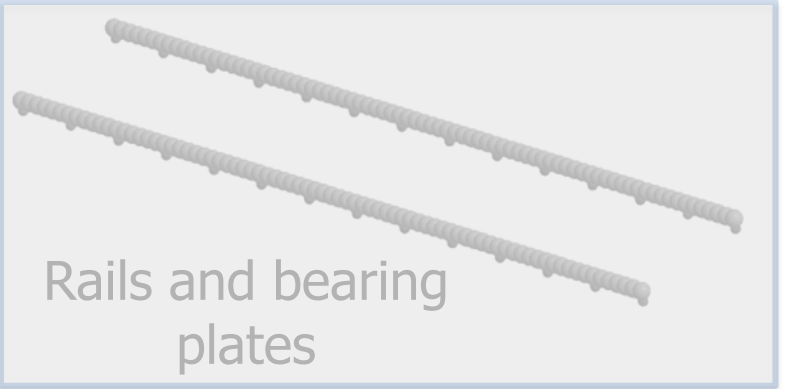


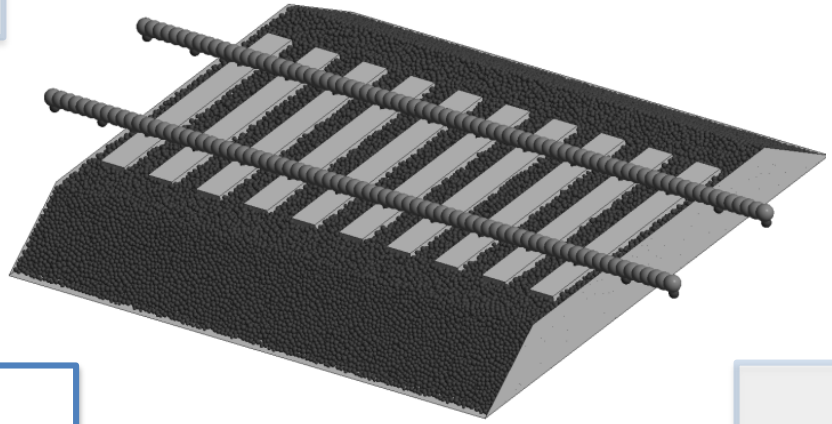
Pita, A. L., Teixeira, P. F., & Robusté, F. (2004). High speed and track deterioration: the role of vertical stiffness of the track. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 218(1), 31-40.

Boundaries

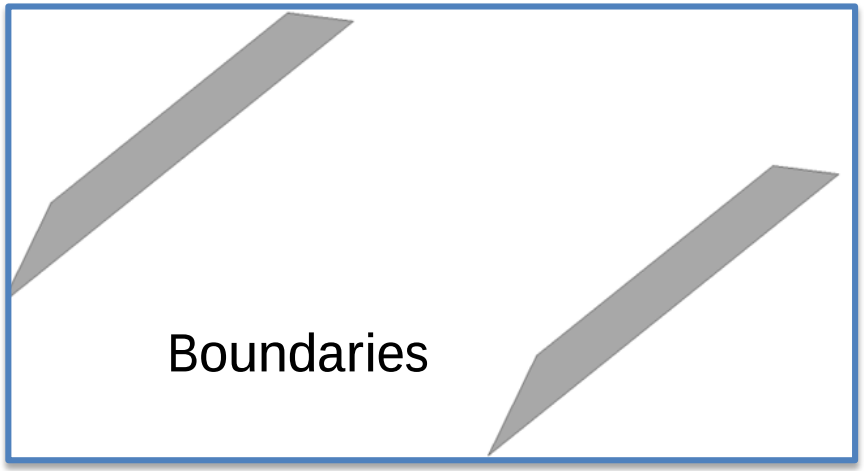


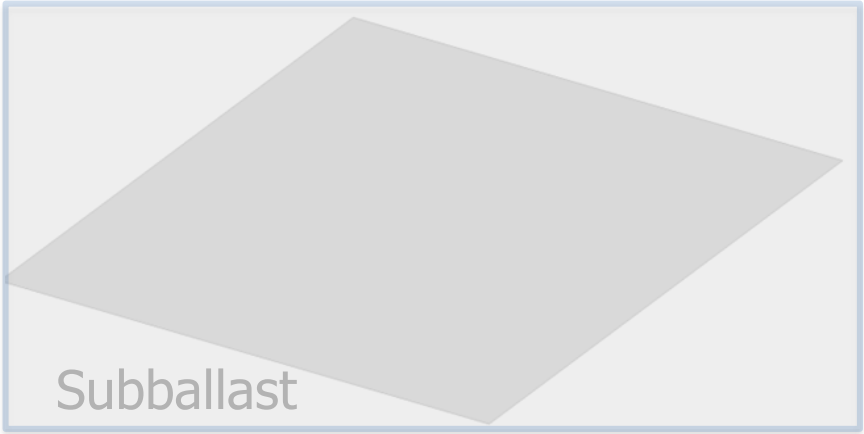




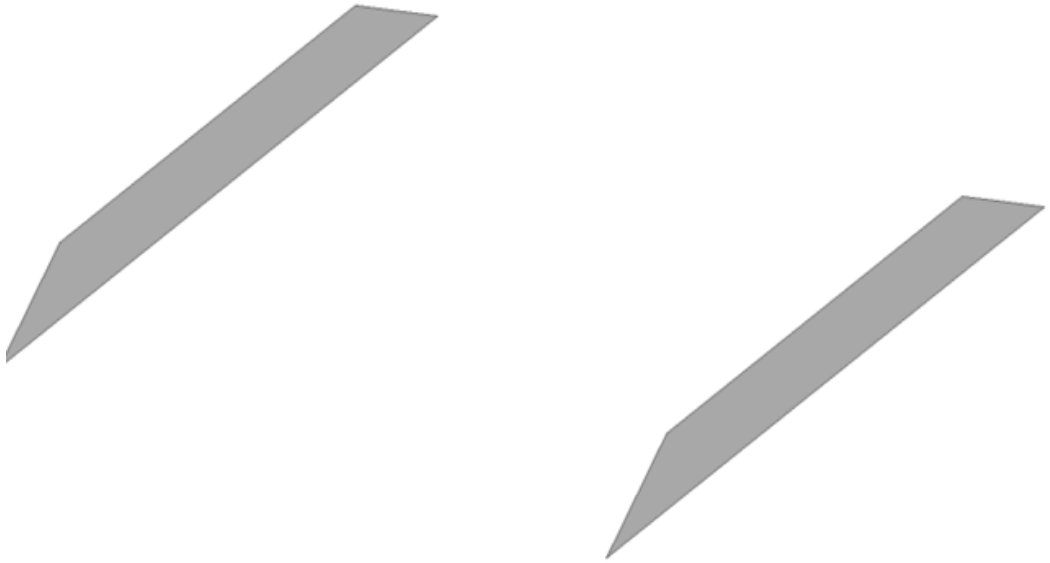


Full-scale test





Boundary walls



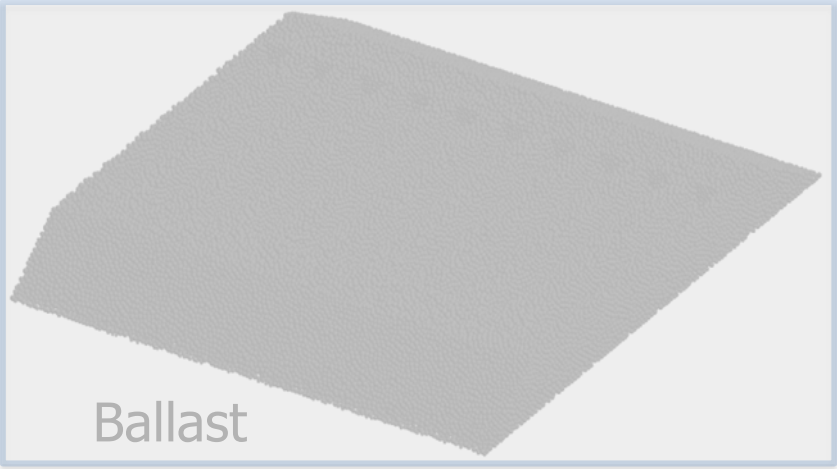
Contact between ballast and boundary walls

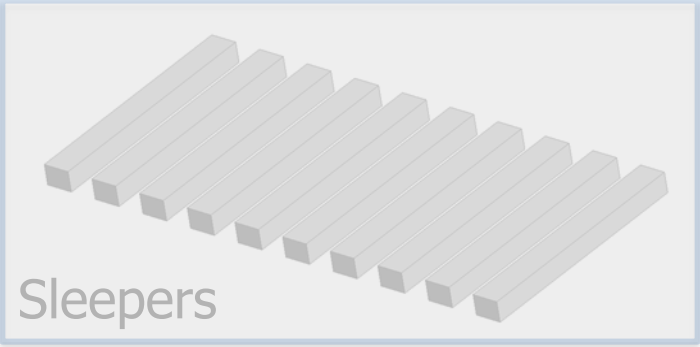
Young modulus = 200 Mpa*

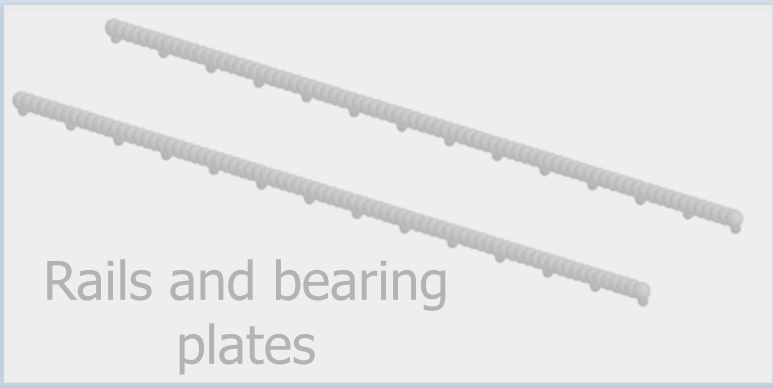
Friction coefficient = 0.0 (“mirrored particles”)

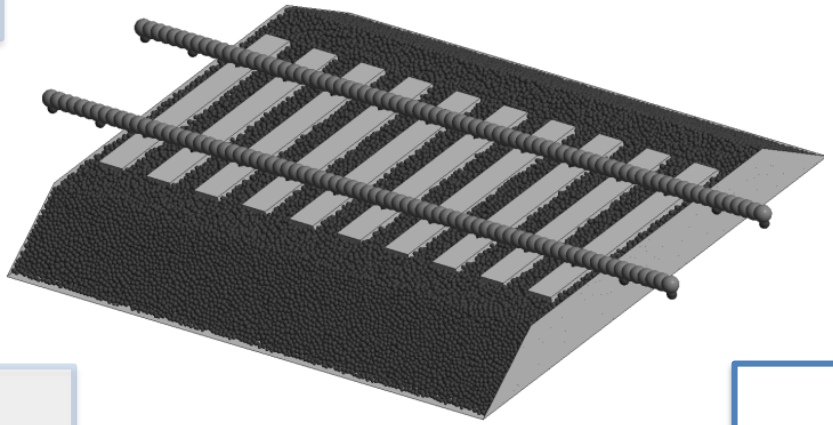
*Paderno, C. Simulation of ballast behaviour under traffic and tamping process. 9th Swiss Transport Research Conference. 2009.

Subballast

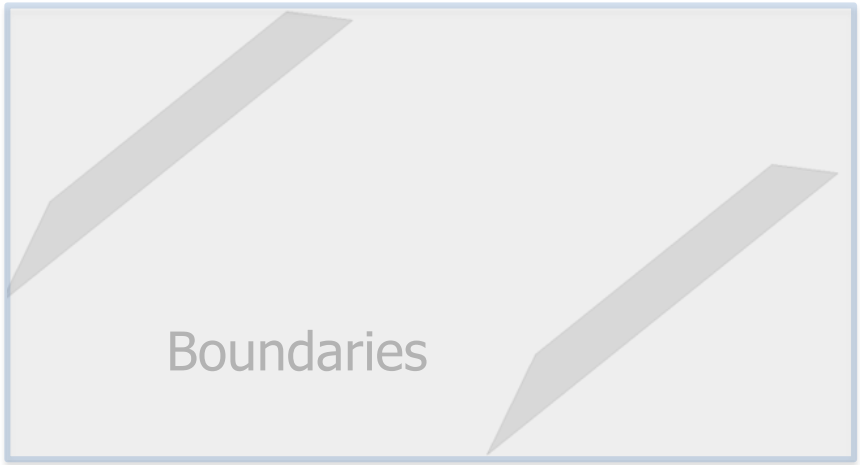


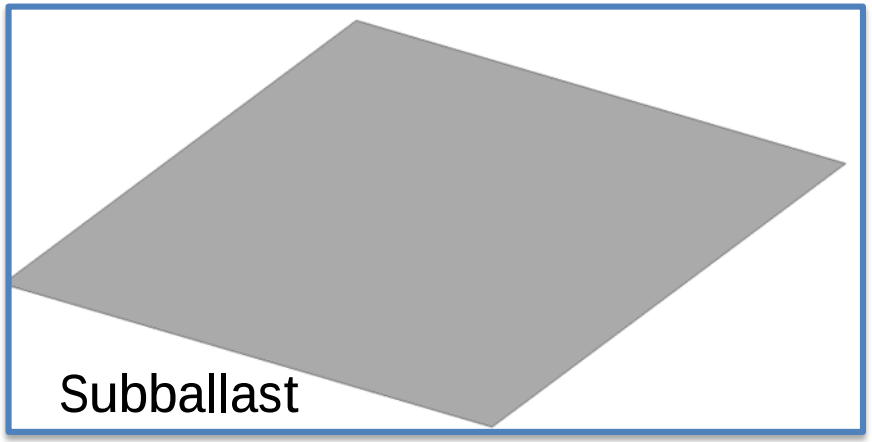




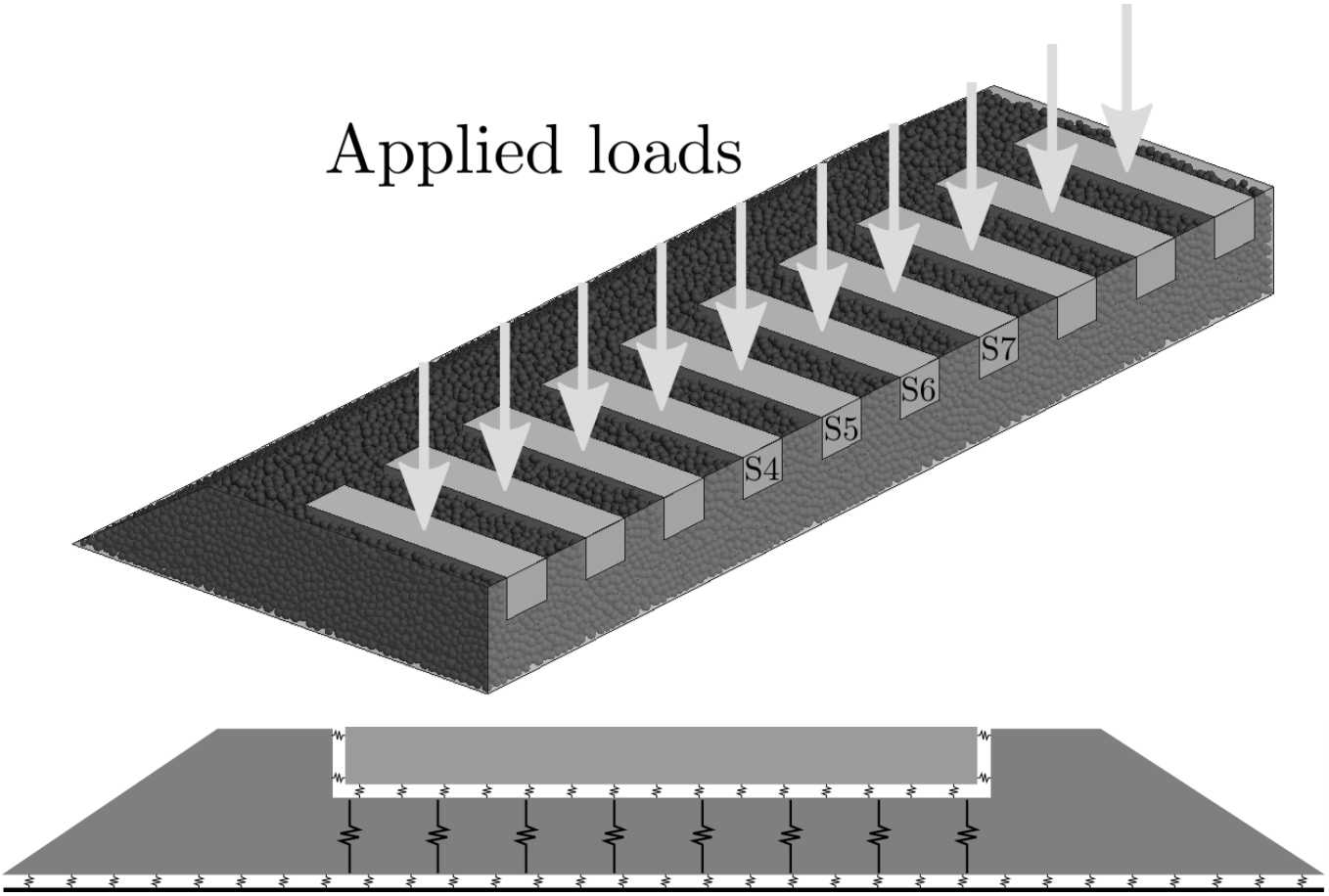


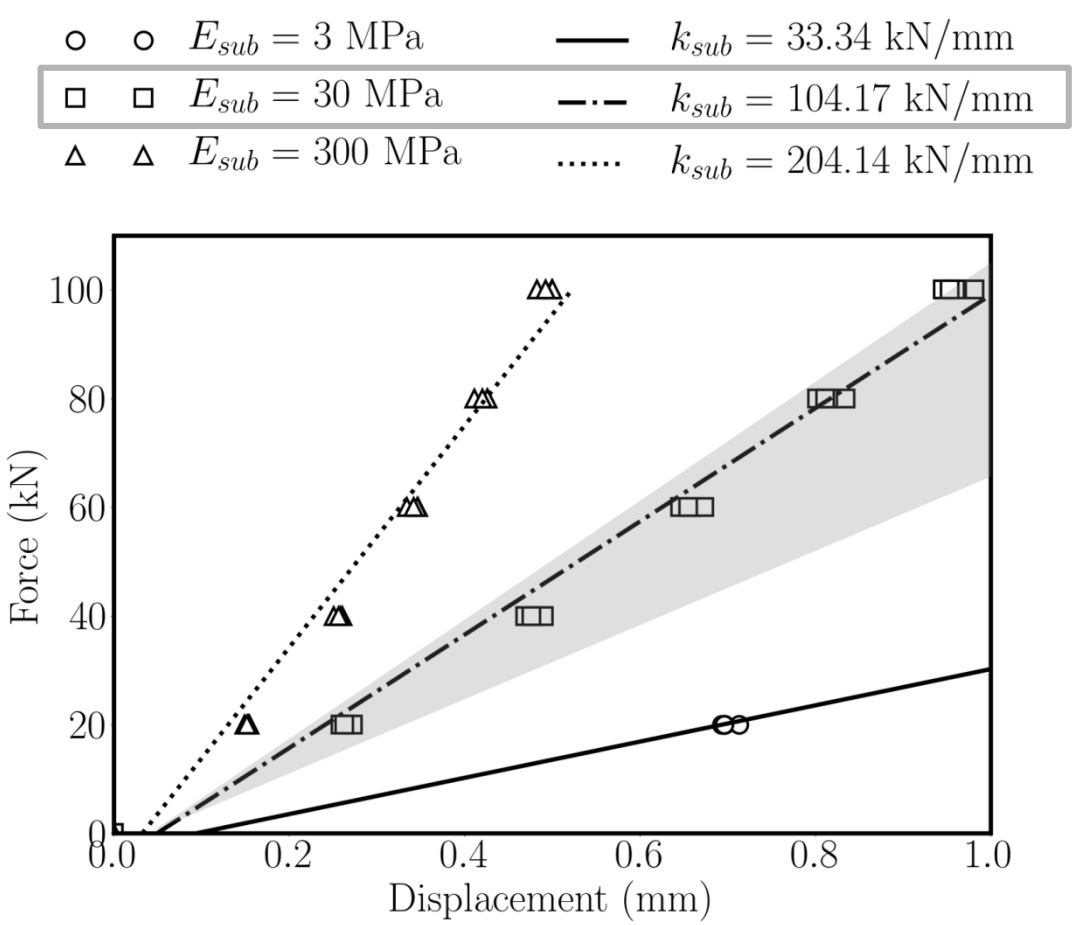
Full-scale test





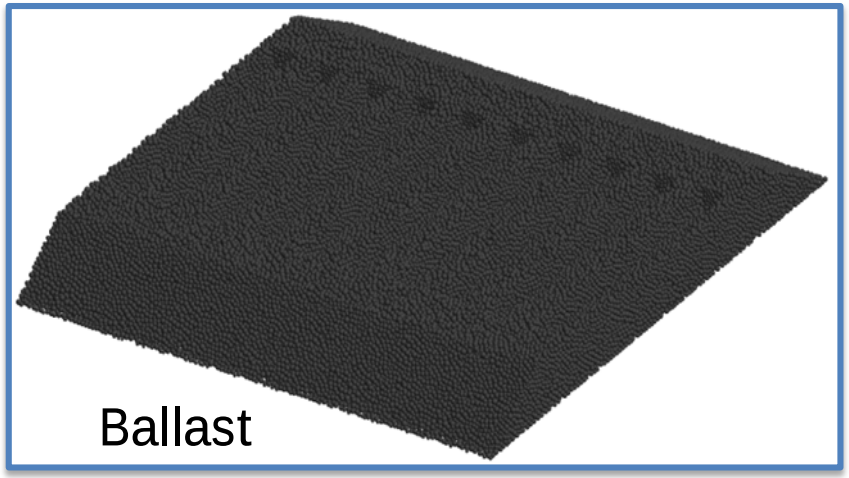
Subballast

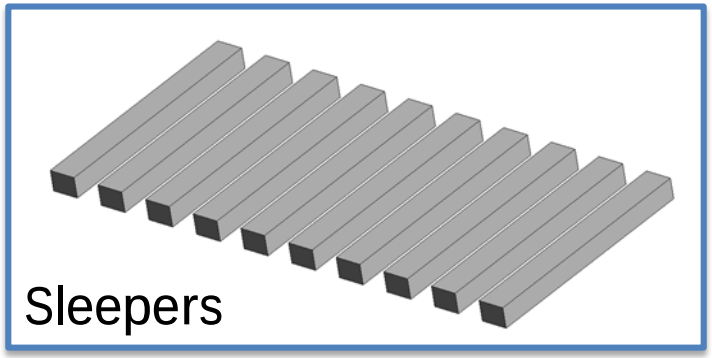


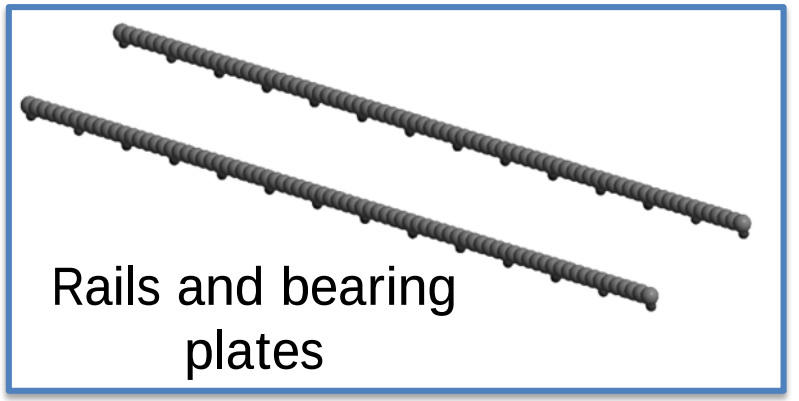


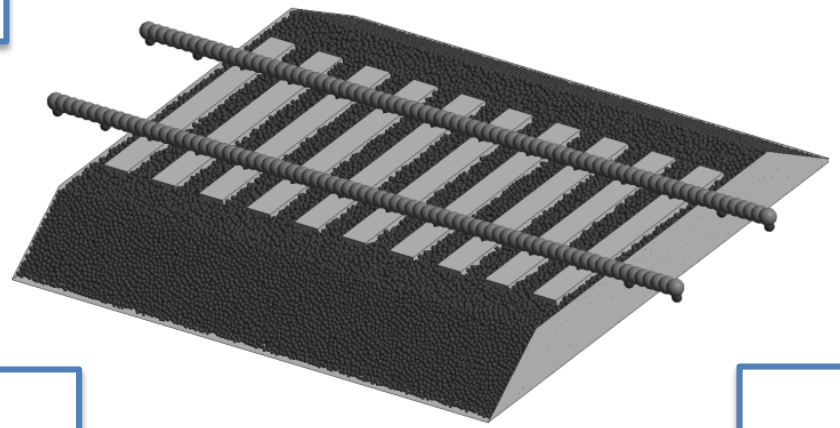
k_{sub} = 70 – 110 kN/mm

Pita, A. L., Teixeira, P. F., & Robusté, F. (2004). High speed and track deterioration: the role of vertical stiffness of the track. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 218(1), 31-40.

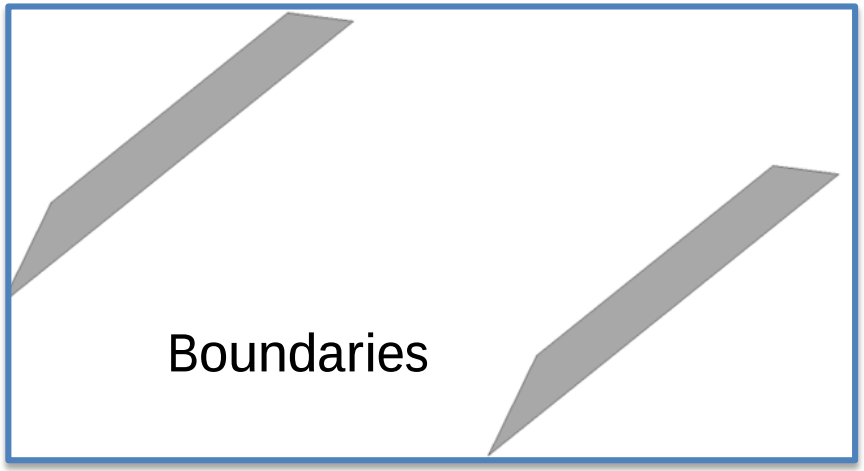


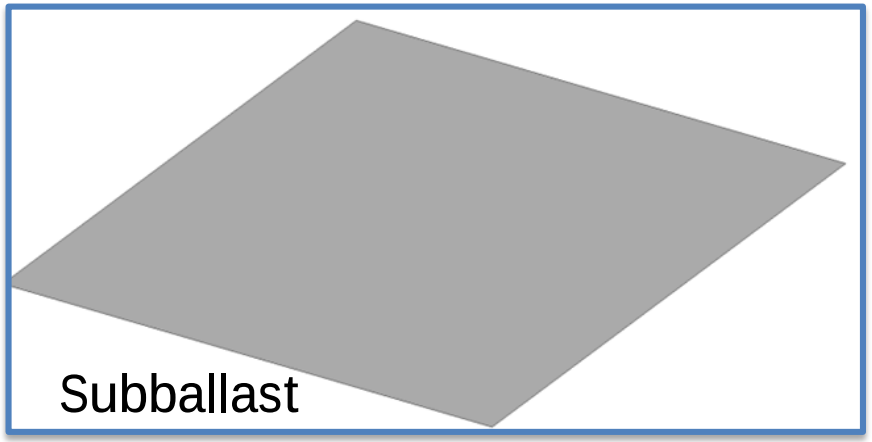




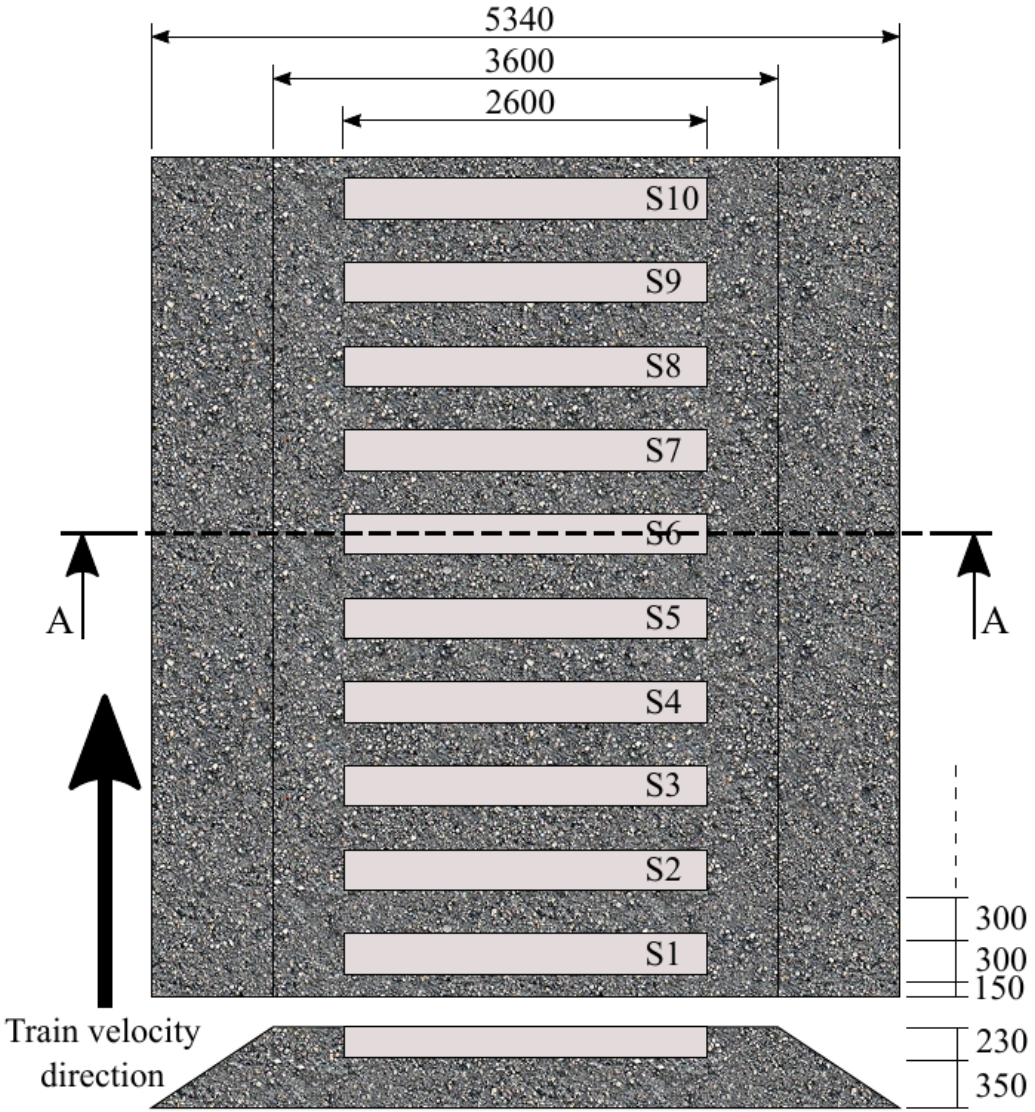


Full-scale test





Full scale tests



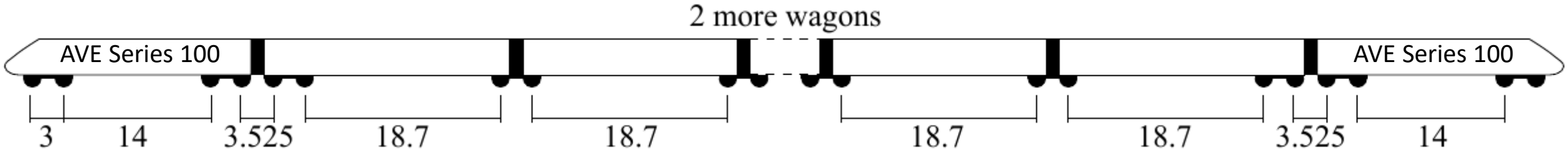
Scenario 1: Well compacted track

Scenario 2: Poorly compacted track

Full scale tests – Train loads

Q = 168732 N **Axle load**

v = 250 km/h **Velocity of the train**



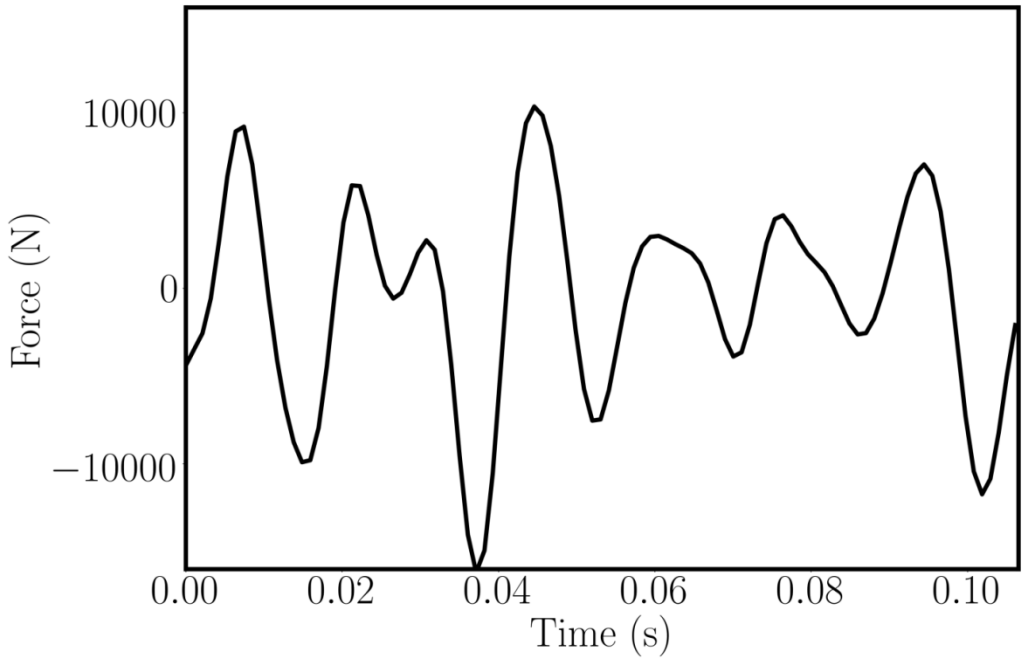
Full scale tests – Dynamic loads

Dynamic loads due to rail irregularities: PSD function obtained in German tracks with auscultation vehicles and defined by ARGER/F*

$$S_\xi(\Omega) = A\frac{\Omega_C^2}{\left(\Omega_r^2+\Omega^2\right)\left(\Omega_C^2+\Omega^2\right)}$$

$$\Omega_C = 0.8246$$
$$\Omega_r = 0.0206$$
$$A = 0.7930\cdot 10^{-6}\ rad\ m$$

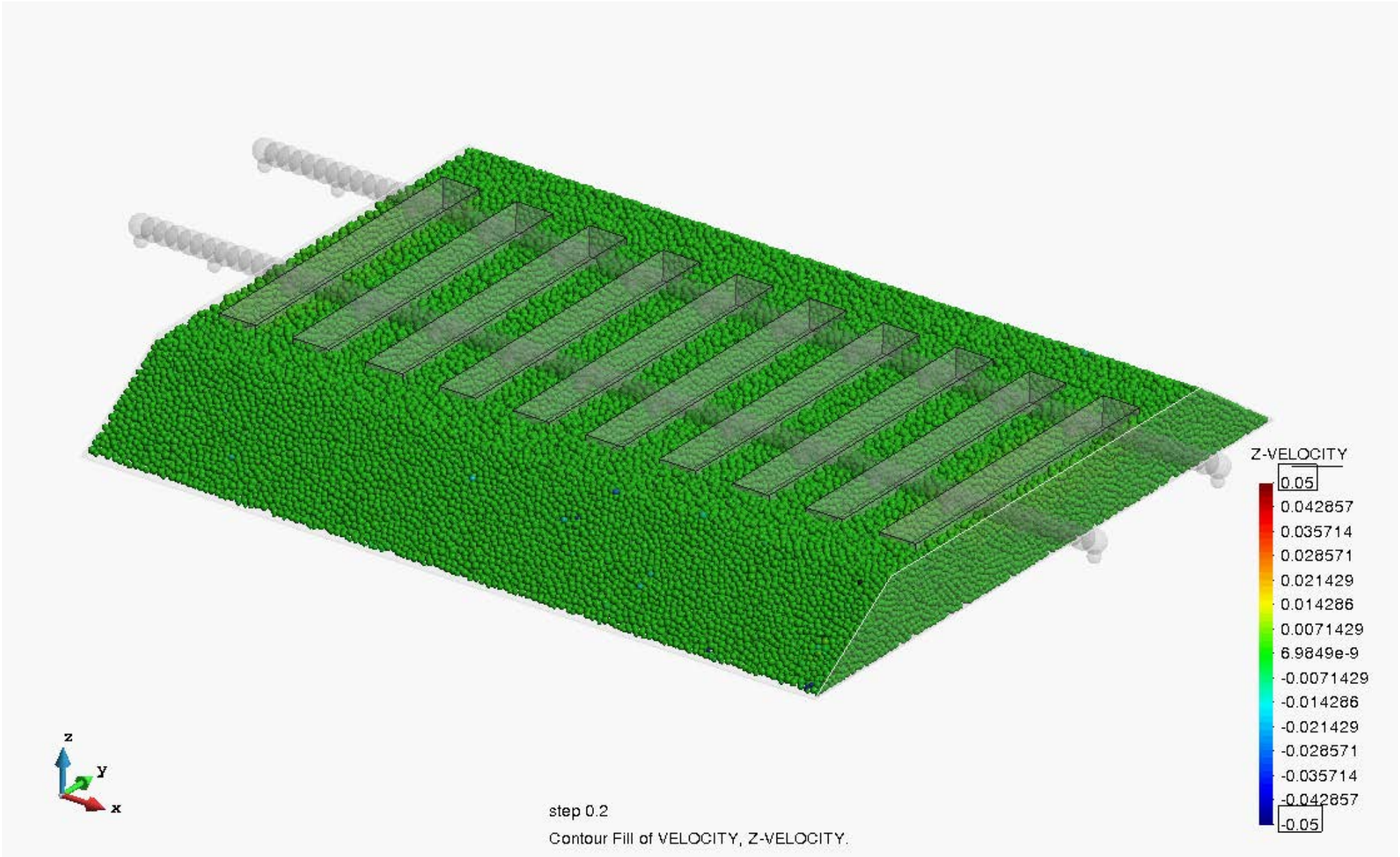
Applying the spectral representation method**



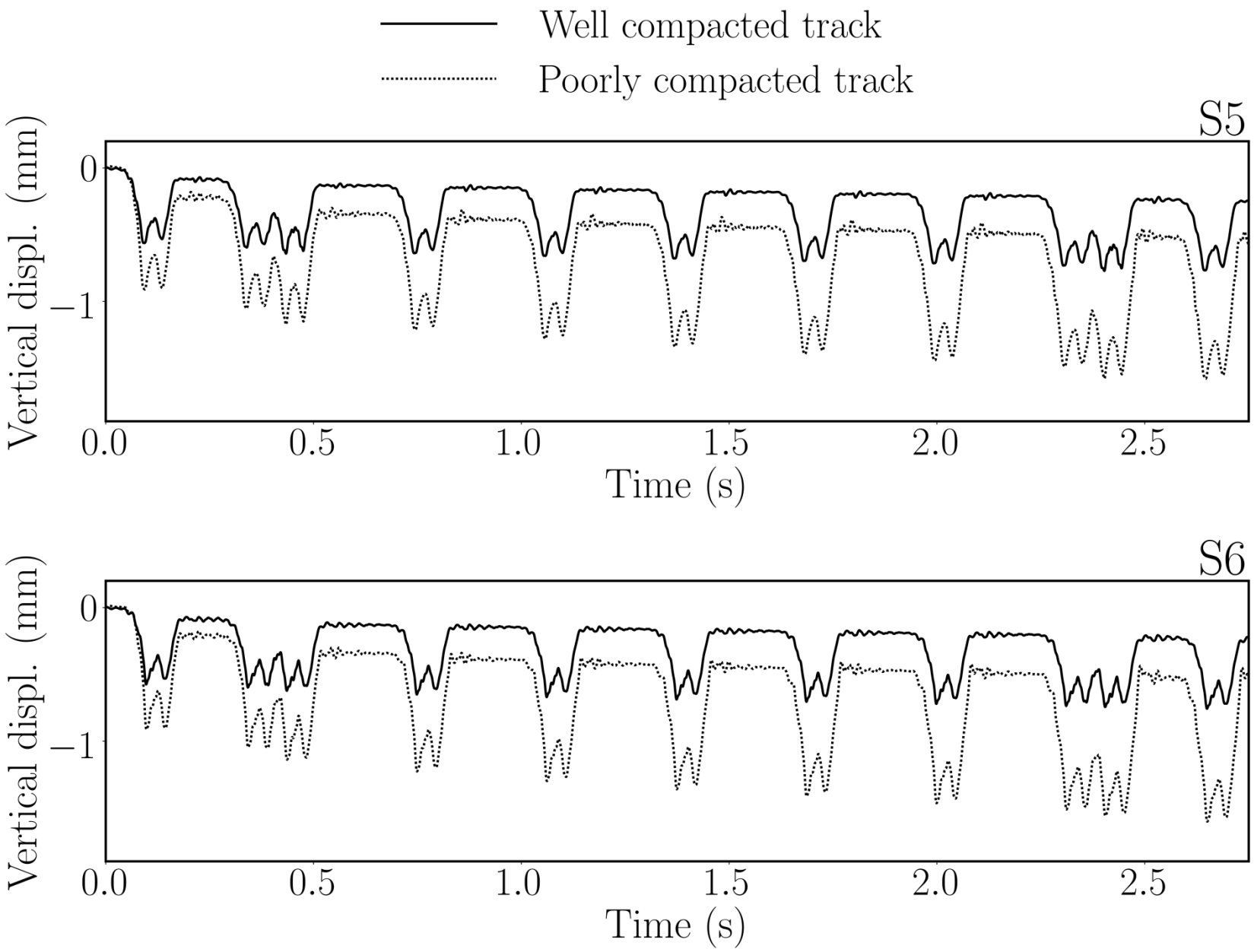
*Arbeitsgemeinschaft Rheine-Freren, \Rad/Schiene-Versuchs-und Demonstrationsfahrzeug, Denitionsphase R/S-VD", Ergebnisbericht der Arbeitsgruppe Lauftechnik, MAN, München, 1980.

**H. Claus & W. Schiehlen. Modeling and simulation of railway bogie structural vibrations. Vehicle System Dynamics Supplement 28. pp. 538- 552. 1998.

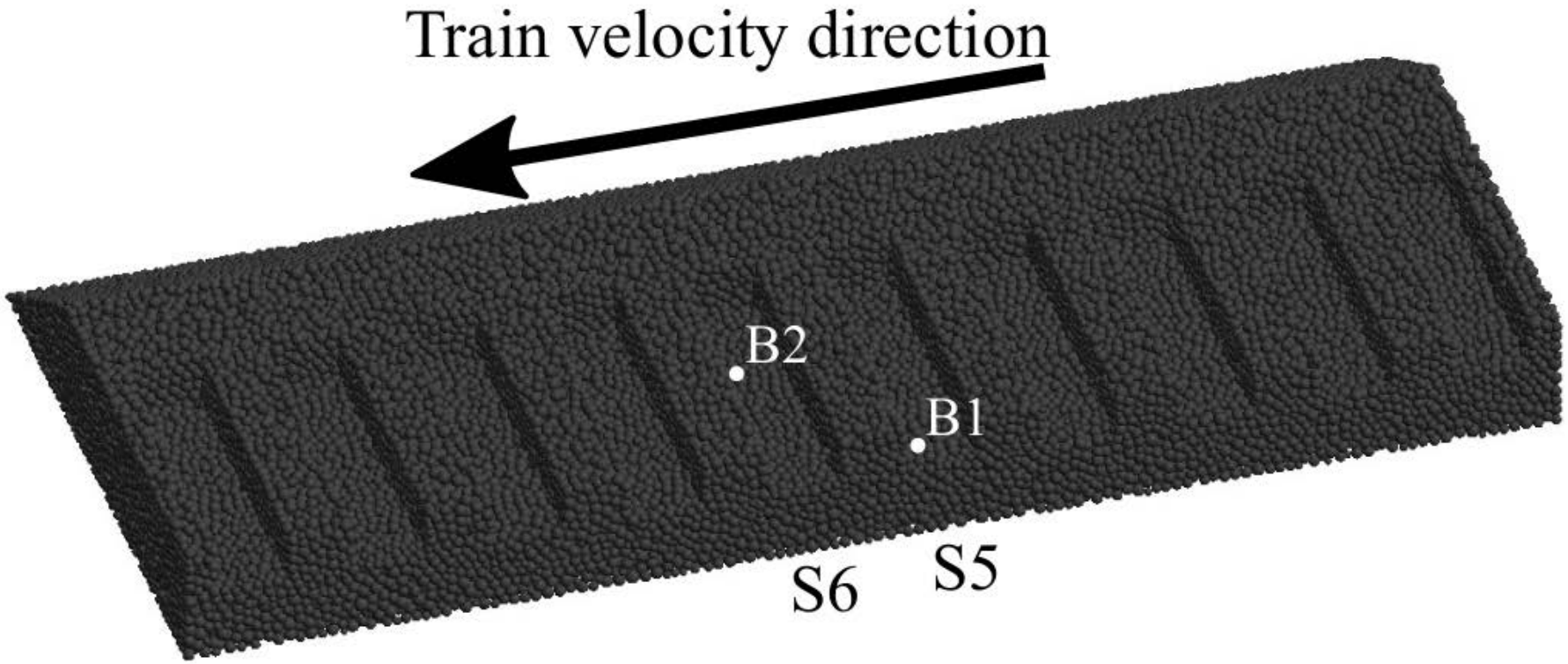
Full scale tests – Ballast lateral velocity



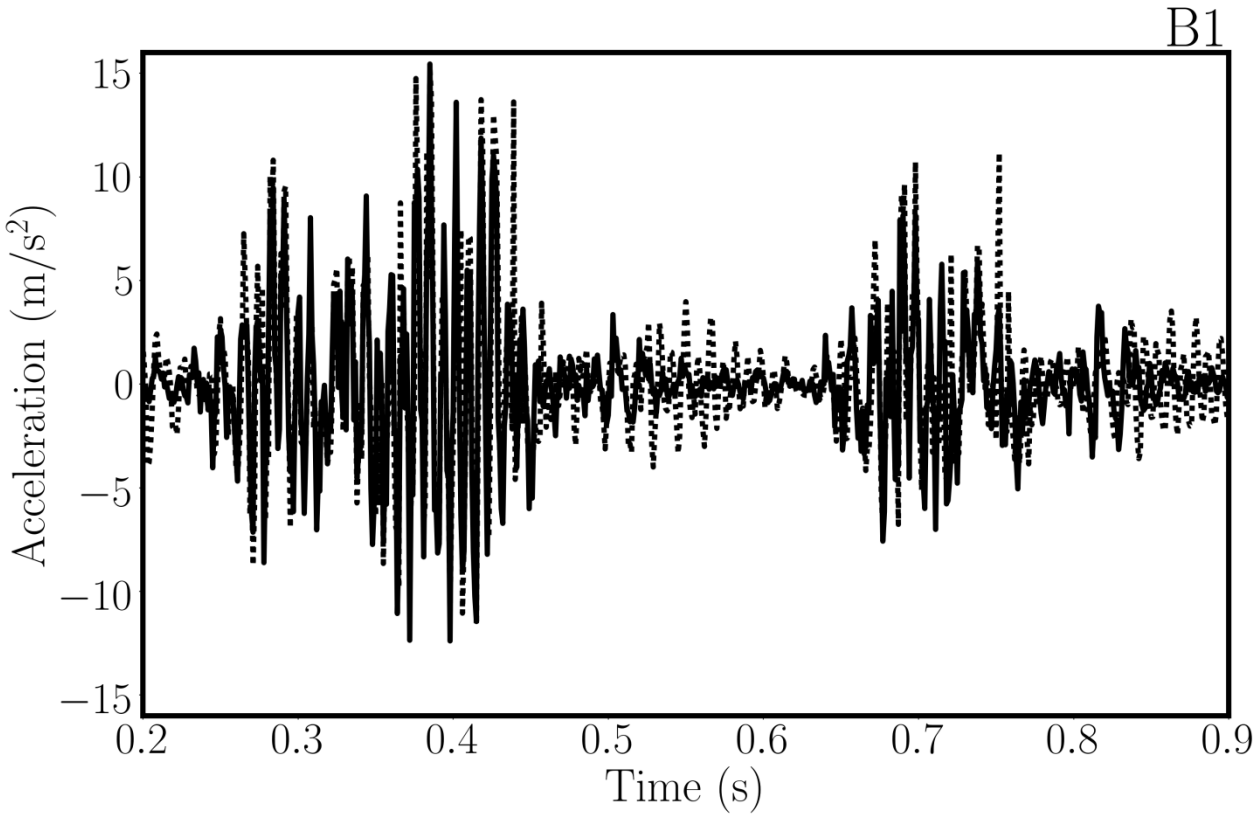
Full scale tests – Results on ballast

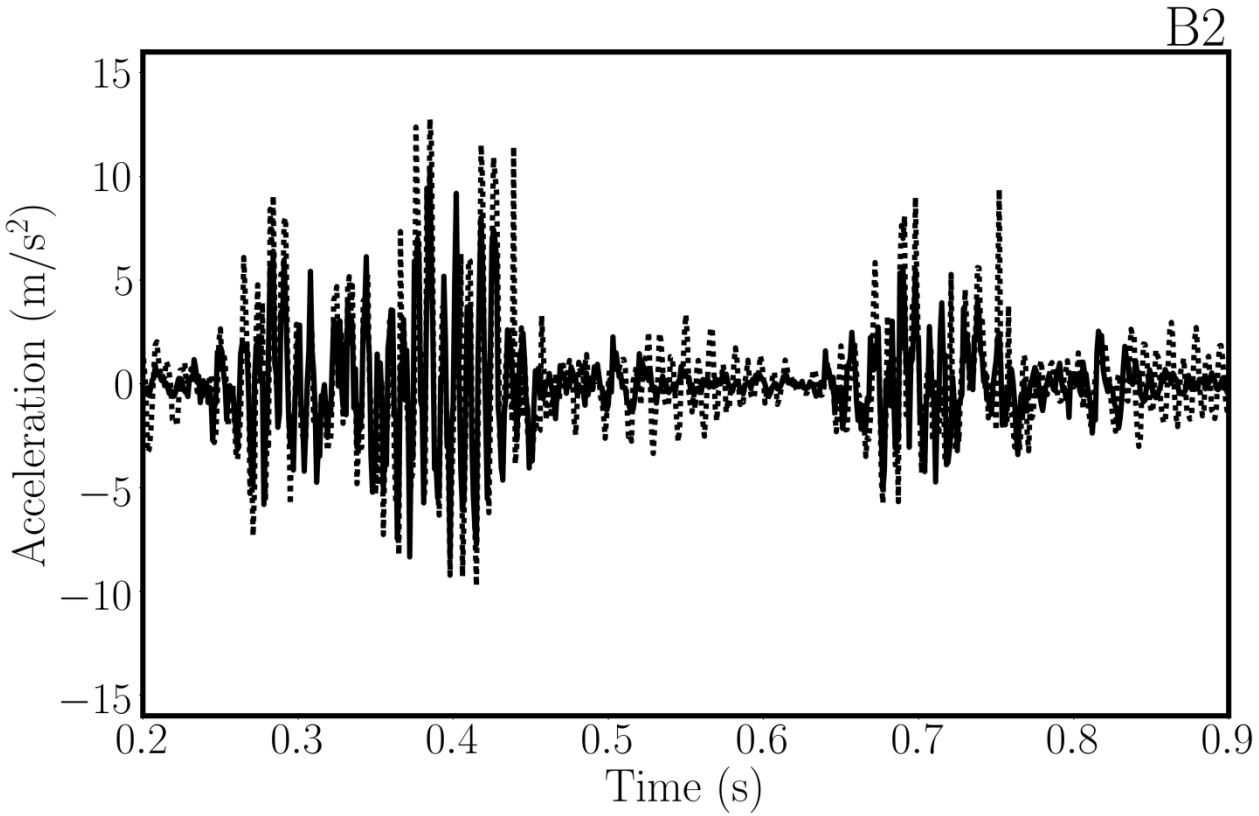


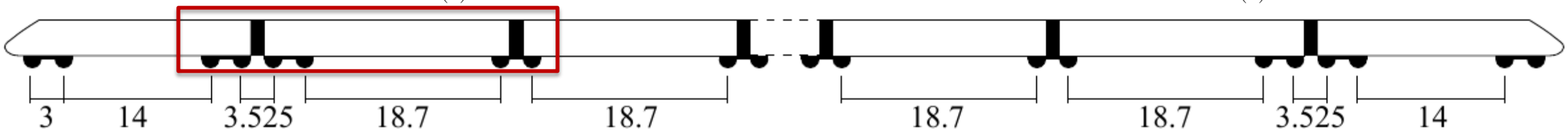
Full scale tests – Sleepers displacement



Full scale tests – Results on ballast







Summary

- To be capable of representing a **large number of particles** (almost 200000), we have applied **several simplifications** to the model (spherical particles, rigid sleepers...).
- **Not valid** to analyse **microscopic results**, such as the distribution of contacts.
- **Very useful** for evaluating the **macroscopic behaviour** of the track and **compare** different configurations.
- Some examples:
  - Ballast granulometry or properties
  - Ballast layer geometry
  - Sleepers design
  - Bearing plates stiffness
  - Type of rails

RESILTRACK (Resilience of Railway Infrastructures Against Climate Change)

- Introduce lateral loads (train axles and dynamic)
- Apply dynamic loads due to irregularities in the wheels
- Test other particle geometries (clusters of spheres) more similar to ballast particles
- Measure track kinematics in a real section to compare them with DEM results

Thank you for your attention!

Questions?

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