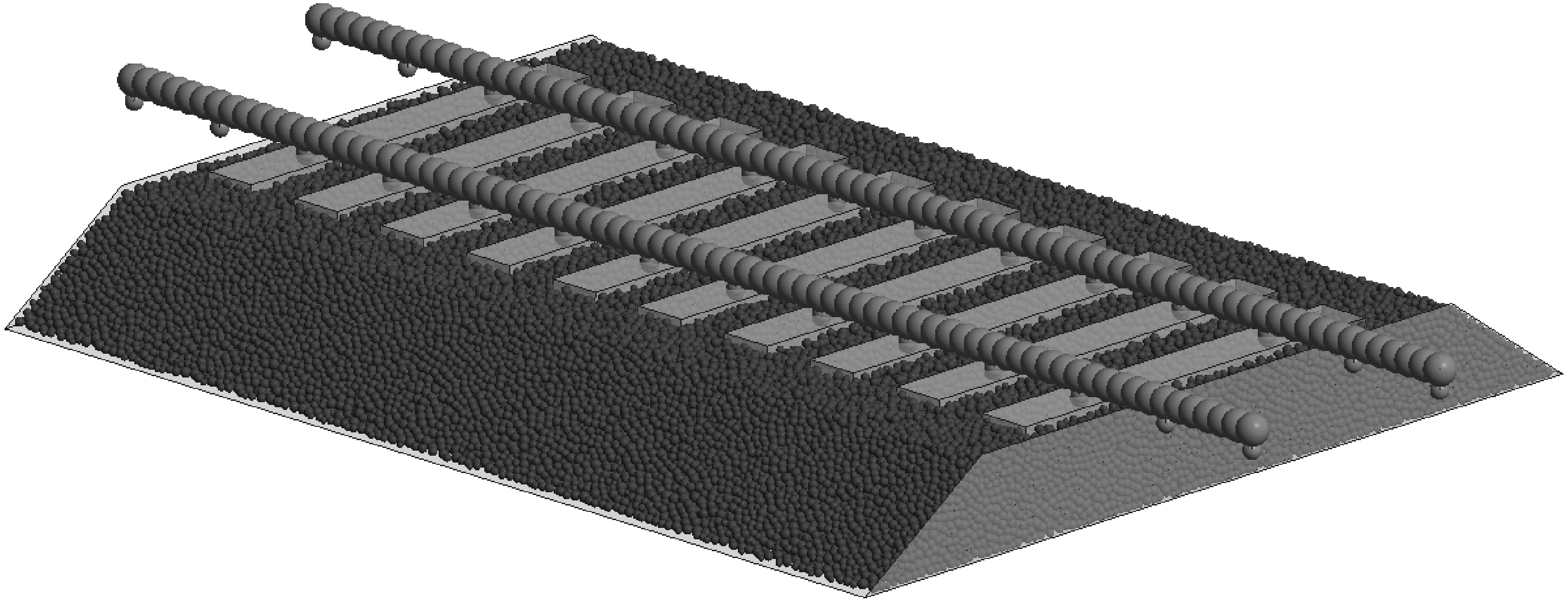
CIMNE

DEM 8

Full-scale numerical calculation of ballasted tracks with the Discrete Element Method



Joaquín Irazábal, Fernando Salazar and Eugenio Oñate

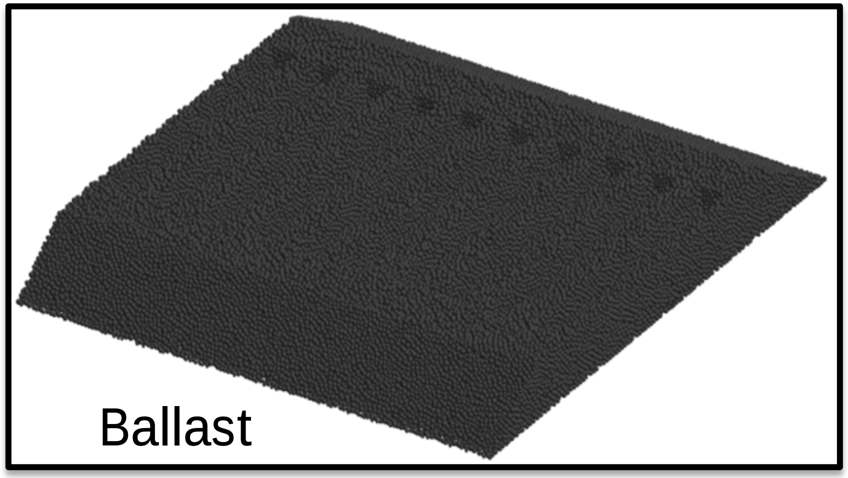
Software

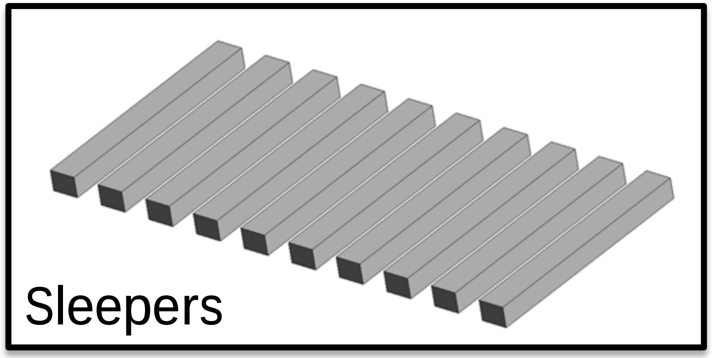
DEMpack Discrete / finite elements simulation software

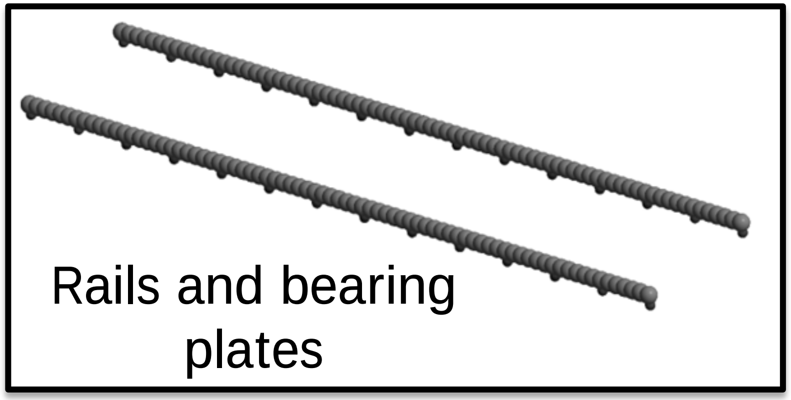
GiD → KRATOS MULTI-PHYSICS → GiD

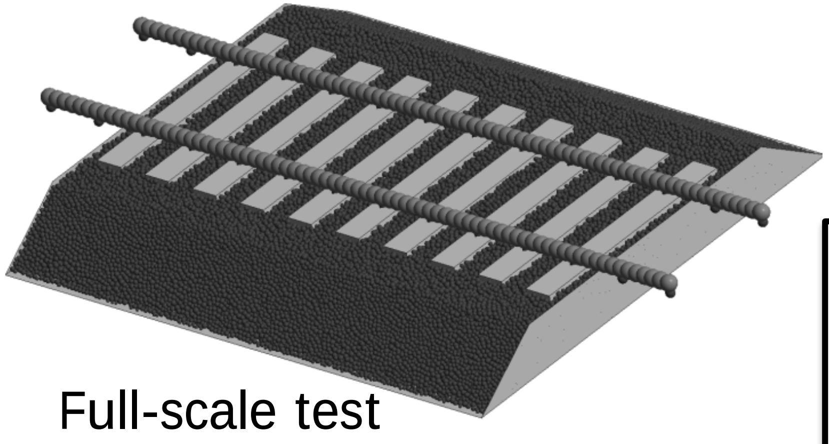
https://github.com/KratosMultiphysics/Kratos
http://gid.cimne.upc.es/

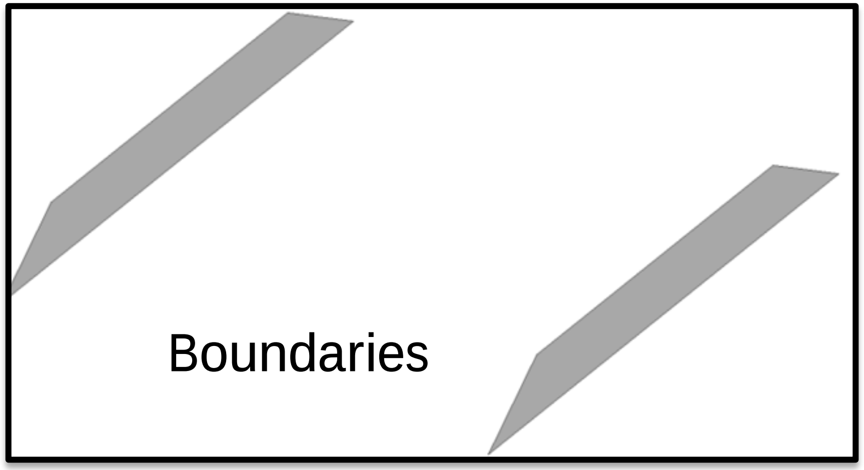
Motivation and Outline

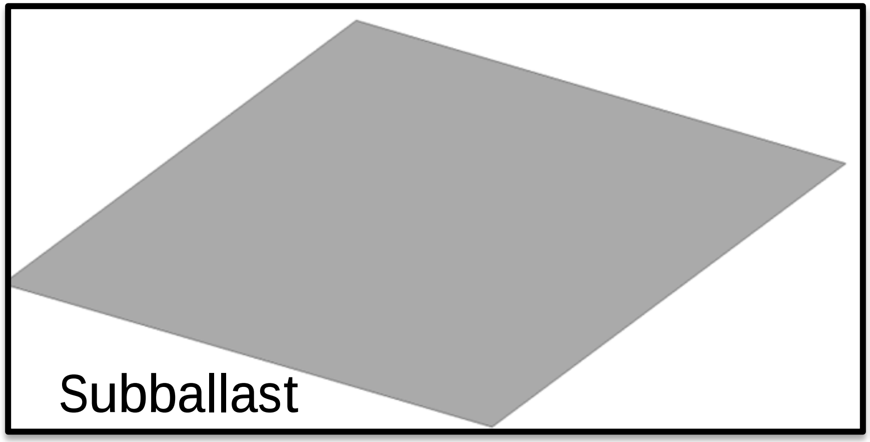




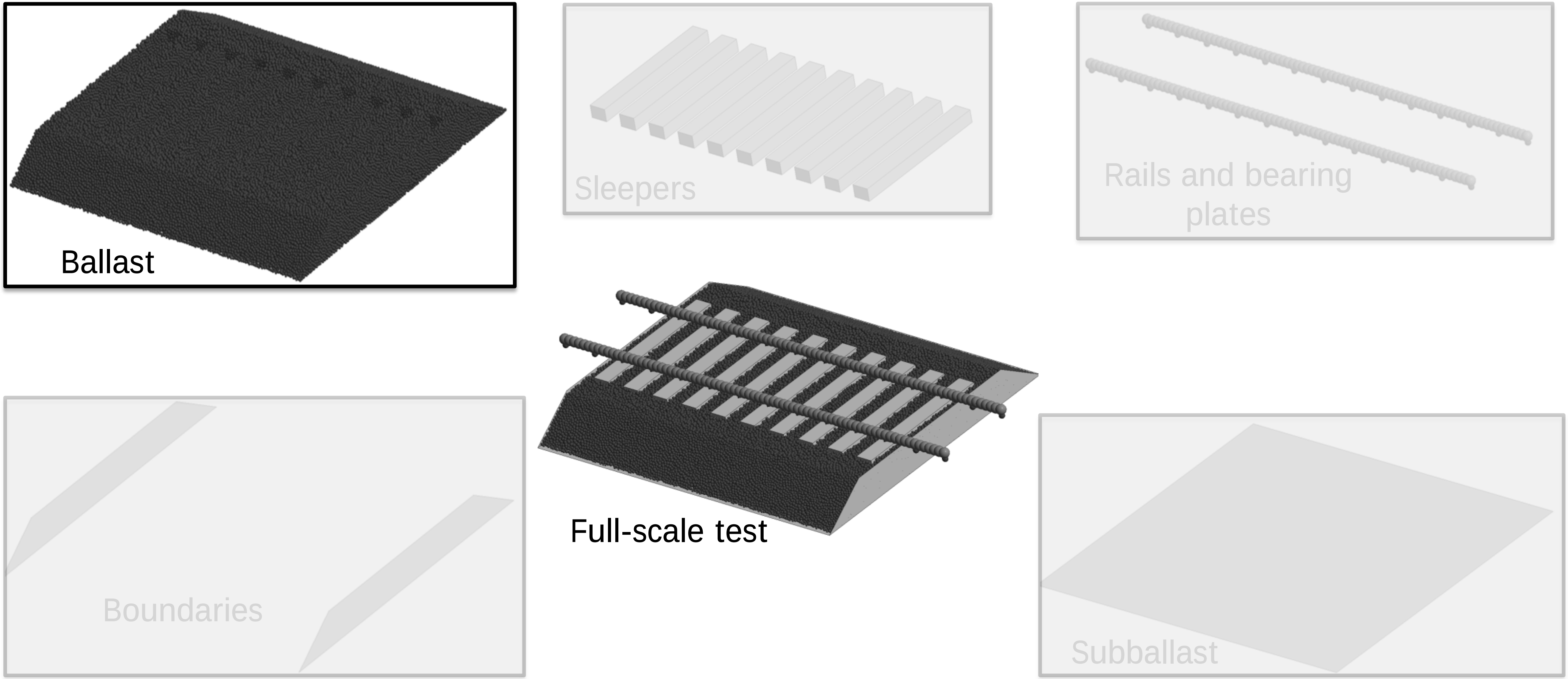




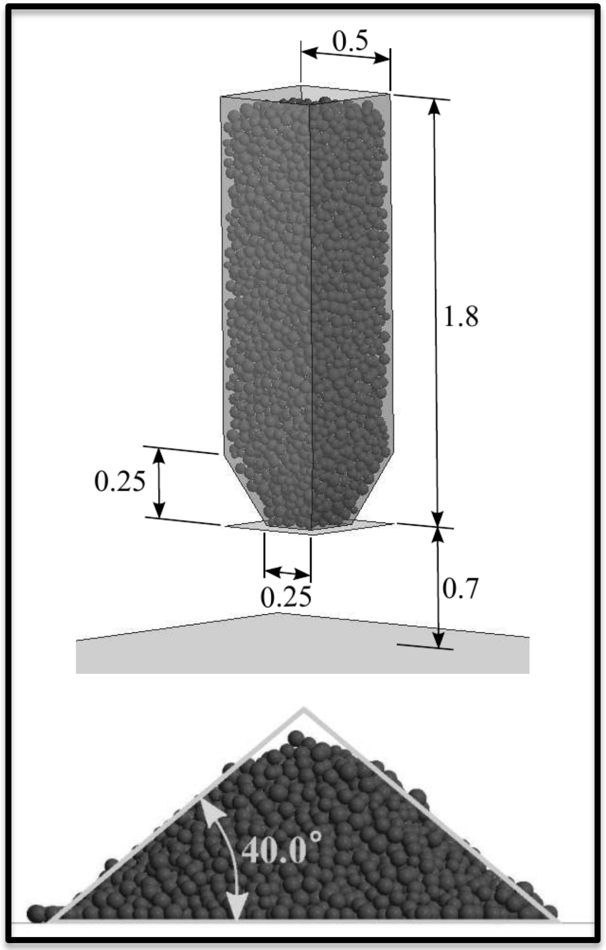


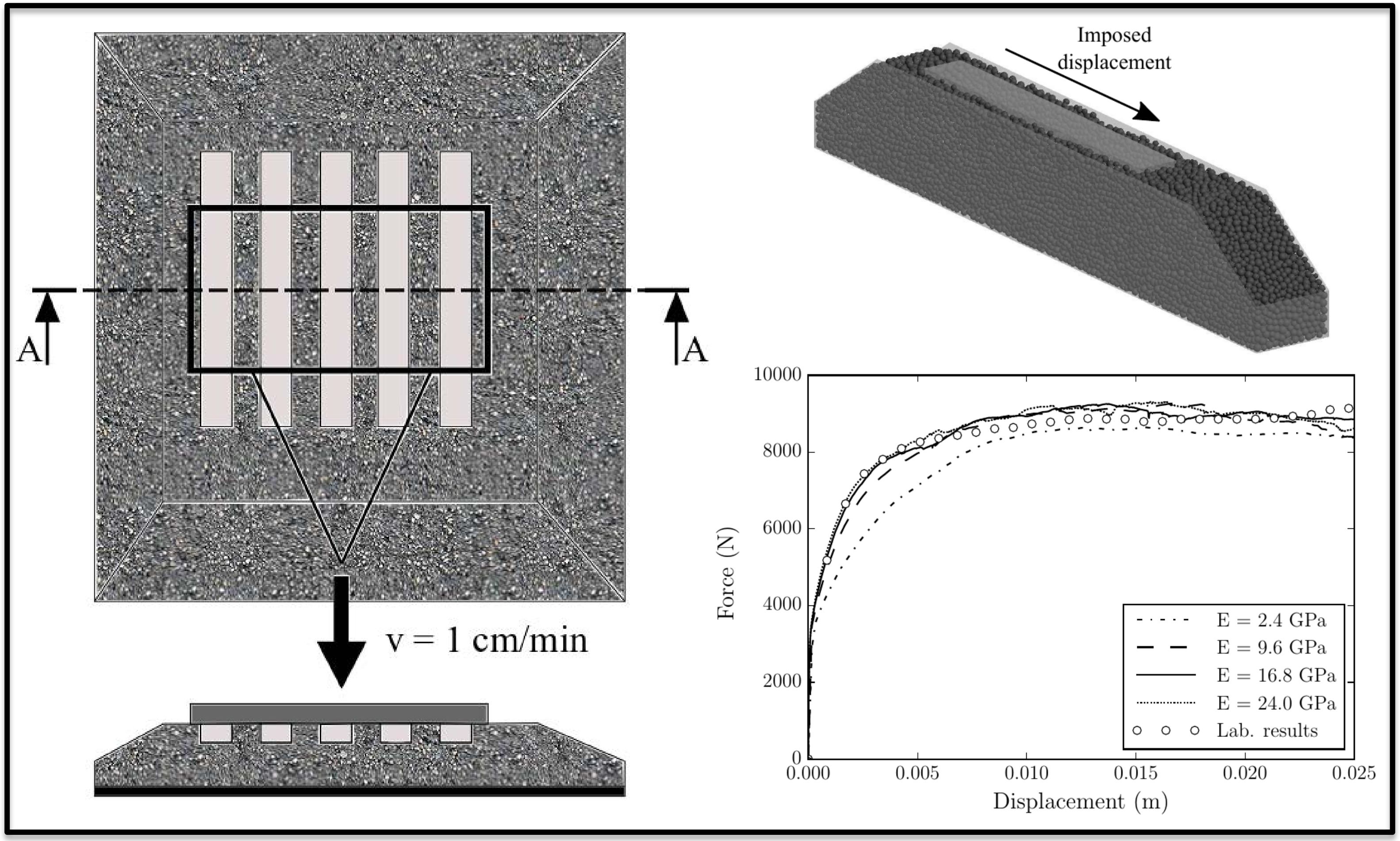


Ballast | Sleepers | Rails, bearing plates | Boundary walls | Subballast |
| Full scale railway track tests | Summary and ongoing work

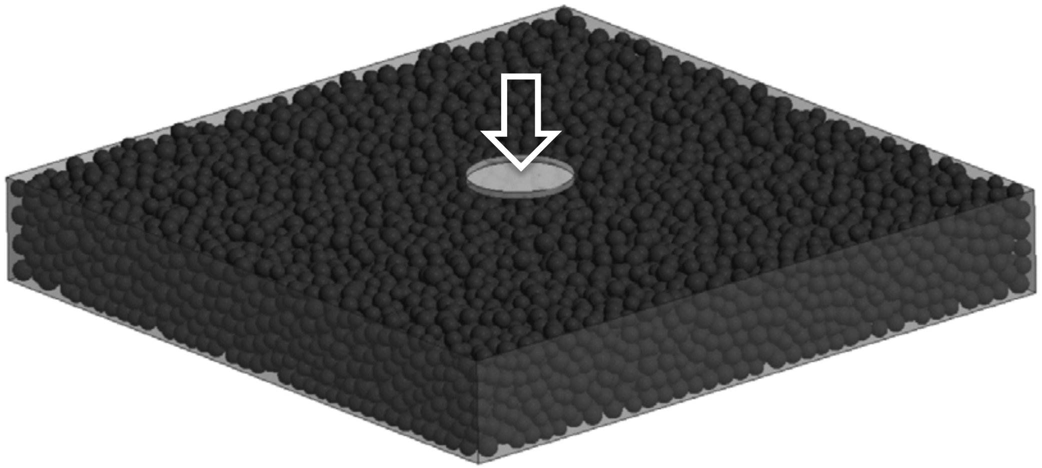

Ballast
Sleepers
Rails and bearing plates
Full-scale test
Boundaries
Subballast

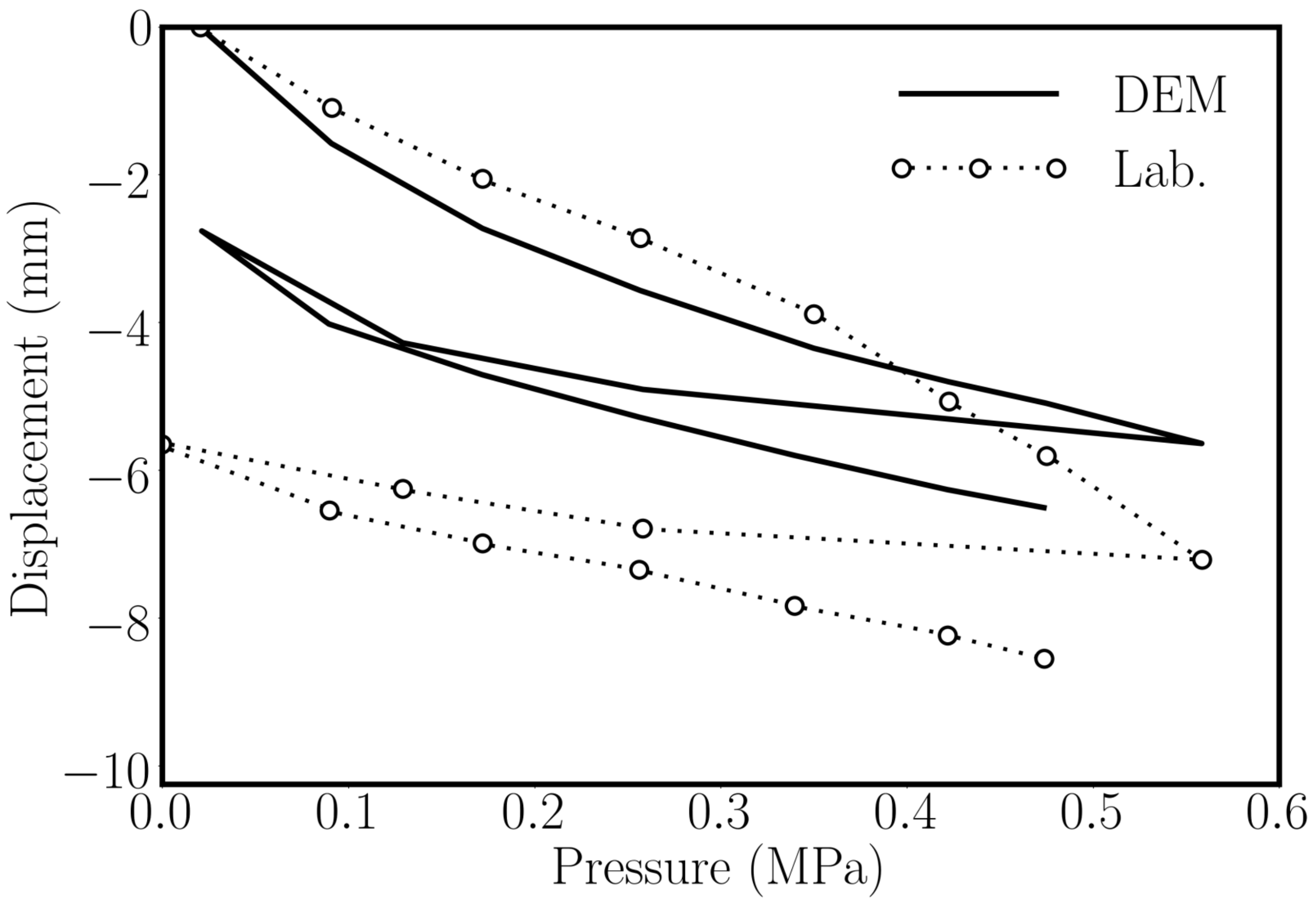
Good results applying the Hertz-Mindlin contact model





Simple compression – Hertz

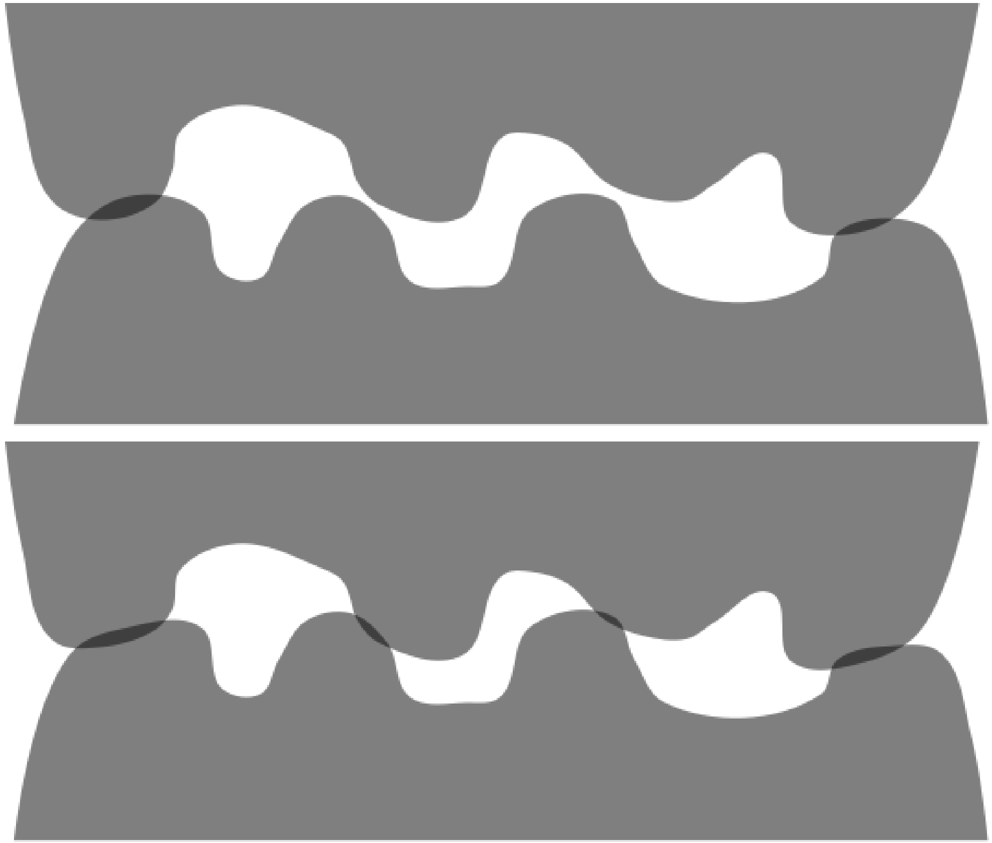




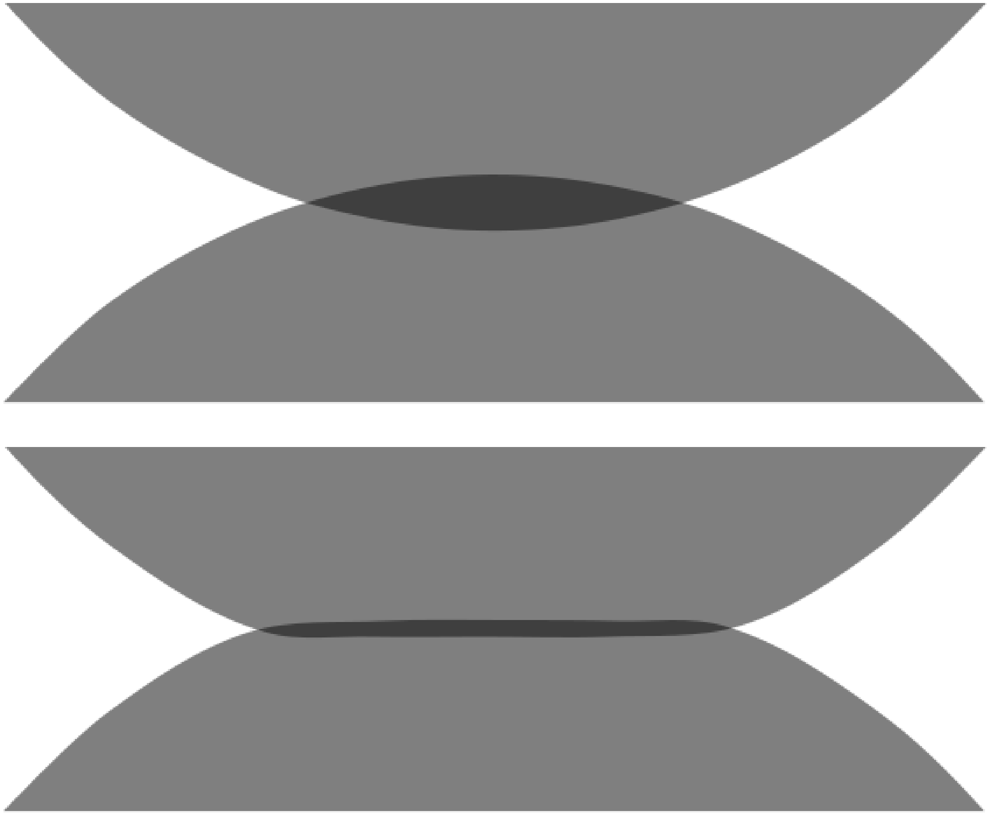
Paderno C. Simulation of ballast behaviour under traffic and tamping process. PhD Thesis 2009.

Contact model

Hertzian contact model: contact stiffness depends on the contact volumen but does not take into account edge breakage



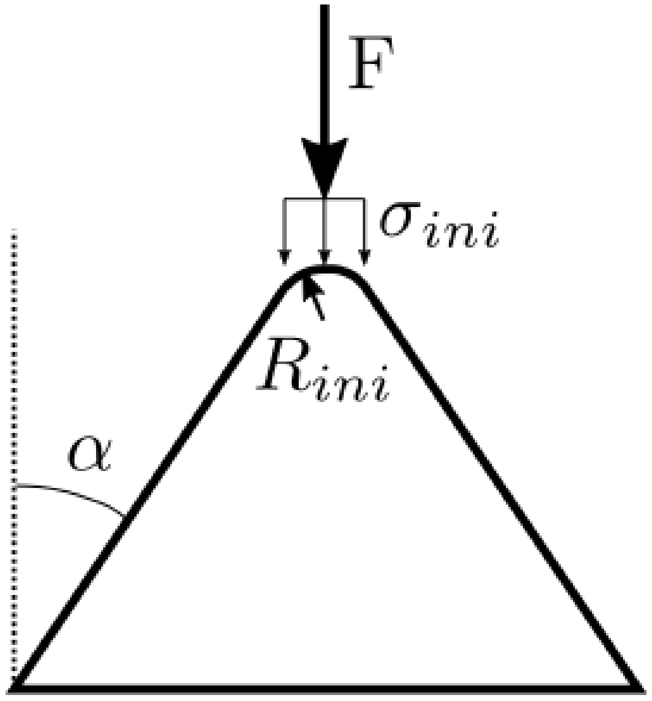
Real contact geometry



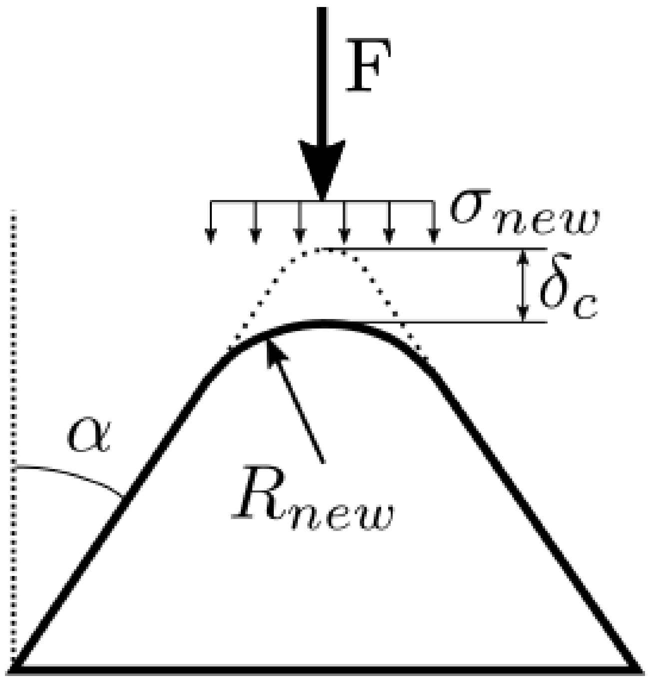
Numerical contact geometry

Conical damage contact model: accounts for edge breakage

Two new material properties to define: Maximum stress and α



Initial radius

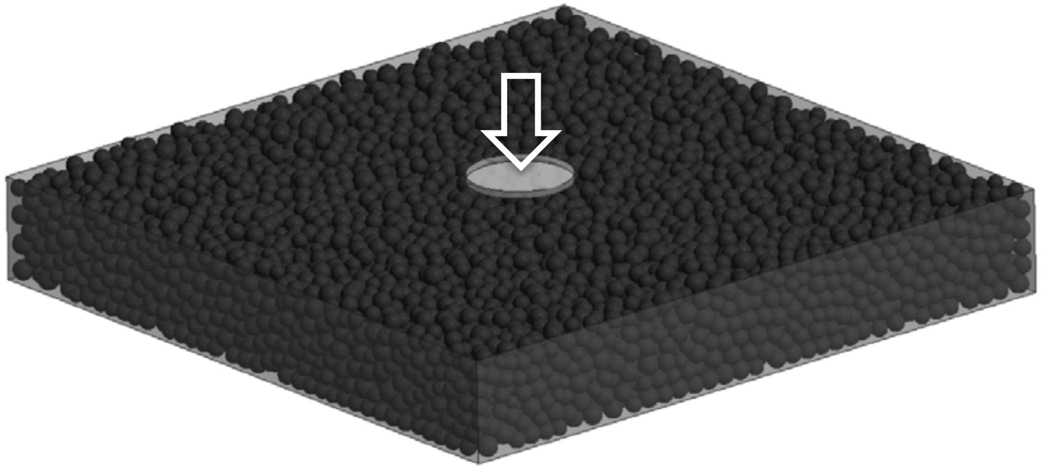


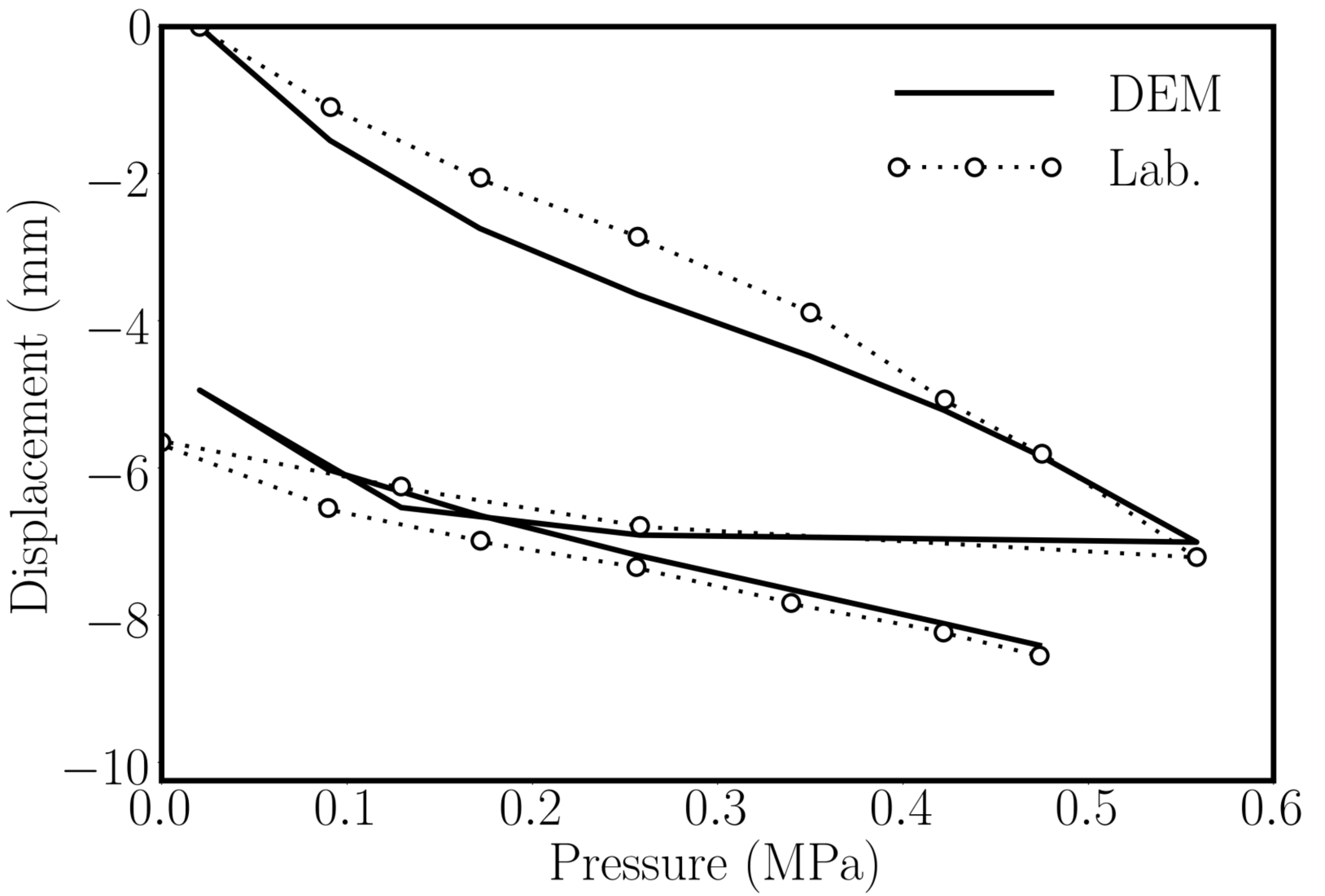
Final Radius and offset

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.

Simple compression – Conical damage

$\sigma_{max} = 500$ MPa
$\alpha = 89.4$ degrees





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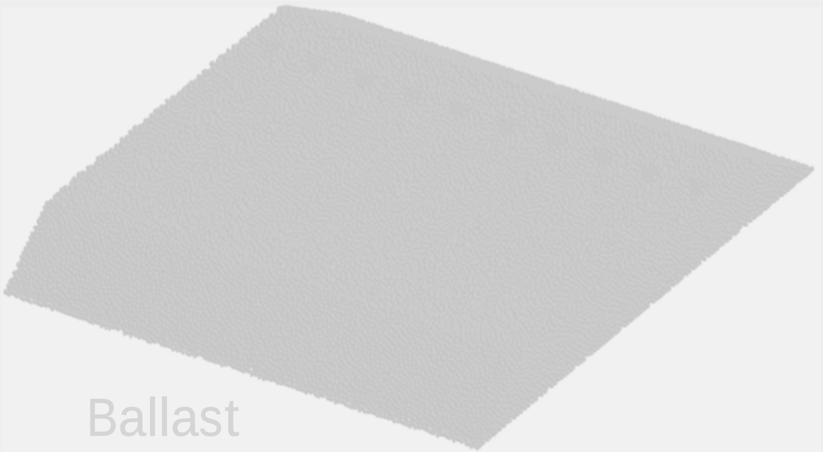
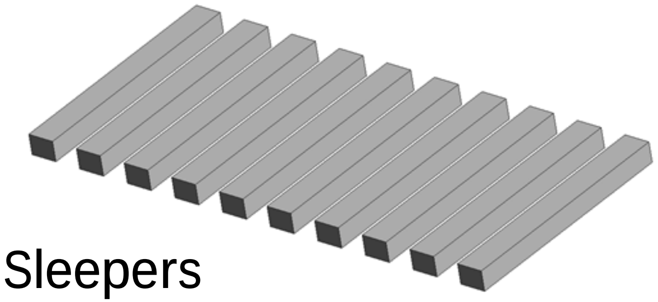
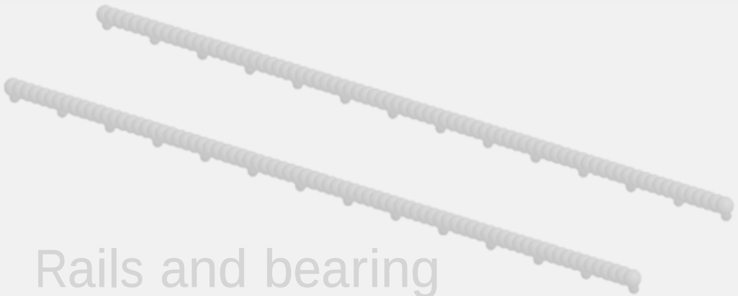
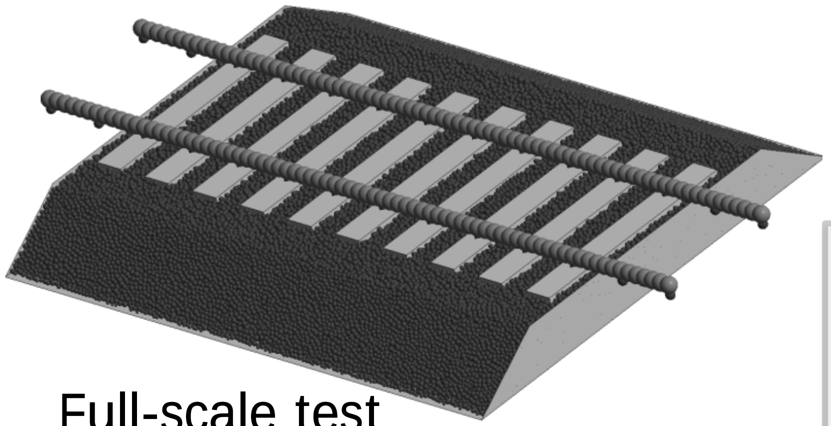
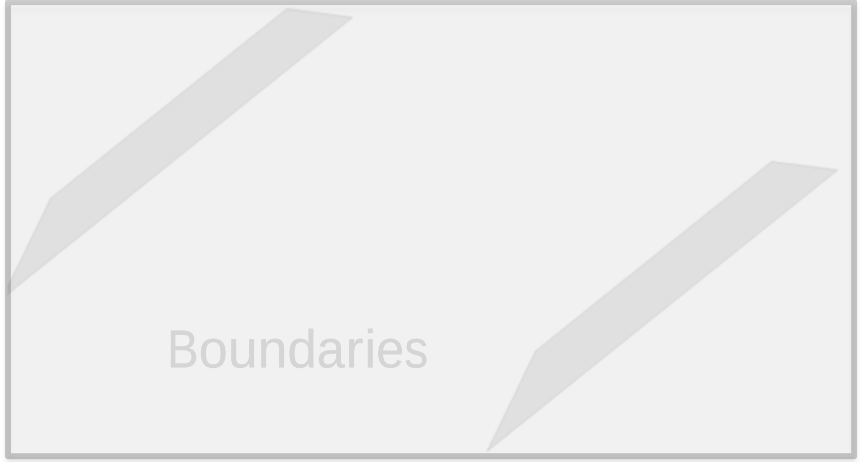
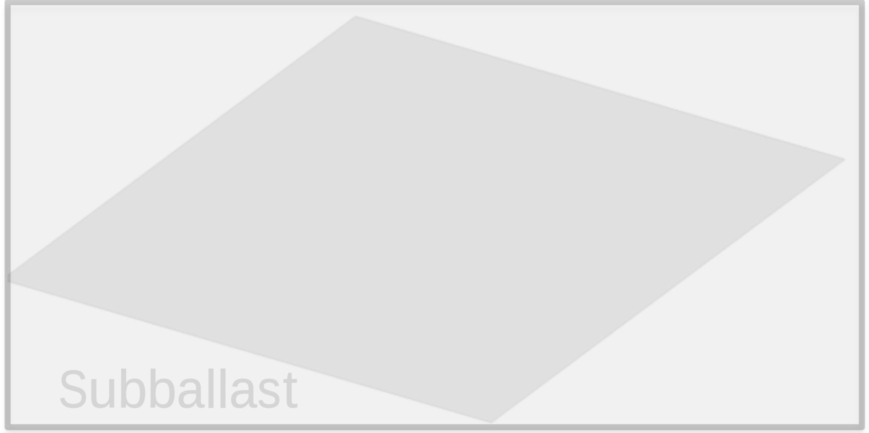

Ballast

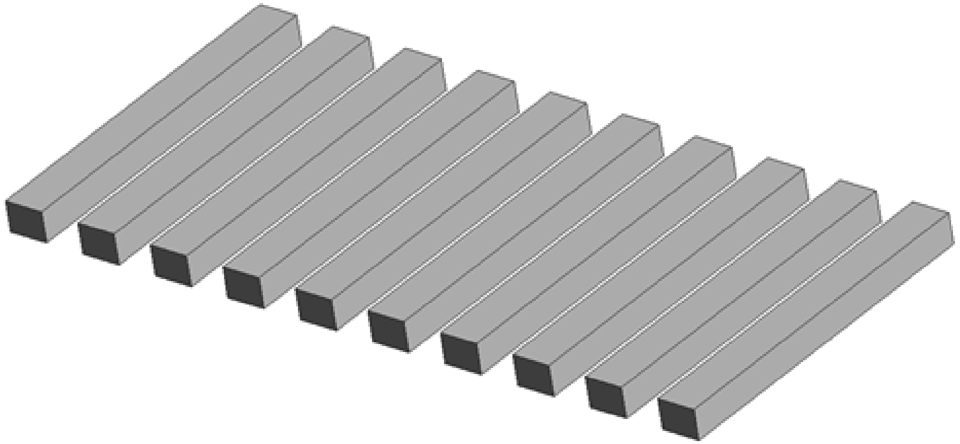

Sleepers


Rails and bearing plates


Full-scale test


Boundaries


Subballast



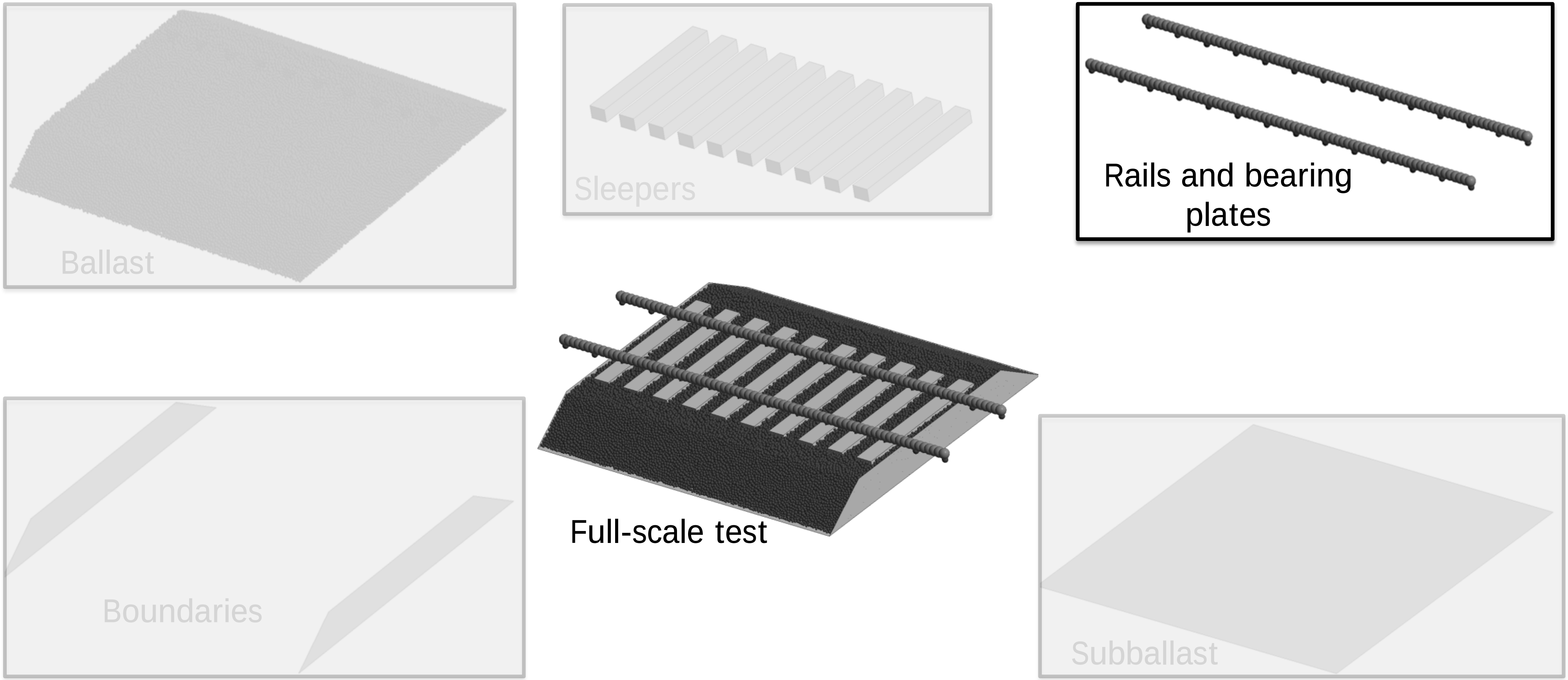
Rigid bodies and simplified geometry

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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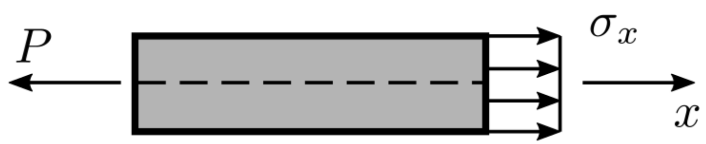
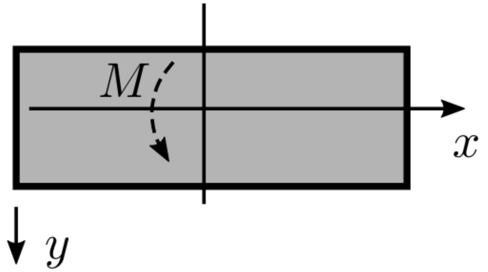
Bonded DEM

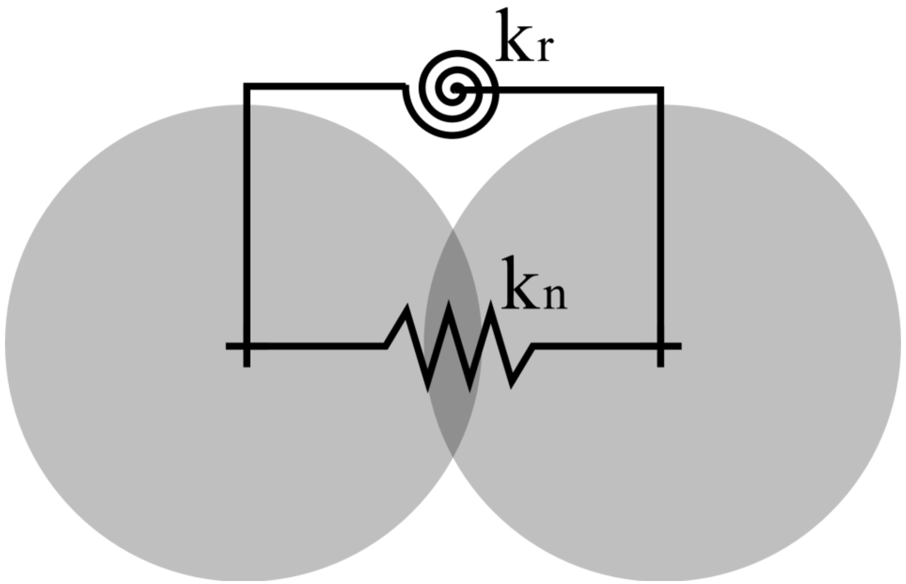


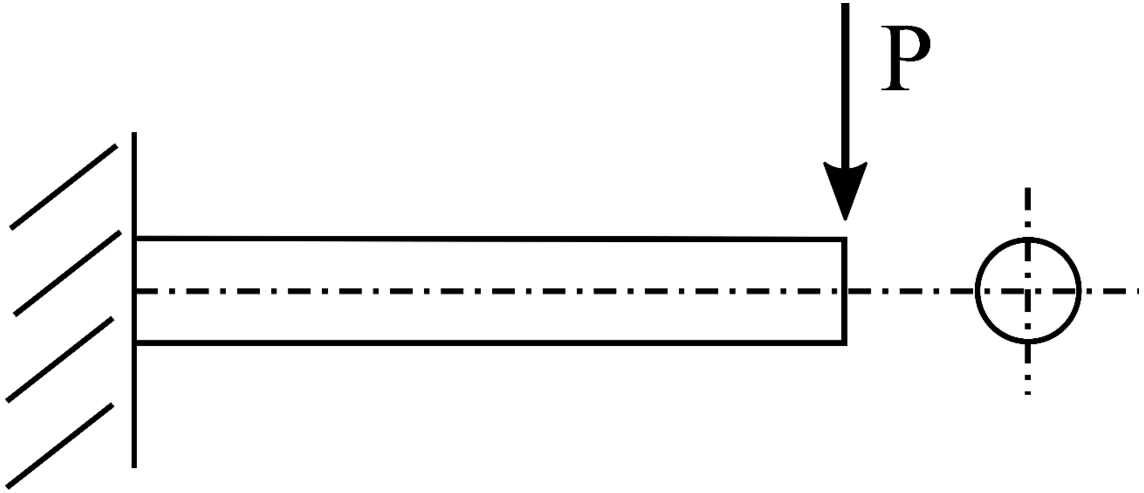
Axial loading: $\sigma_x = \frac{P}{A}$

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

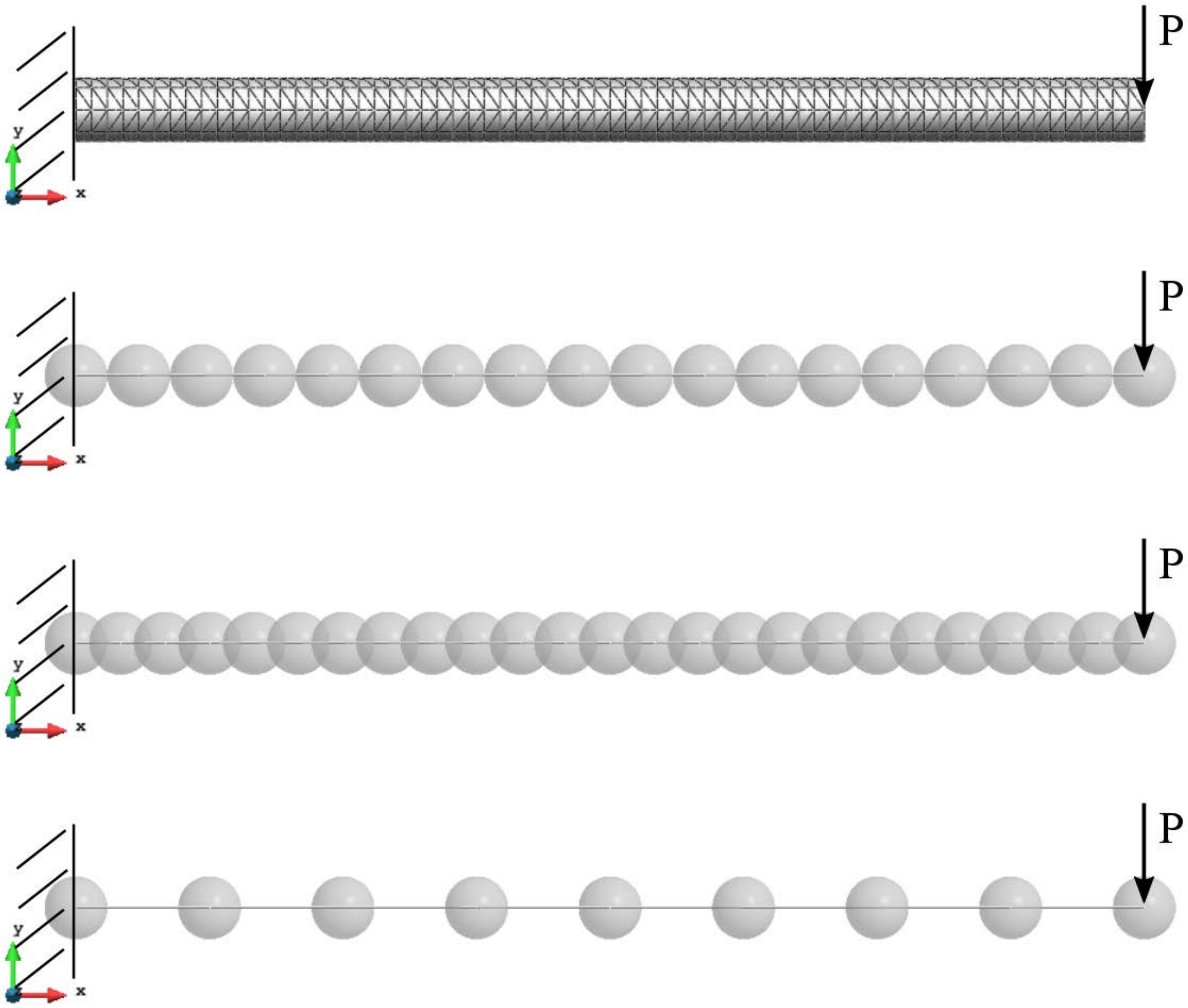


Bending: $\sigma_x = -\frac{My}{I}$





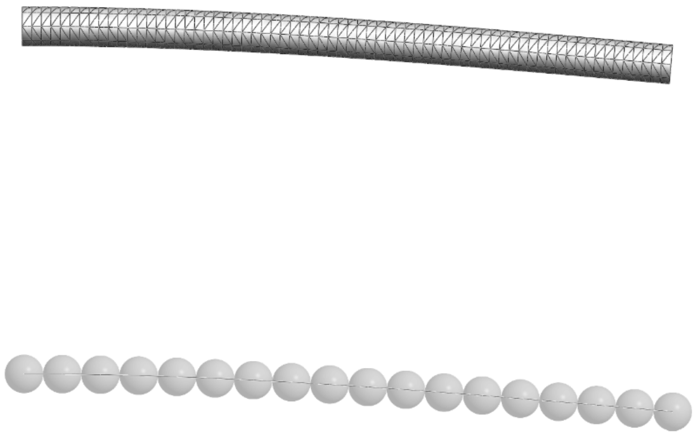
Large deformations
Non-linear problem
} Analytical solution unknown ⇨ FEM

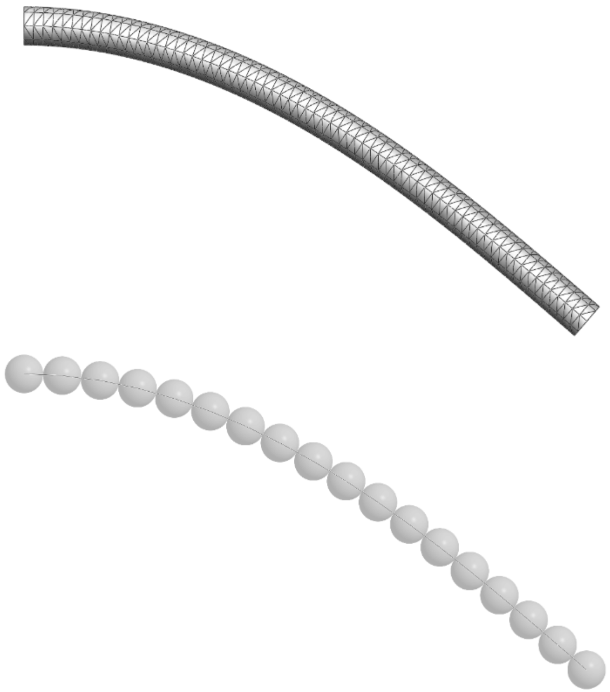

P
y
x
P
y
x
P
y
x
P
y
x

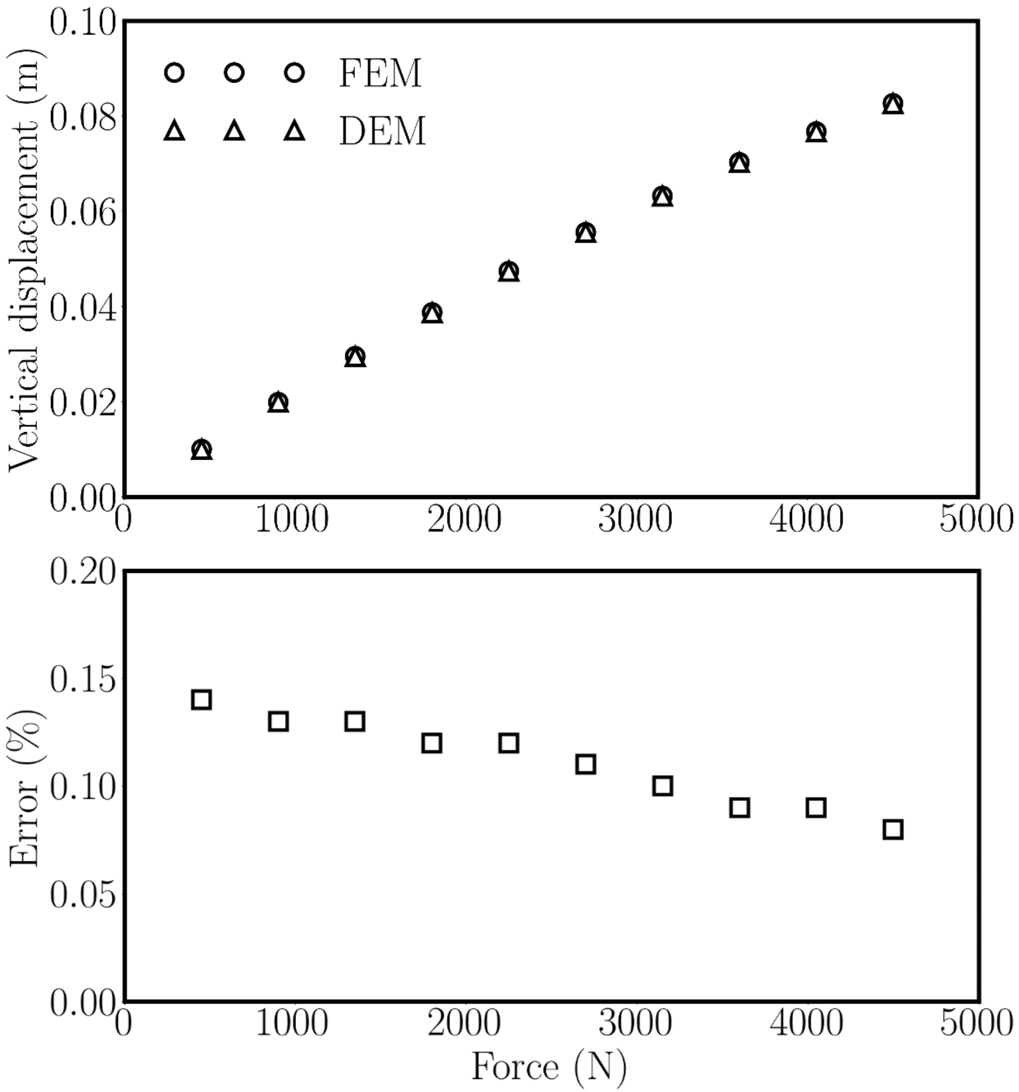
E = 117.21 GPa, v = 0.35,
L = 0.204 m and R = 0.006 m

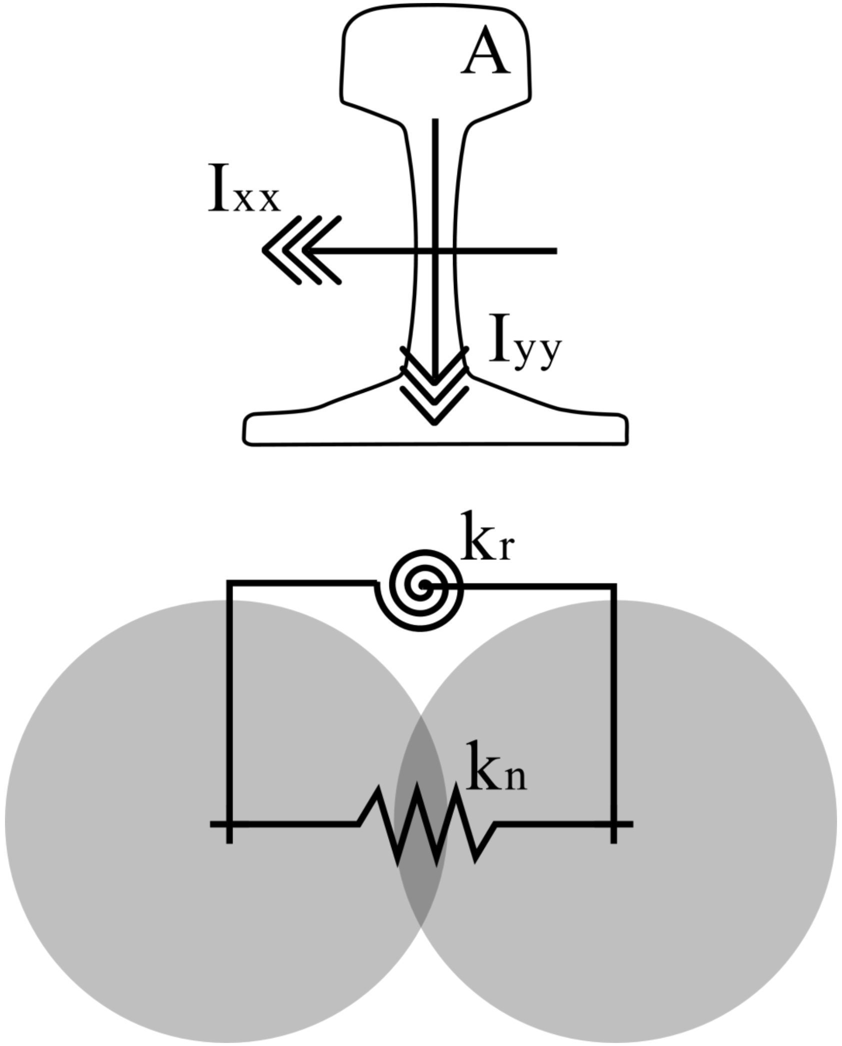
P = 450 N

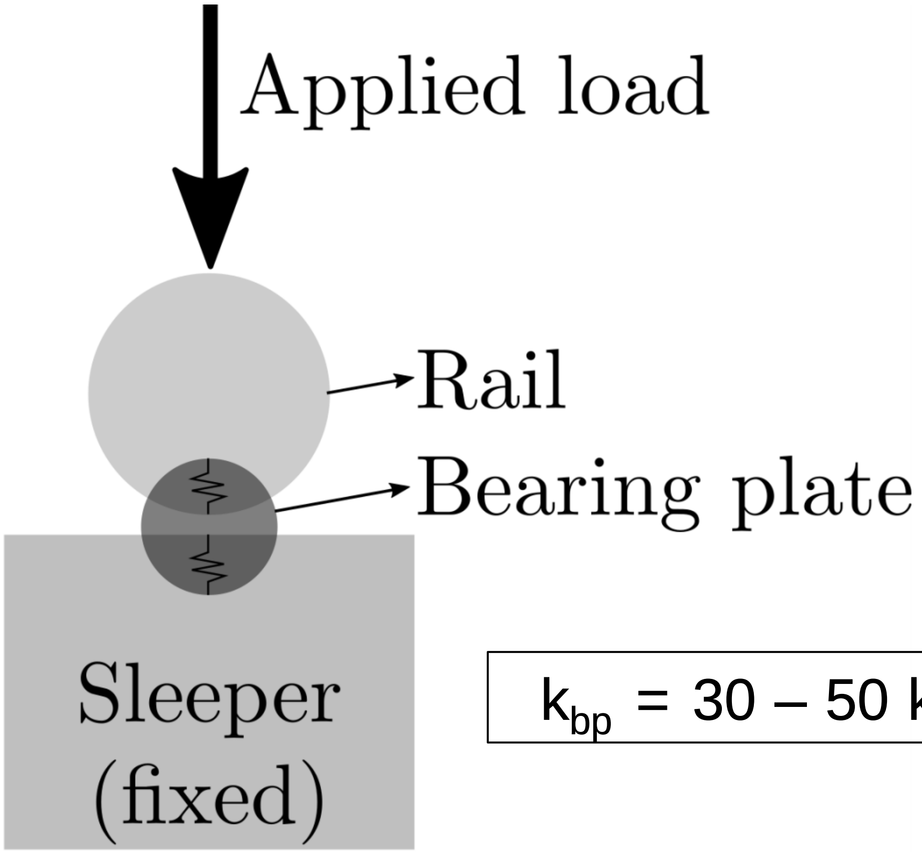
P = 4500 N





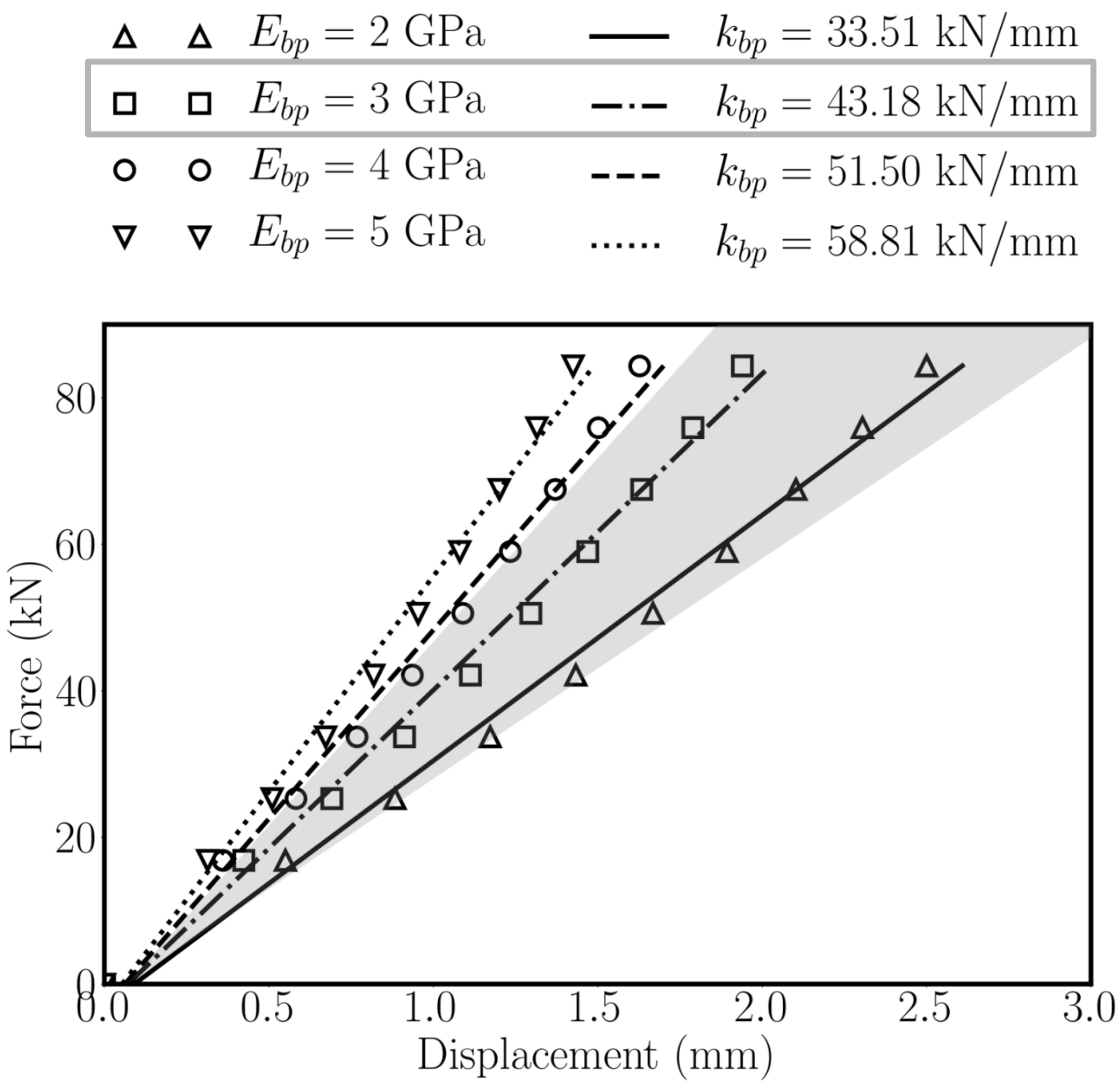


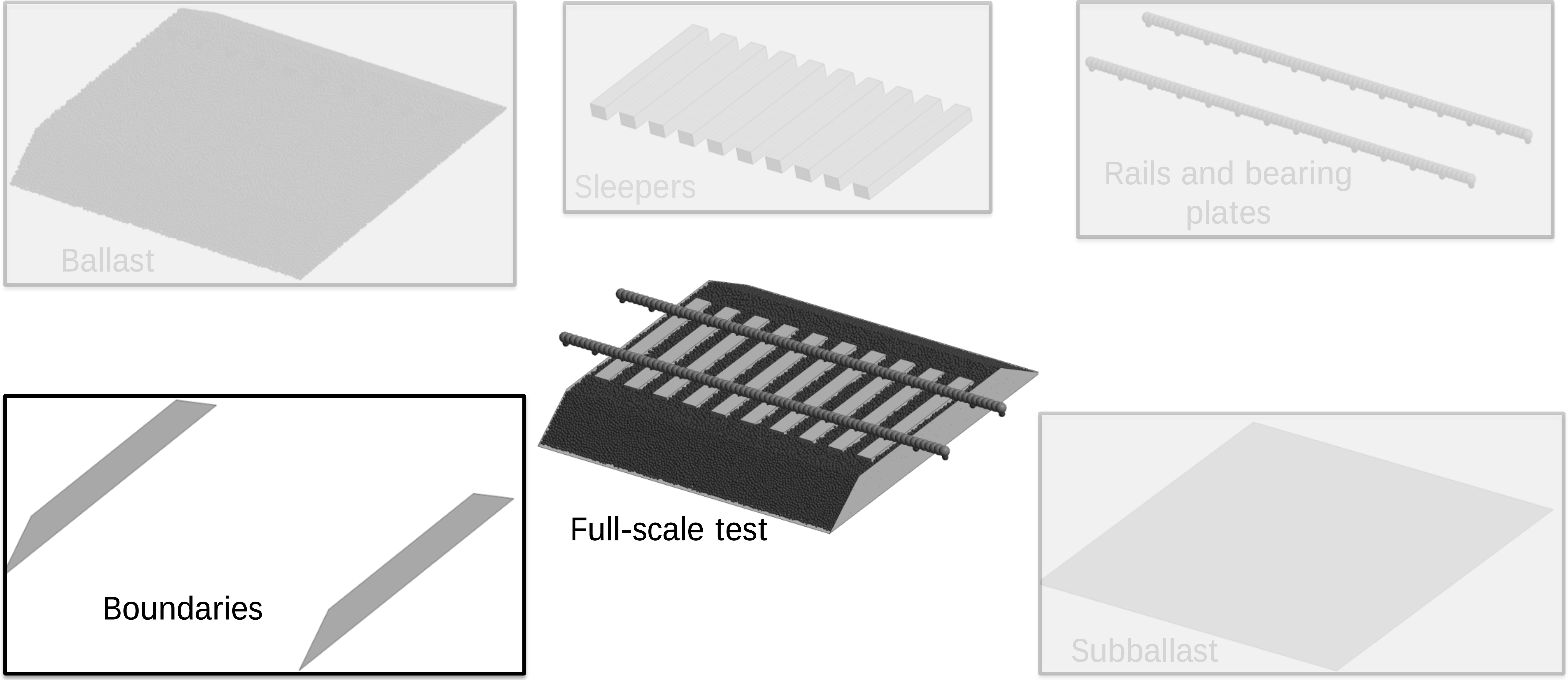

A
Ixx
Iyy
kr
kn



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.

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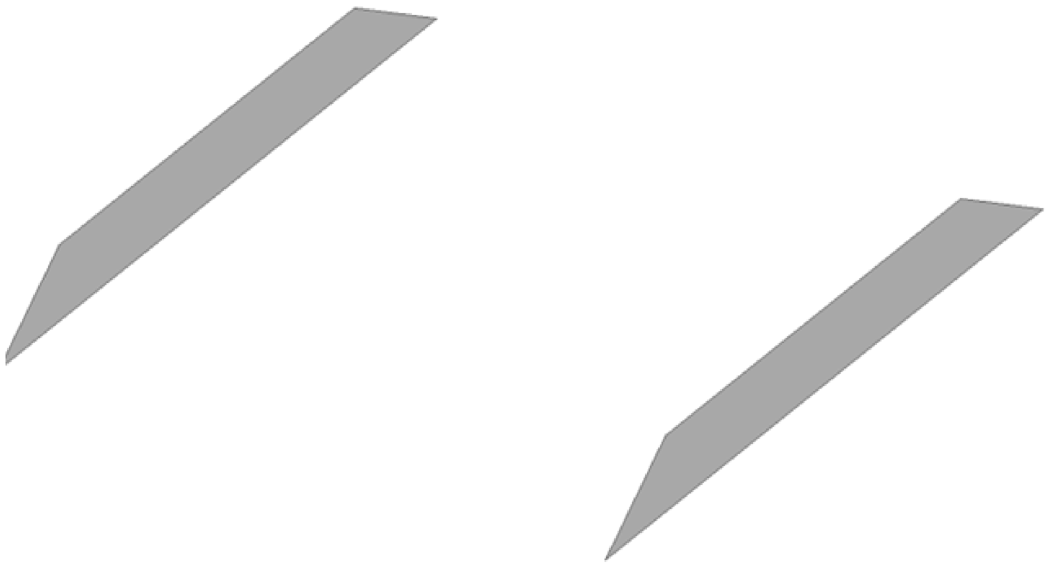
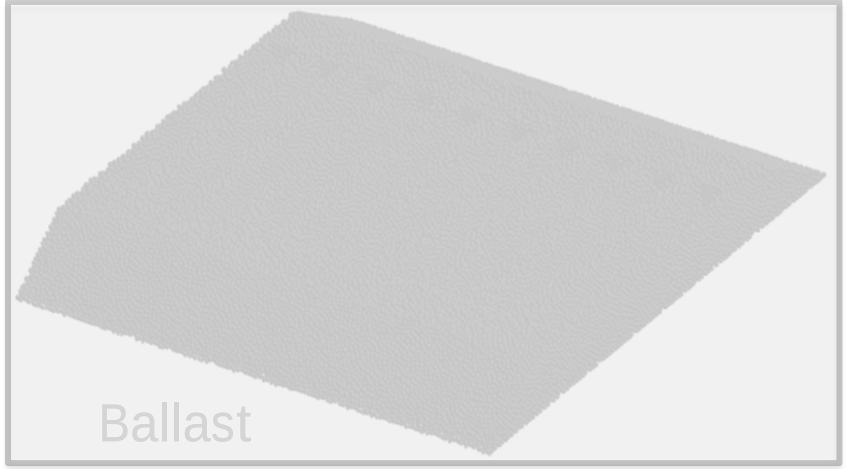


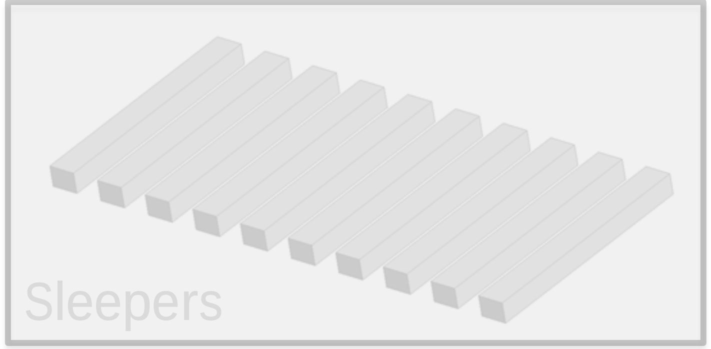
Contact between ballast and boundary walls

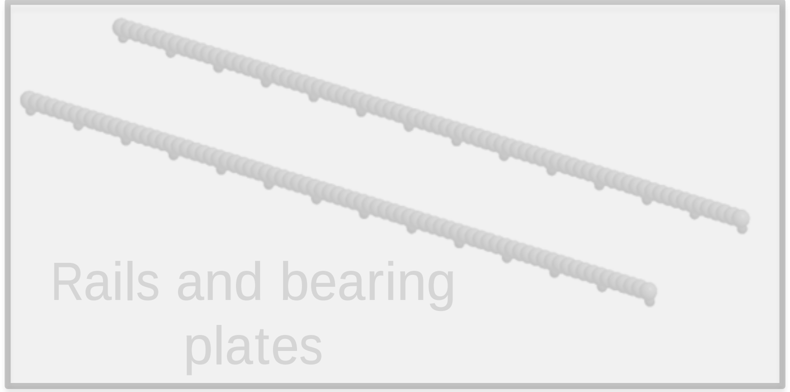
Young modulus = 200 Mpa*

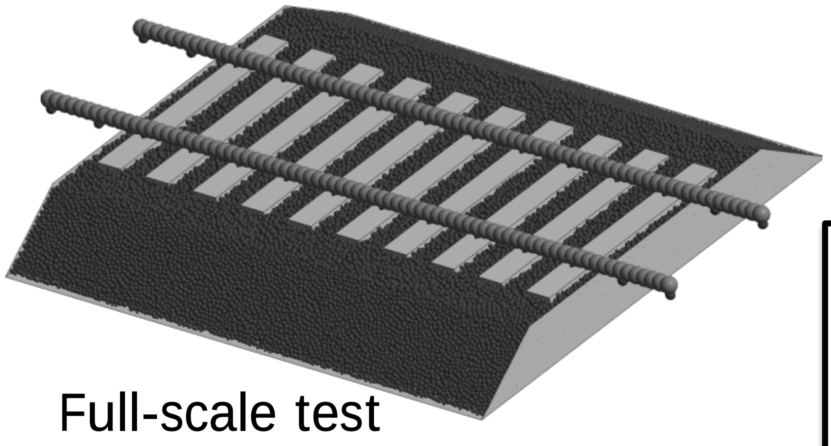
Friction coefficient = 0.0 (“mirrored particles”)

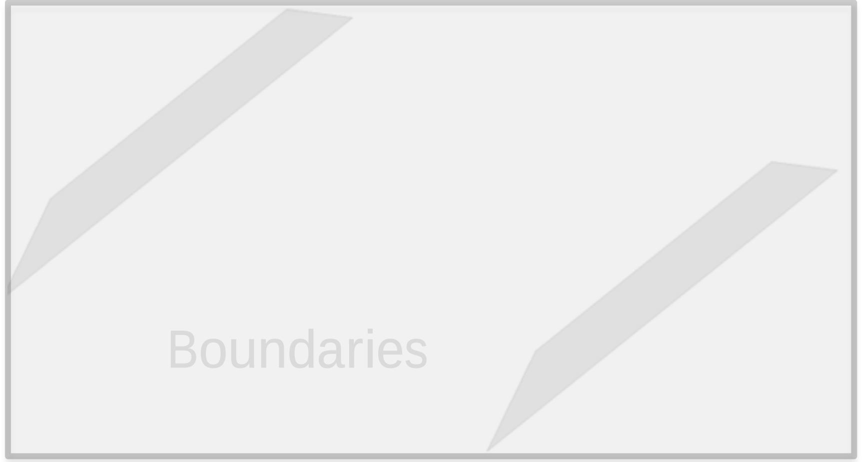
*Paderno, C. Simulation of ballast behaviour under traffic and tamping process. 9th Swiss Transport Research Conference. 2009.

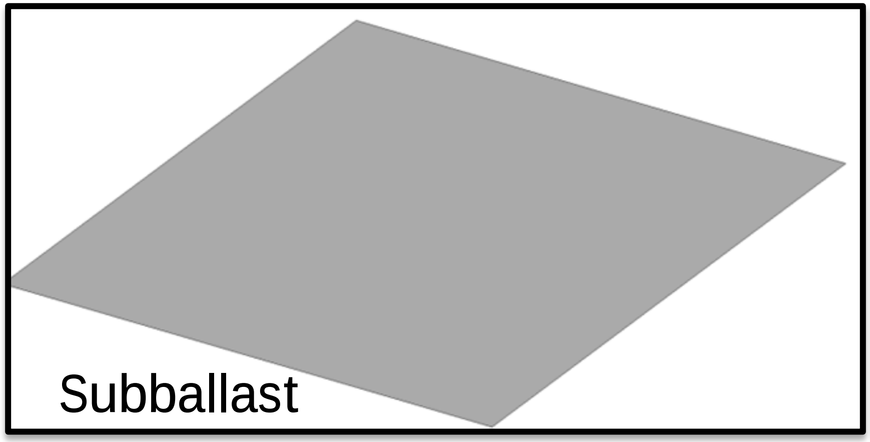

Ballast


Sleepers

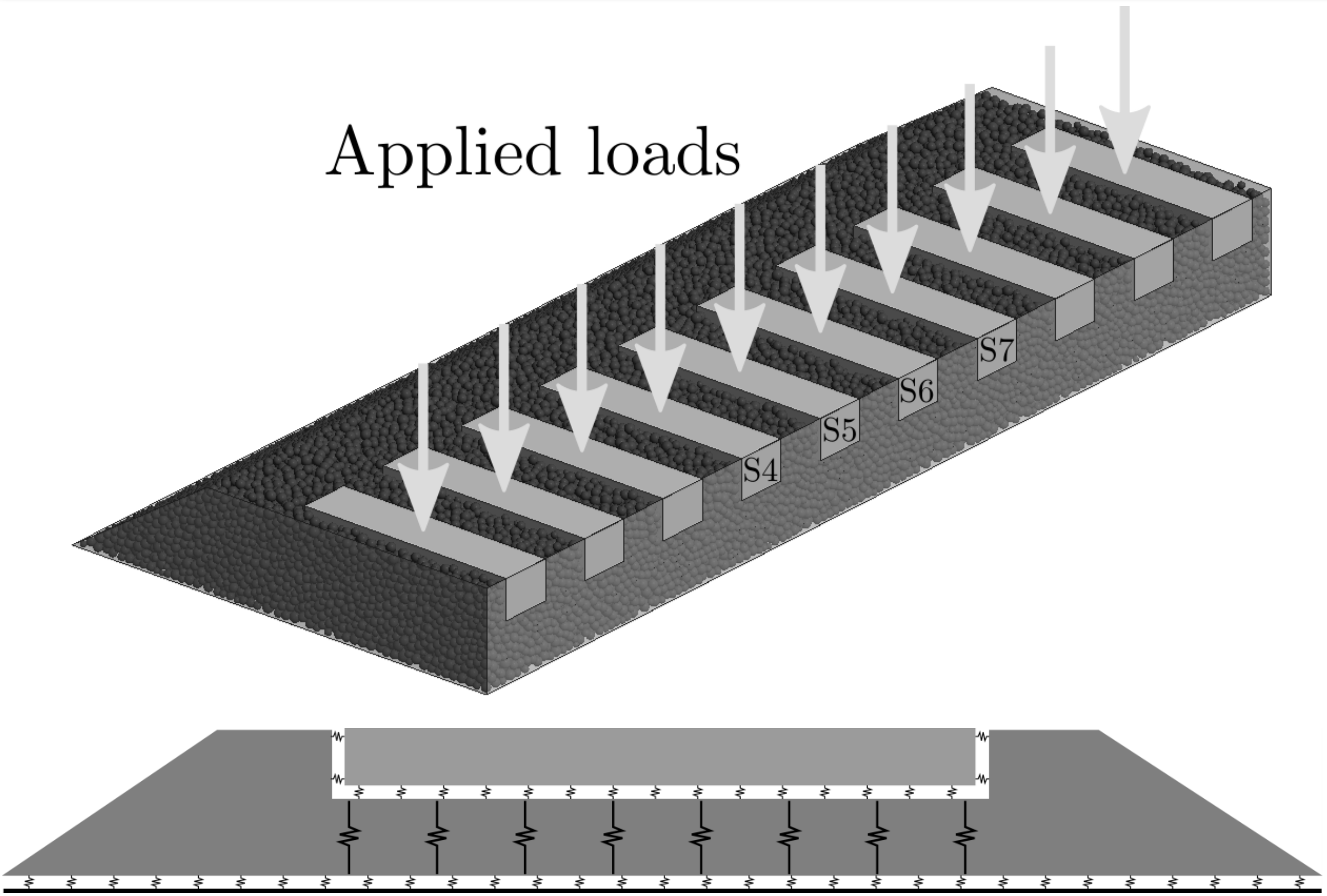

Rails and bearing plates

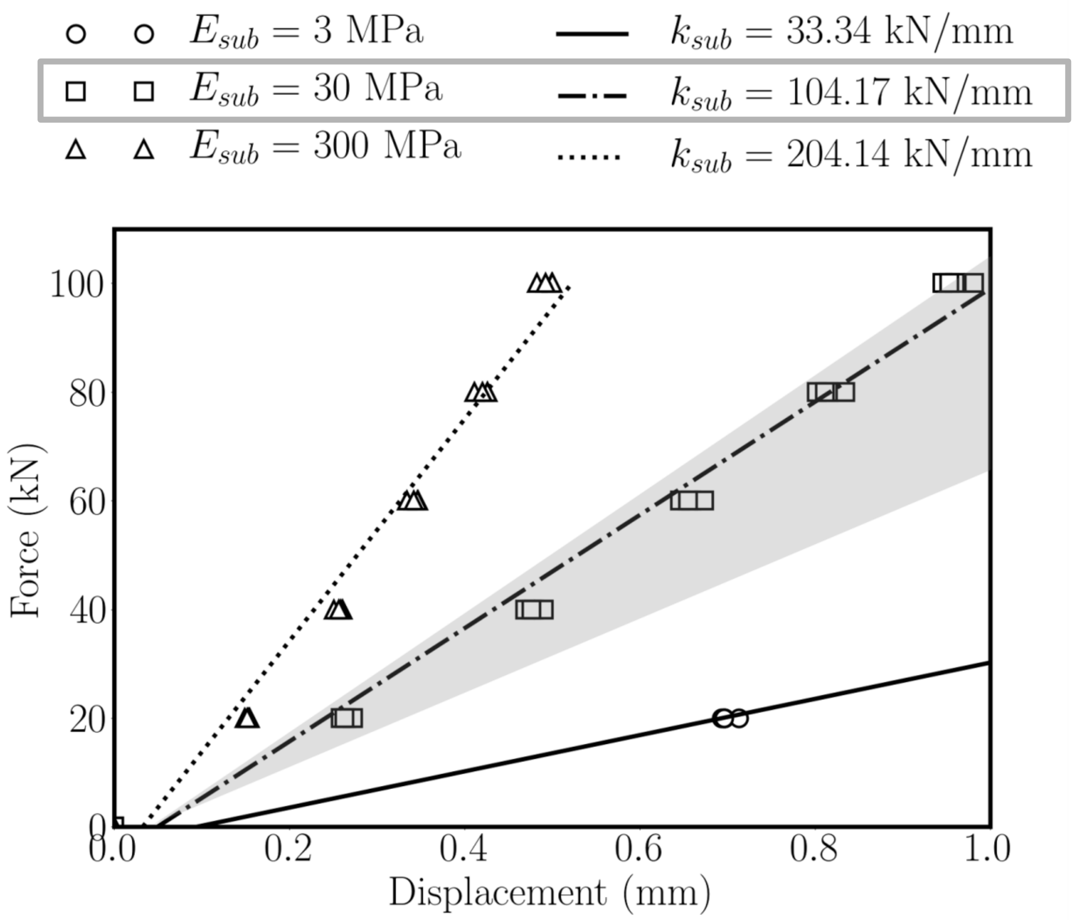

Full-scale test


Boundaries


Subballast

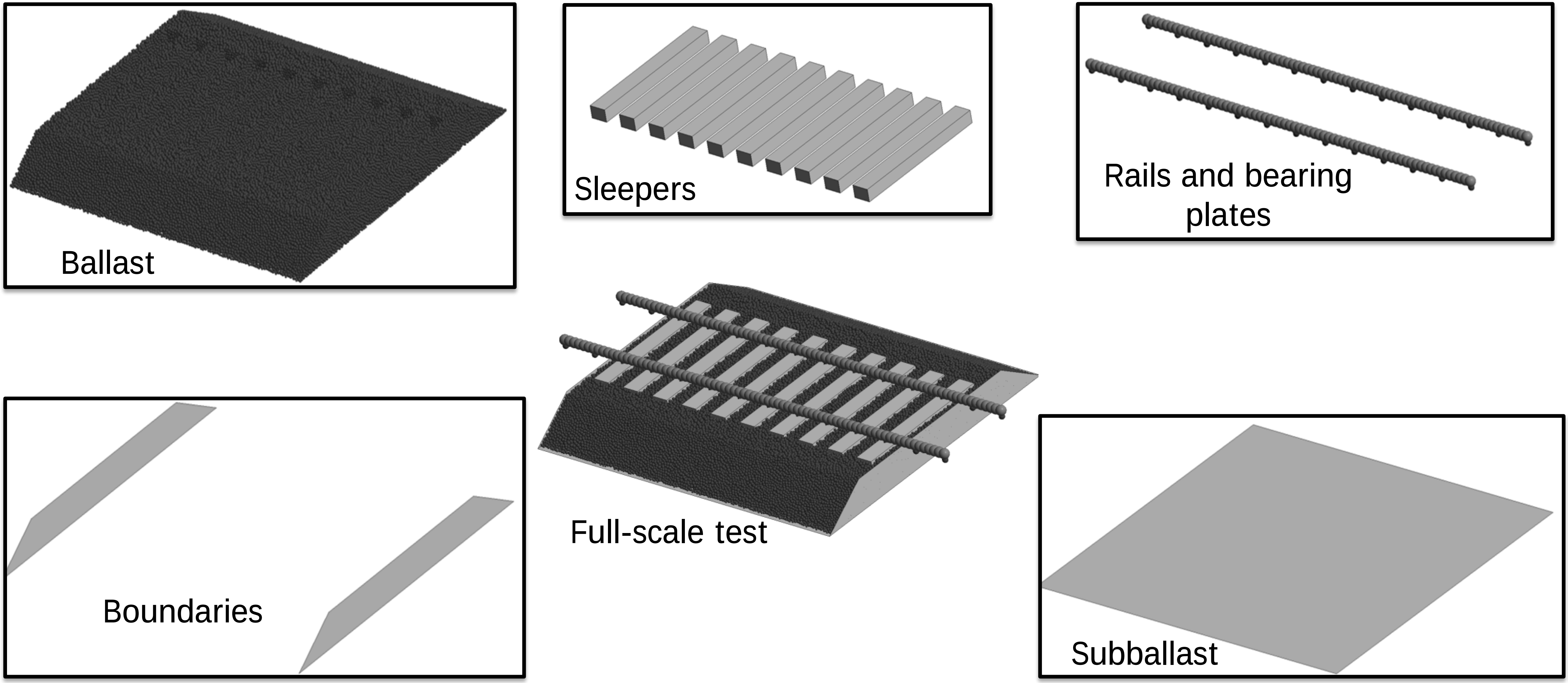
Subballast





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.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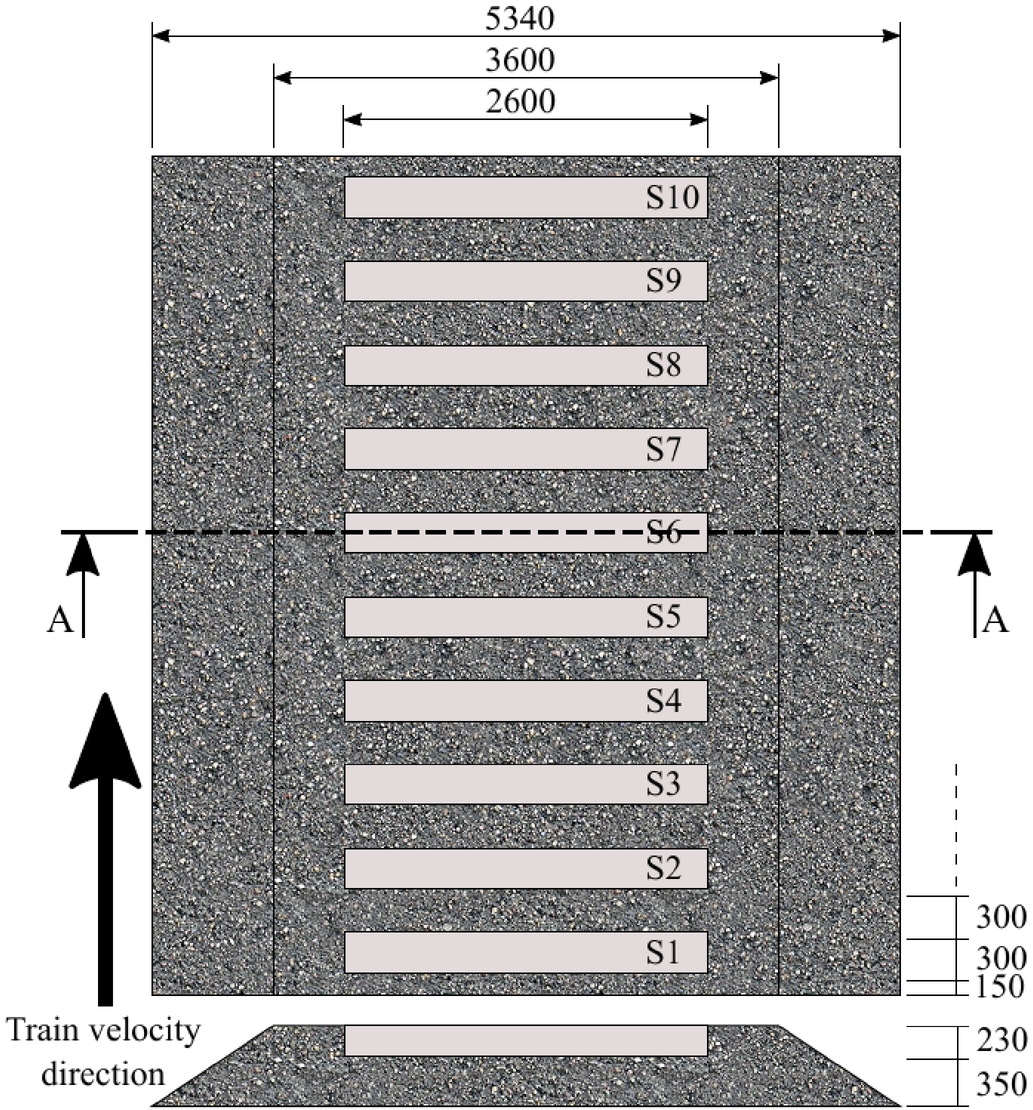
Full scale tests

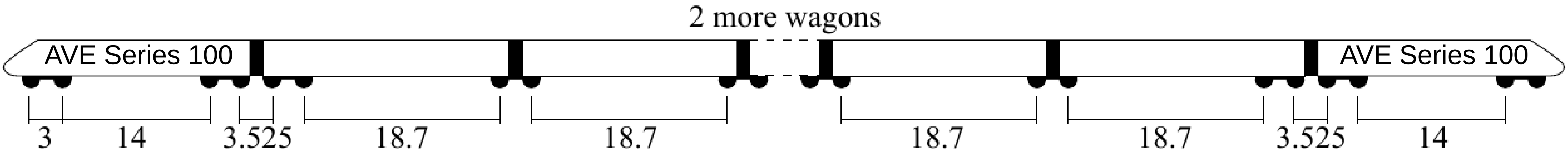


- Scenario 1: Well compacted track
- Scenario 2: Poorly compacted track
- Scenario 3: Fouled track (less friction* and larger contact volume between particles)

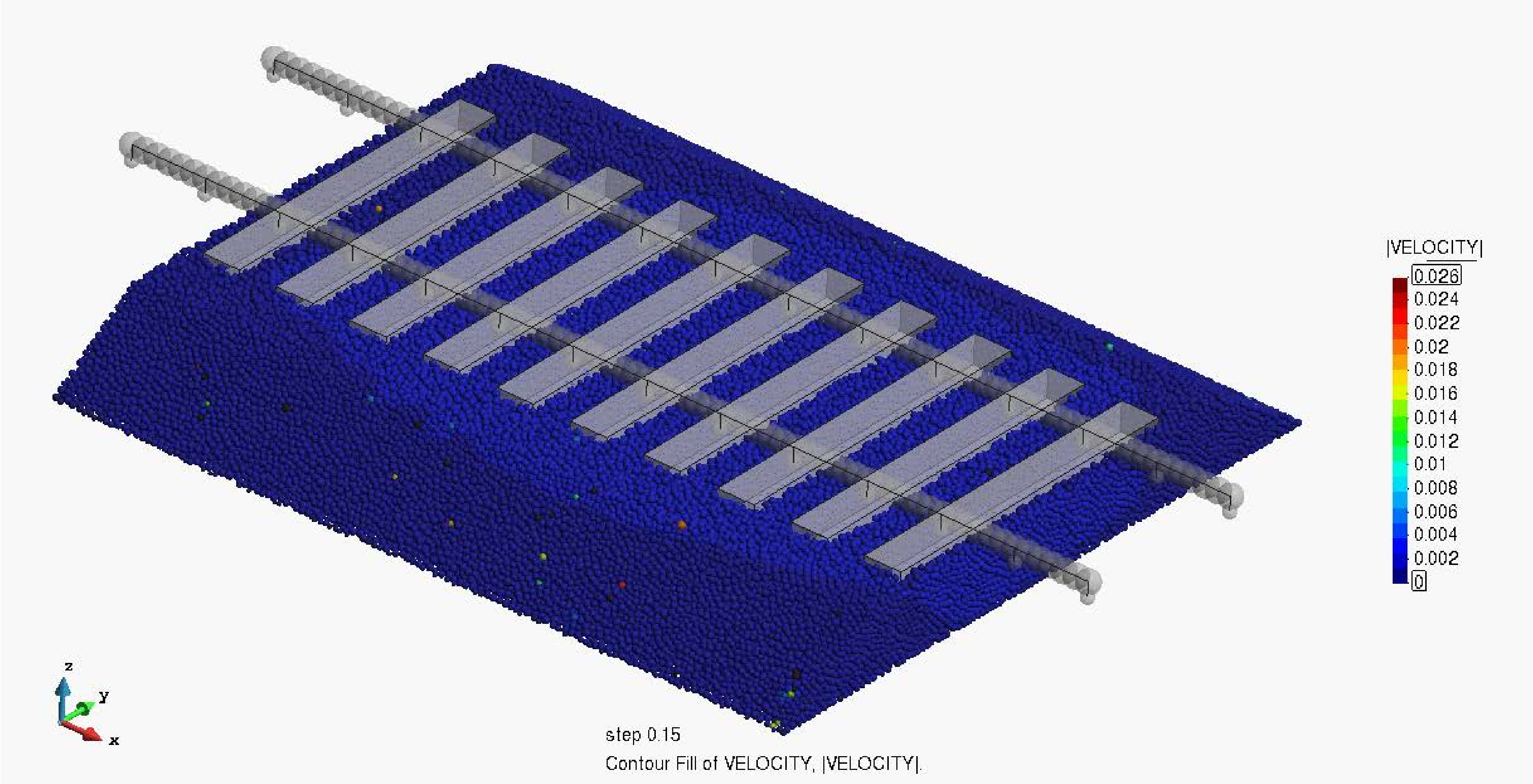
*Huang, H. & Tutumluer, E. (2011). Discrete Element Modeling for fouledrailroad ballast. Construction and Building Materials, 25 (8) 3306–3312.

Full scale tests

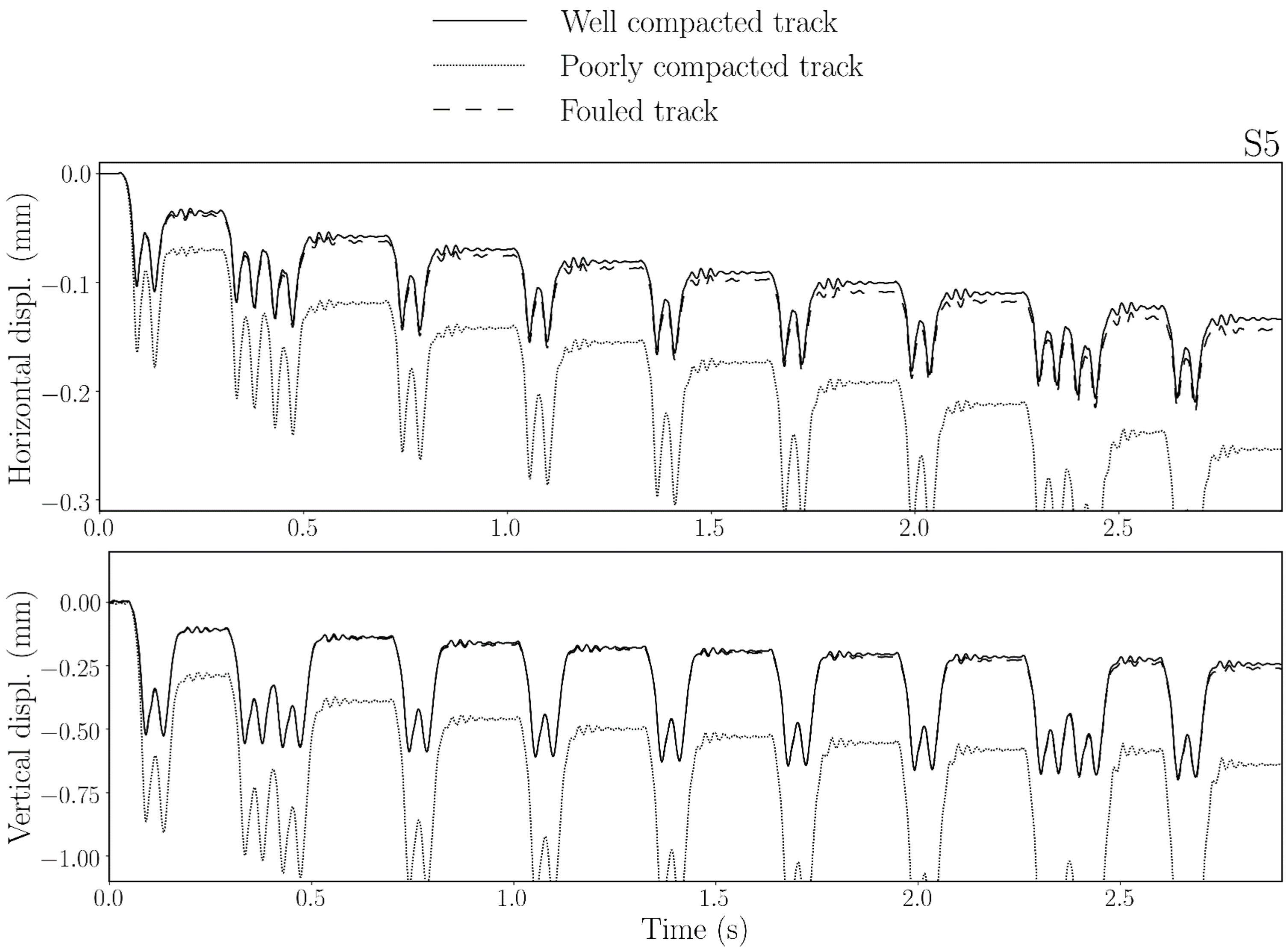
$Q = 168732$ N	Axle load
$v = 250$ km/h	Velocity of the train
$R = 4000$ m	Radius of the curve
$A = 77.45$ cm^2	Rail cross section
$I_{xx} = 3217$ cm^4	Moment of inertia horizontal axis
$I_{yy} = 524$ cm^4	Moment of inertia vertical axis



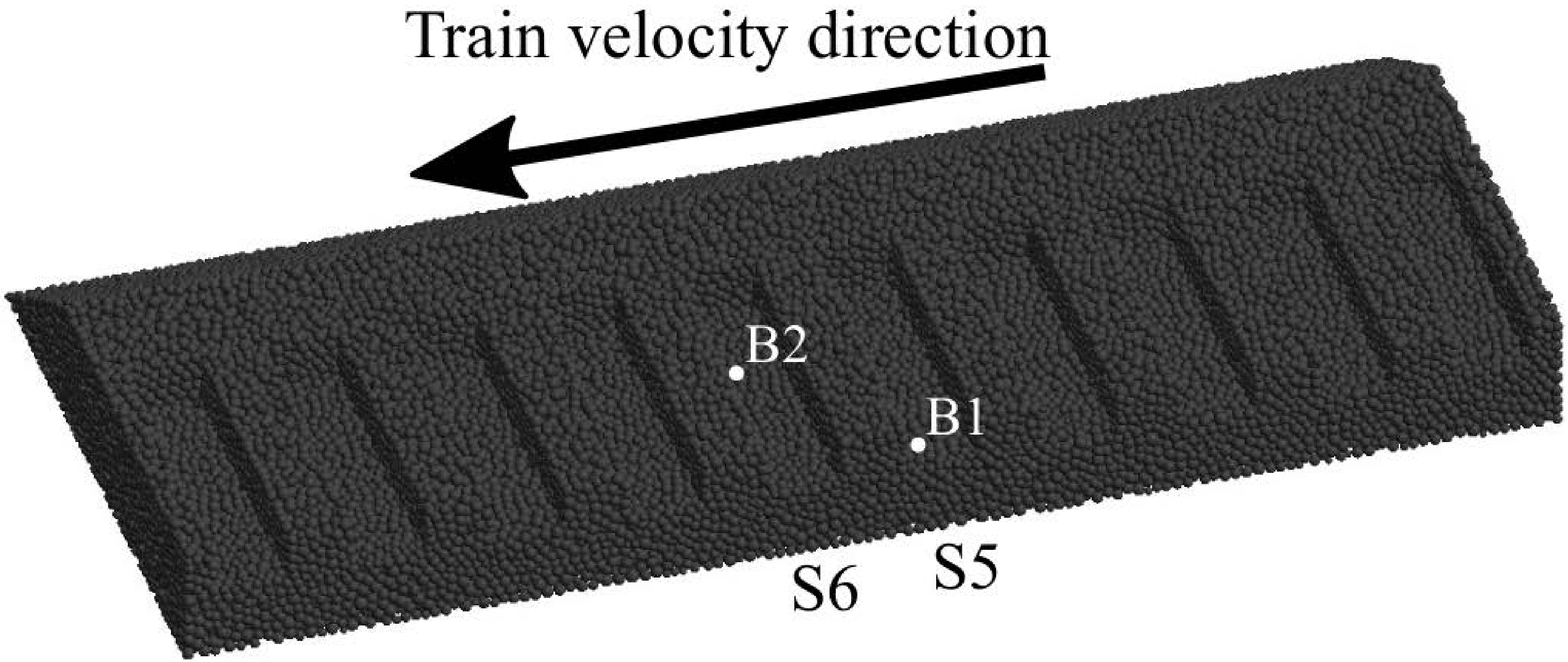
Full scale tests – Ballast lateral velocity



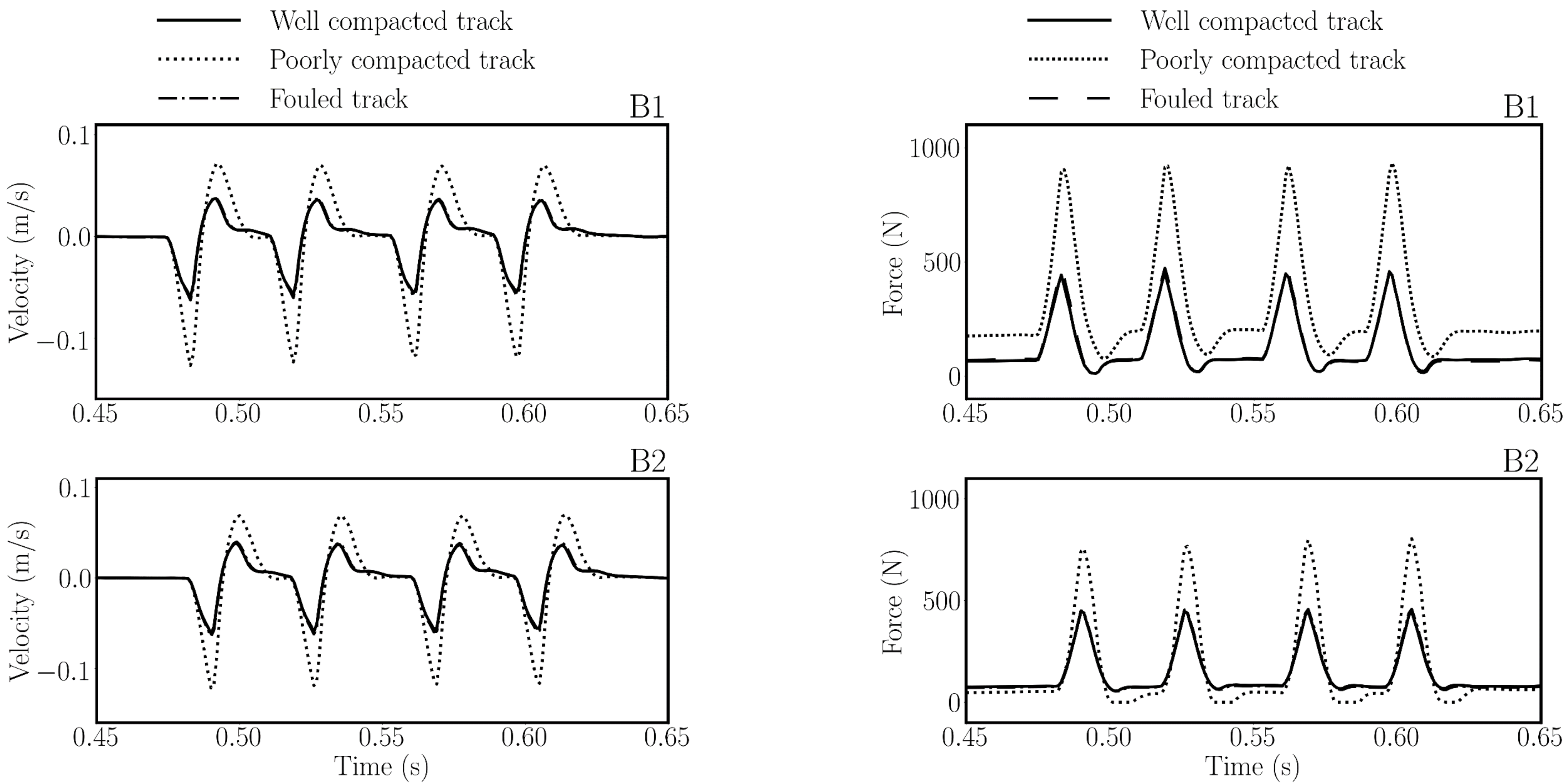
Full scale tests – Sleepers displacement



Full scale tests – Sleepers displacement



Full scale tests – Sleepers displacement



Summary and ongoing work

- Spherical particles are useful for evaluating the macroscopic behaviour of the track (not valid, for example, to analyse the distribution of contacts)
- The DEM can accurately reproduce the behavior of rails and bearing plates making easy the coupling with railway ballast discrete particles
- The numerical tool presented allows the user to test different situations:
  - Ballast granulometry or properties
  - Sleepers design
  - Bearing plates and rails

RESILTRACK (Resilience of Railway Infrastructures Against Climate Change)

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- Analysing how to measure track deflections in a real railway track section (high-speed if possible)
- Searching more data to validate conical damage parameters and ballast fouling conditions
- Testing other particle geometries (clusters of spheres) more similar to ballast particles

Thank you for your attention!

Questions?

jirazabal@cimne.upc.edu