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

Joaquín Irazábal, Fernando Salazar and Eugenio Oñate
Register for free at https://www.scipedia.com to download the version without the watermark

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

Register for free at https://www.scipedia.com to download the version without the watermark
Previous calculations

Good results applying the Hertz-Mindlin contact model

Register for free at https://www.scipedia.com to download the version without the watermark

Simple compression – Hertz
Hertzian contact model: contact stiffness depends on the contact volume but does not take into account edge breakage.

Register for free at https://www.scipedia.com to download the version without the watermark.
Conical damage contact model: accounts for edge breakage
Two new material properties to define: Maximum stress and $\alpha$


Register for free at https://www.scipedia.com to download the version without the watermark
Register for free at https://www.scipedia.com to download the version without the watermark.
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*
Axial loading: $\sigma_x = \frac{P}{A}$

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

Bending: $\sigma_x = -\frac{My}{I}$
Large deformations
Non-linear problem

\[ \begin{align*}
\text{Analytical solution unknown} \quad &\Rightarrow \quad \text{FEM}
\end{align*} \]
Ballast | **Sleepers** | Rails, bearing plates | Boundary walls | Subballast |
| Full scale railway track tests | Summary and ongoing work
E = 117.21 GPa, v = 0.35,
L = 0.204 m and R = 0.006 m

P = 450 N

P = 4500 N

Bonded DEM

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

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

\[ k_{\text{sub}} = 70 - 110 \text{ kN/mm} \]
Ballast | Sleepers | Rails, bearing plates | Boundary walls | Subballast |

**Summary and ongoing work**

- **Full-scale test**

**Ballast**

**Sleepers**

**Rails and bearing plates**

**Boundaries**

**Subballast**

**Full scale railway track tests**

Summary and ongoing work
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)

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 cm²  Rail cross section
$I_{xx} = 3217$ cm$^4$  Moment of inertia horizontal axis
$I_{yy} = 524$ cm$^4$  Moment of inertia vertical axis

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

![Graph showing sleepers displacement over time for well compacted, poorly compacted, and fouled tracks.](image)

- Well compacted track
- Poorly compacted track
- Fouled track

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

Train velocity direction

B1
B2
S5
S6
Full scale tests – Sleepers displacement

Well compacted track
Poorly compacted track
Fouled track

Well compacted track
Poorly compacted track
Fouled track

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

- 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