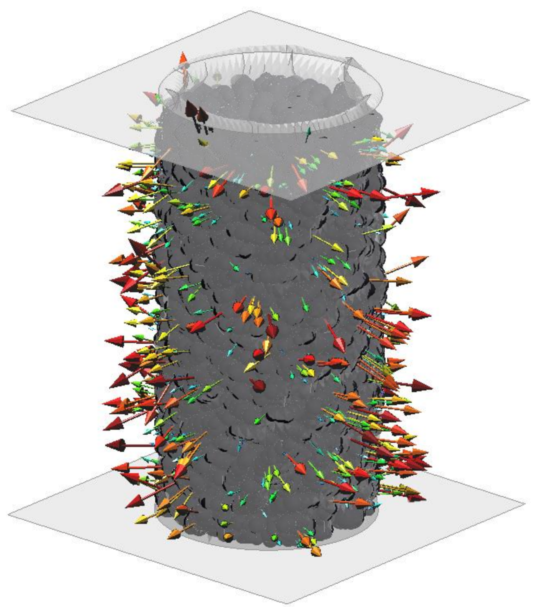
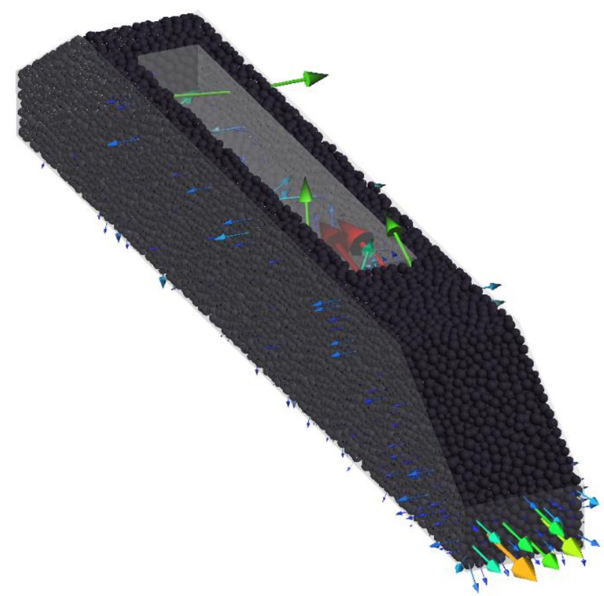
ECCOMAS Congress 2016

5 - 10 JUNE 2016 Crete Island, Greece

European Congress on Computational Methods in Applied Sciences and Engineering

Geometric representation of railway ballast using the Discrete Element Method (DEM)





Authors: Joaquín Irazábal, Fernando Salazar and Eugenio Oñate

OUTLINE

- Motivation and objectives
- Railway Ballast
- Discrete Element Method (DEM)
- Software used
- DEM ballast geometric representation
- Test results
- Conclusions

MOTIVATION AND OBJECTIVES

Motivation:

- Increasing interest all over the world in high-speed trains

Objectives:

- Study railway ballast properties
- <u>Develop a numerical tool to reproduce the behaviour of railway ballast using the DEM</u>
- Validate the code

BALAMED (Jan. 2013 – Dec. 2015)

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MOTIVATION AND OBJECTIVES

Motivation:

– Increasing interest all over the world in high-speed trains → unfavorable conditions

Objectives:

– Study railway ballast properties

– Develop a numerical tool to reproduce the behaviour of railway ballast using the DEM

– Validate the code

– Evaluate the influence of external factors

BALAMED (Jan. 2013 – Dec. 2015)
MONICAB (Jan. 2016 – Dec. 2018)

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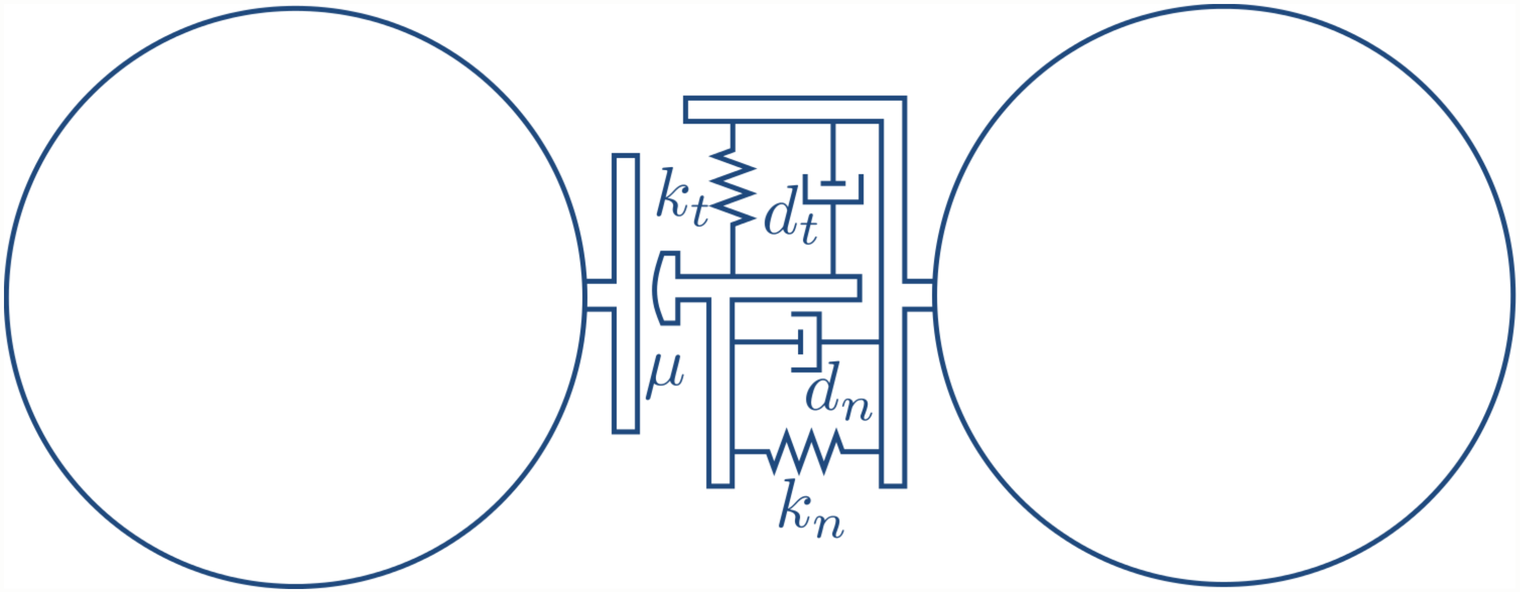
RAILWAY BALLAST

Layer of granular material placed under the sleepers whose roles are: resisting to vertical and horizontal loads and facing climate action

DISCRETE ELEMENT METHOD

Contact constitutive model:

Rigid bodies, deformation concentrated in contact points



Force balance

$$\mathrm{m} \cdot \ddot{\mathbf{u}} = \mathbf{F}^{ext} + \sum_{j=1}^{n_c} \mathbf{F}^c + \mathbf{F}^{damp}$$

Torque balance

$$\mathbf{I} \cdot \dot{\omega} = \mathbf{T}^{ext} + \sum_{j=1}^{n_c} (\mathbf{r}^c \times \mathbf{F}^c) + \mathbf{T}^{damp}$$

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DISCRETE ELEMENT METHOD

Algorithm:

1
- Contact Detection

2
- Forces Evaluation

3
- Integration of Motion

1
- Contact Detection

One Calculation Step

SOFTWARE

DEMpack Discrete / finite elements simulation software

http://www.cimne.com/dempack/

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SOFTWARE

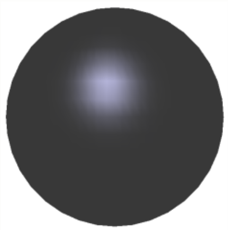
DEMpack Discrete / finite elements simulation software

GiD → KRATOS MULTI-PHYSICS → GiD

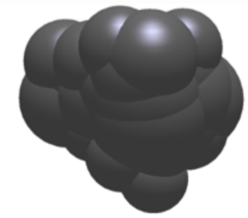
http://www.cimne.com/dempack/
http://www.cimne.com/kratos/
http://gid.cimne.upc.es/

DEM BALLAST GEOMETRIC REPRESENTATION

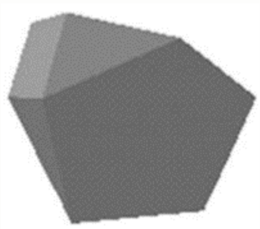
Spheric particles



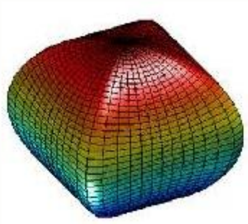
Sphere clusters



Polyhedral particles

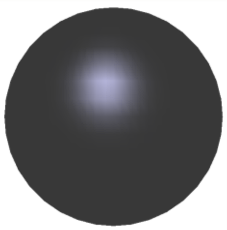


Superquadrics



DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles



Sphere clusters

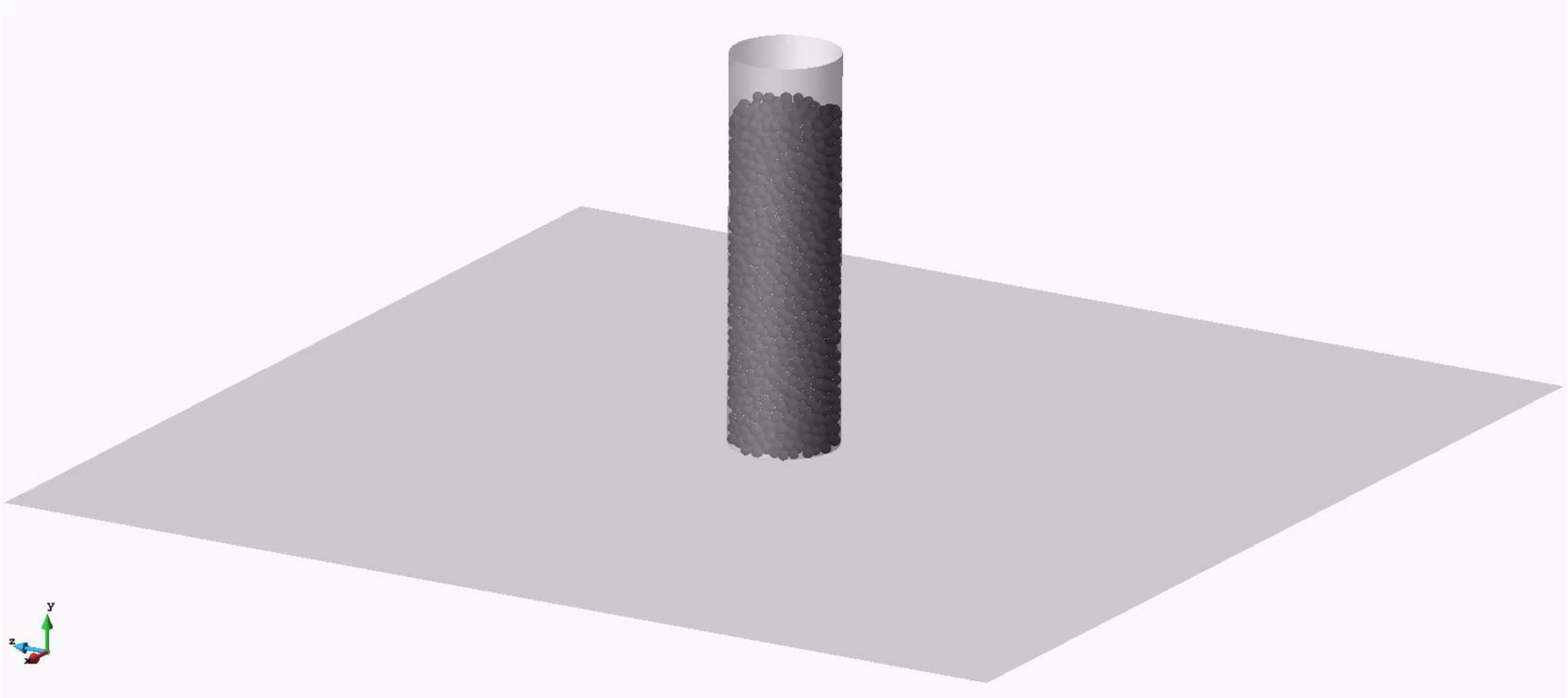
Polyhedral particles

Superquadrics

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles:

Each DE particle is a sphere

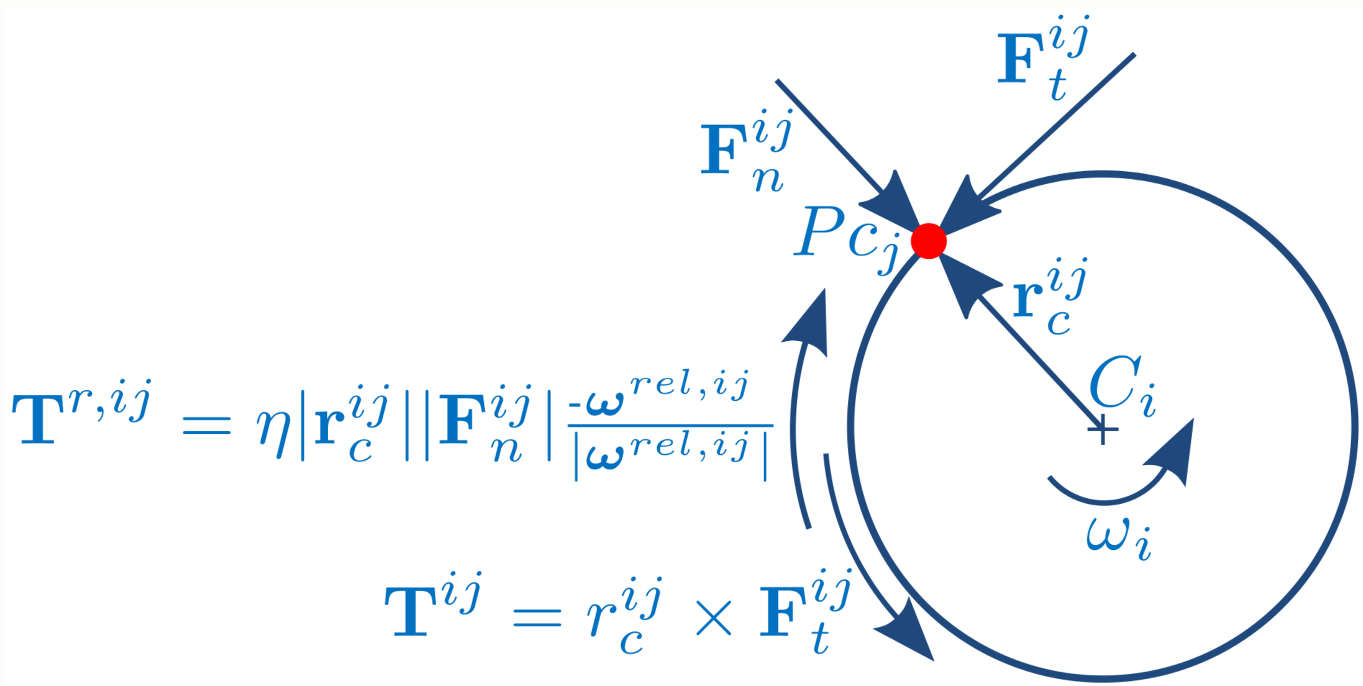


How to avoid excessive particle rotation? → Rolling friction

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles:

<u>Rolling friction</u>: geometrical "*property*" that consist of imposing a virtual torque opposite to particle rotation and dependent on its size



C. M. Wensrich and A. Katterfeld. Rolling friction as a technique for modelling particle shape in DEM. Powder Technol., 217 (2012) 409–417.

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles:

Computational cost, due to easier neighbour search and forces evaluation

Sphere meshers available

DEM-FEM interaction can be computed accurately

M. Santasusana, J. Irazábal, E. Oñate, J. M. Carbonell, The Double Hierarchy Method. A parallel 3D contact method for the interaction of spherical particles with rigid FE boundaries using the DEM, Comp. Part. Mech. (2016) 1–22.

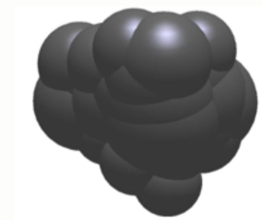
DE particles geometry is very different to real ones

A new unknown parameter is needed to define the material (rolling friction)

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles

Sphere clusters



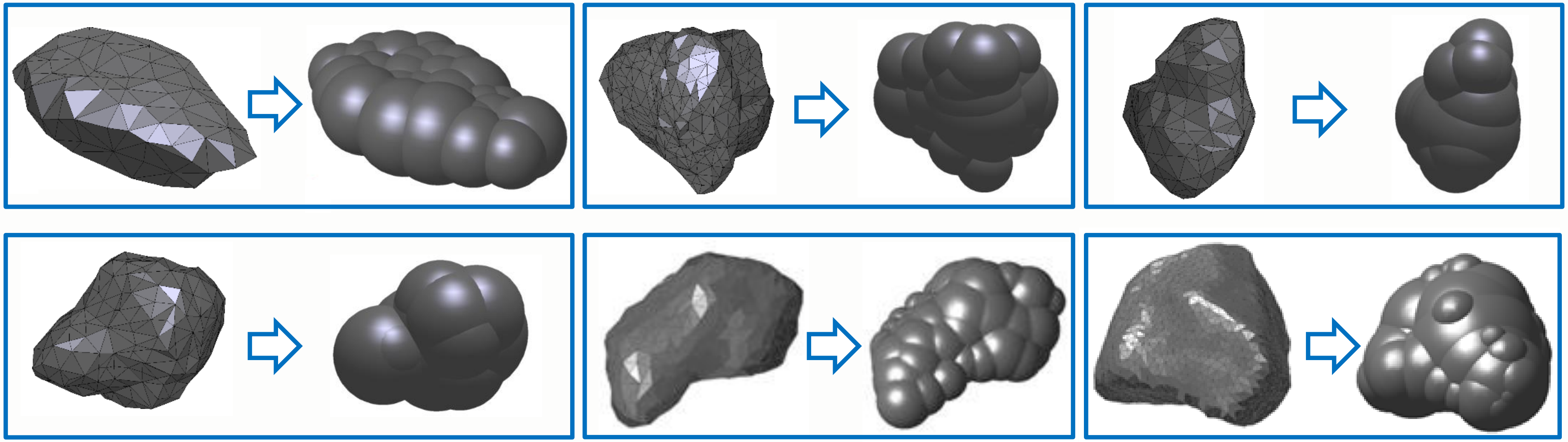
Polyhedral particles

Superquadrics

DEM BALLAST GEOMETRIC REPRESENTATION

Sphere clusters:

Each DE particle is a group of overlapped spheres in a rigid way



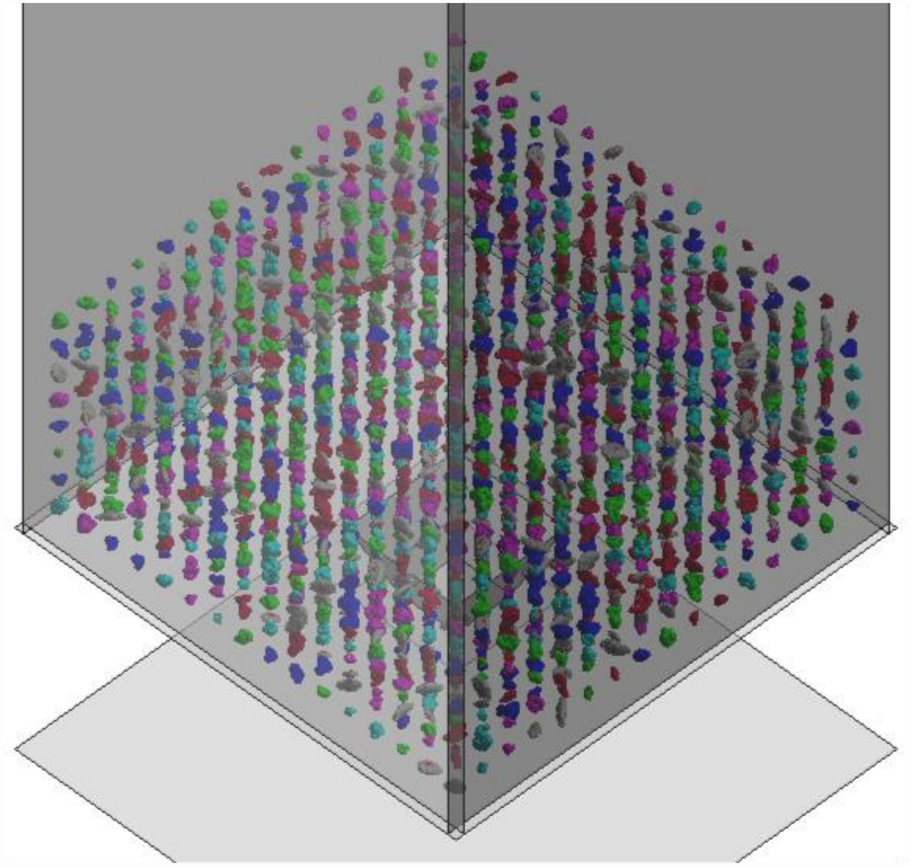
Sphere-Tree Construction Toolkit (http://isg.cs.tcd.ie/spheretree/)

This approach allows the use of algorithms that are extensions of the methods used for spheres

DEM BALLAST GEOMETRIC REPRESENTATION

Sphere clusters:

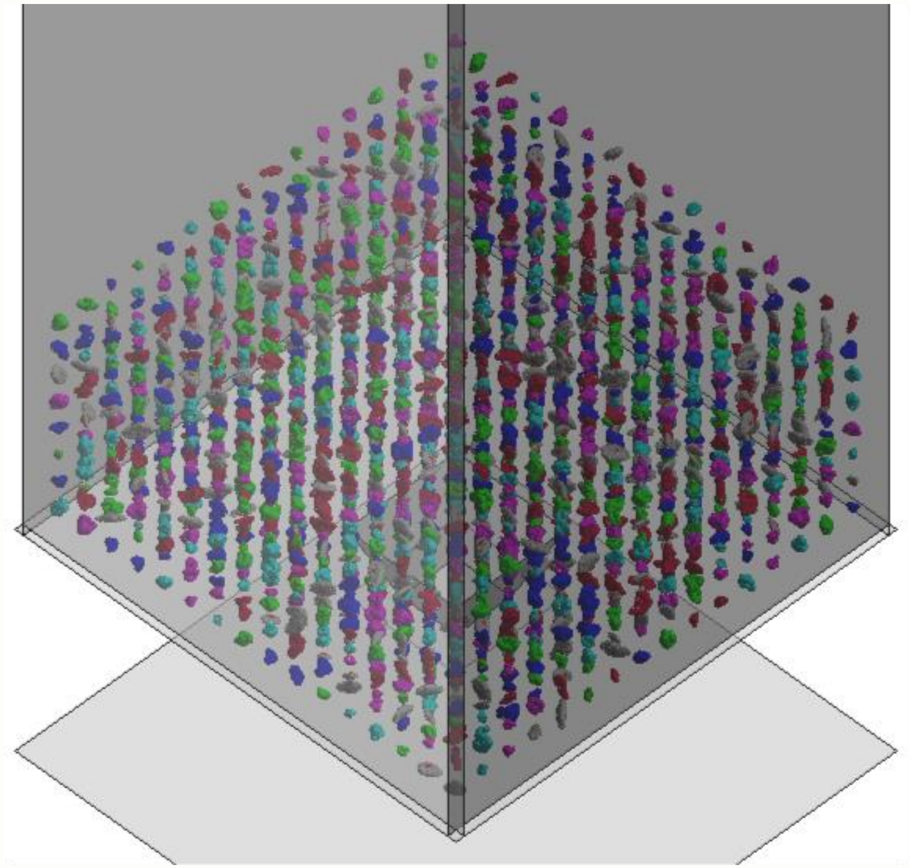
Difficult to generate a cluster mesh

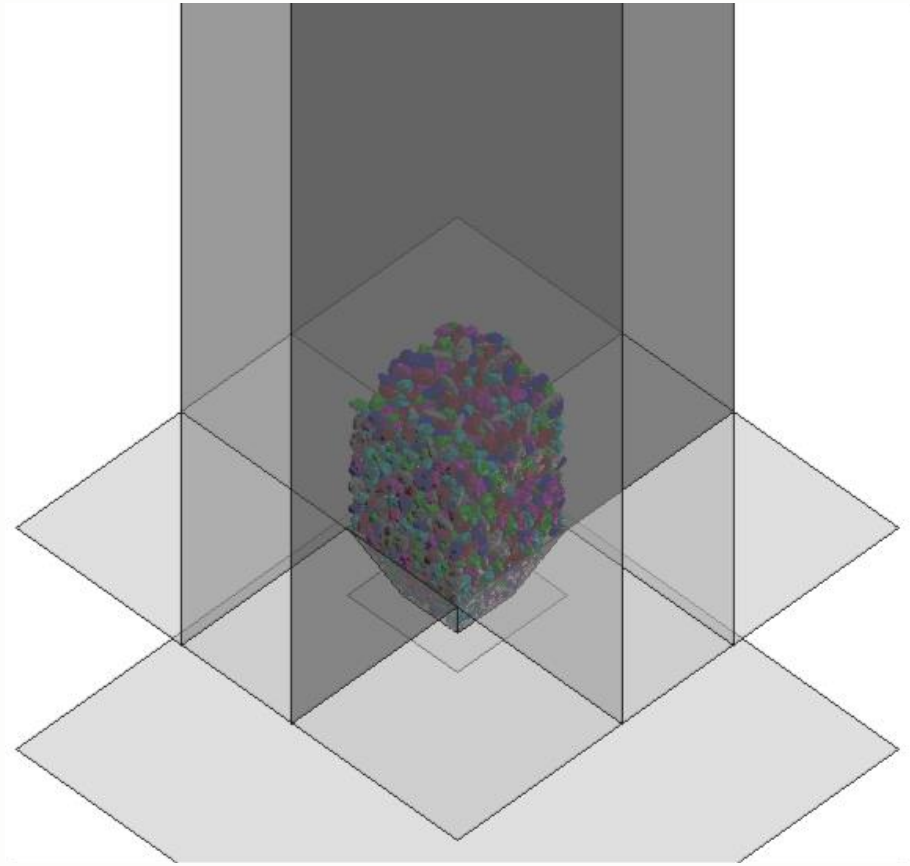


DEM BALLAST GEOMETRIC REPRESENTATION

Sphere clusters:

Difficult to generate a cluster mesh

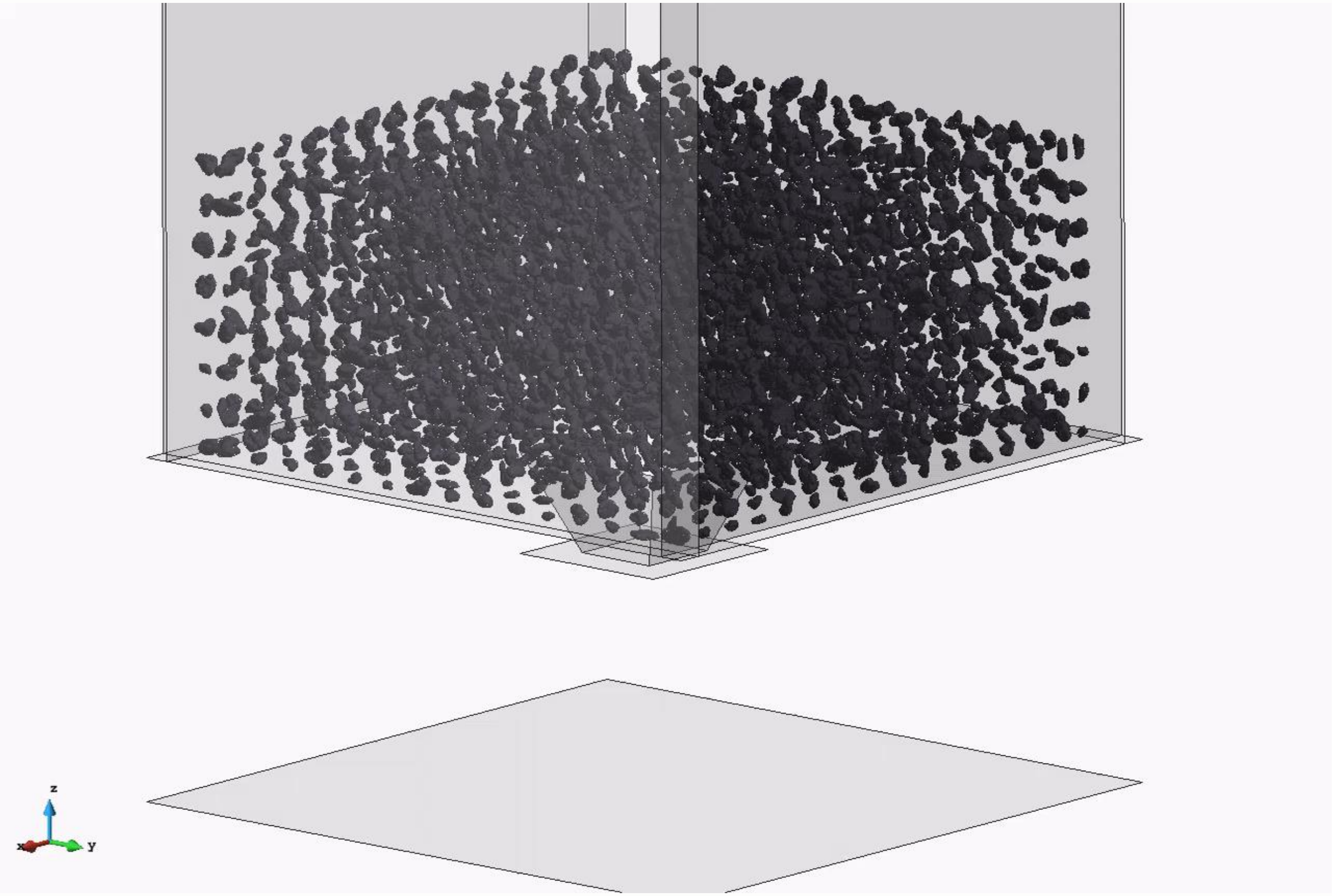




DEM BALLAST GEOMETRIC REPRESENTATION

Sphere clusters:

Difficult to generate a cluster mesh



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DEM BALLAST GEOMETRIC REPRESENTATION

Sphere clusters:

DE particles geometry is accurate

Neighbour search, forces evaluation and DEM-FEM interaction are straightforward extensions of the methods used for spheres

Computational cost is higher due to the increase of the amount of spheres

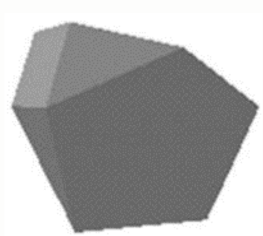
Particle generation and arrangement are not straightforward

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles

Sphere clusters

Polyhedral particles

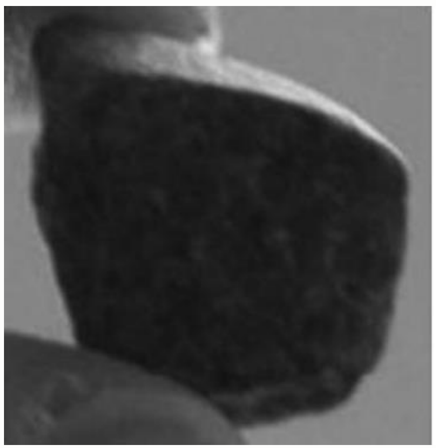


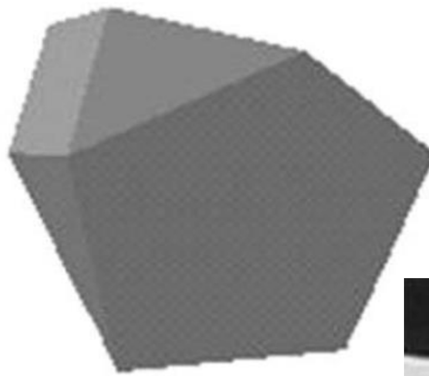
Superquadrics

DEM BALLAST GEOMETRIC REPRESENTATION

Polyhedral particles:

Ballast stones are represented as polyhedra





H. Huang, E. Tutumluer, Image-Aided Element Shape Generation Method in Discrete-Element Modeling for Railroad Ballast, J. Mater. Civ. Eng. 26 (2014) 527-535.

DEM BALLAST GEOMETRIC REPRESENTATION

Polyhedral particles:

DE particles geometry is accurate

Polyhedra generation is easier than clusters generation

Computational cost is very high due to the difficulty to carry out neighbour search and forces evaluation

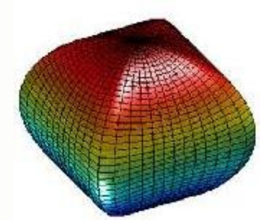
DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles

Sphere clusters

Polyhedral particles

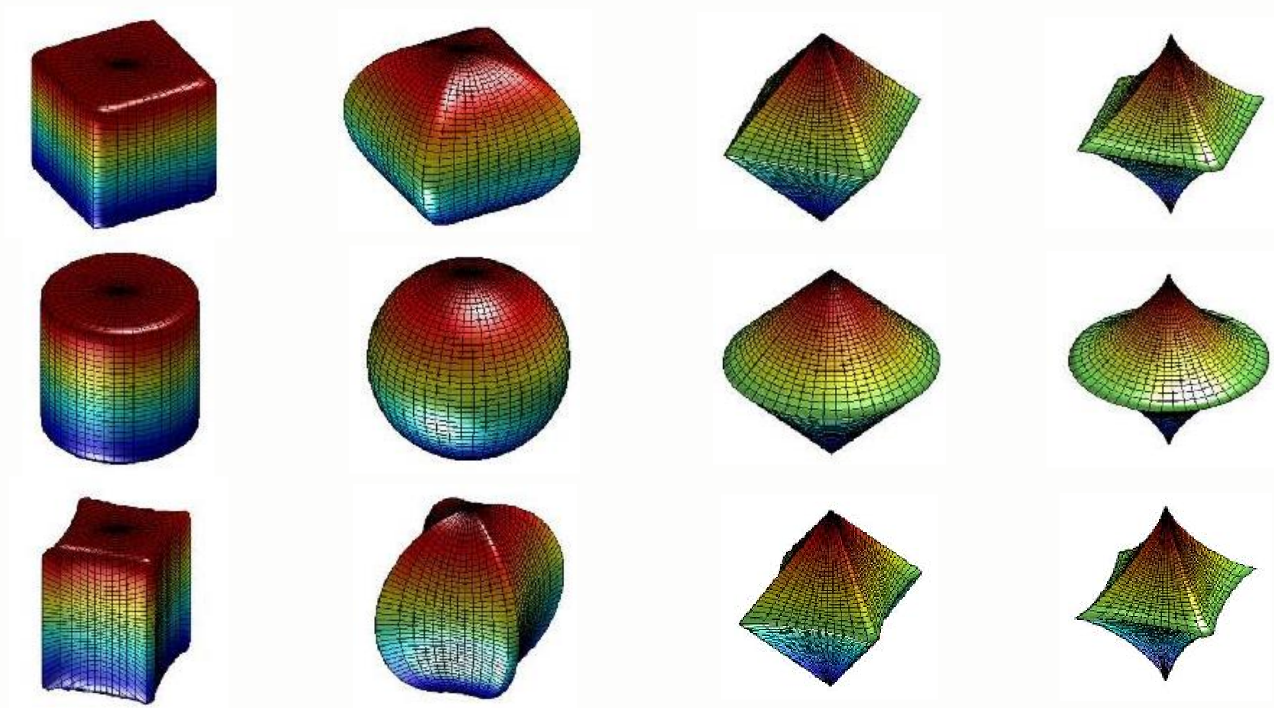
Superquadrics



DEM BALLAST GEOMETRIC REPRESENTATION

Superquadrics:

Family of geometric shapes defined by formulas that resemble those of ellipsoids and other quadrics, but replacing squaring operations by arbitrary powers



Source: http://pointclouds.org/gsoc/

DEM BALLAST GEOMETRIC REPRESENTATION

Superquadrics:

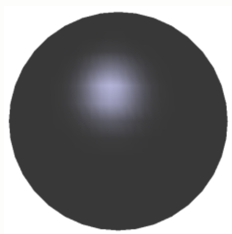
Forces evaluation can be accurately calculated

Computational cost of contact detection is high but less than polyhedral

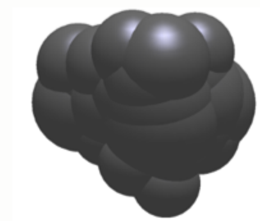
Although superquadrics are a promising approach to reproduce many materials with the DEM, ballast stones are too irregular

DEM BALLAST GEOMETRIC REPRESENTATION

Spheric particles



Sphere clusters



Polyhedral particles

Superquadrics

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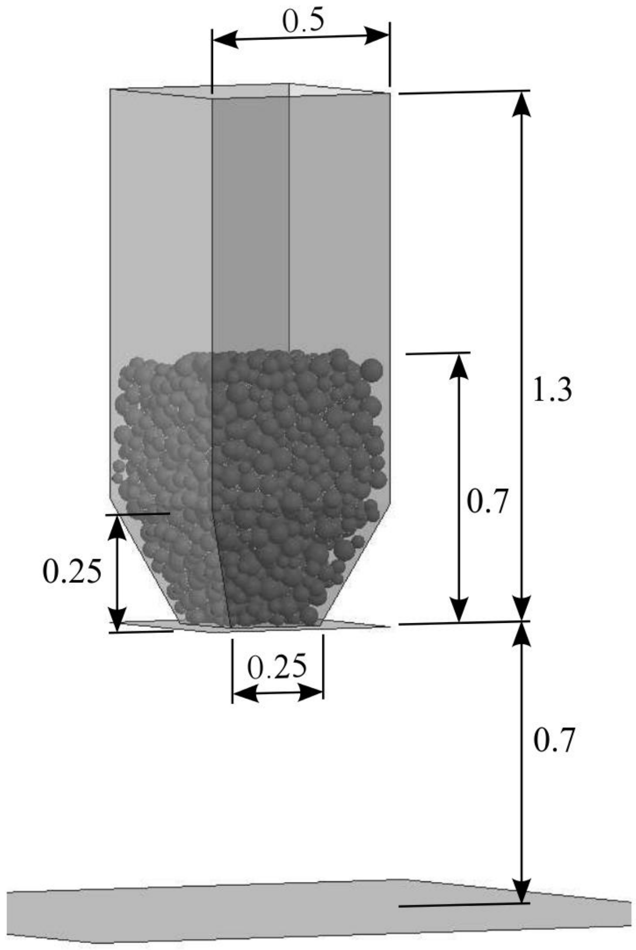
TEST RESULTS

TEST RESULTS (SPHERIC PARTICLES)

Repose Angle test:



Ballast properties

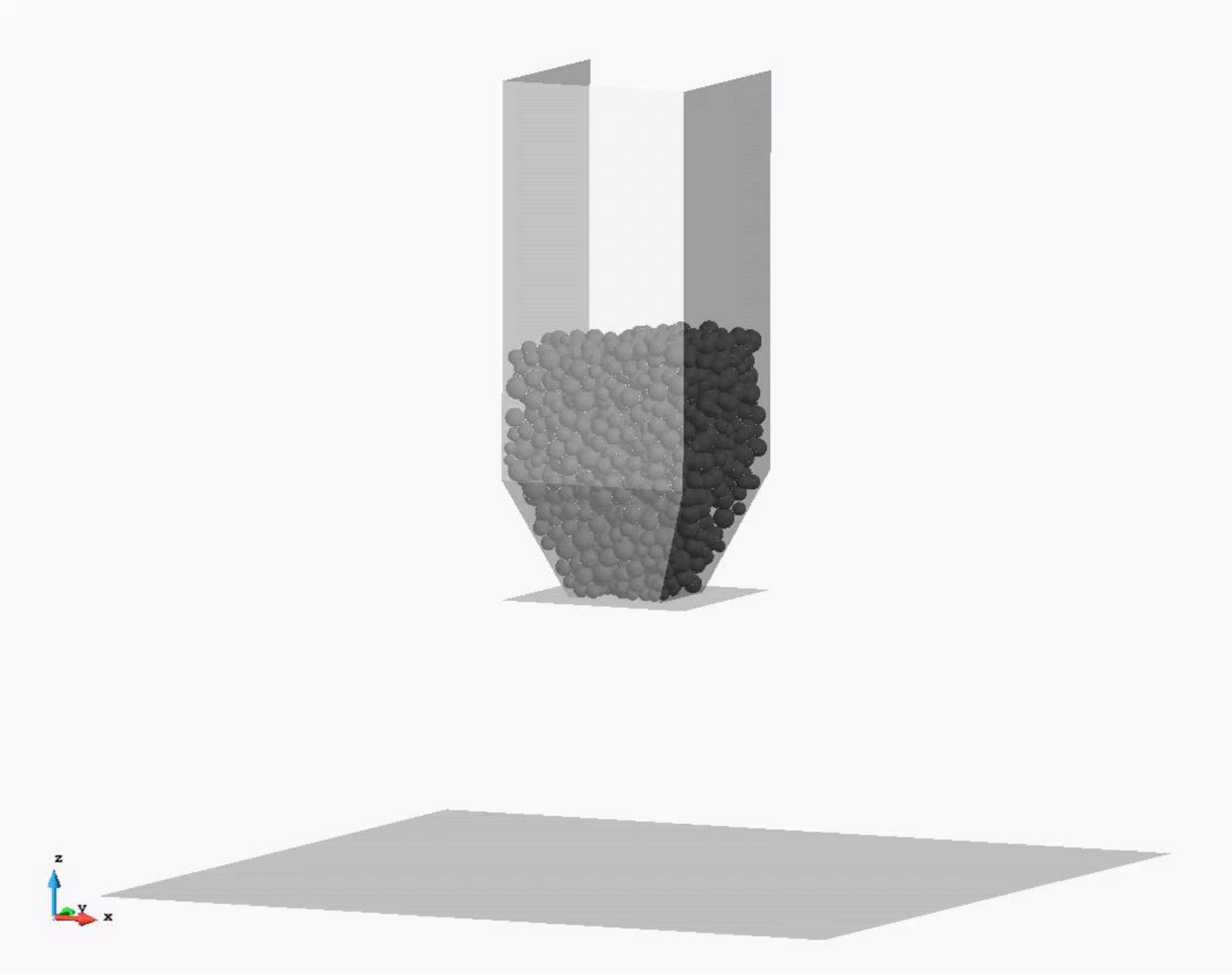
Density (kg/m^3)	2700
Young Modulus (Pa)	$17.7 \cdot 10^9$
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.60
Restitution coeff.	0.40
Rolling fricition coeff.	0.20/0.25/0.30

C. Chen, G. R. McDowell, N. H. Thom, Investigating geogrid-reinforced ballast: Experimental pull-out tests and discrete element modelling, Soils Found. 54 (1) (2014) 1–11.

TEST RESULTS (SPHERIC PARTICLES)

Repose Angle test:

Rolling friction = 0.25



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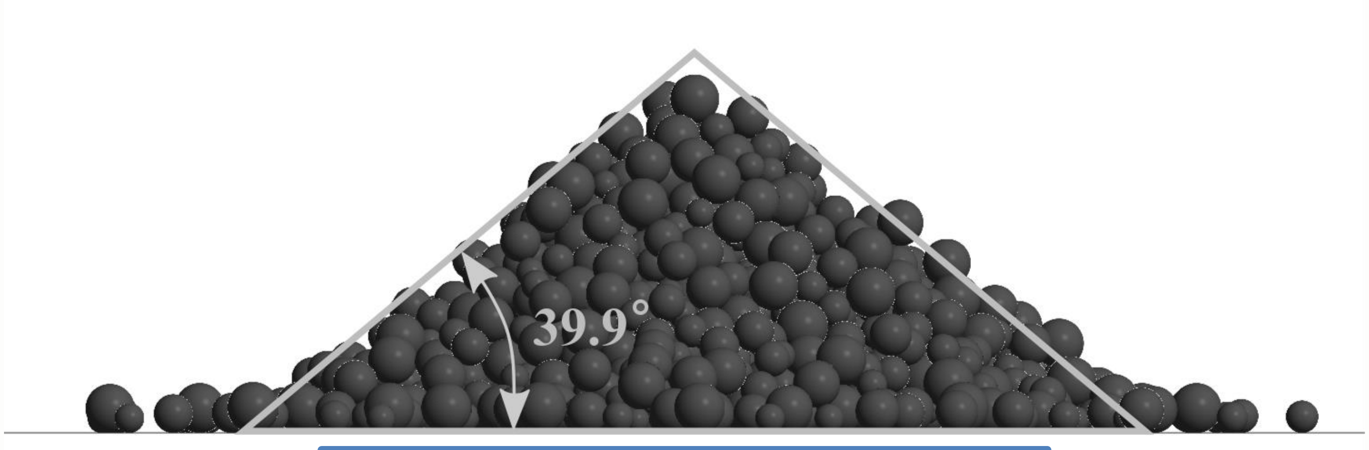
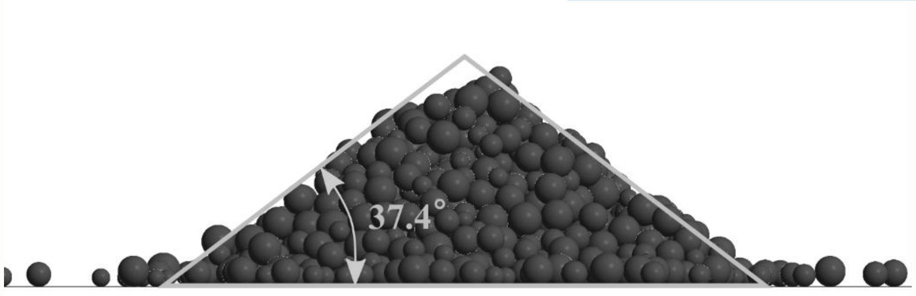
TEST RESULTS (SPHERIC PARTICLES)

Repose Angle test:

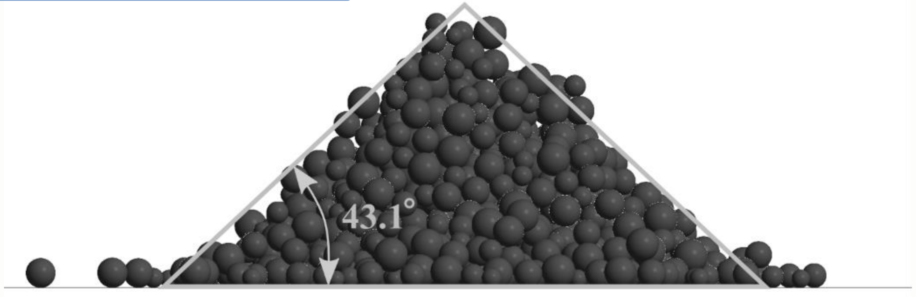
Ballast theorical repose angle: 40 degrees



Rolling friction = 0.25



Rolling friction = 0.20



Rolling friction = 0.30

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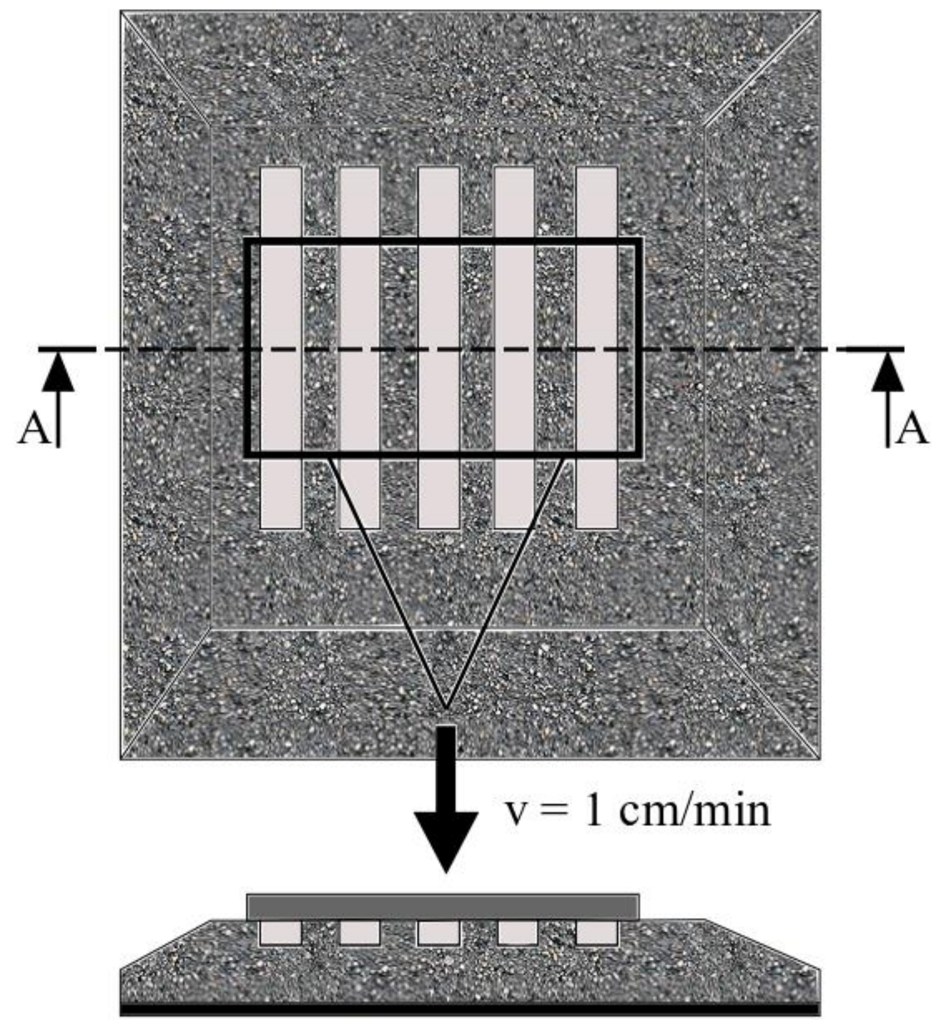
TEST RESULTS (SPHERIC PARTICLES)

Lateral resistance test:

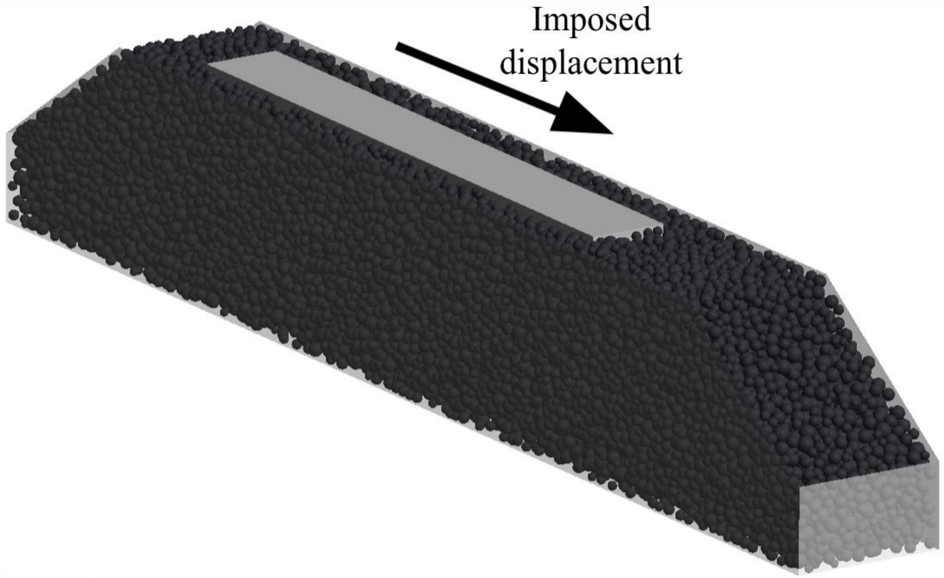
Vertical load= 0 N
Sleepers Velocity = 0.0001667 m/s



Zand and Moraal (1997) Roads and Railways Research Laboratory Technical University of Delft

TEST RESULTS (SPHERIC PARTICLES)

Lateral resistance test:

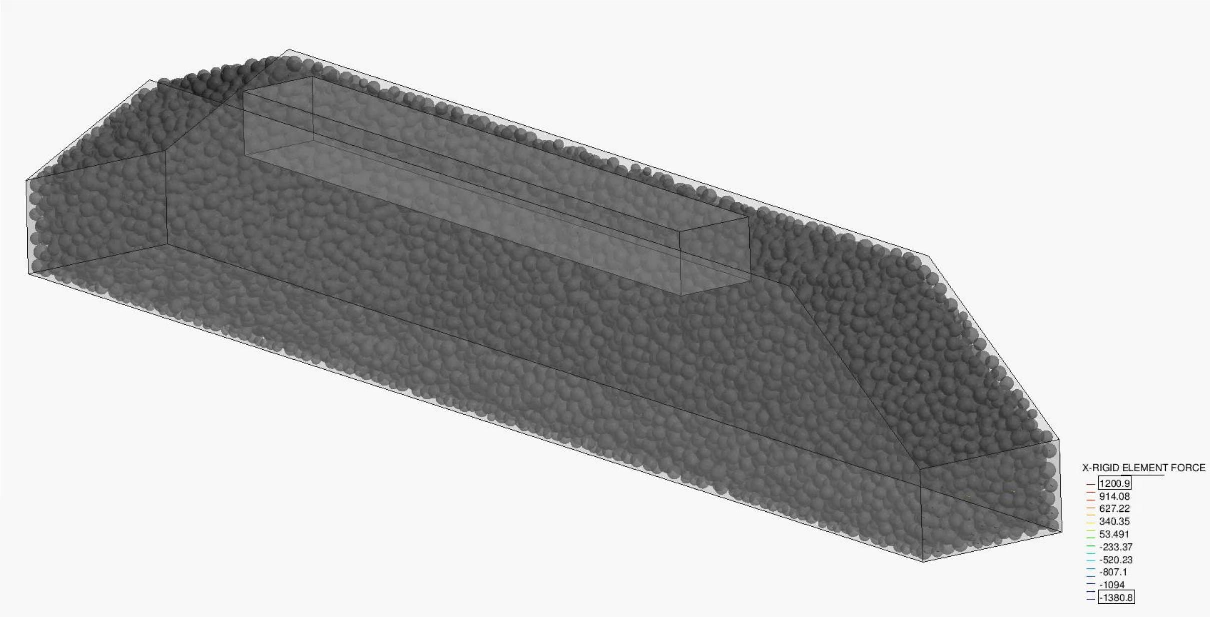


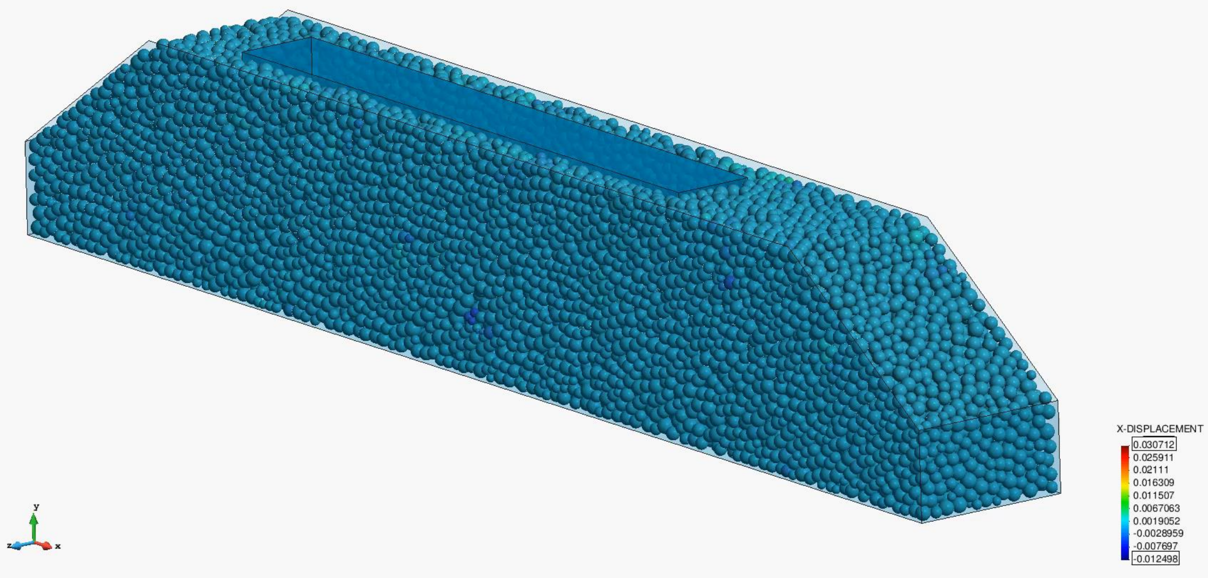
Ballast properties

Density (kg/m^3)	2700
Young Modulus (Pa)	$17.7\cdot10^9$
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.60
Friction coeff. ballast/sleeper	0.7247
Restitution coeff.	0.40
Rolling fricition coeff.	0.25

TEST RESULTS (SPHERIC PARTICLES)

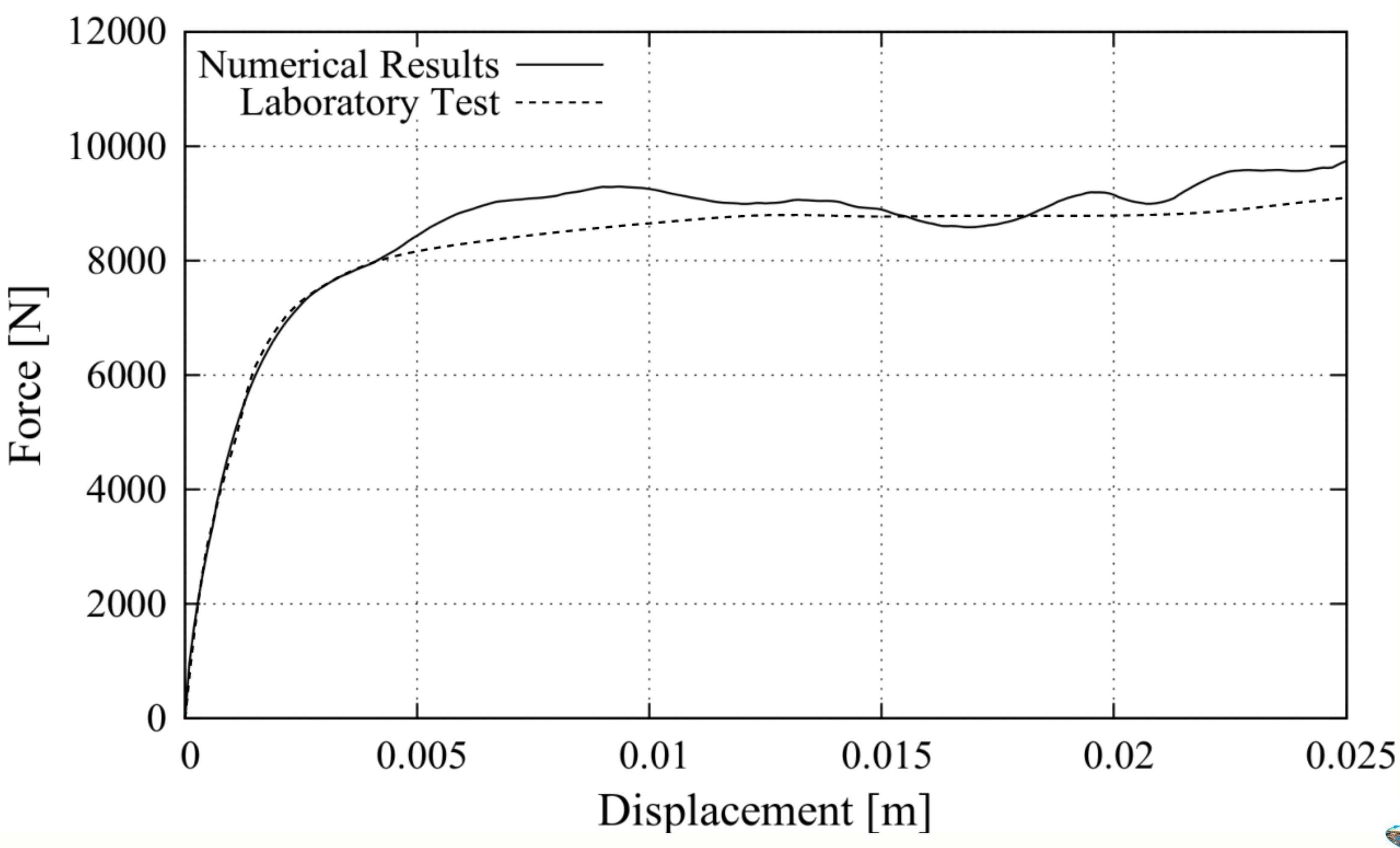
Lateral resistance test:





TEST RESULTS (SPHERIC PARTICLES)

Lateral resistance test:



TEST RESULTS (SPHERIC PARTICLES)

Conclusions:

- **Rolling friction approach is effective to change particles behavior**
- **Spheres with rolling friction can be useful to reproduce railway ballast, but calibration is needed to estimate rolling friction coefficient**
- **Particle packing affects greatly the system response**

TEST RESULTS (SPHERE CLUSTERS)

Triaxial test:

Diameter = 0.305 m
Height = 0.61 m
Confining pressure = 68.9 kPa
Shear velocity = 0.038 m/s

Triaxial compression test device
University of Illinois

Y. Qian, D. Mishra, E. Tutumluer, H.A. Kazmee, Characterization of geogrid reinforced ballast behavior at different levels of degradation through triaxial shear strength test and discrete element modeling, Geotext. Geomembranes, 43 (5) (2015) 393–402.

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TEST RESULTS (SPHERE CLUSTERS)

Triaxial test:

Ballast properties

Density (kg/m3)	2700
Young Modulus (Pa)	$17.7 \cdot 10^9$
Poisson ratio	0.18
Mean diameter (m)	0.05
Friction coeff.	0.40
Friction coeff. ballast/membrane	0.00
Friction coeff. ballast/actuators	0.268
Restitution coeff.	0.40

Membrane properties

Young Modulus (Pa)	$1.5 \cdot 10^6$
Poisson ratio	0.45
Thickness (m)	0.0023

TEST RESULTS (SPHERE CLUSTERS)

Triaxial test:

Ballast properties

Density (kg/m3)	2700
Young Modulus (Pa)	$17.7 \cdot 10^9$
Poisson ratio	0.18
Mean diameter (m)	0.05
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Friction coeff. ballast/actuators	0.268
Restitution coeff.	0.40

Membrane properties

Young Modulus (Pa)	$1.5 \cdot 10^6$
Poisson ratio	0.45
Thickness (m)	0.0023

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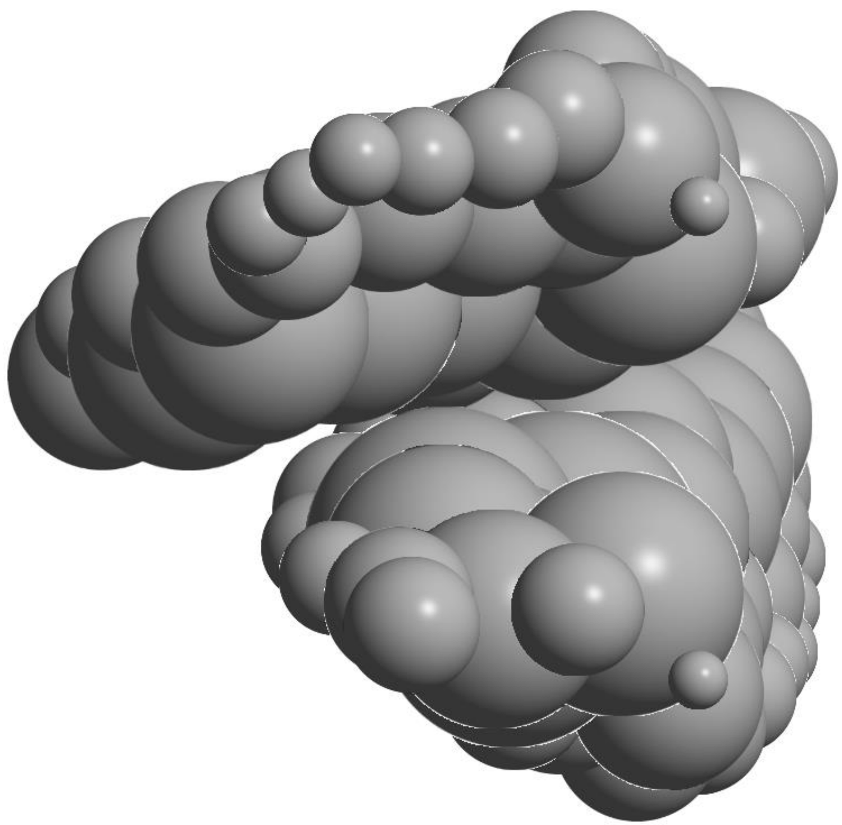
TEST RESULTS (SPHERE CLUSTERS)

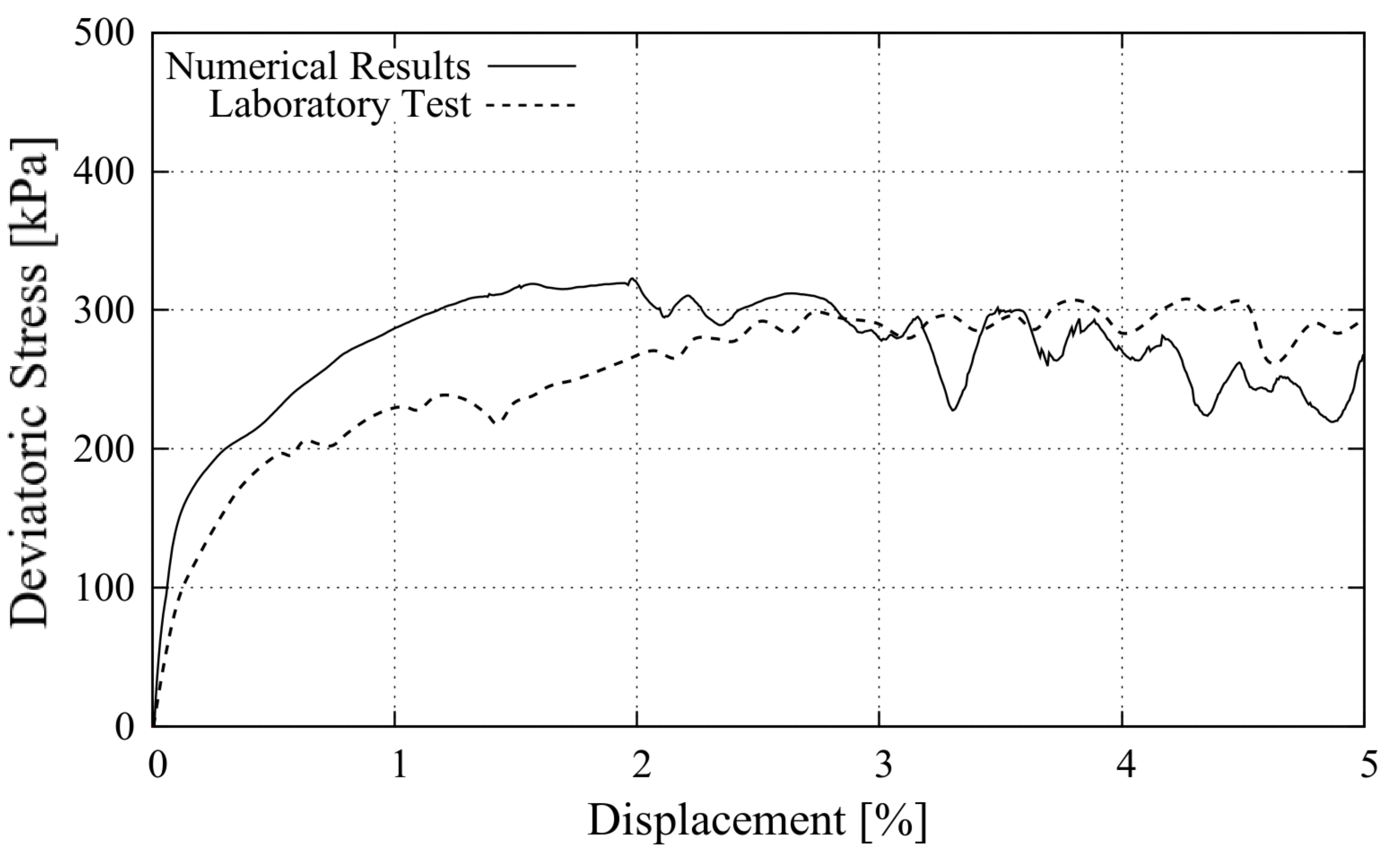
Triaxial test:

Geometrical friction due to interlocks between spheres



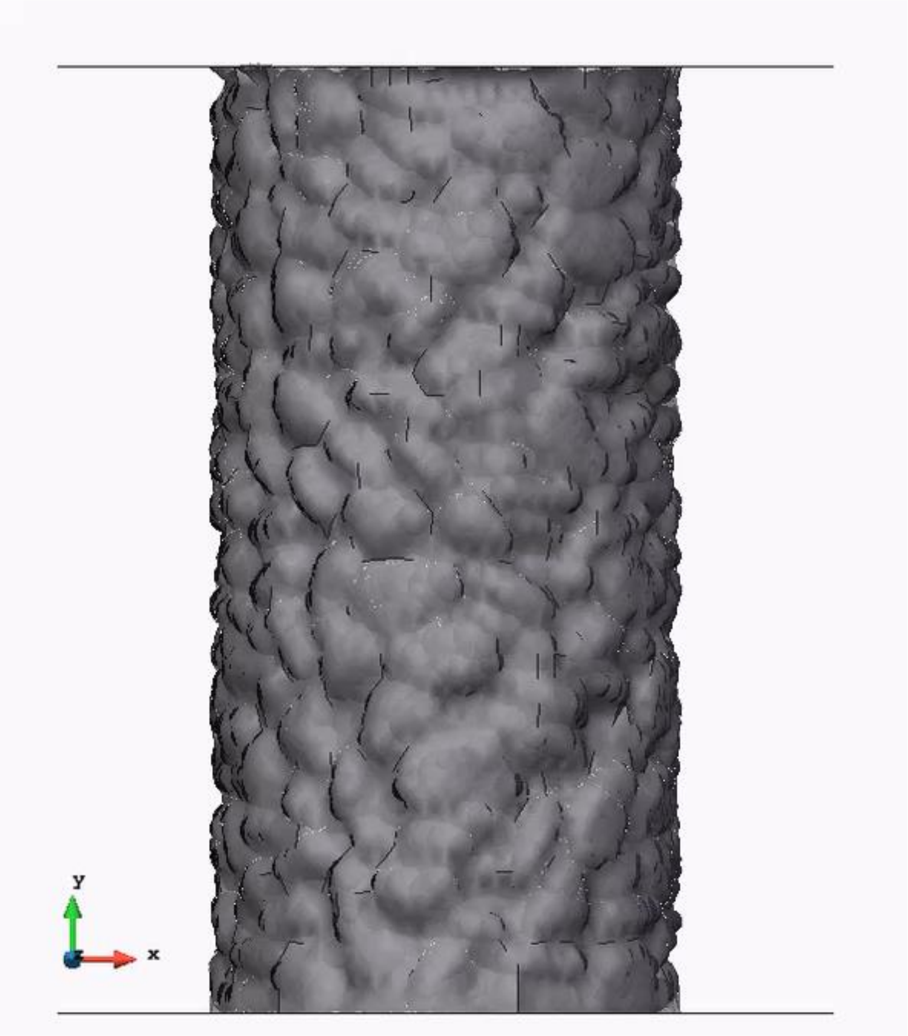
TEST RESULTS (SPHERE CLUSTERS)

Triaxial test:



TEST RESULTS (SPHERE CLUSTERS)

Triaxial test:



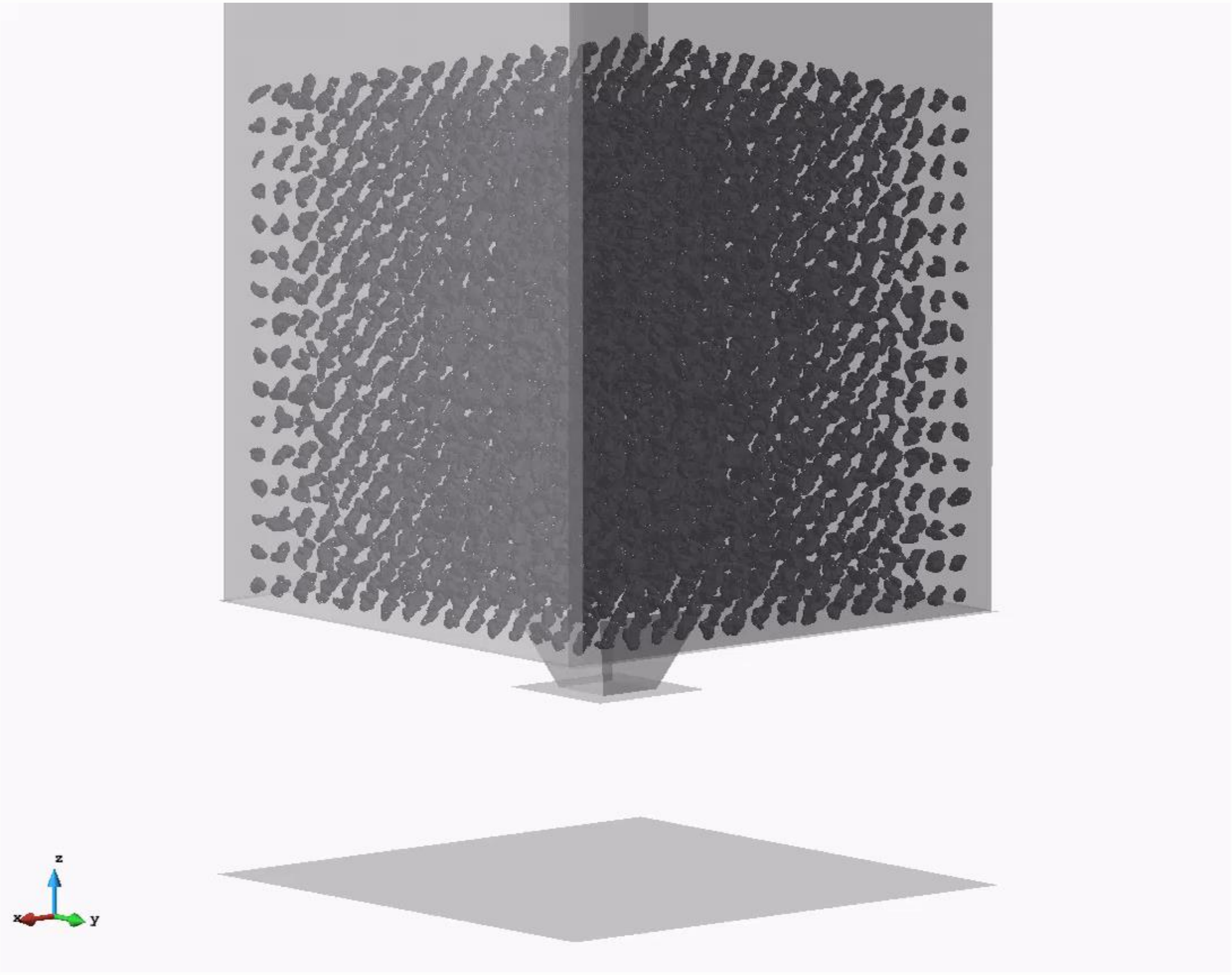
TEST RESULTS (SPHERE CLUSTERS)

Conclusions:

- Sphere clusters approach seems to be suitable to represent railway ballast
- More validation and development should be carried out
- How is geometrical friction affecting calculations?

TEST RESULTS (SPHERE CLUSTERS)

Geometrical friction (ongoing work):



TEST RESULTS (SPHERE CLUSTERS)

Geometrical friction (ongoing work):

CONCLUSIONS

CONCLUSIONS

- The DEM is an appropriate method for the calculation of ballast aggregates
- Spheres with rolling friction is a useful approach, however, calibration is needed
- Particle packing is an important variable
- Sphere clusters represent real geometries with assumable computational cost
- More validation and development work is needed to reproduce railway ballast using sphere clusters

THANK YOU FOR YOUR ATTENTION

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