DigiRoad

Johannes Quist

Project leader

Fraunhofer-Chalmers Centre

Project Leader
Johannes Quist

Coordinating part
Fraunhofer-Chalmers Centre

Duration
2018-05-01 to 2021-10-29

Budget
8 800 000 (50% in-kind)

FRAUNHOFER CHALMERS
RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

NCC

CHALMERS
UNIVERSITY OF TECHNOLOGY

DYNAPAC
FAYAT GROUP

VOLVO
Volvo Construction Equipment


DigiRoad
Bättre miljö och ekonomi
genom hållbara vägar!
Better environment and economy
through durable roads!

”Simulera bergmaterial och dess interaktion med maskiner från bergtäkt till kompakterad vägkropp för att öka kvalité, bärighet och livslängd.”

UNBOUND AGGREGATES

Blasting

Crushing

Stockpile

Loading

Transport

Unloading

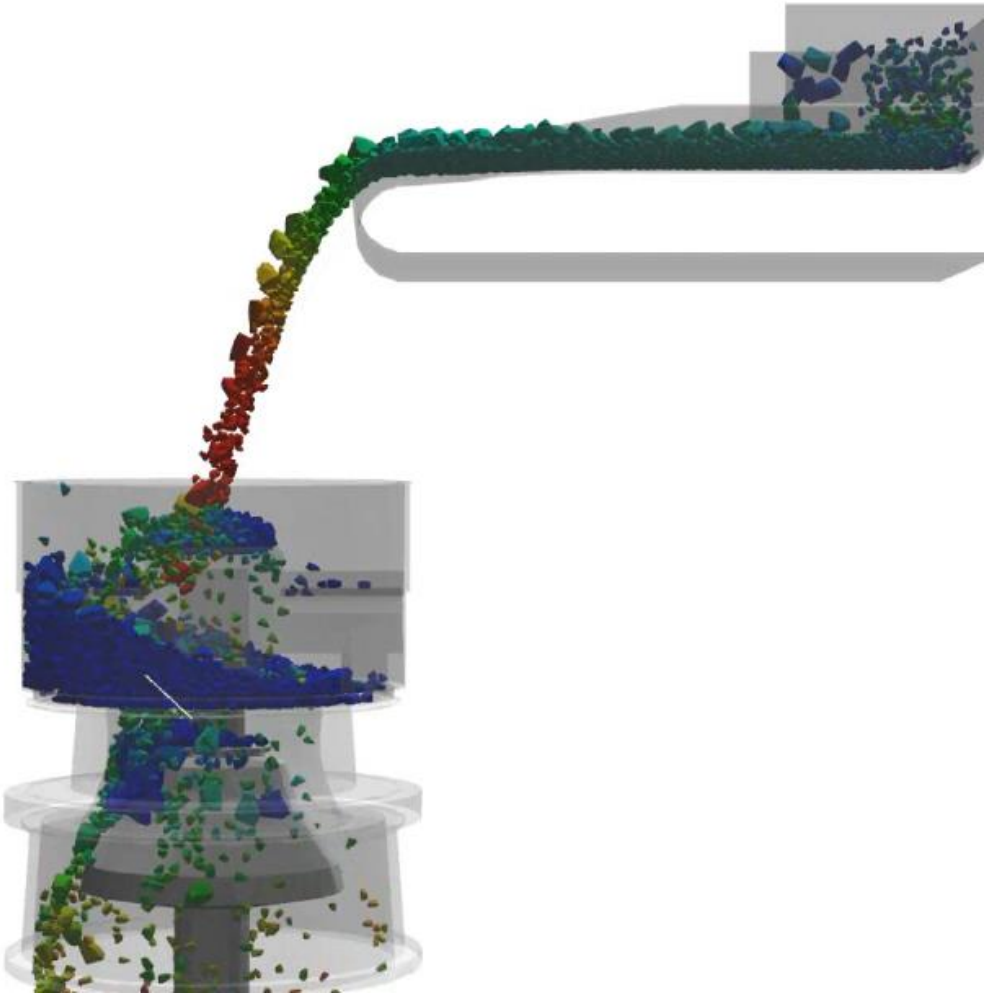
Spreading

Compaction

SOLUTION & INNOVATION

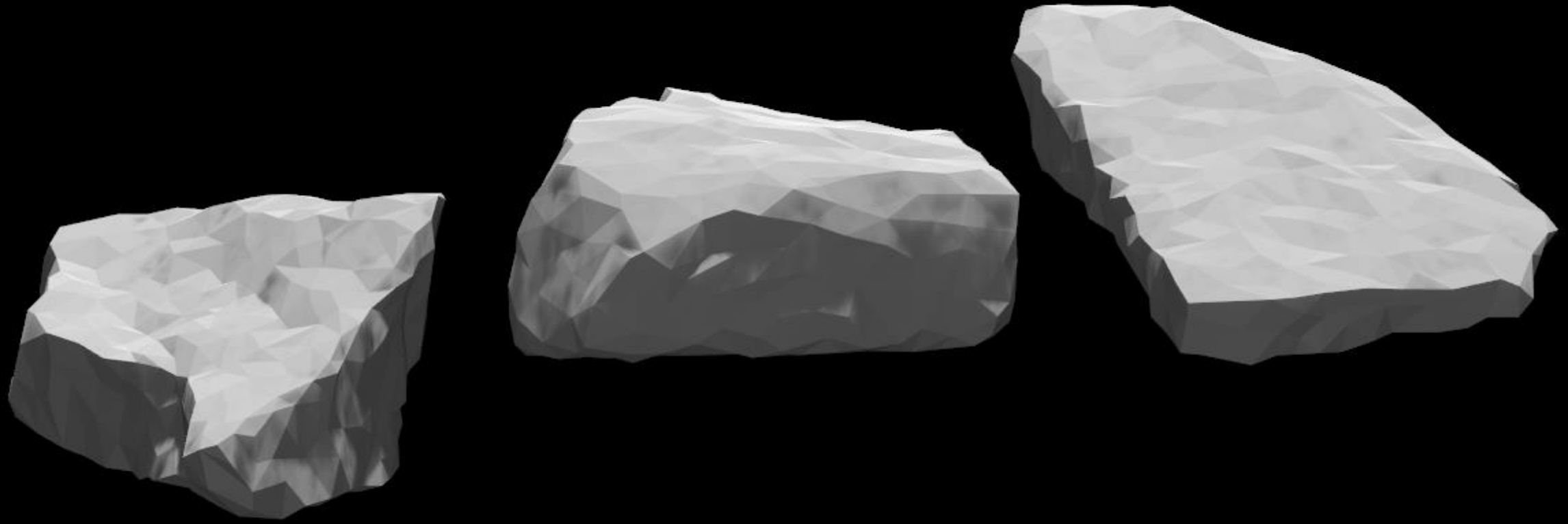
Demify®

- Solver for simulation of particle systems using discrete element method (DEM)
- Particle shape
  - Sphere solver – powders, soil, granules
  - Multi-sphere – compound spheres
  - Polyhedrons – rocks, arbitrary shapes
- State-of-the-art implementation
  - Highly scalable and parallel algorithms
  - Utilizing GPUs, implementation in CUDA

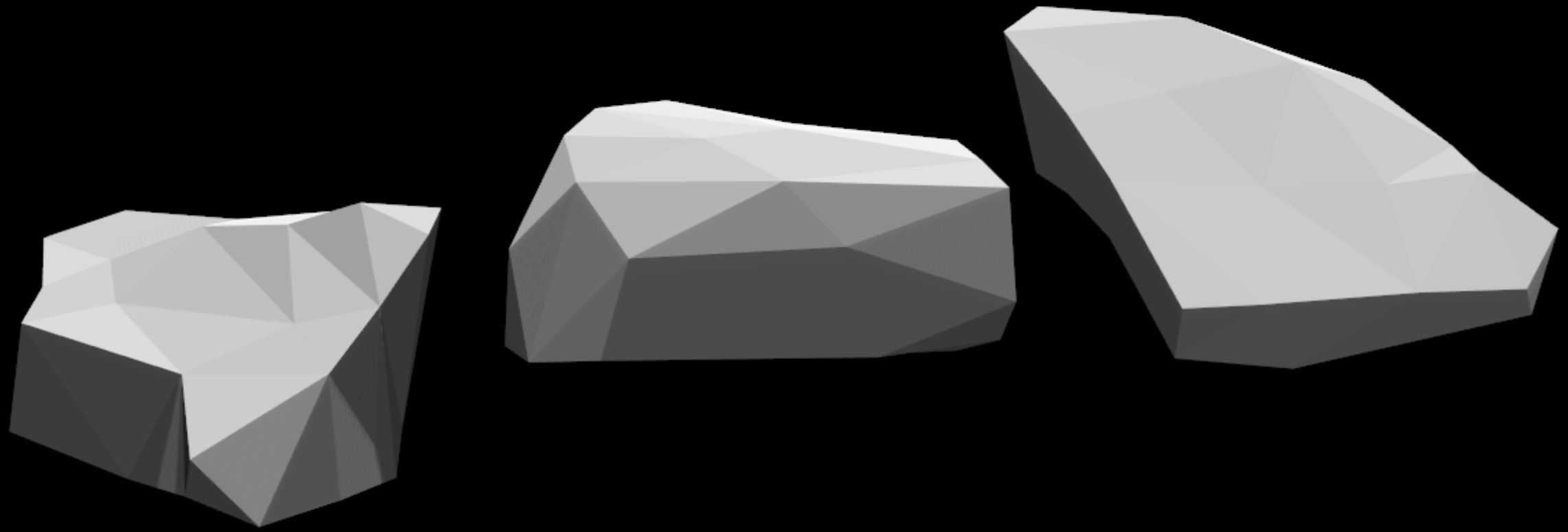


100 000 triangles

1 000 triangles



60 triangles



demify_itwm_issue3_bucket_scene_v04_GCC - Industrial Path Solutions - 3.11a2-267-gc840fcfdb4 INTERNAL

Osprey

File Edit Create View Graphics Tools Flexible Demify Windows Help

Scene

- Rock-Rock
- Rock-Steel
- Parts
  - Bucket
  - Channel_Container
- ParticleModels
  - Rock_n07_20
- Distributions
  - PSD_mono_200mm
  - PSD_norm_50-150mm
- Generators
  - Gen_1
- Cases
  - Session2.0
  - Session3.0
- Static Geometry
  - channel_container_6mlength
  - Examples_geometry_stl_granularfor
  - Generator_box
  - Rock_n07_20
  - Domain
  - Camera 1
  - Camera 2
  - Camera 3
  - Rock_n07_20
  - Camera 4
- Active Objects
  - Examples_geometry_stl_granularforce
  - Control frame
- Mechanisms
- Simulations
  - Motion 4
    - Way Point 1
    - Way Point 2
    - Way Point 3
    - Way Point 4
    - Way Point 5
    - Way Point 6
  - Demify simulation (loaded)
    - Polyhedrons
    - domain
    - bucket
    - channel
- Measures

View Camera 1

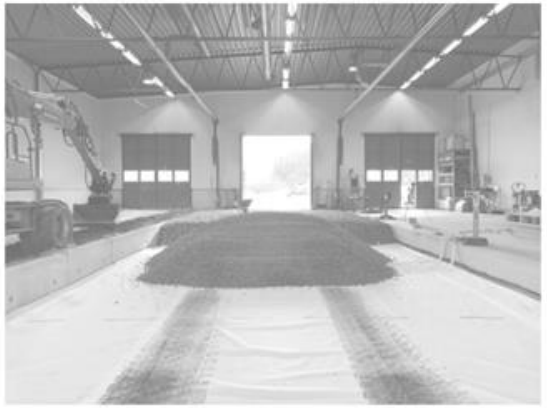
Ready. Clear Log Window g= Synchronize

FRAUNHOFER CHALMERS

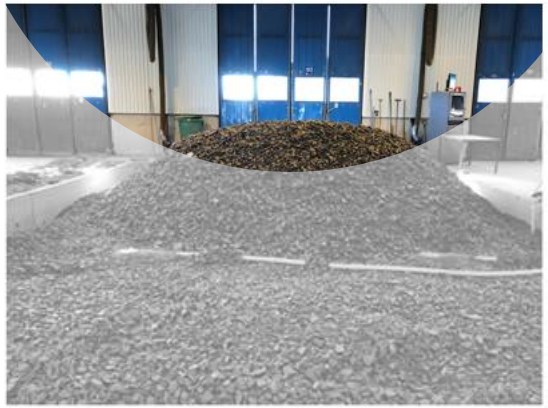
RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

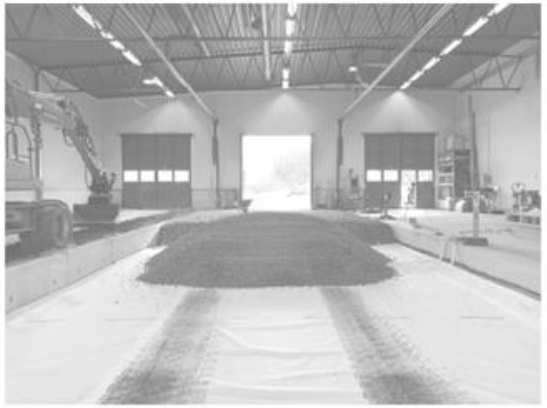
SBUF Study 2

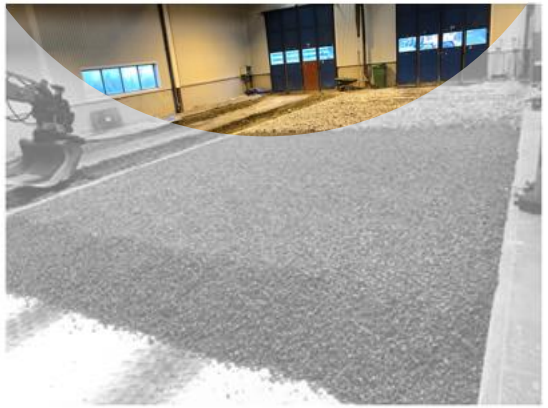
Industrial scale validation of roller compaction of unbound aggregates for road construction

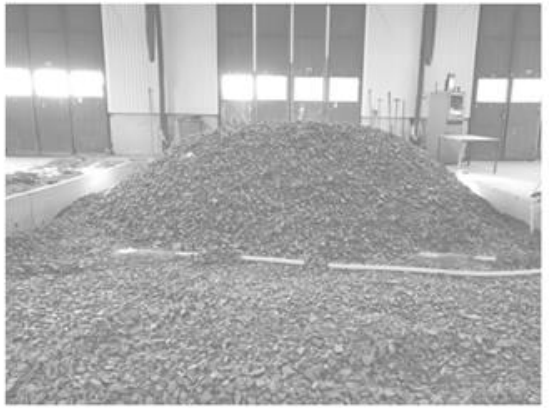


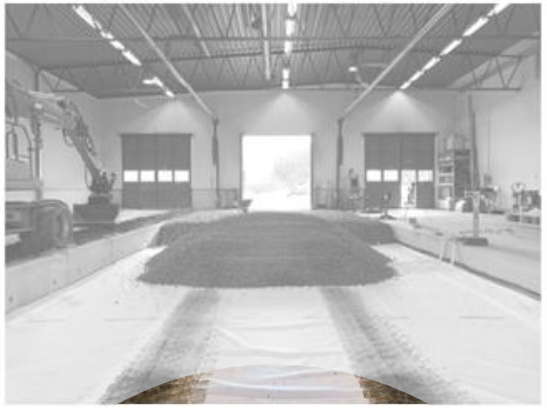

DOOSAN



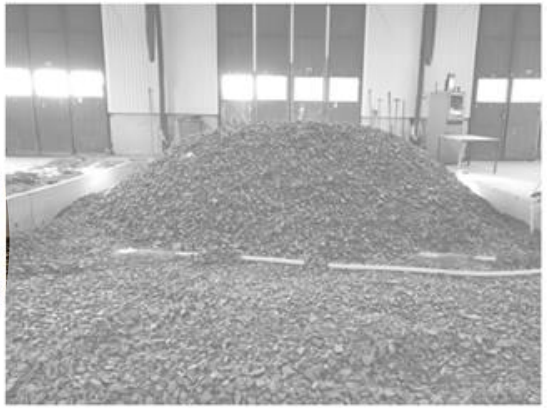




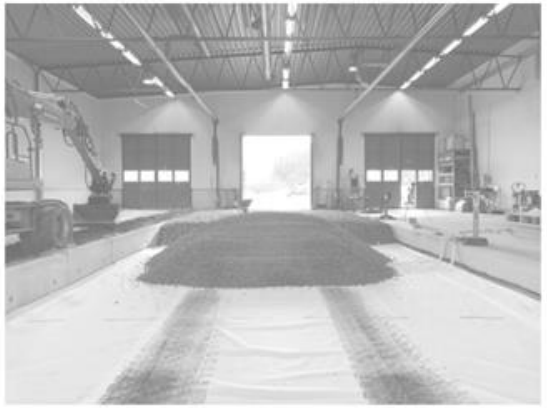


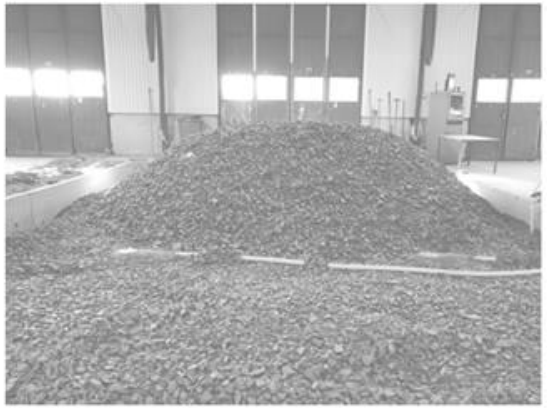


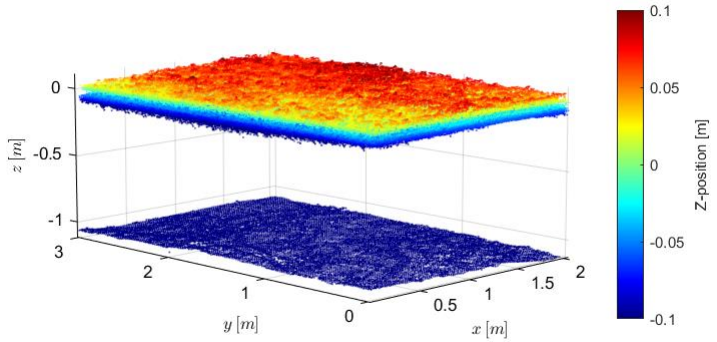








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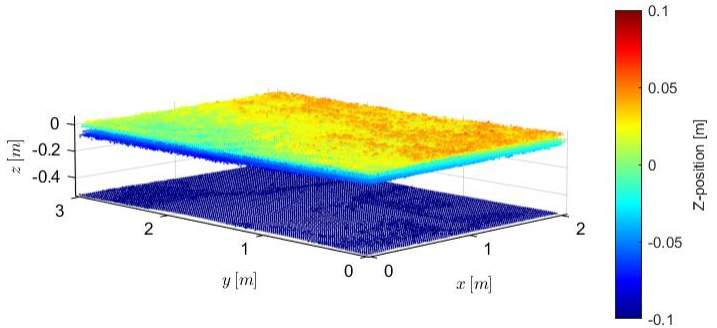
y [m]
x [m]
Z-position [m]


z [m]
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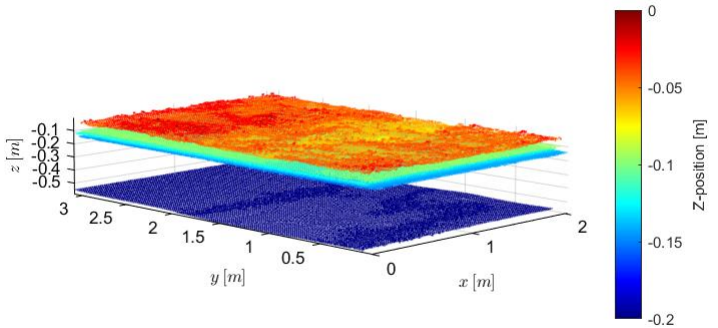
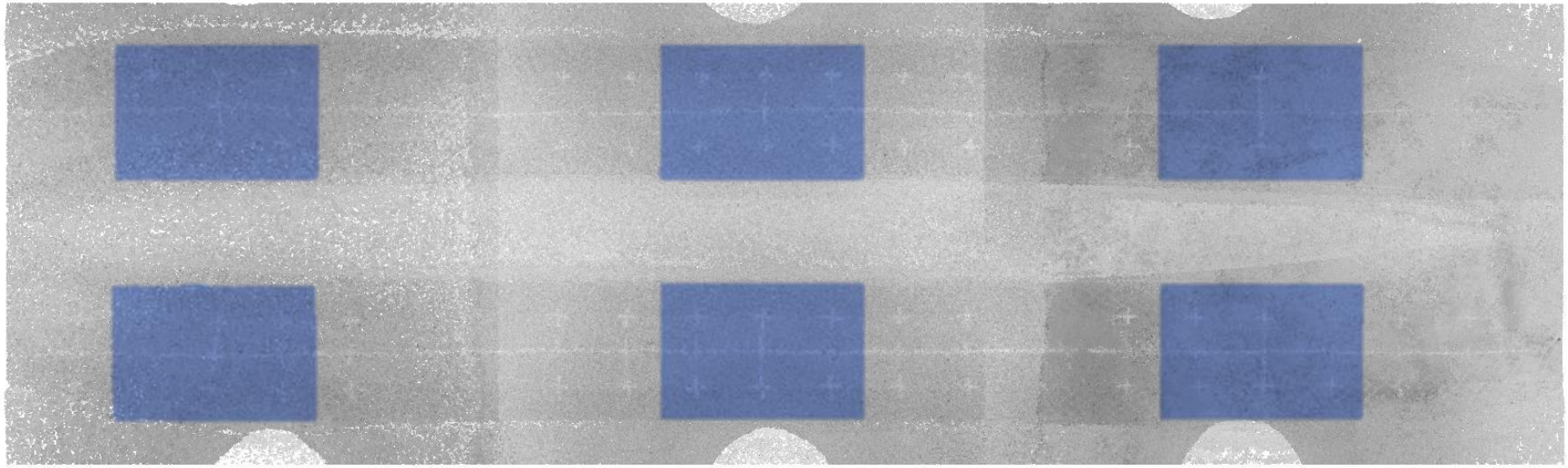
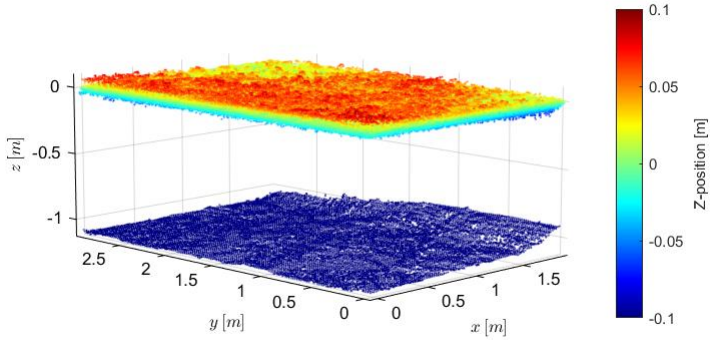
x [m]
Z-position [m]


z [m]
y [m]
x [m]
Z-position [m]

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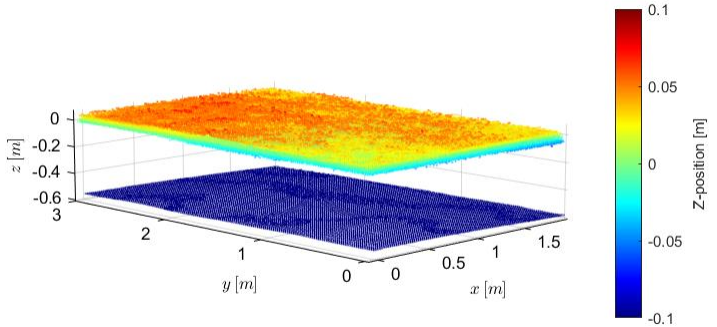
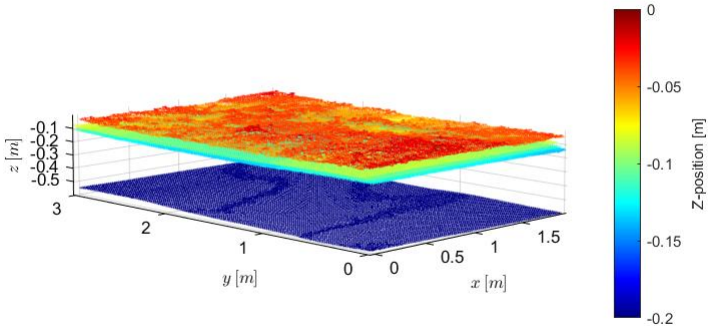
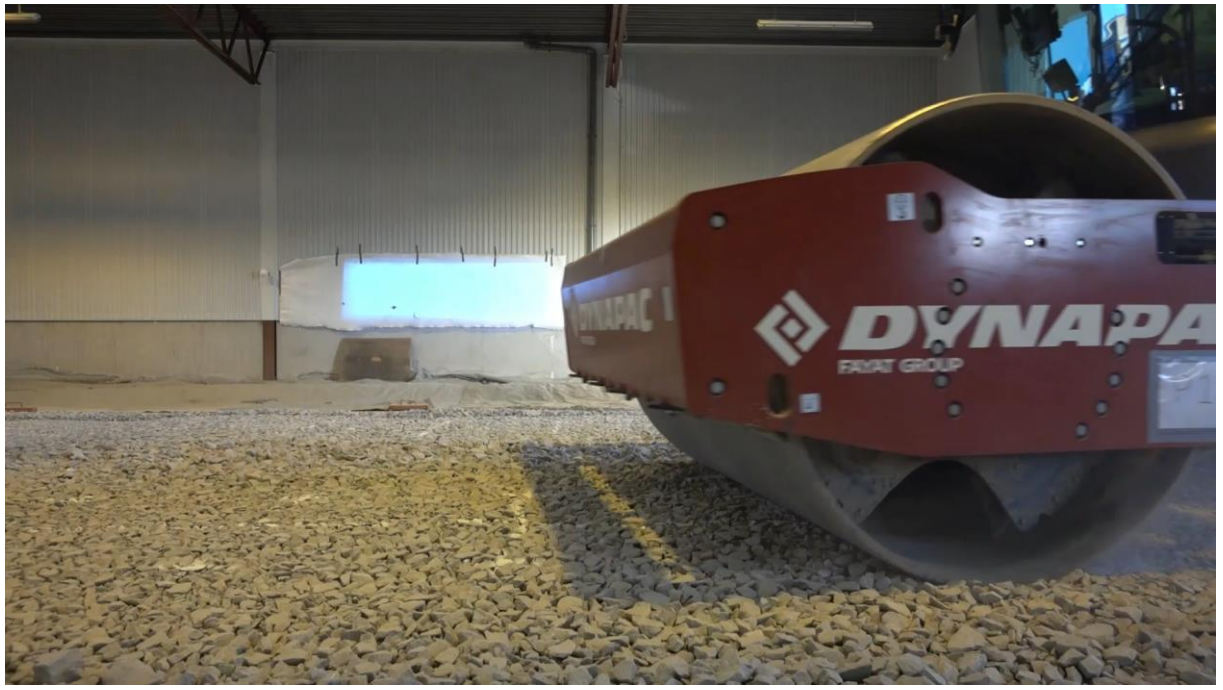
y [m]
x [m]
Z-position [m]

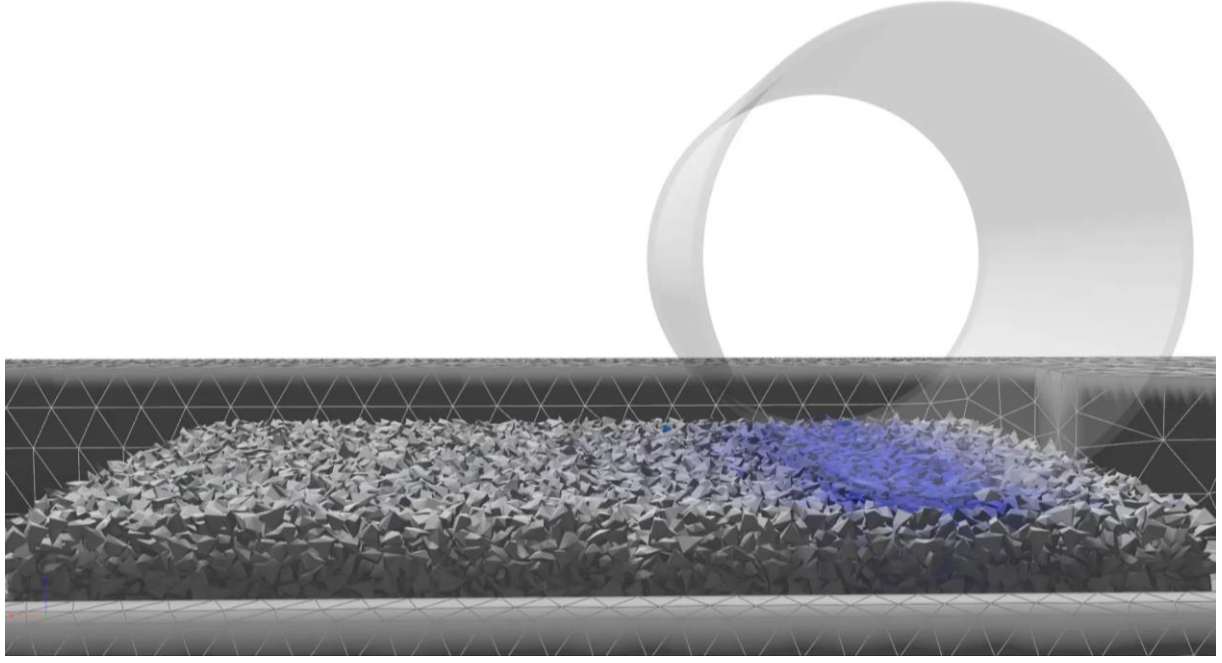

z [m]
y [m]
x [m]
Z-position [m]

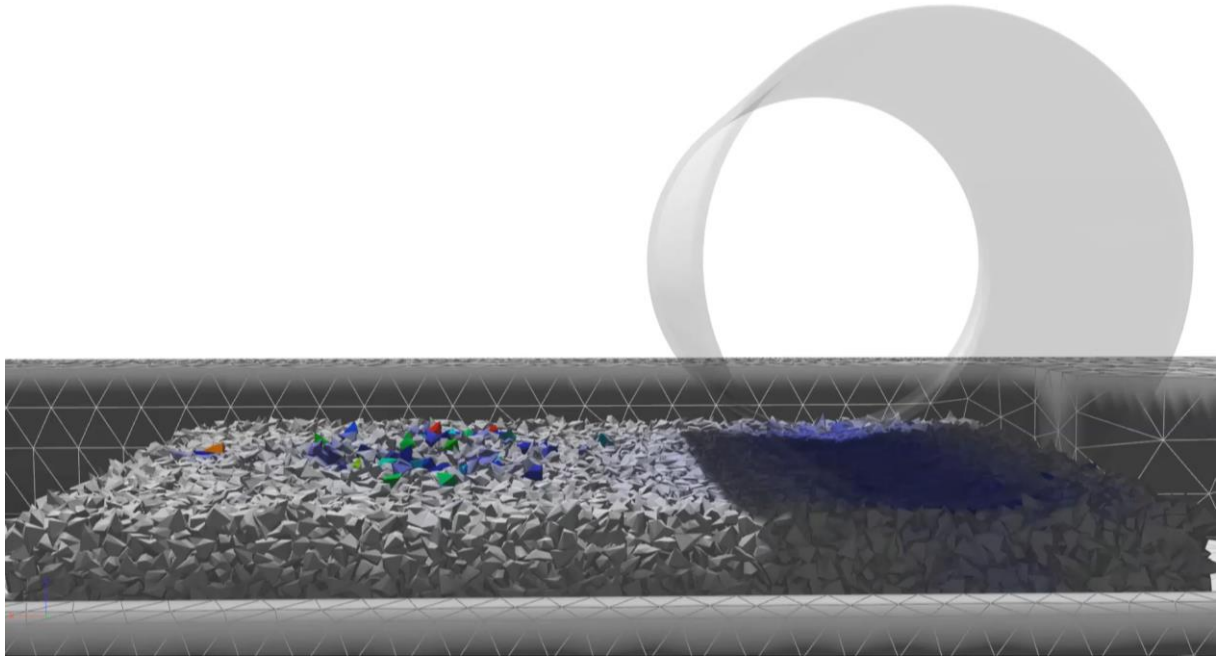

z [m]
y [m]
x [m]
Z-position [m]

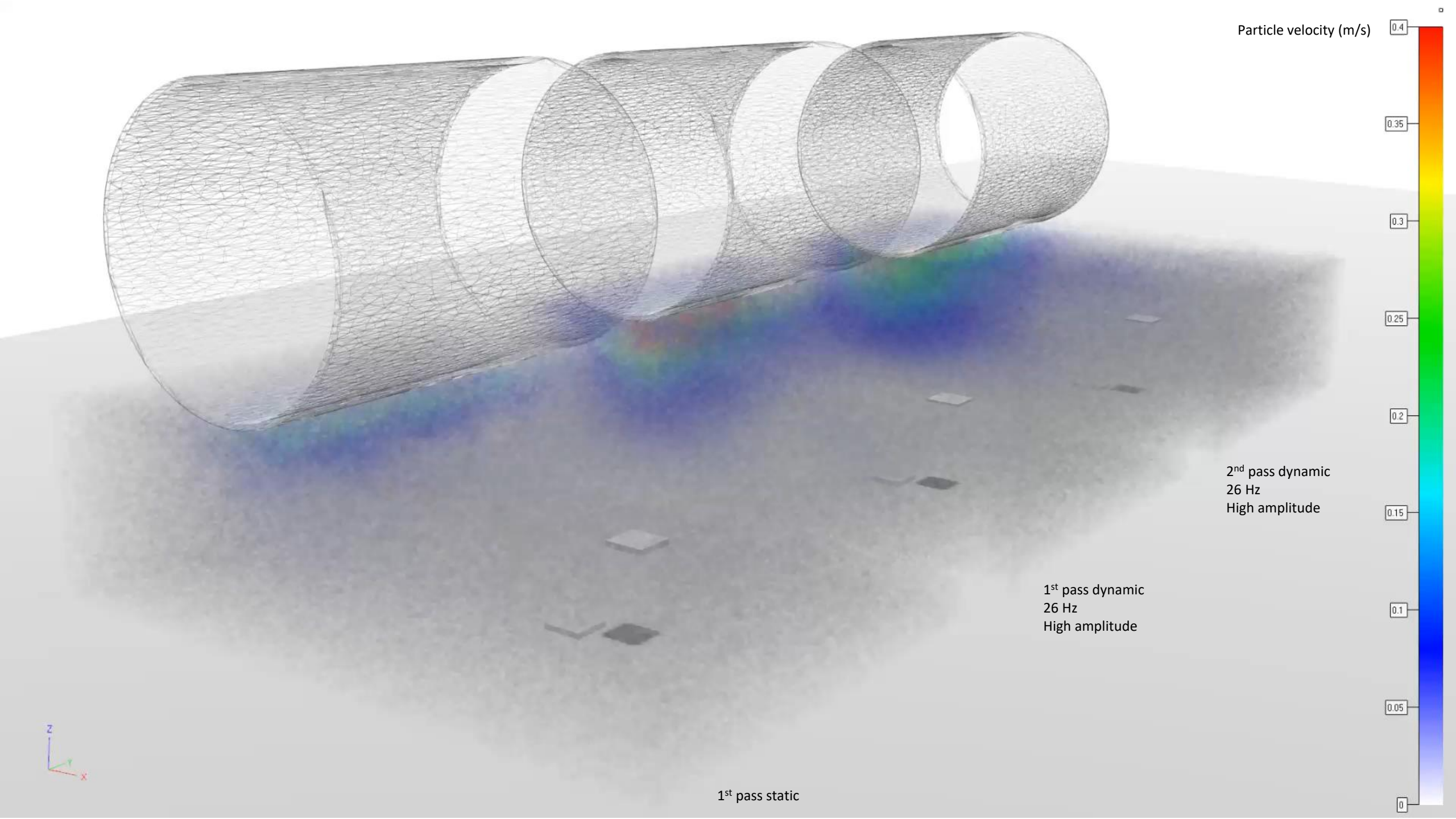
1st pass – Static – Roller velocity 1 m/s

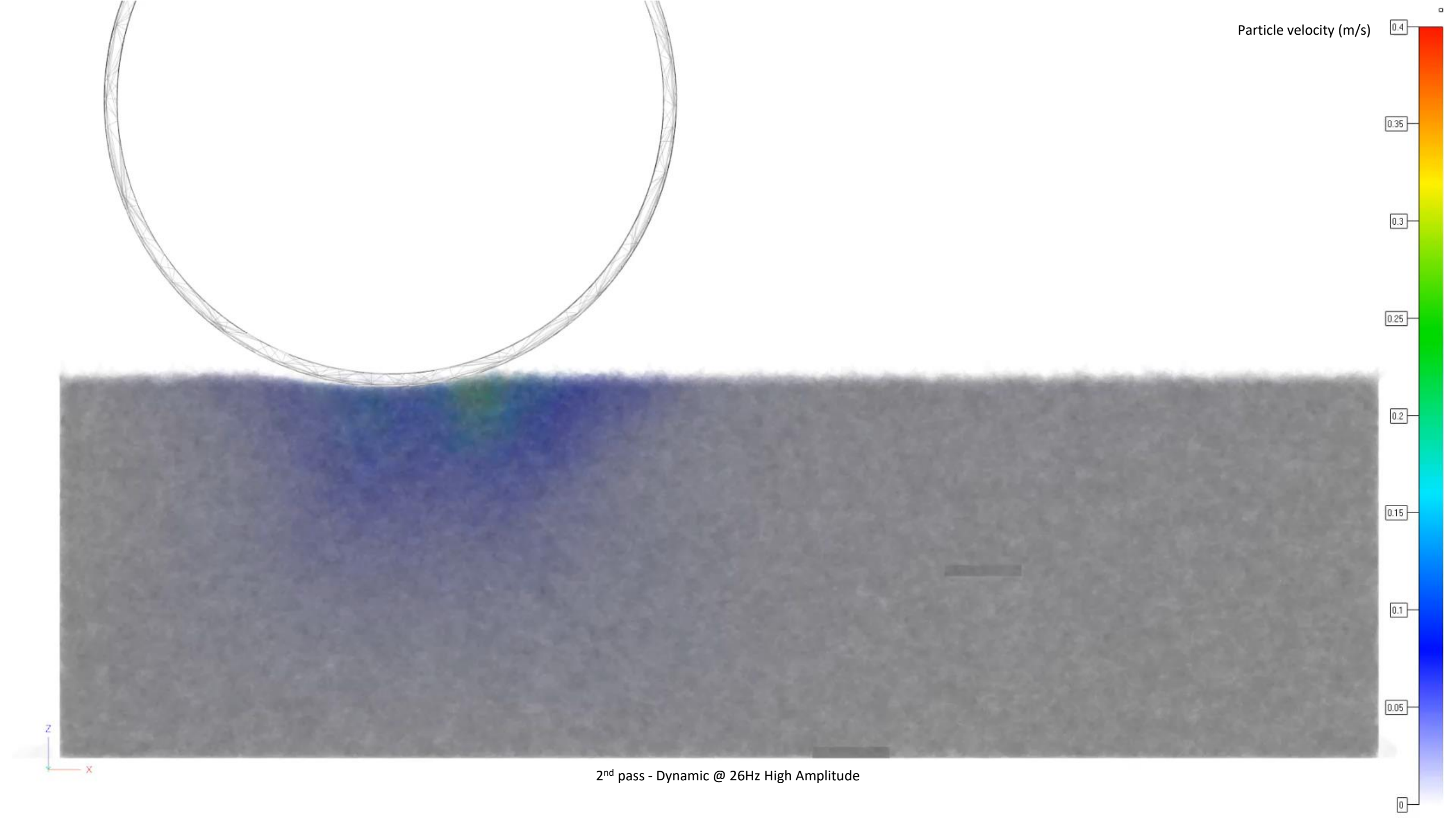
1st pass - Dynamic @ 26Hz High Amplitude – Roller velocity 1m/s





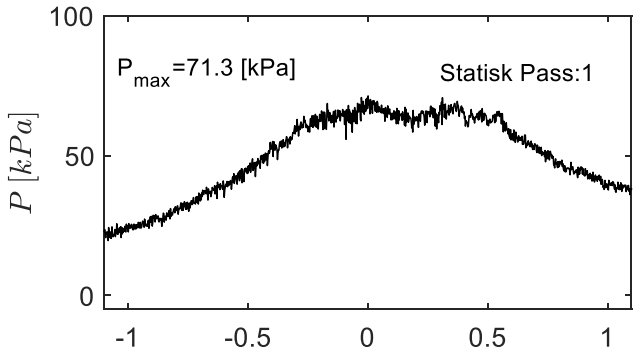


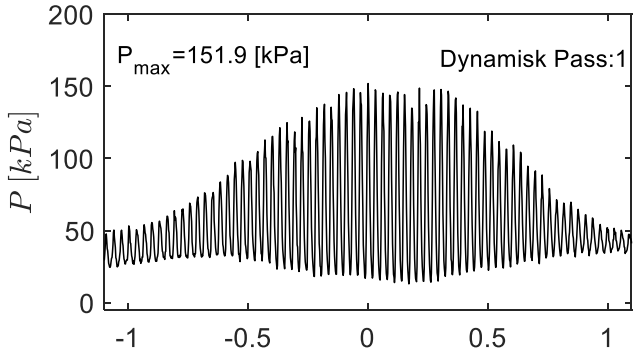

Particle velocity (m/s)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2nd pass dynamic
26 Hz
High amplitude
1st pass dynamic
26 Hz
High amplitude
Z
Y
X
1st pass static

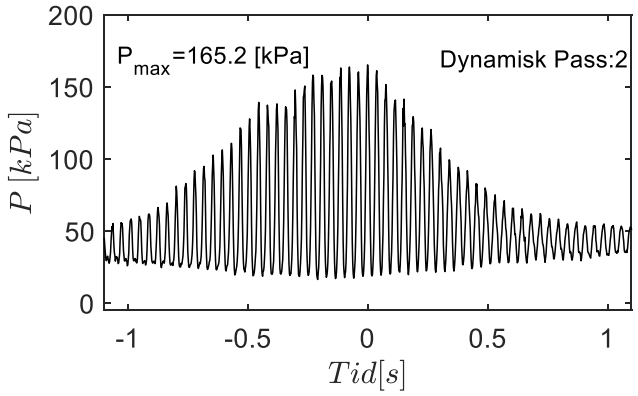


2nd pass - Dynamic @ 26Hz High Amplitude

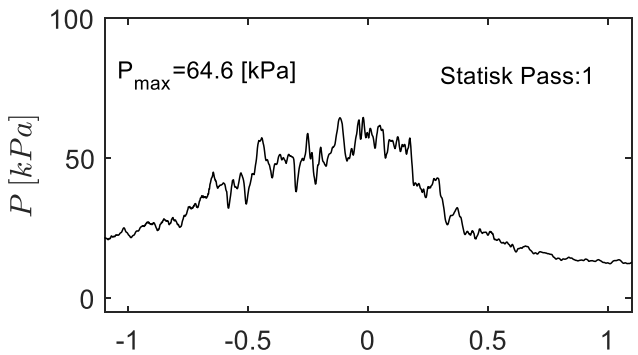
Experiment

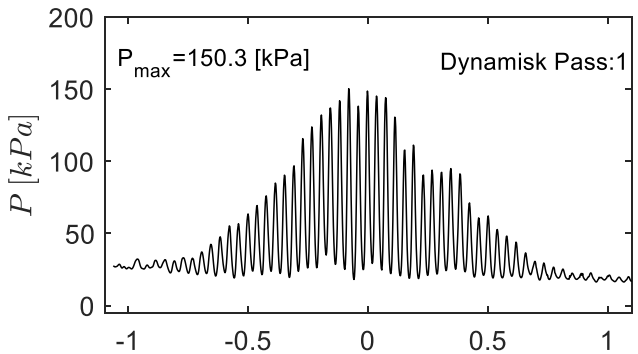


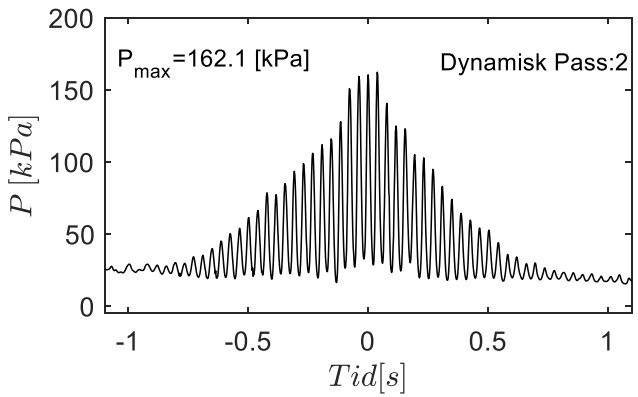


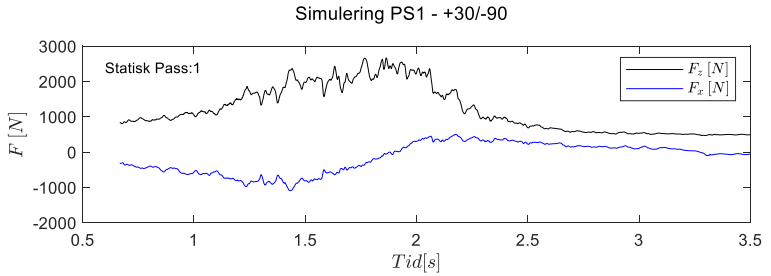


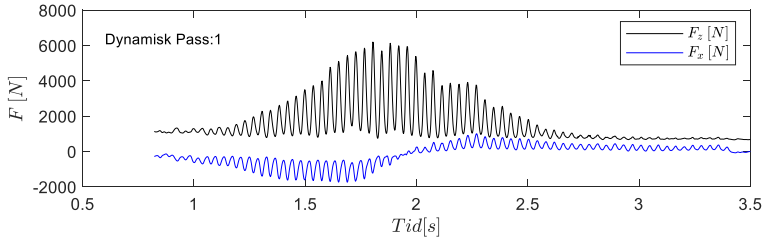
Simulation

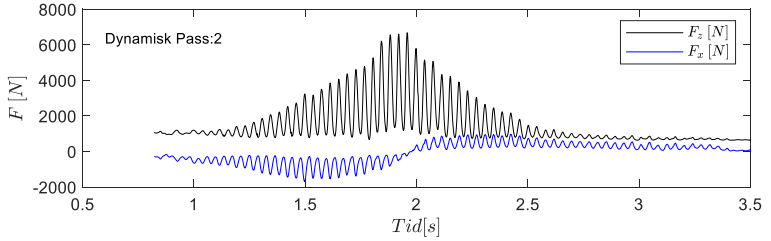


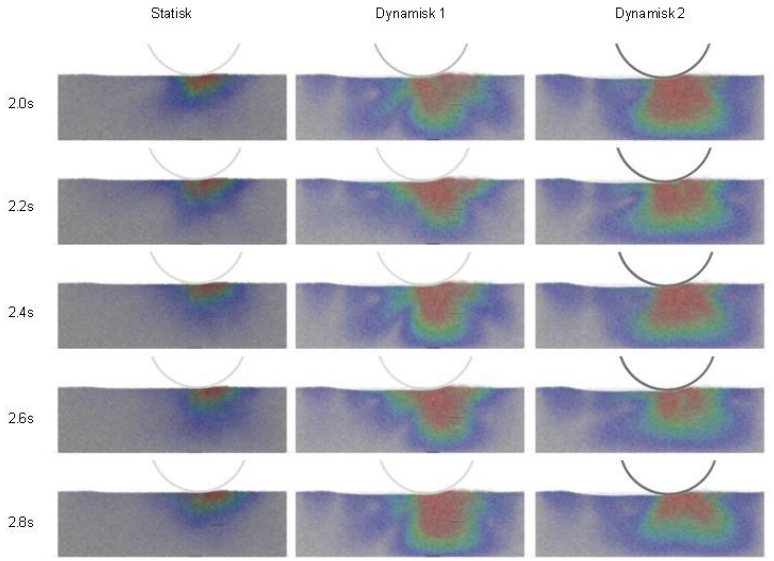






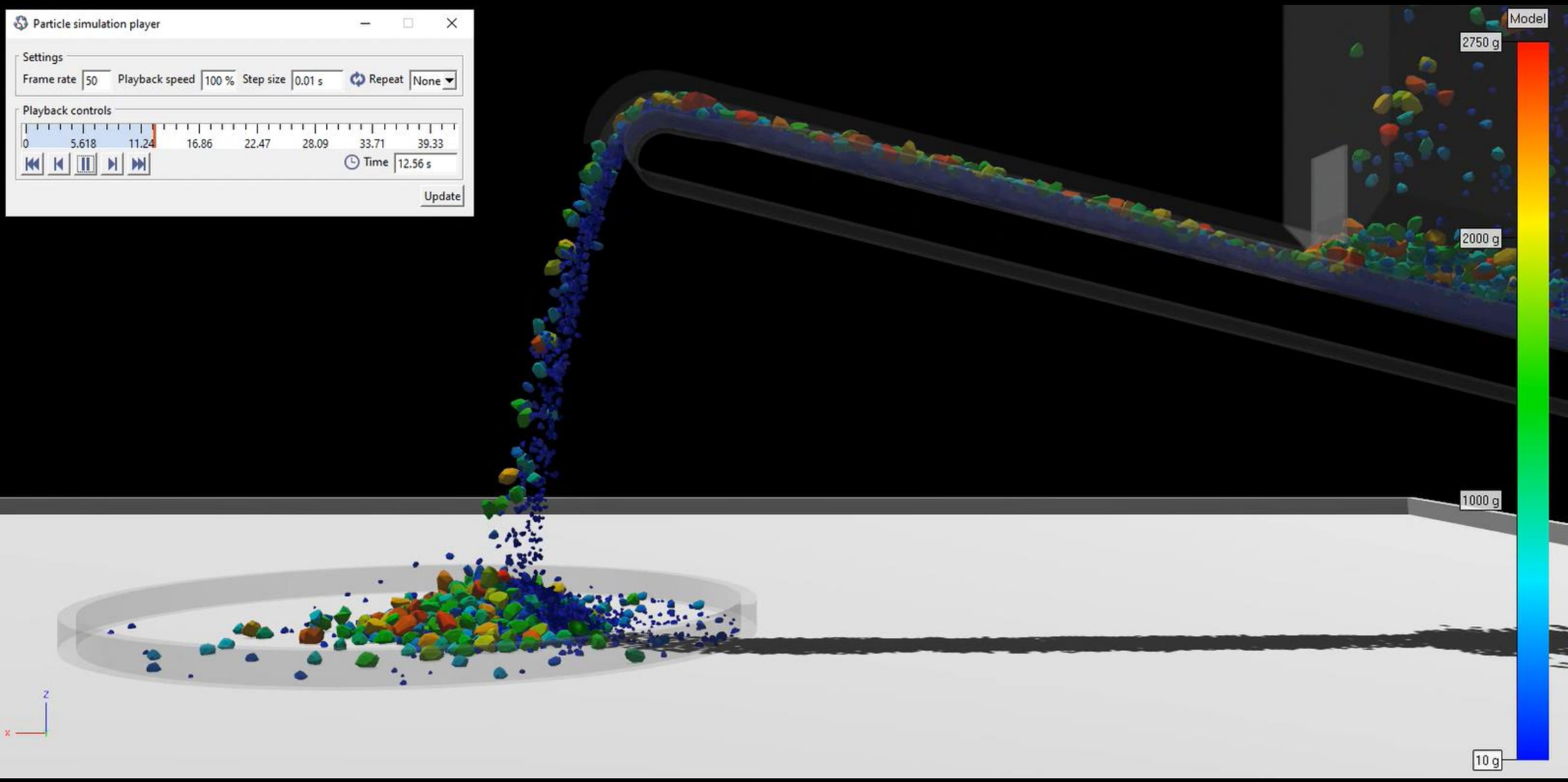






CASE 2 | Summary

- Industrial scale validation data set
- Python API very versatile for advanced modelling
- Good results when comparing simulation and experiments


Particle simulation player
Settings
Frame rate
50
Playback speed
100 %
Step size
0.01 s
Repeat
None
Playback controls
0
5.618
11.24
16.86
22.47
28.09
33.71
39.33
Time
12.56 s
Update
Model
2750 g
2000 g
1000 g
10 g
Z
X

FINDINGS

- Segregation effects have been investigated, identified and quantified in both simulations and experiments

- The local size distribution has a very strong effect on compaction performance and hence road life expectancy

- All steps, from quarry to compacted road layer, needs to be viewed as a process where quality is managed. Not only a focus on capacity of individual equipment.

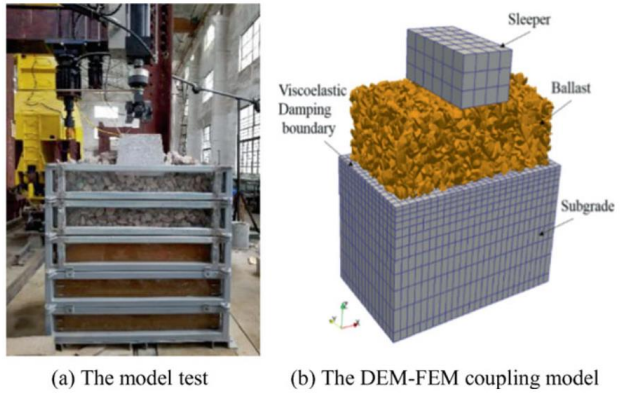
STRATEGY & RESEARCH METHODOLOGY

- Iterative development
  - “Kill your darlings”
- Focus on the technology readiness level and **direct actions** for the next step
- Industrial scale physical experiments - **Validation**
- Work with consortium partners on tangible sub-challenges

NEXT STEP

- Software demonstrator implementation at Volvo CE and Dynapac ongoing
- The developed technology should be used to investigate equipment performance, processes, quality, sampling, standards etc.

- Next call – Ideas:
  - Model bound layers, sub-grade and concrete/steel structures with FEM (FCC LaStFEM) – DEM/FEM/MBS coupling
  - “Complete” railway/road superstructure simulation
  - Discussions with Trafikverket
  - Ongoing research internationally and at KTH
  - DigiRoad solution would enable an extreme scale up, performance and quality
  - Do YOU want to join!?



(a) The model test (b) The DEM-FEM coupling model

Fig. 8 The scene of model test and DEM-FEM coupling model

DISCUSSION

- Sustainability aspects
  - Increased life-span of infrastructure
  - Equipment energy minimization in e.g. loading
  - …
- From nothing to state-of-the-art in three years
- Challenges
- Commercialization
- Gender & Equality

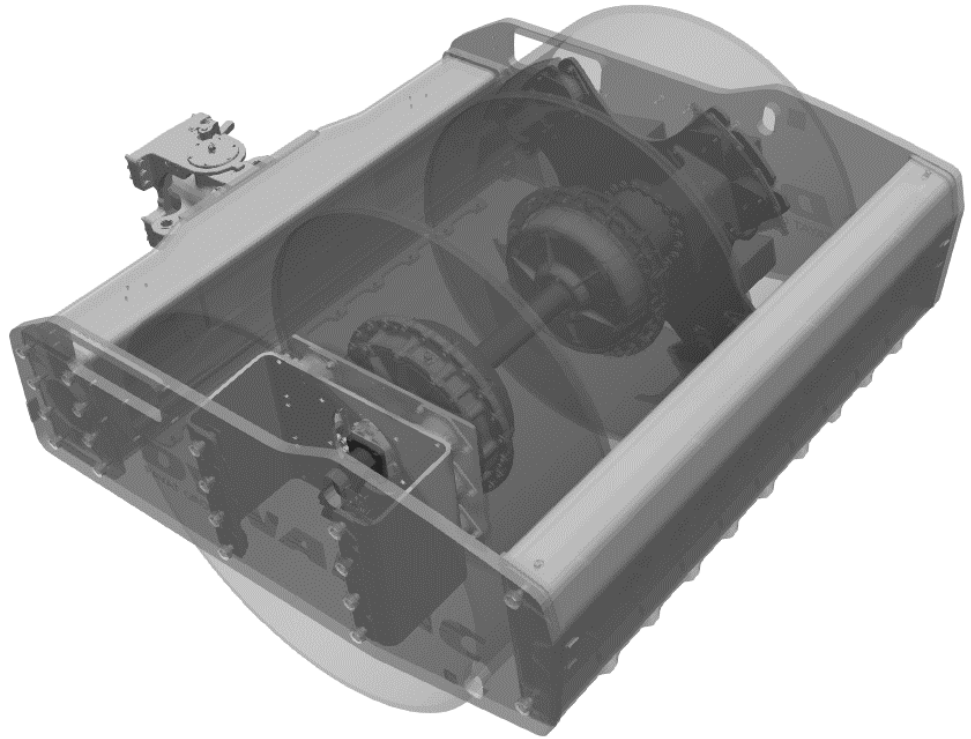
INFRA SWEDEN 2030

EXTRA SLIDES

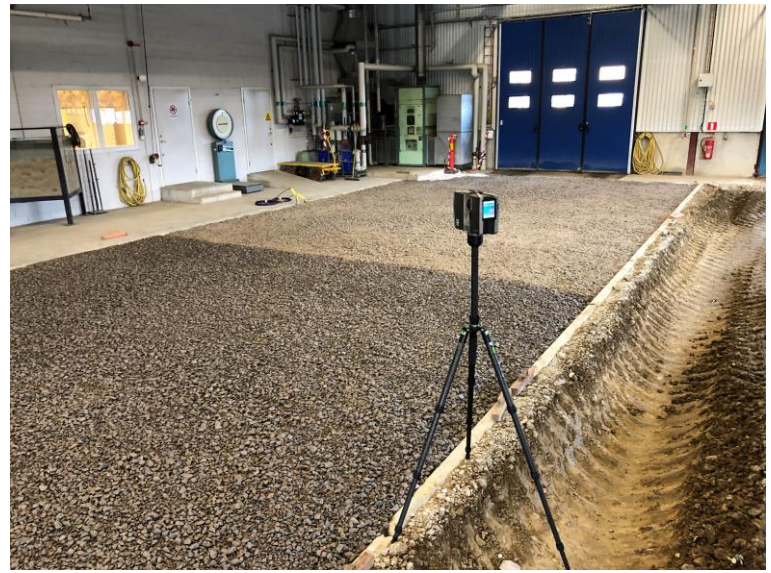
DEM-MBD co-simulation

```
    # for visualisation
    MBS.Point([0.,0.,1.], drivskiva)
    points.append(MBS.Point([1.,0.,0.], drivskiva))
    points.append(MBS.Point([-1.,0.,0.], drivskiva))
    points.append(MBS.Point([0.,0.,-1.], drivskiva))
    points.append(MBS.Point([0.,-1.,1.], vals))
    points.append(MBS.Point([0.83,-1.,-0.5], vals))
    points.append(MBS.Point([-0.83,-1.,-0.5], vals))
    points.append(MBS.Point([0.,1.,1.], vals))
    points.append(MBS.Point([0.83,1.,-0.5], vals))
    points.append(MBS.Point([-0.83,1.,-0.5], vals))
    points.append(MBS.Point([0.,0.,1.], vibbplat))
    points.append(MBS.Point([0.83,0.,-0.5], vibbplat))
    points.append(MBS.Point([-0.83,0.,-0.5], vibbplat))
    points.append(MBS.Point([1.2,1.2,0.], ram))
    points.append(MBS.Point([-1.2,1.2,0.], ram))
    points.append(MBS.Point([1.2,-1.2,0.], ram))
    points.append(MBS.Point([-1.2,-1.2,0.], ram))

    # Constraints
    # for simulation
    constraints = []
    positioningconstraints = []
    constraints.append(c.Spherical(axel, axelvalsp_l, vals, valsaxelp_l))
    constraints.append(c.Slider(axel, axelvalsp_r, vals, valsaxelp_r, [[1,0,0], [0,0,1]]))
    if fixed:
      constraints.append(c.Fixed(ram, ramcp, ground, groundramp))
    else:
      # constraints.append(c.Slider(ram, ramcp, ground, groundramp, [[1,0,0], [0,1,0], [0,0,1]]))
      constraints.append(c.Slider(ram, ramcp, ground, groundramp, [[0,1,0], [0,0,1]]))
    constraints.append(c.Spherical(ram, ramdrivp, drivskiva, drivramp))
    constraints.append(c.Slider(ram, ramdrivp, drivskiva, drivramp, [[1,0,0], [0,0,1]]))
    constraints.append(c.Spherical(vals, valsvibbp, vibbplat, vibbvalsp))
    constraints.append(c.Slider(vals, valsvibbp, vibbplat, vibbvalsp, [[1,0,0], [0,0,1]]))
```




FARO
FARO



DIGIROAD Simulation of handling and compaction of unbound aggregates in road construction

Case study 2021 – Differential compaction of UGM layers due to construction traffic

Scope:

Investigate the effects of articulated hauler tire compaction of base course layer on the final compaction performance and differentiation from the nominal compaction response

Method:

- Multi-camera system
- Laser 3D scanning
- Material sampling
- Ground pressure load cells
- Light deflectometer & CMV
- Material: +0/-32
- 2 Tracks (with/without traffic)
- DEM/MBD Co-Simulations

Info:

- SBUF project support
- Project Idea: Martyn Luby, Volvo CE
- Project Owner: NCC
- Project Leader: Kristoffer Hofling
- Project partners: FCC, Volvo CE
- Test location: VCE Eskilstuna
- Machinery: e.g. Volvo SD135B, A45G
- Time: August 2021

"The first project that we had this discussion was years ago when I worked for NCC and we were tendering for a job in Malmö harbour.

Then since I worked for Volvo the discussion has come up on and off with contractors using our compaction system who see these areas as they get extremely high CMV values when they pass over them with the roller."

DIGIROAD Simulation of handling and compaction of unbound aggregates in road construction

Case study 2018 – Full-scale flow experiments for DEM validation and examination of segregation effects

Scope:

1. Develop a data-set that can be used for industrial scale validation of DEM simulations

2. Investigate the mechanisms and effects of size segregation during unloading

Method:

- Multi-camera system
- Laser 3D scanning
- Material sampling
- Motion capture

Info:

- SBUF project support
- Project owner: NCC
- Project leader: Pär Johnning
- Test location: NCC Stenungsund
- Machinery: Volvo L180H / Volvo FMX (SLP)

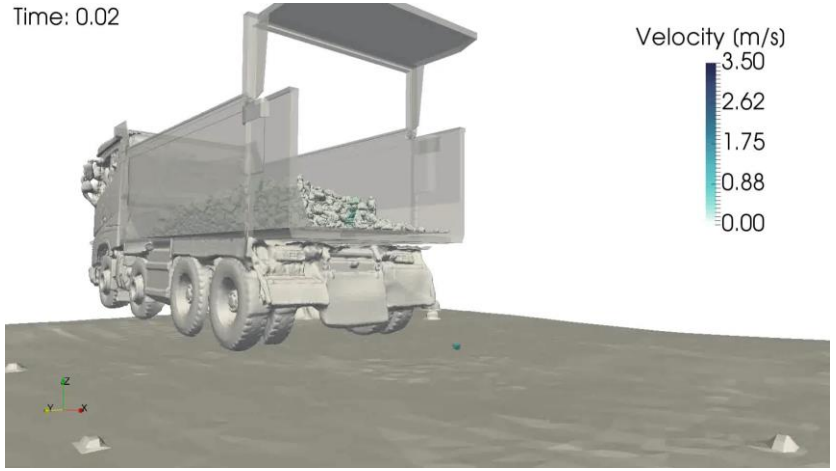
Truck unloading

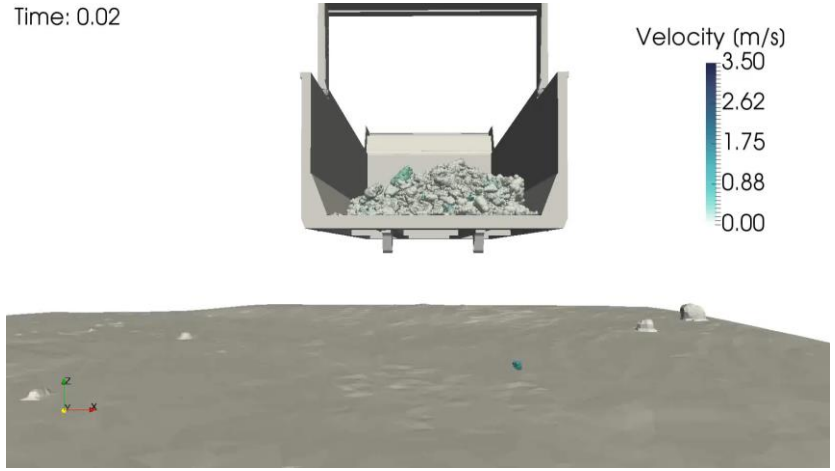
Wheel loader unloading

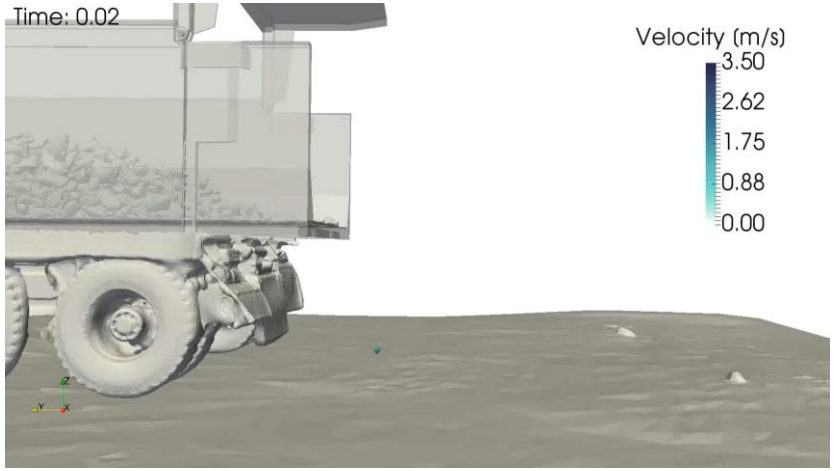
SBUF
SVENSKA BYGGBRANSCHENS UTVECKLINGSFOND
The development fund of the Swedish construction industry

This simulation completed ID: C1_T12

C1 T12 - Comparison

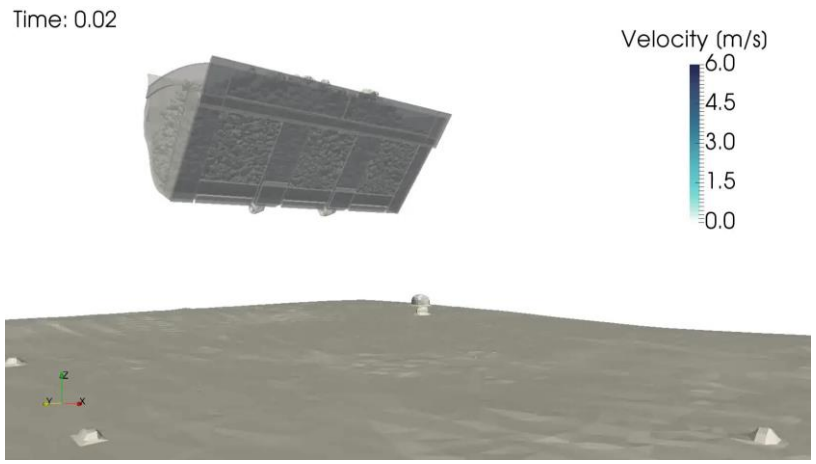


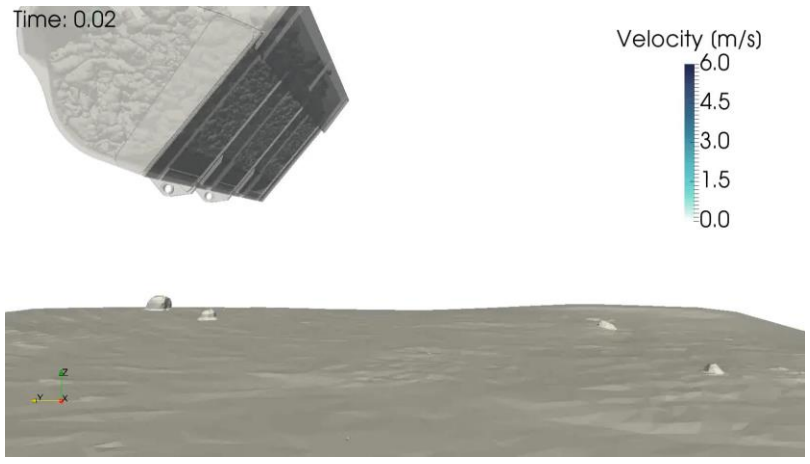


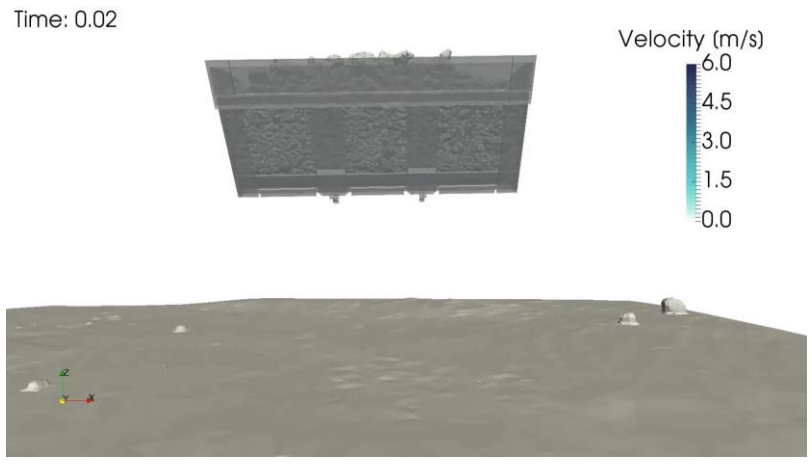


C2 Wheel Loader +22/-250

This simulation ID: C2_V5





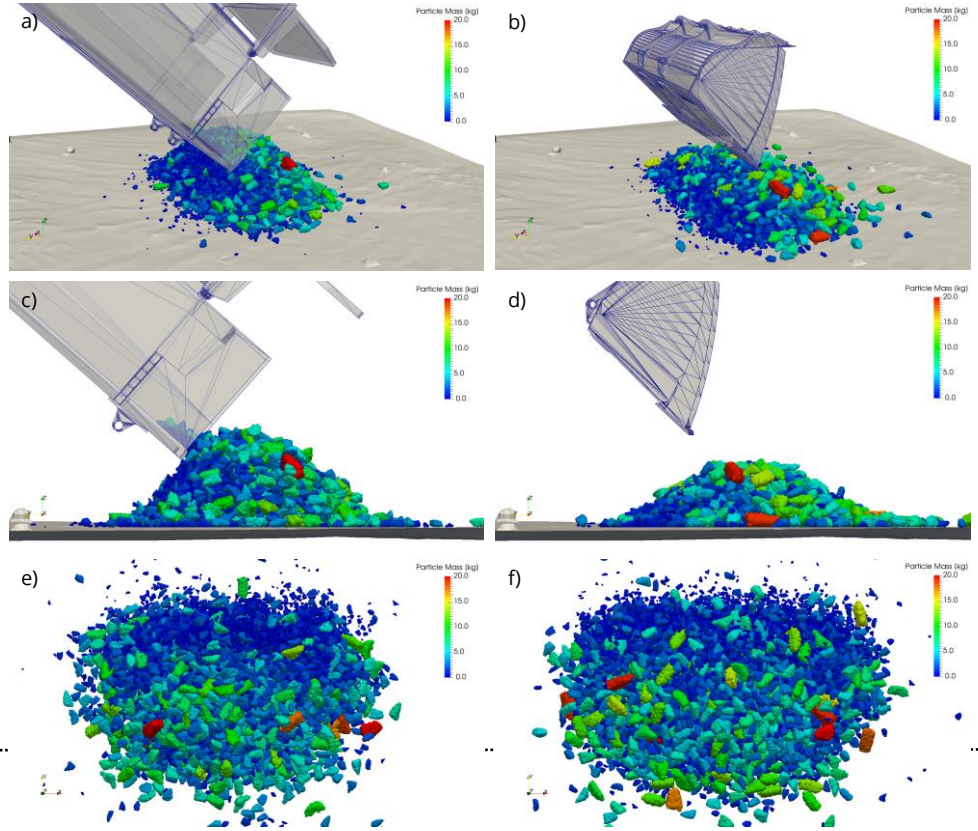


DIGIROAD Simulation of handling and compaction of unbound aggregates in road construction

Case study 2018 – Full-scale flow experiments for DEM validation and examination of segregation effects

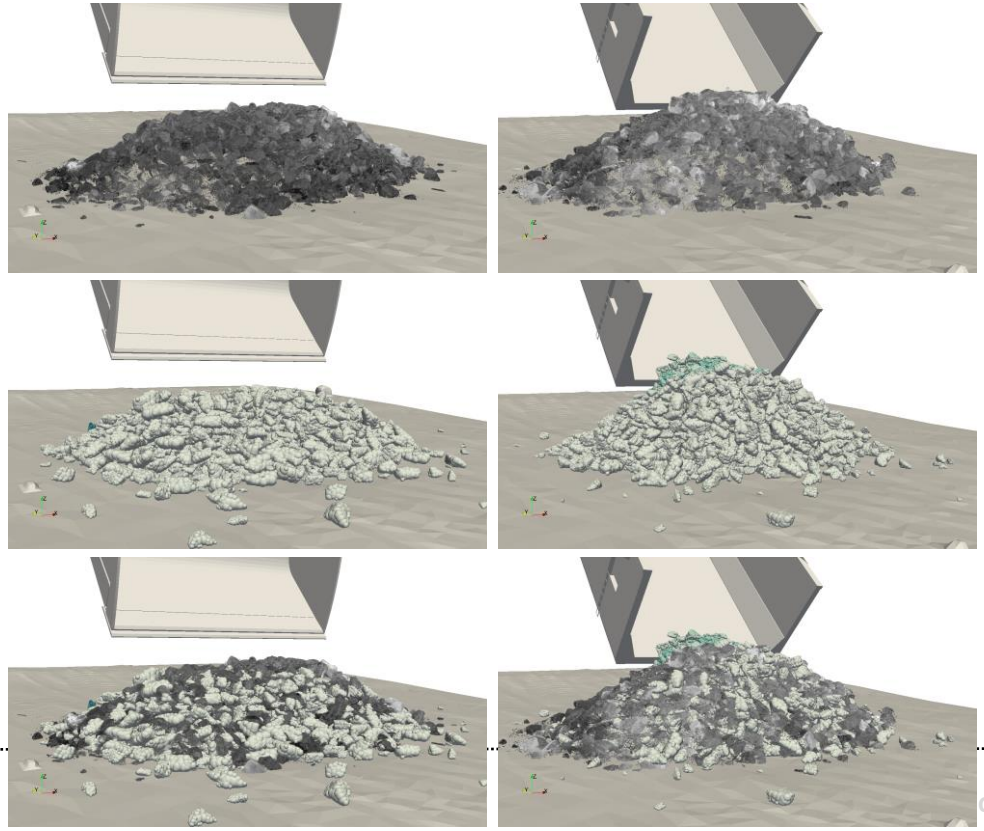
Segregation

The mechanism of size segregation strongly influences the homogeneity of the pile formation in terms of particle size distribution



Validation

The simulation results demonstrated a high level of congruence in terms of particle flow characteristics and rock pile formation topography



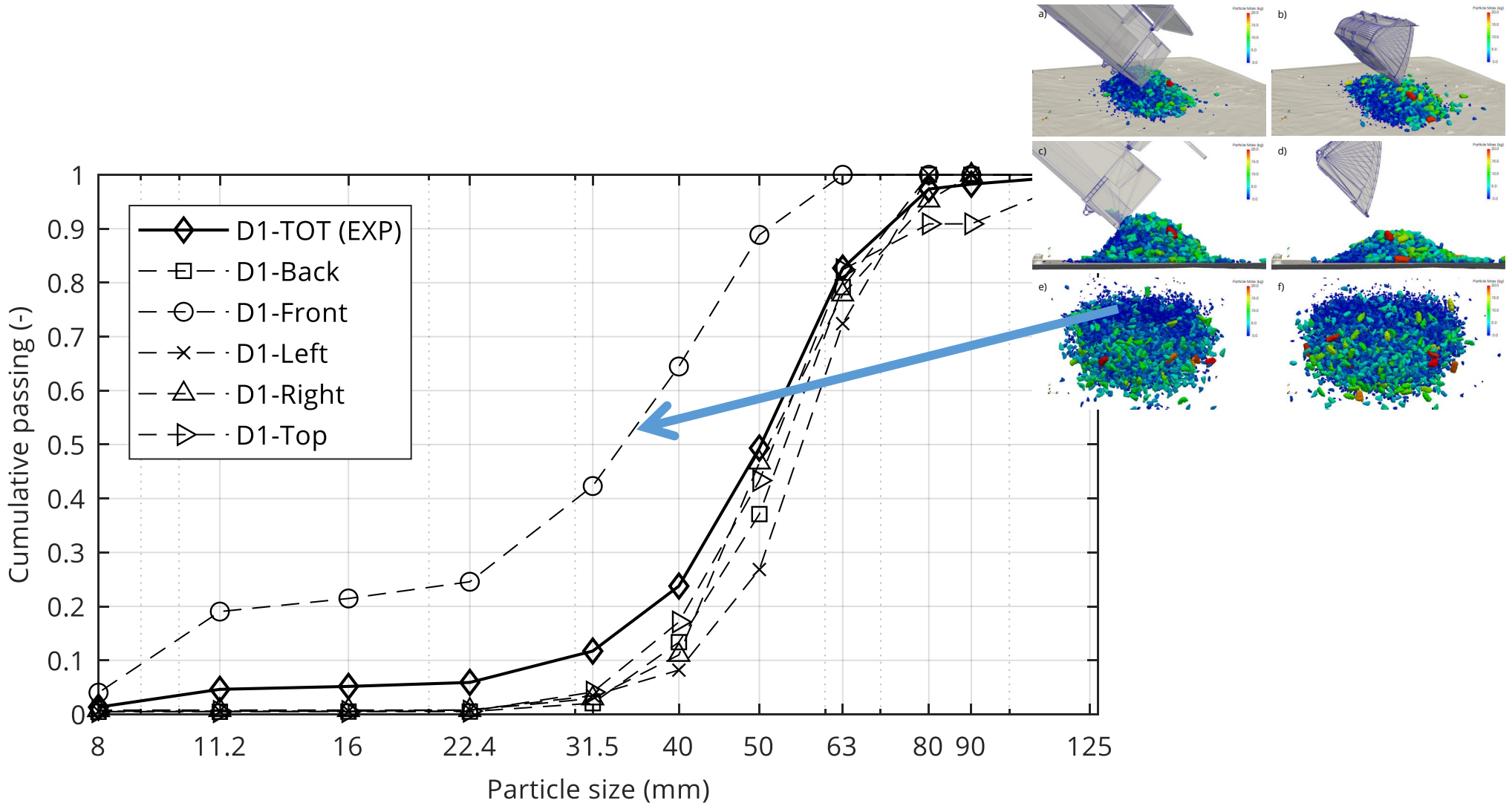


Figure 23. Particle size distribution for the D1 truck unloading test (+22/-90 & +8/-11 mm).

DEMIFY | Interfaces

Python interface for scripting (Windows/Linux)

- Shared library loaded as a standard Python module
- Versatile and a user-friendly syntax
- Allows for advanced customization
- Batch simulations

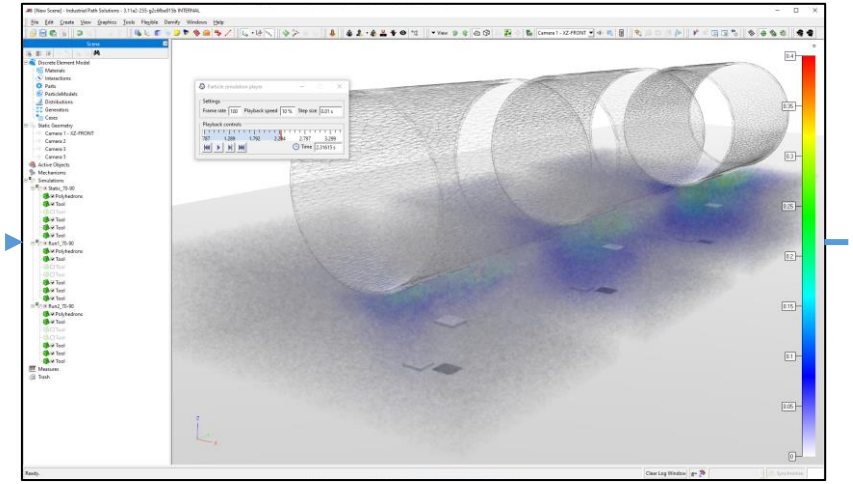
```python
# Particle material
rubber = materials.Material(density=1000,
                            youngs_modulus=1e7,
                            poissons_ratio=0.25)

# Wall material
object_material = materials.Material(density=7000.0,
                                     youngs_modulus=200e7,
                                     poissons_ratio=0.25)

# Particle-particle interaction
pp = inter.HMD(rubber, rubber, friction=0.2, restitution=0.5)

# Particle-wall interaction
pw = inter.HMD(rubber, object_material, friction=0.2, restitution=0.5)

# Floor mesh based on two triangles
floor_mesh = geo.TriangleMesh(
  nodes=[[-5.0, -5.0, -0.03], [-5.0, 5.0, -0.03], [5.0, 5.0, -0.03],
         [5.0, -5.0, -0.03]],
  triangles=[[0, 2, 1], [0, 3, 2]],
  mesh_quality_check=geo.MeshQualityCheck.BYPASS_EXCEPTION)
```



Demify Graphical User Interface:

- Generic DEM environment on the IPS platform
- Pre-processing, running and post-processing
- Generate python script from GUI configuration