Effect of Proximity of Sheet Pile Walls on the Apparent Capacity of Driven Displacement Piles (BDV31 TWO 977-26)

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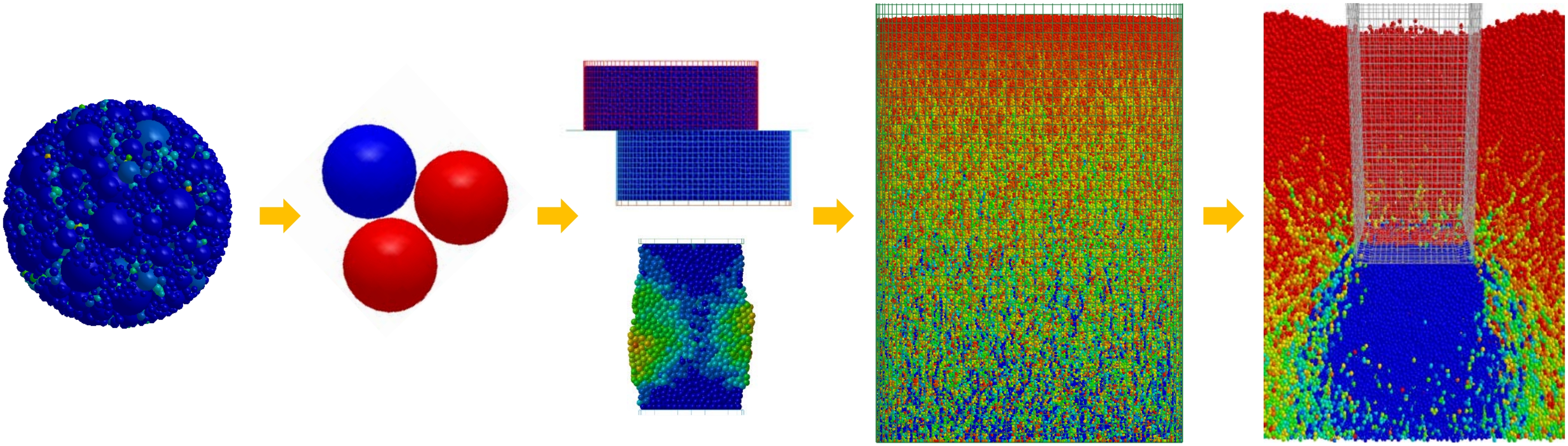


Project Manager: Juan Castellanos, FDOT Structure Design Office

Presented at Geotechnical Research in Progress (GRIP) Meeting
State Materials Office (SMO)
Florida Department of Transportation (FDOT)
Gainesville, Florida
August 21, 2015

Agenda

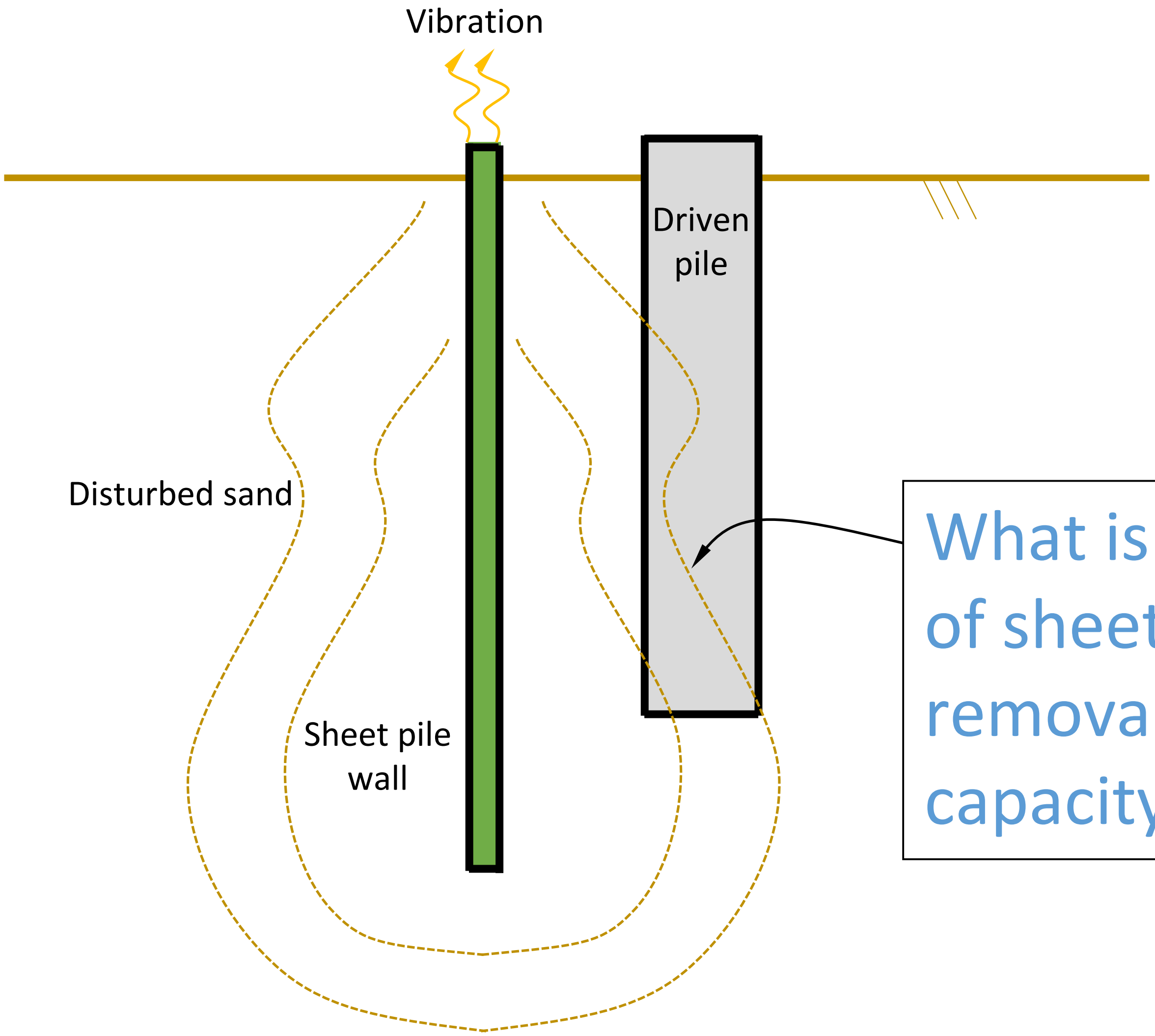
- Introduction

- Task 2 Activities

- Preliminary Progress for Task 3

Introduction

- Effect of Sheet Pile Walls in the Vicinity of Driven Piles



What is the effect of sheet pile wall removal on pile capacity?

Introduction: Project Approach

- Identify design-relevant parameters for calculating pile capacities in the vicinity of SPWs
- Develop design charts and/or tabularized matrices for use in calculation of pile-capacity changes
- Methodology:
  - Combined Discrete (soil) and Finite (pile and sheet pile wall) Element Analysis
  - Spectrum of model validation (laboratory and centrifuge testing)

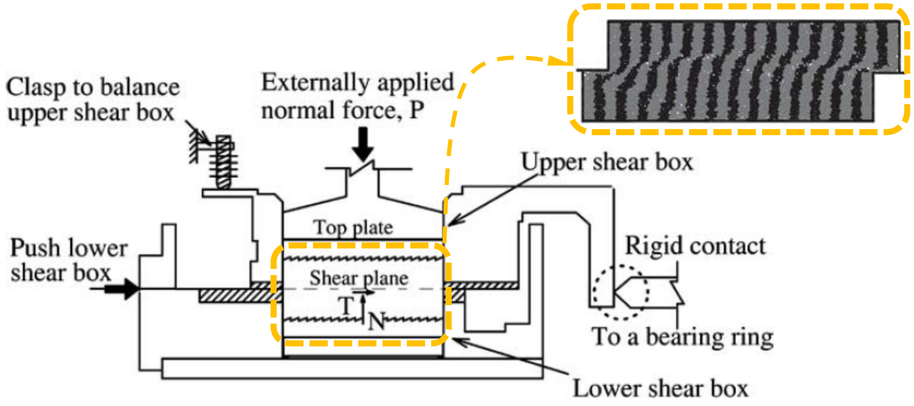
Introduction: Project Approach

- **Phase I (12 months; July 2014 - June 2015)**
- Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition
- Task 2. Numerical Modeling Schemes and Granular Soil Units

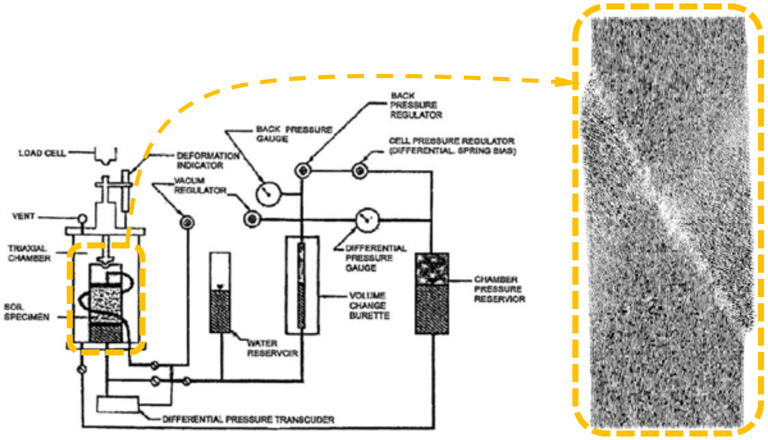
- **Phase II (18 months; July 2015 - December 2016)**
- Task 3. Numerical Modeling of Driven foundation in Granular Soils
- Task 4. Physical Laboratory/Centrifuge Experimentation
- Task 5. Reporting of Findings and Design-Oriented Recommendations
- Task 6. Final Report

Task 2. Numerical Modeling of Granular Soils

- **Deliverables**
  - Methodology for modeling direct shear and triaxial compression tests of granular soil
  - Simulation of macroscopic shear strength (Mohr-Coulomb failure envelopes)
  - Creation of standardized DEM "soil-unit" library



Direct shear test



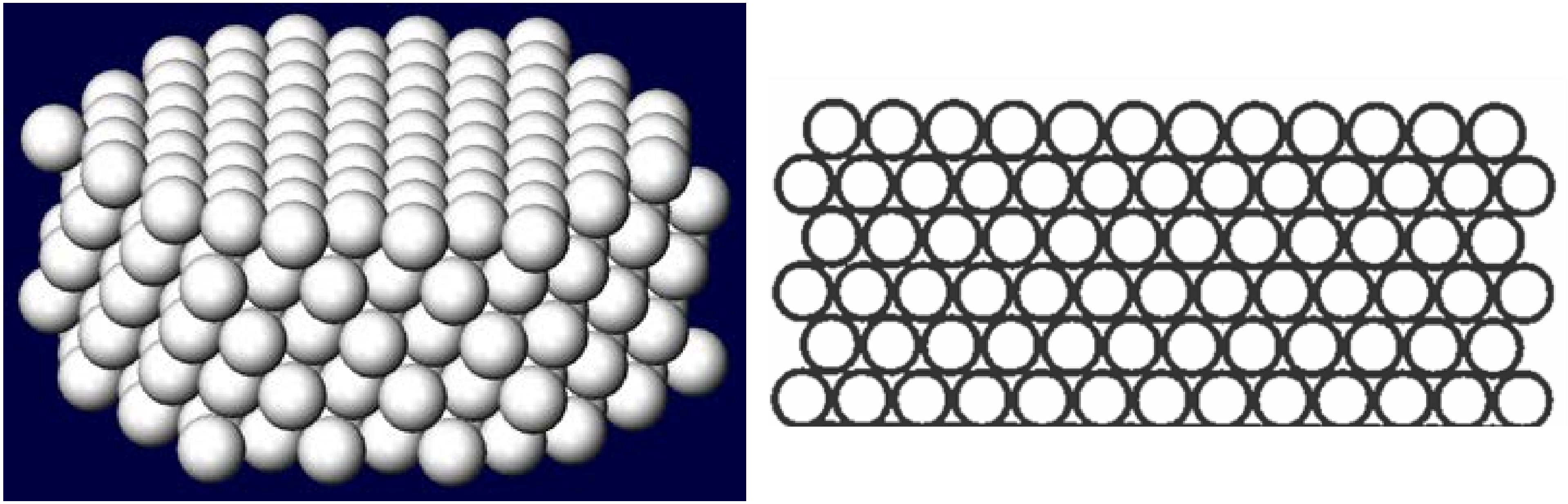
Triaxial compression test

Task 2. Numerical Modeling of Granular Soils

- **Activities**
  - Scale dependency of friction and “Shear Jamming”
  - Contact rheology
  - Direct shear test simulation
  - Triaxial test simulation
  - Soil unit library

Task 2 Activity: Scale Dependency of Friction

- Granular materials have surface texture at multiple scales; the repetitive or randomly-ordered particle arrangement forms 3-D topology of the surface.



Geometrically regular packings: a) Close-packed tetrahedral spheres at the theoretical maximum bulk density of $\pi/(3\sqrt{2})$ (~74%) in a volume; b) An equivalent 2-D planar packing of discs at the theoretical maximum bulk density of $\pi/(2\sqrt{3})$ (~91%) (Israelachvill 2011)

Task 2 Activity: Scale Dependency of Friction

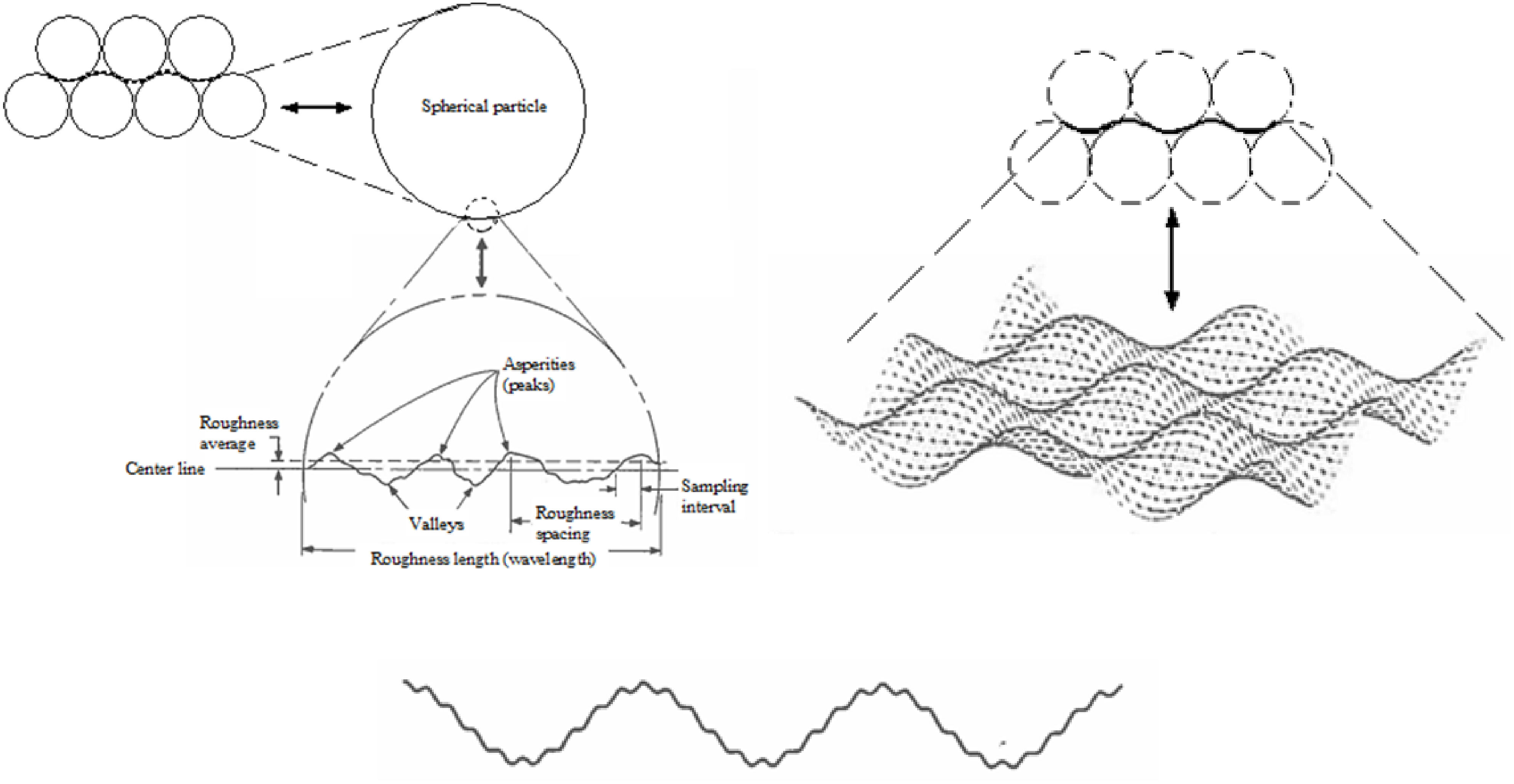


Figure 2.1.2.2. Pictorial surface texture of close-packed spheres: a) Microroughness of a spherical particle; b) Macroroughness of 2-D corrugated surface; c) Representation of a periodic surface with corrugations on the two scales

Task 2 Activity: Scale Dependency of Friction

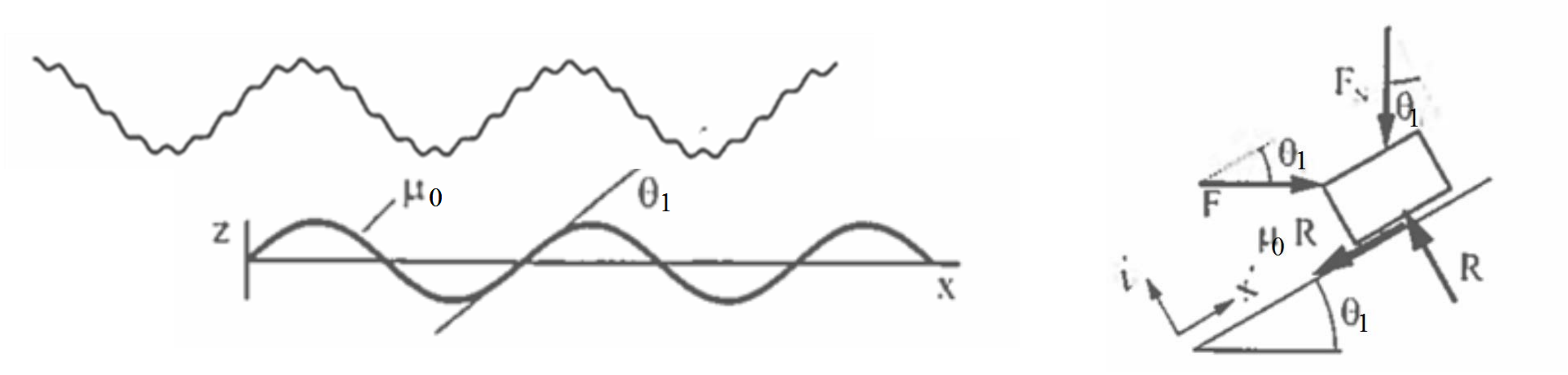


Figure 2.1.2.4. Idealized macroroughness with periodic corrugation: a) Corrugated surface with intrinsic coefficient of friction, μ_0; b) Free-body diagram of a body on a corrugated surface with coefficient of friction, μ_0

$$l': \quad F_N \cos\theta_1 + F \sin\theta_1 = R$$

$$x': \quad F_N \sin\theta_1 + \mu_0 R = F \cos\theta_1$$

$$\frac{F}{F_N} = \frac{\mu_0 + \tan\theta_1}{1 - \mu_0 \tan\theta_1} = \frac{\mu_0 + \mu_1}{1 - \mu_0 \mu_1}$$

$$\mu = \tan\theta = \frac{\sin(\theta_0 + \theta_1)}{\cos(\theta_0 + \theta_1)} = \frac{\sin\theta_0 \cos\theta_1 + \cos\theta_0 \sin\theta_1}{\cos\theta_0 \cos\theta_1 - \sin\theta_0 \sin\theta_1} = \frac{\tan\theta_0 + \tan\theta_1}{1 - \tan\theta_0 \tan\theta_1} = \frac{\mu_0 + \mu_1}{1 - \mu_0 \mu_1}$$

$$\mu = \tan\left(\sum_i \arctan \mu_i\right)$$

Task 2 Activity: Scale Dependency of Friction

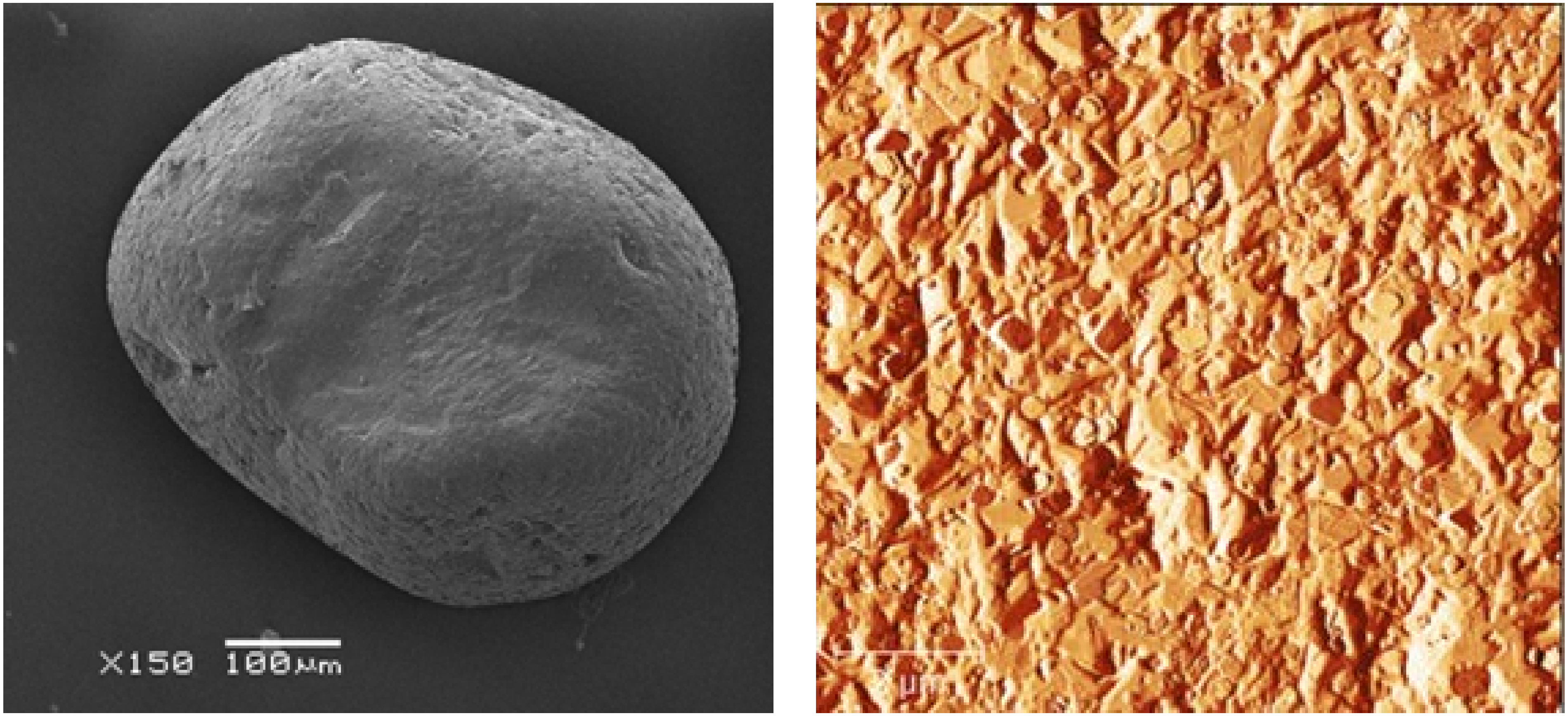


Figure 2.1.5.1. Grain surface topography: SEM (left) and AFM (right) scan size 10 micrometers square.
Semi-round grains with characteristic surf*ace fractures (Konopinski et al. 2012)*

Task 2 Activity: Scale Dependency of Friction JKR Theory (Johnson-Kendall-Robertson, 1971)

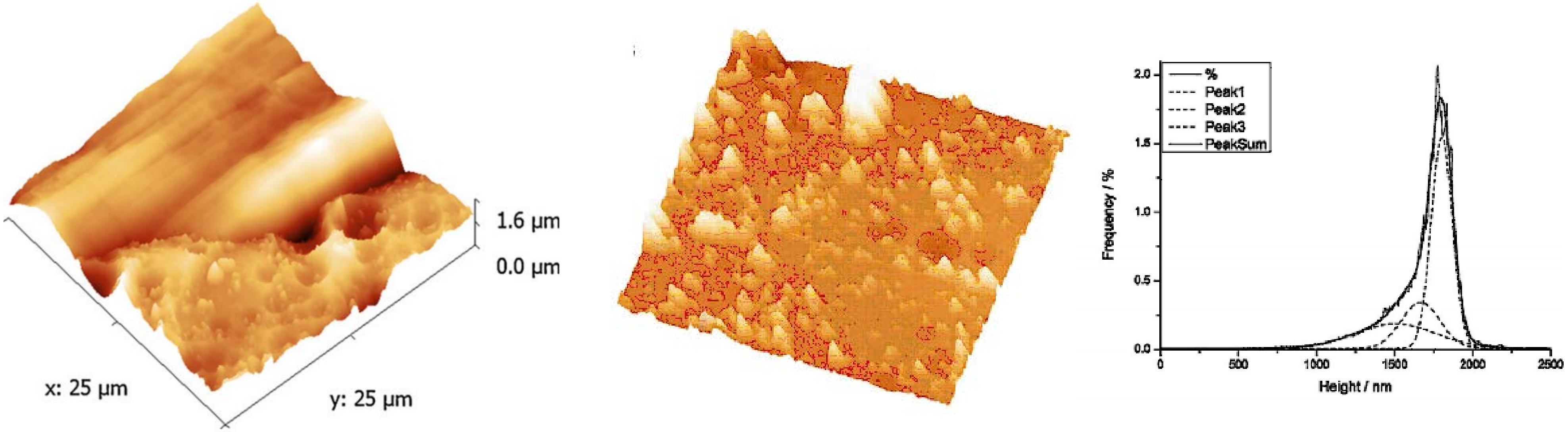


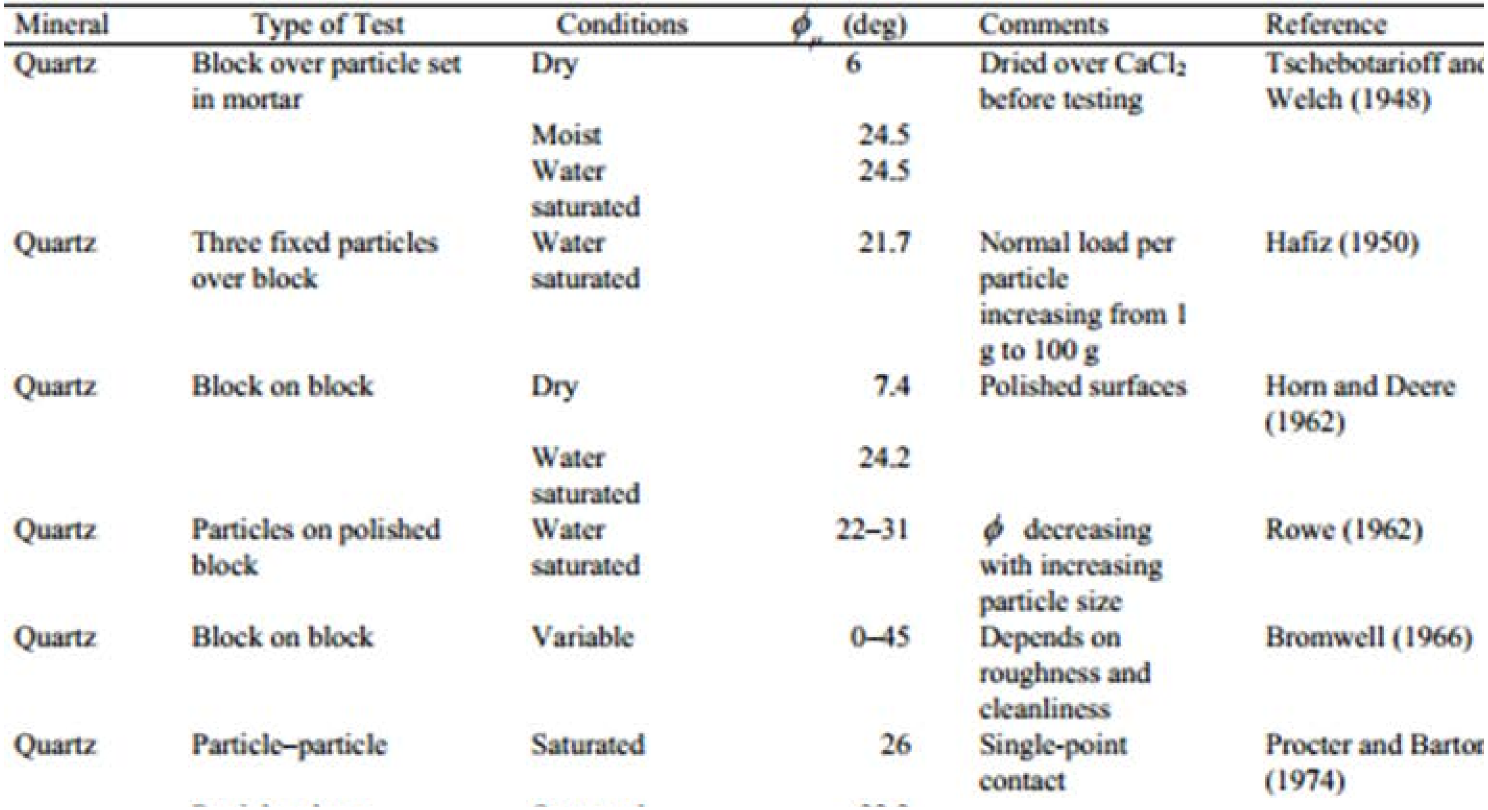
Figure 2.1.2.5. Dimensional representation of the grain surface (from Konopinski et al. 2012): a) 3-D elevation map of Fig. 2.1.5.1b; b) 3-D representation of the microscopic surface texture of a grain; c) Counting estimate of fractal dimension for a 20 µm AFM scan

$$\mu_0 \approx 7.8\left(\frac{d_c}{l}\right)^{8/3} \tan(\langle\theta\rangle_x)$$

$$d_c = \left(\frac{3}{64}\frac{\gamma_{12}^2\pi^2 R}{(E^*)^2}\right)^{1/3} = \left(\frac{3}{64}\frac{(1.2)^2\pi^2(0.0015)}{(83.5E9)^2}\right)^{1/3} = 5.233\times10^{-9}\ m \approx 5.233\,nm$$

$$\mu_0 \approx 7.8\left(\frac{5.233}{9.37}\right)^{8/3} \tan(\langle\theta\rangle_x) = 1.65\tan(\langle\theta\rangle_x)$$

Task 2 Activity: Scale Dependency of Friction



Mineral	Type of Test	Conditions	ϕ_μ (deg)	Comments	Reference
Quartz	Block over particle set in mortar	Dry	6	Dried over $CaCl_2$ before testing	Tschebotarioff an Welch (1948)
		Moist	24.5		
		Water saturated	24.5		
Quartz	Three fixed particles over block	Water saturated	21.7	Normal load per particle increasing from 1 g to 100 g	Hafiz (1950)
Quartz	Block on block	Dry	7.4	Polished surfaces	Horn and Deere (1962)
		Water saturated	24.2		
Quartz	Particles on polished block	Water saturated	22–31	ϕ decreasing with increasing particle size	Rowe (1962)
Quartz	Block on block	Variable	0–45	Depends on roughness and cleanliness	Bromwell (1966)
Quartz	Particle–particle	Saturated	26	Single-point contact	Procter and Barto (1974)

Table 2.1.5.4. Values of microscopic angles of friction for various minerals (Mitchell and Soga 2005)

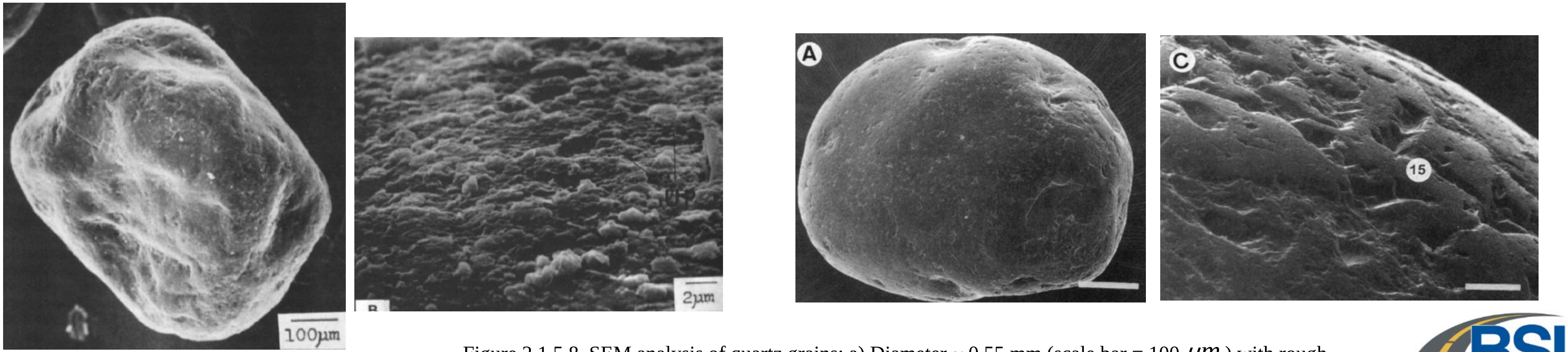
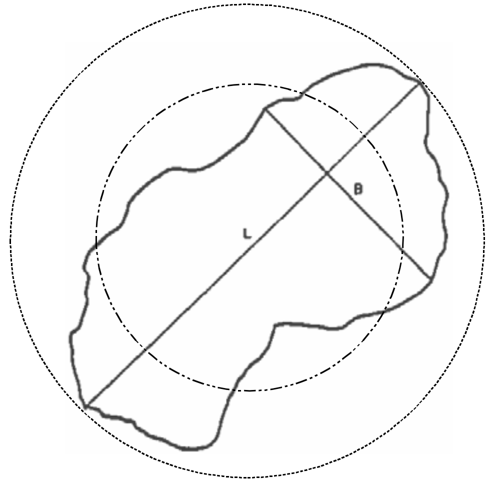


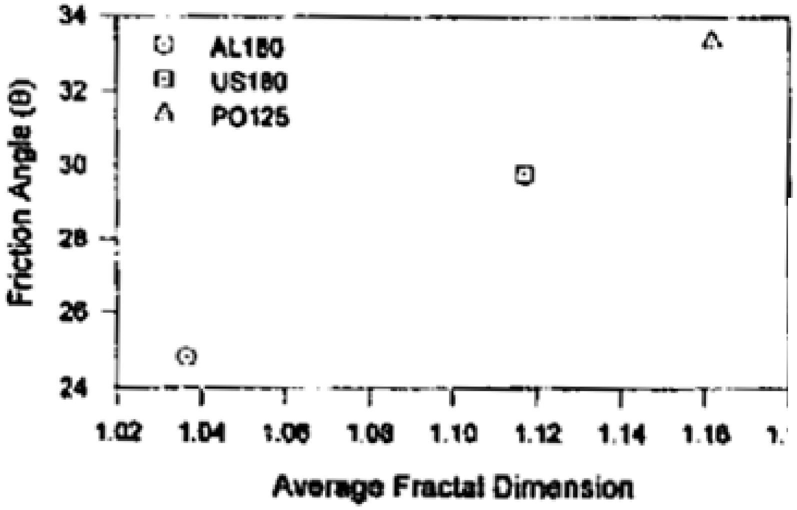
Figure 2.1.5.8. SEM analysis of quartz grains: a) Diameter ~ 0.55 mm (scale bar = 100 μm) with rough surface texture (scan size = 10 µm); b) Diameter ~ 0.8 mm with fairly smooth surface texture; c) Diameter~ 0.6 mm (scale bar = 100 µm) with smooth surface (scale size = 25 µm)

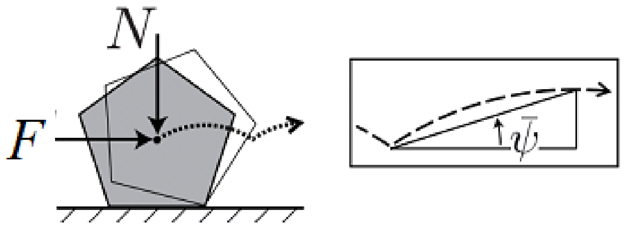
Task 2 Activity: Scale Dependency of Friction

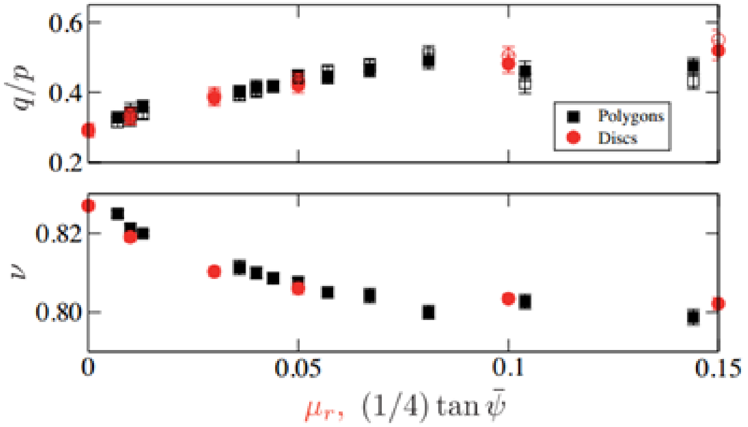
Chan and Page (1997), Sukumaran and Ashmawy (2001), Santamarina and Cho (2004), Anthony and Marone (2005)

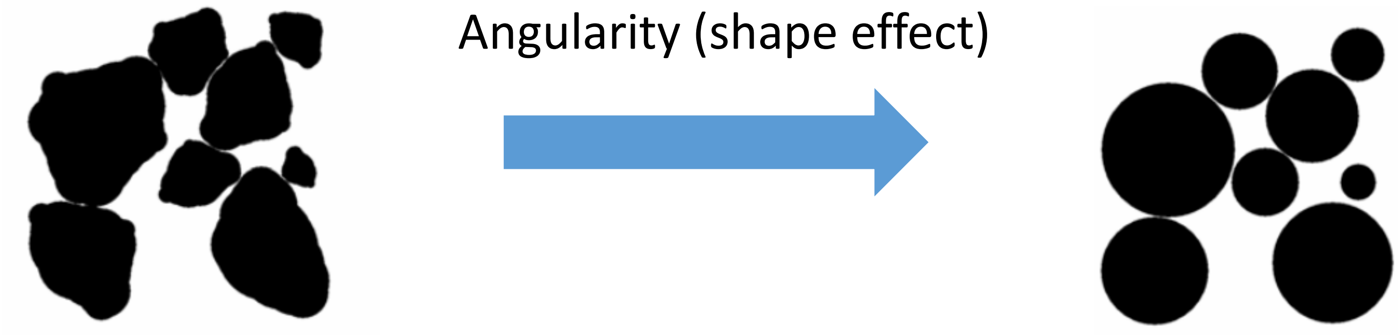
Figure 2.1.7.1. Irregularly shaped grains represented by spheroids: a) Circumscribing diameter (note that the volume of the inner sphere drawn on the larger grain is approximately the same as the volume of the particle); b) Equivalent diameters (note that the surface of the sphere drawn on the smaller grain is approximately the same as the surface area of the particle)







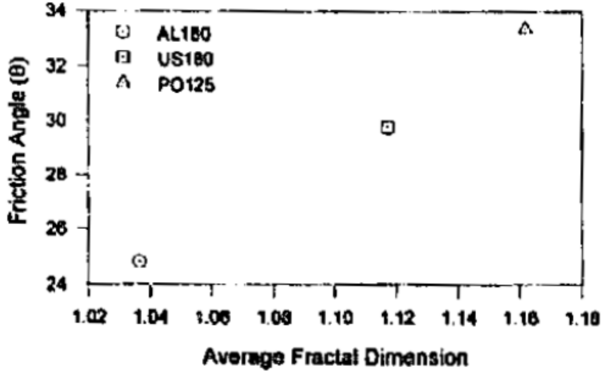




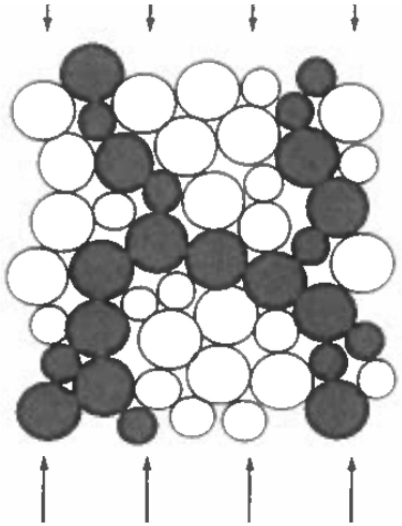
Transformation of Angularity (shape effect)

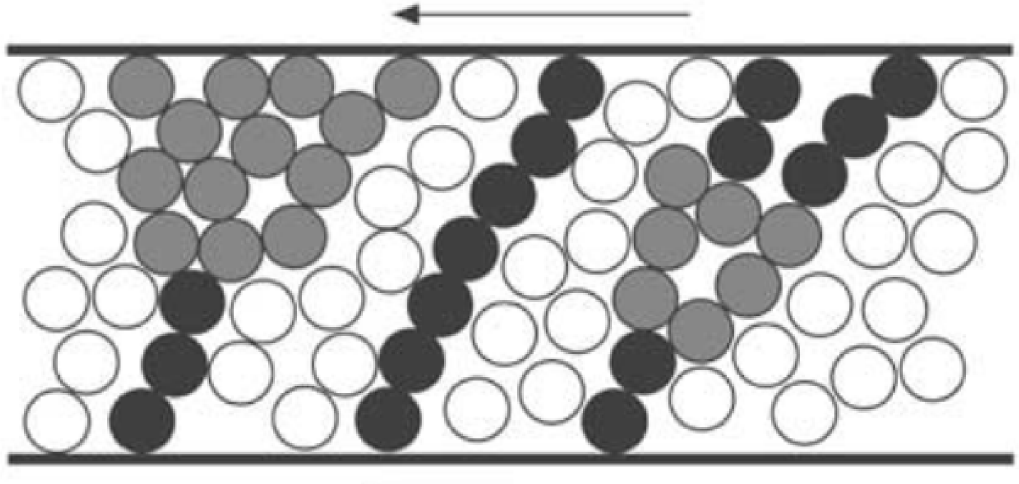
ng in Force Chains

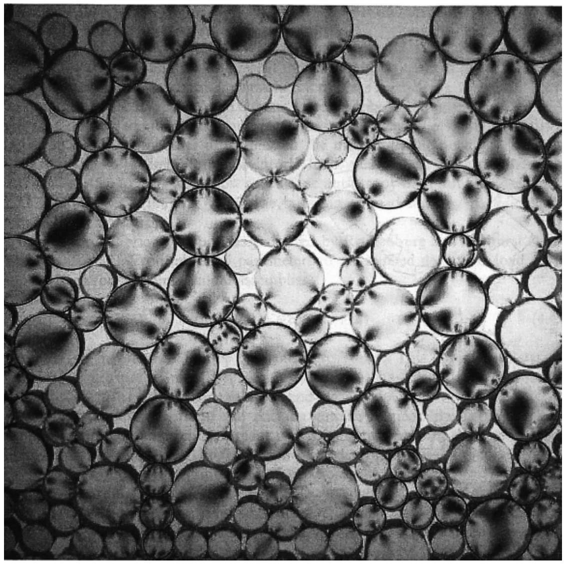
et al. 2011)

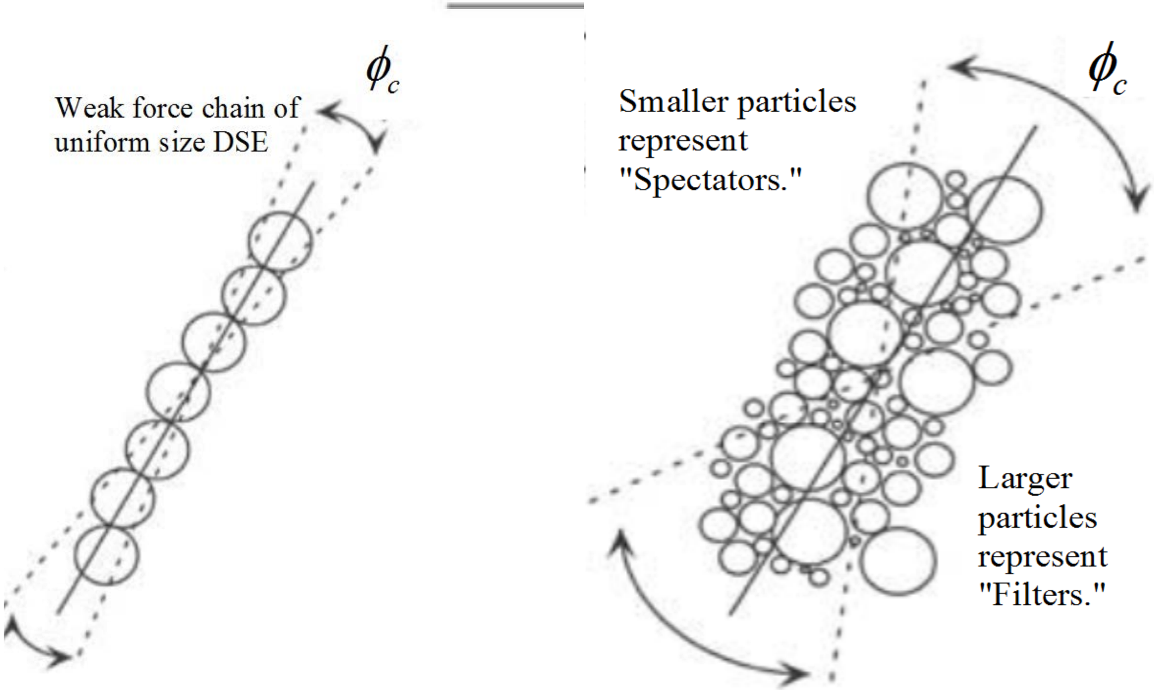


US180	PO125
20.5	31.5
3.46	2.48
3.96	2.96
1.14	1.19
1.1173	1.1618









Weak force chain of uniform size DSE

Smaller particles represent "Spectators."

Larger particles represent "Filters."

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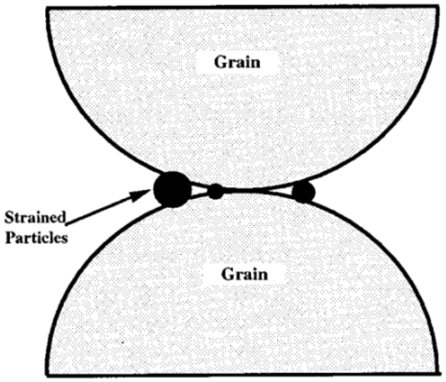
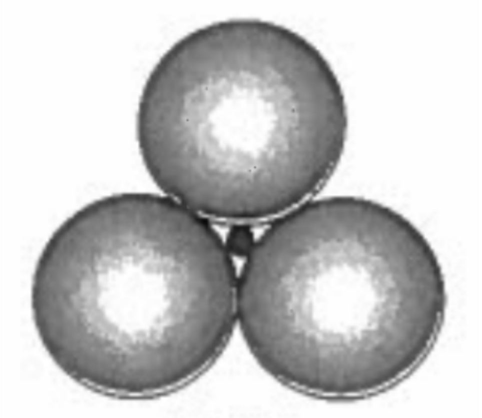
Task 2 Activity: Shear Jamming Mechanism (Concept of Liu-Nagel Theory, 1998)



Increase “stick” in tangential sliding motion

+



Volumetric control in contraction

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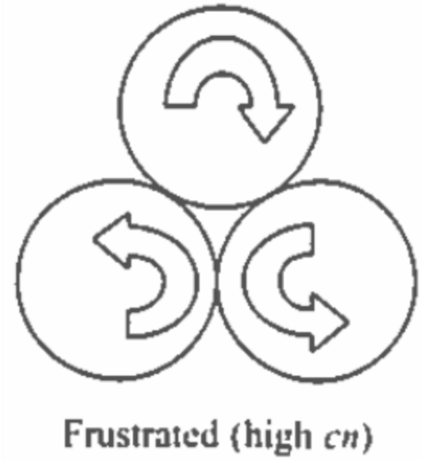
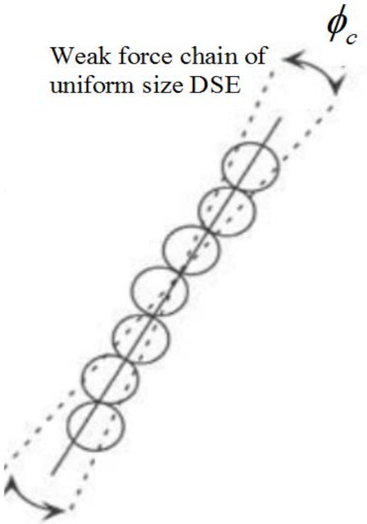
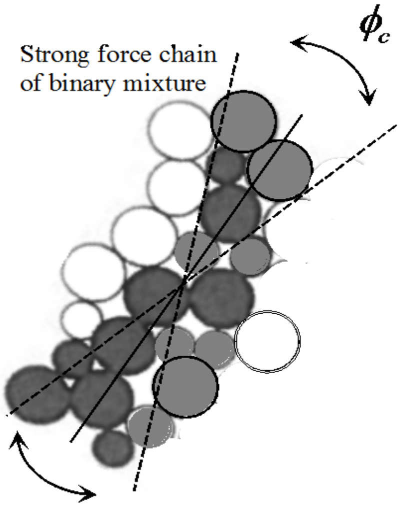


Stronger force chain of primary DSEs



Force chain of Primary DSEs

↔



Primary and Secondary DSEs

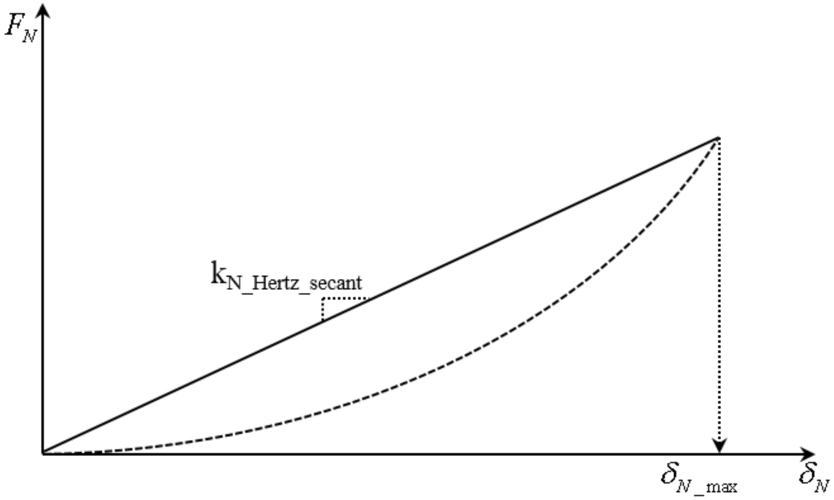
Task 2 Activity: Contact Rheology

- **Viscoelastic spherical bodies in contact**

LS-DYNA DEM Model:

linear damped spring with a sliding friction element

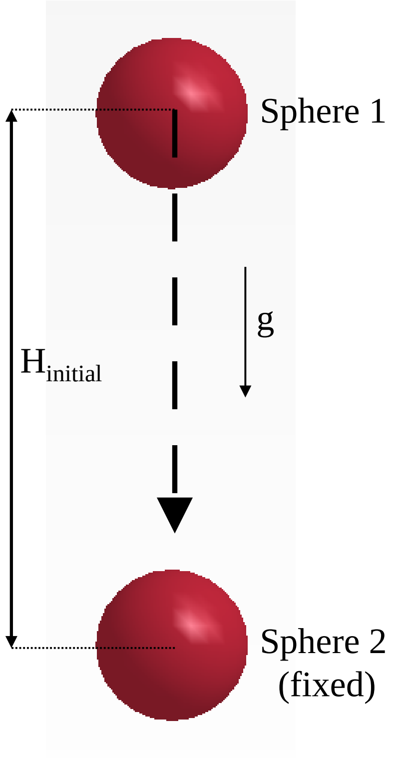
- Hertzian contact theory (normal stiffness)
- Coulombic limits on tangential force and torque
- Natural frequency analysis : critical damping
- Viscous damping in both normal and tangential directions
- Normal and tangential restitution coefficients
- The ratio of normal to tangential stiffness
- Mindlin contact theory (quasi-static tangential stiffness)

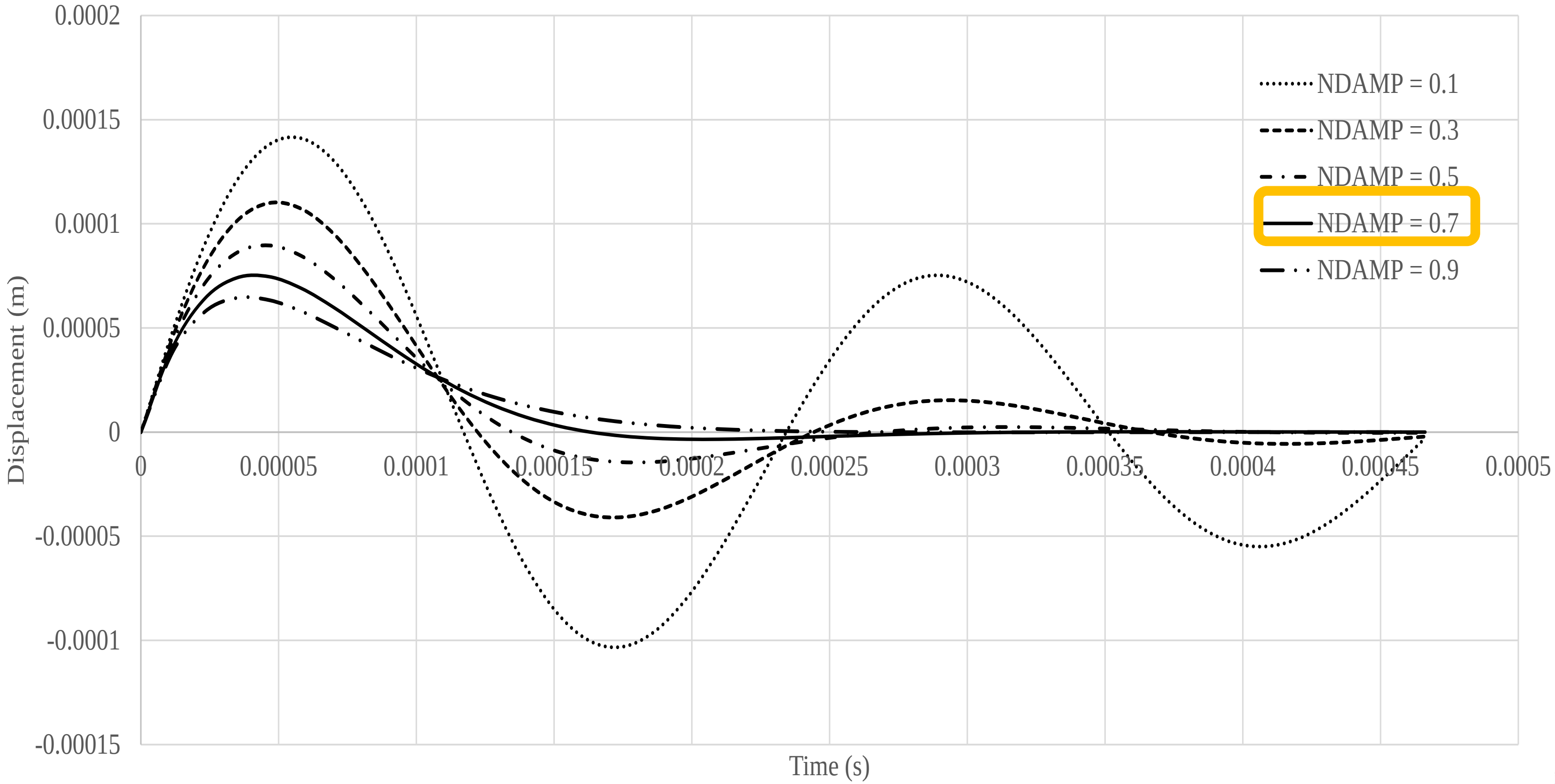


Task 2 Activity: Contact Rheology

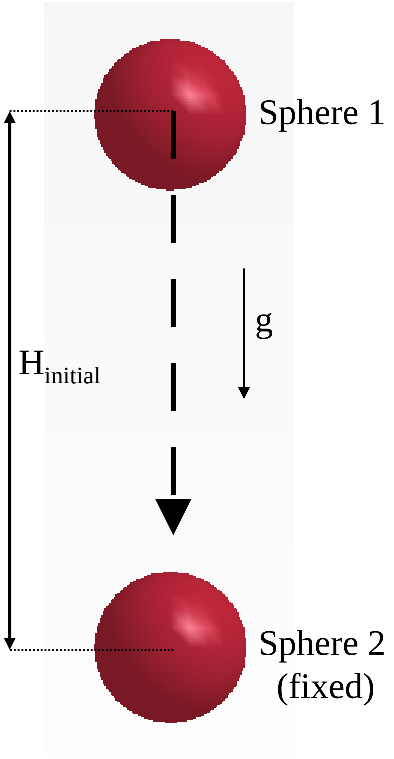
- **Identification of parameter values**
    - Example: Collision test simulation per incidence angles

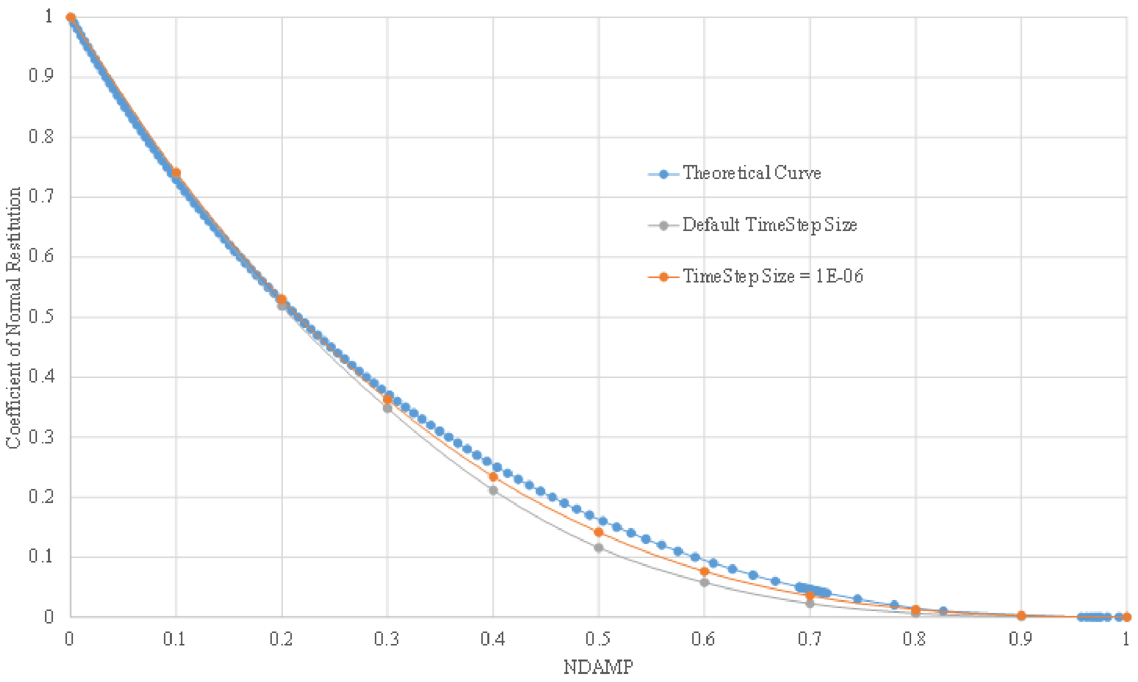
Calibration of normal and tangential restitution coefficients



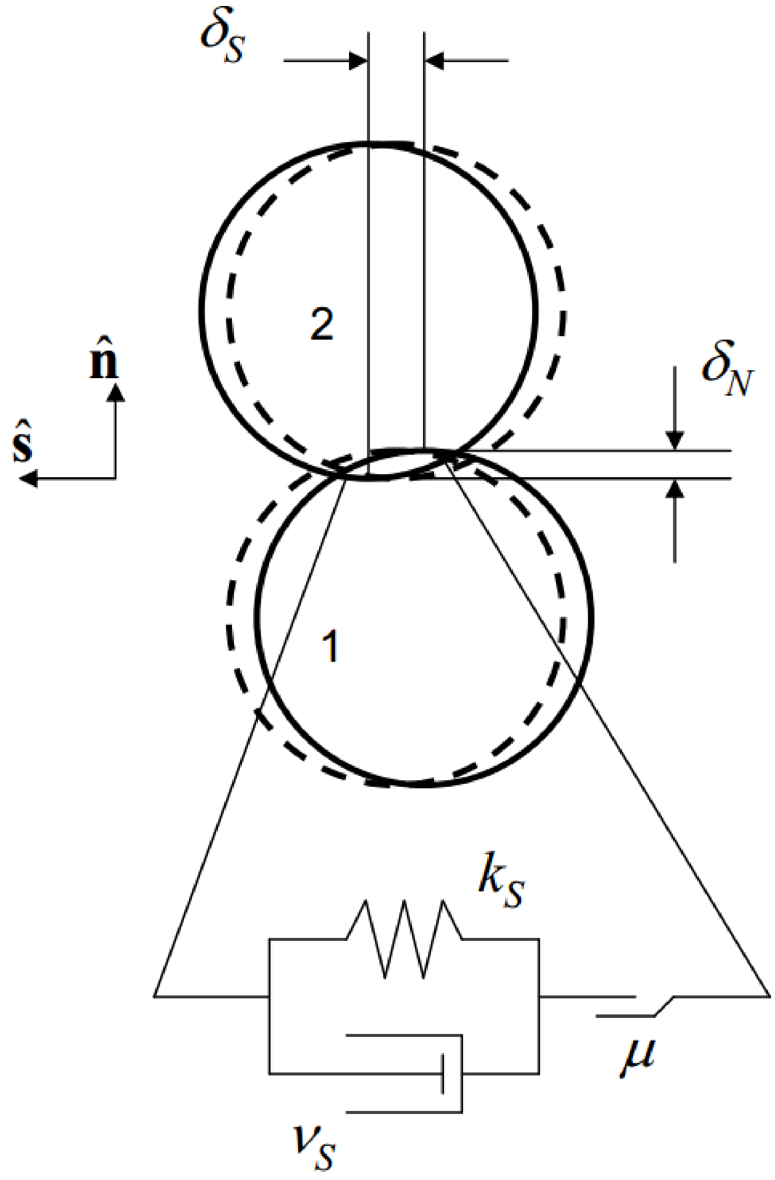


Task 2 Activity: Contact Rheology





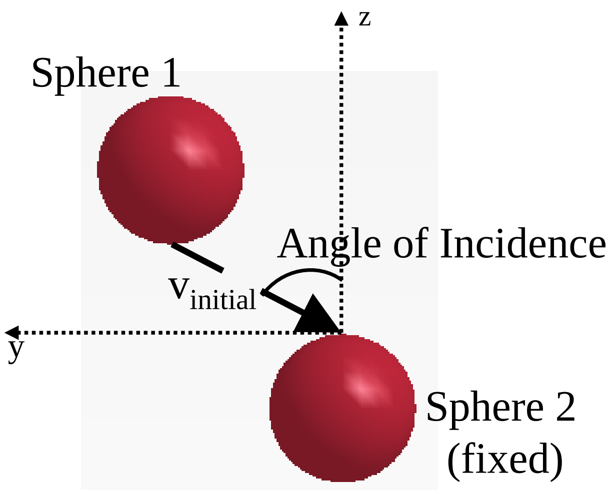
Task 2 Activity: Contact Rheology
For example:



$$\mathbf{F}_{S,\text{ on }1} = \min\left(k_S\delta_S + \nu_S\dot{s}, \mu\left|\mathbf{F}_N\right|\right)\hat{\mathbf{s}}$$

- Widely used
- Moderately difficult model to implement
- Does include tangential stiffness ⇒ possible to have velocity reversal
- Dynamics of impact are governed by the ratio of the tangential to normal impact stiffnesses
    - the normal spring sets the contact duration while the tangential response is a function of the tangential spring stiffness
- If the tangential stiffness is large and the sliding friction coefficient is small, then the sliding friction element dominates during most of the contact.

Task 2 Activity: Contact Rheology



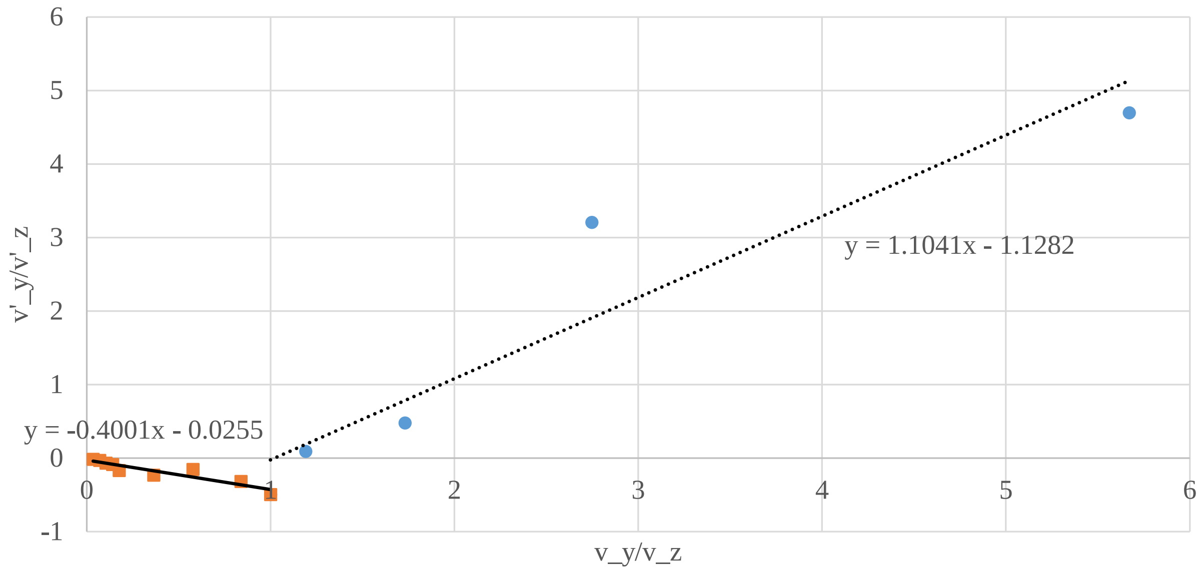
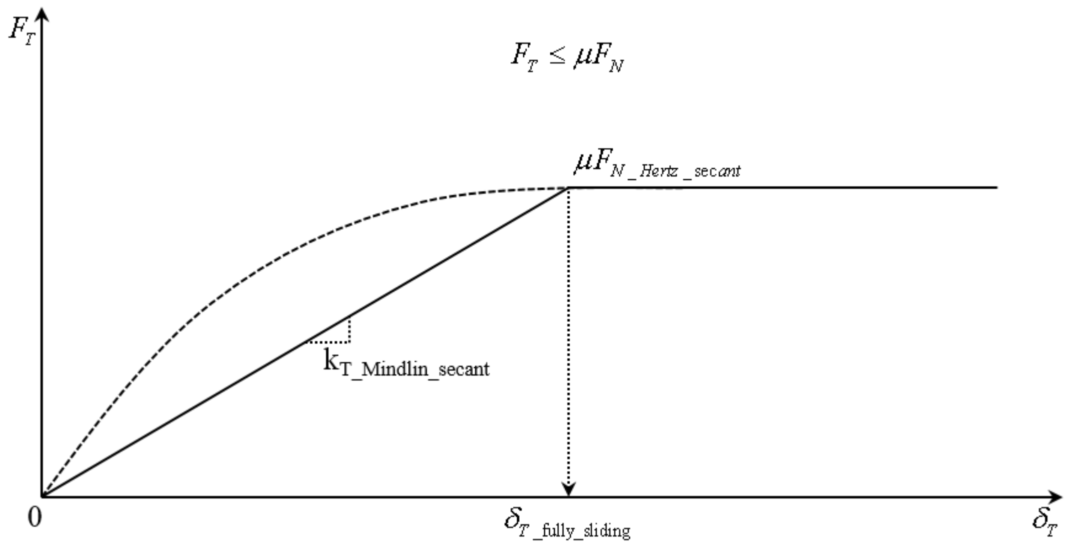


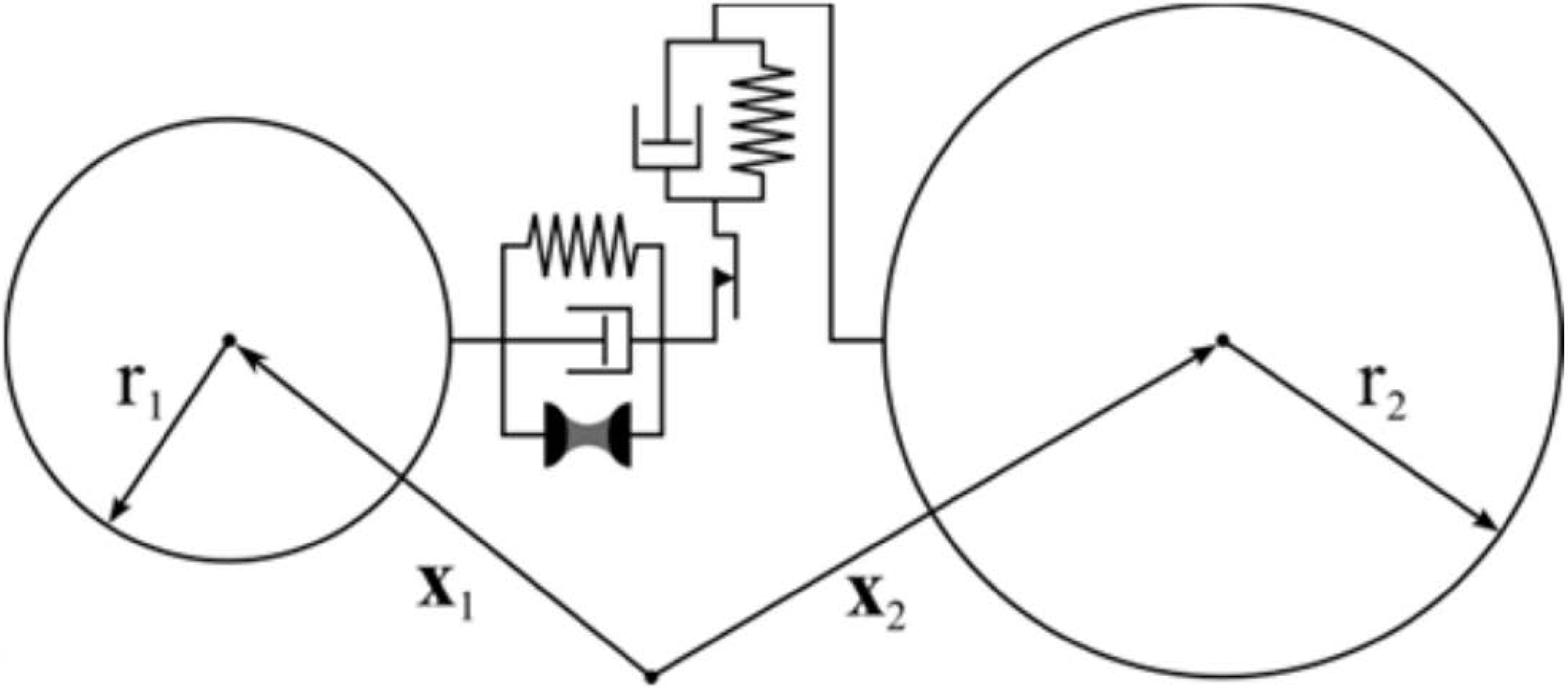
Figure 2.4.5.7. Tangent of effective recoil angle versus tangent of effective incident angle for a ratio of rolling to sliding friction equal to 1.0



Task 2 Activity: Contact Rheology

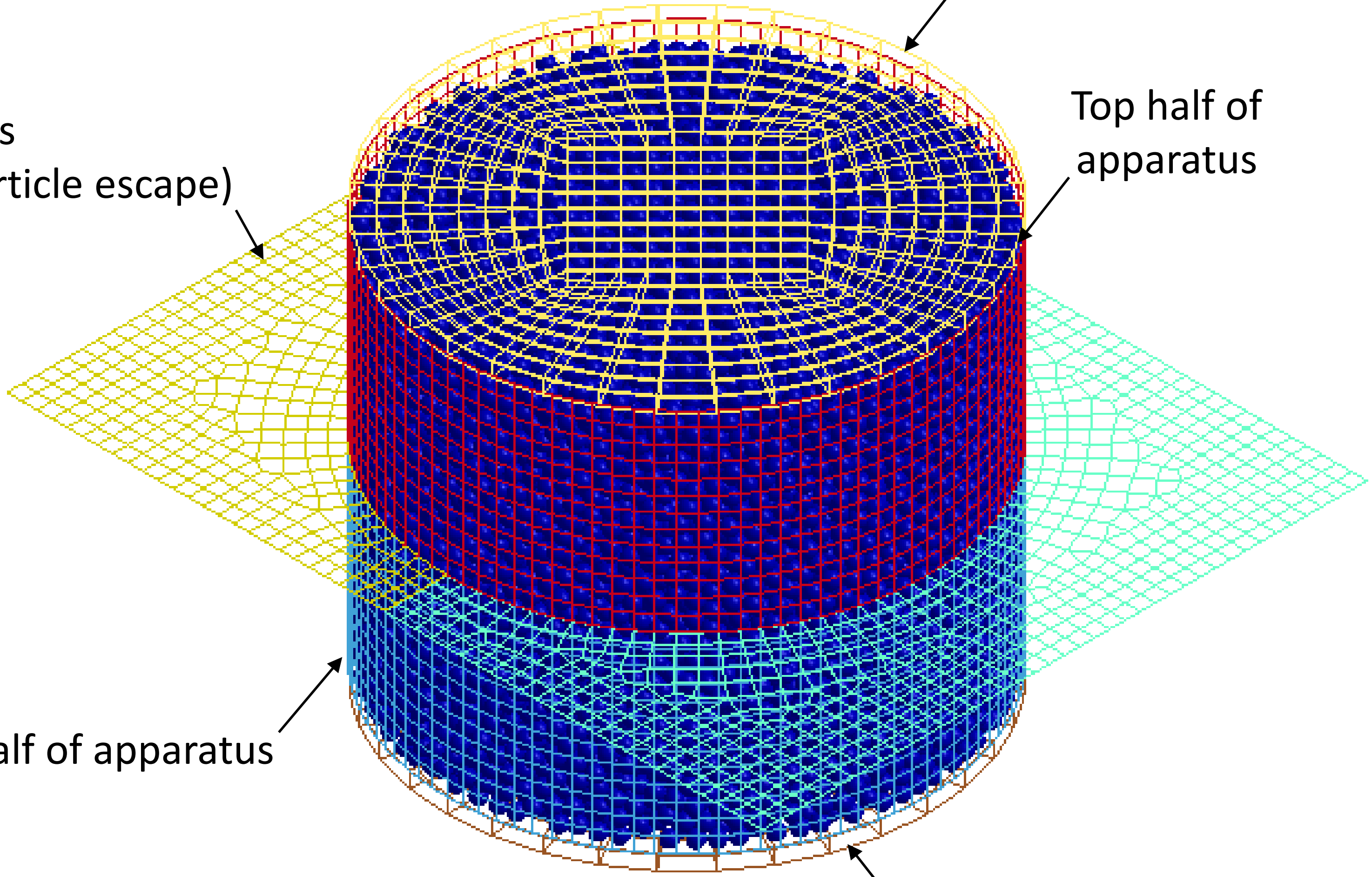
- **Relationships identified between:**
  - Normal and tangential contact stiffness
  - Normal and tangential contact damping
  - Sliding friction and rolling friction

Inter-relationships identified as well



Task 2 Deliverable: Modeling Direct Shear Tests

- **Model of test apparatus**



Top plate

Top half of apparatus

Extender plates (to prevent particle escape)

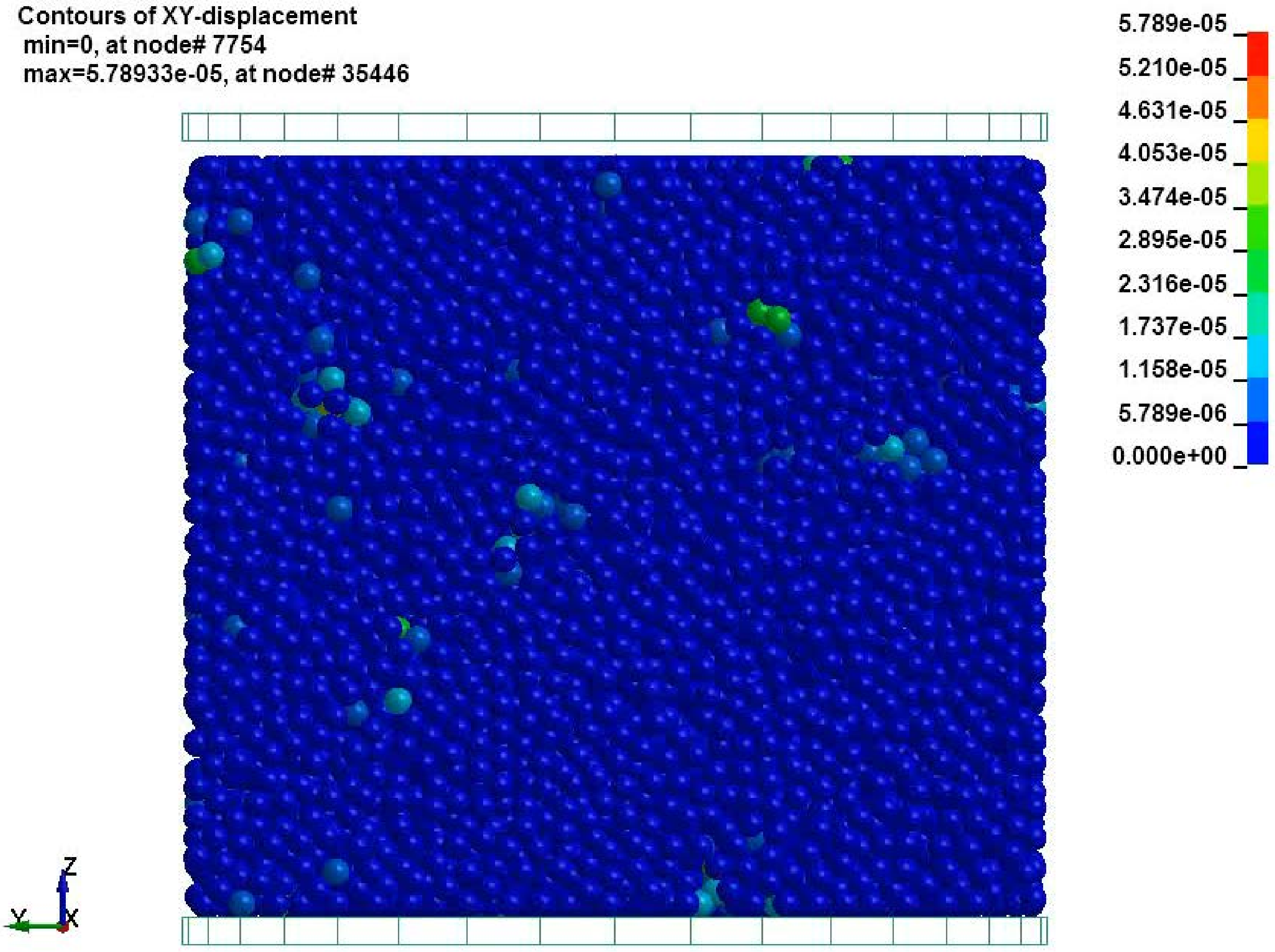
Bottom half of apparatus

Bottom plate

* - Overall dimensions taken from UF lab manual

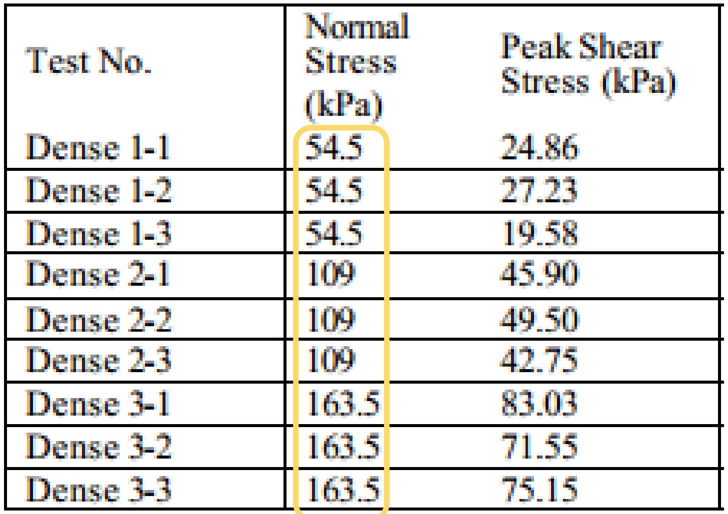
Task 2 Deliverable: Modeling Direct Shear Tests

- **Animation**



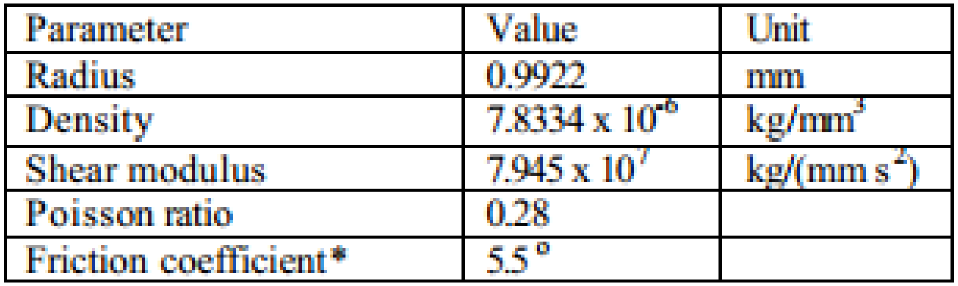
Task 2 Deliverable: Modeling Direct Shear Tests

- **Validation of direct shear test methodology**
  - *Three-Dimensional Discrete Element Simulations of Direct Shear Tests*, O'Sullivan et al. (2004)
  - Direct shear tests using 1 mm steel spheres

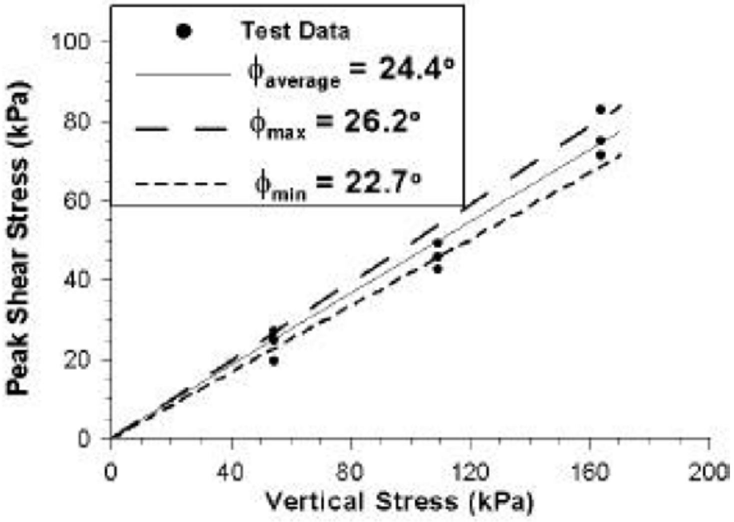


Test No.	Normal Stress (kPa)	Peak Shear Stress (kPa)
Dense 1-1	54.5	24.86
Dense 1-2	54.5	27.23
Dense 1-3	54.5	19.58
Dense 2-1	109	45.90
Dense 2-2	109	49.50
Dense 2-3	109	42.75
Dense 3-1	163.5	83.03
Dense 3-2	163.5	71.55
Dense 3-3	163.5	75.15

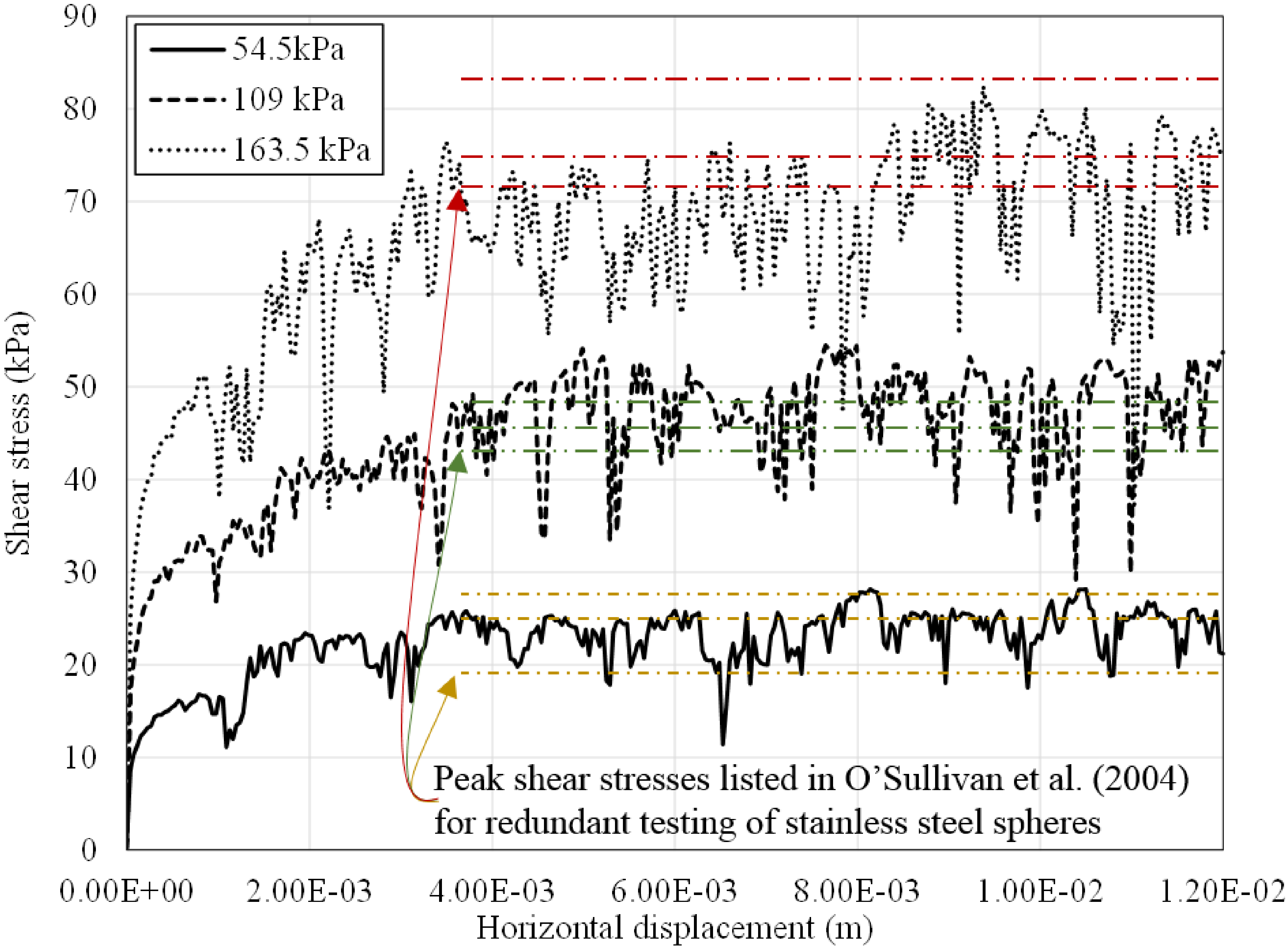
Three runs at each of three pressure levels



Parameter	Value	Unit
Radius	0.9922	mm
Density	7.8334×10^{-6}	kg/mm^3
Shear modulus	7.945×10^{7}	$kg/(mm\ s^2)$
Poisson ratio	0.28	
Friction coefficient*	5.5 °	



Task 2 Deliverable: Modeling Direct Shear Tests



Peak shear stresses listed in O'Sullivan et al. (2004) for redundant testing of stainless steel spheres

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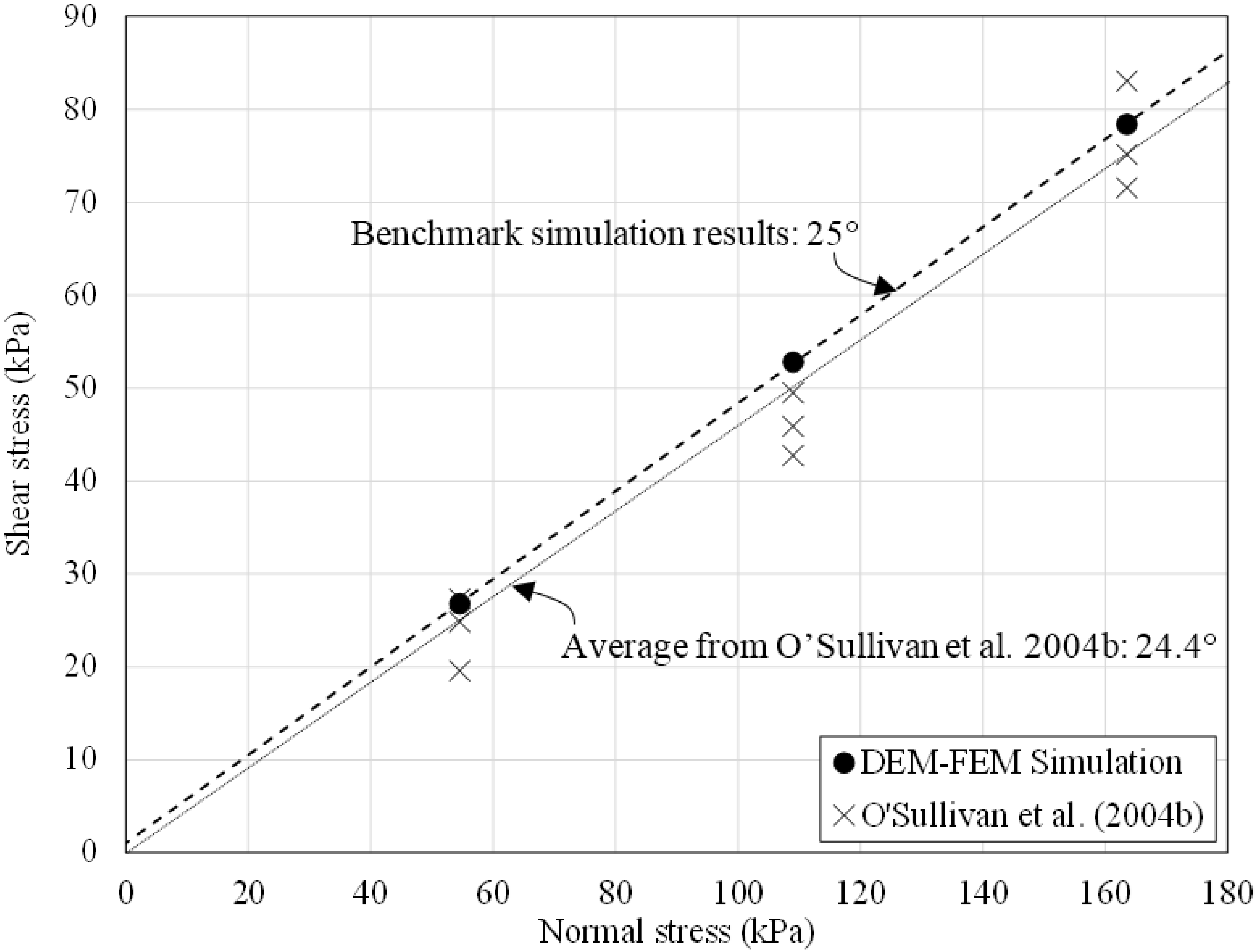
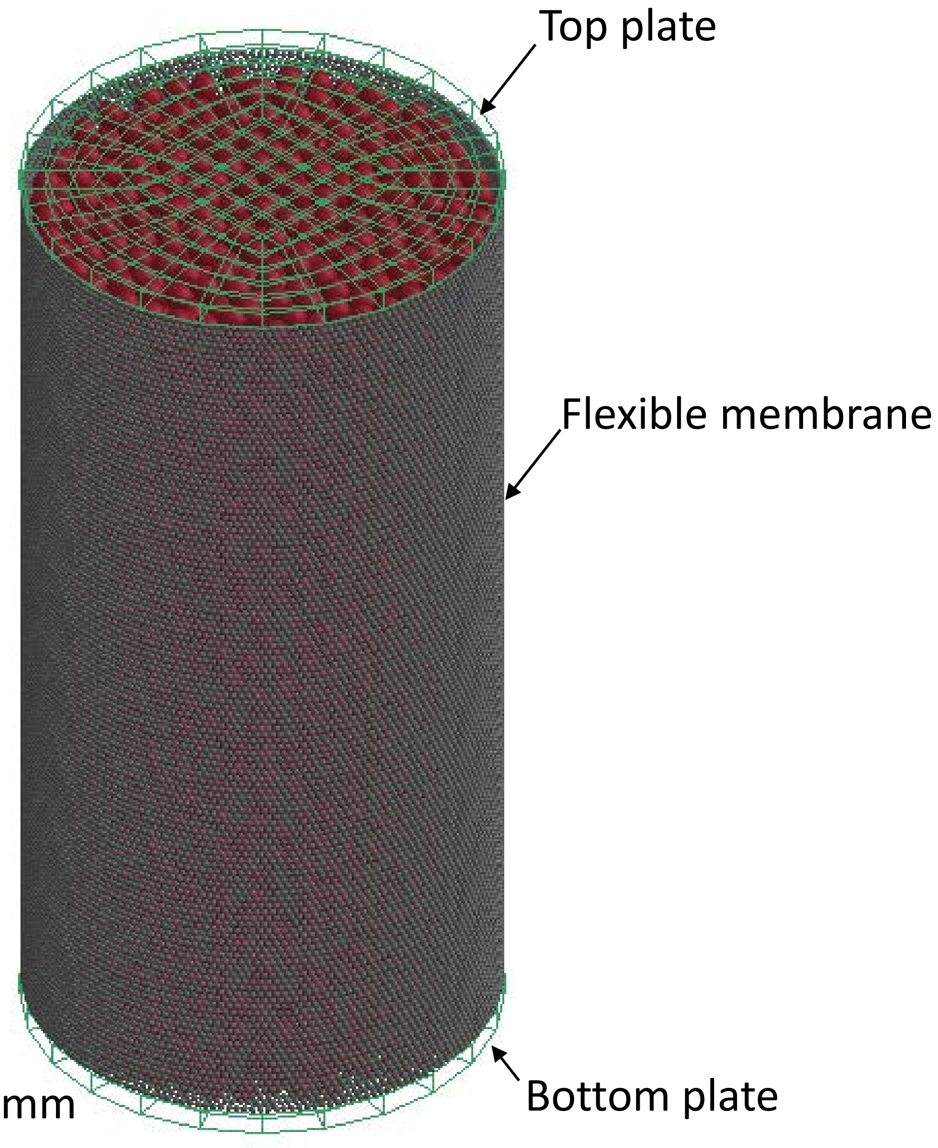
Task 2 Deliverable: Modeling Direct Shear Tests



Task 2 Deliverable: Modeling Triaxial Tests

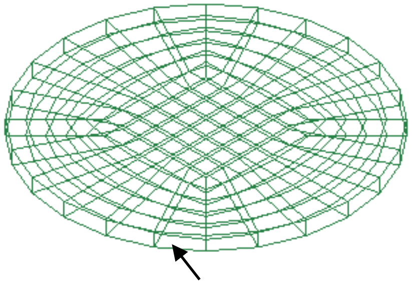
- **Model of test apparatus**



* - Overall dimensions: 102 mm x 203 mm

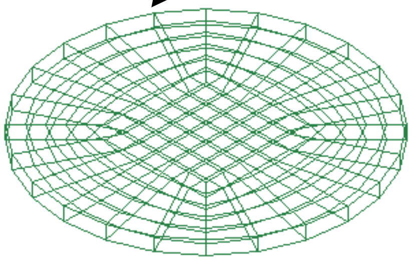
Task 2 Deliverable: Modeling Triaxial Tests

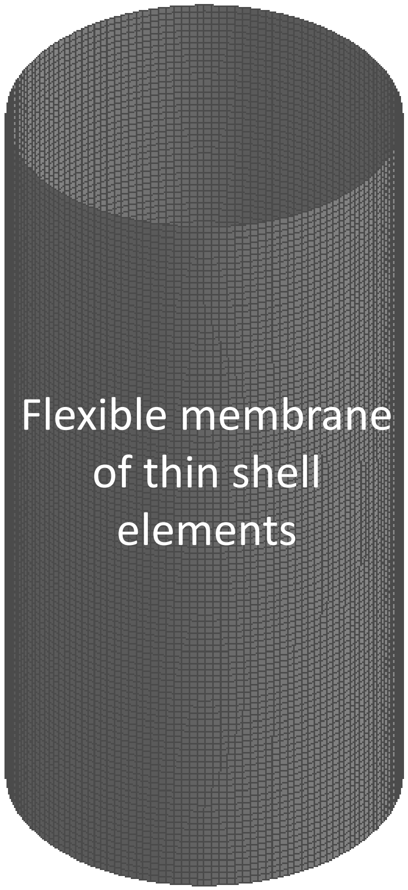
- **Model of Test Apparatus**
  - Finite element membrane (favors efficiency)



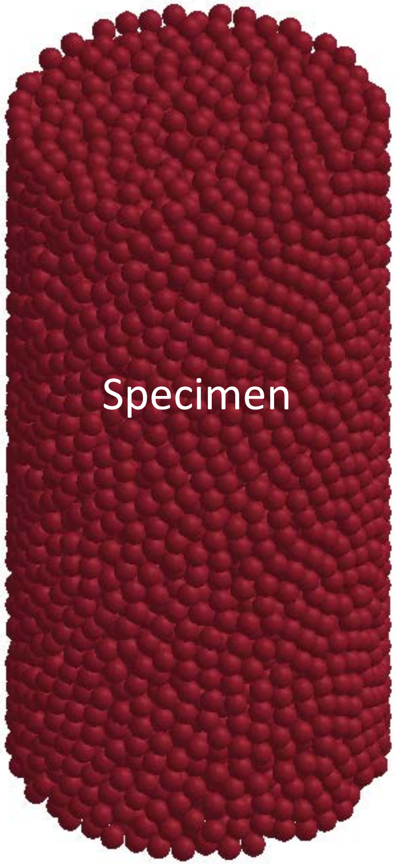
Top plate

Bottom plate

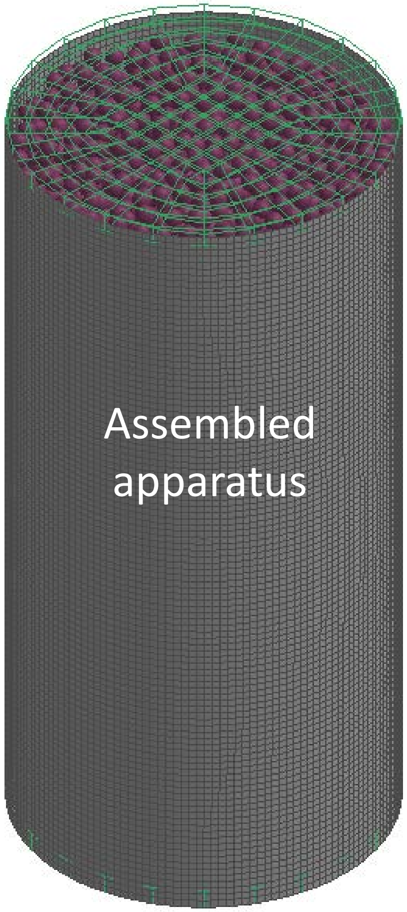




Flexible membrane of thin shell elements



Specimen

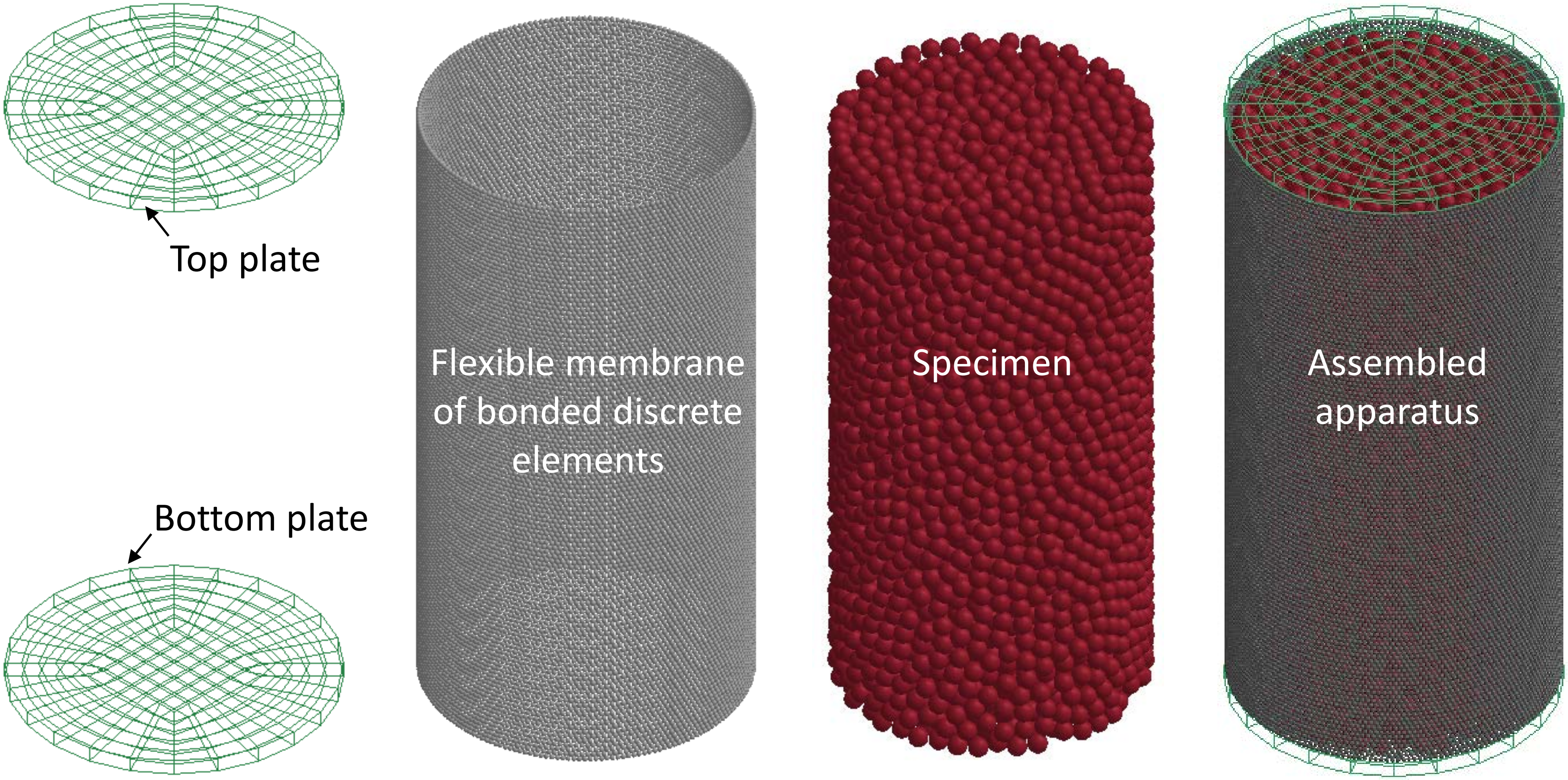


Assembled apparatus

* - Overall dimensions: 102 mm x 203 mm

Task 2 Deliverable: Modeling Triaxial Tests

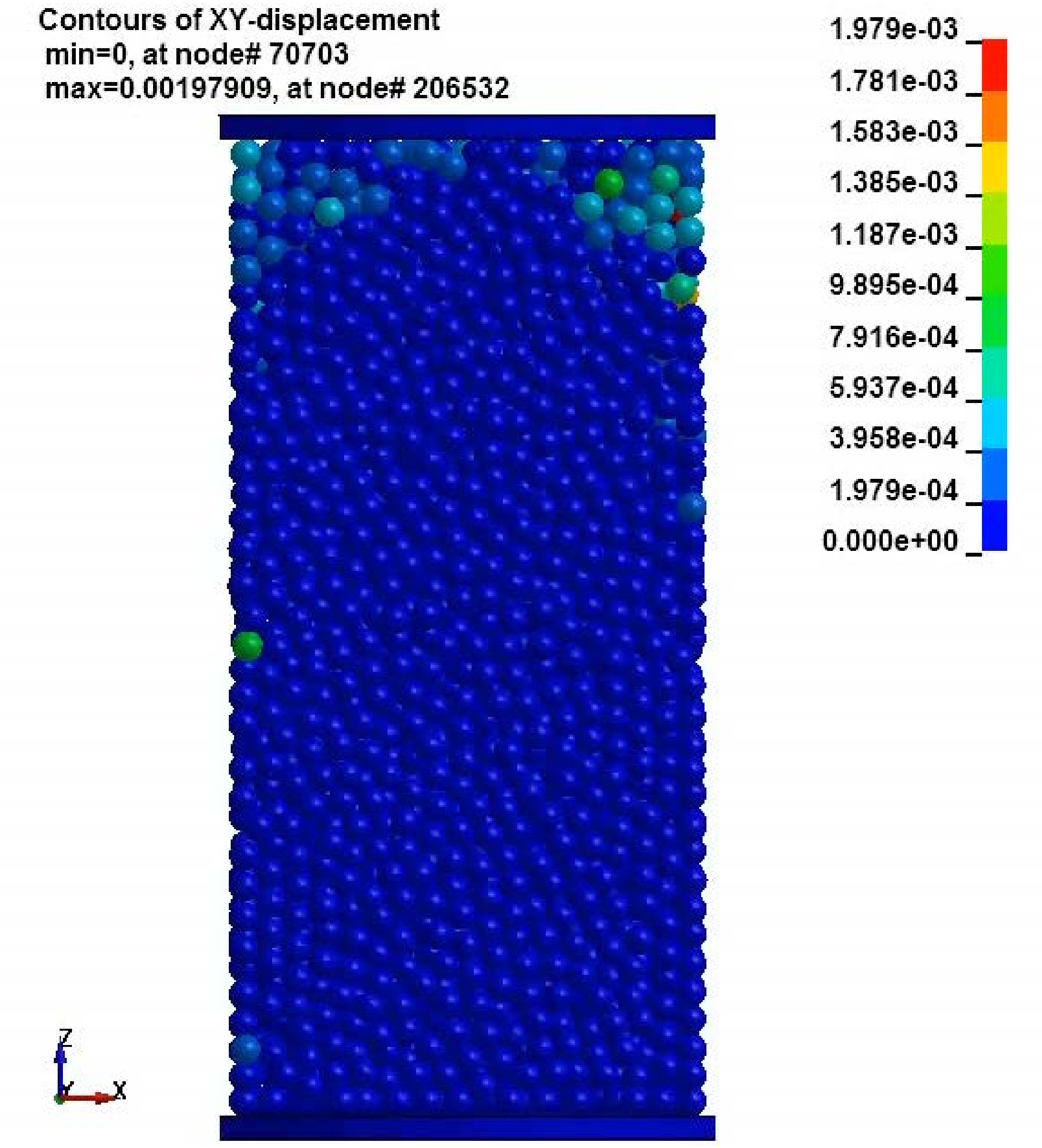
- **Model of Test Apparatus**
  - Discrete element membrane (favors stability)



* - Overall dimensions: 102 mm x 203 mm

Task 2 Deliverable: Modeling Triaxial Tests

- **Animation**



Task 2 Deliverable: Modeling Triaxial Tests

- **Validation of triaxial test methodology**
  - *3D Analysis of Kinematic Behavior of Granular Materials in Triaxial Testing using DEM with Flexible Membrane Boundary* (Cil and Alshibli 2014)
  - Triaxial tests using 3.75 mm plastic spheres

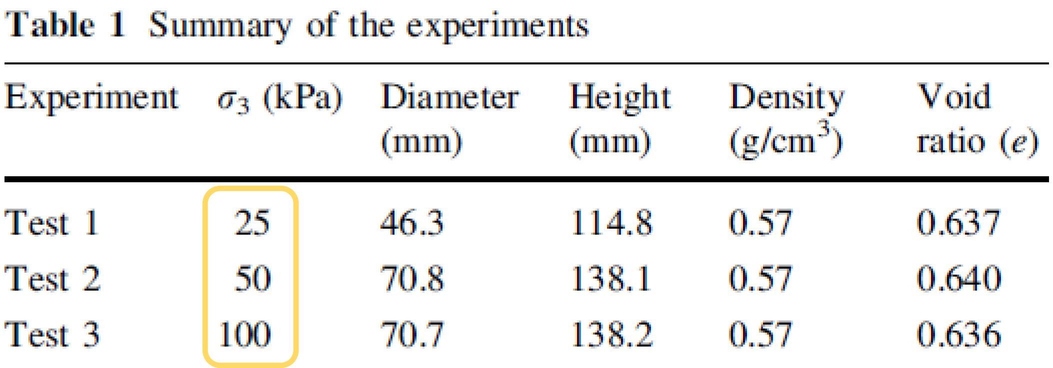
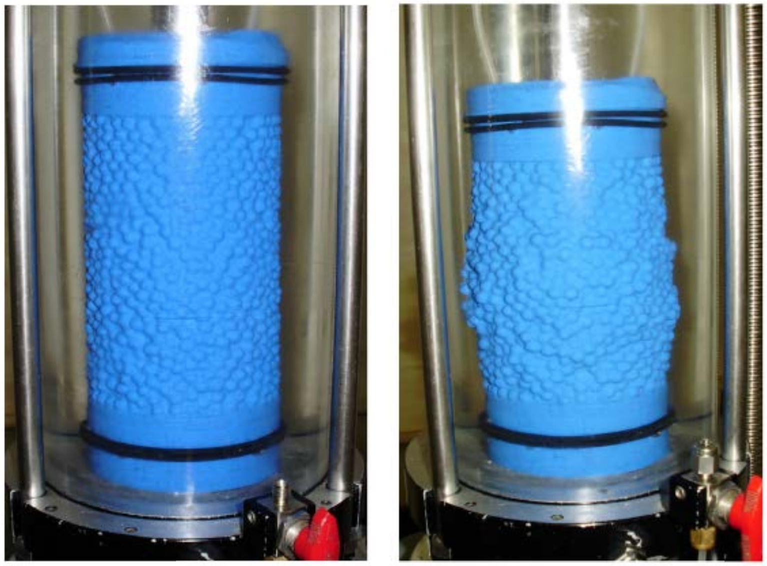


Table 1 Summary of the experiments

Experiment	σ_3 (kPa)	Diameter (mm)	Height (mm)	Density (g/cm^3)	Void ratio (e)
Test 1	25	46.3	114.8	0.57	0.637
Test 2	50	70.8	138.1	0.57	0.640
Test 3	100	70.7	138.2	0.57	0.636

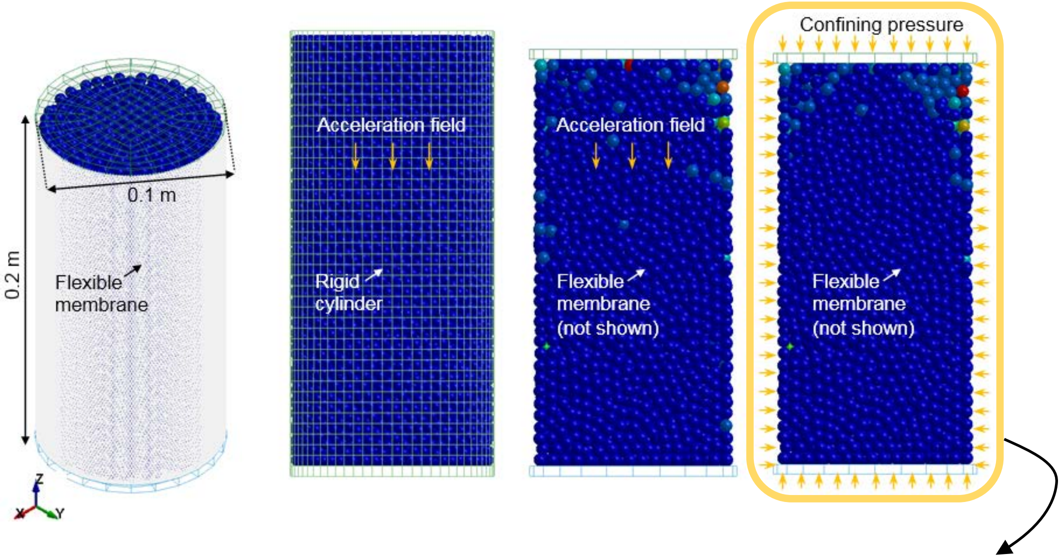
One run at each of three pressure levels



Physical test specimen

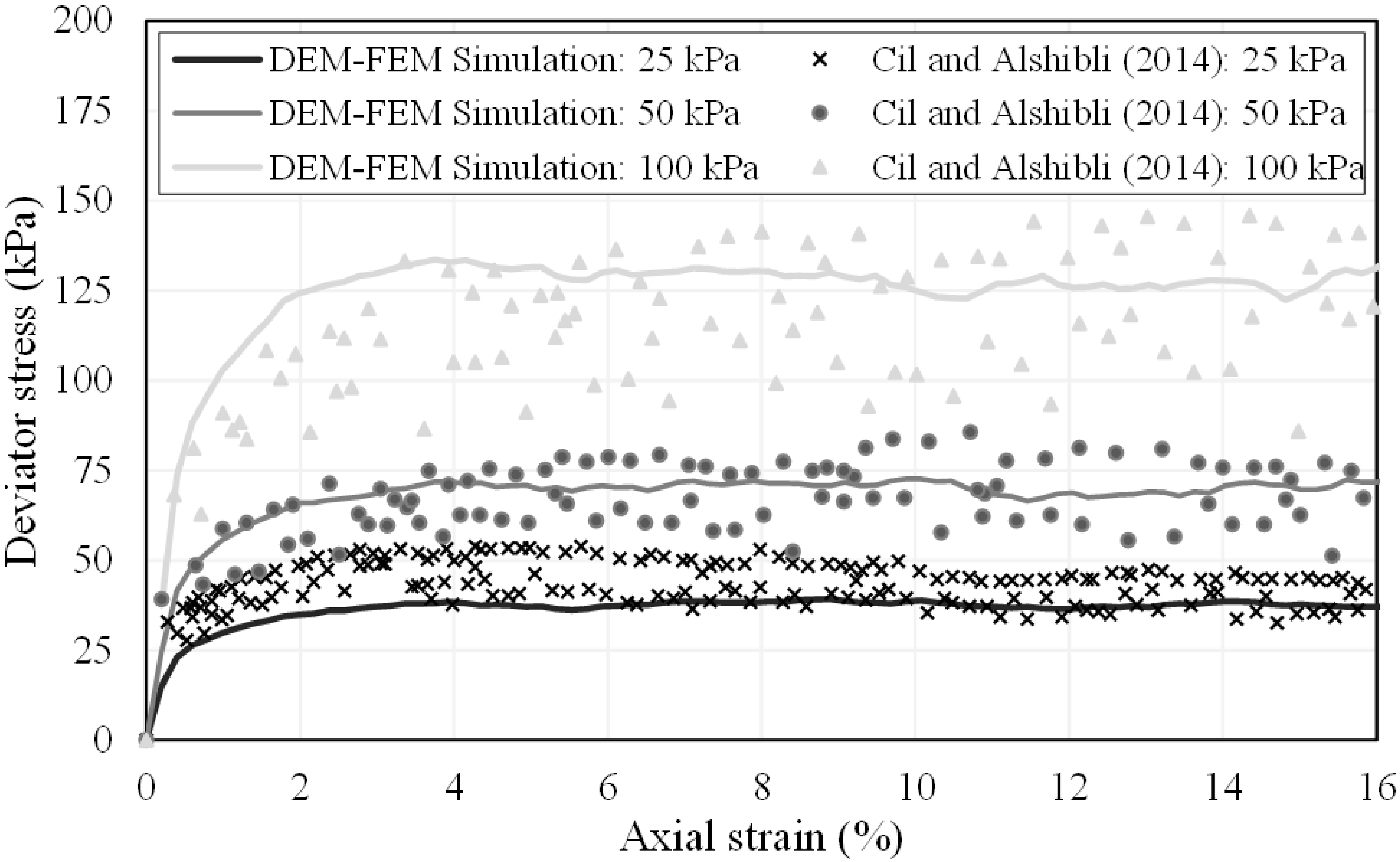
Task 2 Deliverable: Modeling Triaxial Tests

- **Confining pressure**



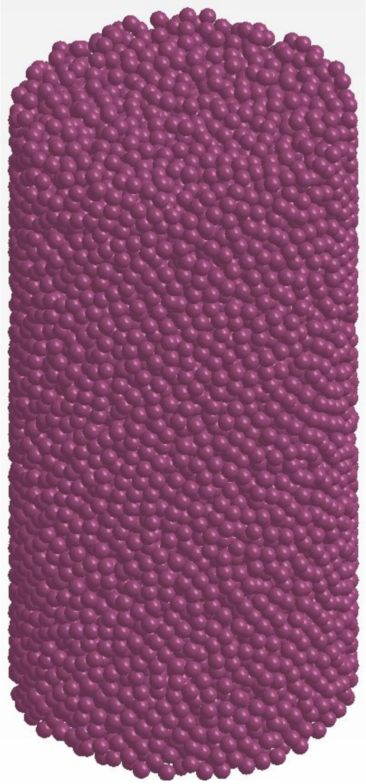
Confining Pressure (kPa)	η	$\tilde{\sigma}_{XX}$ (kPa)	$\tilde{\sigma}_{YY}$ (kPa)	$\tilde{\sigma}_{ZZ}$ (kPa)
25	0.37	-25.0	-25.1	-26.0
50	0.37	-49.6	-49.8	-51.9
100	0.35	-98.1	-98.8	-106

Task 2 Deliverable: Modeling Triaxial Tests

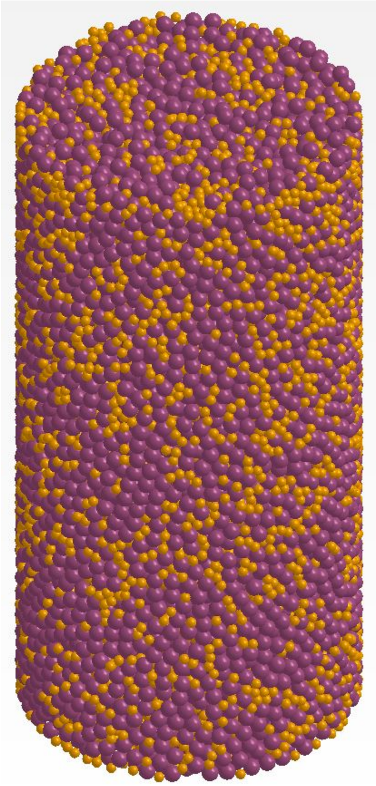


Task 2 Deliverable: Soil Unit Library

- **Triaxial compression tests to assess macro-behaviors**
  - Maintain inter-relationships among rheological parameters for Discrete Spherical Elements (DSEs)
  - Use of uniform size DSEs (Monodisperse system) vs. two various size DSEs (Bidisperse or binary system)



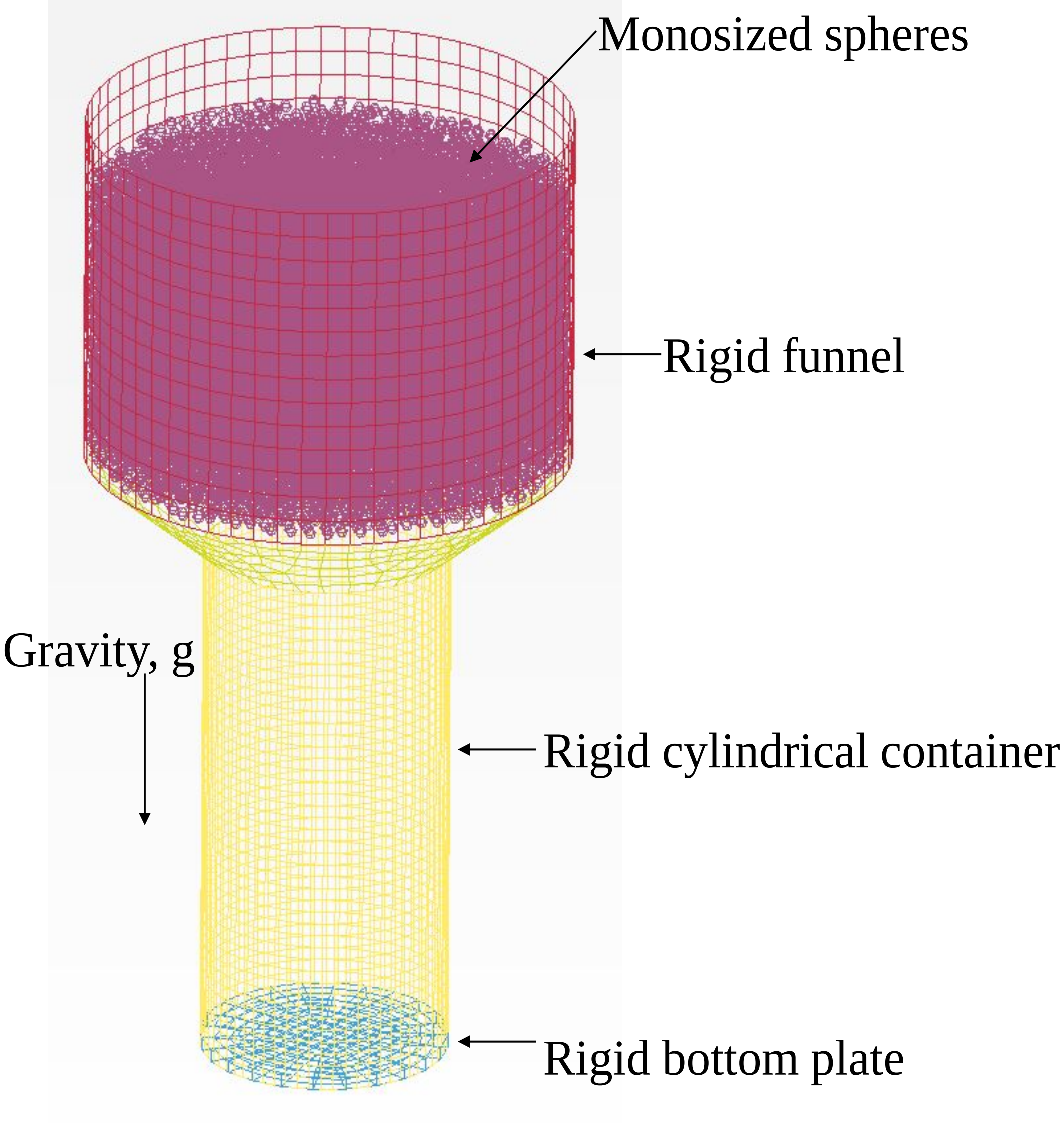
Monodisperse system (5 mm)



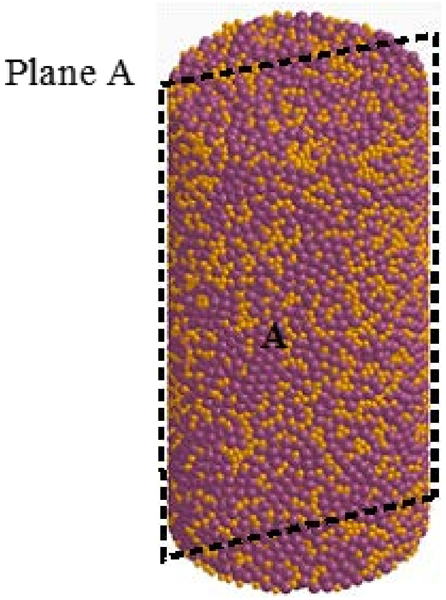
Binary system: primary 5 mm dia. and secondary 3 mm dia.

Task 2 Deliverable: Soil Unit Library

- **Triaxial compression tests to assess macro-behaviors**



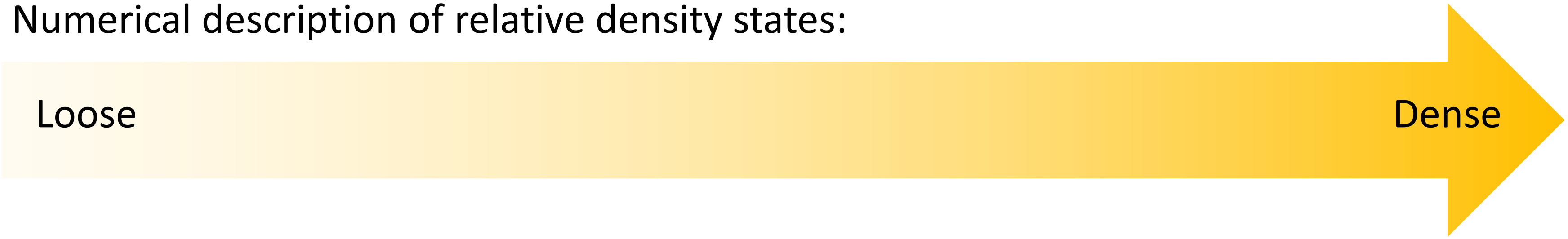
Binary system: primary 5 mm dia. and secondary 3 mm dia.



Task 2 Deliverable: Soil Unit Library

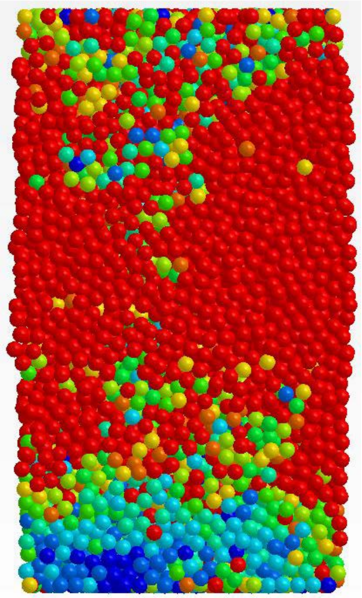
- **Rheological parameters calibrated to generate desired macroscopic behaviors**

Numerical description of relative density states:



Loose

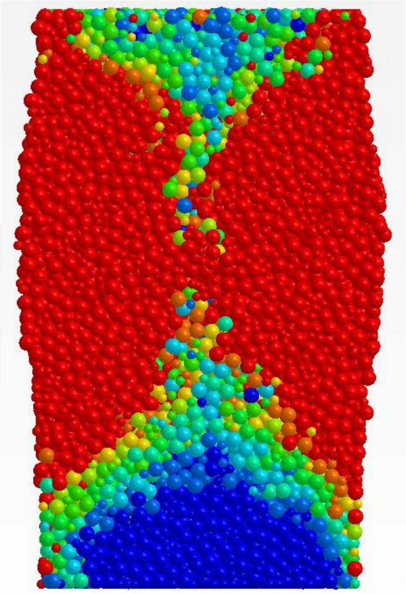
Dense



Monodisperse system:
low strength

Monodisperse
w/ high friction
medium strength

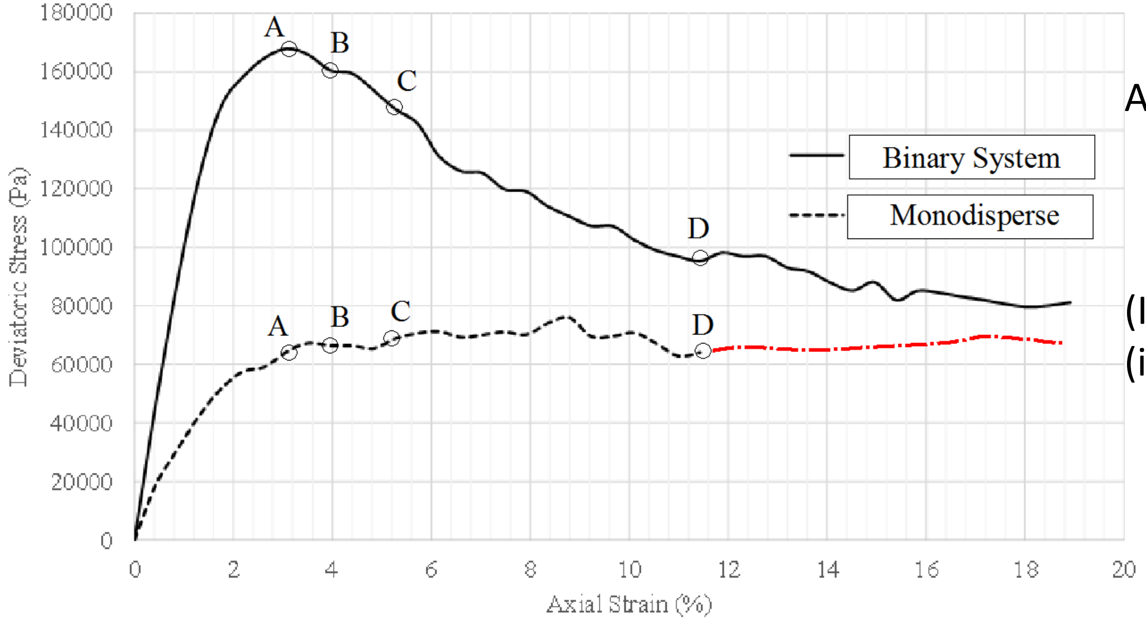
Binary system
w/o shear jamming



Binary system
With shear jamming

Task 2 Deliverable: Soil Unit Library

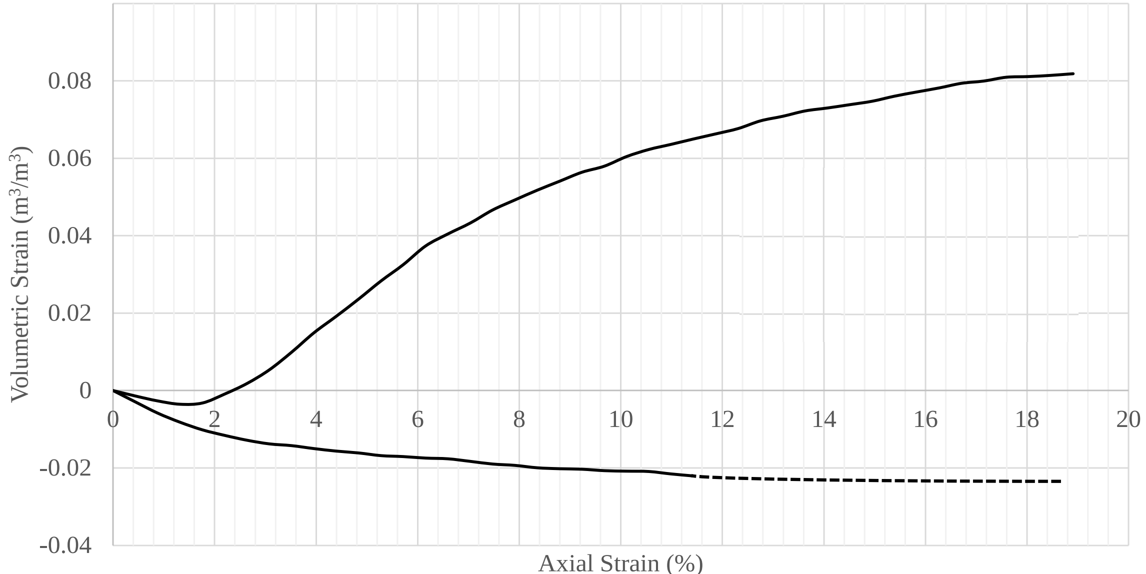
- **A range of macroscopic behaviors is simulated**



At confining stress of 70 kPa

(Initial) denser state

(initial) Loose state

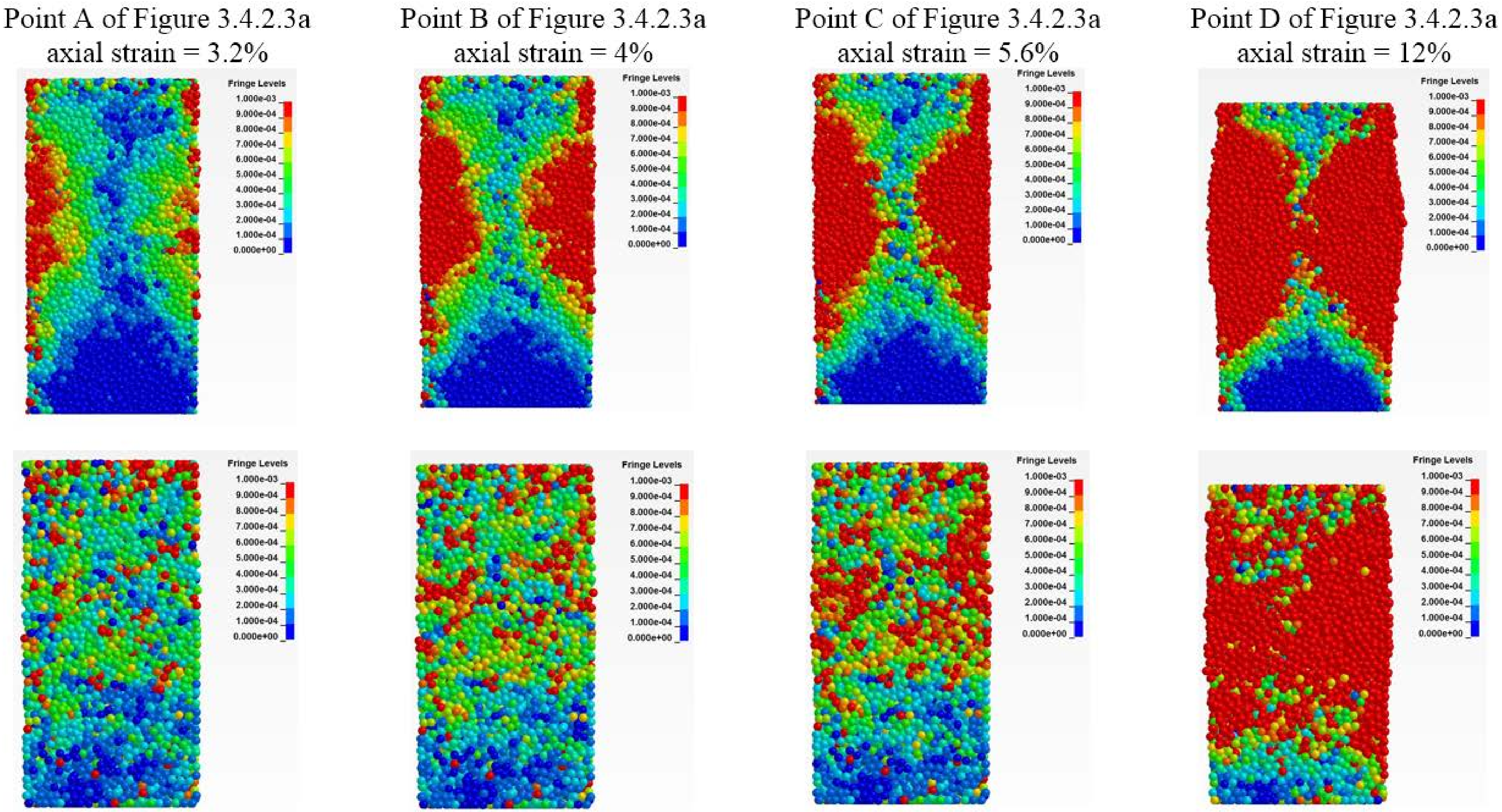


(Initial) denser state

(Initial) denser state

Task 2 Deliverable: Soil Unit Library

Simulated volumetric behaviors



Point A of Figure 3.4.2.3a
axial strain = 3.2%

Point B of Figure 3.4.2.3a
axial strain = 4%

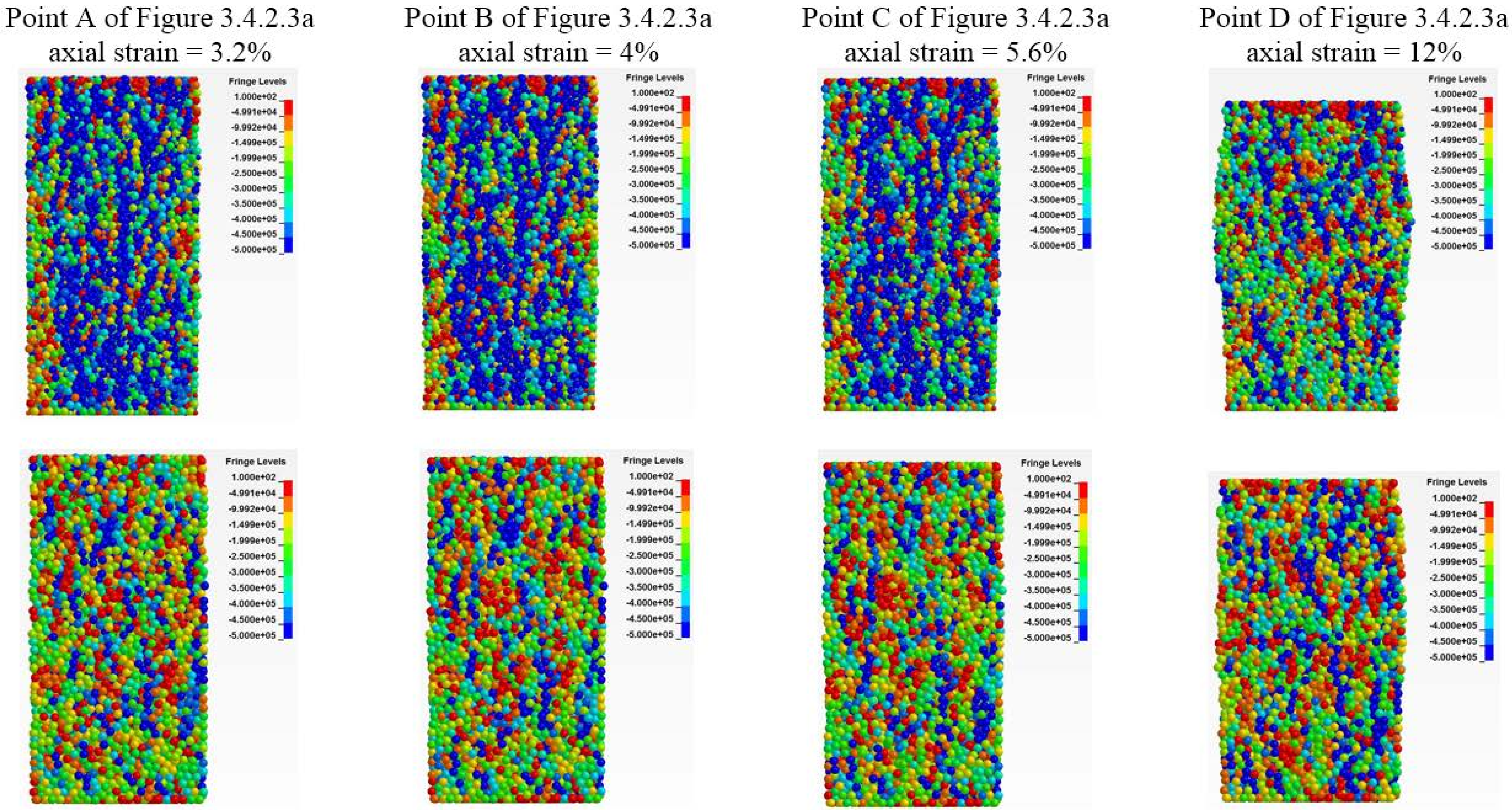
Point C of Figure 3.4.2.3a
axial strain = 5.6%

Point D of Figure 3.4.2.3a
axial strain = 12%

Figure 3.4.2.4 Evolution of particle rearrangement and in-plane displacement (top: binary system and bottom : monodisperse system of Figure 3.4.2.3)

Task 2 Deliverable: Soil Unit Library

Simulated volumetric behaviors



Point A of Figure 3.4.2.3a axial strain = 3.2%

Point B of Figure 3.4.2.3a axial strain = 4%

Point C of Figure 3.4.2.3a axial strain = 5.6%

Point D of Figure 3.4.2.3a axial strain = 12%

Figure 3.4.2.5 Development of force chains (top: binary system and bottom : monodisperse system of Figure 3.4.2.3)

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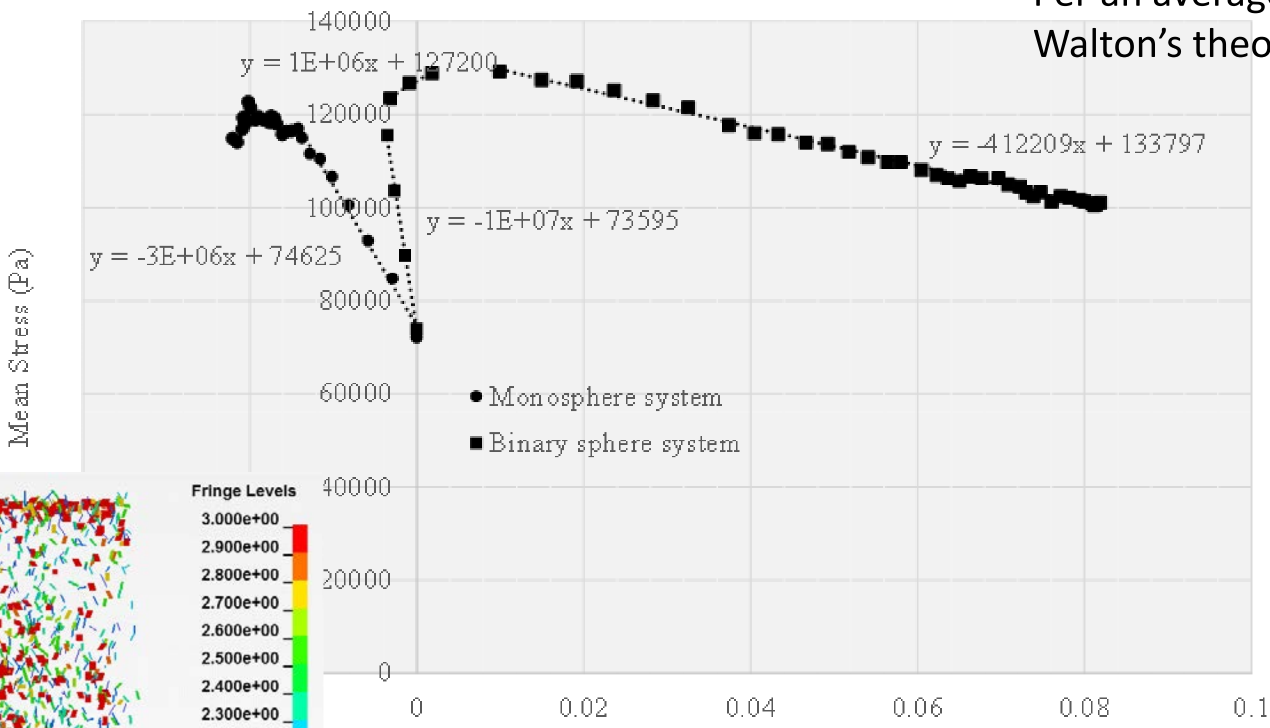
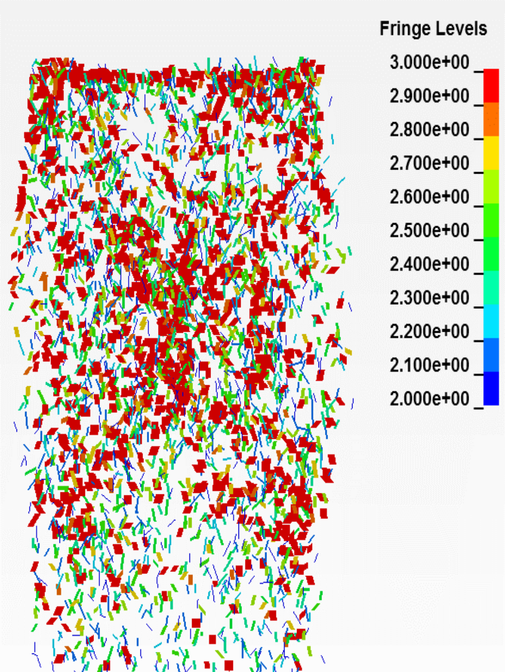
Task 2 Deliverable: Soil Unit Library

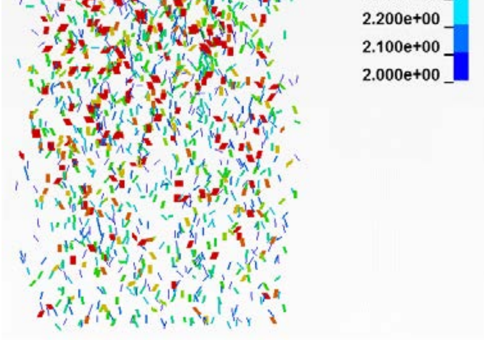
Simulated volumetric behaviors



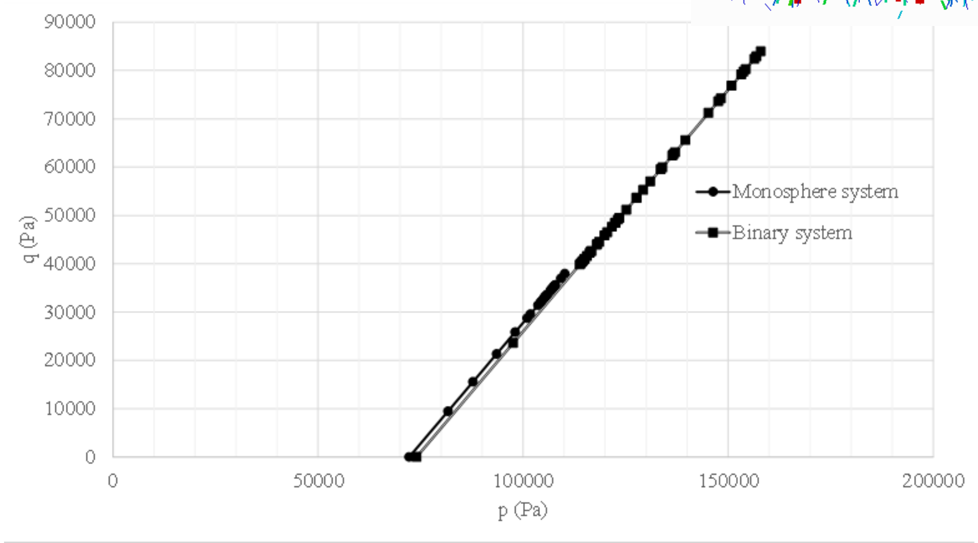
Volumetric strain

Effective bulk modulus = 2.6 MPa at 70 kPa
Per an average coordination number ~4.4 by
Walton's theory (1987): monodisperse system





The slope of p-q is unity

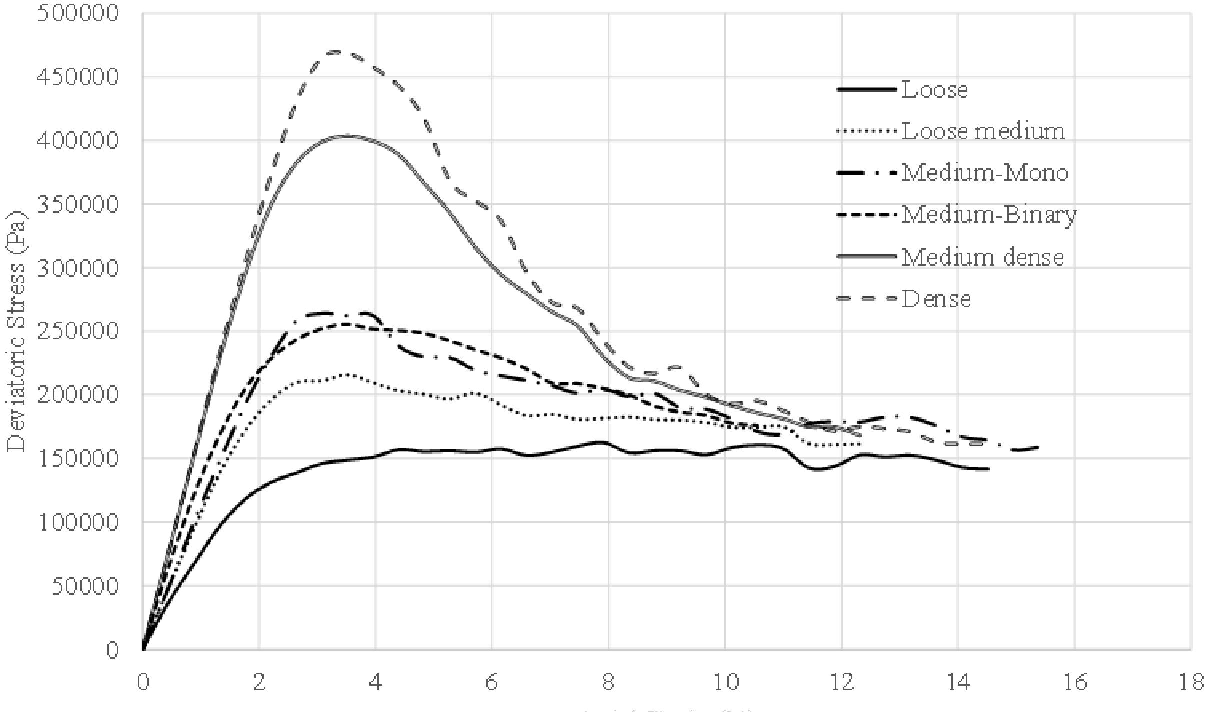


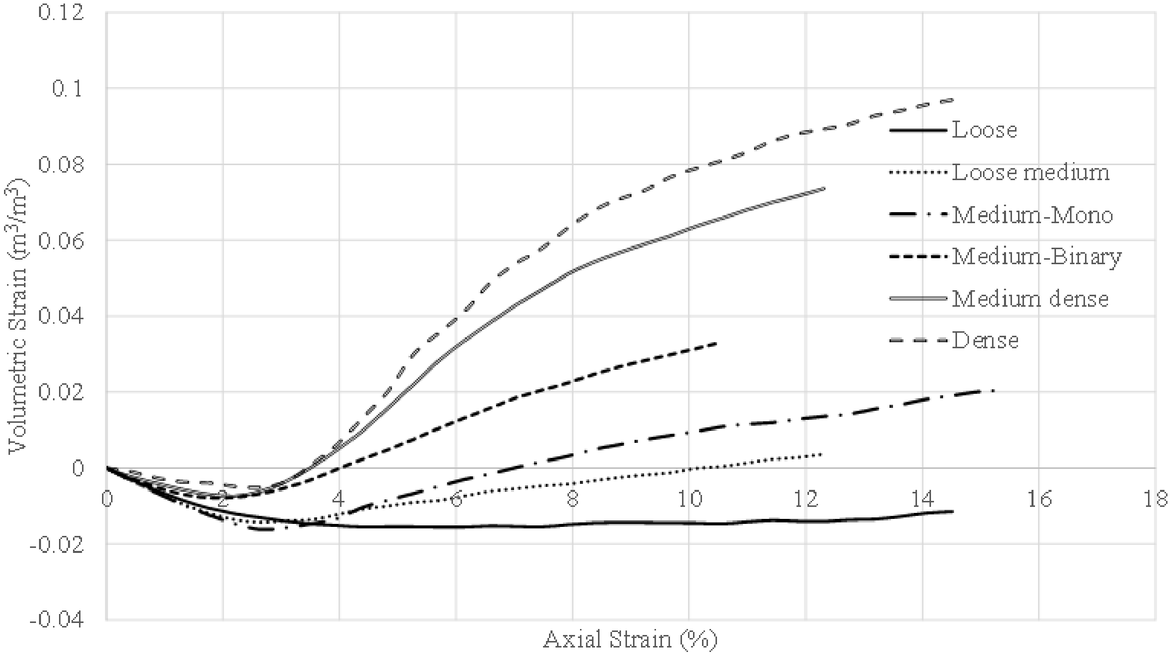
Task 2 Deliverable: Soil Unit Library

Density state being modeled:	Loose	Loose-medium	Medium-mono	Medium-binary	Medium-dense	Dense
Particle size distribution:	Mono-spheres	Mono-spheres	Mono-spheres	Binary-spheres	Binary-spheres	Binary-spheres
Spherical radius 1 (m)	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Spherical radius 2 (m)	-	-	-	0.0015	0.0015	0.0015
Number of spheres created:	1.335E+04	1.376E+04	1.376E+04	2.611E+04	2.611E+04	2.611E+04
Large spheres (n_1)	-	-	-	1.294E+04	1.294E+04	1.294E+04
Small spheres (n_2)	-	-	-	1.317E+04	1.317E+04	1.317E+04
Void ratio	0.88	0.82	0.82	0.60	0.60	0.60
Numerical mass density (kg/m^3)	1.406E+03	1.456E+03	1.456E+03	1.651E+03	1.651E+03	1.651E+03
Numerical relative density (%)	7.0	17.5	17.5	56.0	56.0	56.0
Elastic material properties:						
Mass density (kg/m^3)	2.650E+03	2.650E+03	2.650E+03	2.650E+03	2.650E+03	2.650E+03
Young's modulus 1 (N/m^2)	1.724E+08	1.724E+08	1.724E+08	1.724E+08	1.724E+08	1.724E+08
Young's modulus 2 (N/m^2)	-	-	-	7.00E+08	7.00E+08	7.00E+08
Poisson's ratio 1	0.17	0.17	0.17	0.17	0.17	0.17
Poisson's ratio 2	-	-	-	0.17	0.17	0.17
Rheological model parameters:						
Normal damping	0.7	0.7	0.7	0.7	0.7	0.7
Tangential damping	0.4	0.4	0.4	0.53	0.4	0.4
Coefficient of sliding friction	1.0	1.0	1.0	0.5	1.0(1) & 1.0(2)	1.0(1) & 1.0(2)
Coefficient of rolling friction	0.1	0.1	0.2	0.05	0.2(1) & 0.1(2)	0.2(1) & 0.1(2)
Coefficient of shear jamming	0.0	0.0	1.0	0.0	1.0(1) & 0.0(2)	4.0(1) & 0.0(2)
Normal stiffness factor	1.0	1.0	1.0	1.0	1.0	1.0
Shear stiffness factor	0.9	0.9	0.9	0.5	0.9	0.9
Shear behavior under triaxial compression testing (at 140 kPa confinement):						
Peak shear strength (N/m^2)	-	2.14E+05	2.62E+05	2.55E+05	3.57E+05	4.68E+05
Peak ang. of internal friction (°)	-	25.0	28.5	28.0	35.5	38.0
Ultimate shear strength (N/m^2)	1.56E+05	1.61E+05	1.56E+05	1.58E+05	1.61E+05	1.62E+05
Ultimate ang. of internal friction (°)	20.0	21.0	21.0	21.0	21.0	21.0
Shear behavior under triaxial compression testing (at 70 kPa confinement):						
Peak shear strength (N/m^2)	-	9.53E+04	1.14E+05	1.18E+05	1.70E+05	1.98E+05
Peak ang. of internal friction (°)	-	23.0	26.0	26.0	32.5	35.0
Ultimate shear strength (N/m^2)	7.66E+04	7.64E+04	7.60E+04	7.61E+04	8.42E+04	8.50E+04
Ultimate ang. of internal friction (°)	20.0	20.0	20.0	20.0	21.0	21.0

Task 2 Deliverable: Soil Unit Library

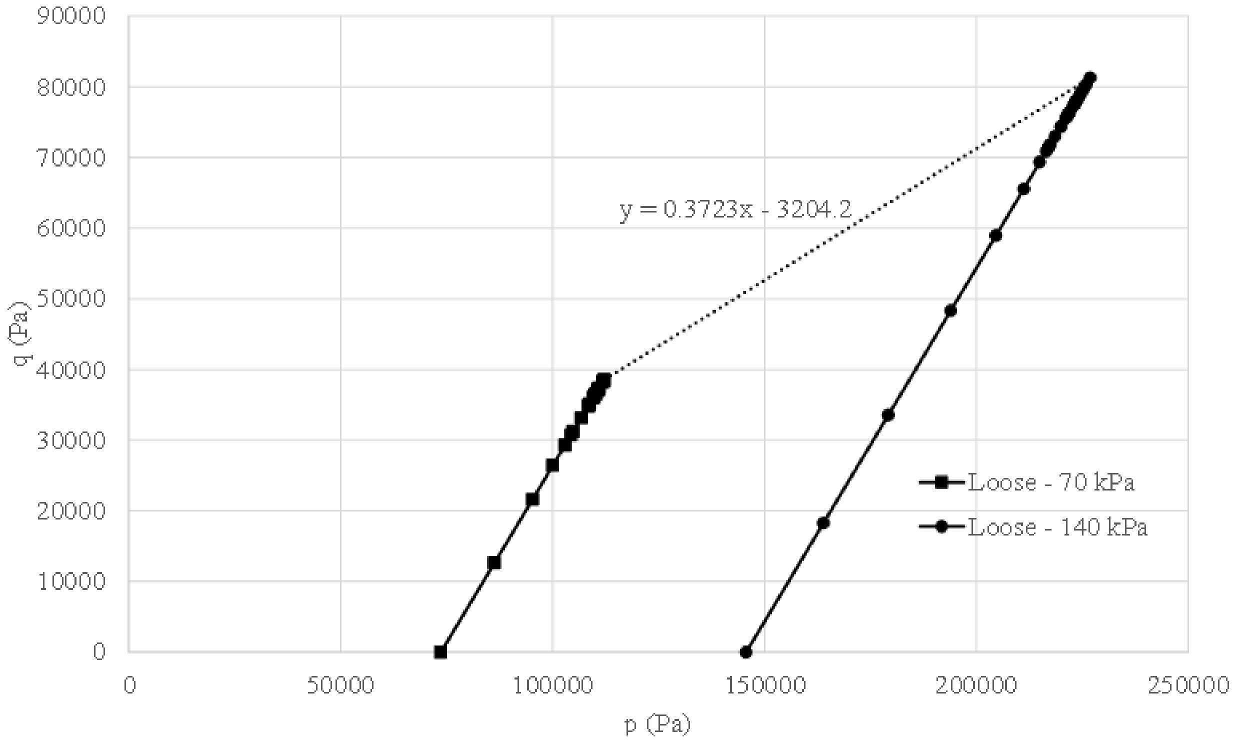
Confining stress = 140 KPa



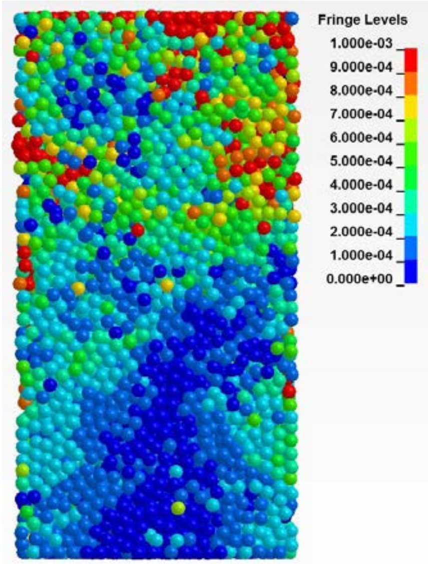


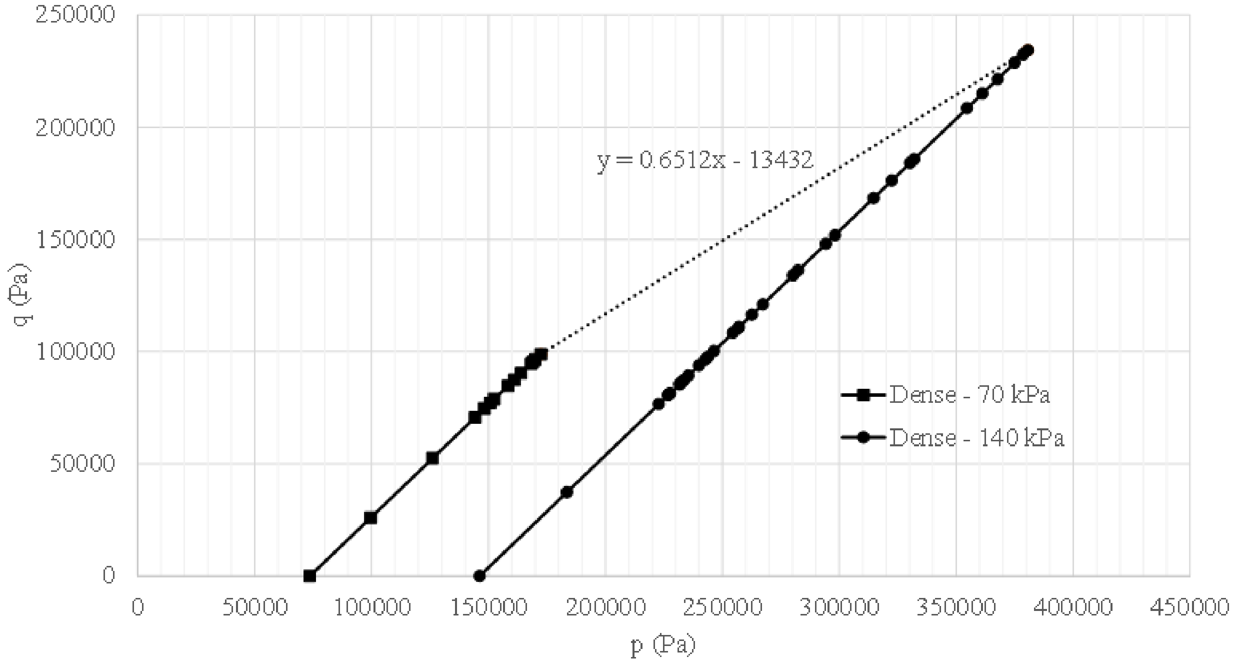
Task 2 Deliverable: K_f lines

$$\sin(\phi) = \tan(\psi)$$

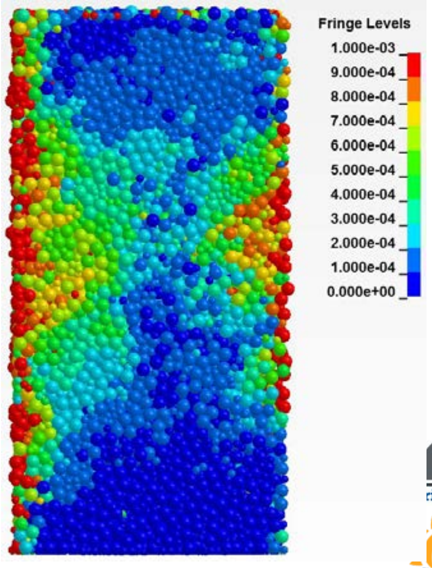


$$\operatorname{asin}(0.3723) = 21.858\,\text{deg}$$



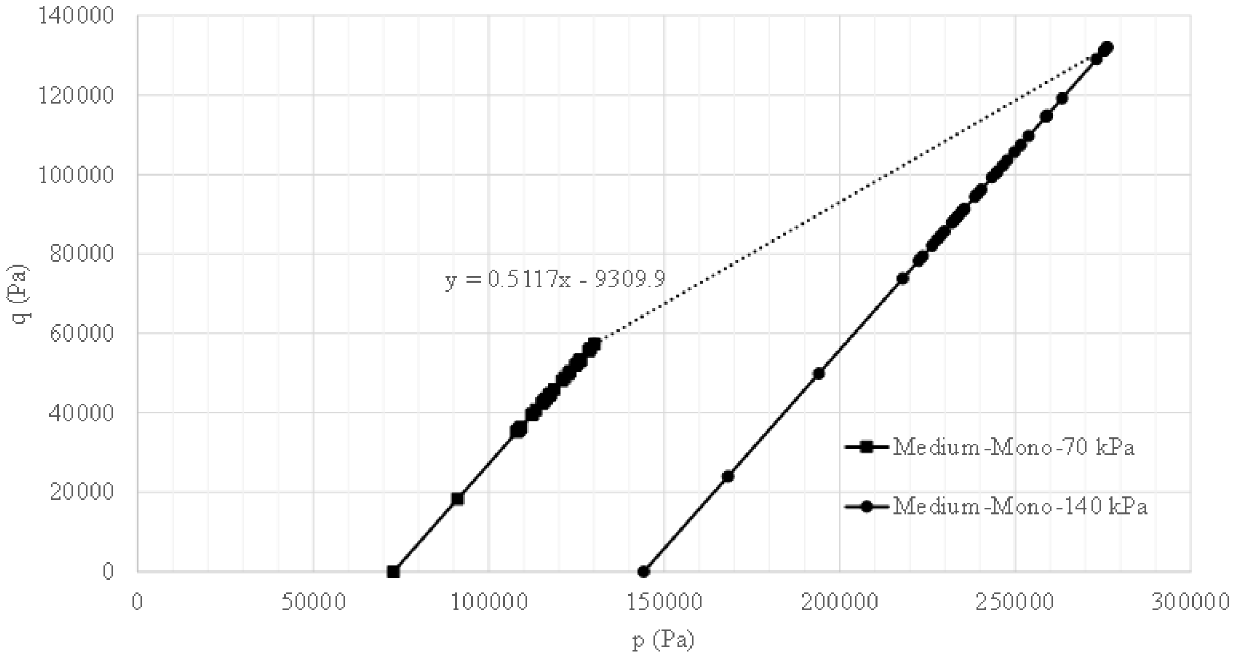


$$\operatorname{asin}(0.6512) = 40.632\,\text{deg}$$

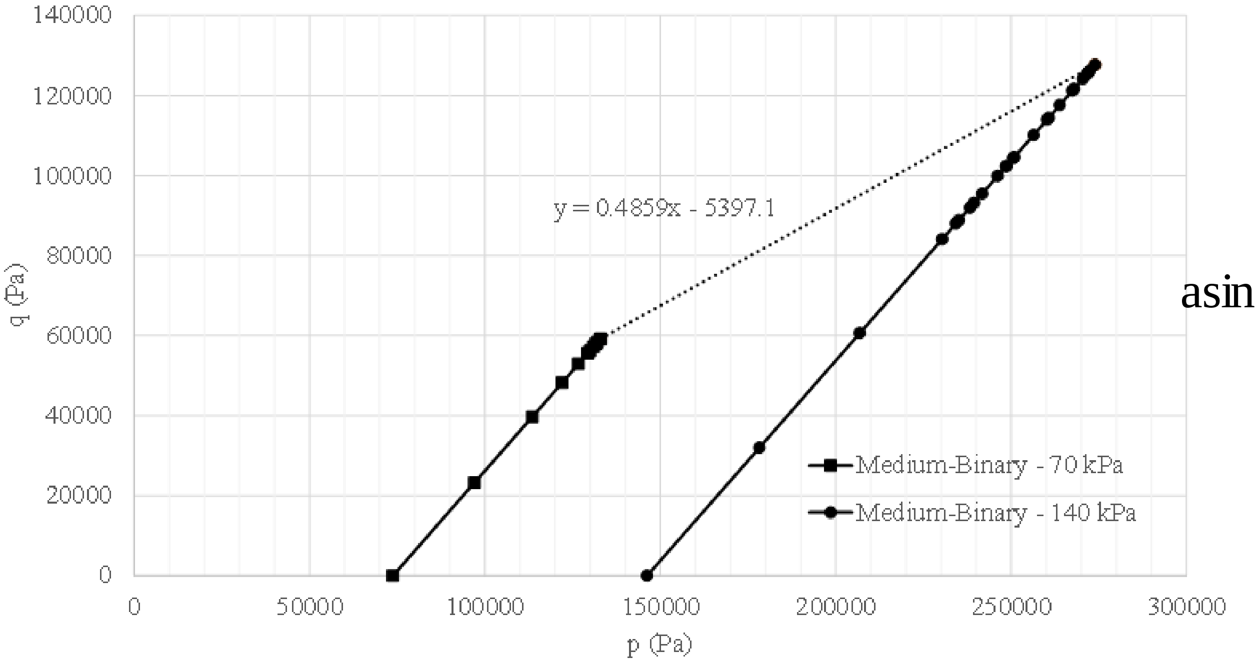


Task 2 Deliverable: K_f lines

$$\sin(\phi) = \tan(\psi)$$



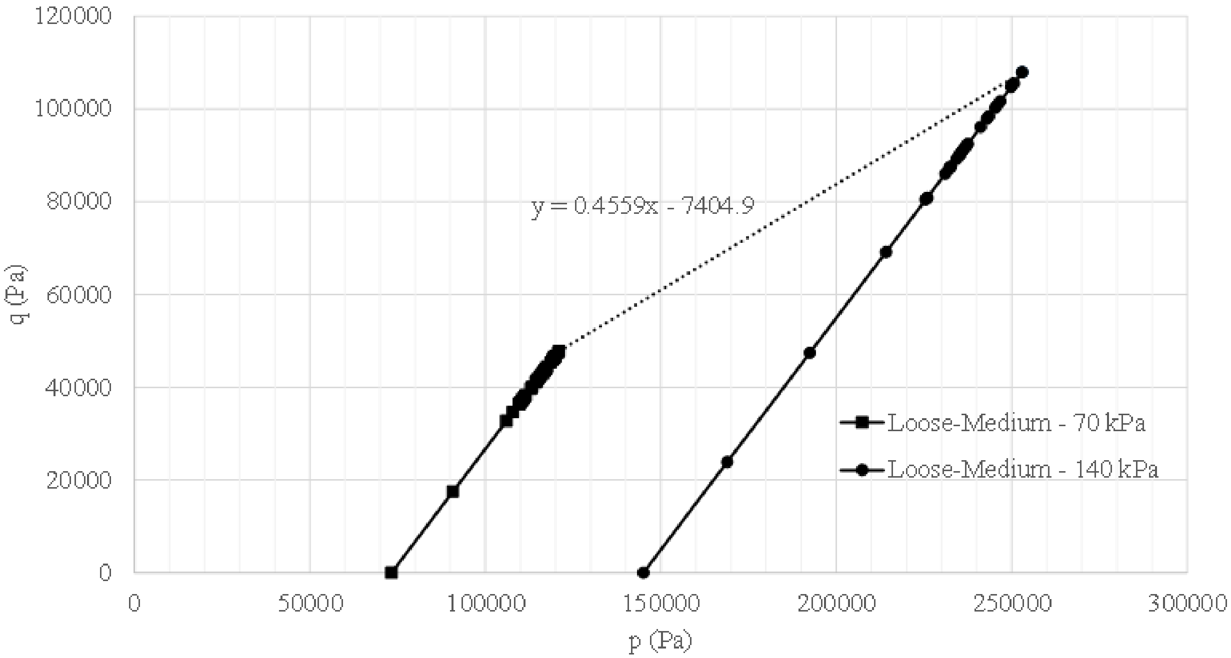
$$\text{asin}(0.5117) = 30.777\,\text{deg}$$



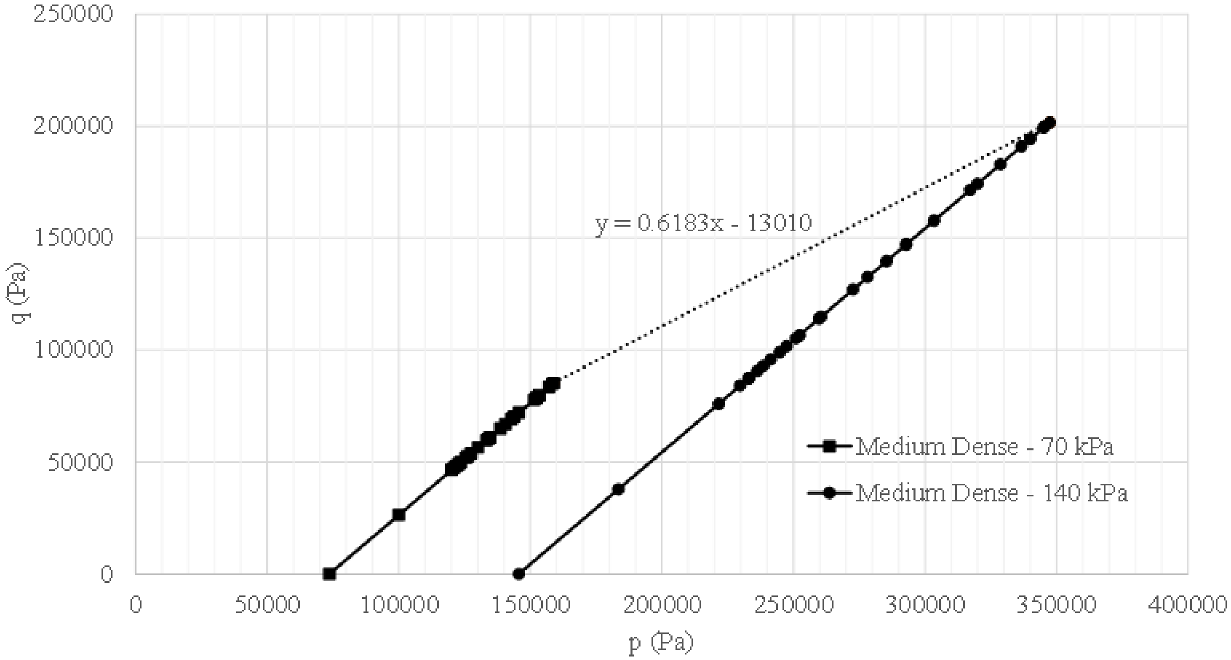
$$\text{asin}(0.4859) = 29.071\,\text{deg}$$

Task 2 Deliverable: K_f lines

$$\sin(\phi) = \tan(\psi)$$



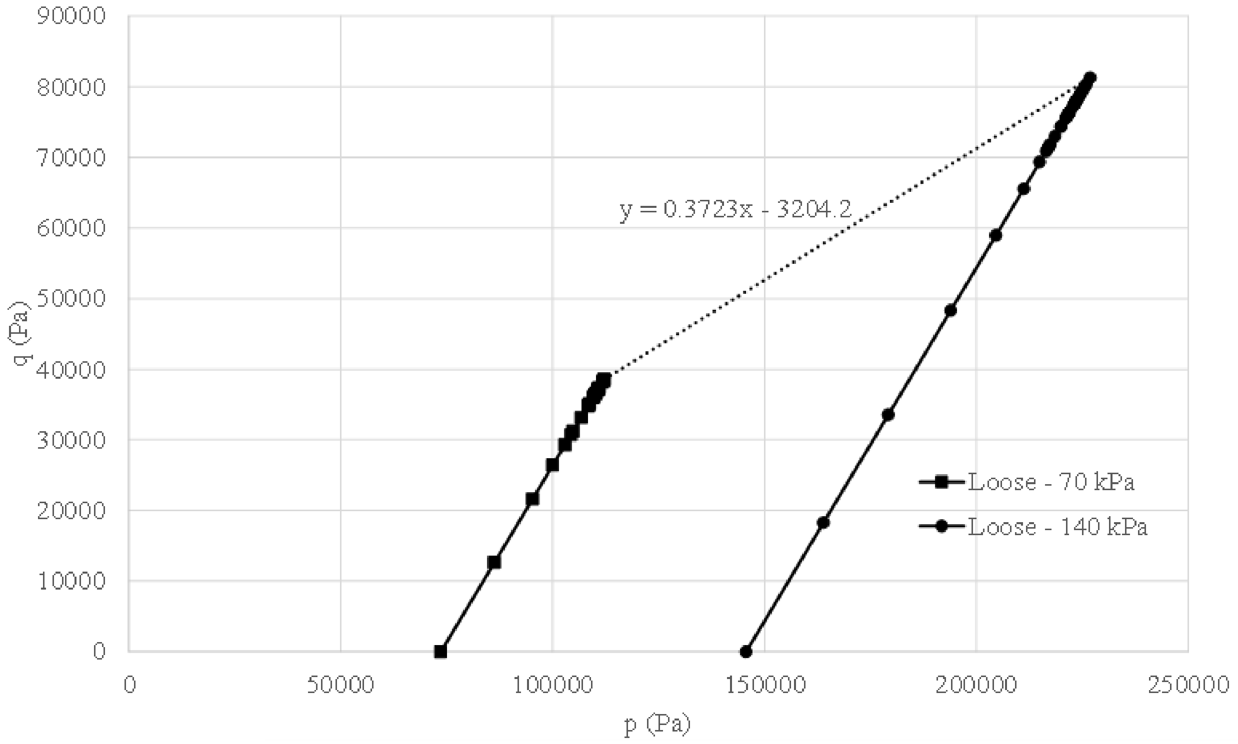
$$\mathrm{asin}(0.4559) = 27.123\,\mathrm{deg}$$



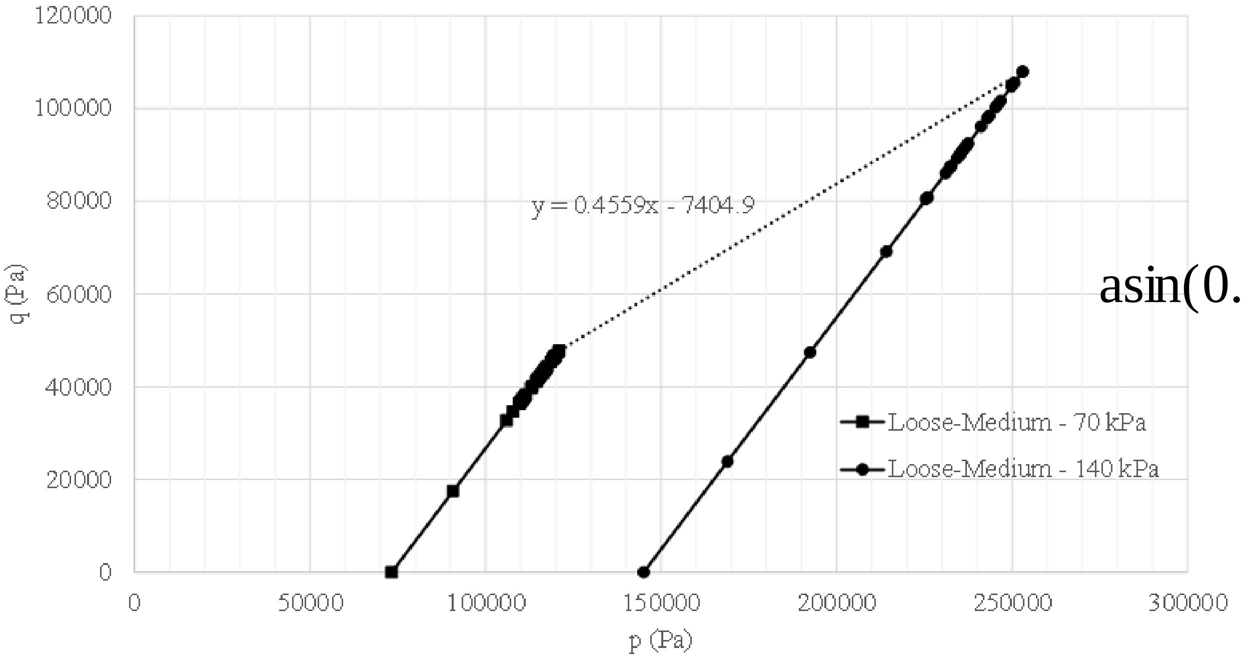
$$\mathrm{asin}(0.6183) = 38.192\,\mathrm{deg}$$

Task 2 Deliverable: K_f lines

$$\sin(\phi) = \tan(\psi)$$



$$\text{asin}(0.3723) = 21.858\,\text{deg}$$



$$\text{asin}(0.4559) = 27.123\,\text{deg}$$

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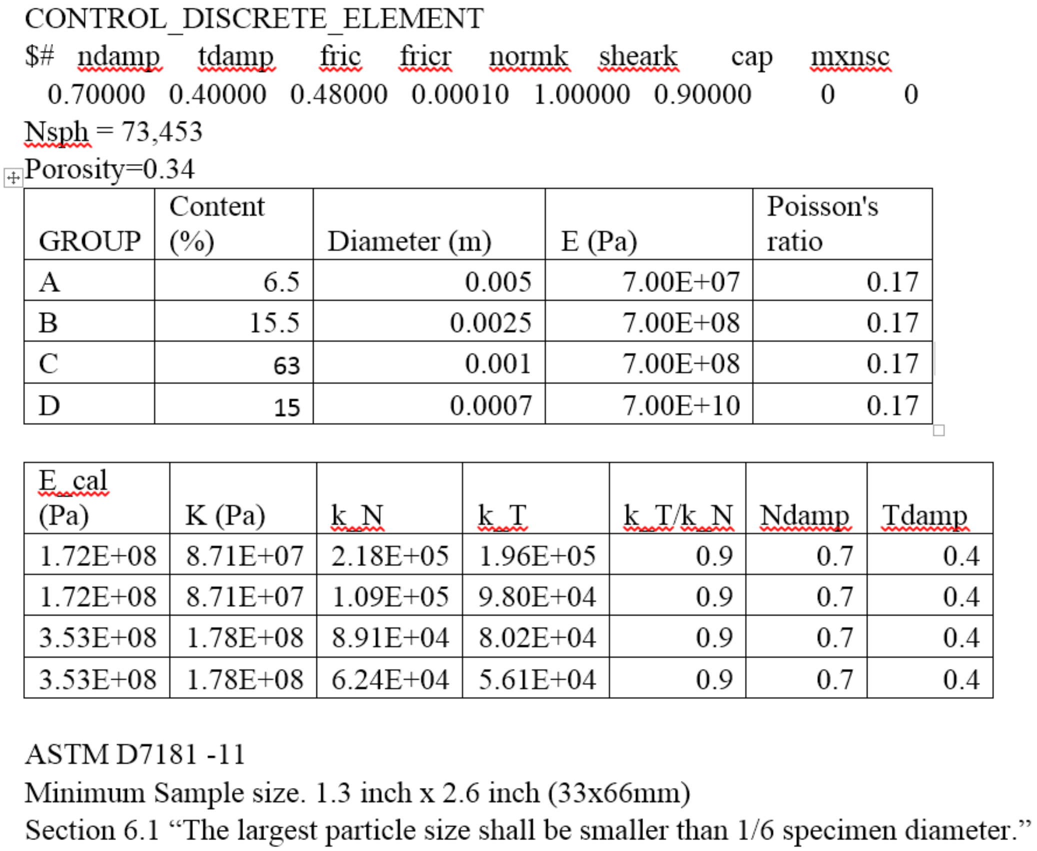
Other Studies: Particle size distribution (per Murzenko 1966)



CONTROL_DISCRETE_ELEMENT

```
$#  ndamp    tdamp     fric     fricr    normk    sheark      cap    mxnsc
  0.70000  0.40000  0.48000  0.00010  1.00000  0.90000        0        0
```

Nsph = 73,453

Porosity=0.34

GROUP	Content (%)	Diameter (m)	E (Pa)	Poisson's ratio
A	6.5	0.005	7.00E+07	0.17
B	15.5	0.0025	7.00E+08	0.17
C	63	0.001	7.00E+08	0.17
D	15	0.0007	7.00E+10	0.17

E_cal (Pa)	K (Pa)	k_N	k_T	k_T/k_N	Ndamp	Tdamp
1.72E+08	8.71E+07	2.18E+05	1.96E+05	0.9	0.7	0.4
1.72E+08	8.71E+07	1.09E+05	9.80E+04	0.9	0.7	0.4
3.53E+08	1.78E+08	8.91E+04	8.02E+04	0.9	0.7	0.4
3.53E+08	1.78E+08	6.24E+04	5.61E+04	0.9	0.7	0.4

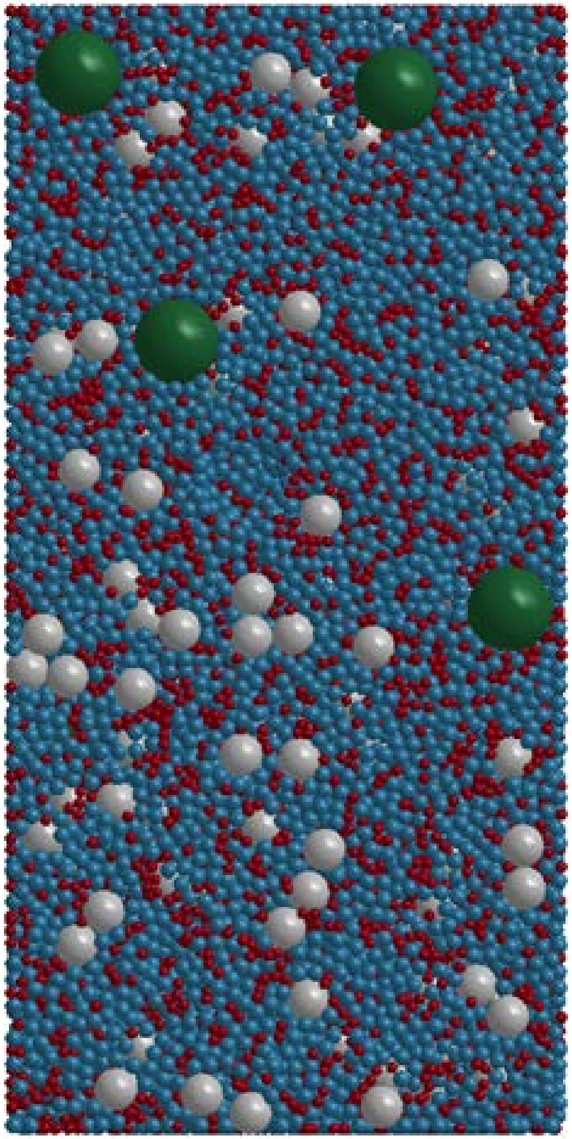
ASTM D7181 -11

Minimum Sample size. 1.3 inch x 2.6 inch (33x66mm)

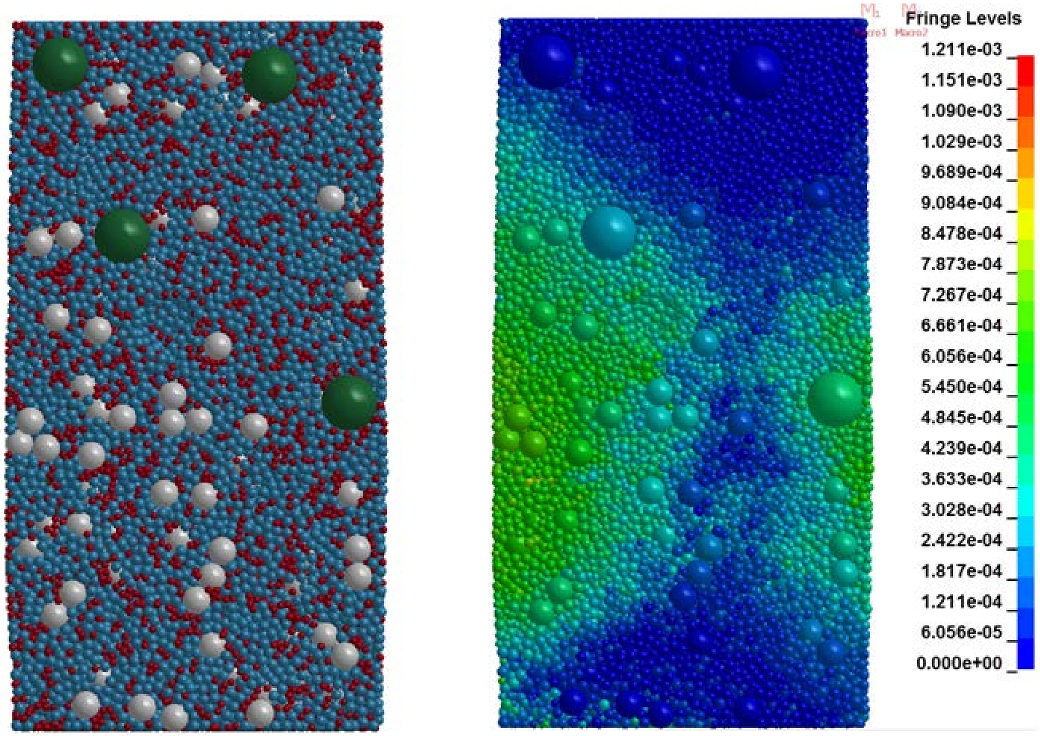
Section 6.1 "The largest particle size shall be smaller than 1/6 specimen diameter."

Dimensions:

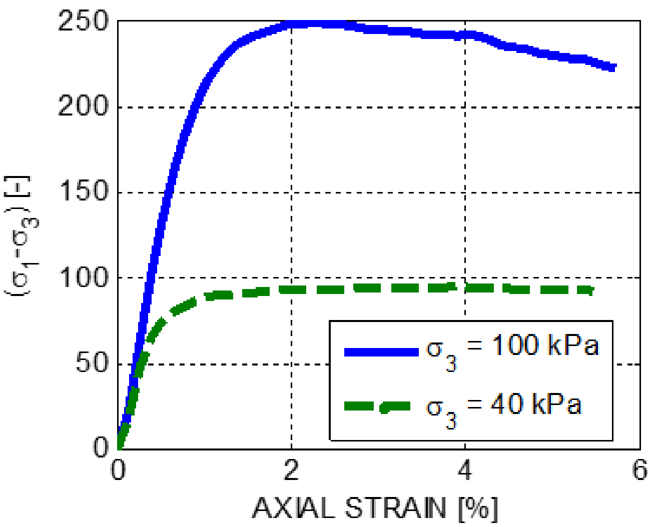
1.3 in. x 2.6 in. (33 mm x 66 mm)

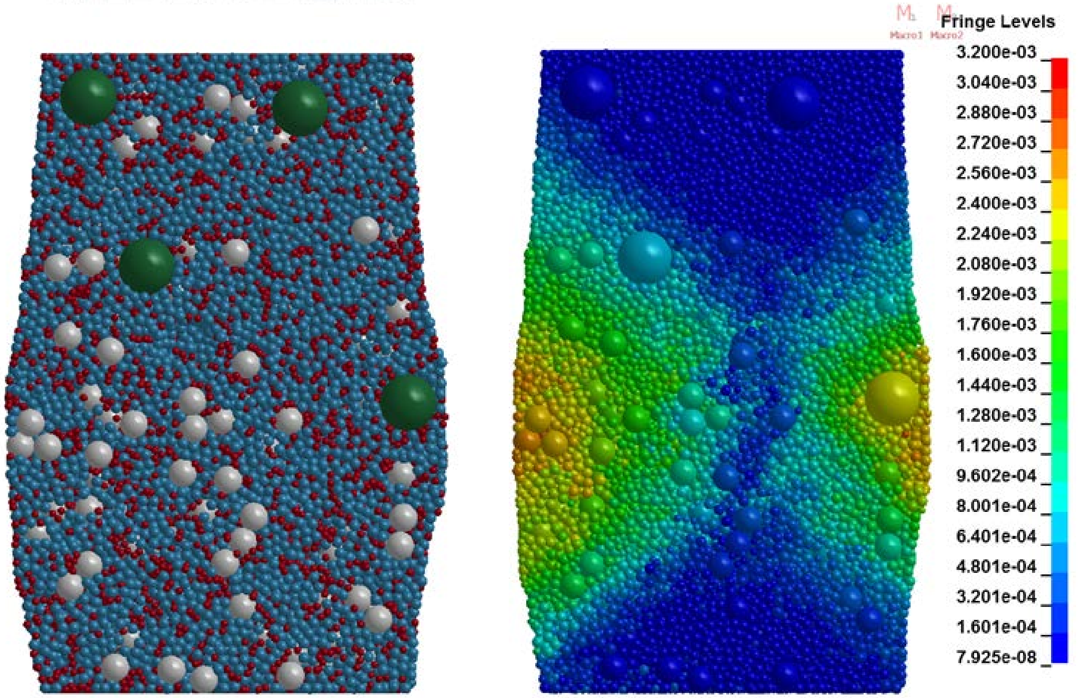


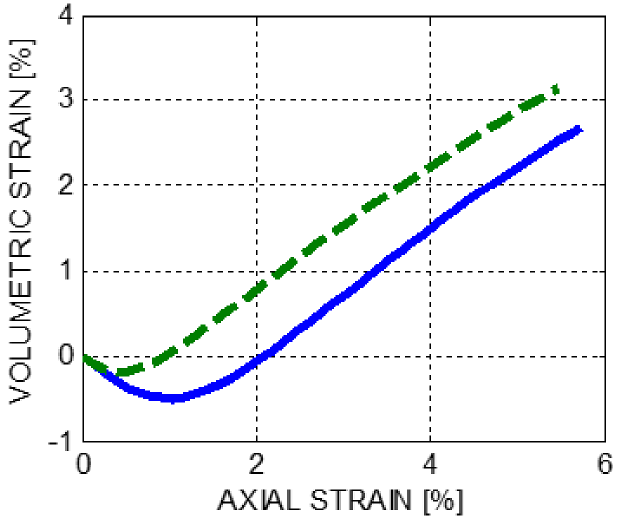
Other Studies : Particle size distribution



The internal friction angle = 34 deg.







Other aspects: Capillary Suction
Apparent cohesion in Pendular regime

Table 3.2.6.2. Direct shear test simulation results

Normal stress (kPa)	Shear stress without Capillary Suction (kPa)	Shear stress with capillary suction (kPa)
54.5	22.87	24.59
109	45.32	48.12
163.5	68.5	70.5

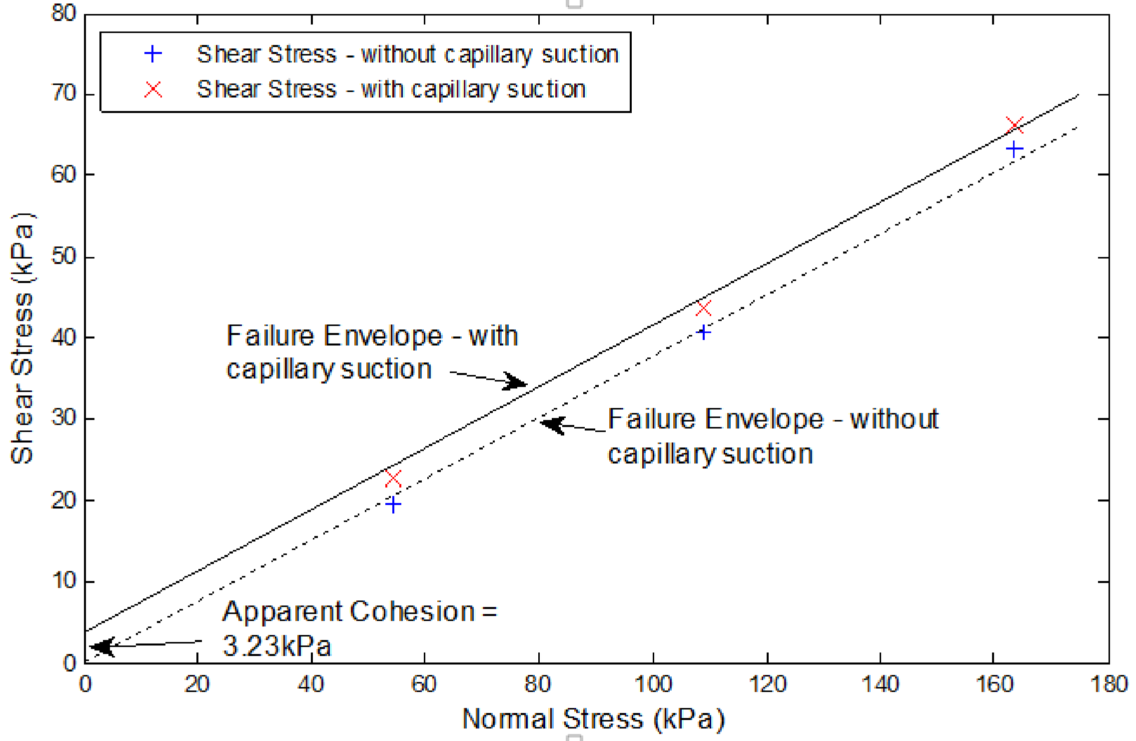


Figure 3.2.6.2. Direct shear test simulations with and without use of capillary force calculations

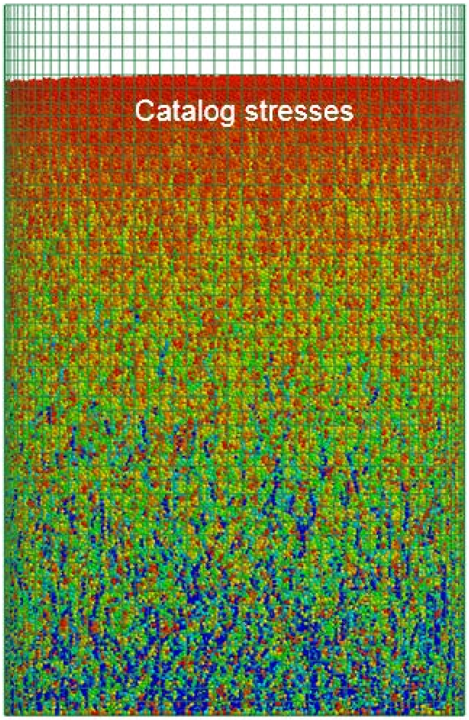
Project Approach

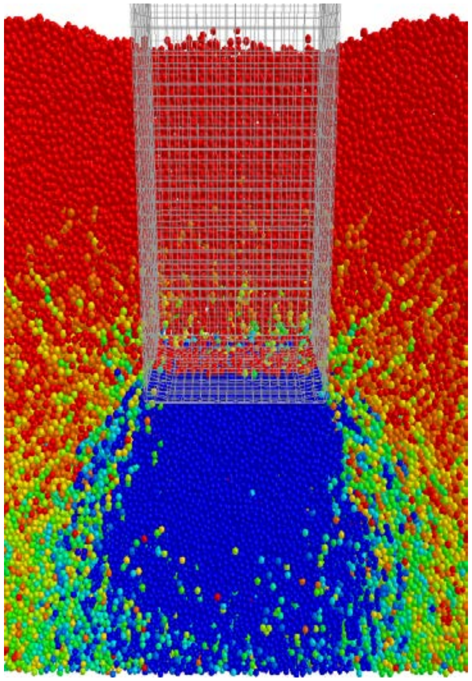
- **Phase I (12 months; July 2014 - June 2015)**
- Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition
- Task 2. Numerical Modeling Schemes and Granular Soil Units

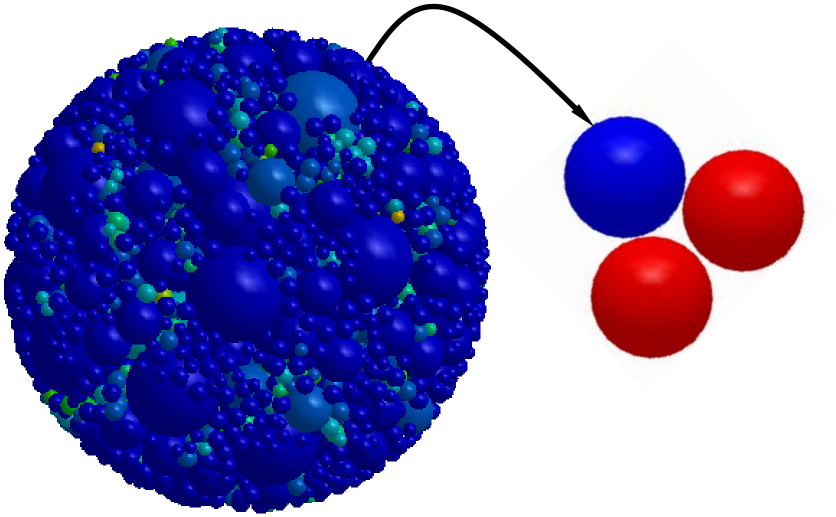
- **Phase II (18 months; July 2015 - December 2016)**
- Task 3. Numerical Modeling of Driven foundation in Granular Soils
- Task 4. Physical Laboratory/Centrifuge Experimentation
- Task 5. Reporting of Findings and Design-Oriented Recommendations
- Task 6. Final Report

Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Activities**
  - Generation of geostatic stress states in megascopic assemblies
  - Preliminary modeling of pile driving simulations
  - Investigation of upscaling

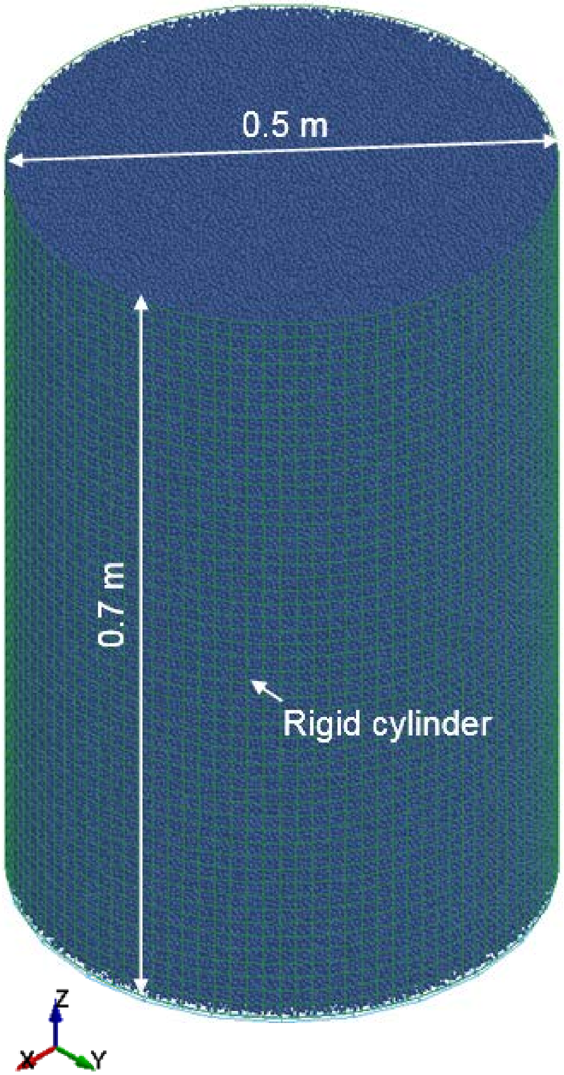


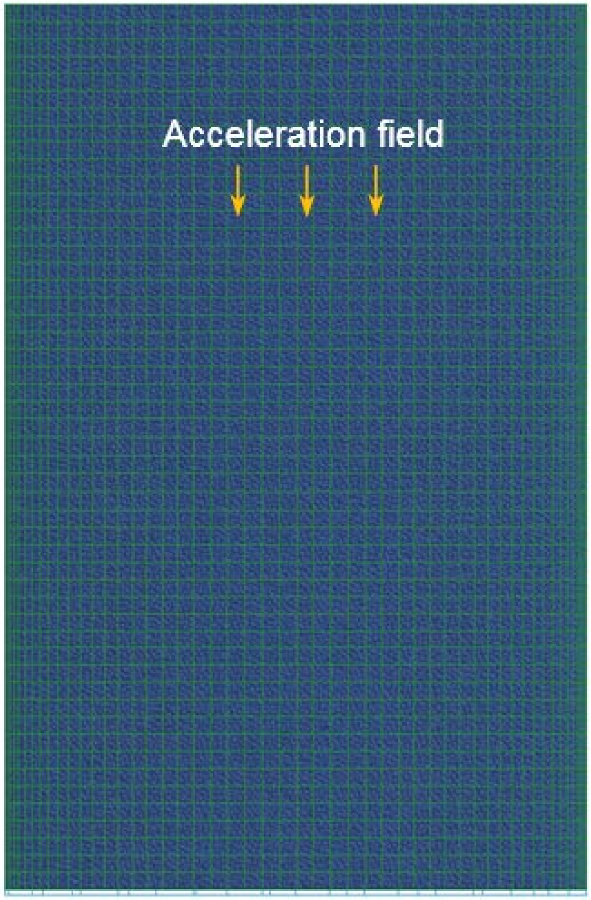


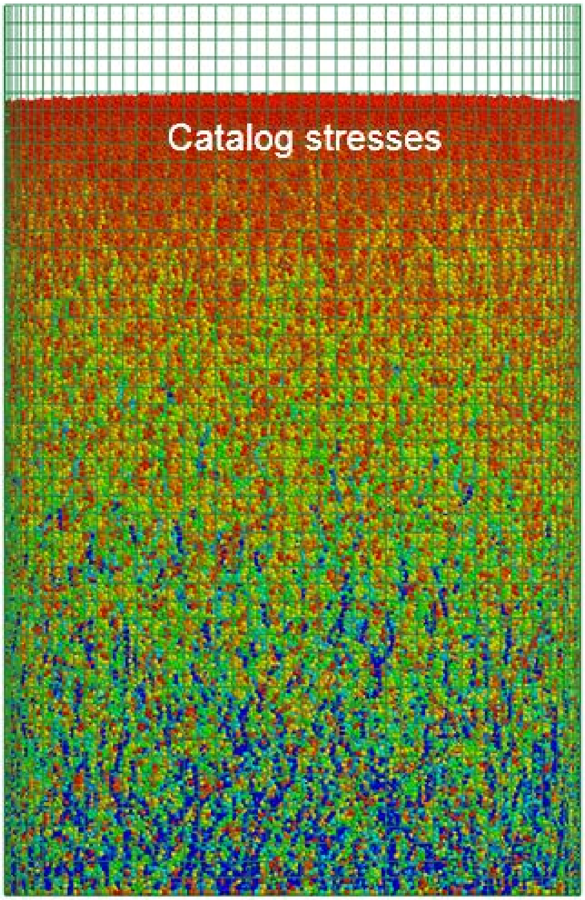


Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Generation of geostatic stress states**



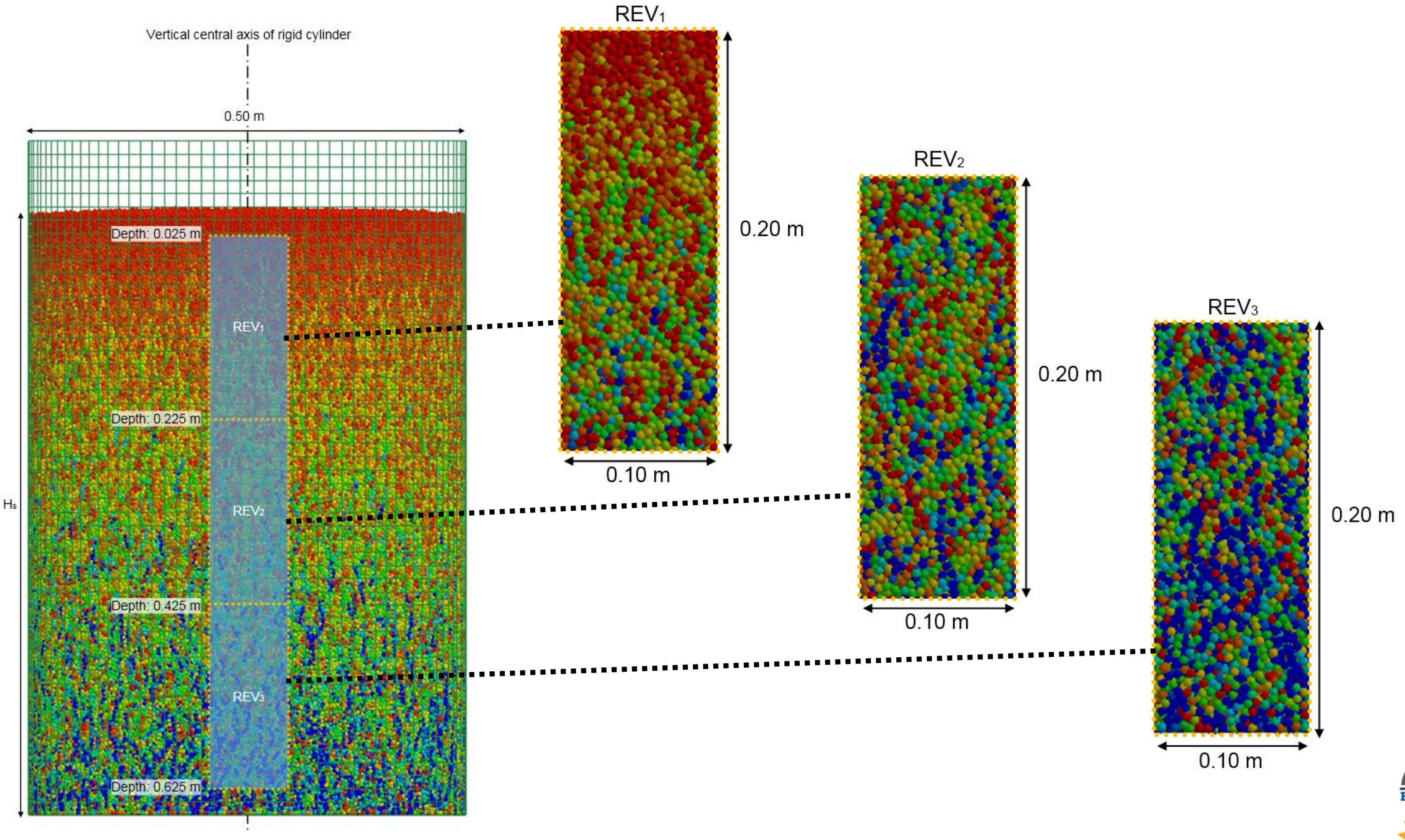




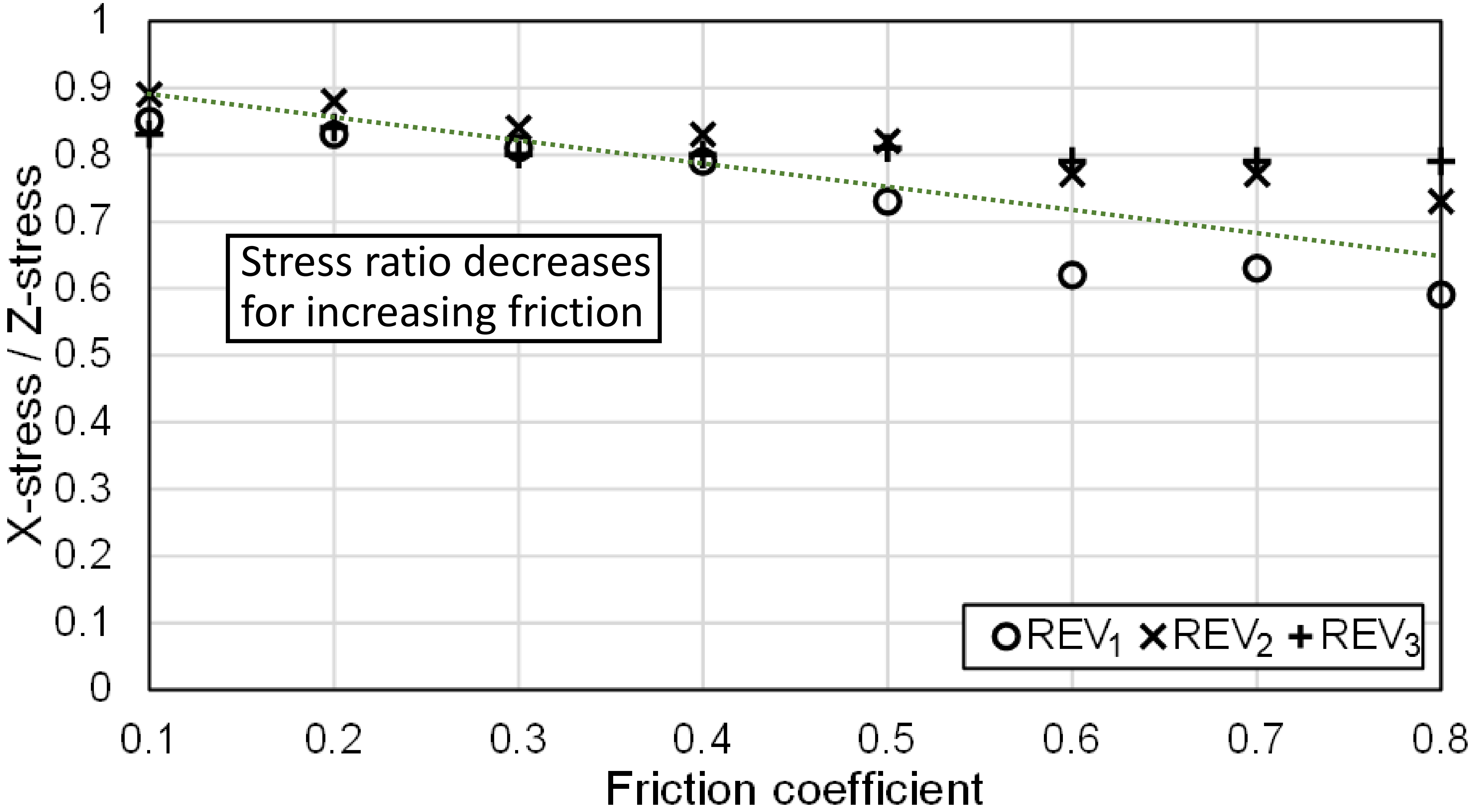
~1.26 million UDES per assembly

Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- Parametric set of assemblies investigated

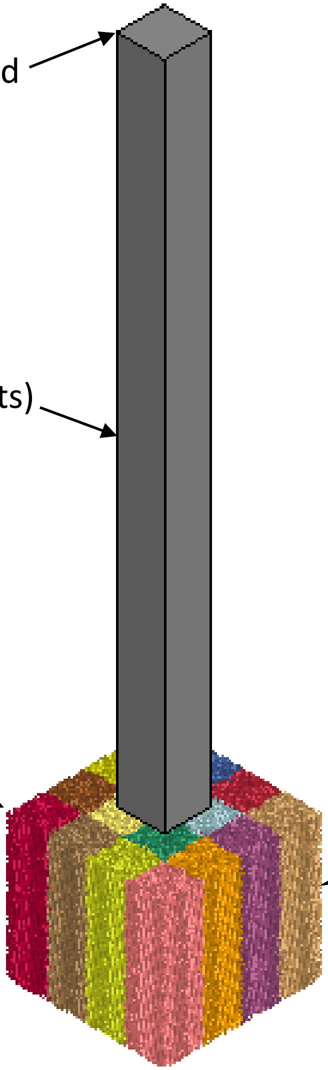


Task 3. Numerical Modeling of Driven Foundation in Granular Soils



Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Preliminary modeling of pile driving**



Periodic pulse force applied to induce pile penetration

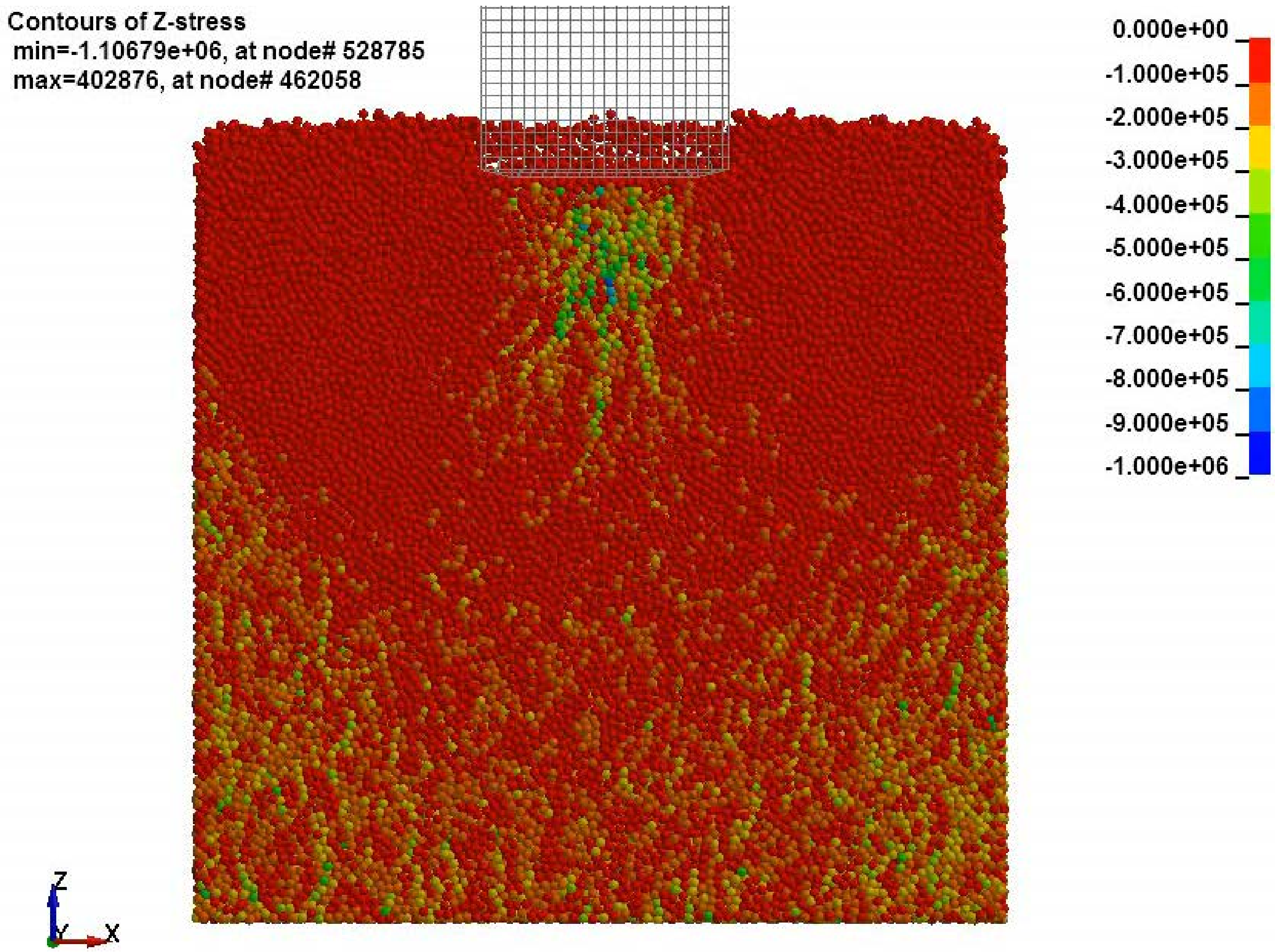
Pile object (eight-node solid elements)

Megascopic DSE assembly (composed of units with known macroscopic properties)

All perimeter spheres are fully restrained from motion

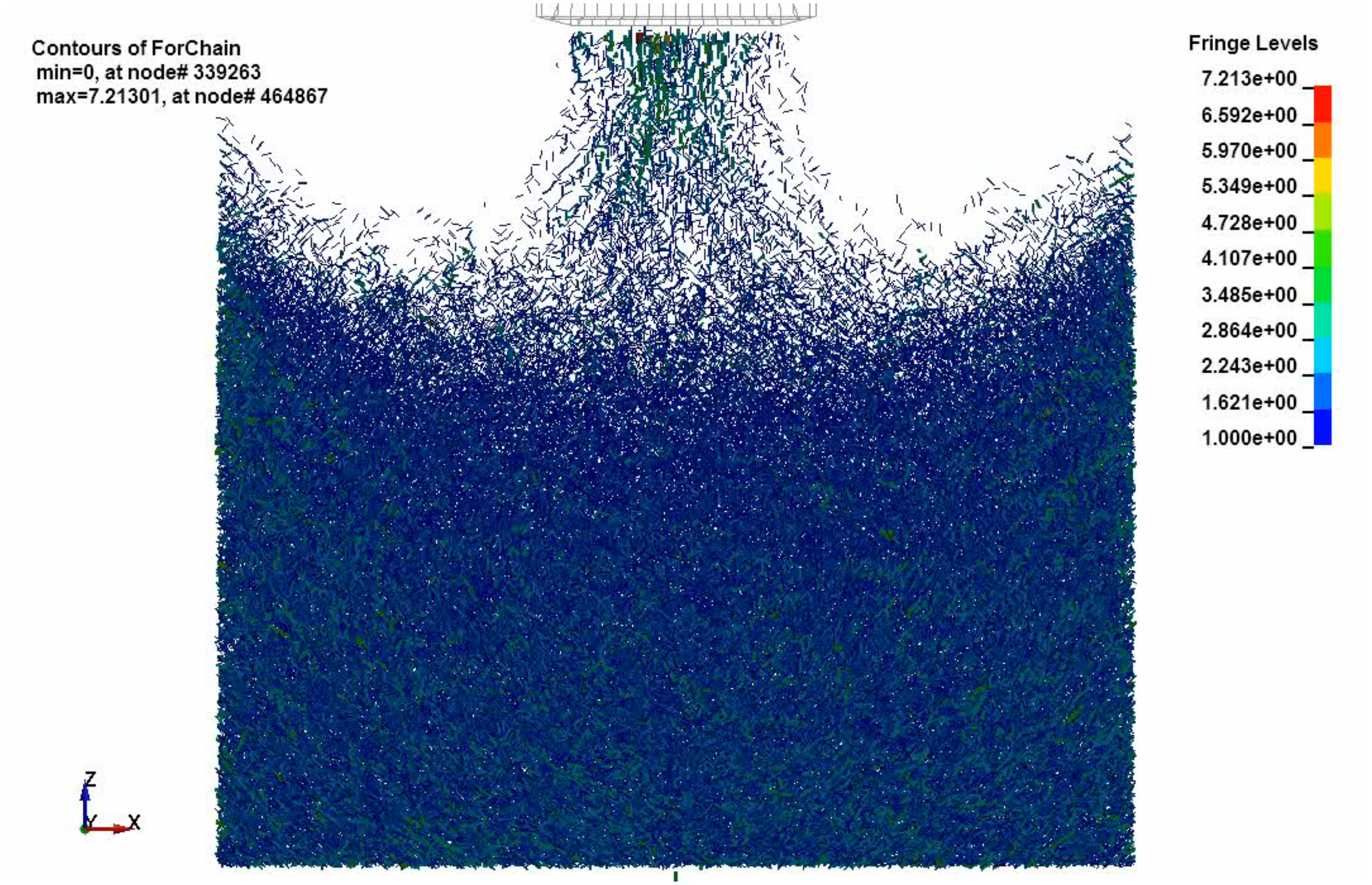
Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Animation (Z-Stresses)**



Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Animation (Force Chains)**



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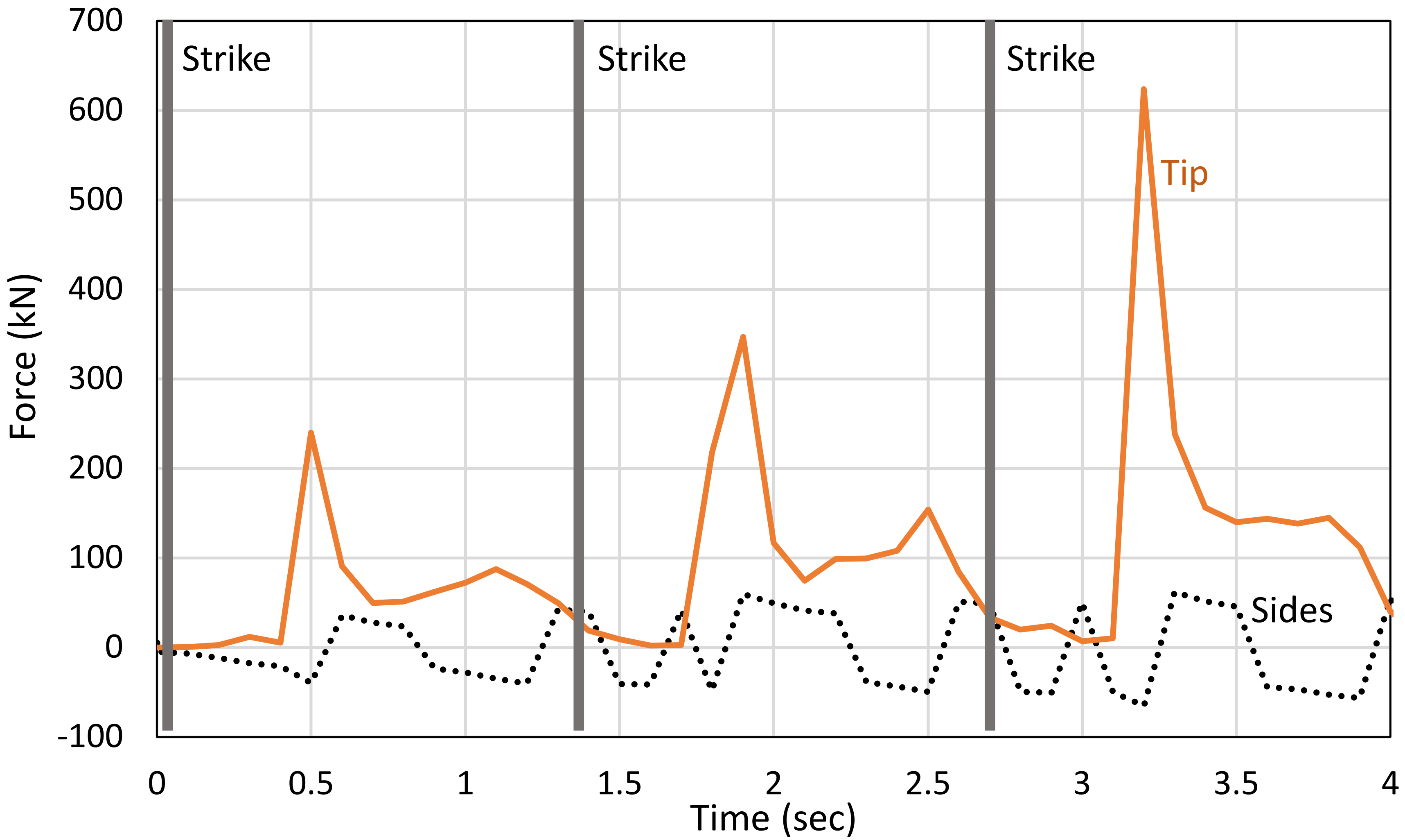
Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Resultant vertical forces at tip and sides**

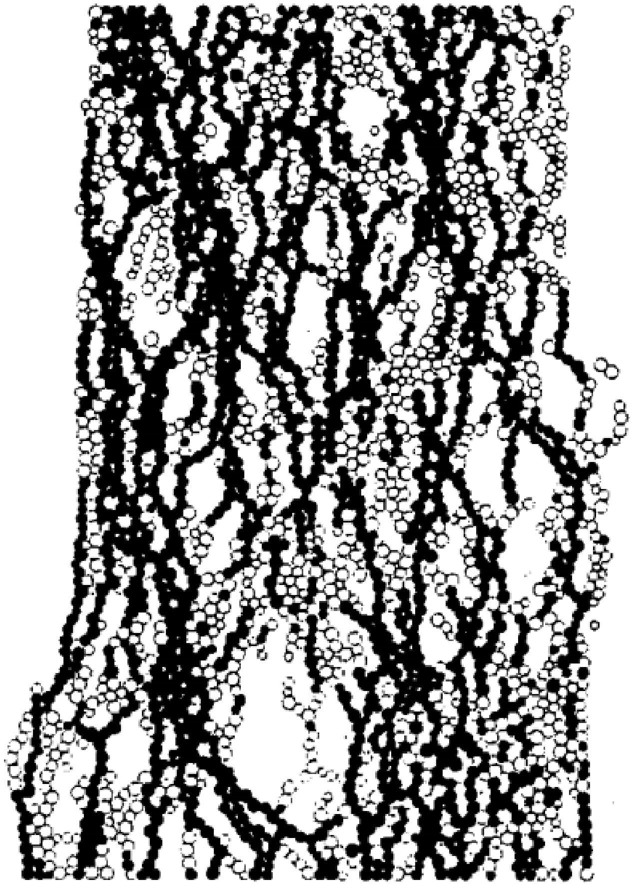


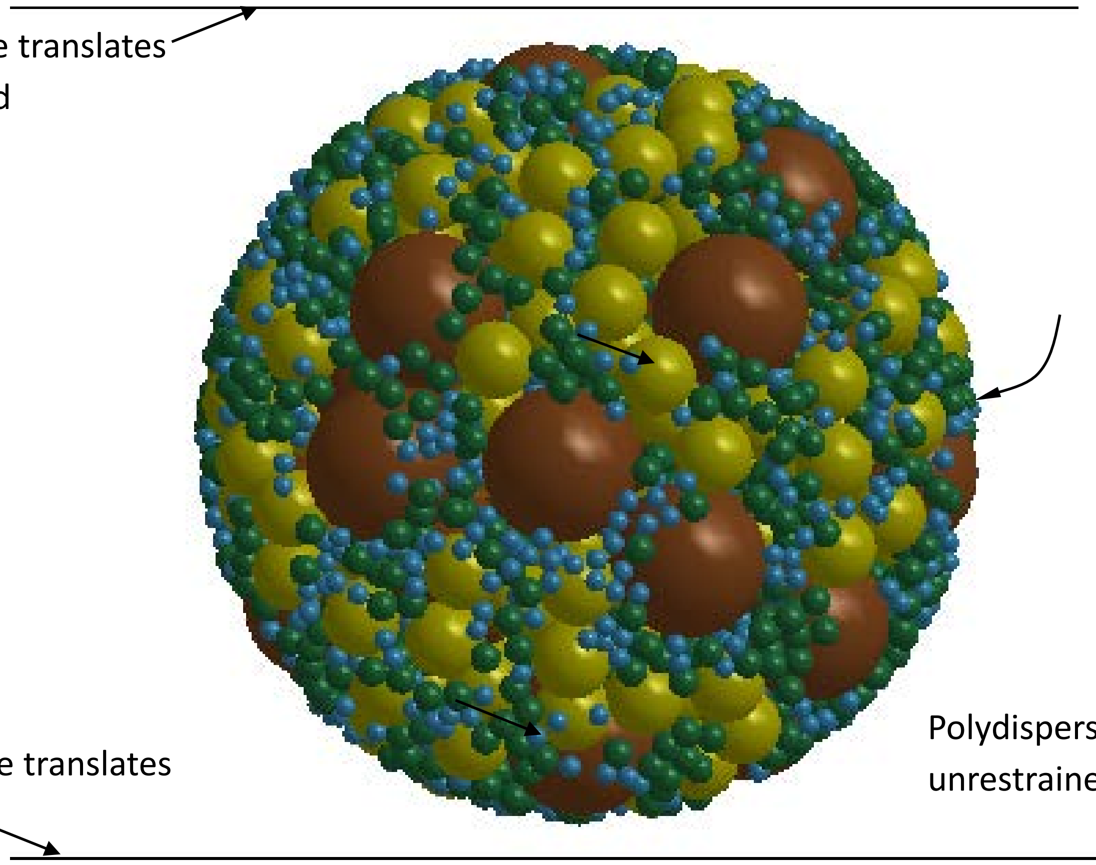
Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Investigation of upscaling**

Strong force chains under plane strain conditio

(Iwashita and Oda 1998)





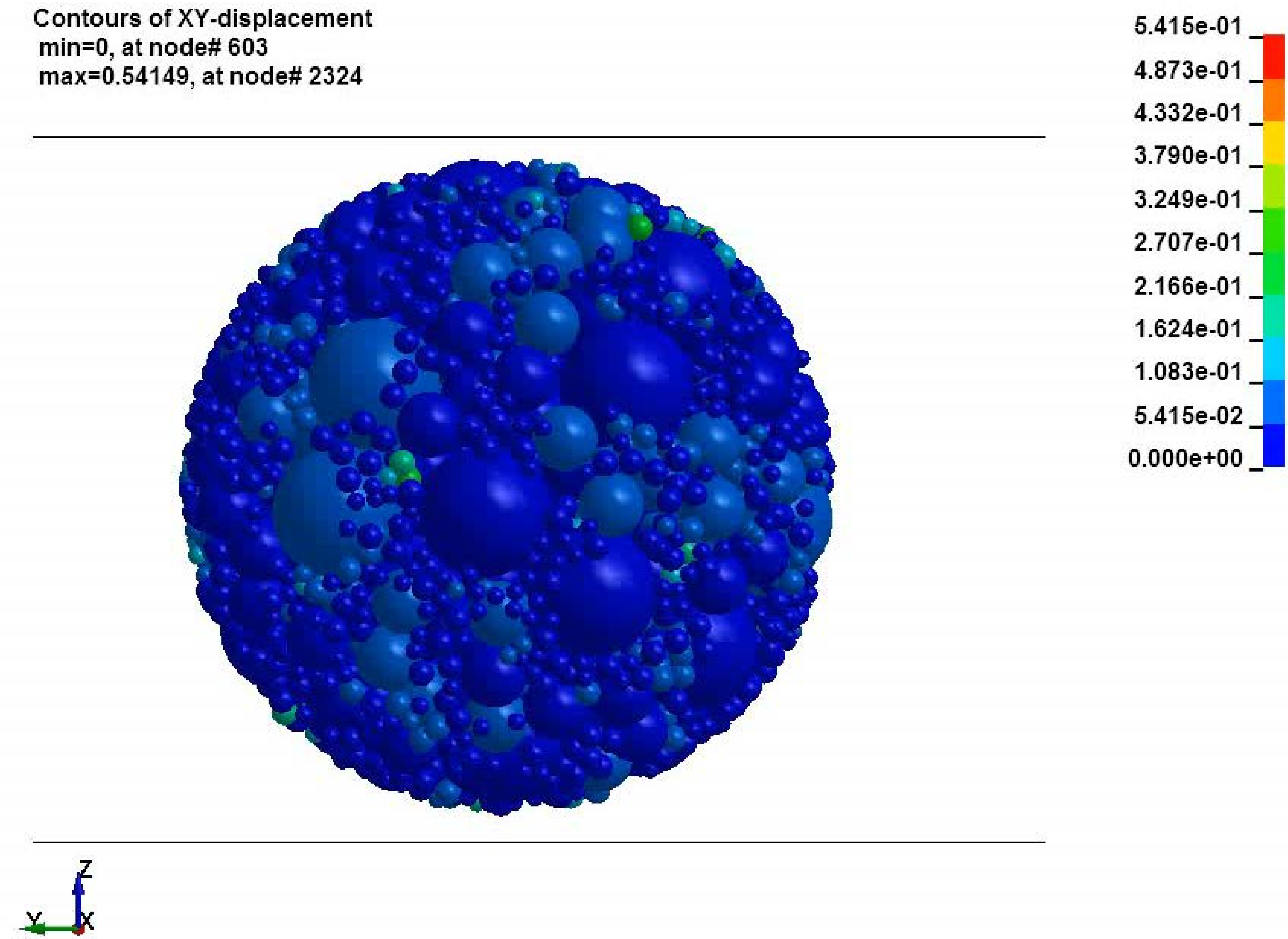
Rigid plate translates downward

Rigid plate translates upward

Polydisperse assembly is unrestrained from motion

Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Animation**



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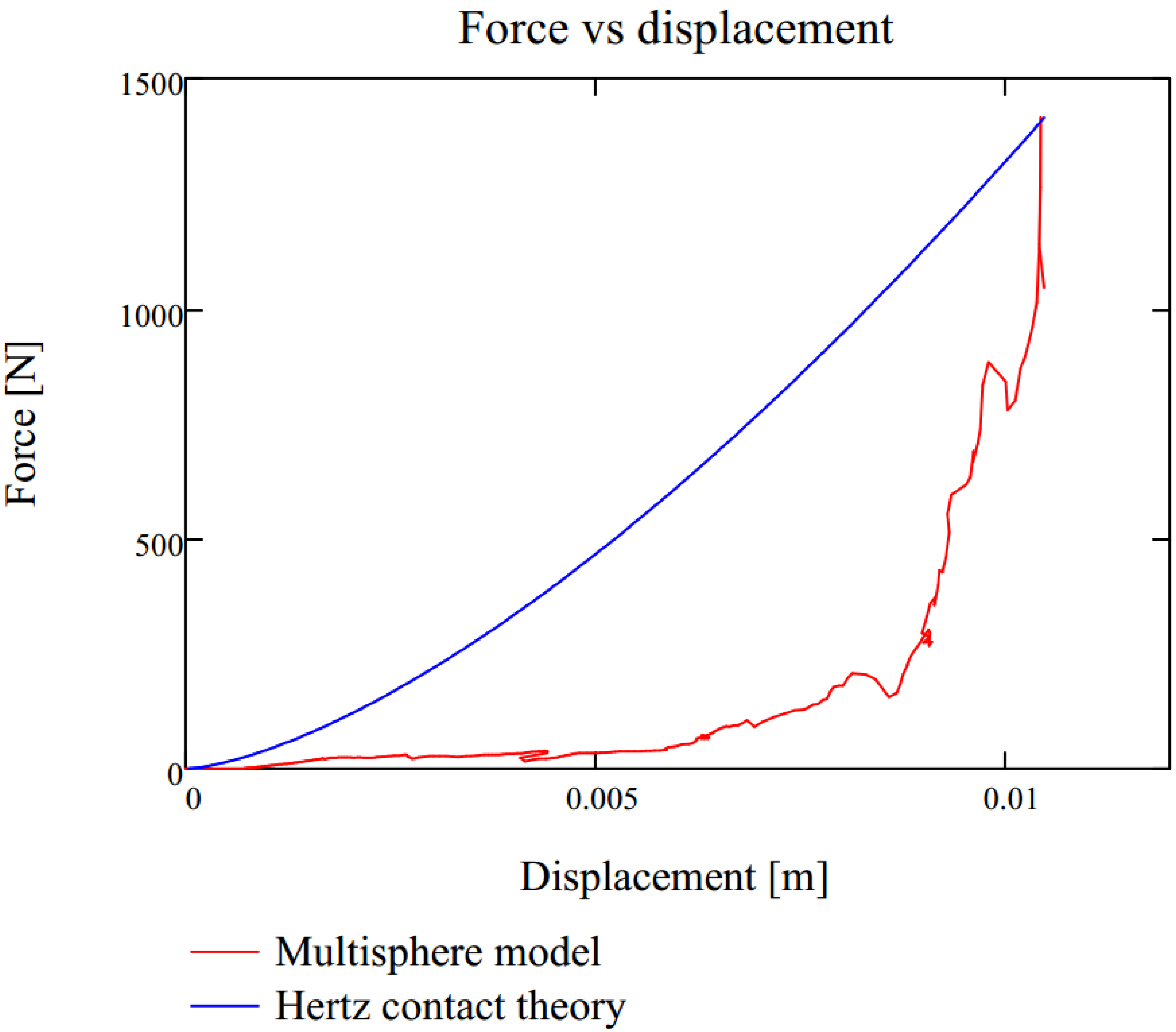
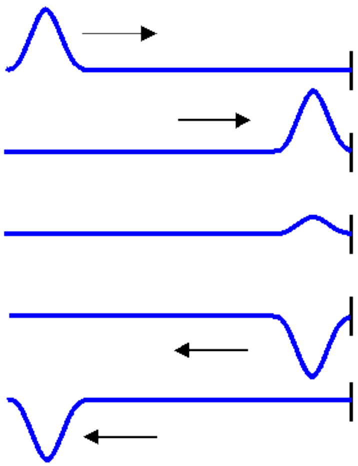
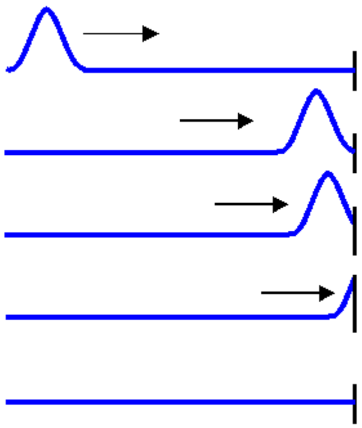


Task 3. Numerical Modeling of Driven Foundation in Granular Soils

- **Next steps**
  - Pile driving simulations: non-reflecting boundary conditions

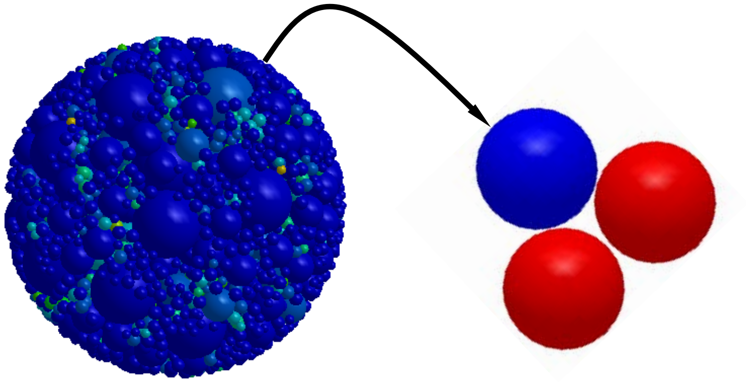


versus



http://labman.phys.utk.edu/phys222core/modules/m9/Thin%20films.htm

  - Upscaling: effect on rheology parameters and inter-relationships



Thank You!

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