
# GeoDualSPHysics: New Geomechanics Model in DualSPHysics

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# Overview

1. Motivations
2. Methods
3. XML Examples
4. Applications
5. Conclusions

# Motivations

- Geomaterials are natural or processed Earth-derived substances such as soil, rock, clay, and aggregates.
- They often involves large deformation free-surface flows, and it is an emerging area that SPH has demonstrated great potential.
- Applications – Why this matters?
  - Geomechanics:
    - ✓ Landslide run-out prediction and impact analysis.
    - ✓ Foundation failure and offshore anchor/pile installation.
  - Terramechanics:
    - ✓ Mobility of off-road vehicle;
    - ✓ Soils cutting and tillage.
  - Industrial Processes (Granular flow):
    - ✓ Silo discharge, conveyor transport.
    - ✓ Ball mills and pharmaceutical powder mixing.

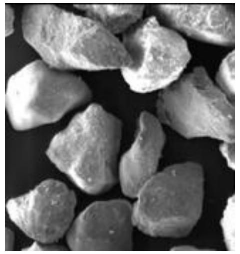
Granular flow (physics.aps.org)

Soil-machine interaction (sare.org)

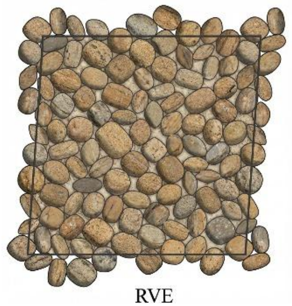
# Methods

- The Challenge: Discrete vs. Continuous
  - In reality, geomaterials are discontinuous. Forces are transmitted through contact between grains.

Geomaterials



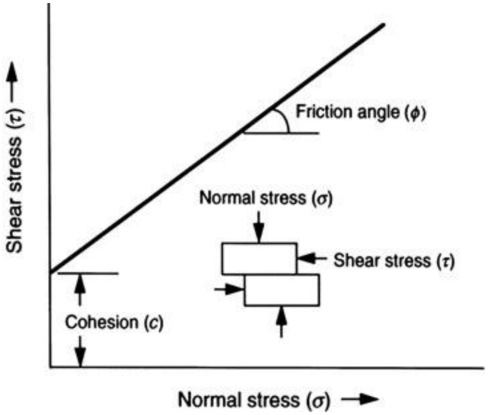
Grain scale ($10^{-5}$~$10^{-2}$ m)




RVE scale ($10^{-4}$~$10^{-1}$ m)

Engineering scale ($10^{0}$ ~$10^{2}$ m)

  - We consider the bulk behaviour of a Representative Volume Element (RVE) and describe it as continuum.
  - Key physics to capture: internal friction, cohesion, dilation.
  - ✓ Friction: shear resistance due to interparticle friction and interlocking.
  - ✓ Cohesion: shear strength at zero effective normal stress.
  - ✓ Dilation: volume change during shearing.




(Chaulya and Prasad 2016)

# Methods

- Mathematical description of geomaterials based on continuum mechanics.

- Mass and momentum conservation $\frac{d\rho}{dt} = -\rho\nabla\cdot\mathbf{v}$ $\frac{d\mathbf{v}}{dt} = \frac{1}{\rho}\nabla\cdot\boldsymbol{\sigma} + \mathbf{b}$

- Strain and spin rate equation $\dot{\boldsymbol{\varepsilon}} = \frac{1}{2}\left(\nabla\mathbf{v} + (\nabla\mathbf{v})^T\right)$ $\dot{\boldsymbol{\omega}} = \frac{1}{2}\left(\nabla\mathbf{v} - (\nabla\mathbf{v})^T\right)$

- SPH discretisation $\left\langle \frac{d\rho}{dt} \right\rangle_i = \rho_i \sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(v_i^\alpha - v_j^\alpha\right)\frac{\partial W_{ij}}{\partial x_i^\alpha}$ $\left\langle \frac{dv^\alpha}{dt} \right\rangle_i = \frac{1}{\rho_i} \sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(\sigma_i^{\alpha\beta} + \sigma_j^{\alpha\beta}\right)\frac{\partial W_{ij}}{\partial x_i^\beta} + g^\alpha$

$$\left\langle \dot{\varepsilon}^{\alpha\beta} \right\rangle_i = \frac{1}{2}\left(\sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(v_j^\alpha - v_i^\alpha\right)\frac{\partial W_{ij}}{\partial x_i^\beta} + \sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(v_j^\beta - v_i^\beta\right)\frac{\partial W_{ij}}{\partial x_i^\alpha}\right) \quad \left\langle \dot{\omega}^{\alpha\beta} \right\rangle_i = \frac{1}{2}\left(\sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(v_j^\alpha - v_i^\alpha\right)\frac{\partial W_{ij}}{\partial x_i^\beta} - \sum_{j=1}^{N} \frac{m_j}{\rho_j}\left(v_j^\beta - v_i^\beta\right)\frac{\partial W_{ij}}{\partial x_i^\alpha}\right)$$

- We employ constitutive models to describe the stress-strain relationship.

- Implemented in DualSPHysics_v5.2

# Constitutive model

- We follows the classical elastic-plastic theory to capture the stress-strain relationship of the geomaterials.
  - Yield function $f$

    *Determines whether plastic deformation begin*

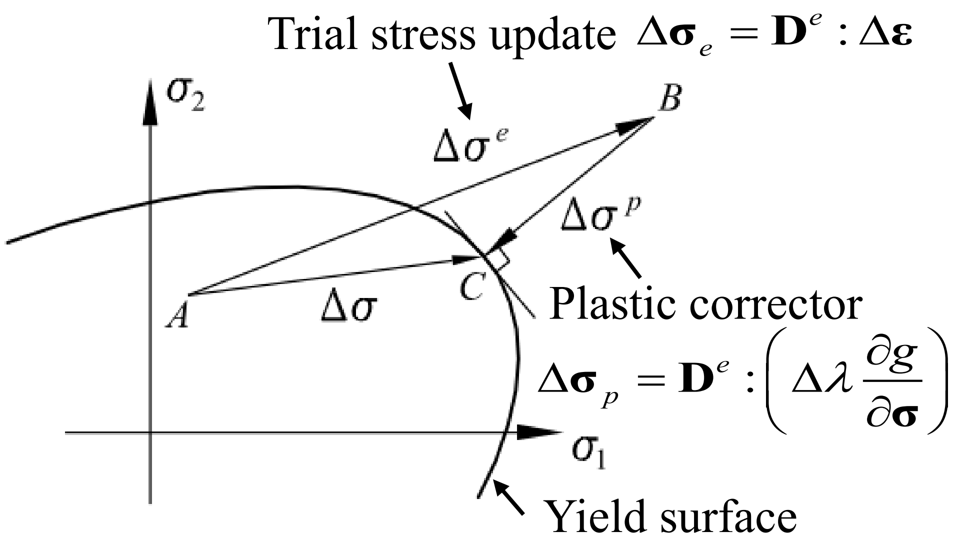
  - Plastic potential function $g$

    *Determines how the material deforms once yielding*

- In current implementation, the Drucker–Prager yield criterion is available, together with a non-associated flow rule.

$$f = \alpha_{\varphi} I_1 + \sqrt{J_2} - k_c, \; g = \alpha_{\psi} I_1 + \sqrt{J_2}.$$

where $I_1$ and $J_2$ are respectively the first principal stress invariant and the second deviatoric stress; $\alpha_{\varphi}$, $k_c$, and $\alpha_{\psi}$ are model constants related to cohesion $c$, internal friction angle $\varphi$, and dilation angle $\psi$.

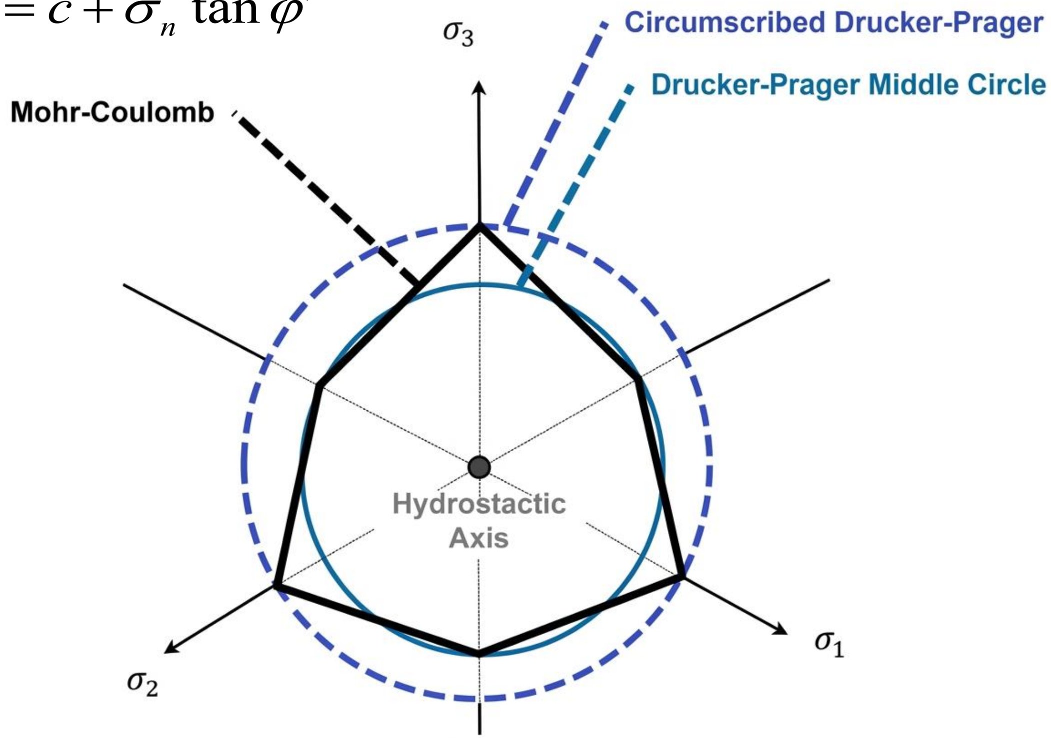



Principle of stress update

# Constitutive model

- Several options exist to describe classical Mohr–Coulomb yield surface that defines the shear strength i.e., cohesion and friction angle.

$$\tau = c + \sigma_n \tan\varphi'$$




1. Drucker–Prager yield surface circumscribes the Mohr–Coulomb yield surface in 3D;

$$\alpha_\varphi = \frac{2\sin\varphi'}{\sqrt{3}\left(3-\sin\varphi'\right)},\ k_c = \frac{6c\cos\varphi'}{\sqrt{3}\left(3-\sin\varphi'\right)},\ \alpha_\psi = \frac{2\sin\psi}{\sqrt{3}\left(3-\sin\psi\right)}.$$

2. Drucker–Prager yield surface middle circumscribes the Mohr–Coulomb yield surface in 3D;

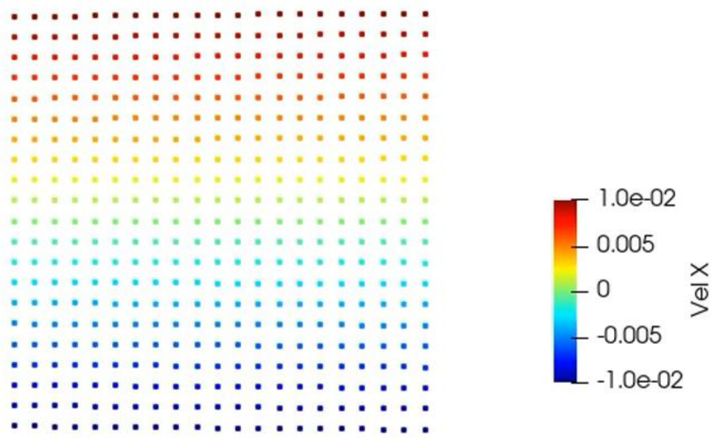
$$\alpha_\varphi = \frac{2\sin\varphi'}{\sqrt{3}\left(3+\sin\varphi'\right)},\ k_c = \frac{6c\cos\varphi'}{\sqrt{3}\left(3+\sin\varphi'\right)},\ \alpha_\psi = \frac{2\sin\psi}{\sqrt{3}\left(3+\sin\psi\right)}.$$

3. Plane strain version in 2D.

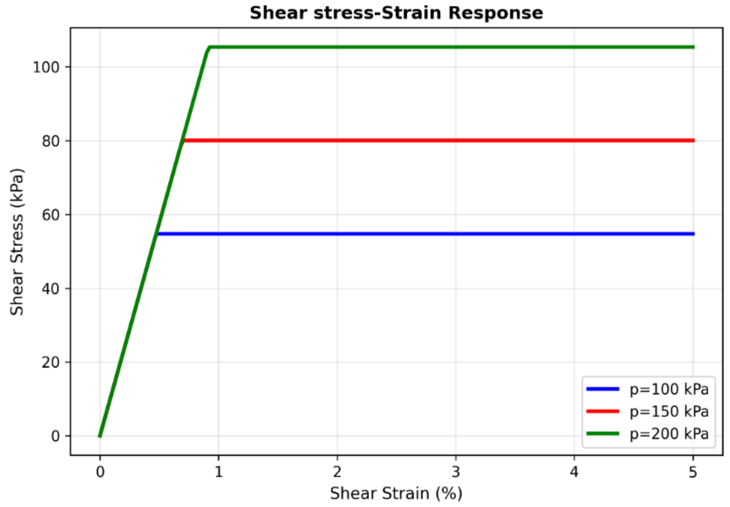
$$\alpha_\varphi = \frac{\tan\varphi'}{\sqrt{9+12\tan^2\varphi'}},k_c = \frac{3c}{\sqrt{9+12\tan^2\varphi'}},\alpha_\psi = \frac{\tan\psi}{\sqrt{\left(9+12\tan^2\psi\right)}}.$$

# Constitutive model

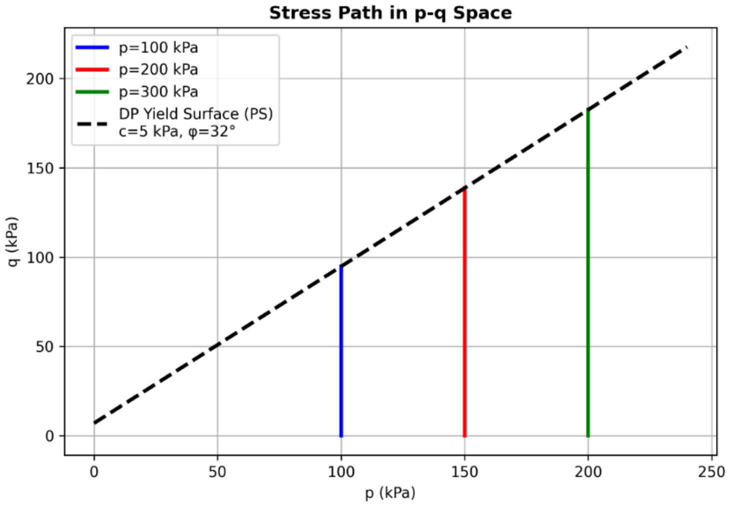
- Elastic-perfectly plastic
  - Elastic (Young's modulus, Poisson ratio); Plastic (Cohesion, Friction angle).
  - When the stress state reaches the yield criterion, plastic deformation develops.
  - No plastic volume change involves.




Pure shear test

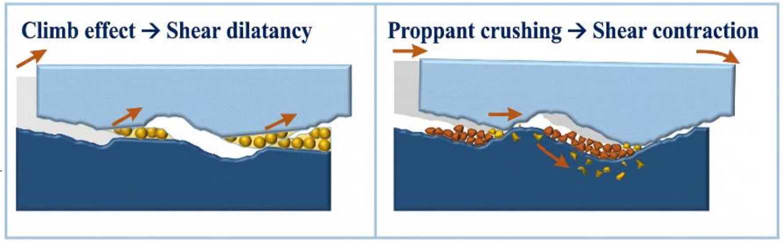



Pressure-dependence




Stress state remains after yield

# Constitutive model



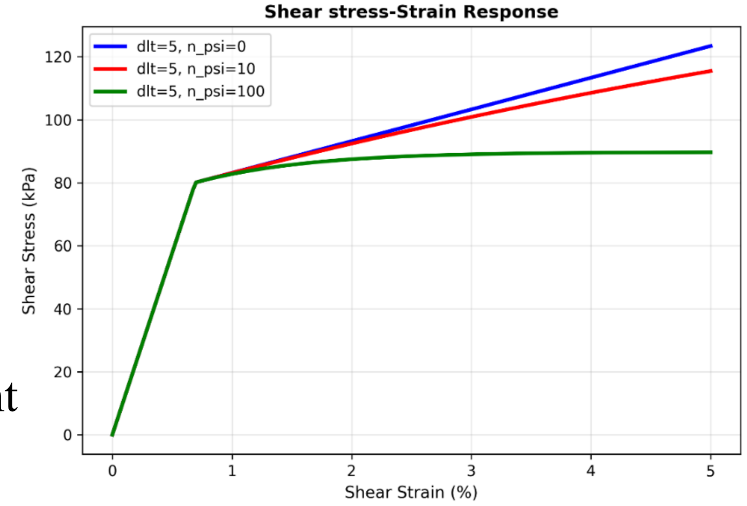

- Dilation
  - Geomaterials dilate (bulk up) or contract during shearing because grains rotate and climb over, or slide past, neighbouring grains.
  - Volume change is not unlimited, as shearing continues, the material reaches a “critical state" density.
- Strain-softening
  - In addition, as the geomaterial yields, the internal structure degrades (cementation breaks, grains align), resulting in the reduction of shear strength.

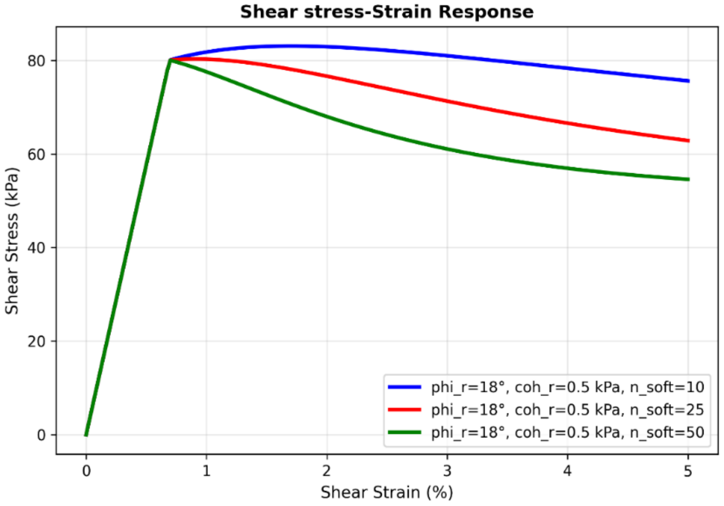
$$\psi = \psi_p \exp\left(-\eta_\psi \varepsilon_d^p\right),$$

$$c' = c_r' + \left(c_p' - c_r'\right)\exp\left(-\eta \varepsilon_d^p\right),$$

$$\varphi' = \varphi_r' + \left(\varphi_p' - \varphi_r'\right)\exp\left(-\eta \varepsilon_d^p\right).$$

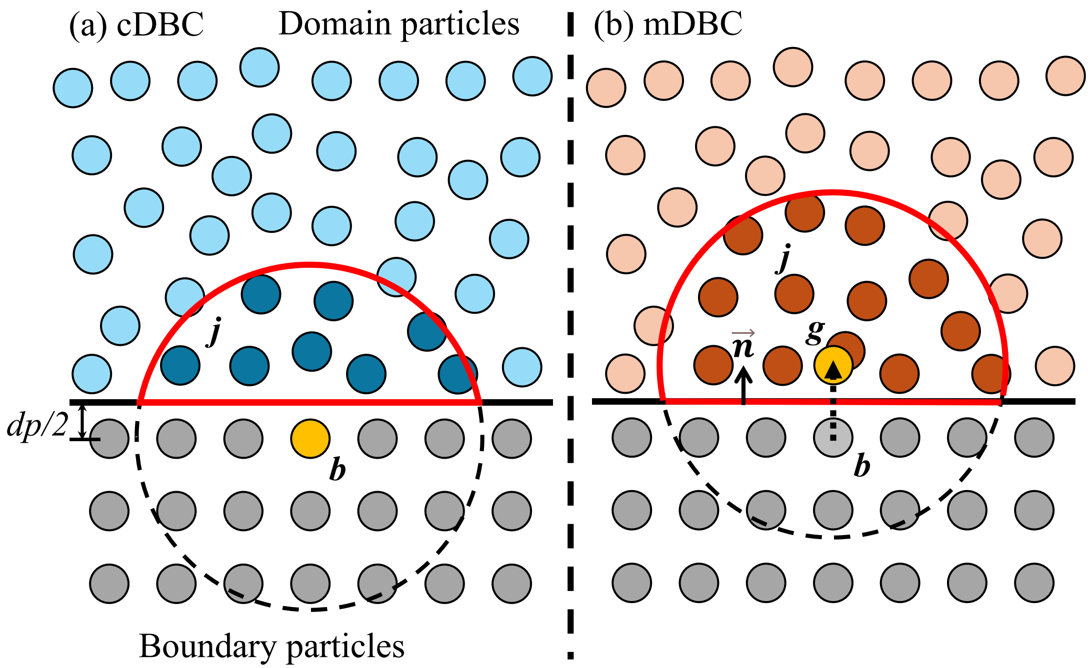
Assumes exponentially decrease with equivalent plastic strain, $\varepsilon_d^p$, (Bui and Nguyen, 2021, CG)



# Boundary treatment

- Consistent with the fluid solver, we include two options for boundary treatment. 1. cDBC (corrected dummy boundary condition), which is based the local interpolation; 2. mDBC, the extension of fluid mDBC method for geomechanics modelling.




Easy and quick

Need boundary normal initialisation but more accurate

In the mDBC extension,

$$\sigma_b^{\alpha\beta} = \sigma_g^{\alpha\beta} + (x_b - x_g)\partial_x \sigma_g^{\alpha\beta} + (y_b - y_g)\partial_y \sigma_g^{\alpha\beta} + (z_b - z_g)\partial_z \sigma_g^{\alpha\beta}$$

$$\mathbf{A}_g \cdot \begin{bmatrix} \sigma_g^{\alpha\beta} \\ \partial_x \sigma_g^{\alpha\beta} \\ \partial_y \sigma_g^{\alpha\beta} \\ \partial_z \sigma_g^{\alpha\beta} \end{bmatrix} = \begin{bmatrix} \sum_j \sigma_j^{\alpha\beta} W_{gj} V_j \\ \sum_j \sigma_j^{\alpha\beta} \partial_x W_{gj} V_j \\ \sum_j \sigma_j^{\alpha\beta} \partial_y W_{gj} V_j \\ \sum_j \sigma_j^{\alpha\beta} \partial_z W_{gj} V_j \end{bmatrix}$$

$$\mathbf{A}_g = \begin{bmatrix} \sum_j W_{gj} V_j & \sum_j (x_j - x_g) W_{gj} V_j & \sum_j (y_j - y_g) W_{gj} V_j & \sum_j (z_j - z_g) W_{gj} V_j \\ \sum_j \partial_x W_{gj} V_j & \sum_j (x_j - x_g) \partial_x W_{gj} V_j & \sum_j (y_j - y_g) \partial_x W_{gj} V_j & \sum_j (z_j - z_g) \partial_x W_{gj} V_j \\ \sum_j \partial_y W_{gj} V_j & \sum_j (x_j - x_g) \partial_y W_{gj} V_j & \sum_j (y_j - y_g) \partial_y W_{gj} V_j & \sum_j (z_j - z_g) \partial_y W_{gj} V_j \\ \sum_j \partial_z W_{gj} V_j & \sum_j (x_j - x_g) \partial_z W_{gj} V_j & \sum_j (y_j - y_g) \partial_z W_{gj} V_j & \sum_j (z_j - z_g) \partial_z W_{gj} V_j \end{bmatrix}$$

In cDBC, the first-order consistent interpolation is also used but we do it locally at boundary particle and without gradients

# Case setup in XML

- Three main XML setup for running geomechanics modelling

```xml
            <mainlist>
                <!-- Actual geometry at dp/2 -->
                <runlist name="GeometryForNormals" />
                <!-- Boundary particles -->
                <setdrawmode mode="full" />
                <setmkbound mk="0" />
                <setshapemode>actual | dp | bound</setshapemode>
                <setmkbound mk="0" />
                <setdrawmode mode="face" />
                <setfrdrawmode auto="false" />
                <drawcylinder radius="#r0*4.0" mask="14">
                    <layers vdp="0,1,2,3" />
                    <point x="0.0" y="0.0" z="0" />
                    <point x="0.0" y="0.0" z="#h0*2.0" />
                </drawcylinder>
                <!-- Soil particles -->
                <setmkfluid mk="0" />
                <setdrawmode mode="full" />
                <setfrdrawmode auto="false" />
                <drawcylinder radius="#r0" objname="Cylinder">
                    <point x="0.0" y="0.0" z="#Dp" />
                    <point x="0.0" y="0.0" z="#h0" />
                </drawcylinder>
                <setfrdrawmode auto="false" />
                <shapeout file="" />
            </mainlist>
        </commands>
    </geometry>
</casedef>
<execution>
    <special>
        <geomech>
            <phi value="35" comment="friction angle" units_comment="deg" />
            <coh value="0e3" comment="cohesion"  units_comment="Pa" />
            <ModulusE value="15e6" comment="elastic modulus" units_comment="Pa" />
            <PRvs value="0.3" comment="possion ratio"  units_comment="-"  />
        </geomech>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="DPCtes" value="2" comment="DP constants type 1:3D DP circumscribed, 2:3D mid circumscribes, 3:2D Plane strain
        <parameter key="Boundary" value="1" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
```

Geometry definition

Material properties definition

Selection of constitutive model constants

Selection of boundary treatment

# Case setup in XML

- Other options available

```xml
<special>
    <geomech>
        ...
        <dlt value="2" comment="dilation angle" units_comment="deg" />
        <phi_r value="18" comment="residual friction angle" units_comment="deg" />
        <coh_r value="0.5e3" comment="residual cohesion" units_comment="Pa"/>
        <n_soft value="5" comment="strength softening" units_comment="-"/>
        <n_psi value="5" comment="dilation angle decay rate" units_comment="-"/>
    </geomech>
</special>
```

The following tags define the parameters of the strain softening/hardening properties of the materials.

**< dlt />** : The tag defines the dilation angle that describes the material's tendency to expand (dilate) during plastic shearing.

**<phi_r />** : The tag defines residual value of friction angle. This is the lower limit that the friction angle will drop to after the material has undergone significant shearing.

**<coh_r/>** : The tag defines residual value of cohesion. This is the lower limit that the cohesion will drop to after the material has undergone significant shearing.

**<n_soft />** : The tag defines the rate of decrease of strength parameters as the plastic strain accumulates. It determines the speed at which the material weakens. A higher value implies a more brittle failure (rapid drop to residual strength), while a lower value implies a more gradual loss of strength.

**<n_psi />** : The tag defines the decay rate of dilation as the plastic strain accumulates. It determines how fast the dilatancy disappears.

# Case setup in XML

- Other options available

```
<parameter key="DensityDT" value="3" comment="Noise-free treatment 0:None, 1:Molteni, 2:Fourtakas, 3:Fourtakas(full) (default=0)" />
<parameter key="DensityDTvalue" value="0.1" comment="DDT value (default=0.1)" />
<parameter key="Shifting" value="3" comment="Shifting mode 0:None, 1:Ignore bound, 2:Ignore fixed, 3:Full (default=0)" />
<parameter key="ShiftCoef" value="-2" comment="Coefficient for shifting computation (default=-2)" />
<parameter key="ShiftTFS" value="2.75" comment="Threshold to detect free surface. Typically 1.5 for 2D and 2.75 for 3D (default=0)" />
```

The following tags define the stabilisation techniques to be used in the tag <**parameters/**> of the XML.

<**DensityDT/**> : The tag defines the diffusion technique to smooth the stress profile. Option 1 construct the diffusion term from the local stress difference, and Option 2, 3 applies diffusion only to the dynamic component of the stress difference. Option 2 is applied to particles that do not interact with boundaries, while Option 3 is applied to all the particles.

<**Shifting/**> : The tag defines the shifting technique to regularize the particle distributions. This technique is commonly not necessary for cohesionless material simulation but important for cohesive material modelling due to the presence of particle clustering. The formulation of the shifting technique is the same as that of the fluid solver.

# Case setup in XML

- Other options available
  - Forces gauges (adapted for the formulation using stress tensor, XML settings are the same as original)

```
<gauges>
    <default>
        <savevtkpart value="false" comment="Creates VTK files for each PART (default=false)" />
        <computedt value="0.05" comment="Time between measurements. 0:all steps (default=TimeOut)" units_comment="s" />
        <_computetime start="0.1" end="0.2" comment="Start and end of measures. (default=simulation time)" units_comment="s" />
        <output value="true" comment="Creates CSV files of measurements (default=false)" />
        <outputdt value="0" comment="Time between output measurements. 0:all steps (default=TimeOut)" units_comment="s" />
        <outputtime start="0" end="10" comment="Start and end of output measures. (default=simulation time)" units_comment="s" />
    </default>
    <force name="Force1">
        <target mkbound="1" comment="indicate the mkbound to calculate forces" />
    </force>
</gauges>
```

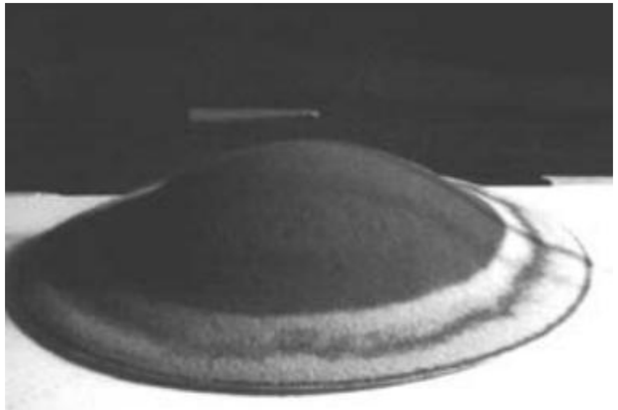
  - Chrono (adapted for the formulation using stress tensor, XML settings are the same as original)

```
<chrono>
    <_savedata value="0.01" comment="Saves CSV with data exchange for each time interval (0=all steps)" />
    <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />
    <collision activate="true">
        <distancedp value="0.1" comment="Allowed collision overlap according Dp (default=0.5)" />
        <contactmethod value="0" comment="Contact method type. 0:NSC (Non Smooth Contacts), 1:SMC (SMooth Contacts).
    </collision>
    <_bodyfloating id="block" mkbound="11-34" modelfile="AutoActual" />
    <_bodyfloating id="block" mkbound="11-106" modelfile="AutoActual" />
    <_bodyfloating id="block" mkbound="11-226" modelfile="AutoActual" />
    <_bodyfloating id="block" mkbound="11-394" modelfile="AutoActual" />
    <bodyfloating id="block" mkbound="$[ftmkbrange]" modelfile="AutoActual" />
    <bodyfixed id="tank" mkbound="0" modelfile="AutoActual" modelnormal="invert" />
</chrono>
```

# XML Examples

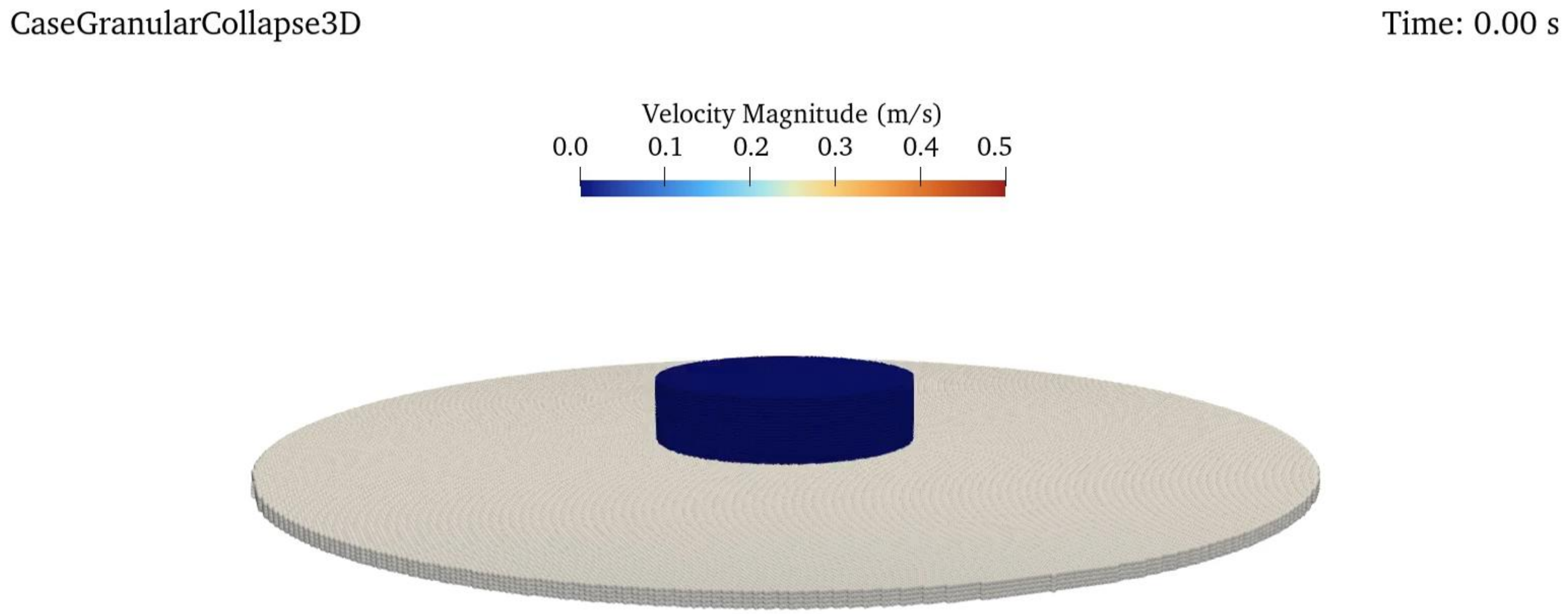
- CaseGranularCollapes3D
  - Example with the basic case set up.

```
        <mainlist>
            <!-- Actual geometry at dp/2 -->
            <runlist name="GeometryForNormals" />
            <!-- Boundary particles -->
            <setdrawmode mode="full" />
            <setmkbound mk="0" />
            <setshapemode>actual | dp | bound</setshapemode>
            <setmkbound mk="0" />
            <setdrawmode mode="face" />
            <setfrdrawmode auto="false" />
            <drawcylinder radius="#r0*4.0" mask="14">
                <layers vdp="0,1,2,3" />
                <point x="0.0" y="0.0" z="0" />
                <point x="0.0" y="0.0" z="#h0*2.0" />
            </drawcylinder>
            <!-- Soil particles -->
            <setmkfluid mk="0" />
            <setdrawmode mode="full" />
            <setfrdrawmode auto="false" />
            <drawcylinder radius="#r0" objname="Cylinder">
                <point x="0.0" y="0.0" z="#Dp" />
                <point x="0.0" y="0.0" z="#h0" />
            </drawcylinder>
            <setfrdrawmode auto="false" />
            <shapeout file="" />
        </mainlist>
    </commands>
  </geometry>
</casedef>
<execution>
    <special>
        <geomech>
            <phi value="35" comment="friction angle" units_comment="deg" />
            <coh value="0e3" comment="cohesion"  units_comment="Pa" />
            <ModulusE value="15e6" comment="elastic modulus" units_comment="Pa" />
            <PRvs value="0.3" comment="possion ratio"  units_comment="-"  />
        </geomech>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="DPCtes" value="2" comment="DP constants type 1:3D DP circumscribed, 2:3D mid circumscribes, 3:2D Plane strain
        <parameter key="Boundary" value="1" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
```



(Lube et al., 2004, JFM)

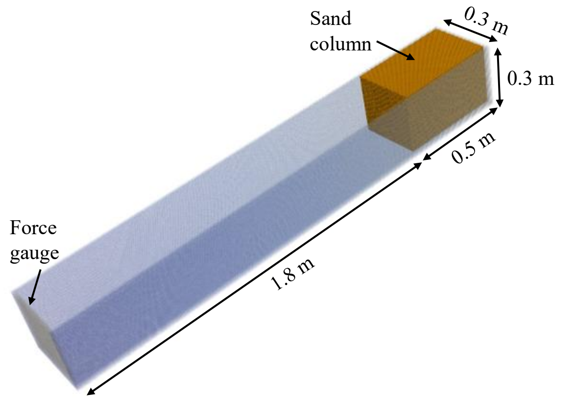
# XML Examples




Particles: 425,064
Physical time: 0.5 s
Runtime (RTX 4090): 28 s

# XML Examples

- CaseImpactForces3D
  - Example for adopting the force gauge to measure the impact force time series during simulation



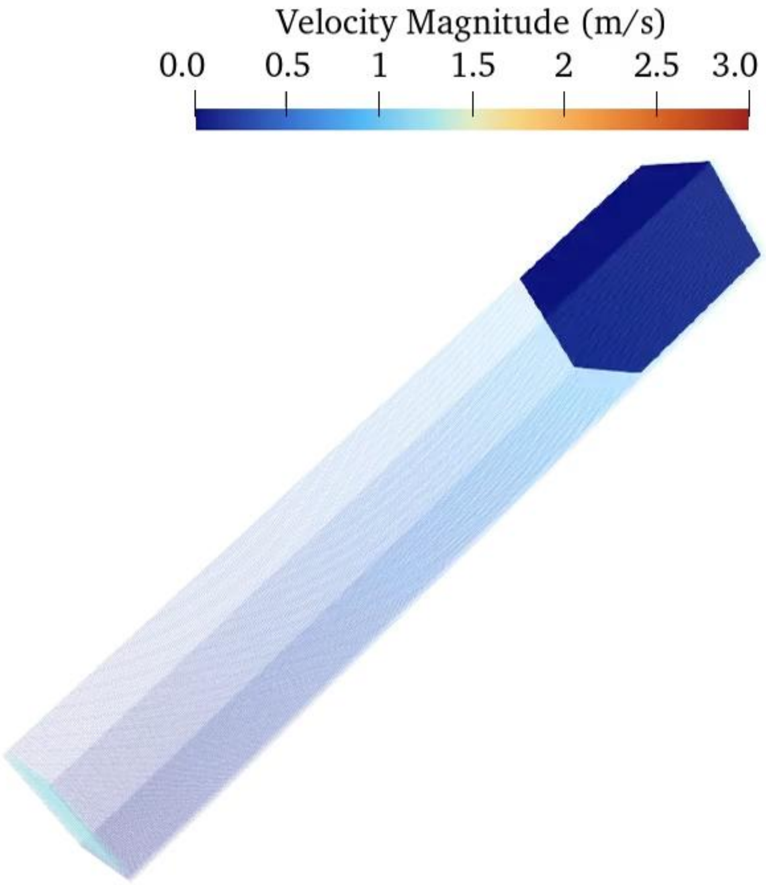

(Moriguchi et al., Acta Geotech. 2009)

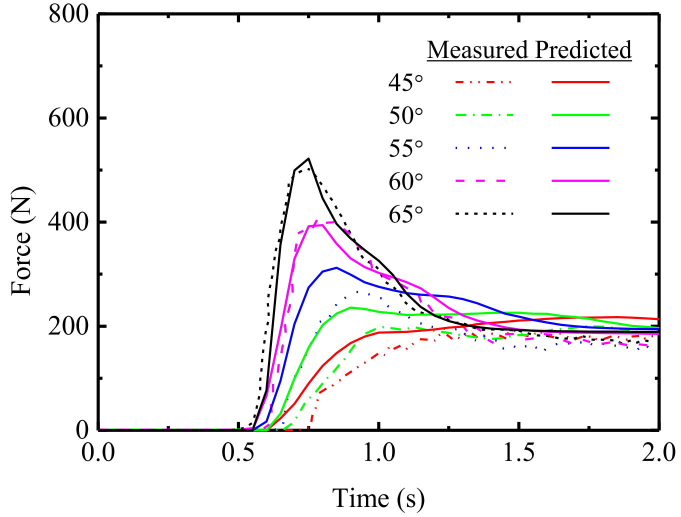
```xml
<execution>
    <special>
        <geomech>
            <phi value="35" comment="friction angle" />
            <coh value="0e3" comment="cohesion" />
            <ModulusE value="21.6e6" comment="elastic modulus" />
            <PRvs value="0.3" comment="possion ratio" />
        </geomech>
        <gauges>
            <default>
                <savevtkpart value="false" comment="Creates VTK files for each PART (default=false)" />
                <computedt value="0.05" comment="Time between measurements. 0:all steps (default=TimeOut)" units_comment="s" />
                <_computetime start="0.1" end="0.2" comment="Start and end of measures. (default=simulation time)" units_comment="s"
                <output value="true" comment="Creates CSV files of measurements (default=false)" />
                <outputdt value="0" comment="Time between output measurements. 0:all steps (default=TimeOut)" units_comment="s" />
                <outputtime start="0" end="10" comment="Start and end of output measures. (default=simulation time)" units_comment="s
            </default>
            <force name="Force1">
                <target mkbound="1" comment="indicate the mkbound to calculate forces" />
            </force>
        </gauges>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="DPCtes" value="2" comment="DP constants type 1:3D DP circumscribed, 2:3D mid circumscribes, 3:2D Plane strain
        <parameter key="Boundary" value="1" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
```

# XML Examples

CaseImapctForces3D

Time: 0.00 s



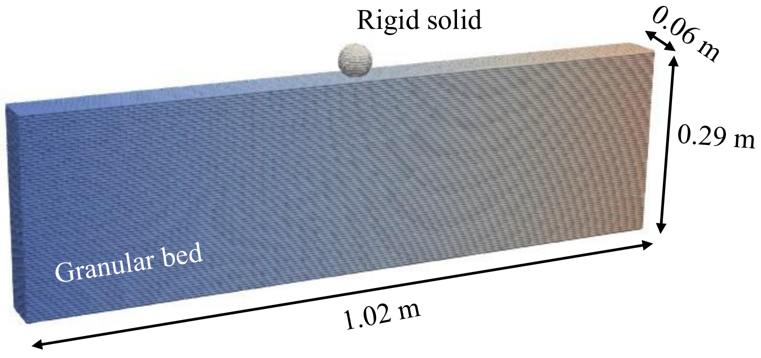




Particles: 633,315
Physical time: 2 s
Runtime (RTX 4090): 8.2 mins

# XML Examples

- CaseBallDrop3D
  - Example for moving solid impacting granular beds

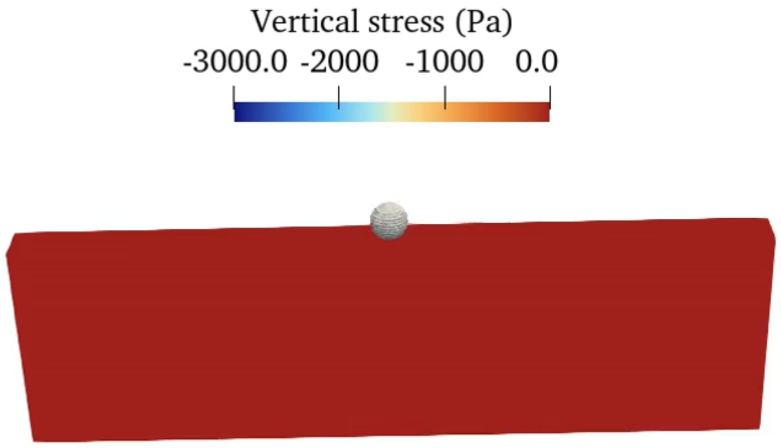
```xml
    <floatings>
        <floating mkbound="1" property="steel">
            <massbody value="0.3646" />
            <linearvelini x="0" y="0" z="#vel0"/>
        </floating>
    </floatings>
    <properties>
        <propertyfile file="Floating_Materials.xml" path="materials" />
        <links>
            <link mkbound="1" property="steel" comment="Property for the tank" />
        </links>
    </properties>
</casedef>
<execution>
    <special>
        <geomech>
            <phi value="16" comment="friction angle" />
            <coh value="0e3" comment="cohesion" />
            <dlt value="0" comment="dilatancy angle" />
            <ModulusE value="1.3e6" comment="elastic modulus" />
            <PRvs value="0.2" comment="possion ratio" />
        </geomech>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="Boundary" value="1" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
        <parameter key="SlipMode" value="1" comment="Slip mode for mDBC 1:DBC vel=0, 2:No-slip (default=1)" />
```




(Pica Ciamarra et al. 2004, PRL)

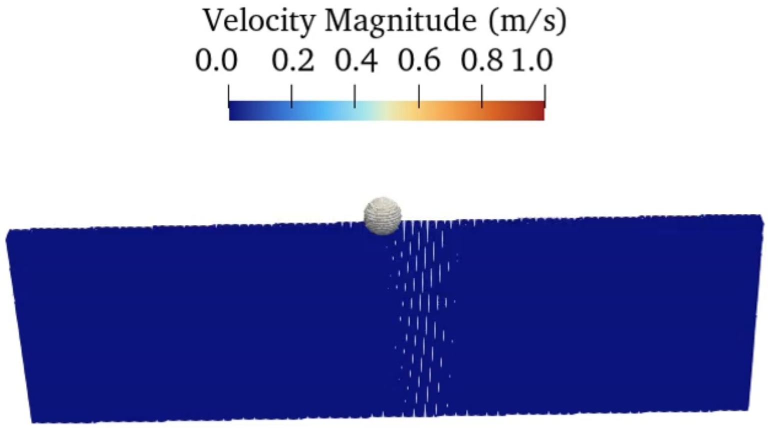
# XML Examples

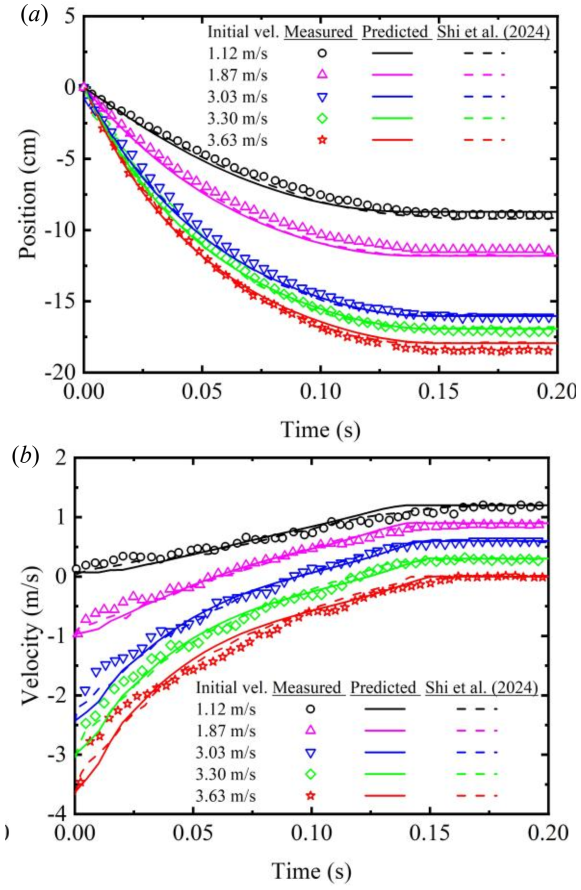
CaseBallDrop3D




Particles: 444,893
Physical time: 0.2 s
Runtime (RTX 4090): 69 s

Time: 0.000 s



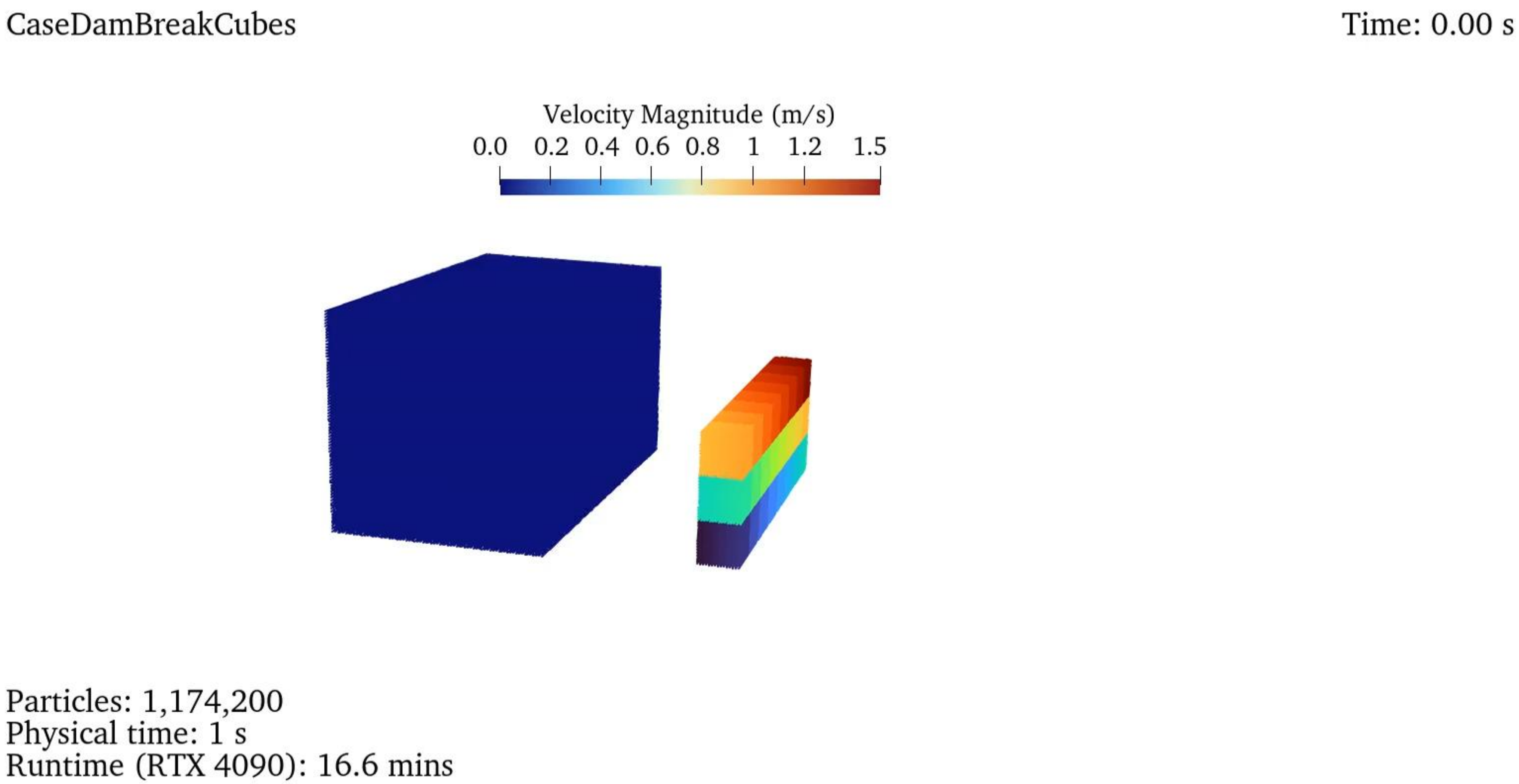



# XML Examples

- CaseDamBreakCubes
  - Example for geo-multibody interactions using the coupling with Chrono

```
<execution>
    <special>
        <chrono>
            <_savedata value="0.01" comment="Saves CSV with data exchange for each time interval (0=all steps)" />
            <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />
            <collision activate="true">
                <distancedp value="0.1" comment="Allowed collision overlap according Dp (default=0.5)" />
                <contactmethod value="0" comment="Contact method type. 0:NSC (Non Smooth Contacts), 1:SMC (SMooth Contacts). (default=
            </collision>
            <_bodyfloating id="block" mkbound="11-34" modelfile="AutoActual" />
            <_bodyfloating id="block" mkbound="11-106" modelfile="AutoActual" />
            <_bodyfloating id="block" mkbound="11-226" modelfile="AutoActual" />
            <_bodyfloating id="block" mkbound="11-394" modelfile="AutoActual" />
            <bodyfloating id="block" mkbound="$[ftmkbrange]" modelfile="AutoActual" />
            <bodyfixed id="tank" mkbound="0" modelfile="AutoActual" modelnormal="invert" />
        </chrono>
        <geomech>
            <phi value="25" comment="friction angle" />
            <coh value="0e3" comment="cohesion" />
            <dlt value="0" comment="dilation angle" />
            <ModulusE value="15e6" comment="elastic modulus" />
            <PRvs value="0.3" comment="possion ratio" />
        </geomech>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="DPCtes" value="2" comment="DP constants type 1:3D DP circumscribed, 2:3D mid circumscribes, 3:2D Plane strain
        <parameter key="Boundary" value="1" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
```

# XML Examples



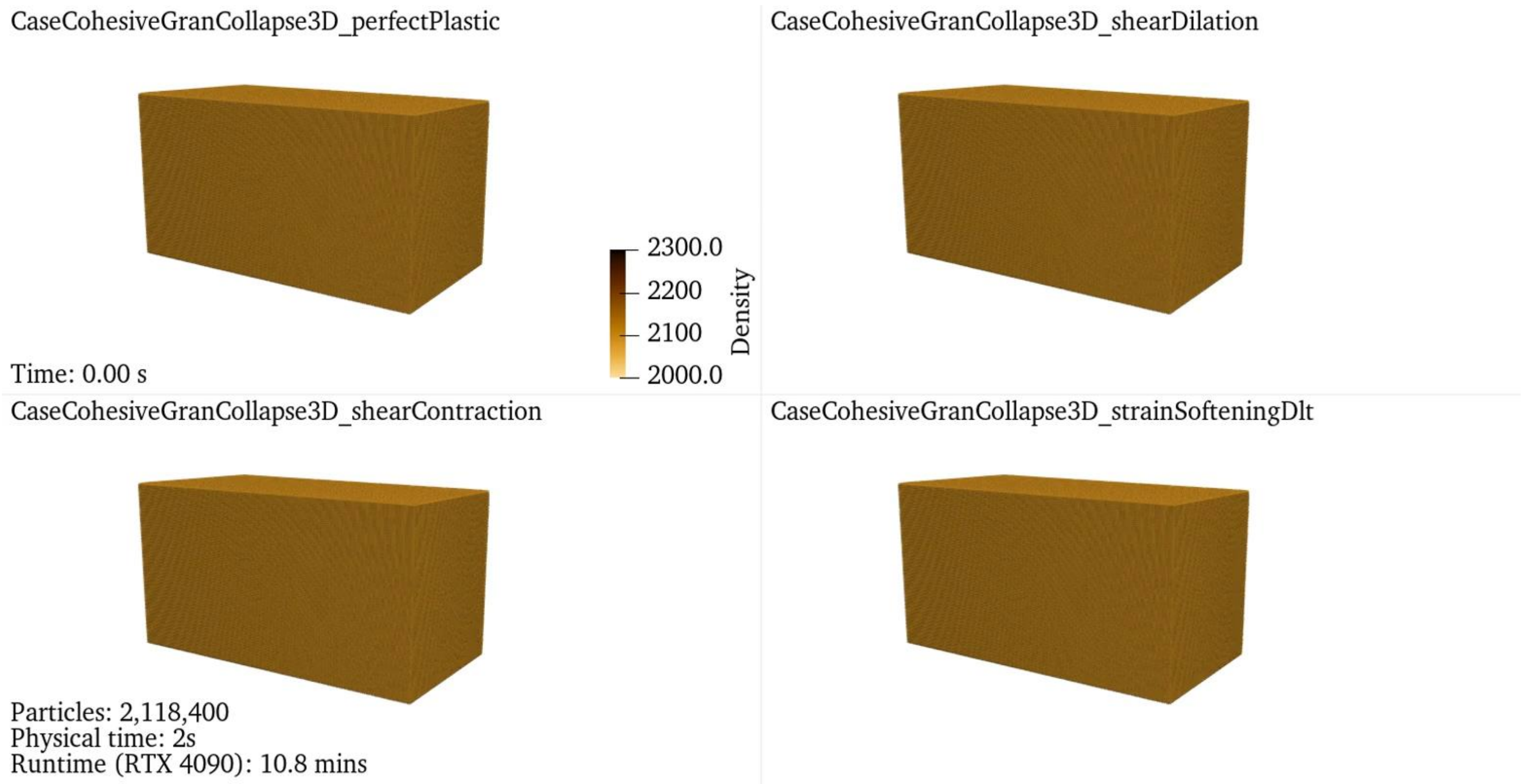
# XML Examples

- CaseCohesiveGranCollapse
  - Example for testing constitutive parameters.
  - 4 cases available for perfectly plastic, shear dilation, shear contraction, and strain softening.
  - Shifting is applied for the cohesive material modelling.

// This is one example of them for strain softening

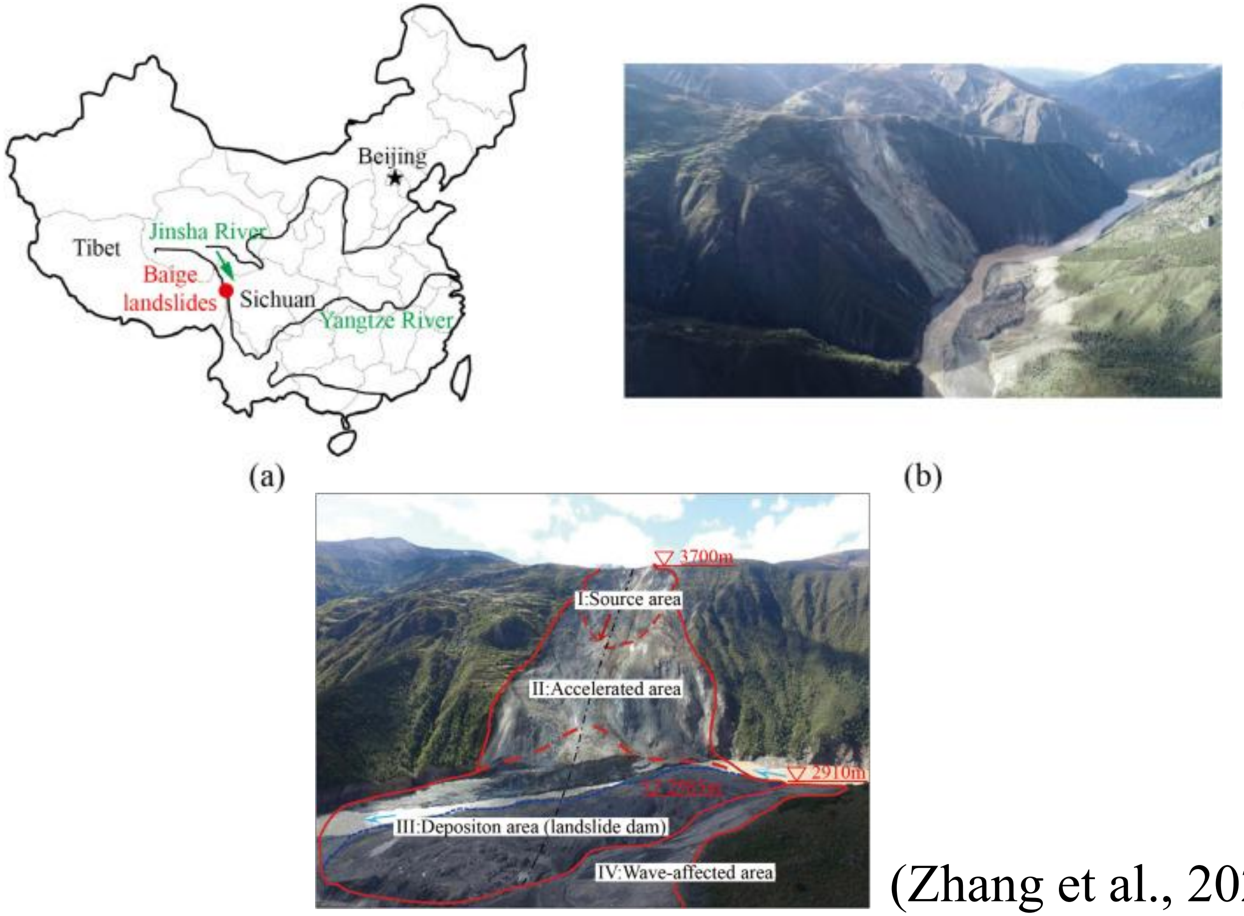
```
<execution>
    <special>
        <geomech>
            <phi value="25" comment="friction angle" />
            <coh value="5e3" comment="cohesion" />
            <dlt value="5" comment="dilation angle" />
            <ModulusE value="10e6" comment="elastic modulus" />
            <PRvs value="0.3" comment="possion ratio" />
            <phi_r value="15" comment="residual friction angle" />
            <coh_r value="0.5e3" comment="residual cohesion" />
            <n_soft value="5" comment="strength softening" />
            <n_psi value="5" comment="dilation angle decay rate" />
        </geomech>
    </special>
    <parameters>
        <parameter key="SavePosDouble" value="0" comment="Saves particle position using double precision (default=0)" />
        <parameter key="DPCtes" value="2" comment="DP constants type 1:3D DP circumscribed, 2:3D mid circumscribes, 3:2D Plane strain
        <parameter key="Boundary" value="2" comment="Boundary method 1:cDBC, 2:mDBC (default=1)" />
```

# XML Examples



# Applications

- Landslides simulation
  - Applicability to realistic terrains and large-scale landslide simulation.

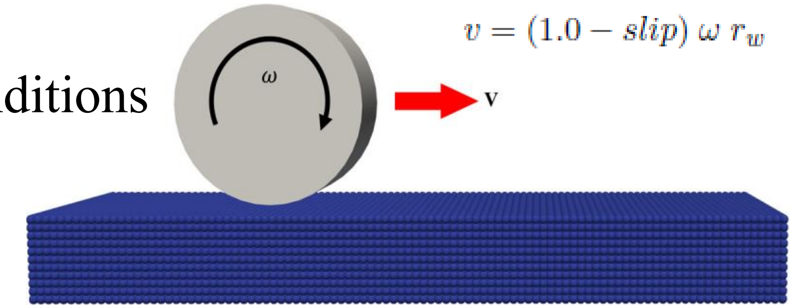



(Zhang et al., 2023, CG)

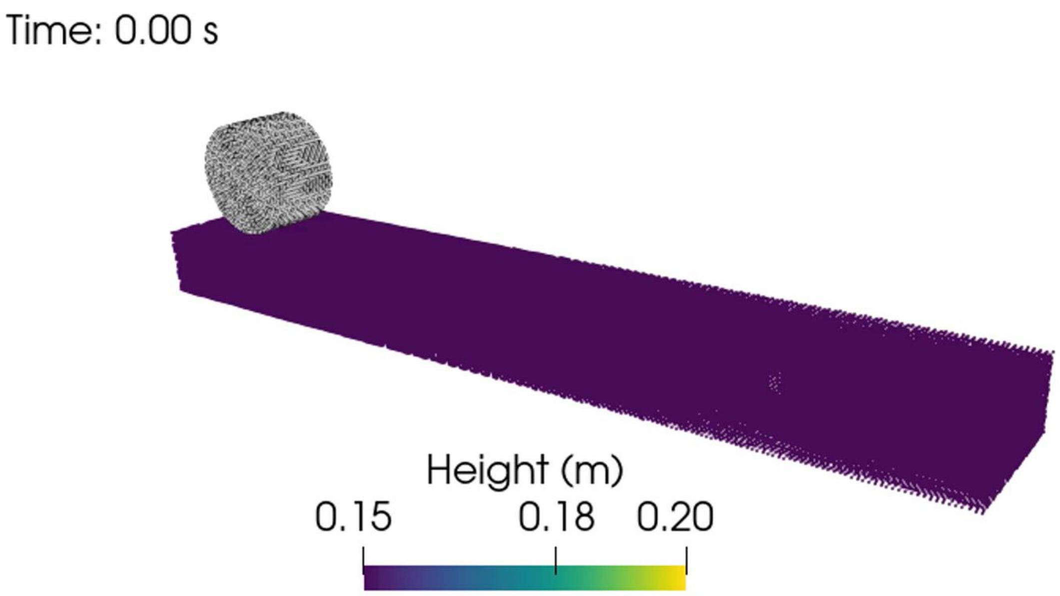

Baige landslide

# Applications

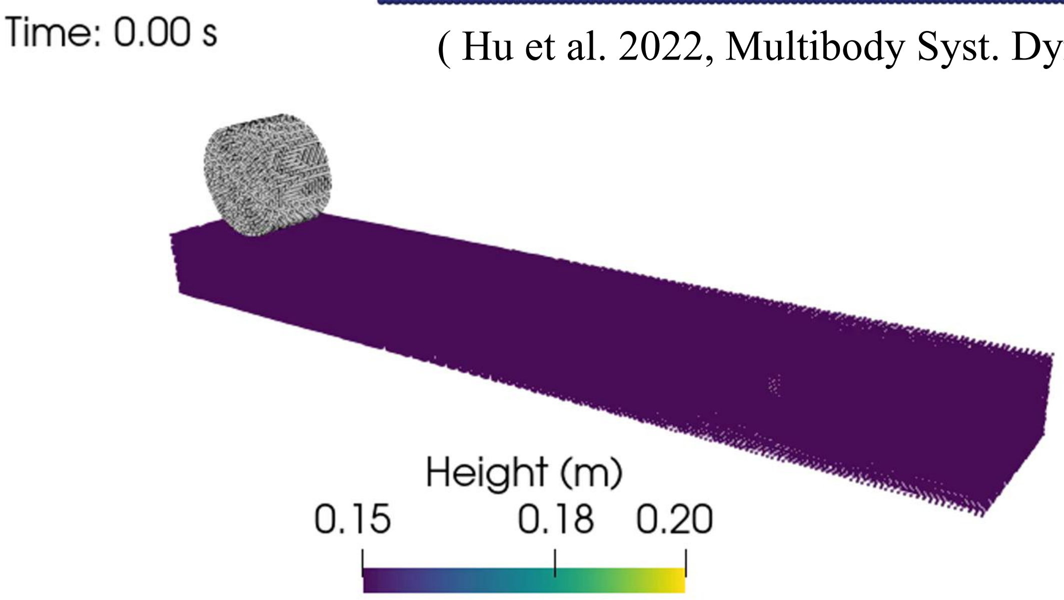
- Wheel-terrains interaction
  - Wheel's motion under controlled slip and normal loading conditions




( Hu et al. 2022, Multibody Syst. Dyn.)



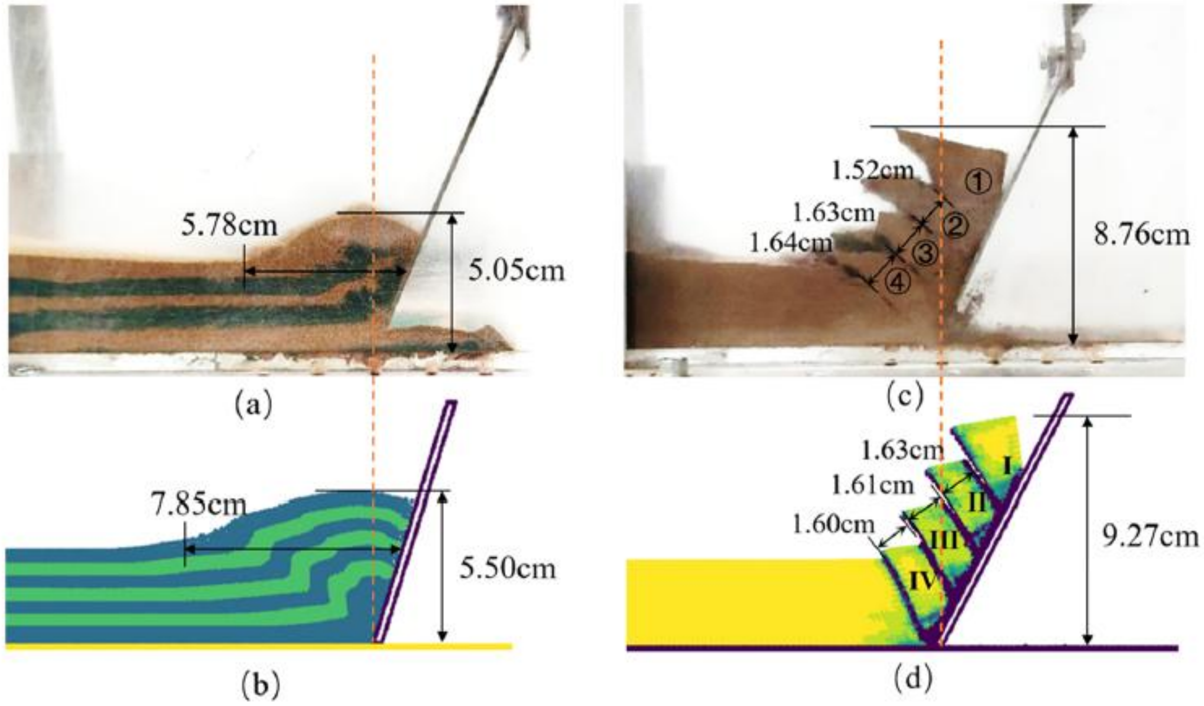

Slip ratio = 0.7



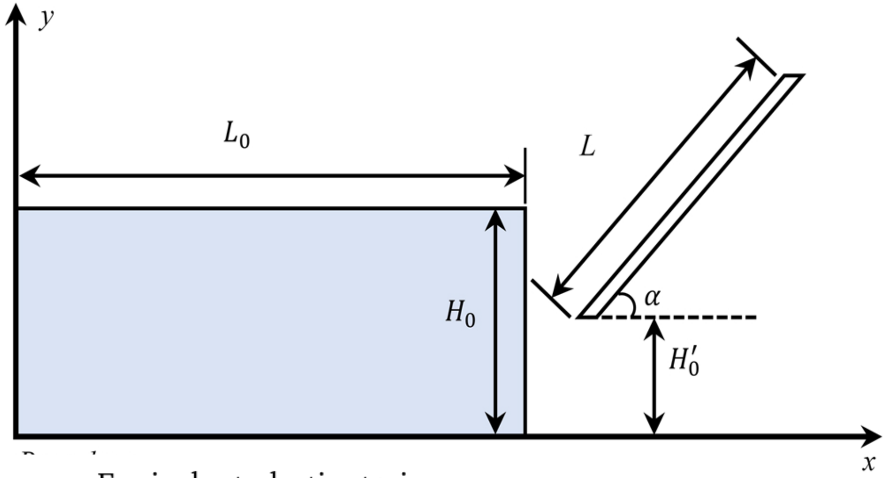

Slip ratio = -0.7

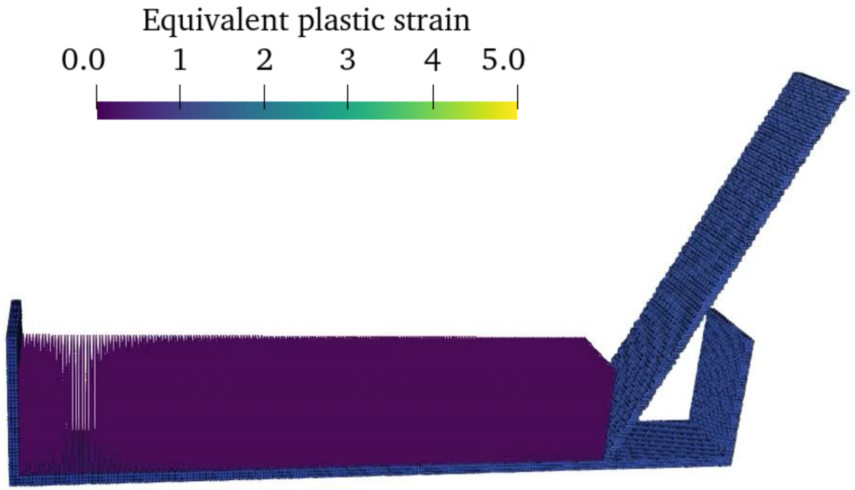
# Applications

- Soil cutting process
  - Estimate the cutting force during the tillage process.
  - Optimized design for soil-engaging tools.



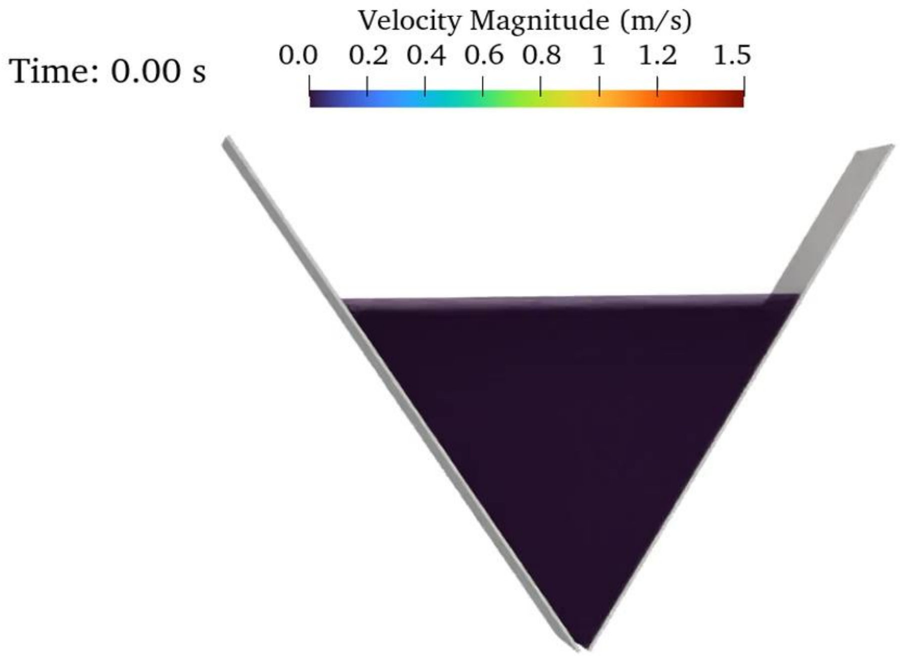

(Hu et al., 2023, Soil Till Res )

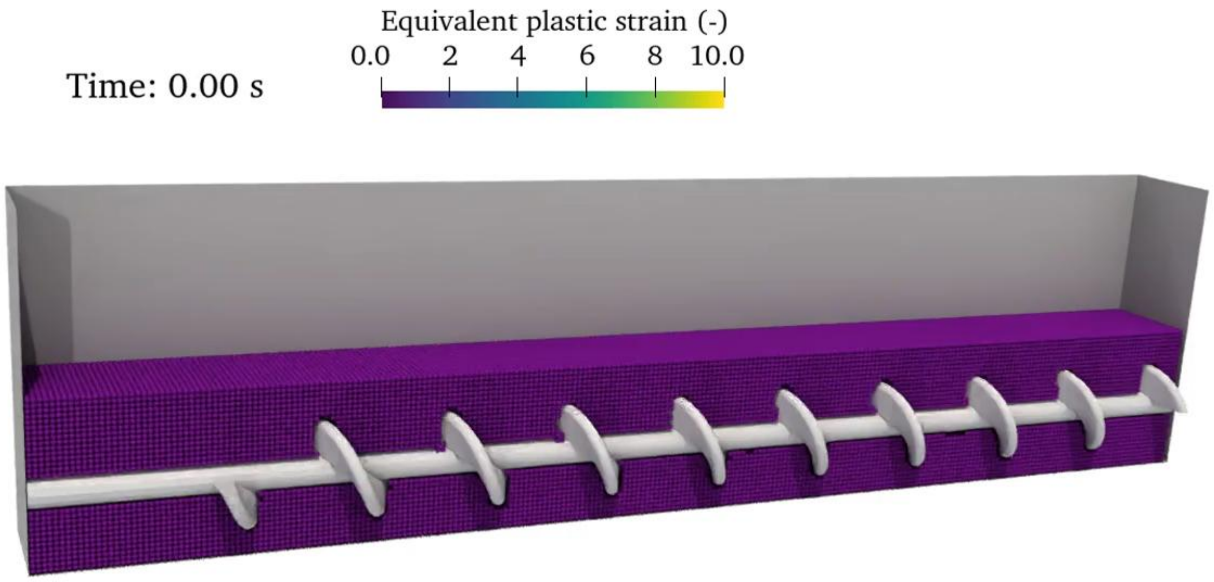


# Applications

- Granular handling
  - Example demonstrations of hopper flow and screw conveyors.




(Zhao et al., 2024, ACS Sustain. Chem. Eng.)

# Conclusions

- New geomechanics module has been developed in DualSPHysics for the simulation of large deformations of geomaterials.
  - The constitutive behaviour follows the elastic-plastic theory with strain-softening model.
- The coupling with Project Chrono is enabled for geo-multibody interactions.
- Force gauge option is available to measure the impact force time series during the simulation.
- Two boundary treatment are implemented for the interaction with solid boundary or rigid bodies:
  - cDBC (based on local interpolations and boundary normal is not needed).
  - mDBC (extension of the fluid mDBC method and the initialisation of boundary normal is needed).
- Stabilisation techniques includes the numerical diffusion term and particle shifting.
  - Shifting will be important for cohesive material modelling.

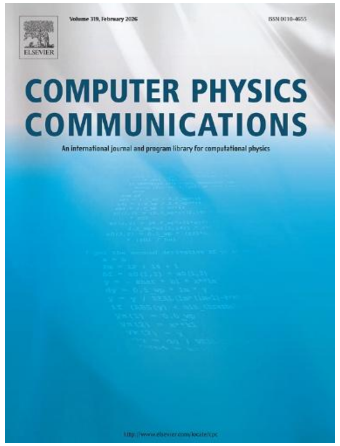
# Work in progress

- More constitutive models
  - Mohr-coulomb model, Cam-clay model, and other advanced models ….
- Coupled flow-deformation in porous materials (see Feng et al., 2024, CMAME).
  - Allows the resolution of pore water flow within the materials.
- Integrates geomech module with hydro module.

# Reference & Acknowledgement

For more details, please refer to:

Feng, R., Zhao, J., Fourtakas, G., & Rogers, B.D. (2026). GeoDualSPHysics: a high-performance SPH solver for large deformation modelling of geomaterials with two-way coupling to multi-body systems. *Computer Physics Communications*, 320, 109965.

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