Geomaterial Model Parameters: Challenges

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Agenda

• Geomaterials
• Numerical Models (*Constitutive and MicroMechanics*)
• Experimental Evidences
• Micro-parameters
• Phenomenological parameters
• Conclusions.
Geomaterials

- Geomaterials: is composed of individual grains that vary in shape, size, roughness and stiffness.

- Unfortunately, soils are made by nature and not by man and the products of nature are always complex

- Never uniform. Its properties change from point to point while our knowledge of its properties is limited to those few spots at which the samples have been collected.

- Furthermore, its properties are too complicated for rigorous theory, and approximate mathematical solutions are difficult for even most common problems.

- In soil mechanics the accuracy of computed results never exceeds that of a crude estimate, and field observations are essential.
Numerical Models

Macroscopic level

- Stress
- Strain

Constitutive relation

Microscopic level (contact)

- Force
- Relative displacement

Micromechanics

Caterpillar Non-Confidential
Numerical Models

Constitutive Models

\[ \mathbf{k} \Delta \mathbf{u} = \Phi \]

\[ \{ \dot{\sigma} \} = [\mathbf{D}]\{ \dot{\gamma} \} \]

Micro-mechanics

\[ \mathbf{M}_i \ddot{\mathbf{x}}_i = \mathbf{f}_i + g_i \]

No particle rotation:

\[ s_{ij} = k_{ij} n_j - k_{ij} \dot{f}_j \]

\[ f_u = k_u N_u \]

\[ f_i = k_i \dot{N}_i \]

Macro response

Micro Structure
Micro Structural Properties

- Moisture content
- Local void ratio
- Coeff of friction
- Size
- Surface roughness
- Shape
- Stiffness
- Physico-Chemical Forces
Shape

- Shape of individual grain will influence how soil mass is assembled.

- Interlocking and angular friction is essentially decided by shape and packing.
Particle Shape

(Alsaleh et al 2006)
Size

- Size and size distribution influences packing, micro-force distribution (force network).

- Uniform size distribution limits compaction range.

- Well-graded distribution produces stronger assembly.

- In DEM we magnify size distribution and FEA we discretize the domain using large elements.

Fine Silica Sand
<table>
<thead>
<tr>
<th>Location</th>
<th>Soil description</th>
<th>Job No.</th>
<th>Sample No.</th>
<th>Borehole No.</th>
<th>Depth</th>
<th>m</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Test method</th>
<th>Date</th>
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</thead>
</table>

**Triaxial Tests - Granular Material: SSP**

<table>
<thead>
<tr>
<th>Size</th>
<th>Deviatoric Stress (kPa)</th>
<th>Axial Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td><img src="image1" alt="Graph showing deviatoric stress and axial strain for 50 mm size" /></td>
<td></td>
</tr>
<tr>
<td>75 mm</td>
<td><img src="image2" alt="Graph showing deviatoric stress and axial strain for 75 mm size" /></td>
<td></td>
</tr>
<tr>
<td>100 mm</td>
<td><img src="image3" alt="Graph showing deviatoric stress and axial strain for 100 mm size" /></td>
<td></td>
</tr>
<tr>
<td>125 mm</td>
<td><img src="image4" alt="Graph showing deviatoric stress and axial strain for 125 mm size" /></td>
<td></td>
</tr>
<tr>
<td>150 mm</td>
<td><img src="image5" alt="Graph showing deviatoric stress and axial strain for 150 mm size" /></td>
<td></td>
</tr>
<tr>
<td>175 mm</td>
<td><img src="image6" alt="Graph showing deviatoric stress and axial strain for 175 mm size" /></td>
<td></td>
</tr>
<tr>
<td>200 mm</td>
<td><img src="image7" alt="Graph showing deviatoric stress and axial strain for 200 mm size" /></td>
<td></td>
</tr>
</tbody>
</table>

*Graphs for each size showing deviatoric stress and axial strain.*
Surface Roughness

• In reality, surface roughness directly influences coefficient of friction.

• Surface roughness has not been incorporated into DEM models.

• It mostly influences repose angle, as well as peak angle.
Surface Roughness

Triaxial Tests - Granular Material: SSP

Deviatoric Stress (kPa)

Axial Strain (%)

Volumetric Strain (%)

Shear deformation (µm)

Shear force (N)

Ball milled gneiss
Normal force = 2.33 N
Ramp: 1 N s⁻¹

Norwegian gneiss
Sliding sphere-sphere contact

Normal force = 7.76 N
1 Hz sine wave

Shear deformation 2 µm
Surface Roughness

Effect of surface roughness on frictional resistance

(Alshibli and Alsaleh 2004)
Particle to Particle Stiffness

- Particle to particle stiffness directly affects the penetration forces

- Rate of volumetric changes is affected by P-P stiffness

- Material flow is also affected by this micro property.
Particle to Particle Stiffness

JSC-1A
Normal contact
Ramp: 1 N s⁻¹

Normal deformation (μm)

Normal force (N)

Milled gneiss (B)
Crushed gneiss (C)
Milled gneiss (D, 1.47, 3.93)
JSC-1A (B, 0.19, ∞)
Milled gneiss (E, 0.19, ∞)
FJS-1 (C, 0.52, 0.97)
Ottawa sand (B, 0.57, 1.28)
Ottawa sand (B, 0.57, 1.28)
JSC-1A (A, 4.94, 8.20)
Milled gneiss (A, 4.94, 8.20)
Milled gneiss (C)
Milled gneiss (C)
Crushed gneiss (B)
Macro Parameters

\[ \{ \dot{\sigma} \} = [D] \{ \dot{\gamma} \} \]

\[ I_{I} = \sigma_{ii} \]

\[ I_{II} = h_1 \left[ \sigma_{13} \sigma_{31} - \sigma_{11} \sigma_{22} - \sigma_{11} \sigma_{33} - \sigma_{22} \sigma_{33} \right] - h_2 \frac{m_1 m_3}{l^2} \]

\[ I_{III} = h_3 \left[ \sigma_{11} \sigma_{22} \sigma_{33} - \sigma_{22} \sigma_{31} \sigma_{31} \right] \]
Modulus of Elasticity
Friction Angle

\[ \tau = \mu \sigma_N \]

\[ \sigma_2 = \text{constant} \]

\[ \sigma_1 = \text{constant} \]

\[ \frac{\sigma_1 - \sigma_2}{\sigma_1 + \sigma_2} \]

\[ \varepsilon_1 + \varepsilon_2 \]

\[ \varepsilon_1 - \varepsilon_2 \]

\[ \text{Dilation} \]

\[ \text{Compression} \]

\[ \phi = 44 \]

\[ \sigma_1 = 320 \text{ kPa} \]

\[ \sigma_1 = 214 \text{ kPa} \]

\[ \sigma_1 = 131 \text{ kPa} \]
Apparent Cohesion

![Diagram showing Alumina sheet, Silica sheet, Hydrogen bonds, Silica sheet, Alumina sheet, Potassium ions, and T solid, d air with shear stress and normal stress graphs with C = 55 and φ = 22.](image)
Elastic range is very small in geomaterials, plasticity kicks in very early, Poisson’s ratio is often assumed.

\[ \nu = -\frac{\varepsilon_x}{\varepsilon_y} \]

Ranges from -1.0 to 0.5

- Some foam
- Saturated undrained soils
  - No volumetric changes

\( \varepsilon_x \)
\( \varepsilon_y \)
**Damping Ratio**

Soil damping: is the dissipation of strain energy during cyclic loading. The energy dissipated is proportional to the area of the hysteresis loop.

\[ c_{cr} = 2\sqrt{k \otimes m} \]

\[ D = \frac{c}{c_{cr}} \]

\[ D = \frac{A}{4\pi A_s} \]

Cyclic Triaxial test; ASTM D 3999

Damping ratio is pretty tough to measure, assumed most of the time
Damage Parameters

- Post peak is difficult to model, softening rate.
- Damage mechanics
- Plasticity
- Crystal plasticity
Conclusions

• Geomaterials is very complex structured material, challenging to model.

• We ought to understand microstructure and approximate it to obtain reasonable macro response.

• Micromechanics needs micro quantities that are impossible to measure.

• Continuum mechanics requires more measurable Phenomenological properties.

• However, it lacks accurate micro-structure approximation.

• We must focus on bridging micro level to macro response
Conventional Triaxial Test: CT images