Effect of Particle Shape on the Elastic Anisotropy of Granular Materials

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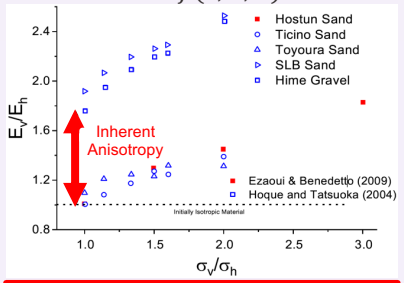
Highly Adaptive materials

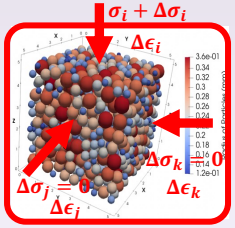
Develop ***SMART*** constitutive models that can account for key Microscopic Features:
Shape, size, contact behavior, networks etc.

$$\boldsymbol{\sigma} = f(\boldsymbol{\epsilon}, \boldsymbol{a}, \alpha)$$



Experimentally observed ***ELASTIC*** adaptivity in granular materials is often neglected in existing constitutive models

Goal: To understand how ***Elastic Stiffness*** anisotropy adapts based on the contact network and shape of the particles



$$E_i = \frac{\Delta\sigma_i}{\Delta\epsilon_i}$$

Probes during triaxial loading using ***Discrete Element Method (DEM)*** by inhibiting ***inelastic mechanisms***

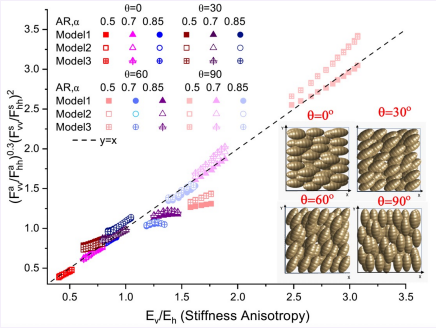
An analytical scaling relation of the elastic anisotropy E_v/E_h of assembly composed of ellipsoidal particles :

$$\frac{E_i}{E_j} = \left(\frac{F_i^a}{F_j^a}\right)^{0.3} \left(\frac{F_i^s}{F_j^s}\right)^{2} *$$

Induced Anisotropy (related with contact area adaptativity)

Inherent Anisotropy (related with particle shape and orientation)

Comparison against the DEM simulations



Enhancing Existing Anisotropic Models

Anisotropic Hyperelastic model: Houlsby et. al (2019)

$$\psi = f(\boldsymbol{\epsilon}^e, \boldsymbol{a}) \rightarrow \mathbb{D}(\boldsymbol{\epsilon}^e, \boldsymbol{a})$$

$\boldsymbol{a}$ *reflects microstructural anisotropy*

Enhancement:

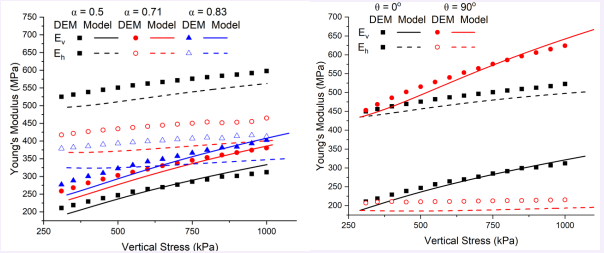
For assemblies composed of spherical/ellipsoidal Particles

Motivated by $(*)$ at DEM scale:

$$a_{ij} = \underbrace{S_{ik}^*}_{\text{Inherent}} \underbrace{\left(\delta_{kj} + C_a \epsilon'_{kj}\right)}_{\text{Induced}}$$

Evolution law for the fabric in the model

$$Z_{ijpq} = \frac{\partial a_{ij}}{\partial \epsilon_{pq}} = C_a S_{ik}^* P_{kjpq}$$



Prediction of the model against DEM for multiple aspect ratios and orientation of particles