COMPUTATIONAL GEOMECHANICS

Mechanical behavior of entangled, non-convex granular particles: Experimental analysis of the angle of repose

Presented by: Jade Leong

Professor Jose Andrade
Siavash Monfared
Raj Pal

Caltech

Roadmap

- Motivation
- Chosen Designs
- Objective
- Lab Experiment
- Level Set Discrete Element Method Simulations
- Result Comparisons
- Ongoing Work

Motivations

(https://en.wikipedia.org/wiki/Granular_material)

(https://archpaper.com/2019/01/boston-city-hall-50-anniversary/)

(http://www.starexc.com/whatwedo-demolition.htm)

(Keller & Jaeger, 2016)

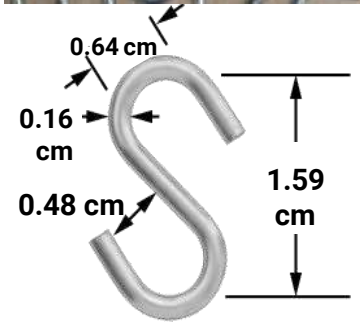
(Dierichs, Wood, Correa, & Menges, 2017)

Motivations - Example of Non-Convex Granular Material

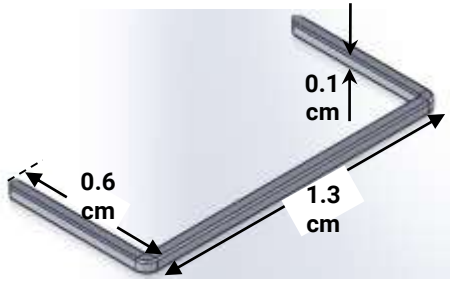
("Public talk on Z-forms." *Youtube*, uploaded by UChicagoArts, January 9, 2018.)

Chosen Non-Convex Shapes

Zinc Plated Steel S-Hooks



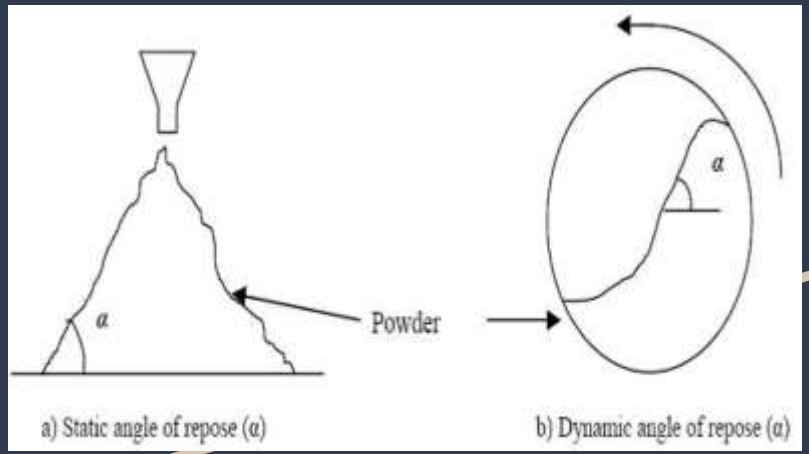
Standard Staples



Objective

Create a static angle of repose experiment to better understand the mechanical behavior of the designed granular material and to validate simulations from LS-DEM by comparing experimental results.

What is the angle of repose (AoR)?



(Al-Hashemi & Al-Amoudi, 2018)

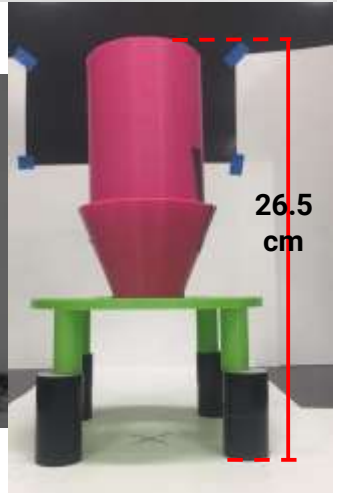
"Defined as the angle of inclination of the free surface to the horizontal of a conical bulk solid pile"
(Frankowski & Morgeneyer, 2013)

- Dependent on particle characteristics and material properties
- Static AoR Test Methods
  - Fixed Funnel
  - Hollow Cylinder
  - Tilting Box
- Dynamic AoR Test Methods
  - Revolving cylinder/ drum

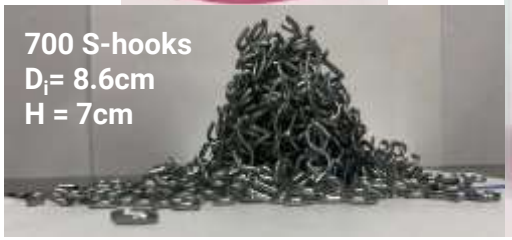
(https://en.wikipedia.org/wiki/Angle_of_repose)

Lab Experiment: Methods

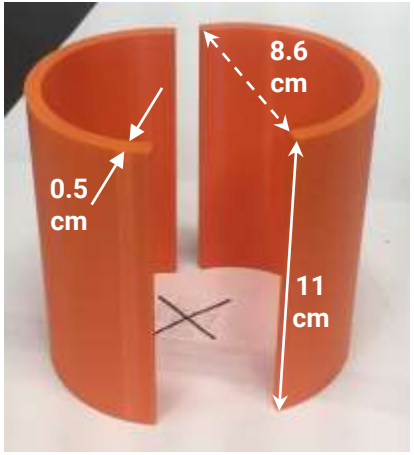
700 S-hooks
Funnel height = 9.5cm



Fixed Funnel Method



Hollow Cylinder Method



Pile formation with wall removal

Lab Experiment: Image Processing

Original Image

Matlab

Binarized Image

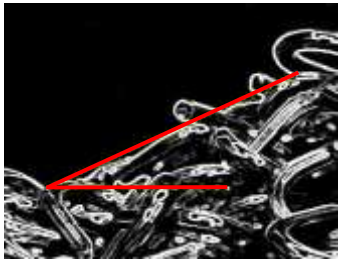
Cropped Left Slope

Cropped Right Slope

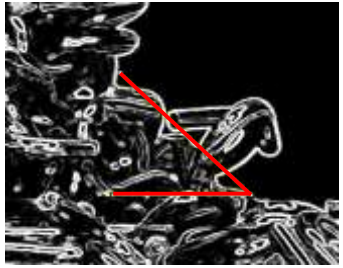
Angle	Matlab	ImageJ
Left	28.57º	26.31º
Right	25.02º	44.20º

ImageJ - FIJI

Outlining Edges

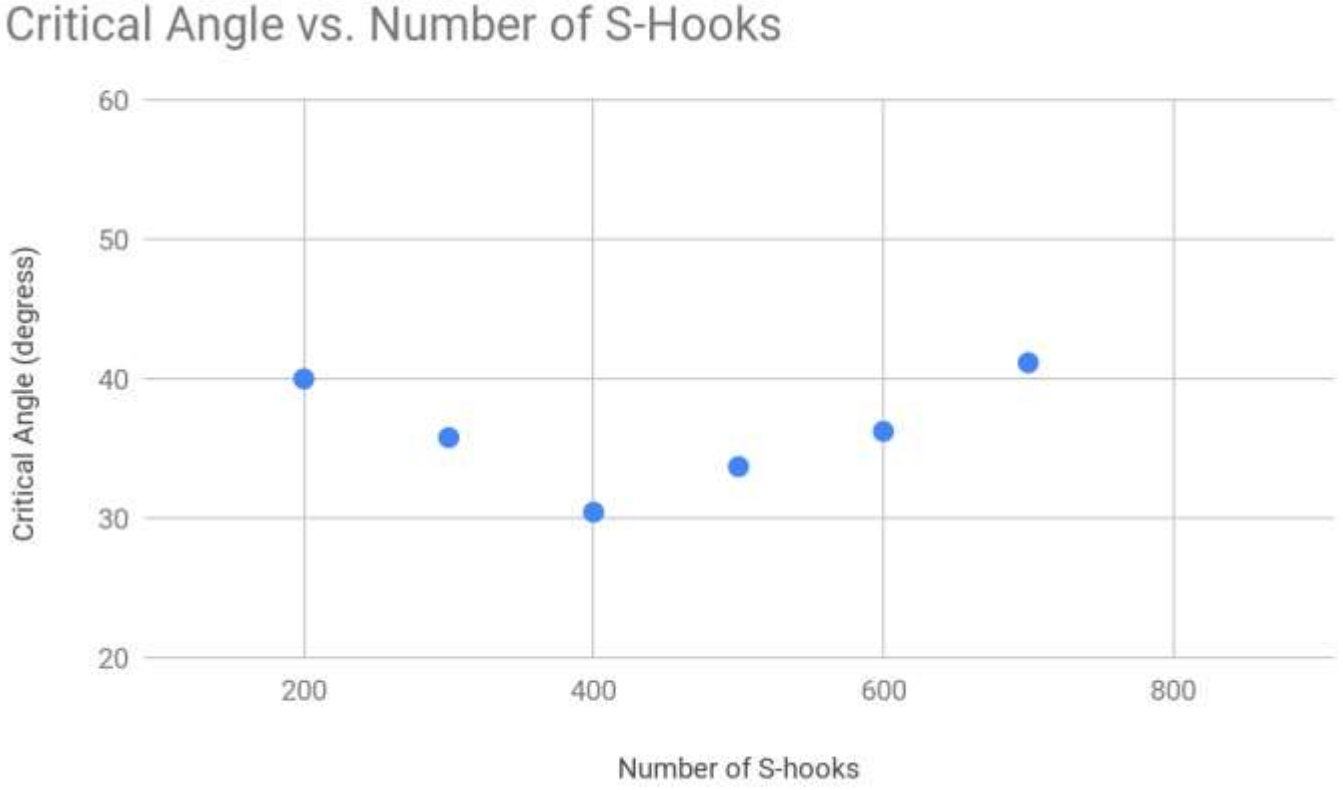


Zoom on Right Slope



Zoom on Left Slope

Lab Experiments: Results



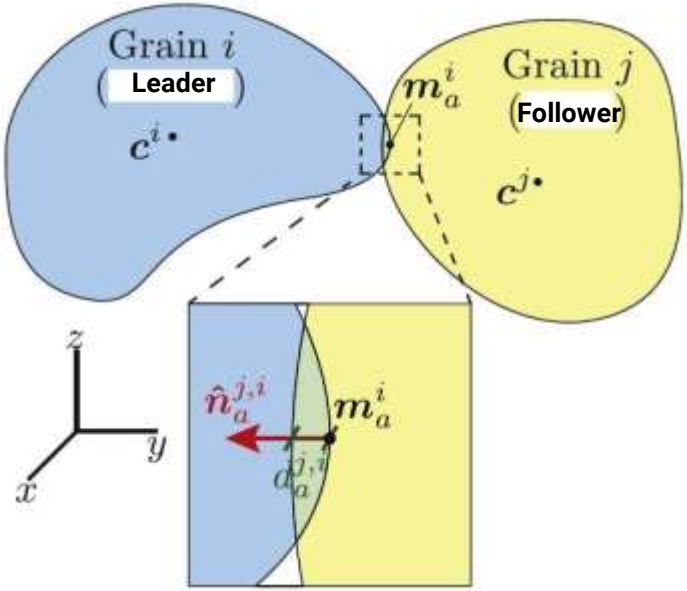
Simulations

Level Set Discrete Element Method (LS-DEM):

- Simulates systems of arbitrarily shaped particles using level set functions
- Captures the kinematics and mechanics of a system of discrete particles

Visualization Toolkit (VTK):

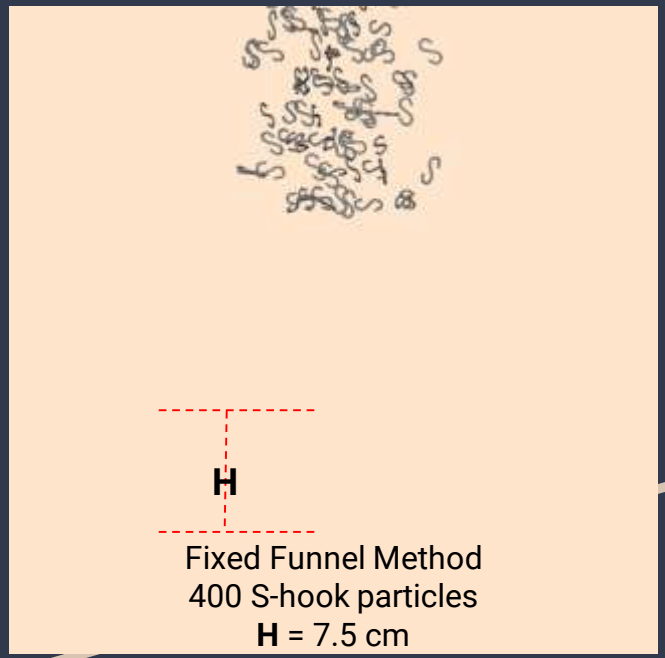
- Software system for 3D computer graphics, image processing and visualization



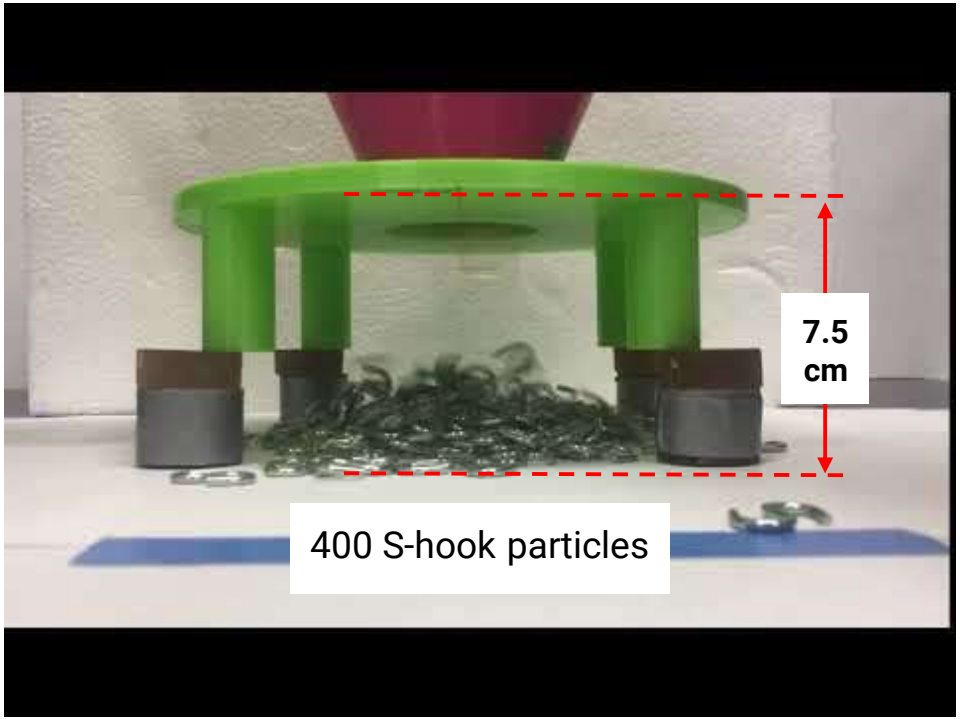
(Kawamoto, Andò, Viggiani, & Andrade, 2016)

(https://en.wikipedia.org/wiki/VTK)

Result Comparison



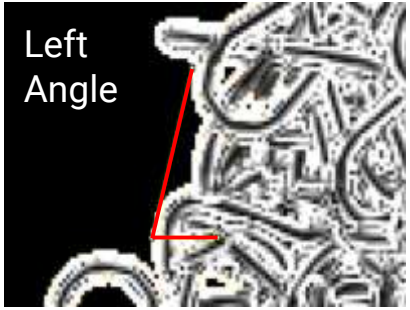
Fixed Funnel Method
400 S-hook particles
H = 7.5 cm

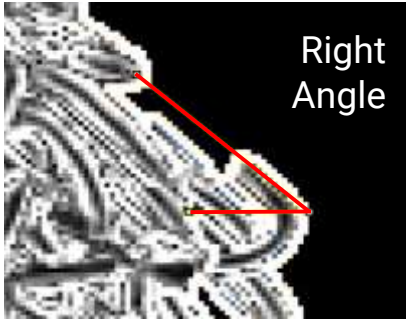


Result Comparison

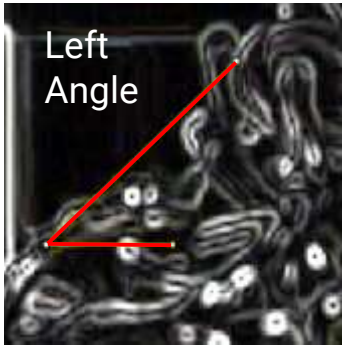
Angles	Simulation	Experiment
Left	74.98°	38.91°
Right	41.31°	26.82°

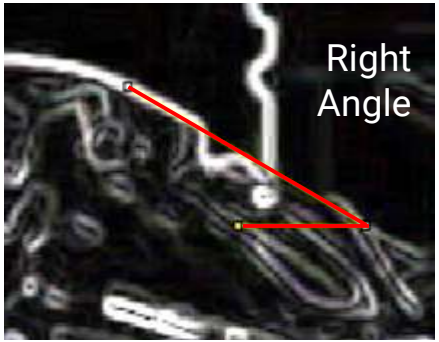
Simulation





Experiment





Ongoing Work

- Continue testing the angle of repose for both S-hook particles and staples
- Understand other mechanical properties through other experiments
  - Uniaxial compression
  - Three Point Bending
  - Vibration Testing
- Create and validate simulations that compare to lab testing

Thank you

Professor José Andrade
Siavash Monfared
Raj Pal
Computational Geomechanics group
Student Faculty Programs

Caltech