

# Tensile Behavior of Entangled Non-Convex Granular Particles

Presented By: Sydney Richardson

Professor José Andrade  
Siavash Monfared

# Outline

- Motivation
- Beginning the Project
- Particle Design
- Performed Tests
- Ongoing Work

# Motivation

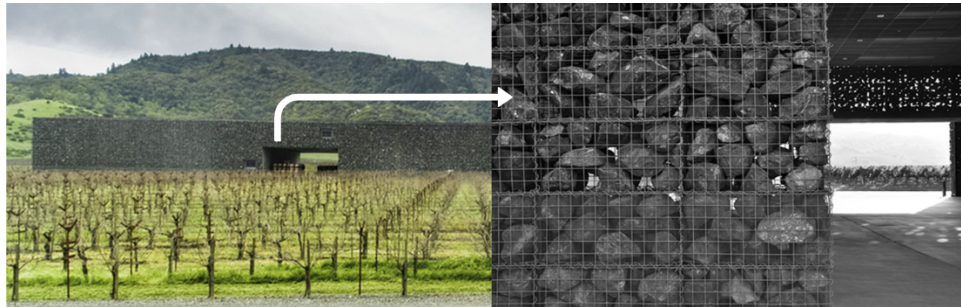


<https://www.cam.ac.uk/research/news/study-reveals-mysterious-equality-with-which-grains-pack-it-in>



<https://www.mattconstruction.com/projects/higher-ed/caltech-bechtel-residence/>

Why should I care about granular materials?



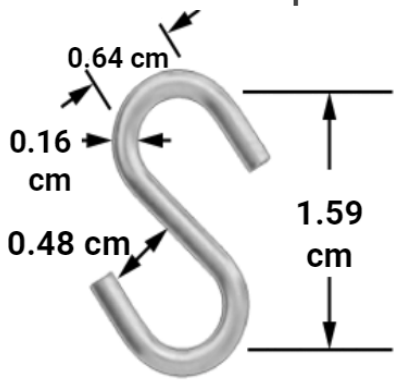
Keller & Jaeger, 2016



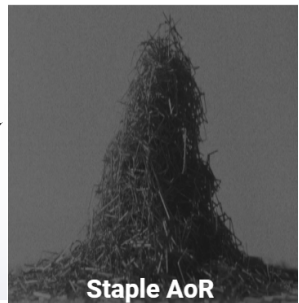
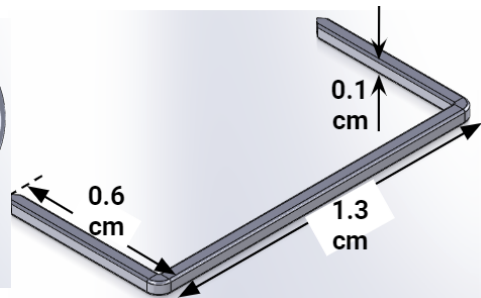
Dierichs, Wood, Correa, & Menges, 2017

# Practical Beginnings

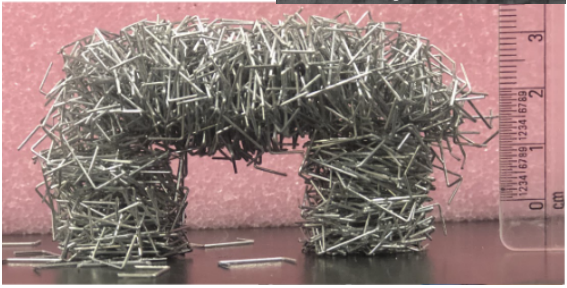
Zinc-plated steel s hooks



Standard staples

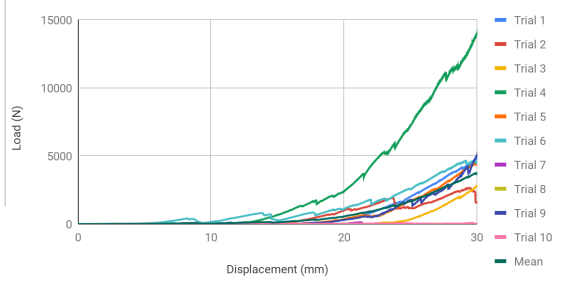


Aiden Sund

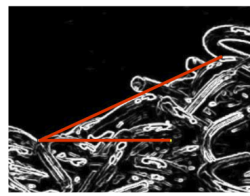


Load vs. Displacement

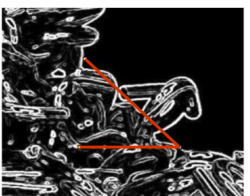
One piece cylinder



Katheryn Wang



Zoom on Right Slope

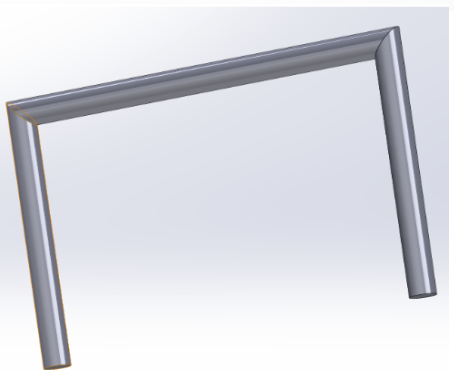
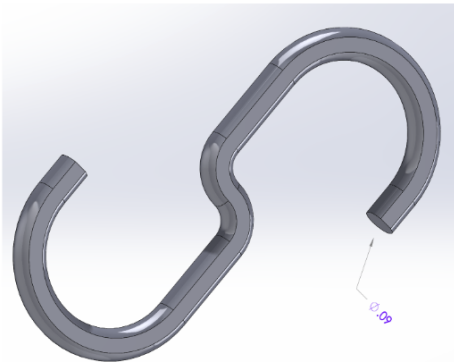


Zoom on Left Slope

Jade Leong



# Particle Design



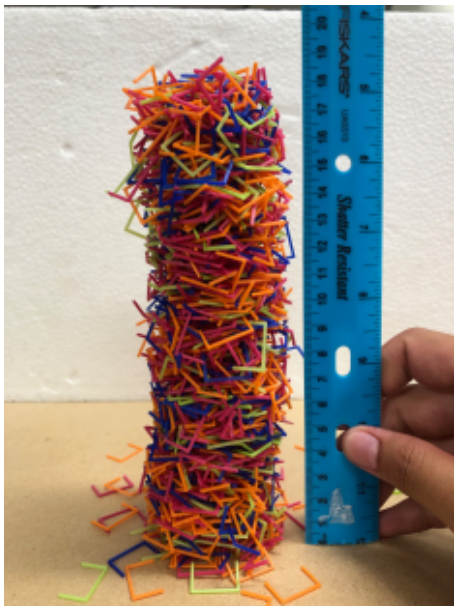
# Aspect Ratio

## Staple

Width:  
5.5 cm

Max  
Height:  
18.2 cm

Aspect  
Ratio:  
~1:3.30



## S

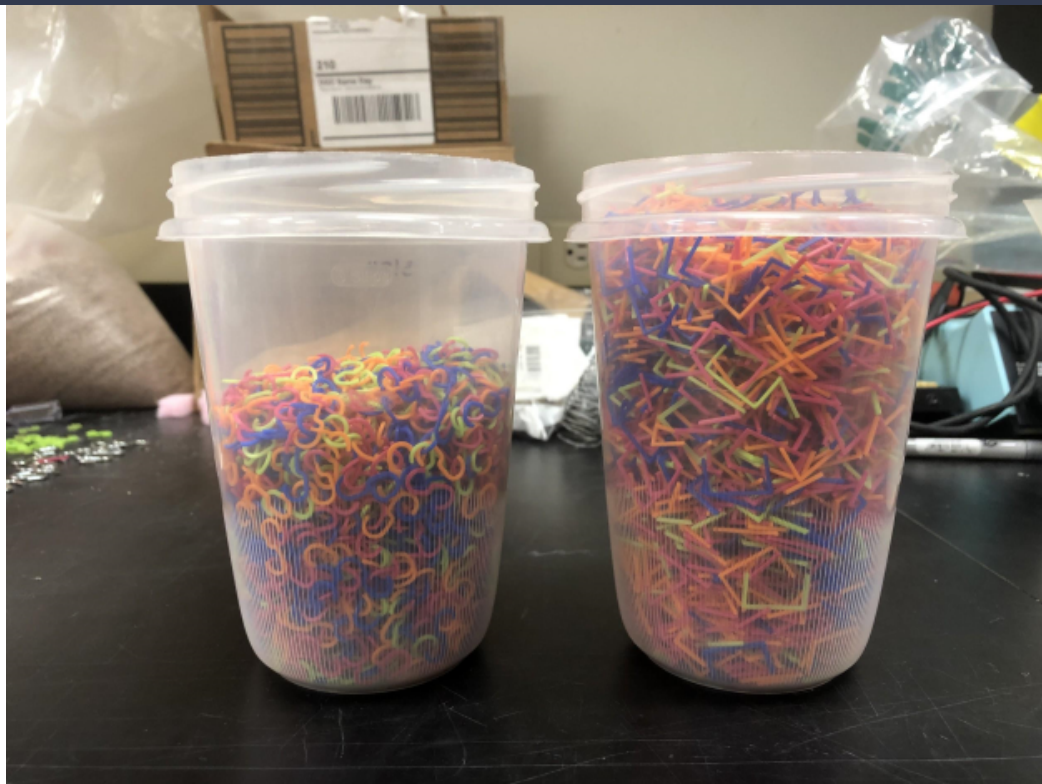
Width:  
5.5 cm

Max  
Height:  
18.4 cm

Aspect  
Ratio: ~  
1:3.35



# Packing Density

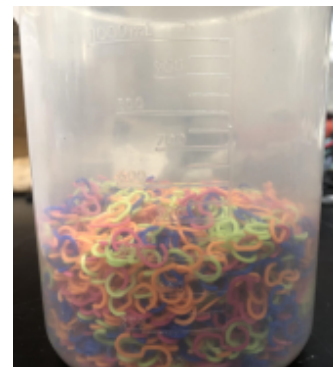


Staple:

2.30

$946.5 \text{ cm}^3_{\text{avg}} / 3120_{N_p}^*$

$.038647 \text{ cm}^3_V$



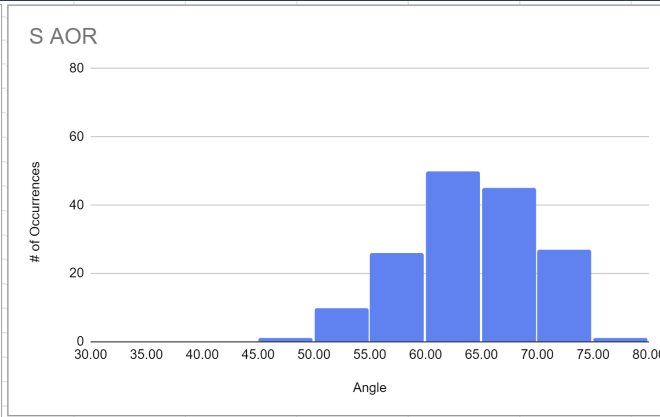
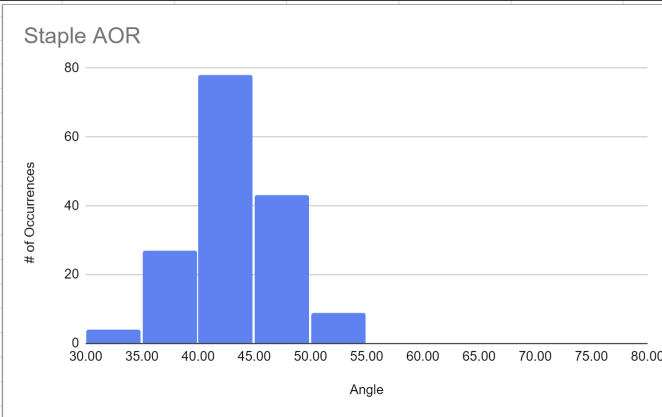
S:

5.14

$617 \text{ cm}^3_{\text{avg}} / 3104_{N_p}^*$

$.131796 \text{ cm}^3_V$

# Angle of Repose



Average = 43.2 (mean)  
Min = 30.1  
Max = 54.5  
Standard Deviation = 4.343

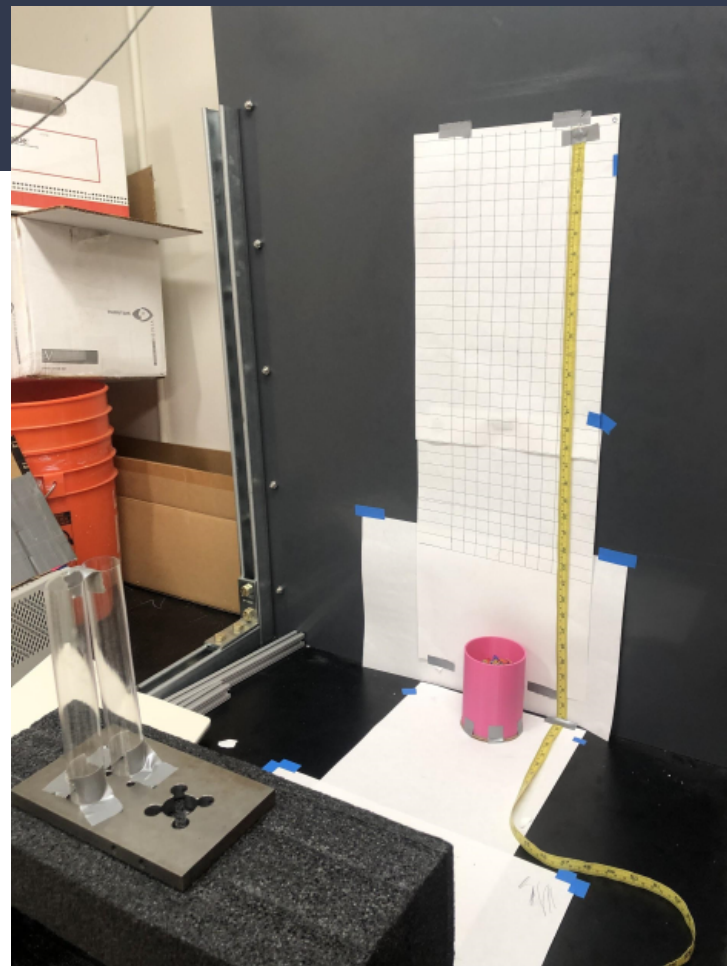
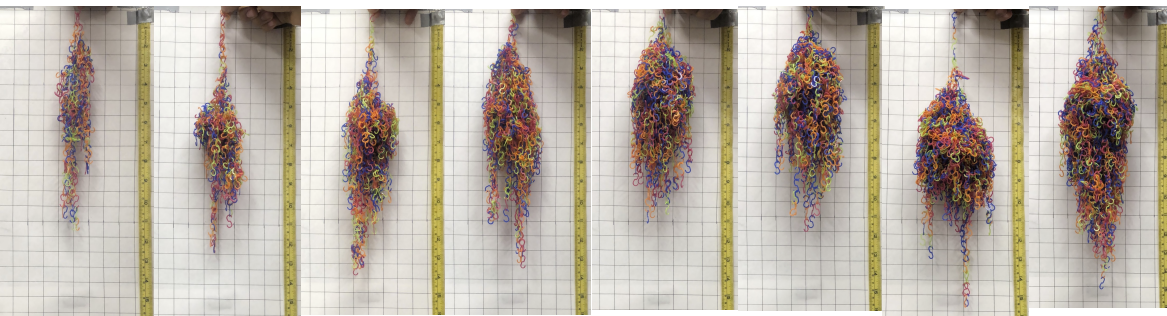
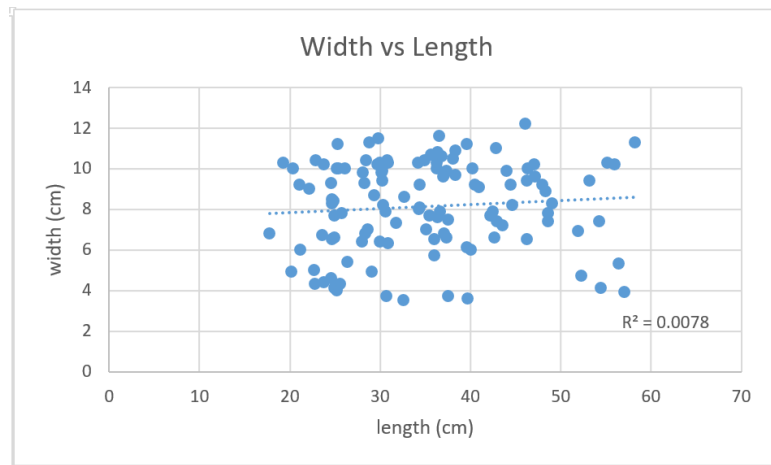
Average = 64.4 (mean)  
Min = 49.9  
Max = 76.5  
Standard Deviation = 5.706

Friction?





# Interlocking Capabilities

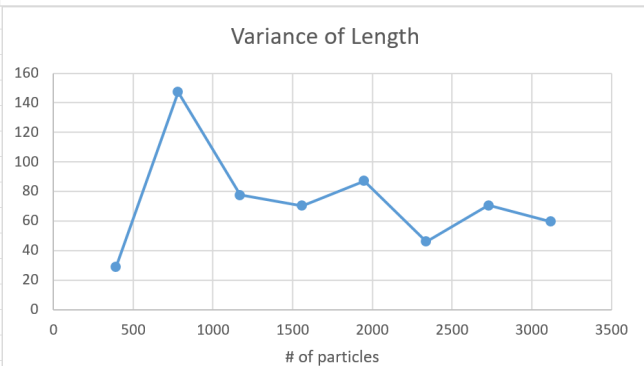
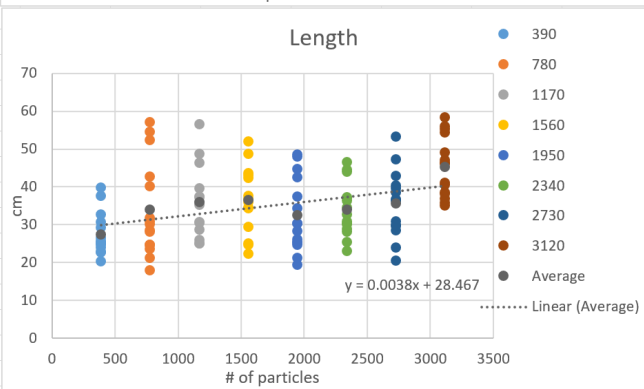
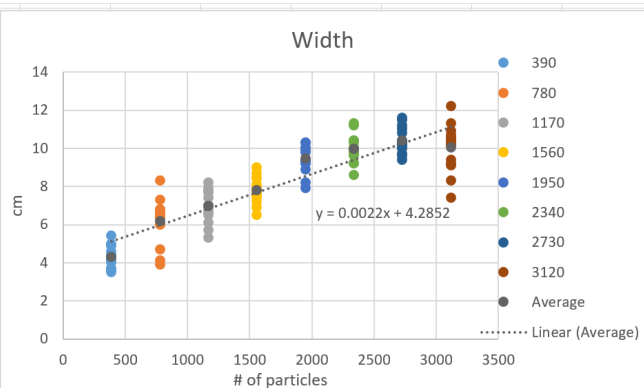




# Continued



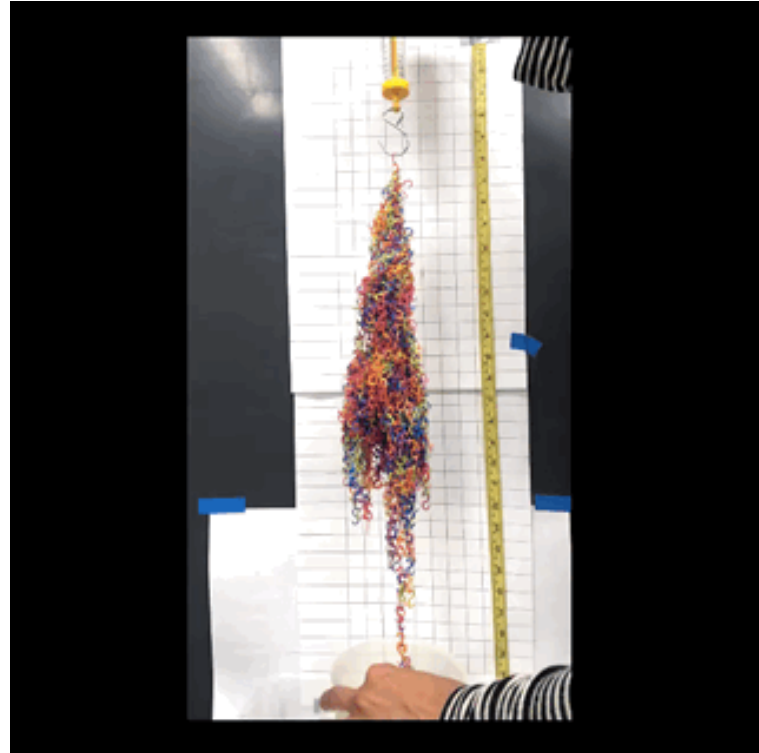
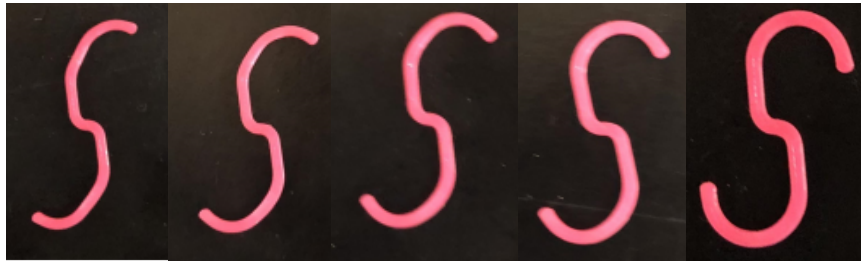
Convergence?



# Interlocking Strength

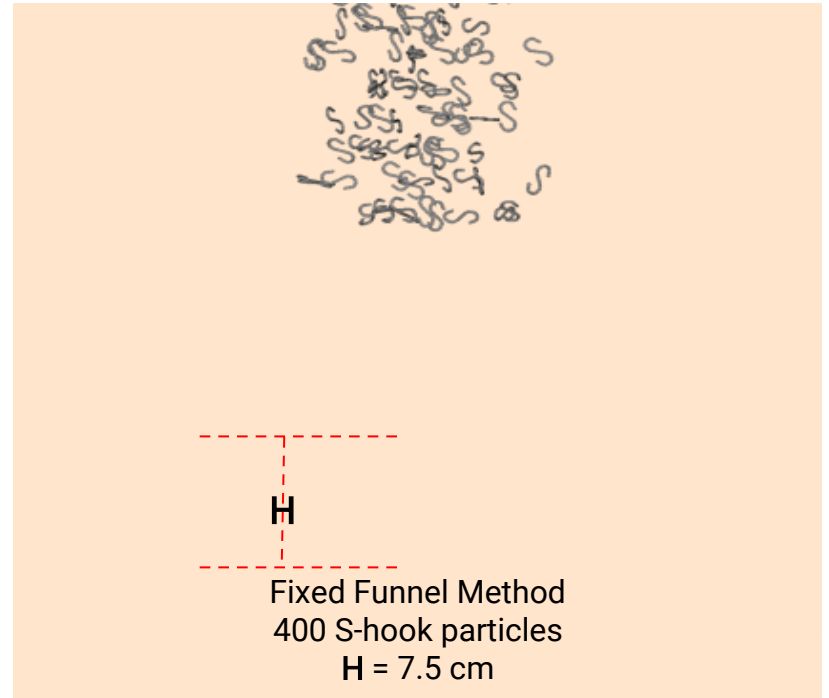


4-5 N applied,  
warping  
instead of  
breakage



# Ongoing Work

- Use the LS-DEM code to simulate these real life experiments
- Shake table testing with 3D printed particles
- 1D compression testing of 3D printed particles
- Design different shaped particles
- Print more particles



# Thank you!

Professor José Andrade  
Siavash Monfared  
Computational Geomechanics group  
Summer Students  
Student Faculty Programs  
Northern California Associates

Questions?