Size Effect of Inclusions in Granular Media

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Outline

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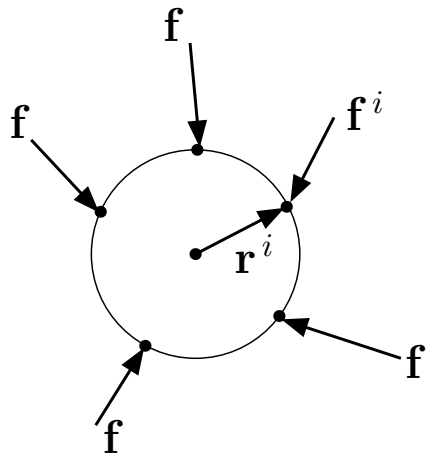
Particle Stress

Particle stress



$$\sigma_{\text{particle}} = \frac{1}{V_{\text{particle}}} \sum \mathbf{r}^i \otimes \mathbf{f}^i$$

Average (assembly) stress

$$\overline{\boldsymbol{\sigma}} = \frac{1}{V_{\text{assembly}}} \sum V_{\text{particle}}\, \boldsymbol{\sigma}_{\text{particle}}$$

$$\overline{\boldsymbol{\sigma}} \approx \frac{\text{Average particle stress}}{\text{Solid fraction}}$$

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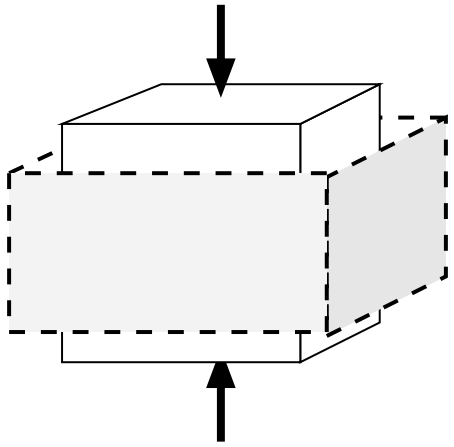
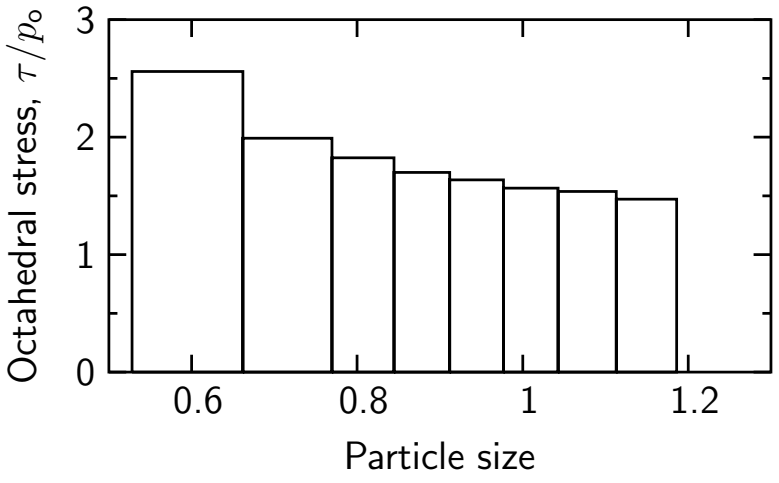
Particle Size vs. Particle Stress

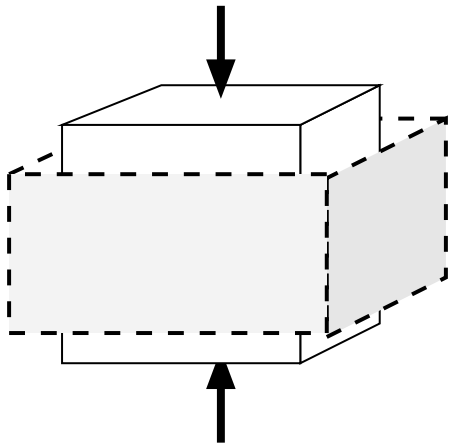


Triaxial compression
4100 particles
Size range 0.5 – 1.4



$$\left.\begin{array}{c}\text{Coefficient of correlation} \\ \text{Stress} \Leftrightarrow \text{Size}\end{array}\right\} = -0.21$$

Particle Size vs. Particle Stress



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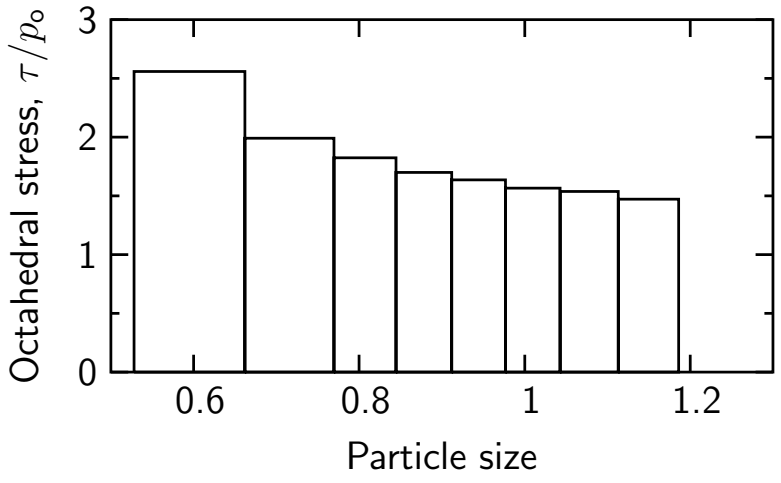

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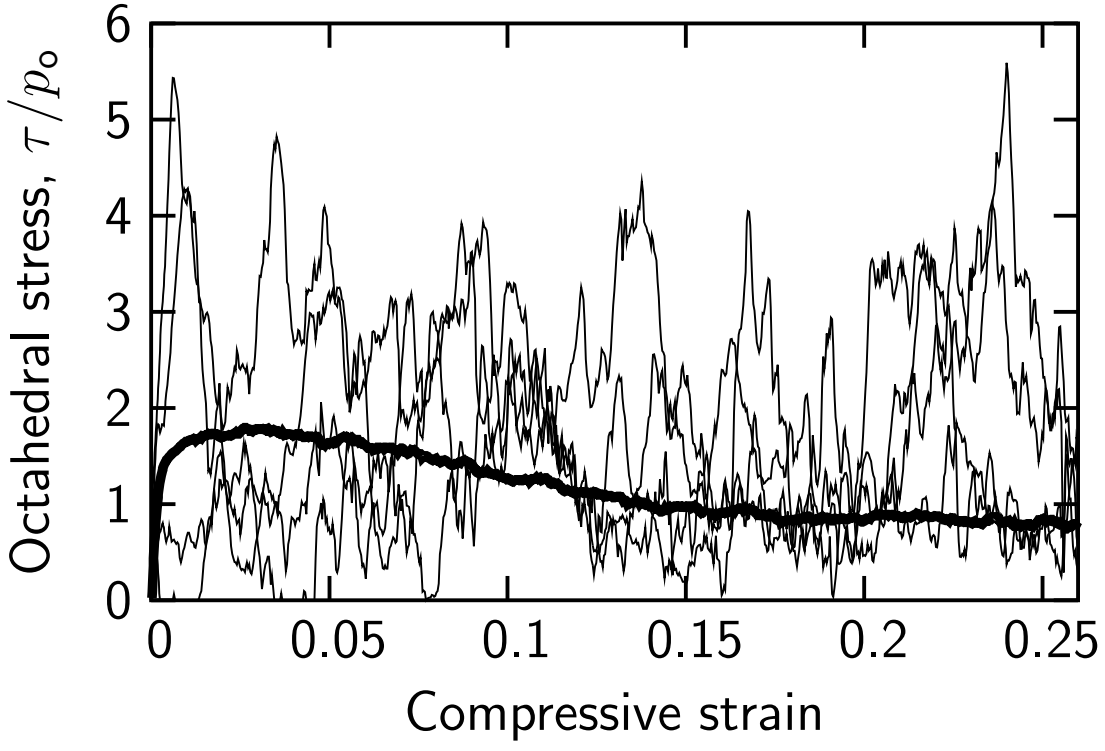
Individual Particle Stresses

Stresses in 4 individual particles
&
Average of 4096 particles



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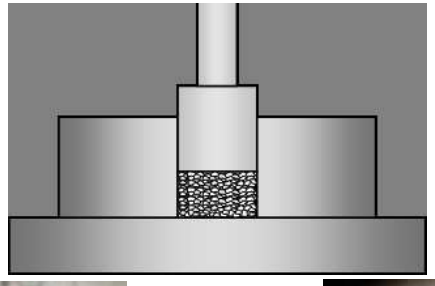
Crushable Particle Tests

Uniaxial compression of an embedded agglomerate
1MPa normal pressure



Size ratio ≈ 10

Size ratio ≈ 3.5

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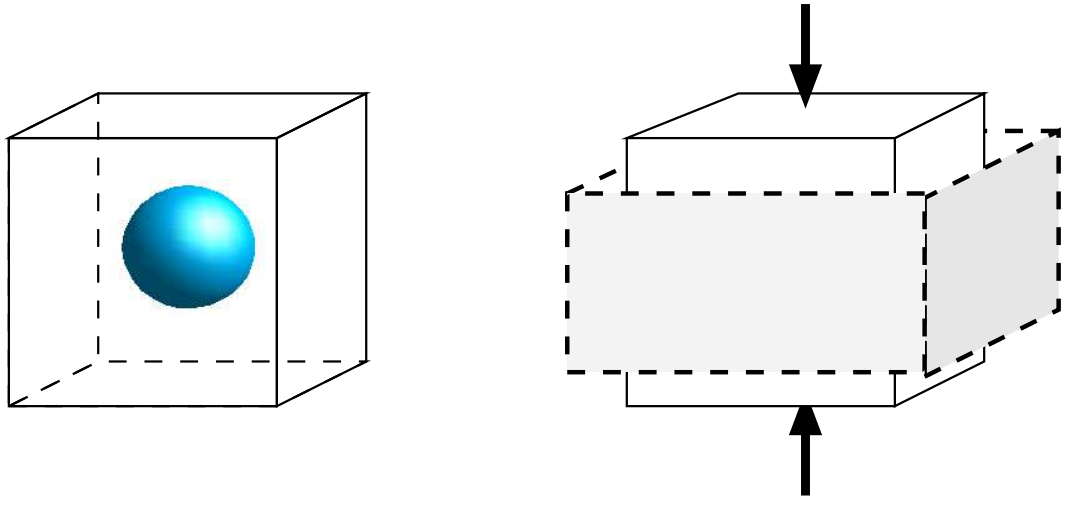
DEM Tests

DEM tests with a single “submerged” inclusion



80,000 spheres with a narrow size range

+

1 submerged particle of a given size: 4, 6, 8, 10, 12.5, 16

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Granular Behavior $\Leftrightarrow$ Questions

Questions:

1. How does size of submerged particle affect its stress condition?
2. Is a characteristic length associated with submerged particle response?

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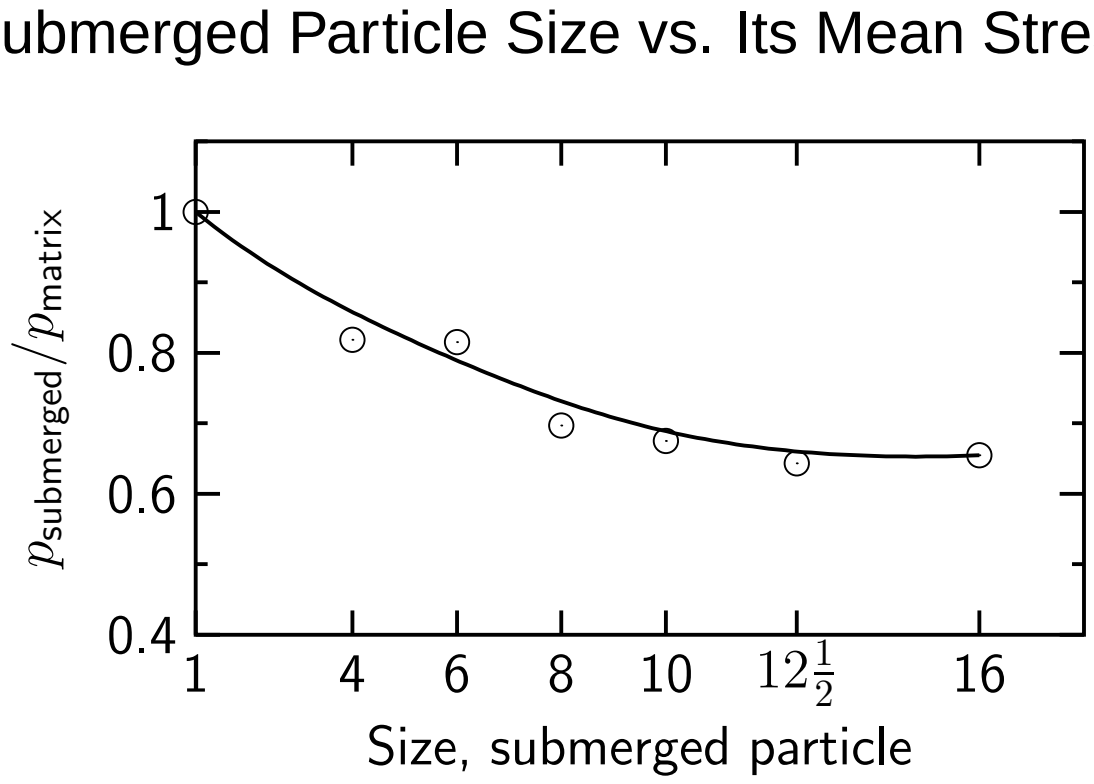
Mean Stress – Submerged Particle

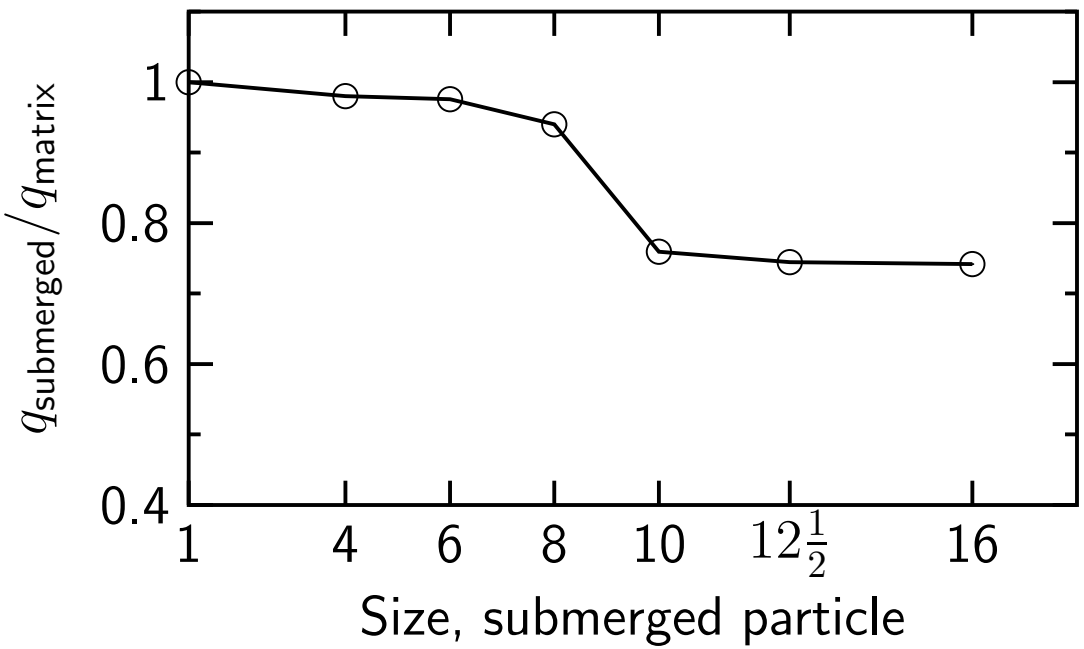


Deviator Stress – Submerged Particle

Submerged Particle Size vs. Its Deviator Stress

$$q = \sigma_{11} - \sigma_{33}$$

$$\frac{q_{\text{submerged}}}{q_{\text{matrix}}}$$



Summary

- Particle stress decreases with particle size.
- In smaller particles, stress varies greatly during loading.
- With large submerged particles, the mean stress and shearing stress decrease with size.
- A characteristic length is associated with stress in submerged particles.

Further Reading I

S. J. Antony and M. Ghadiri 2001.
Size effects in slowly sheared granular media.
J. Applied Mechanics, 68(3):772–775.

M. R. Kuhn 2003.
Heterogeneity and patterning in the quasi-static behavior of granular materials.
Granular Matter, 4(4):155–166.