UCL

Effect of Particle Shape on Shearing Behavior of Soil

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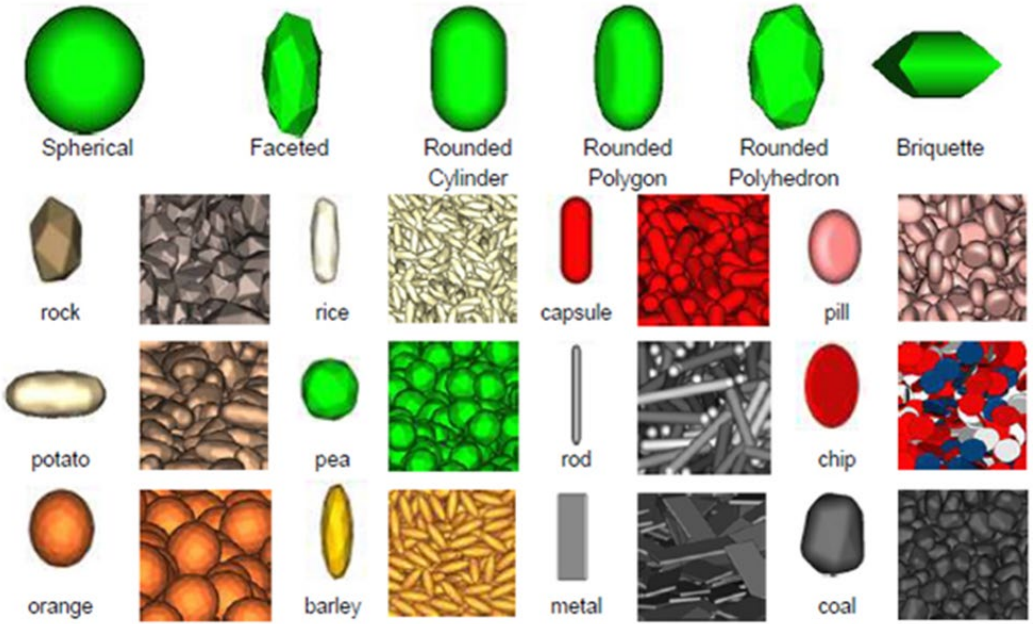
OUTLINE

1. Background
2. Sample Preparation
3. Results and Discussion
4. Conclusions

❑ Background – Wide Applications

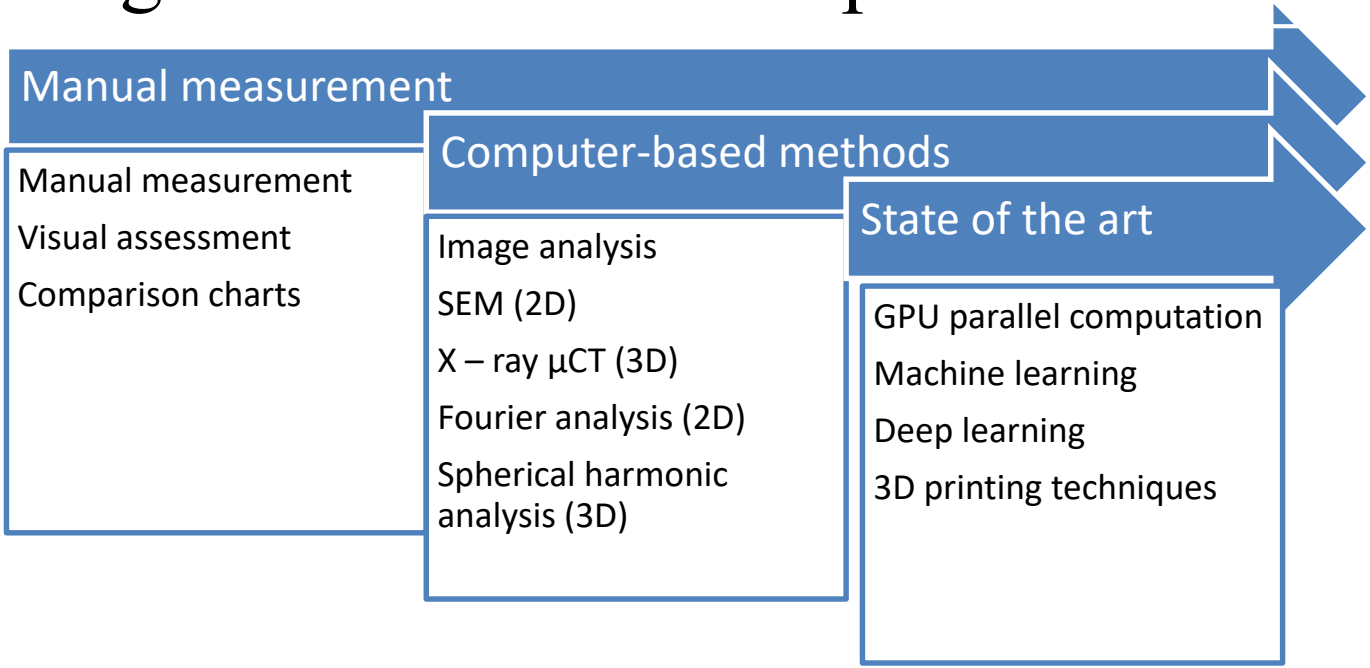


pharmaceutical processing
biomedical science

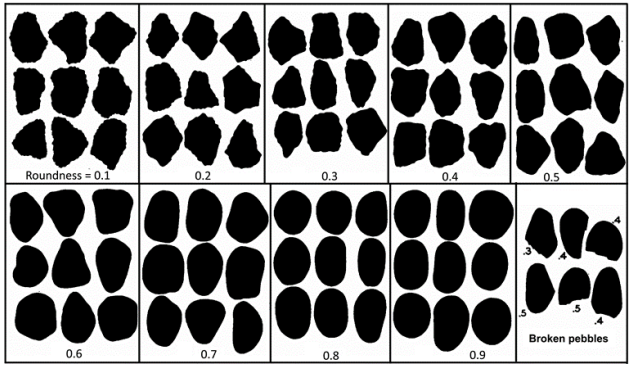
civil engineering

… …

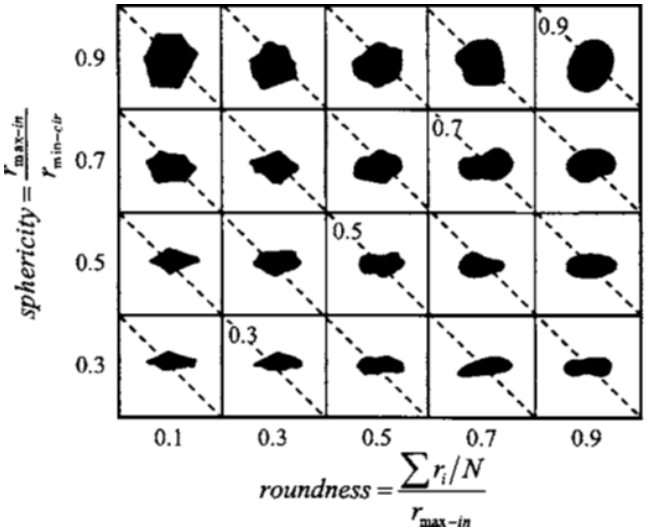
❑ Background - Particle Shape Characterization



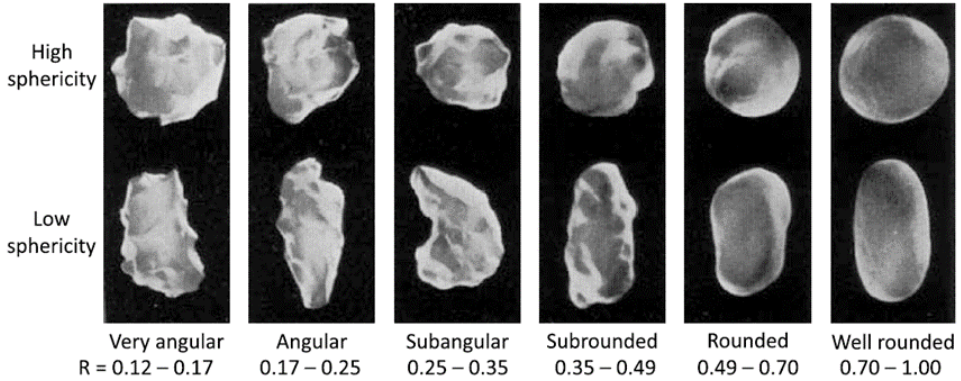
SEM: scanning electron microscopy
µCT: micro-computed tomography



Comparison chart for roundness by Krumbein (1941)



Cho after Krumbein and Sloss (2006)



Power Chart (1953)

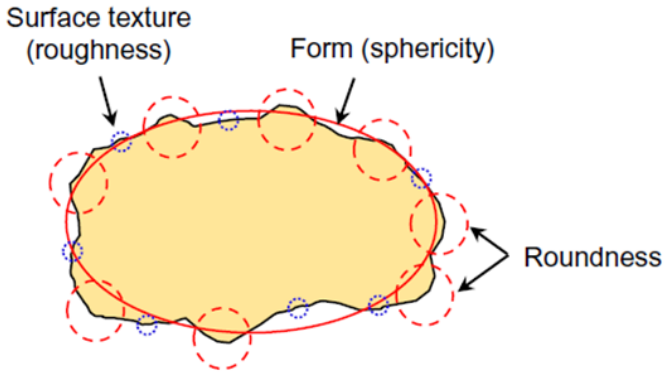
Krumbein, W. C. (1941). Measurement and geological significance of shape and roundness of sedimentary particles. *Journal of Sedimentary Research*, *11*(2), 64-72.

Powers, M. C. (1953). A new roundness scale for sedimentary particles. *Journal of Sedimentary Research*, *23*(2), 117-119.

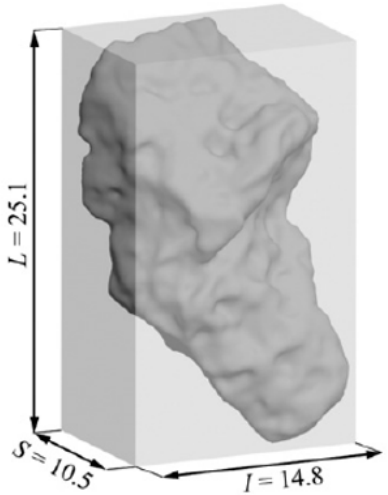
Krumbein, W. C., & Sloss, L. L. (1951). *Stratigraphy and sedimentation* (Vol. 71, No. 5, p. 401). LWW.

Cho, G. C., Dodds, J., & Santamarina, J. C. (2006). Particle shape effects on packing density, stiffness, and strength: natural and crushed sands. *Journal of geotechnical and geoenvironmental engineering*, *132*(5), 591-602.

❑ Background - Shape Descriptors in This Study



Particle shape characterisation at different quantities
(Barrett, 1980; Mitchell and Soga, 2005; Zheng & Hryciw, 2015)



Minimum bounding box (MBB) method

(Blott & Pye, 2008)

- Elongation index (EI) = I/L
- Flatness index (FI) = S/I

L: the longest,

I: intermediate,

S: the shortest edge

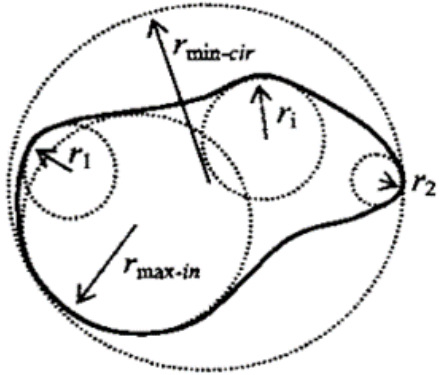
- Advantages of MBB method

Easily achieved

Reduce measurement errors

Barrett, P. J. (1980). The shape of rock particles: a critical review. *Sedimentology*, 27(3), 291–303.
Mitchell, J. K., & Soga, K. (2005). *Fundamentals of soil behavior* (Vol. 3). New York: John Wiley & Sons.
Zheng, J., & Hryciw, R. D. (2015). Traditional soil particle sphericity, roundness and surface roughness by computational geometry. *Géotechnique*, *65*(6), 494-506.
Blott, S. J., & Pye, K. (2008). Particle shape: a review and new methods of characterization and classification. *Sedimentology*, *55*(1), 31-63.

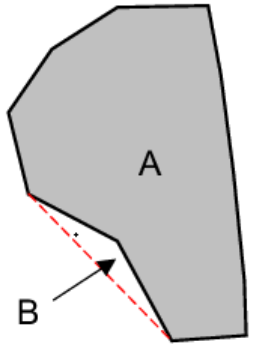
❑ Background - Shape Descriptors in This Study



○Roundness (R) is independent of form, and relates to the relative rounding or angularity (sharpness) of corners and edges.

○ $R = \dfrac{\sum(r_i/N)}{r_{max}}$

Cho & Santamarina (2006)



Convexity: C= A/(A+B)

○ Cx (Convexity index) = VP/VCH

VP: the volume of the particle (A)

VCH: the volume of the convex hull enclosing the sample (A+B)

Mora & Kwan (2000); Yang & Luo (2015)

Cho, G. C., Dodds, J., & Santamarina, J. C. (2006). Particle shape effects on packing density, stiffness, and strength: natural and crushed sands. *Journal of geotechnical and geoenvironmental engineering*.
Mora, C. F., & Kwan, A. K. H. (2000). Sphericity, shape factor, and convexity measurement of coarse aggregate for concrete using digital image processing. *Cement and concrete research*, *30*(3), 351-358.
Yang, J., & Luo, X. D. (2015). Exploring the relationship between critical state and particle shape for granular materials. *Journal of the Mechanics and Physics of Solids*, *84*, 196-213.

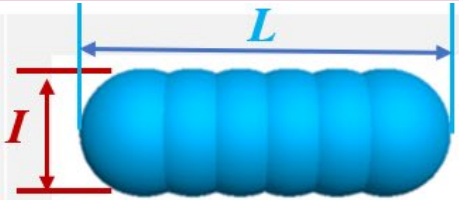
Elongation Effect

(FI = 1, R = 1)

(Cx ≈ 0.98)

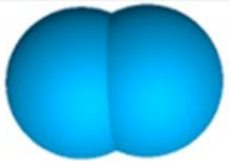
EI = *I*/*L*

FI = *S*/*I*

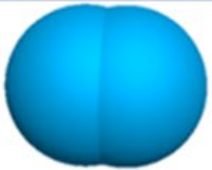


EI = 0.35

EI = 0.53



EI = 0.7



EI = 0.8

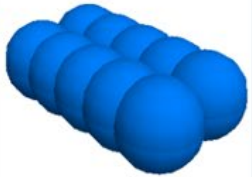
EI = 0.9

EI = 1.0

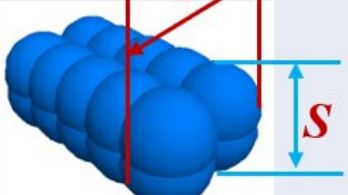
Flatness Effect

(EI = 0.6, R = 1)

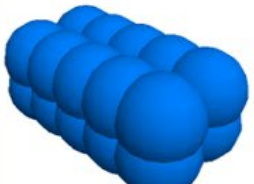
(Cx ≈ 0.75)



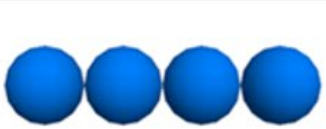
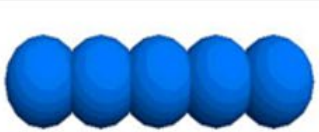
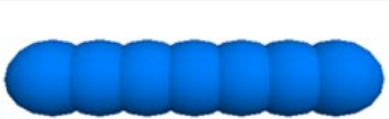
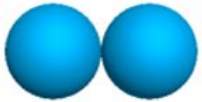
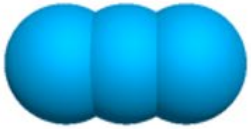
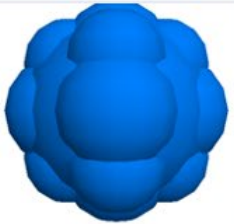
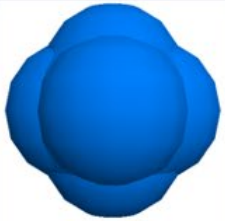
FI = 0.6



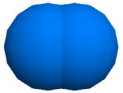
FI = 0.7



FI = 0.8

Convexity Effect (EI = 0.25, R = 1) (FI = 1)	 Cx = 0.73	 Cx = 0.85	 Cx = 0.93
Convexity Effect (EI = 0.5, R = 1) (FI = 1)	 Cx = 0.8	 Cx = 0.96	 Cx = 0.99
Roundness Effect (EI = 1, FI = 1) (Cx ≈ 0.75)	 R = 0.45	 R = 0.57	 R = 0.83

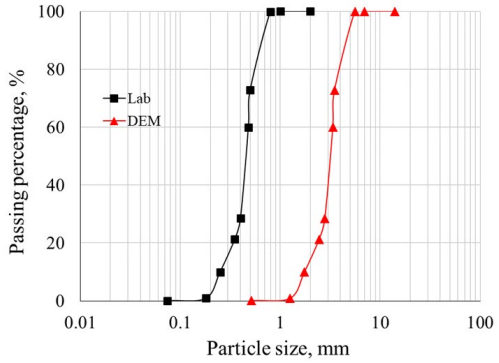
❑ Sample Preparation

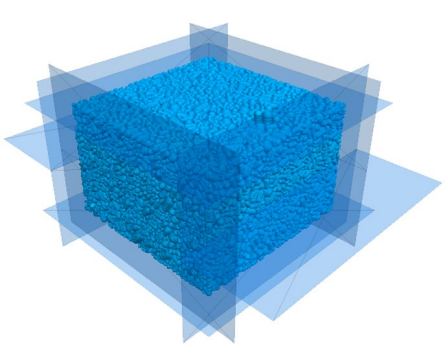


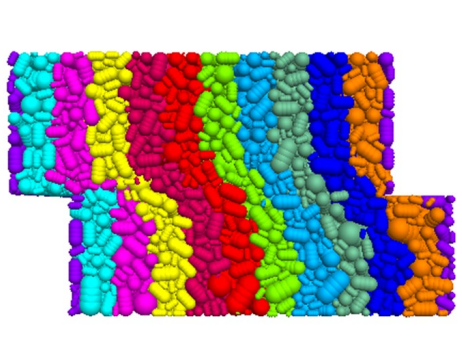
- Shear box
  60(L) X 60 (W) x 40 (H) (mm)
- Fujian Standard Sand
  scaled up by a factor of 7
- Input parameters
  emod = 4e7
  kratio= 1.2

- n= porosity
- f1: Particle friction μ from 0 - 4.5 kPa loading.
- f2: 4.5 kPa to 5 kPa & then 30kPa and shearing.

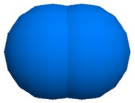
- Loose sample (e-min)
  n=0.15, f1=0.5, f2=0.2
- Medium dense
  n=0.15, f1=0.2, f2=0.2
- Dense sample (e-max)
  n=0.15, f1=0, f2=0.2

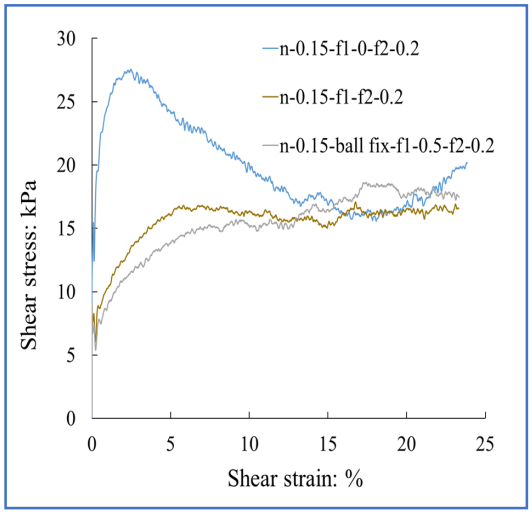




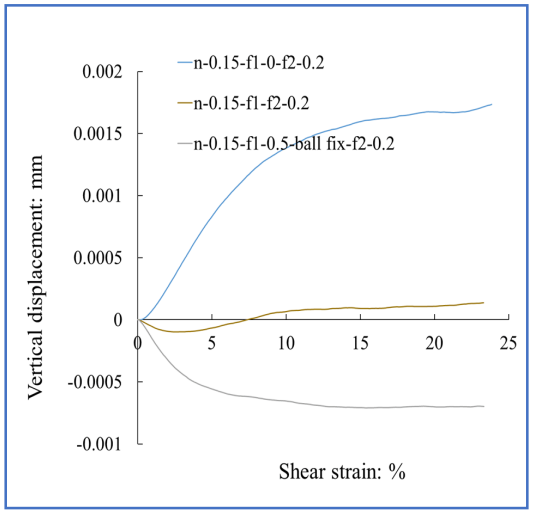


❑ Sample Preparation

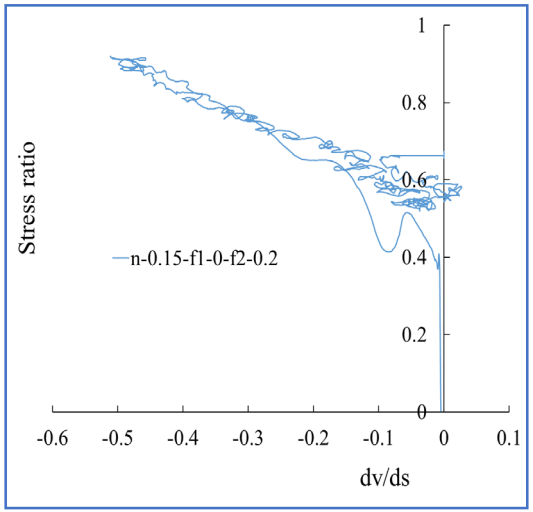




- Peak friction angle
- Critical friction angle

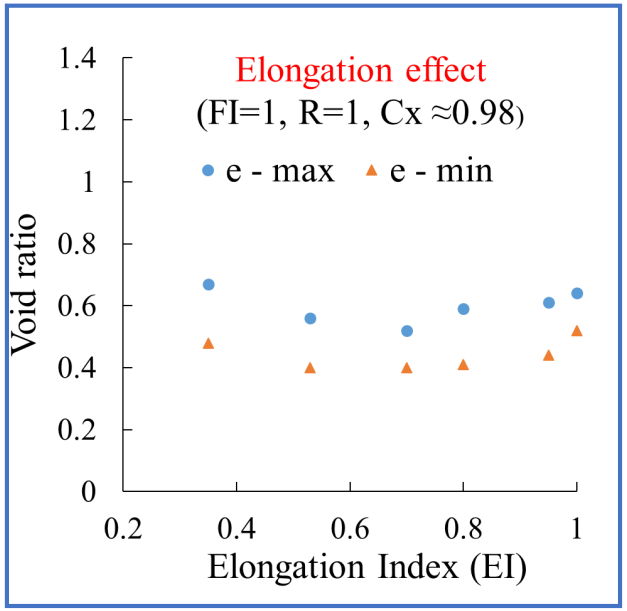


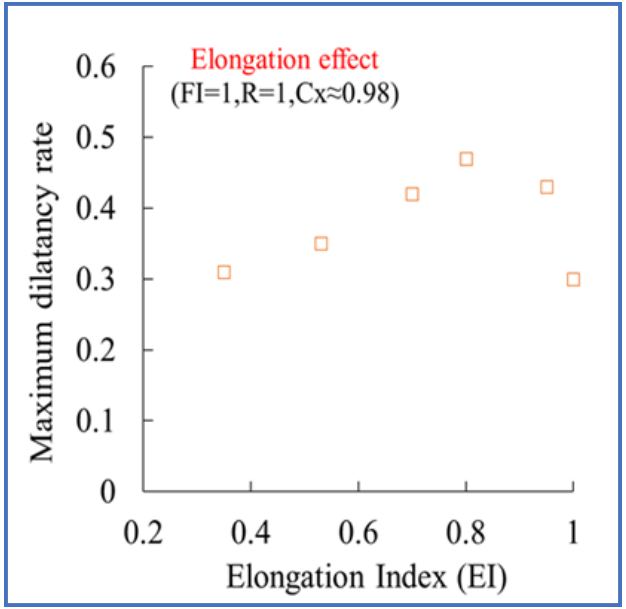
- dv/ds ratio is the gradient of volumetric strain increment and shear strain increment.

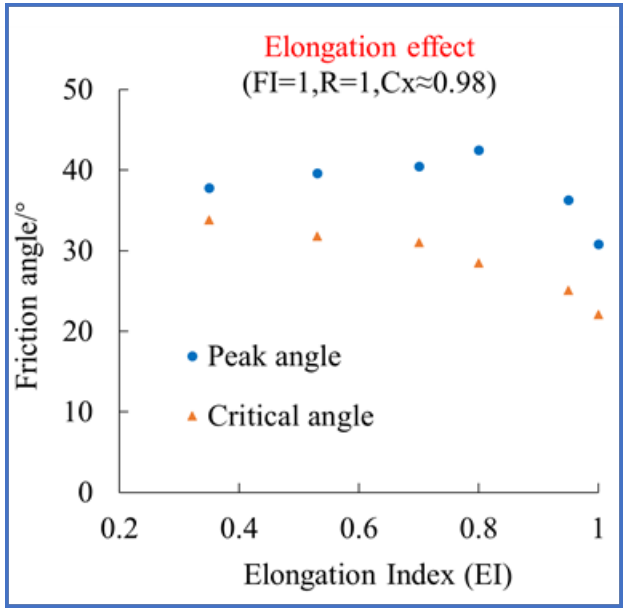


- Maximum dilatancy rate
- Y-axis: stress ratio
  X-axis: dv/ds

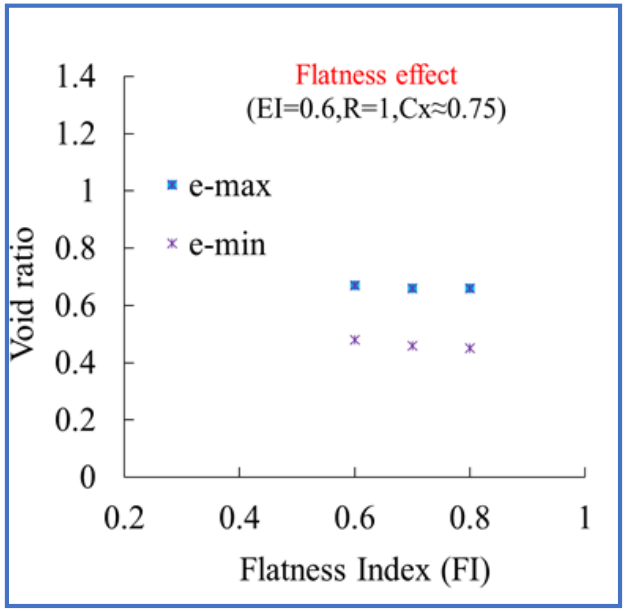
❑ Results – Elongation Effect

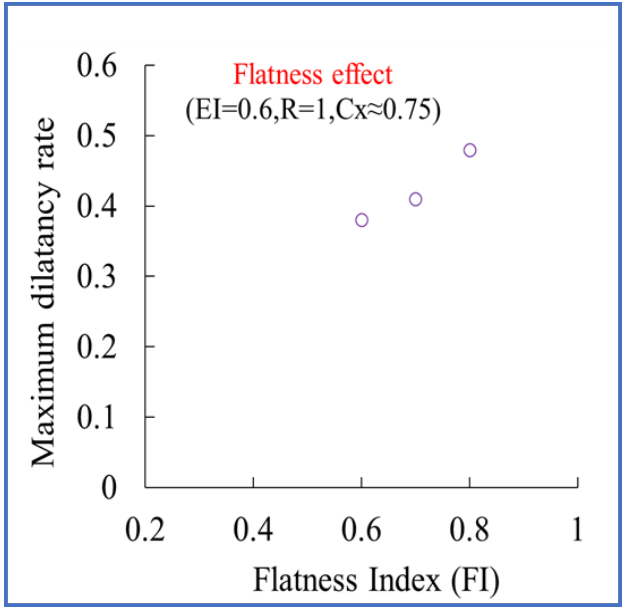


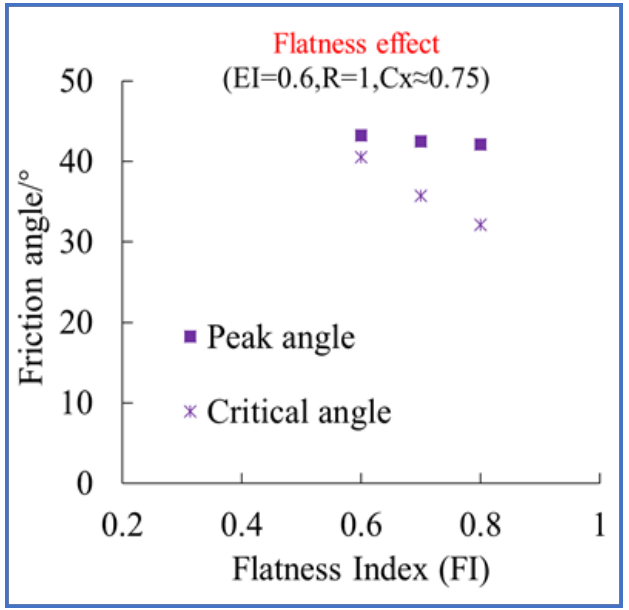




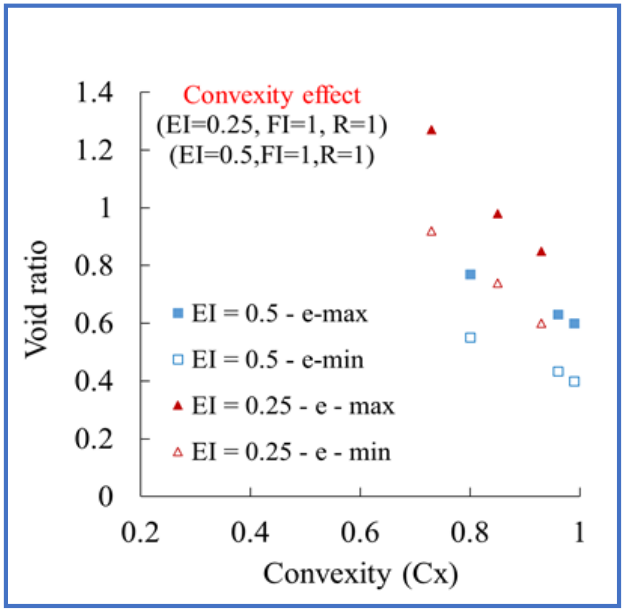
❑ Results – Flatness Effect

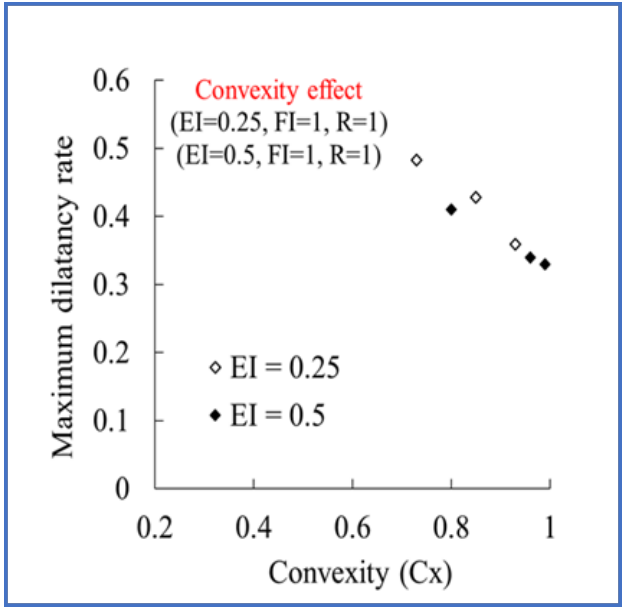


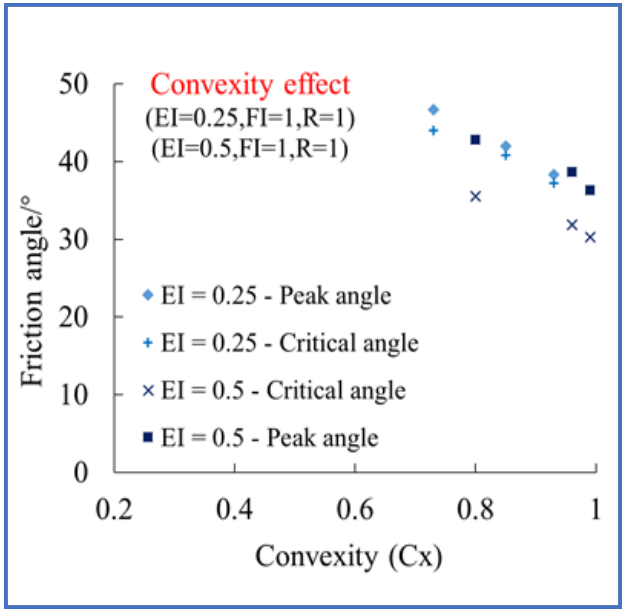




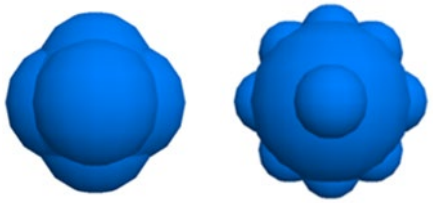
❑ Results – Convexity Effect

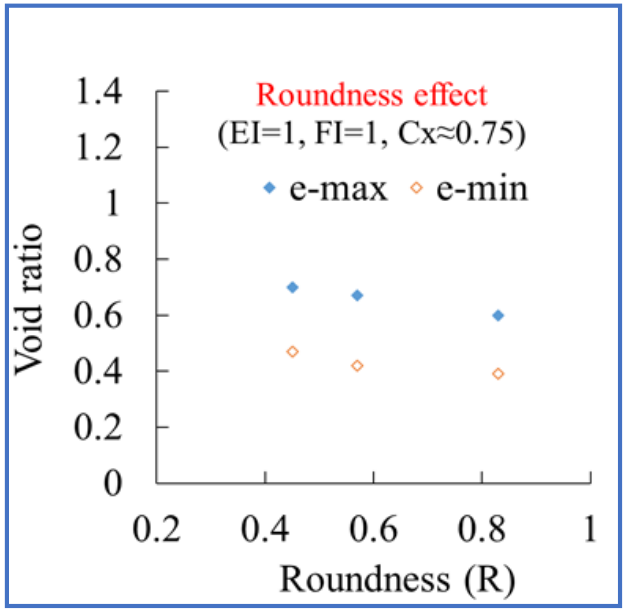


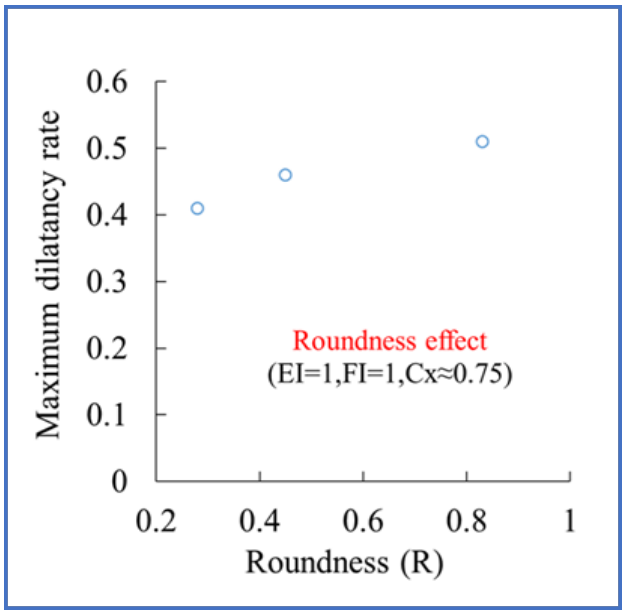


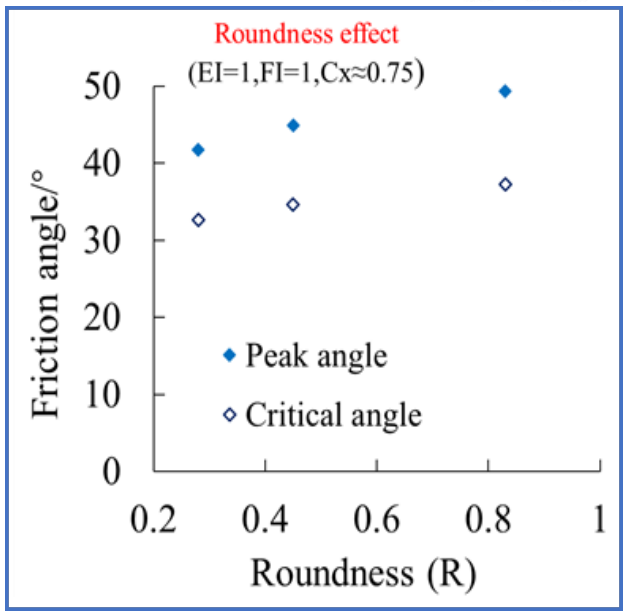


❑ Results – Roundness Effect

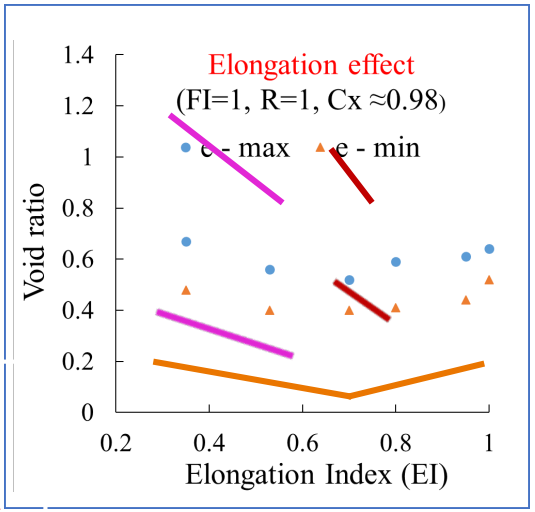


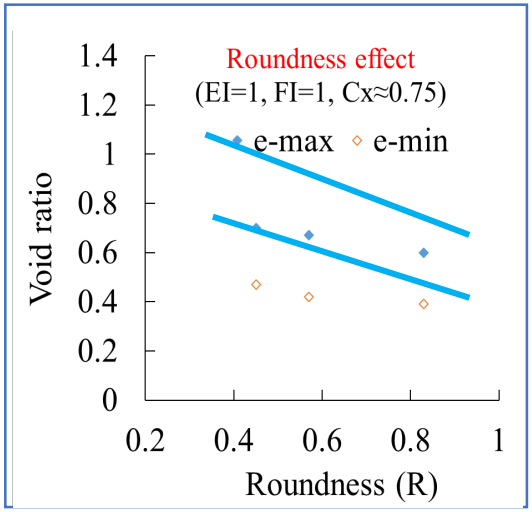


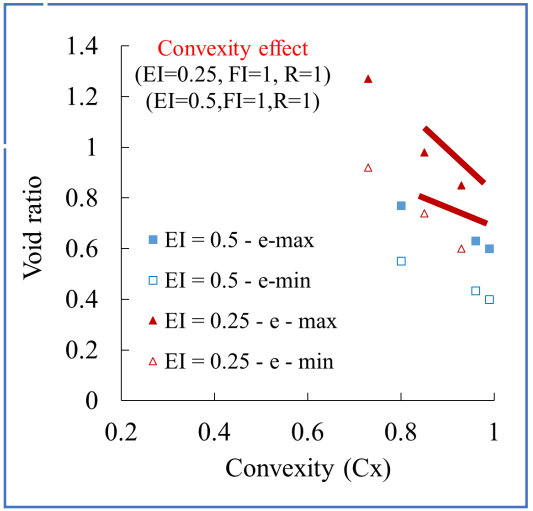




❑ Comparison & Discussion – Packing Ability







Uniformly graded silica

Altuhafi, F. N., Coop, M. R., & Georgiannou, V. N. (2016). Effect of particle shape on the mechanical behavior of natural sands. *Journal of Geotechnical and Geoenvironmental Engineering.*

Zhujiang River sand, Leighton Buzzard sand, Quarts sand

Yang, H., Zhou, B., & Wang, J. (2019). Exploring the effect of 3D grain shape on the packing and mechanical behaviour of sands. *Géotechnique Letters*, *9*(4), 299-304.

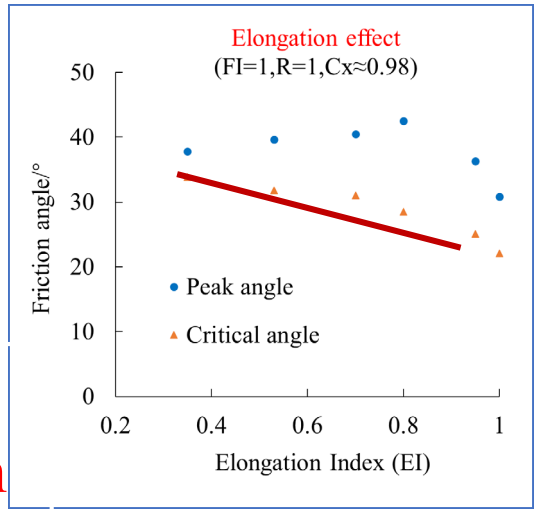
2D DEM Simulation

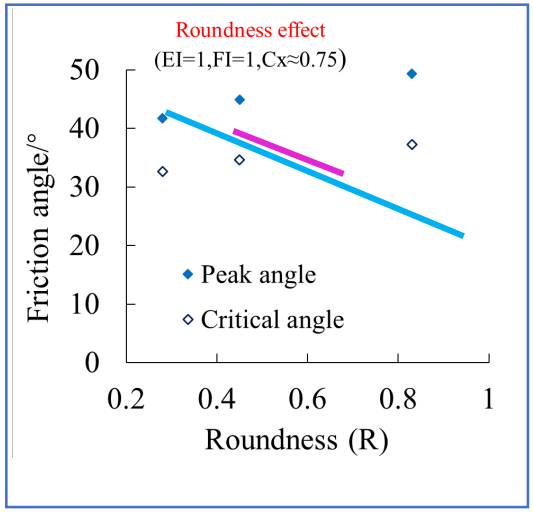
Nouguier-Lehon, C. (2010). Effect of the grain elongation on the behaviour of granular materials in biaxial compression. *Comptes Rendus Mécanique*, *338*(10-11), 587-595.

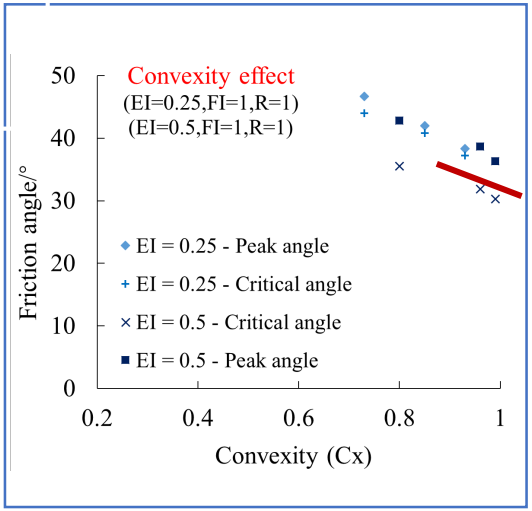
Natural sands

Cho, G. C., Dodds, J., & Santamarina, J. C. (2006). Particle shape effects on packing density, stiffness, and strength: natural and crushed sands. *Journal of geotechnical and geoenvironmental engineering*, *132*(5), 591-602.

❑ Comparison & Discussion – Angles of Friction







Uniformly graded silica

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UNIQUE CONTRIBUTION

- A systematic study on particle shape
- Investigate a specific shape factor effect on shear behavior
- Separate the relative contributions of EI, FI, Cx and Roundness
- Prepare sample via 3D DEM (PFC3D version 5.0)

❑ Conclusions

- Friction angle for roundness shows an opposite trend compared with published results. This imply that there is a packing effect that influences dilation and friction angle.
- The elongation index has an interesting packing effect. Too elongated and too short particles (pure spherical particles) create a particularly loose sample, and the best packing appears at when EI = 0.75.
- The flatness index doesn't change initial packing too much, but it has a big impact to critical friction angle.
- The packing ability, maximum dilatancy rate and friction angle follow a decreasing trend with an increase of convexity.

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