Fabric Analysis of Internally Unstable Soils

Fonseca, J., Sim, W. W., Shire, T., and O’Sullivan, C.
Fabric Analysis of Internally Unstable Soils

- Consideration of the shape of the particle size distribution curve is often used to assess susceptibility to internal erosion.

- What is the link between quantitative assessment of the PSD and the particle-scale fabric of the soil?

- Research considered Kézdi criterion using micro computed tomography.
Micro Computed Tomography (microCT)

- High resolution, three-dimensional images created using X-rays
- Non-destructive
Materials Considered

Leighton Buzzard Sand

WG – Well graded

G1:
86%: 2360\(\mu m\) > D > 1180\(\mu m\)
12%: 300\(\mu m\) > D > 150\(\mu m\)

G2:
73%: 2360\(\mu m\) > D > 1180\(\mu m\)
24%: 300\(\mu m\) > D > 150\(\mu m\)
Sample preparation

Mould placed around membrane

Membrane rolled around mould and suction applied

Dry pluviation
Gap graded pluviated in 200g batches

Gentle vibration

50 kPa vacuum confinement
Mould removal

Cell chamber placed
Cell pressure applied
Suction removed
Sample preparation: Stress path

\[ q \quad [\text{kPa}] \]

-20  50  300

\[ \rho' \quad [\text{kPa}] \]

275.7

\[ 46.6 \]

\[ 300 \]

\[ \phi' = 35^\circ \]

\[ K_0 \quad \text{consolidation} \]

\[ K_0 = 0.43 \]
Sample preparation

- **Displacement Sensor**
- **Load Cell**
- **Loading shaft**
- **Topcap O-rings**
- **Membrane**
- **Suction**
- **Cell Pressure**
- **Ram Pressure**
- **Resin reservoir**
- **Resin feed lines to base of specimen**

Diagram showing the sample preparation setup with various components labeled.
Sample preparation

Well Graded

Gap Graded 1

Gap Graded 2
Micro Computed Tomography (microCT)

Fonseca et al. (2014)
Géotechnique
MicroCT scanning

X-Ray source + typical sample for scanning

(H. Taylor, current PhD student)  

Image source: http://www.nikonmetrology.com
MicroCT Data Analysis

Raw output – 3D attenuation map

(H. Taylor)

2D Slice from μCT image

Binary image

Taylor et al. (2015)
Computers and Geotechnics
Individual particles and contacts from watershed segmentation

(H. Taylor)
Measuring size in μCT data
Measuring size in sieve
Well Graded Sample

% Smaller by volume

Particle Size (µm)

WG Top

WG Middle

WG Bottom

µCT - int. axis, top
µCT - int. axis, mid
µCT - int. axis, base
\( F^{LS} \_	ext{MIN} \)
\( F^{LS} \_	ext{MAX} \)
Sieve
Empirical Filter Criteria: Kézdi (1979)

Split PSD into coarse and fine “PSDs”

Stable if: \( d_{85}^{\text{fine}} > \left( \frac{D_{15}^{\text{coarse}}}{4} \right) \)

i.e. if

\( \frac{D_{15}^{\text{coarse}}}{d_{85}^{\text{fine}}} < 4 \)

Relates to Terzaghi filter rule
Well Graded Sample

WG Top
\[ D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 1.56 \]

WG Middle
\[ D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 1.62 \]

WG Bottom
\[ D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 1.54 \]
Sample G1 (12%: 300μm>D>150μm)

G1 Top

$D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 4.66$

G1 Middle

$D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 3.90$

G1 Bottom

$D_{15}^{\text{coarse}} / d_{85}^{\text{fine}} = 3.30$
Sample G2 (24%: 300μm>D>150μm)

G2 Top

$D_{15\text{ coarse}}/d_{85\text{ fine}}=4.01$

G2 Middle

$D_{15\text{ coarse}}/d_{85\text{ fine}}=4.29$

G2 Bottom

$D_{15\text{ coarse}}/d_{85\text{ fine}}=4.07$
Coordination Number

\[ N_c = \text{Coordination number} \]

No of contacts per particle

Leighton Buzzard Sand
Blue particle
20 contacts

Glass beads
Blue particle
50 contacts

Leighton Buzzard Sand
Blue particle
2 contacts

No of contacts gives indication of kinematic constraint

Images from H. Taylor
Contact Identification
Variation in Coordination No. with Kézdi Ratio

Increasing Kézdi no.

Decreasing stability

Fonseca et al. (2014)
Geotechnique
Shire and O'Sullivan (2013)
Acta Geotechnica
Discrete element method simulations

Spherical particles
Simple contact models
Isotropic samples
Gravity neglected

Shire and O’Sullivan (2013)
Acta Geotechnica
Variation in Coordination No. with Kézdi Ratio

Increasing Kézdi no.

Decreasing stability

Fonseca et al. (2014)
Géotechnique
Shire and O’Sullivan (2013)
Acta Geotechnica
Variation in Coordination No. with $e$

![Graph showing variation in coordination number with void ratio, $e$.](image-url)
Conclusions

• Micro computed tomography enables us to quantify soil structure

• The need to achieve good resolution restricts sample size

• There is a clear correlation between the Kézdi ratio $(D_{15}^{\text{coarse}}/d_{85}^{\text{fine}})$ and coordination number