# Evolution of the contact network toward liquefaction in cyclic shearing of a granular assembly

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# Soil liquefaction

Niigata 1964

Tangshan 1976

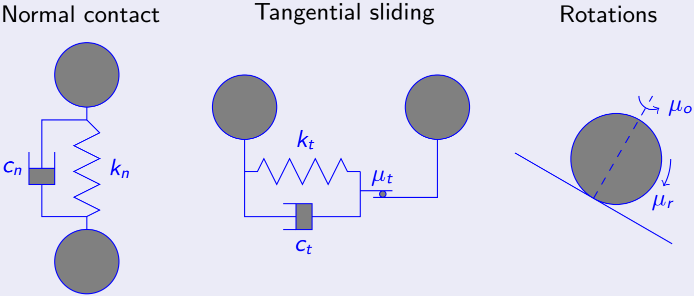
Kobe 1995

Christchurch 2011

What can we learn from the micro-mechanics of granular materials when approaching cyclic liquefaction?

# DEM program - GRFlow3D

## Rheological model




## Model constants

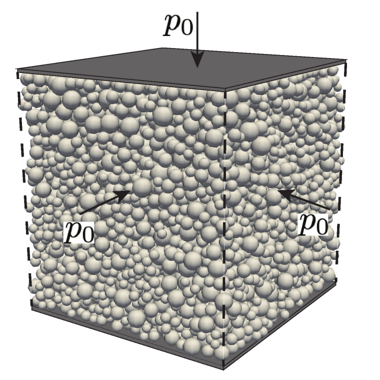
| Symbol | Value |
|---|---|
| $k_n$ (N/m) | $10^6$ |
| $c_n$ (kg/s) | 1.15 |
| $k_t$ | $0.8k_n$ |
| $c_t$ | $0.2c_n$ |
| $\mu_t$ | 0.5 |
| $k_r = k_o$ | $0.1k_n$ |
| $c_r = c_o$ | $0.05c_n$ |
| $\mu_r = \mu_o$ | 0.1 |

## Configuration of simple shear tests

- Assembly of 8000 spherical spheres, with low polydispersity $D_{\max}/D_{\min} = 2$
- Initial condition: isotropic compression until a target $p_0$
- Bi-periodic boundary conditions to constrain lateral normal strains
- Constant height unidirectional cyclic shearing with specified CSRs

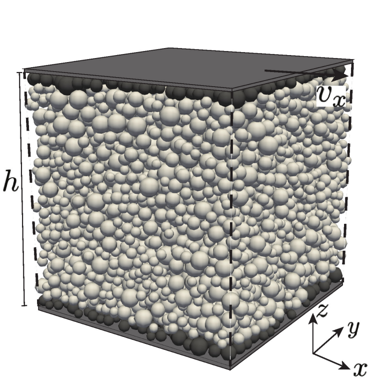
# Simulation procedure: bi-periodic cell

## Sample construction




- Isotropic consolidation
- Velocity & stress control until network is stabilized
- Different $\mu_t$ $\rightarrow$ different densities

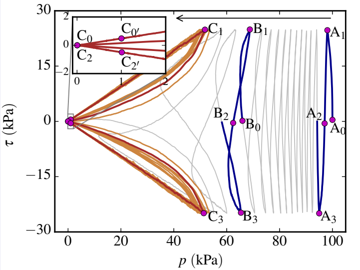
## Cyclic shearing

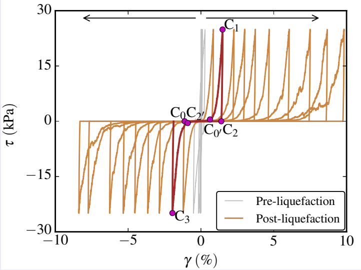


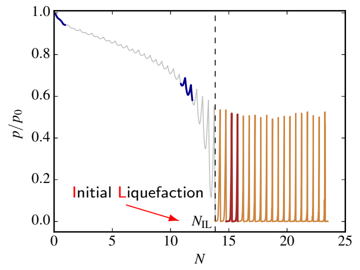

- Constant height
- Constant-velocity shear (reverse the direction when $|\tau| = \tau^{\text{amp}}$)
- $\mu_t$ is fixed as 0.5

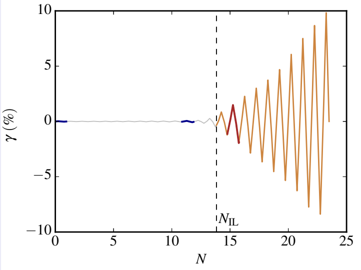
# Macroscopic response

## 4-way: $e_0 = 0.647$, $p_0 = 100$ kPa, CSR $= 0.25$



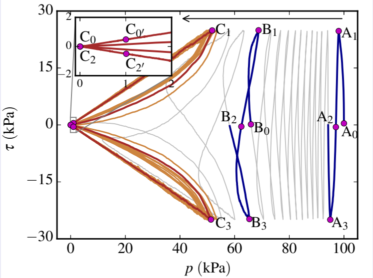



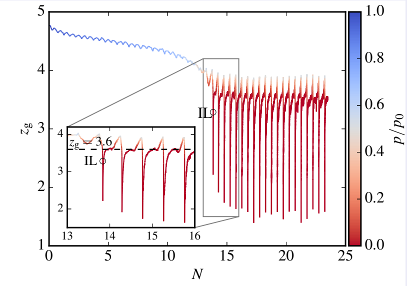



# Particle connectivity

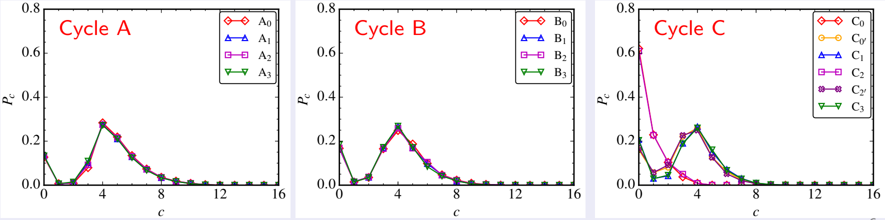
## Stress path




## $z_g$: number of contacts per particle

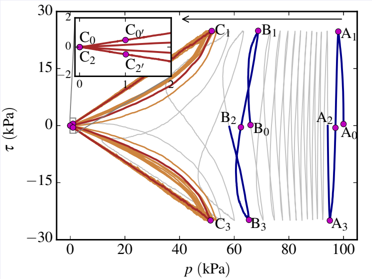



## $P_c$: fraction of particles with $c$ contact



# Force transmission

## Stress path




## Descriptors

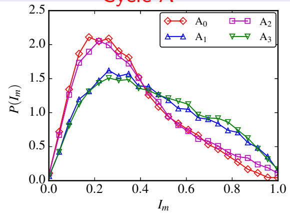
- Friction mobilization index $I_m$ at each contact:

$$I_m = \frac{|\boldsymbol{f}_t|}{\mu_t f_n}$$

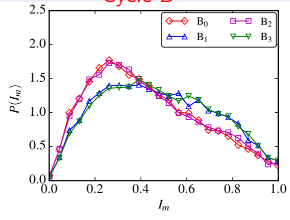
$I_m = 1$ refers to sliding contact

## $P(I_m)$ vs $I_m$

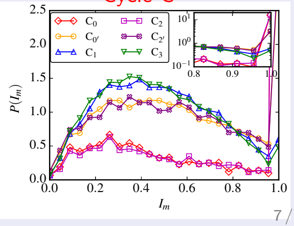
Cycle A




Cycle B




Cycle C



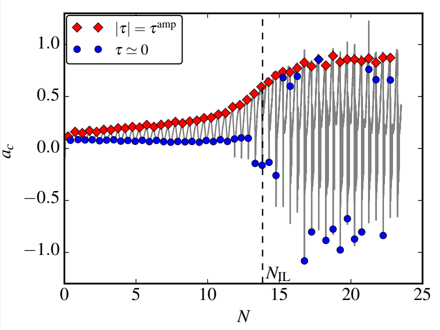
# Anisotropies

## Descriptors

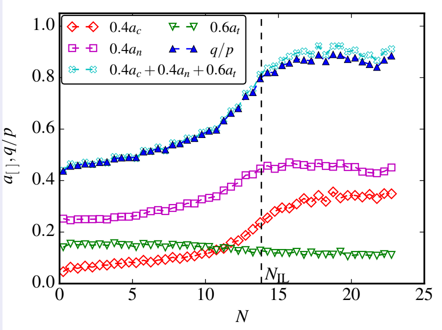
- Fabric and force anisotropies: $a_c$, $a_n$, and $a_t$, distributions of $\boldsymbol{n}$, $\langle f_n \rangle(\boldsymbol{n})$, and $\langle \boldsymbol{f}_t \rangle(\boldsymbol{n})$
- Stress-force-fabric (S-F-F) (Ouadfel and Rothenburg 2001)

$$\frac{q}{p} \simeq \frac{2}{5}\left(a_c + a_n + \frac{3}{2} a_t\right)$$

## Fabric anisotropy $a_c$




## S-F-F at $\tau = \tau^{\mathrm{amp}}$



# Between fluid-like and solid-like

## A post-liquefaction cycle

# Take away points

- Approaching liquefaction, the granular system presents
  - rapid drop of coordination number following a gradual weakening of the contact force network due to prevented dilation at constant volume
  - high friction mobilization and high anisotropies developed to support shear forces with a reduced number of contacts
- To exit liquefaction state, the granular system deforms significantly to reconstruct the contact network for a specific value of the coordination number ($z_g \simeq 3.6$)
- For more details, refer to: Yang et al. (2021), Evolution of granular materials under isochoric cyclic simple shearing. *Physical Review E*, 103: 032904.

# Bibliography I

[1] H. Ouadfel and L. Rothenburg. "'Stress–force–fabric' relationship for assemblies of ellipsoids". In: *Mechanics of Materials* 33.4 (2001), pp. 201–221. DOI: https://doi.org/10.1016/S0167-6636(00)00057-0.