# Geometrical network of granular materials under isochoric cyclic shearing

Ming Yang[1,*] Mahdi Taiebat[1,**] Patrick Mutabaruka[2,***] Farhang Radjaï[3,****]

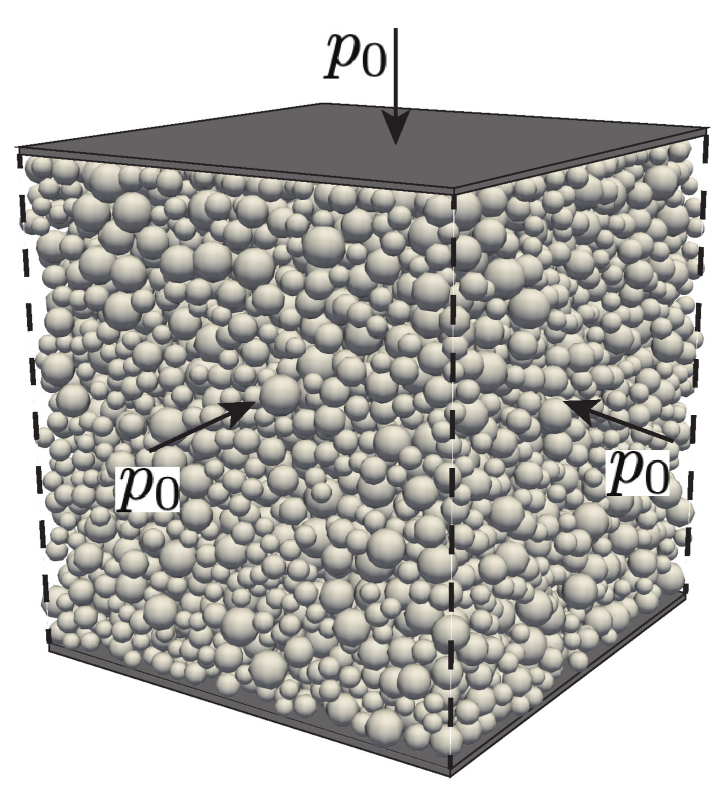
[1]University of British Columbia, Vancouver, Canada [2]IFREMER, DYNECO/DHYSED, Plouzané, France [3]University of Montpellier, Montpellier, France

## Introduction

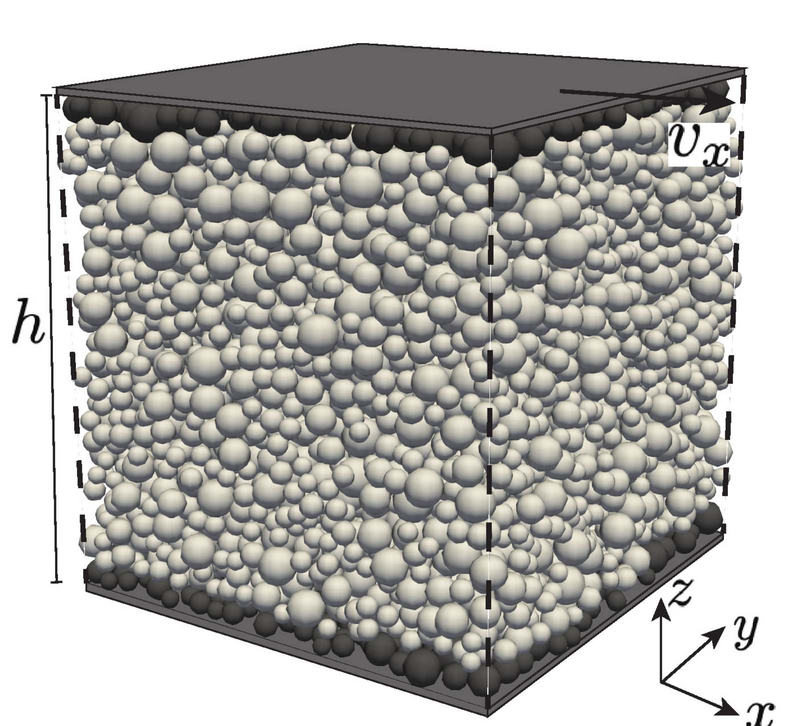
- Cyclic liquefaction of granular materials
- Long-term evolution of contact network
- Jamming transition between solid-like and fluid-like

## Protocols

- Bi-periodic boundary
- Isotropic compression with $p_0 = 100$ kPa
- Constant-volume cyclic shear with a constant shear strain rate




(a)

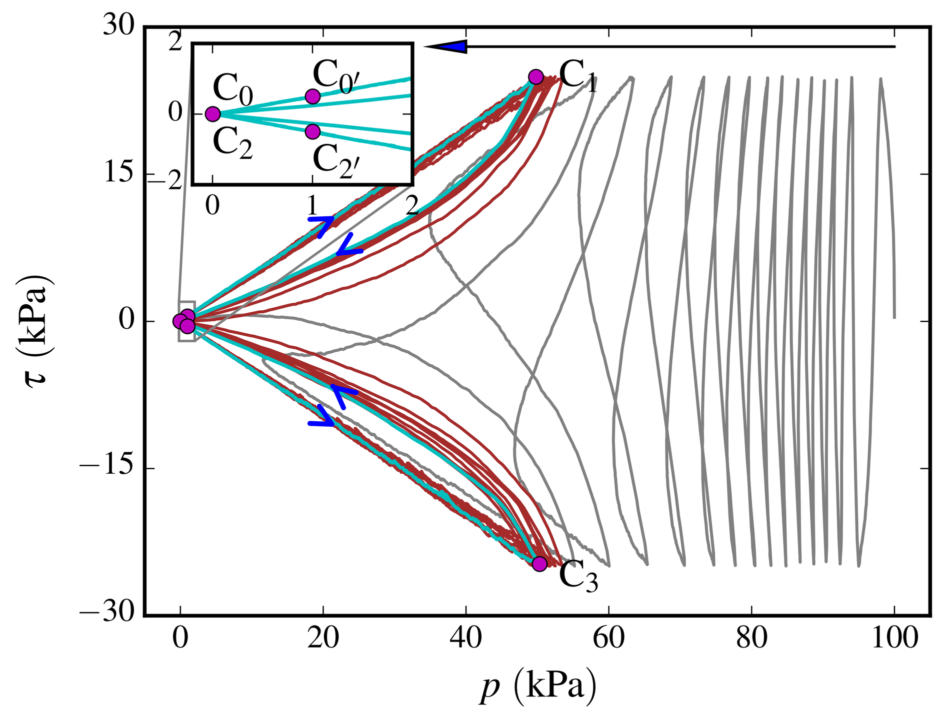



(b)

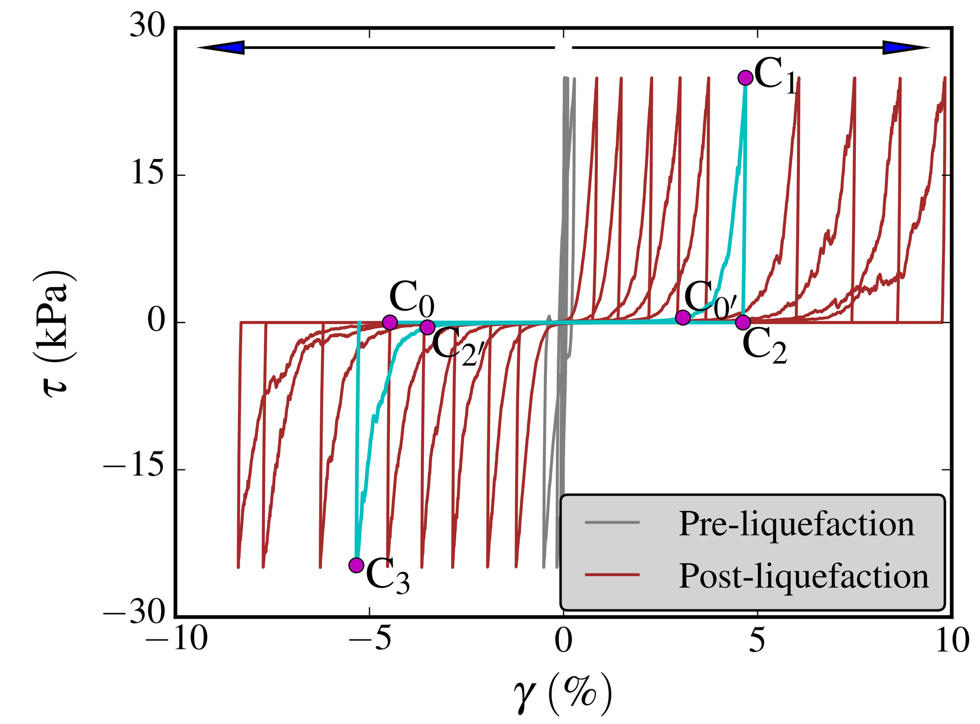
Figure 1: Particle arrangements and boundary conditions for a sample composed of 8000 spheres: (a) at the end of sample preparation; (b) during constant height cyclic shearing. Gray particles are glued to the top and bottom walls of the bi-periodic cell.

Contact info: *yangm15@civil.ubc.ca
**mtaiebat@civil.ubc.ca
***patrick.mutabaruka@ifremer.fr
****franck.radjai@umontpellier.fr

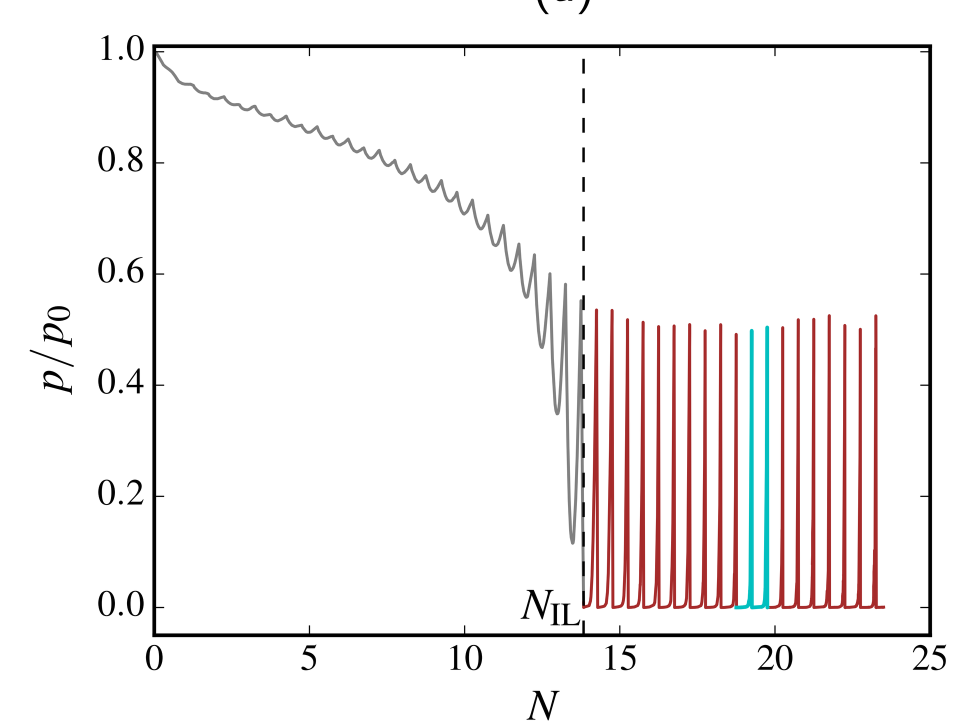
## Macro



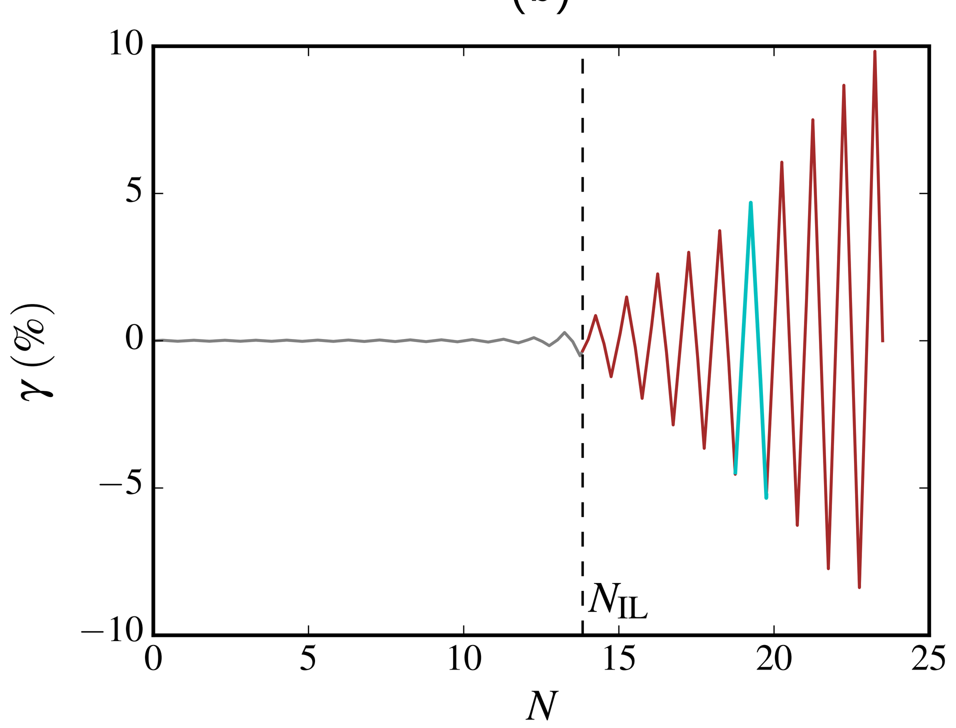

(a)




(b)




(c)




(d)

Figure 2: Macroscopic response of isochoric cyclic shear test: (a) stress path; (b) stress-strain curve; (c) normalized mean stress evolution; (d) shear strain development. Initial liquefaction ($N_{IL}$) refers to the first time that $p/p_0$ drops below 0.01. A post-liquefaction cycle C is highlighted in cyan. Points $C_0$(or $C_2$), $C_{0'}$(or $C_{2'}$), and $C_1$(or $C_3$) correspond to selected states of $\tau \simeq 0$, $p/p_0 \geq 0.01$ (exiting liquefaction), and $|\tau| \simeq \tau^{amp}$ (shear stress amplitude), respectively.

## Micro

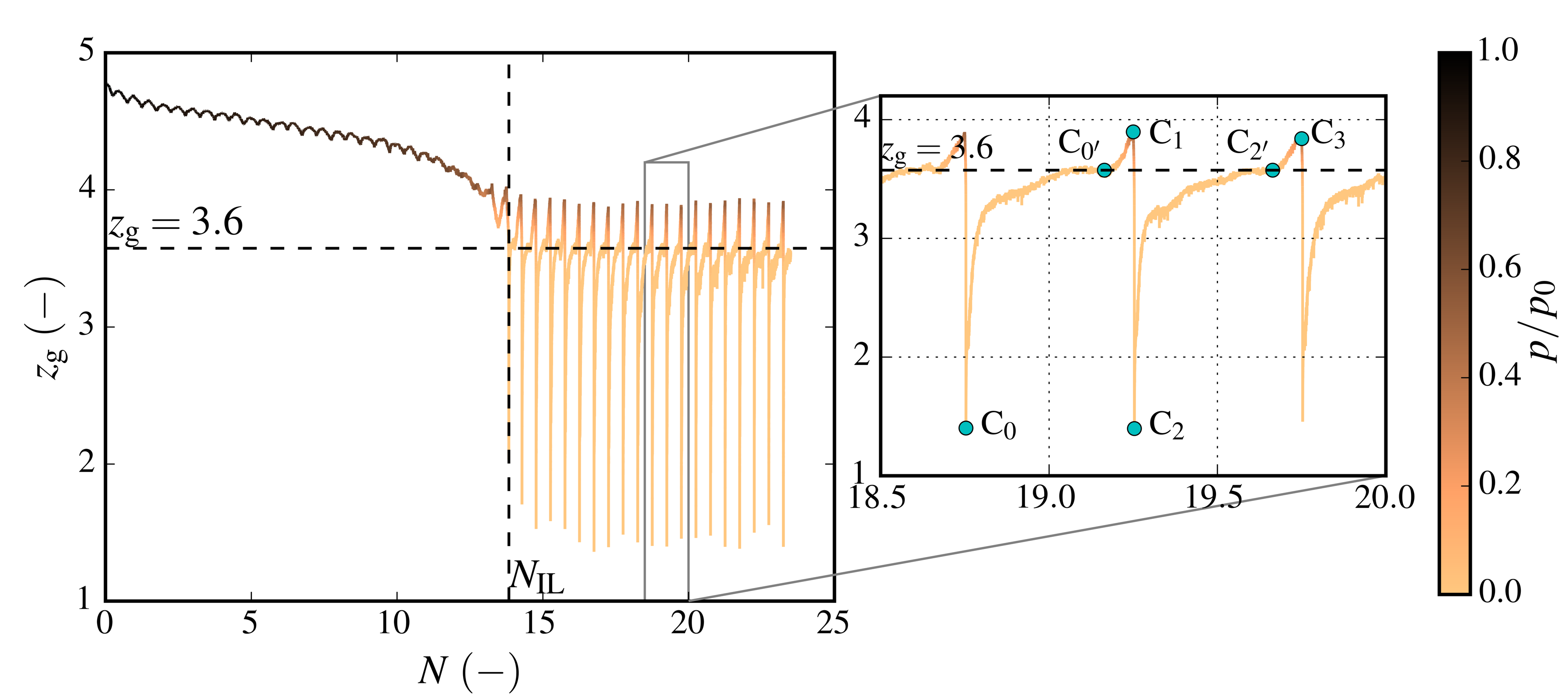



Figure 3: Evolution of coordination number $z_g$ during cyclic shearing. $z_g = 2N_c/(N_p - N_p^0)$ where $N_p$ is the number of particles, $N_p^0$ is the number of particles without contacts, and $N_c$ is the number of contacts. The zoomed-up window is to present details of $z_g$ evolution in cycle C. $z_g \simeq 3.6$ coincides with the exit of liquefaction ($C_{0'}$ or $C_{2'}$).

## Micro

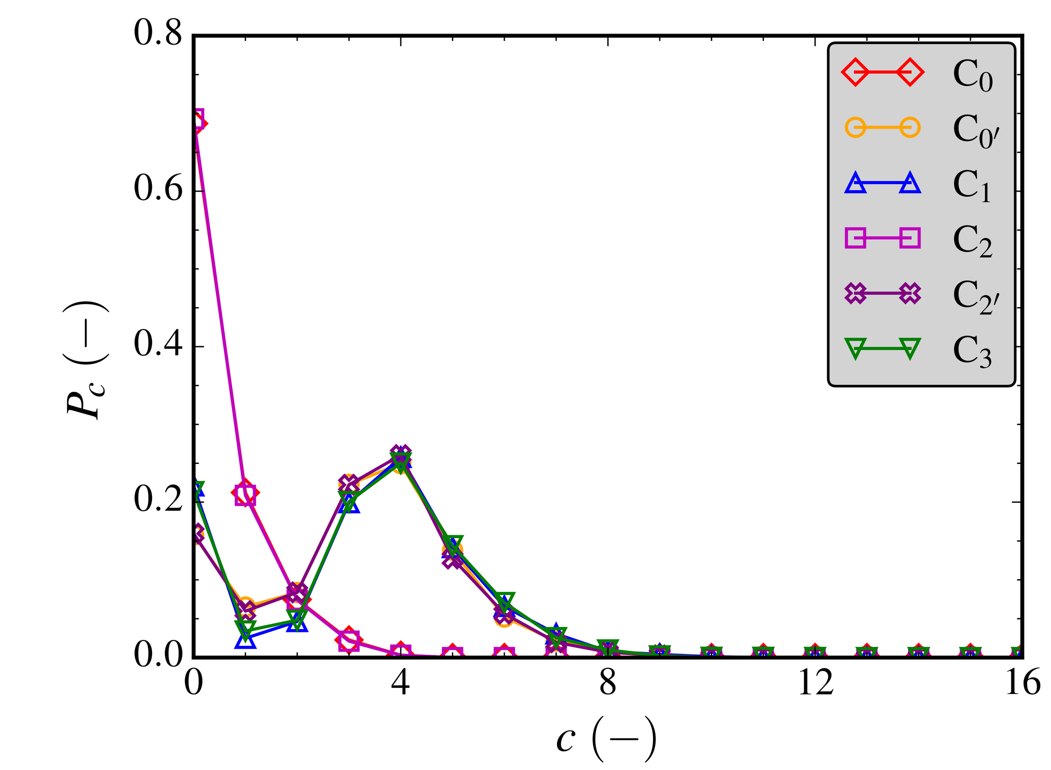



Figure 4: The connectivity $P_c$ of the contact network in the post-liquefaction cycle C. $P_c$ is defined as the proportion of particles with exactly $c$ contacts.

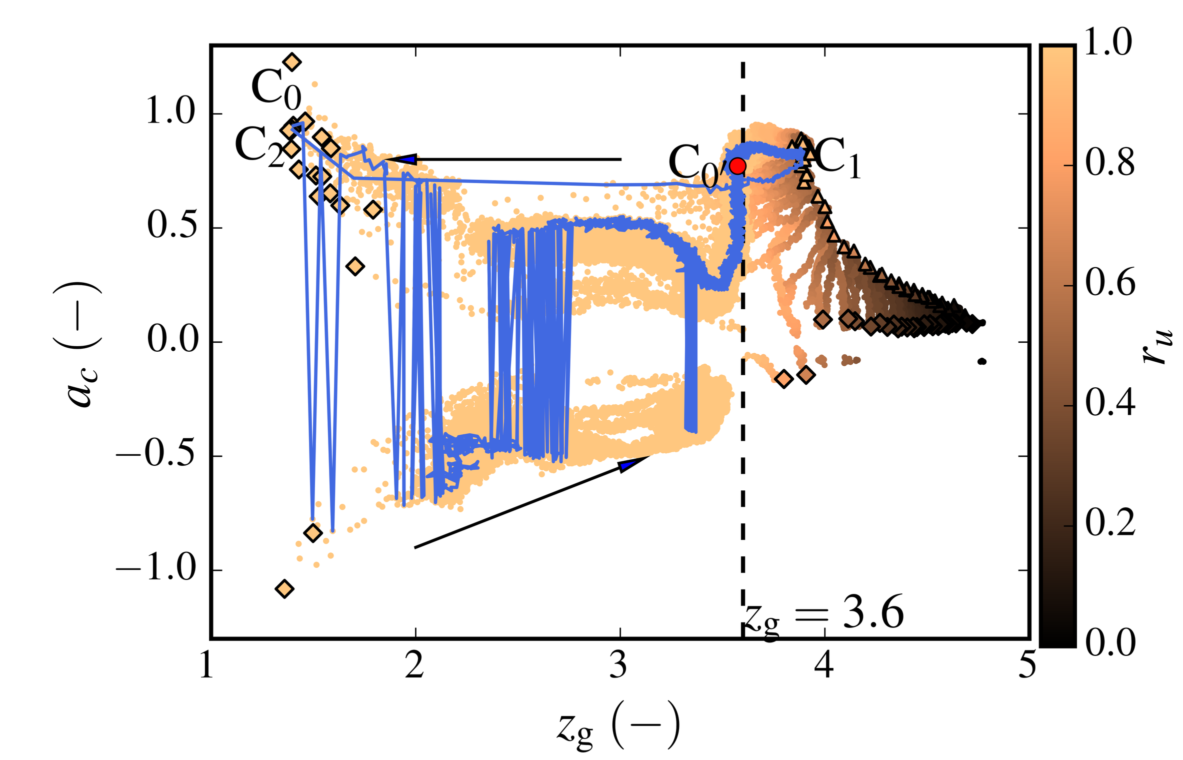



Figure 5: Evolution of the fabric anisotropy $a_c$ versus coordination number $z_g$ during cyclic shearing. $a_c = \text{sign}(S_c)\sqrt{(3/2)\mathbf{a}_c : \mathbf{a}_c}$ where $S_c = \mathbf{a}_c : \mathbf{s}/(\sqrt{\mathbf{a}_c : \mathbf{a}_c}\sqrt{\mathbf{s} : \mathbf{s}})$, $\mathbf{s}$ is the deviatoric stress tensor, and $\mathbf{a}_c$ is fabric anisotropy tensor related to contact normals.

## Conclusion

- Contact network collapses with unloading to liquefaction and isotropic loss of contacts: high proportion of floaters
- Rebuilding contact network in liquefaction occurs with large deformation and anisotropic gain of contacts, the exit quantified by $z_g \simeq 3.6$

1. M. Yang, M. Taiebat, P. Mutabaruka, F. Radjaï, EPJ Web Conf. **249**, 11004 (2021)
2. M. Yang, M. Taiebat, P. Mutabaruka, F. Radjaï, Physical Review E **103**, 032904 (2021)
3. M. Yang, M. Taiebat, P. Mutabaruka, F. Radjaï, Acta Geotechnica (2021) doi: 10.1007/s11440-021-01239-0