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Multidirectional cyclic shearing of granular media using discrete element simulations

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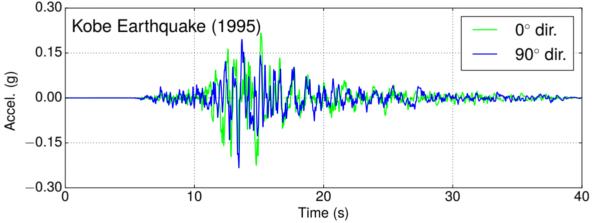
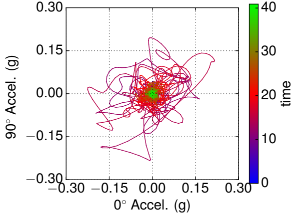
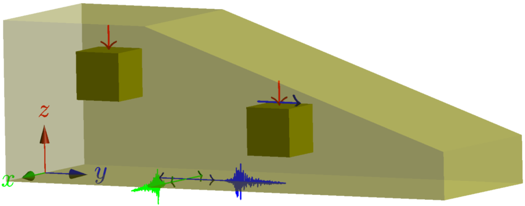
Motivation: multidirectional shear mode



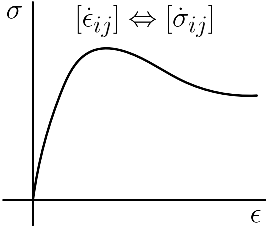
Time history



Accel. orbit

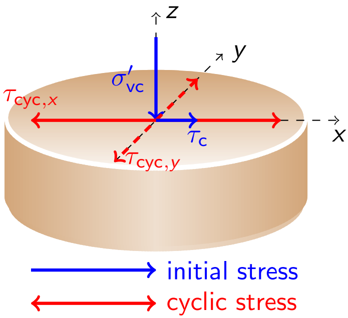


Level and sloping grounds



Stress-strain response

Multidirectional cyclic shear test



Schematic illustration

Static & Cyclic Stress Ratios:

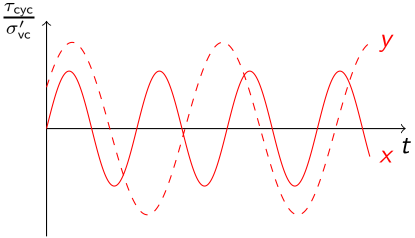
$$\mathrm{SSR} = \frac{\tau_c}{\sigma'_{vc}}$$

$$\mathrm{CSR}_{[\ ]} = \frac{\mathrm{Amplitude}\{\tau_{cyc,[\ ]}\}}{\sigma'_{vc}}$$

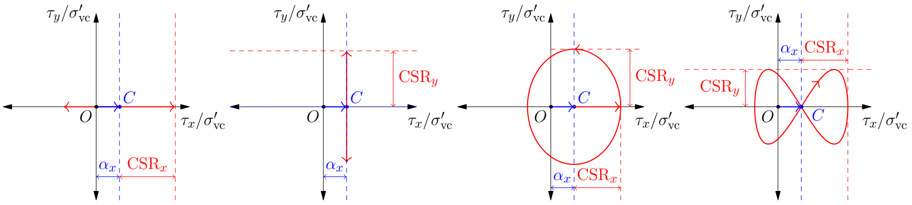
Yang et al. (2016):

$$\frac{\tau_{cyc,x}}{\sigma'_{vc}} = \mathrm{CSR}_x \sin(2\pi f_x t)$$

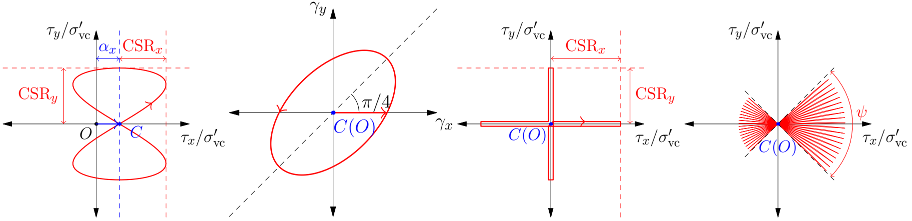
$$\frac{\tau_{cyc,y}}{\sigma'_{vc}} = \mathrm{CSR}_y \sin(2\pi f_y t + \phi)$$



Idealized multidirectional shear path - Yang et al. (2018)



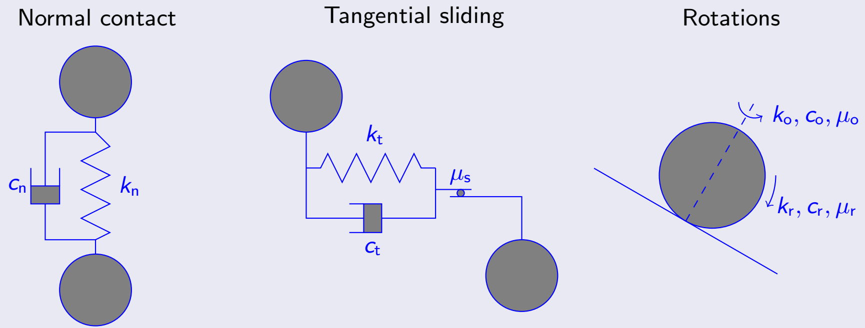
(a) Simple shear (b) 2-D linear (c) Circular/oval (d) Fig-8 type A



(e) Fig-8 type B (f) Rotated oval (g) Alternate (h) Sector

DEM program - GRFlow3D by Mutabaruka (2013)

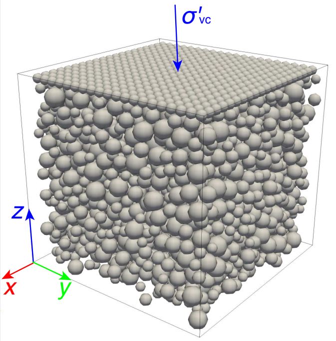
Rheological model



- Assembly of spherical particles, with low polydispersity
- Bi-periodic boundary conditions to constrain lateral normal strains
- Initial condition: $\sigma'_{vc} = 100$ kPa, $e_0 = 0.622$ (Medium dense)
- Constant volume multidirectional cyclic shearing with $\mathrm{CSR}_{[\,]} = 0.25$

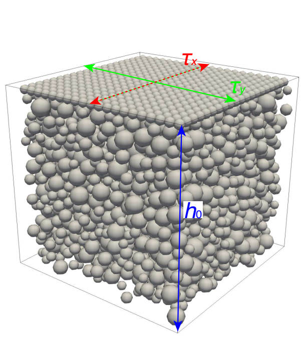
Simulation procedure

1. Sample construction



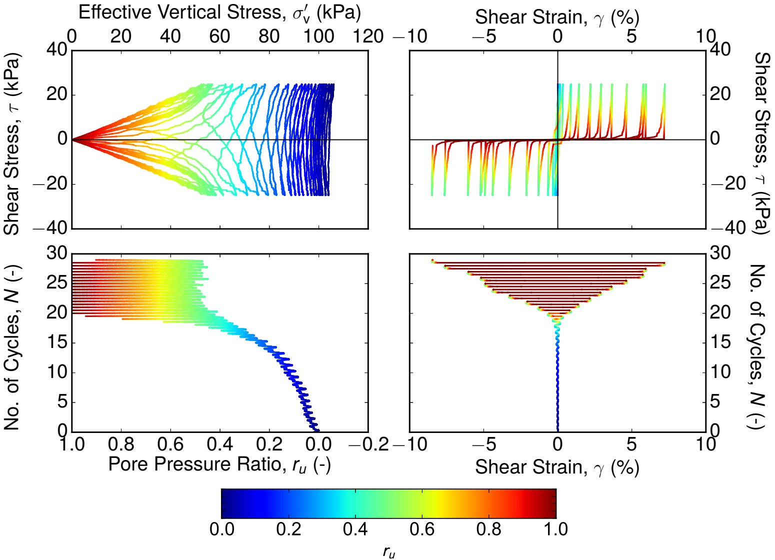
- K_0 compression
- Velocity & stress control until network is stabilized

2. Undrained cyclic shearing

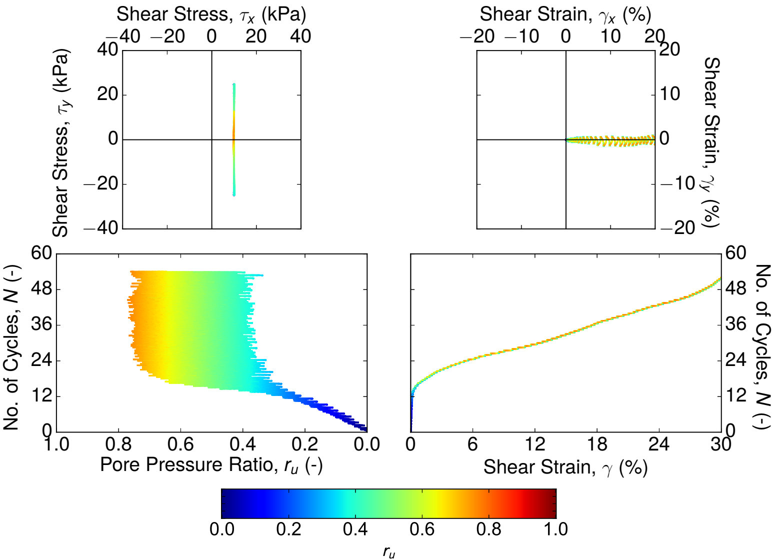


- Constant height
- Stress control: iterative scheme to follow specified shear stress path

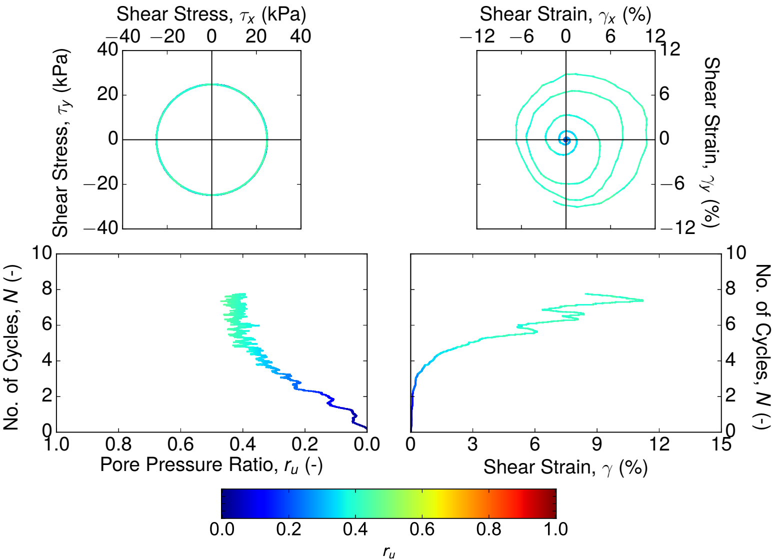
Stress-strain response - Simple shear



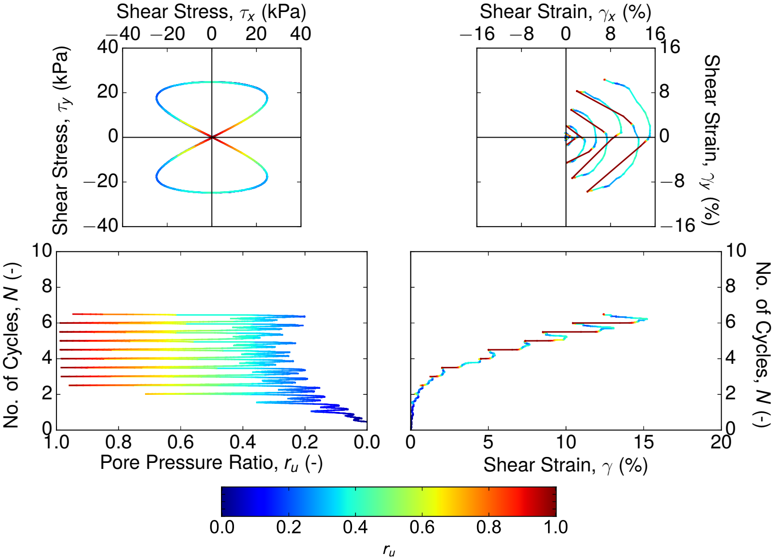
Stress-strain response - 2-D linear



Stress-strain response - Circular



Stress-strain response - Figure-8



Relevant definitions

Coordination number

- Average number of contacts per particle
- Floating particles (N_p^0) are neglected
- "Geometrical coordination number" by Thorton (2015)
- Critical value: 4.0 $\Rightarrow$ statistically (in)determinate

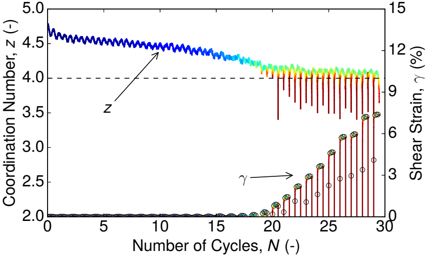
$$z = \frac{2N_c}{N_p - N_p^0}$$

Index of redundancy

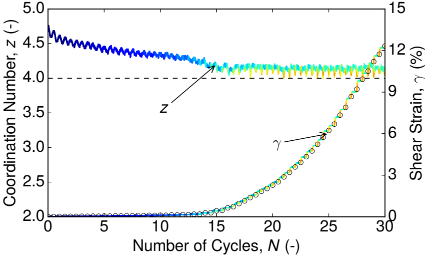
- Total number of constraints over total number of degrees of freedom
- Reduced number of constraints for sliding contacts (proportion: f)
- Floating particles (N_p^0) are neglected
- Critical value: 1.0 $\Rightarrow$ mechanically (un)stable

$$I_R^{NR} = \frac{(3 - 2f)N_c}{6(N_p - N_p^0)}$$

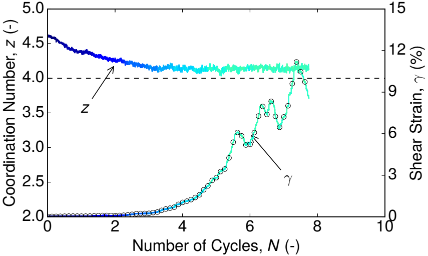
Coordination number



Simple shear



2-D linear



Circular

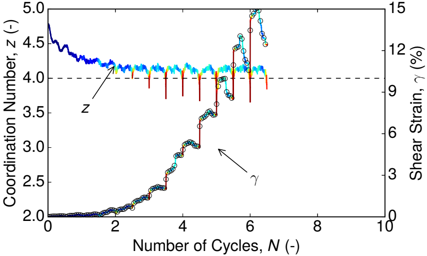
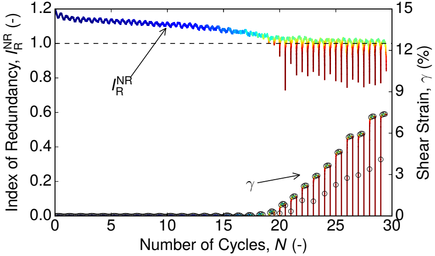
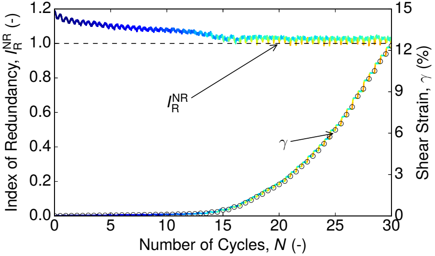


Figure-8

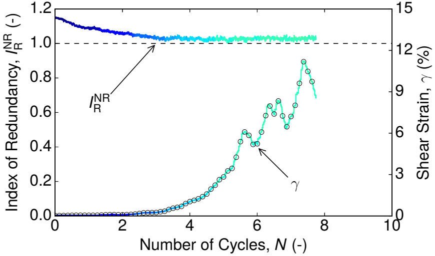
Index of redundancy



Simple shear



2-D linear



Circular

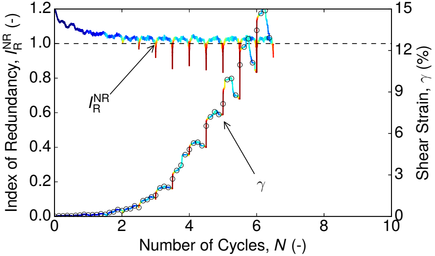


Figure-8

Conclusions

- "Numerical experiments" from DEM reproduce accumulation of shear strains and excess pore pressure as observed in the laboratory experiments. Abrupt large deformation happens at low mean effective stress. Large deformation can accumulate gradually when mean effective stress is not very low.
- Instant drop of coordination number is related to low mean effective pressure, which accounts for abrupt large deformation.
- Index of redundancy is a good indicator of mechanical stability of a granular system, which accounts for abrupt large deformation.
- Extra work on micromechanics-driven measures (beyond contacts) should be done to reveal why large deformation can accumulate gradually.

Thank you!

Bibliography I

Ming Yang et al. "Bidirectional monotonic and cyclic shear testing of soils: state of knowledge". In: *69th Canadian Geotechnical Conference*. Paper ID: 4198, 8 pages. Vancouver, BC, Canada, 2016.