Contact longevity, speed, and migration during loading of dense granular materials

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Regime of interest

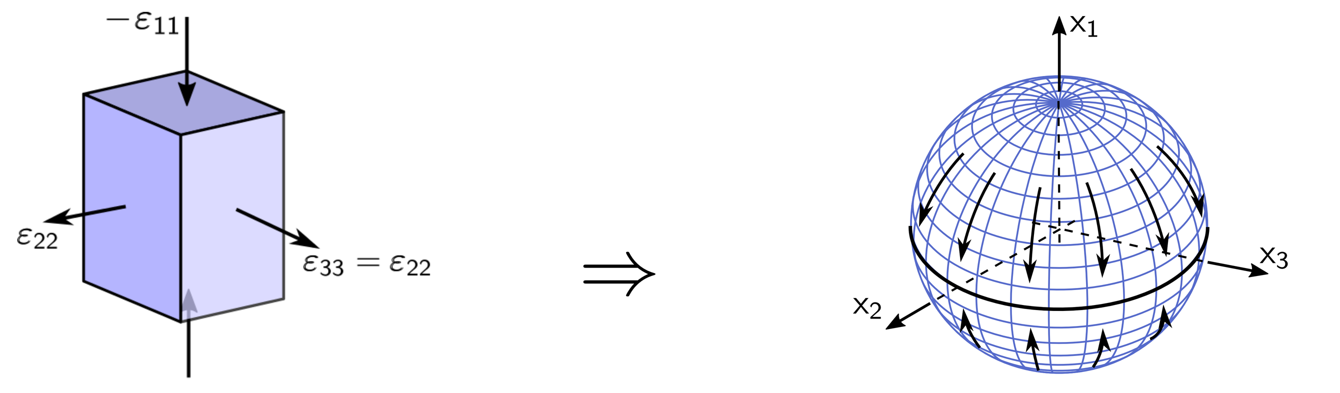
Slow quasi-static deformation of granular assemblies: spheres and non-convex sphere clusters. DEM simulations.

Questions concerning slow quasi-static loading

1. How active are particle and contact motions during slow loading?
2. How closely do motions conform with an affine field?
3. How frequently are contacts created and separated?

General contact migration — trixial compression

Contacts mapped onto the unit sphere of orientations:

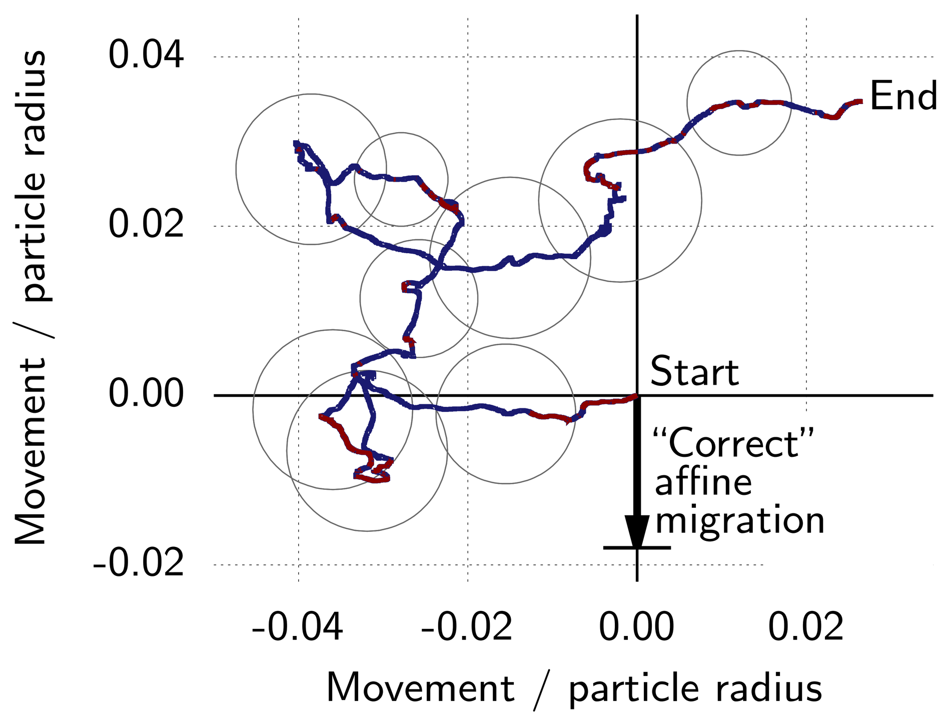


Vertical triaxial compression

General migration of contacts on the unit sphere

- In general, contacts are "conveyed" from directions of compressive strain toward directions of extensional strain.
- These are "general trends," which are only distinguished by observing the motions of thousands of contacts.

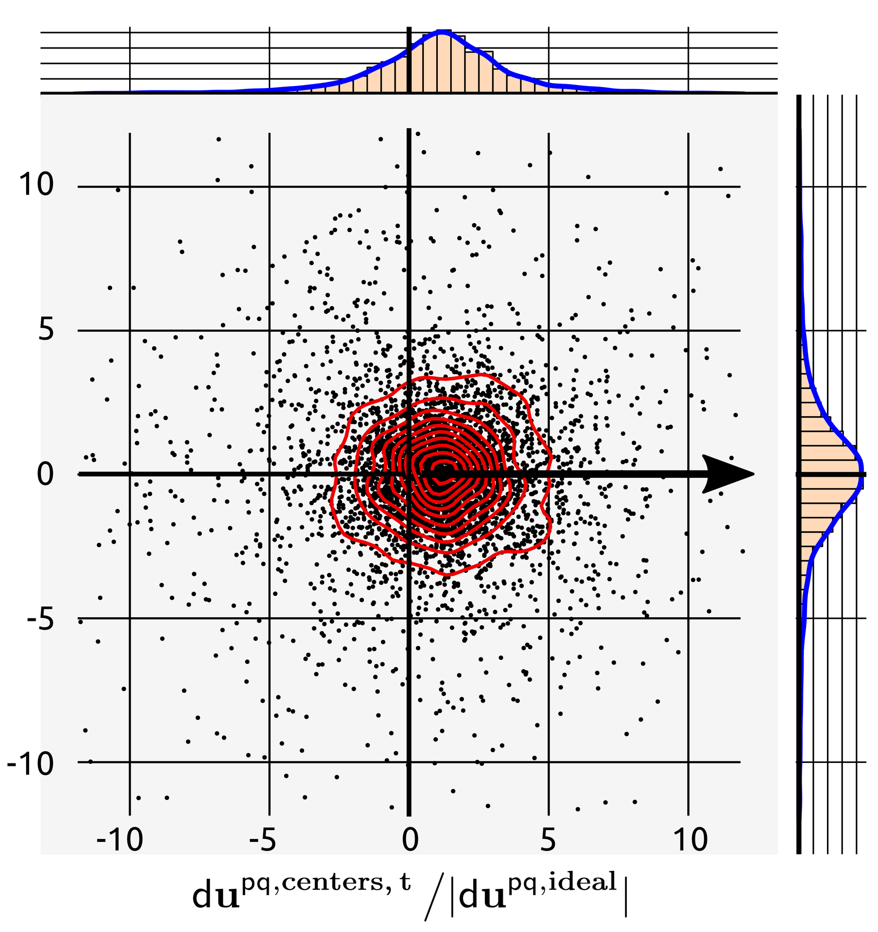
"Trail" of a typical contact moving across a particle



Circles show size of contact "patch" at various times. Affine movement is downward (and of the size of the arrow).

- Actual contact motions are quite erratic.
- Contact slip occurs intermittently (in red).
- Motion is often in the "wrong direction" — opposite the general direction of contact migration.
- Motion rates are much larger than the strain rate (see below).

Particle motions rarely conform with an affine field



- In the figure, a value of $(0,1)$ corresponds to the affine field. Affine motion is to the right.
- Motions are large and highly varied, and many particles move in the "wrong direction."
- Dispersion of contact motions increases with strain.

Tangential contact motions are a complex combination of rolling, sliding, and rigid rotation

	Average ratio: movement / affine value	
	Spheres	Clusters
Small strain		
$\lvert d\mathbf{u}^{\text{particle centers}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	7.4	5.4
$\lvert d\mathbf{u}^{\text{contact sliding}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	5.9	5.4
$\lvert d\mathbf{u}^{\text{contact roll}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	14.4	1.9
Large strain		
$\lvert d\mathbf{u}^{\text{particle centers}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	15.4	7.5
$\lvert d\mathbf{u}^{\text{contact sliding}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	9.7	7.9
$\lvert d\mathbf{u}^{\text{contact roll}}\rvert / \lvert d\mathbf{u}^{\text{affine}}\rvert$	39.4	5.1

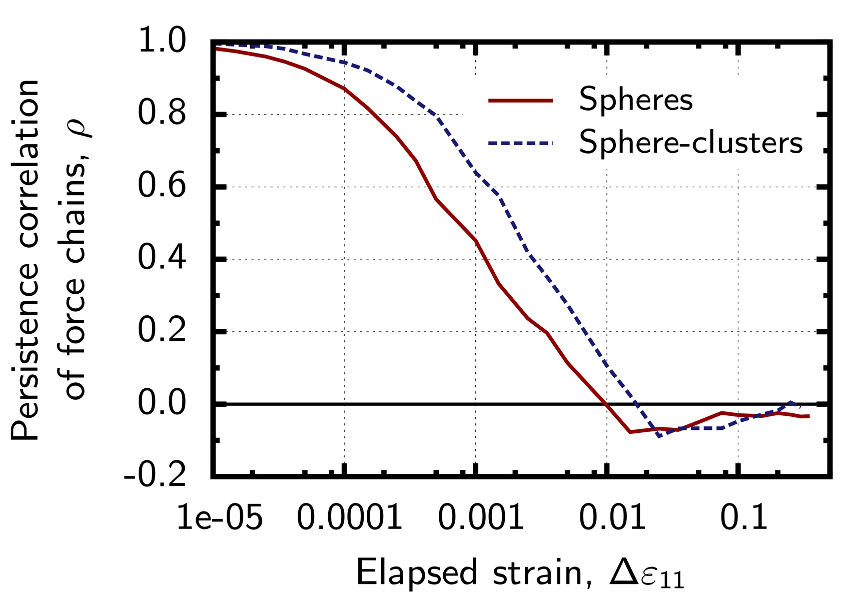
- Contact motions are 2–40 times larger than affine values.
- Contact motions increase with increasing strain.
- Spheres vs. clusters: Cluster motions are closer to the affine condition.

Contact longevity: half-life (in strain) of a contact

	Half-life, strain	
	Spheres	Clusters
Initial contacts	0.0068	0.0041
Subsequent contacts	0.00018	0.0024

- During slow loading, contacts are ephemeral. Only half of the initial contacts remain after 1% strain. Subsequently created contacts have a much shorter half-life.
- For each contact at a current strain, 4–7 contacts will be created (and 4–7 will be broken) during the next 1% strain.

Persistence of "force chains" across strains



- Figure shows the fraction of remaining force chains, starting at strain $\varepsilon_{11} = 6\%$.
- Force chains are ephemeral.
- The "half-life" of force chains is a strain of 0.05%–0.2%.

Observations and more questions

- How are we to develop continuum models that are based on micro-mechanics when grain motions are so varied, irregular, and nearly erratic?
- Motions are more regular for non-convex particles than for spheres, and motions are more regular at small strains than at large strains. Perhaps micro-mechanics of highly non-convex particles and be effectively used for sands at small strains.
- Perhaps non-deterministic models — kinetic theories and entropy-based approaches — can give better results for granular materials than can deterministic multi-scale models.

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