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Effect of grain fracture on stick-slip dynamics of granular fault gouge

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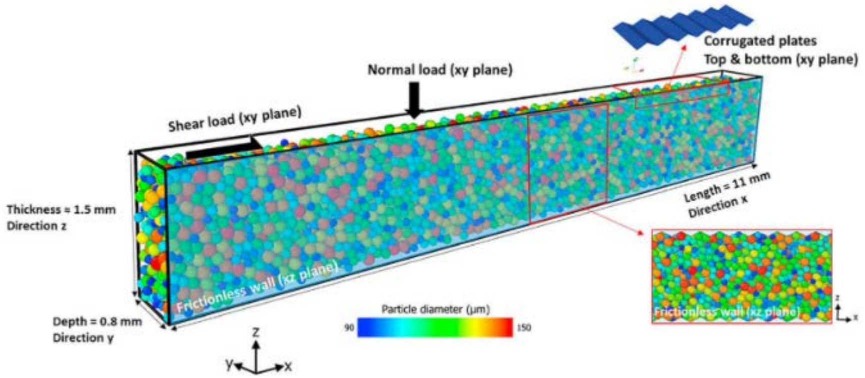
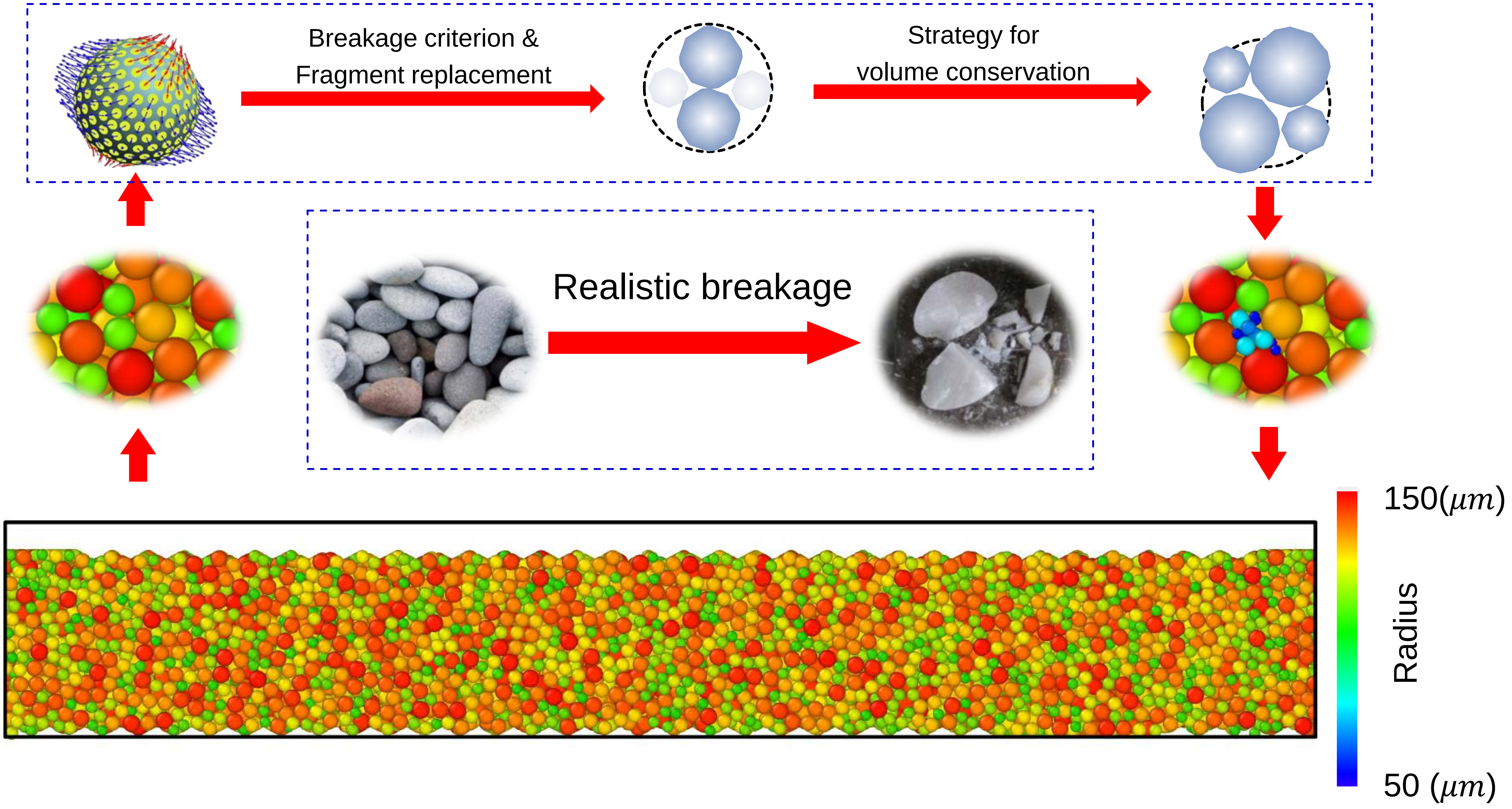
Research background

Effect of grain fracture on stick-slip dynamics of granular fault gouge



- Granular in fault gouge usually under high confining or shear stress where easy to get crushed.
- If particles get broken, it will cause immediate stress drop, force chain break and reorganization, changes of angularity of each grain, the evolution of grain size distribution, and as a result, changes the property of fault gouge.
- We are interested in the influence of grain fracture and evolution, especially on the stick-slip dynamic. It helps us understand the relationship between grain fracture and properties of tectonic fault or earthquake processes.

Breakage model

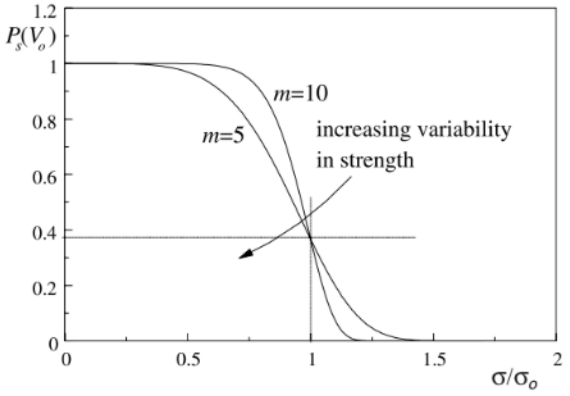


Breakage criterion & Fragment replacement

Particle stress threshold (Strength)

Weibull survival probability

$$P_s(d) = exp\left(-\left(\frac{d}{d_0}\right)^3\left(\frac{q_0}{q_{crit}}\right)^m\right)$$



$P_s(d)$ - Survival probability

q_0 - Particle threshold

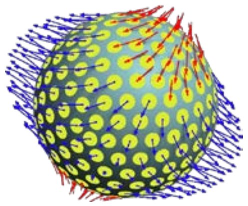
q_{crit} – Particle threshold with 37% survival probability

m – Weibull Module

d – Particle size

Larger particles are weaker
Smaller particles are stronger

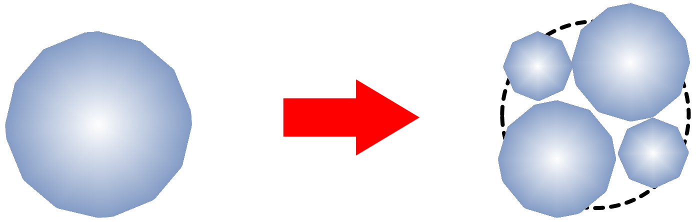
Particle shear stress



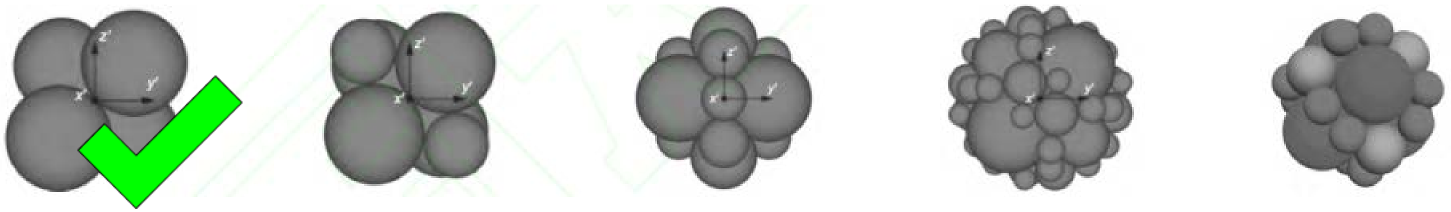
Octahedral shear stress

$$q = \frac{1}{3}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2\right]^{1/2}$$

If $q > q_0$, particle get broken

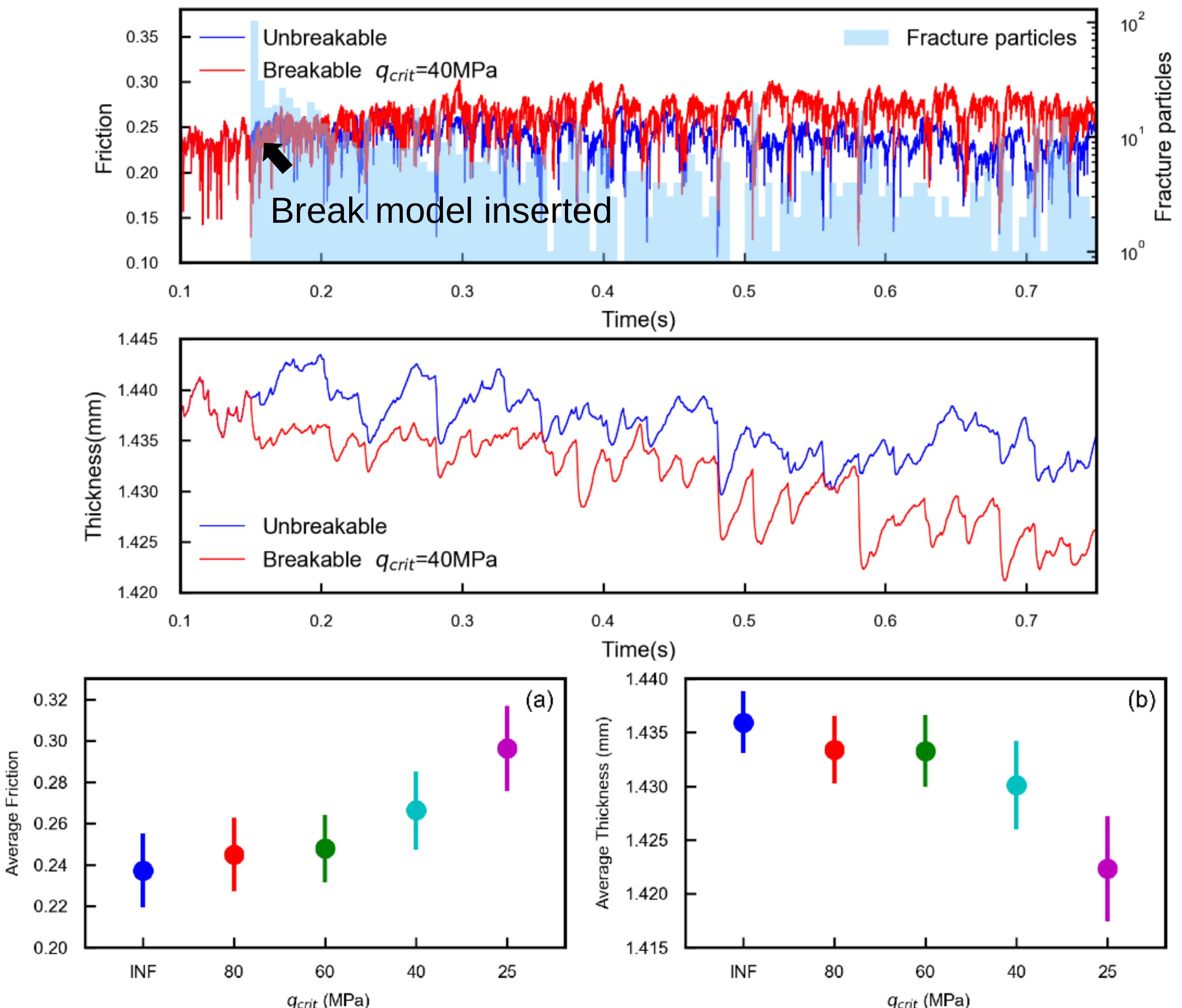


Replacement mode



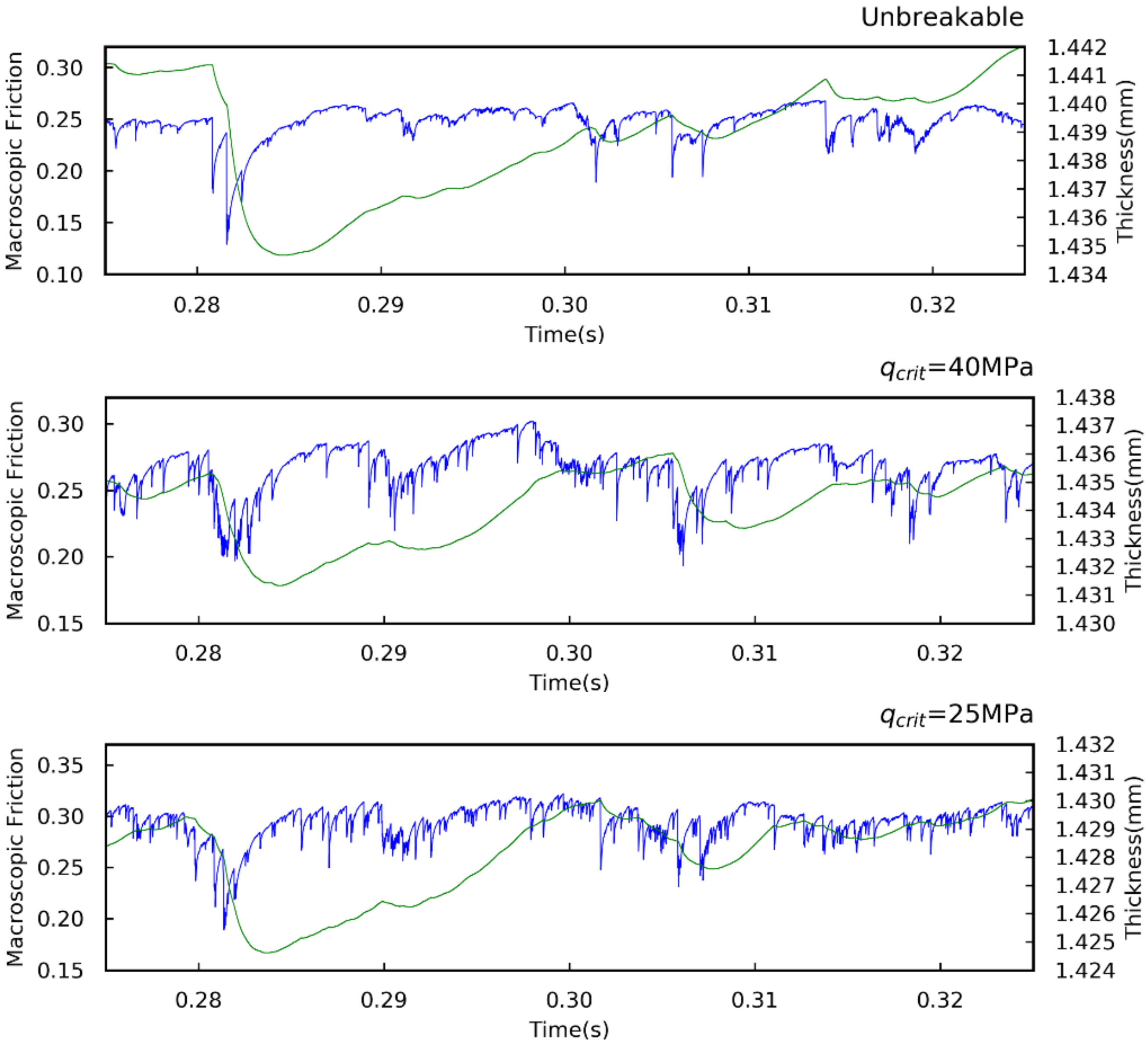
- W.L. Lim,et al. Granular Matter. 2004

Macroscopic Result

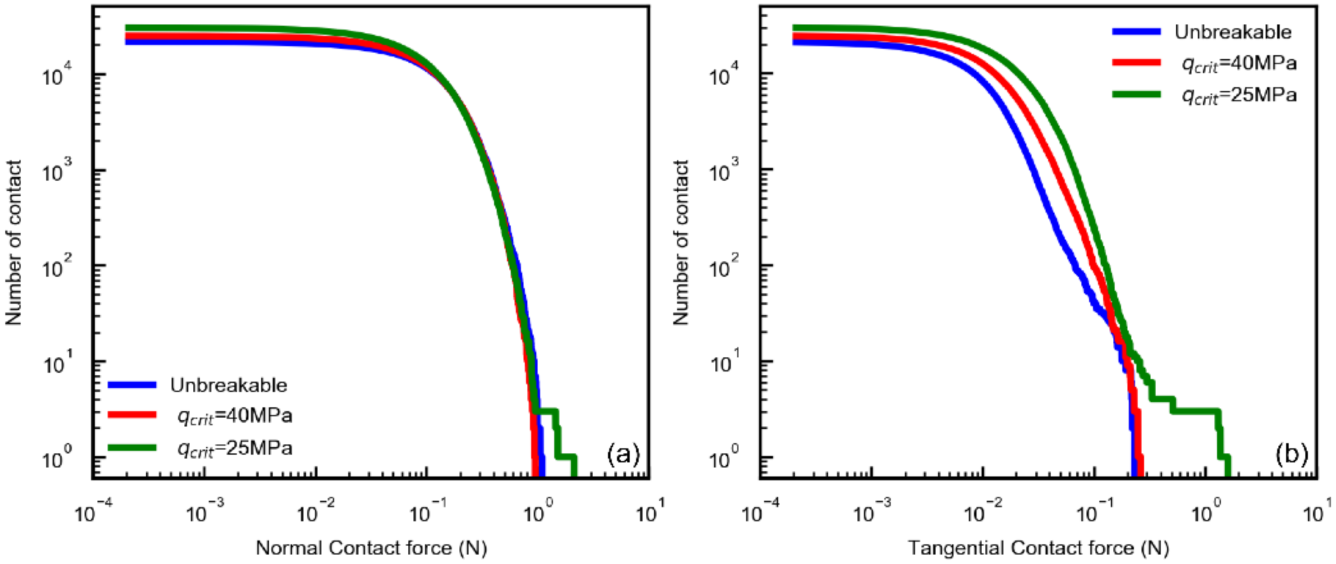


- The breakage model was inserted after the fault gouge is sheared into a stick-slip regime.
- Due to the increasing angularity of fragments and particle size evolution, the friction of fault gouge will increase and the thickness will decease.
- If we changes the particle strength(q_{crit}), these two changes will be more obvious.

Friction drop changes

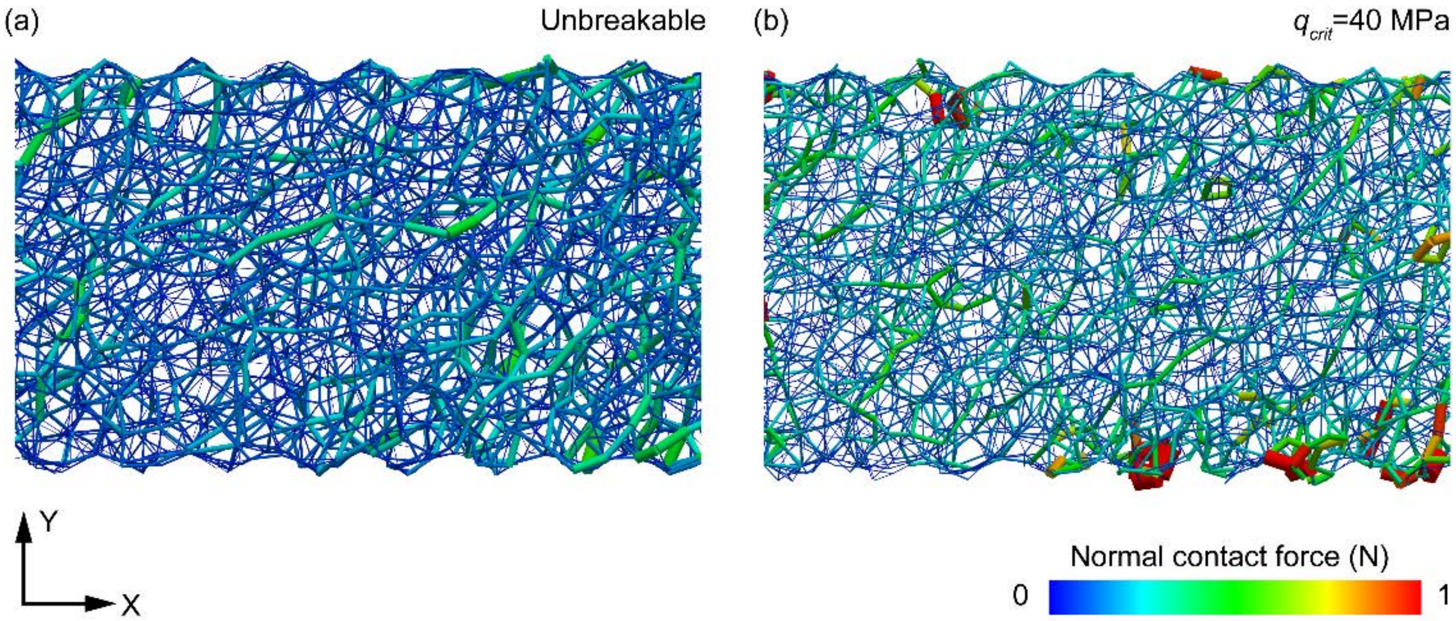


- Particle breakage will introduce many vibration or small slip events into the stick-slip cycle
- When particles break intensively, they dramatically increase the frequency of slip event but decrease the scale (friction drop) of each slip events.
- Some large slip events will be influenced by previous small slip events and become several stages slip.



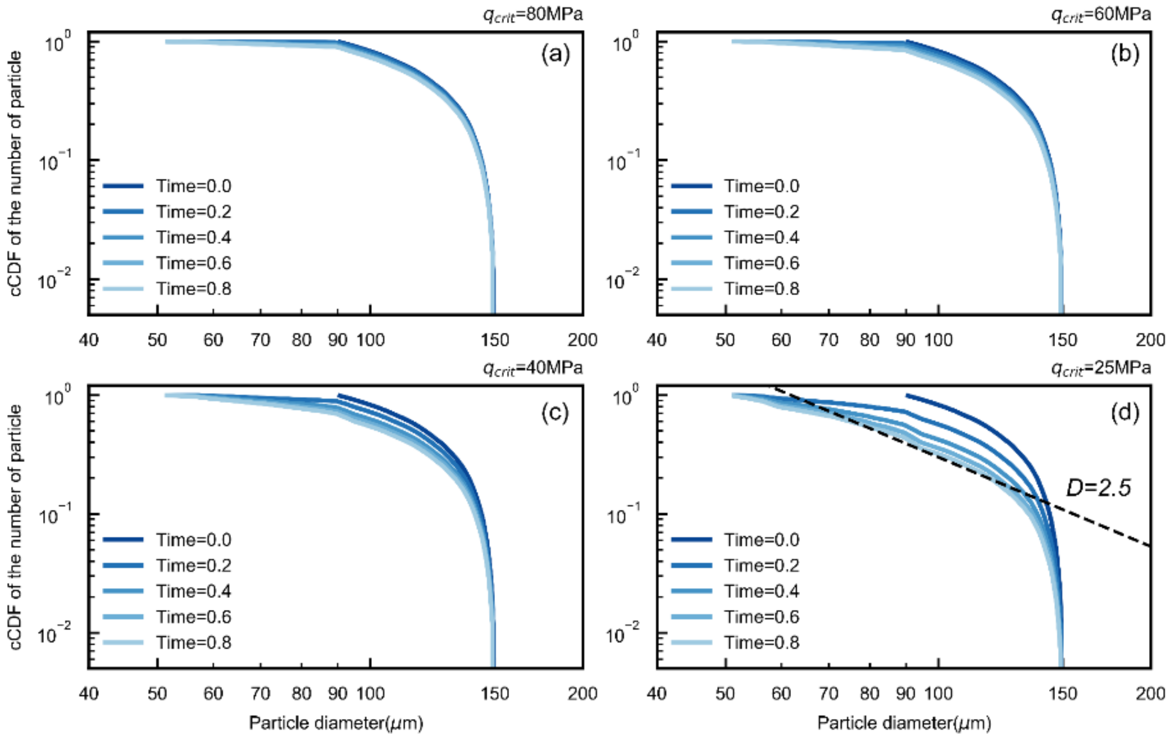
We can find the increase number of weak normal contact and slightly changes in strong normal contact force.

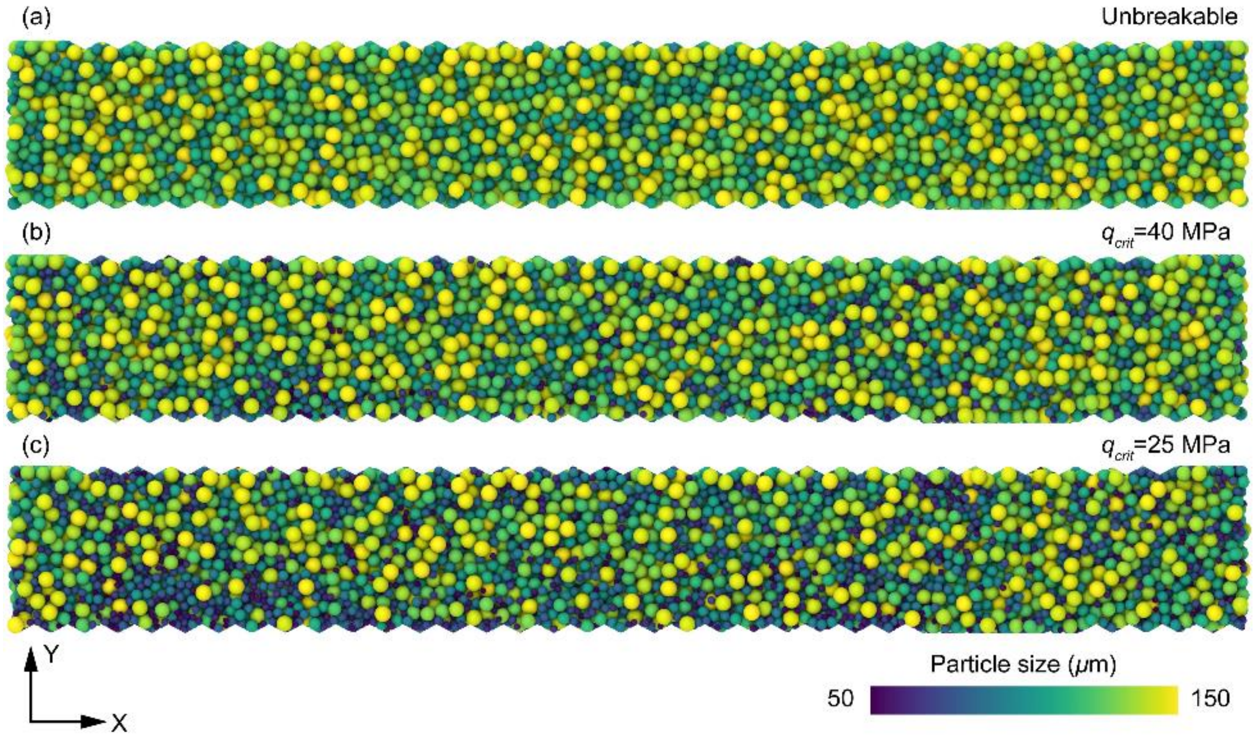
The tangential contact force show an overall increase



The force chain has been dramatically changed. Basically all those small contact force become weaker and large contact force get increased.

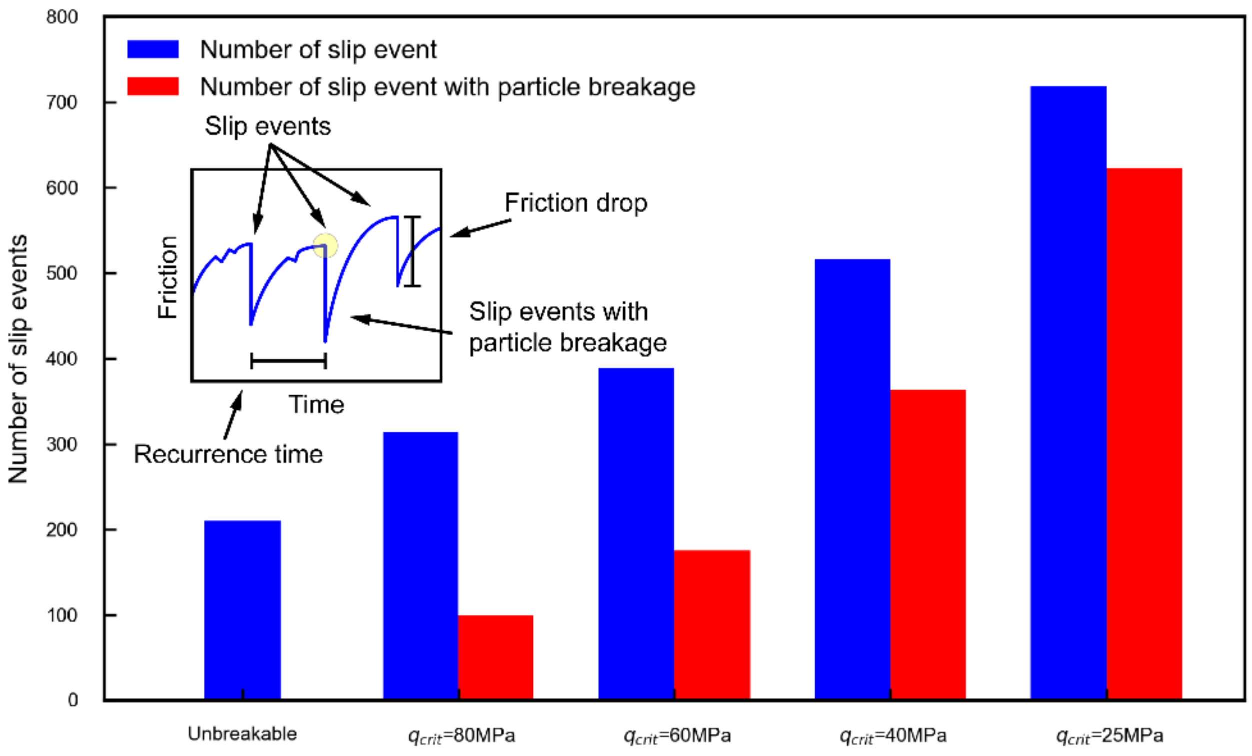
Reduction of particle size

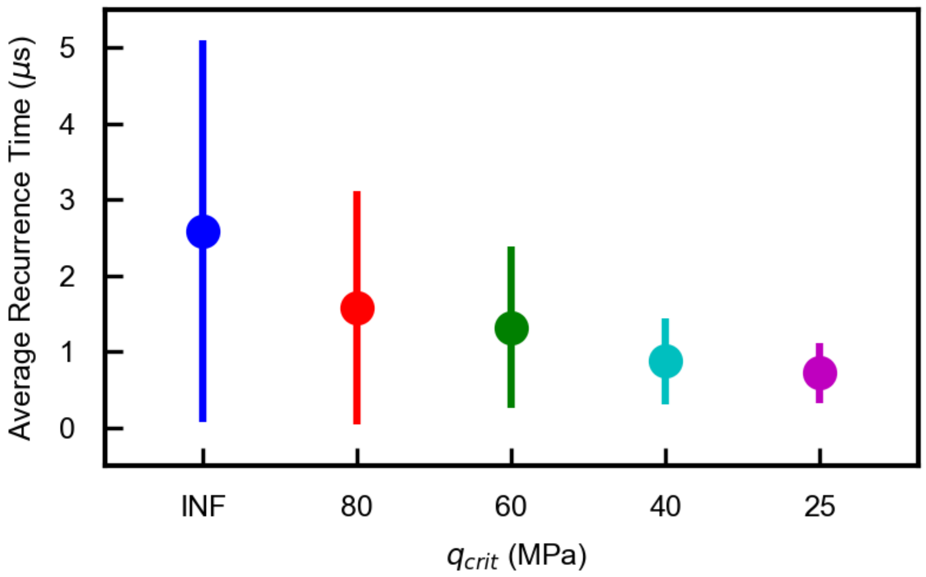




- The particle size distribution evolve toward a power law with exponential D=2.5.
- Lower particle strength show lower evolution.
- The evolution speed gradually decrease as shearing.

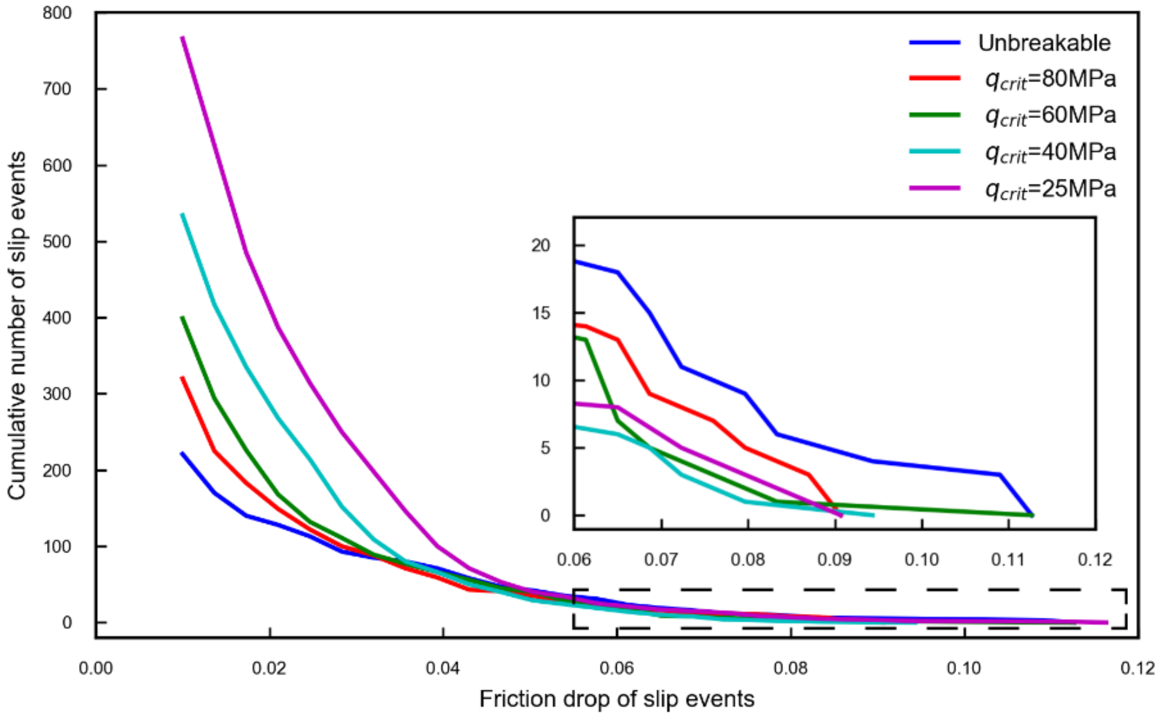
Statistics on slip event

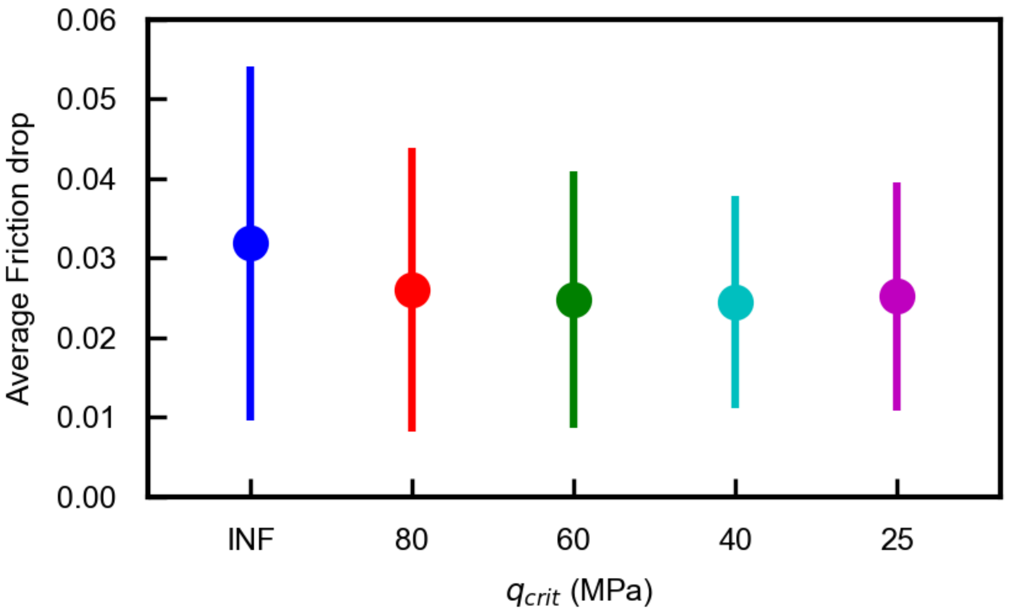




- Statistics include slip events with friction drop > 0.01
- As strength decrease, the effect of breakage is getting stronger and the slip events keep increasing
- As strength decrease, the slip event shows a higher correlation with breakage.
- The average recurrence time is decreasing, so as its standard deviation.

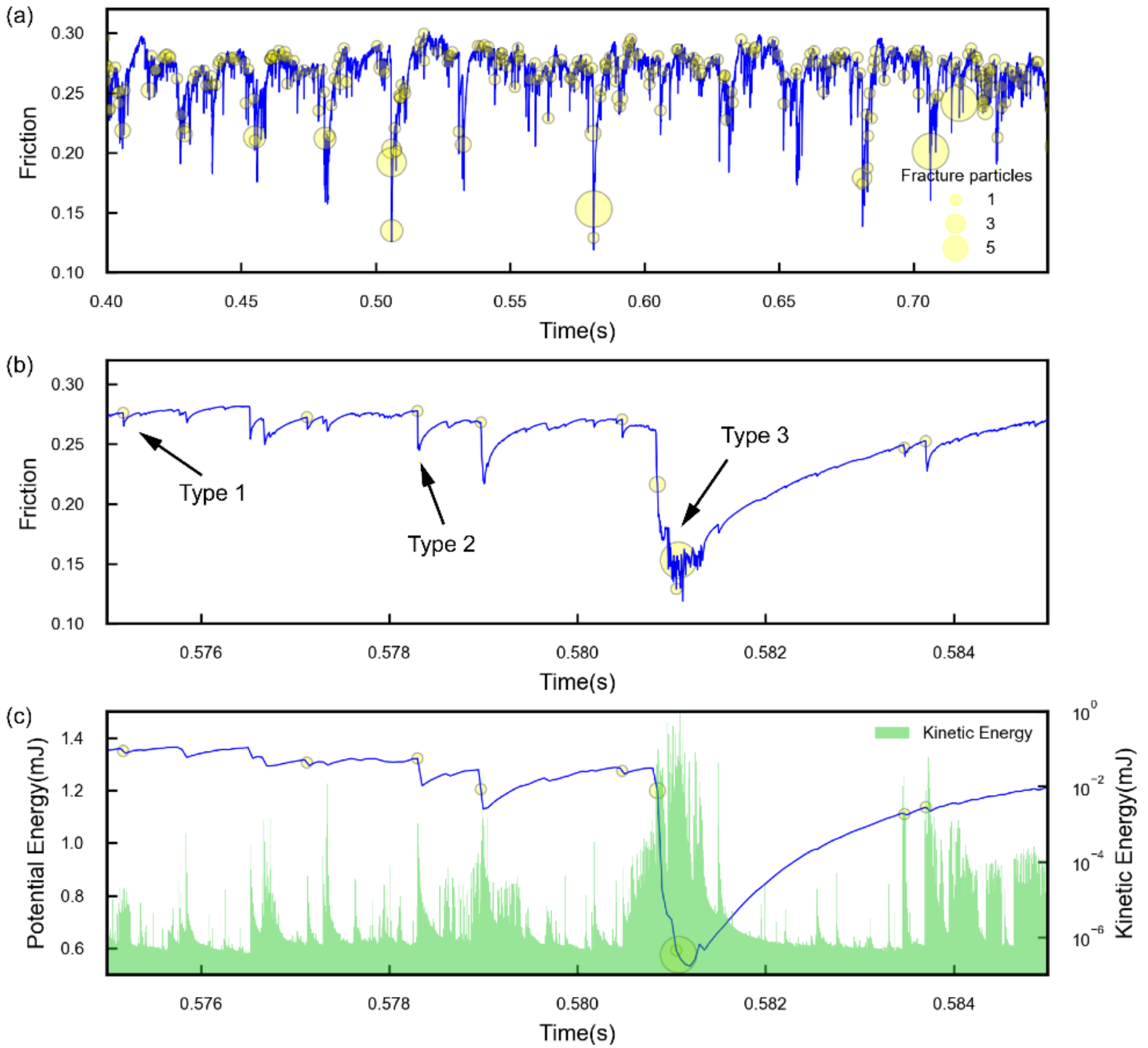
Distribution of slip events





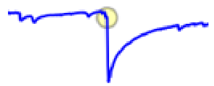
- Breakage leads to an increasing in small slip events.
- And the decrease of larger slip events. (Direct friction drop>0.06)
- With the increase of a large number of small slip events, the average friction drop decreases.

Relationship between Breakage and slip event



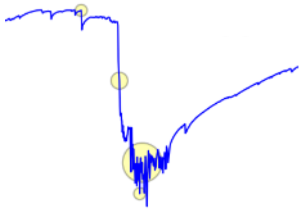
Type1: Small Disturbance

Small changes in friction and energy caused by particle breakage. Most common type after breakage.



Type2: Slip Triggering

Directly trigger a slip event. Relatively larger friction drop and potential energy release.

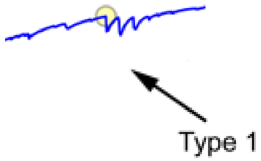


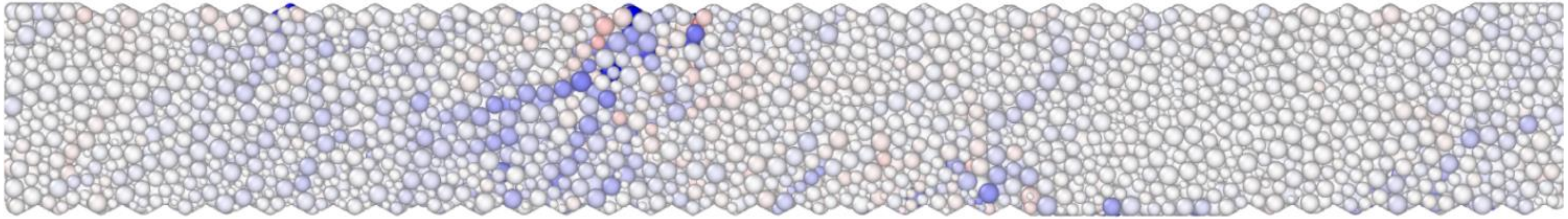
Type3: After slip Breakage

Mostly with a larger number of fracture particles. Caused by slip events.

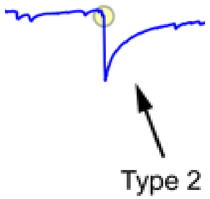
Potential Energy difference before and after slip event

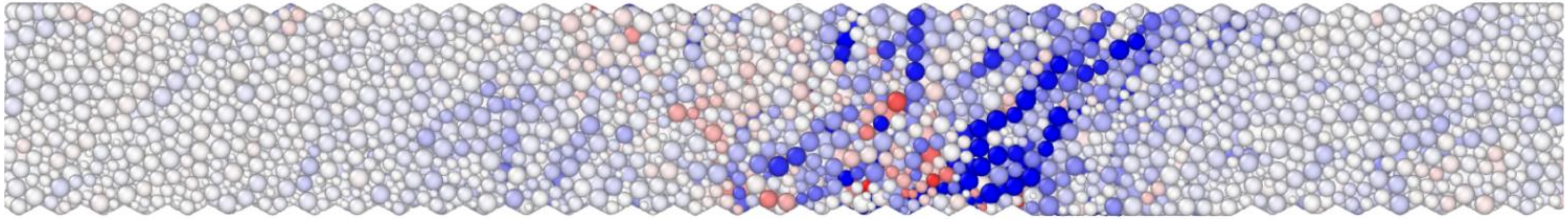
(a) The influence of breakage is limited, only a few surrounding particles get potential energy decreasing



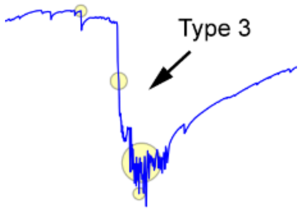


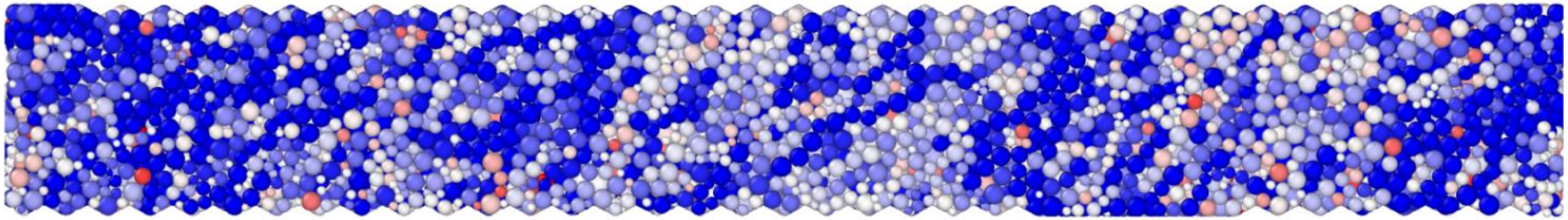
(b) The influence of breakage is extended, the force chain is damaged and loses a lot of potential energy.



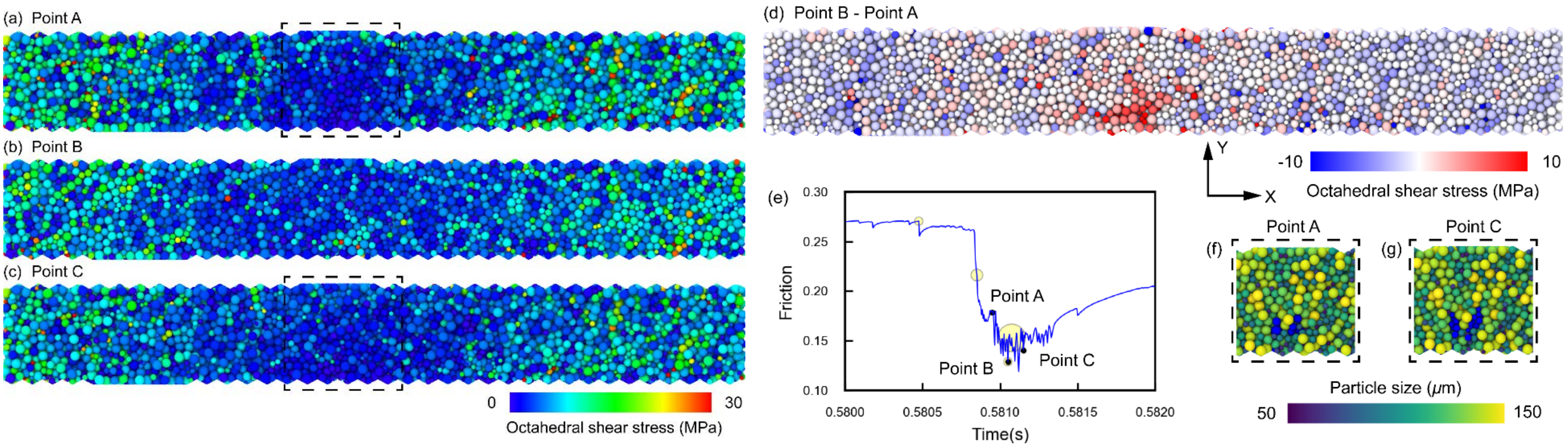


(c) The slip event causes an overall decrease of potential.





Stress localization after slip event



- The reason for breakage in Type 3 is different from 1&2. It comes from stress localization due to particle rearrangement rather than continually increasing stress in the chain.
- Point A, B, C shows the state of stress before breakage and we use Point B-A to show the stress variation before particles get broken, fracture particles, and fragments are displayed in (f) and (g) respectively.

Conclusion

- In general, breakage and evolution lead to an increase in small slip events and a decrease in larger slip events.
- In the short term, breakage will lead to local particle rearrangement and sometimes trigger slip events. In the long term, the stick-slip cycle will mainly be changed by particle size evolution.
- Large scale breakage more likely occurs during the particle rearrangement duration after larger slip events.
- Particle strength will influence the scale of breakage and the speed of evolution.

Thank You!