Static Liquefaction and Flow Failure of Sand: Several New Findings

（砂土静态液化及流动破坏：一些新发现）

Jun Yang

The University of Hong Kong

International Geotechnics Symposium, 14-17 December 2016, Hong Kong

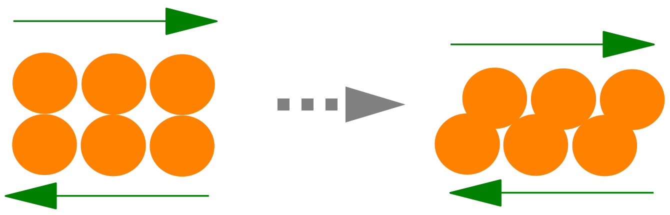
Outline

- Overview of soil liquefaction and remaining issues
- Laboratory investigation of the role of fine grains
- Summary of key findings

General concept of soil liquefaction

- Liquefaction is a variety of phenomena in which a saturated soil transforms from a solid to a liquefied state as a consequence of increased pore-water pressure and reduced effective stress

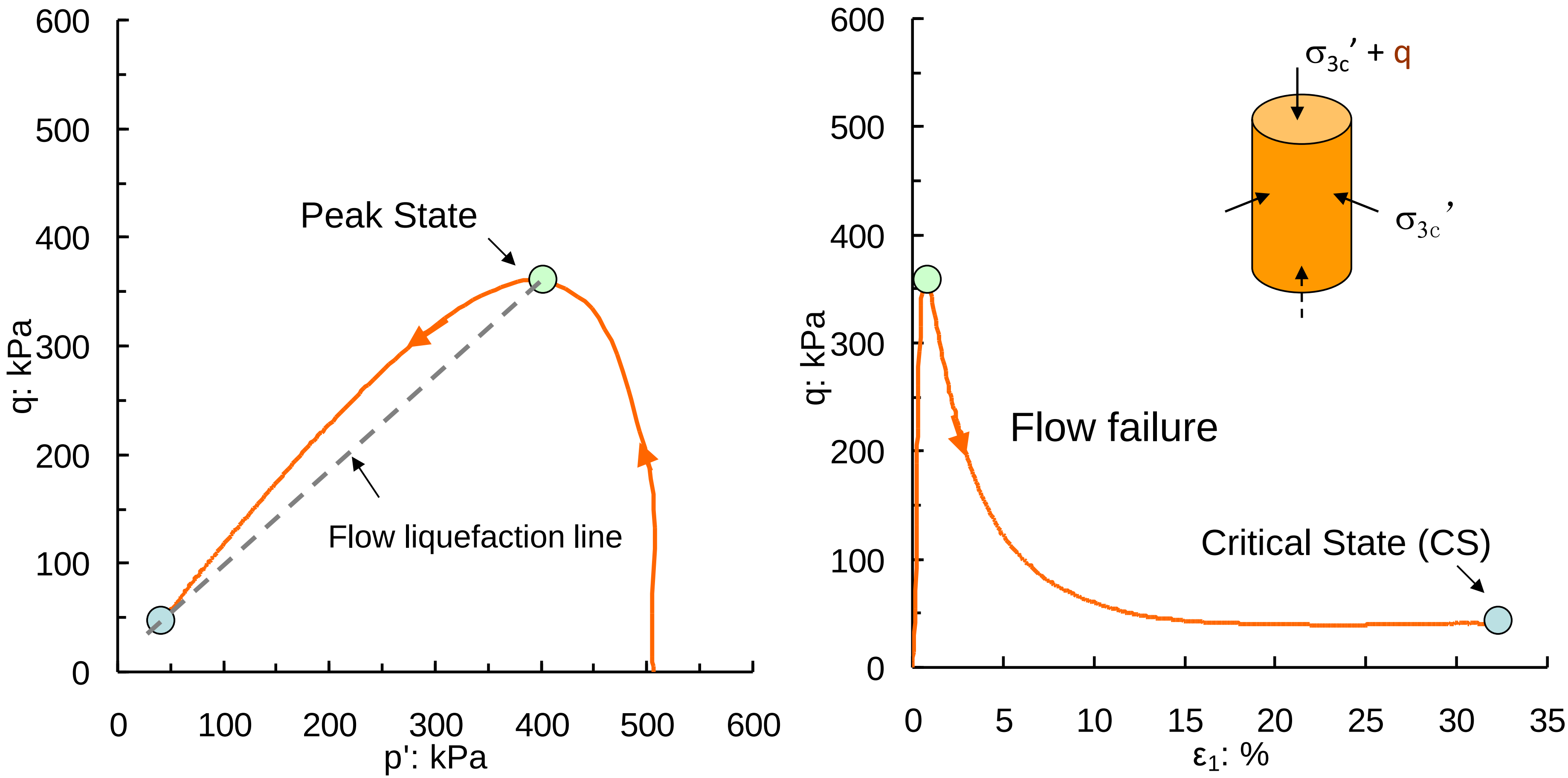
- Liquefaction occurs in a saturated granular soil (typically sands) where the pore water pressure influences how tightly the particles are pressed together



$$\delta\varepsilon_v = \delta\varepsilon_{ve} + \delta\varepsilon_{vp} = 0$$

$$\delta p' < 0$$

General concept of soil liquefaction



Static liquefaction or flow liquefaction is characterized by a sudden loss of strength and a rapid development of deformation in a mass of saturated granular soil. It can be triggered by either monotonic or cyclic loading and can produce the most catastrophic effects of all liquefaction-related phenomena.

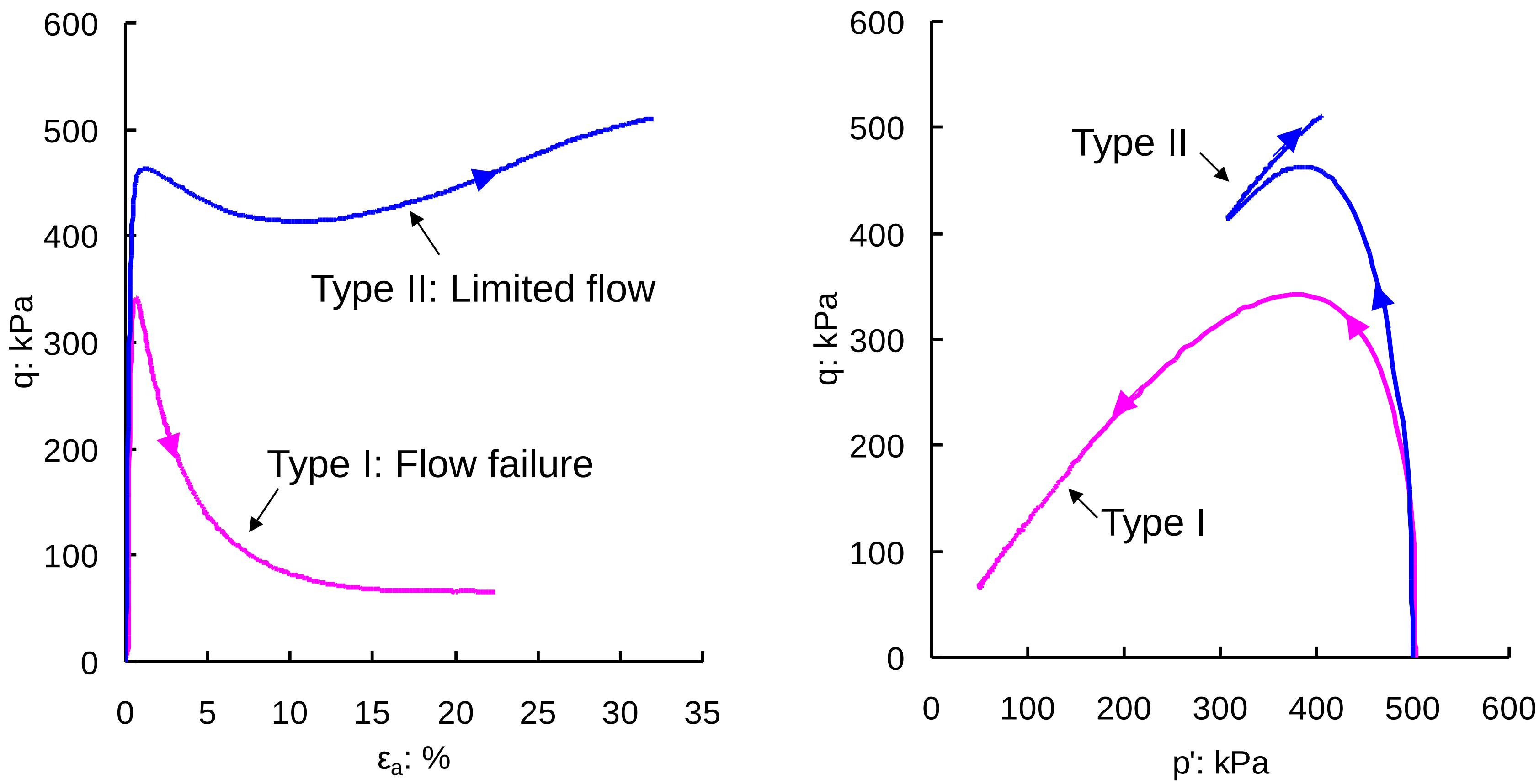
General concept of soil liquefaction

Research need

- A fundamental understanding of this behavior has been established, mainly through well-controlled laboratory experiments on clean sands in the past decades (*e.g*. Casagrande, 1971; NRC 1985; Ishihara 1993).

- Very often natural sands are not clean, but contain a certain amount of fine grains (typically less than 75μm); so what is the influence of fines is a matter of concern.

- Existing studies give diverse views on whether the effect of fines is beneficial or detrimental for liquefaction resistance.

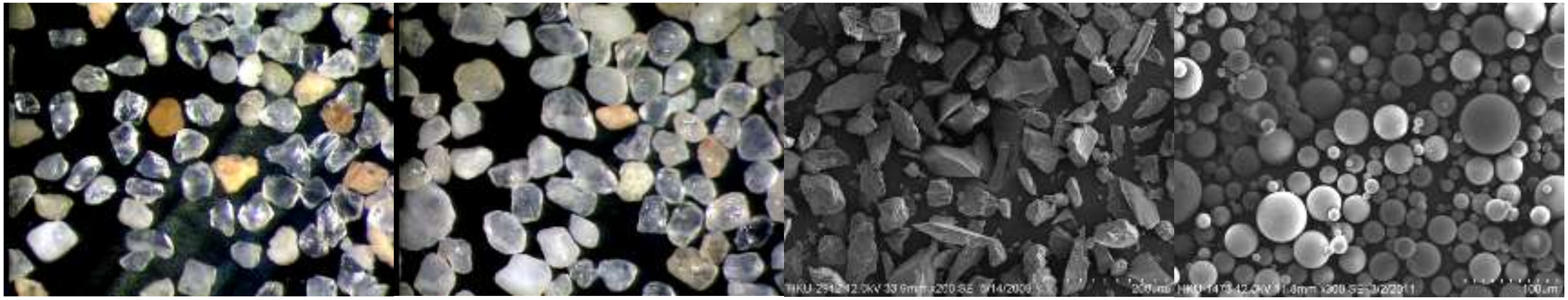


Diverse views on the role of fines: *e.g*. Kuerbis *et al*. 1988; Pitman *et al*. 1994; Zlatovic & Ishihara 1995; Lade & Yamamuro 1997; Thevanayagam *et al*. 2002; Georgiannou 2006; Murthy *et al*. 2007

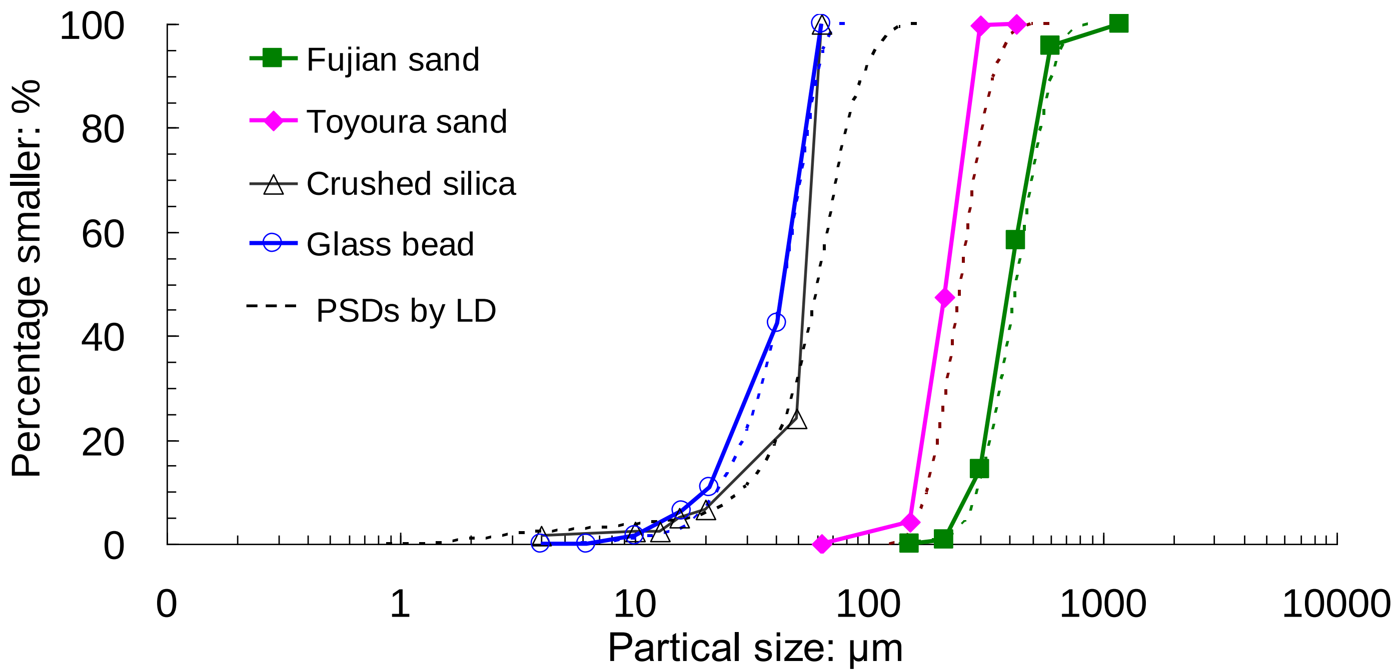
Research need

- This divergence indicates that the influence of fines remains an area of difficulty and uncertainty. Previous work has tended to concentrate on the effect of fines content by testing sand samples mixed with a specific type of fines of varying quantities.
- From a fundamental point of view, the characteristics of both fine and coarse particles (*e.g.* shape, size and plasticity) can significantly affect the packing patterns and interactions of the particles, and hence their overall behavior.
- It is essential to explore how particle characteristics play a role in the overall response of sand-fines mixtures. This is exactly the motivation for our study.

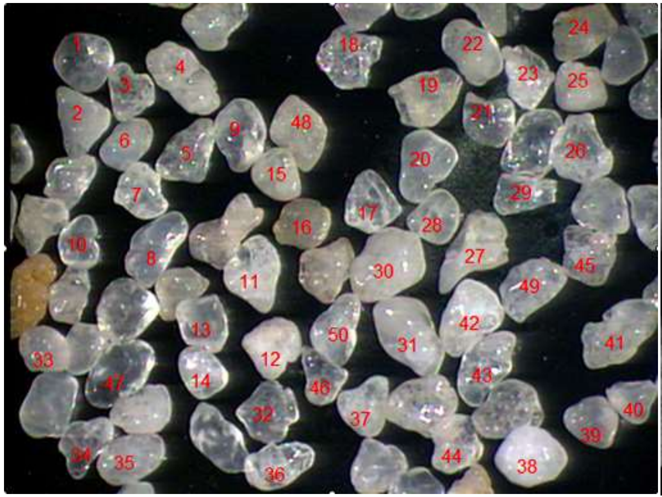
Experiment: test material and particle characteristics

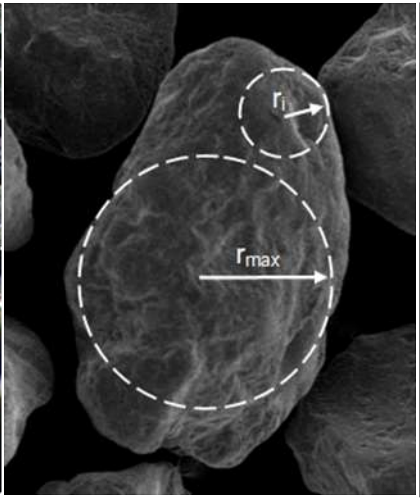


Toyoura sand Fujian sand Crushed silica Glass bead

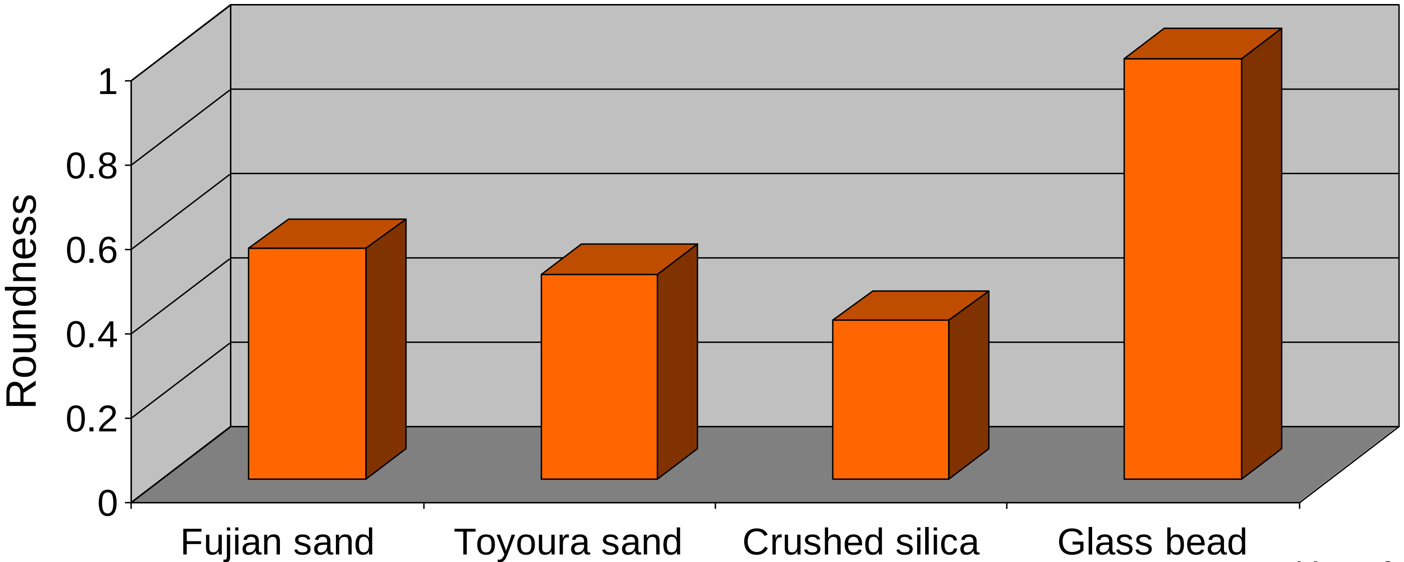


Experiment: test material and particle characteristics



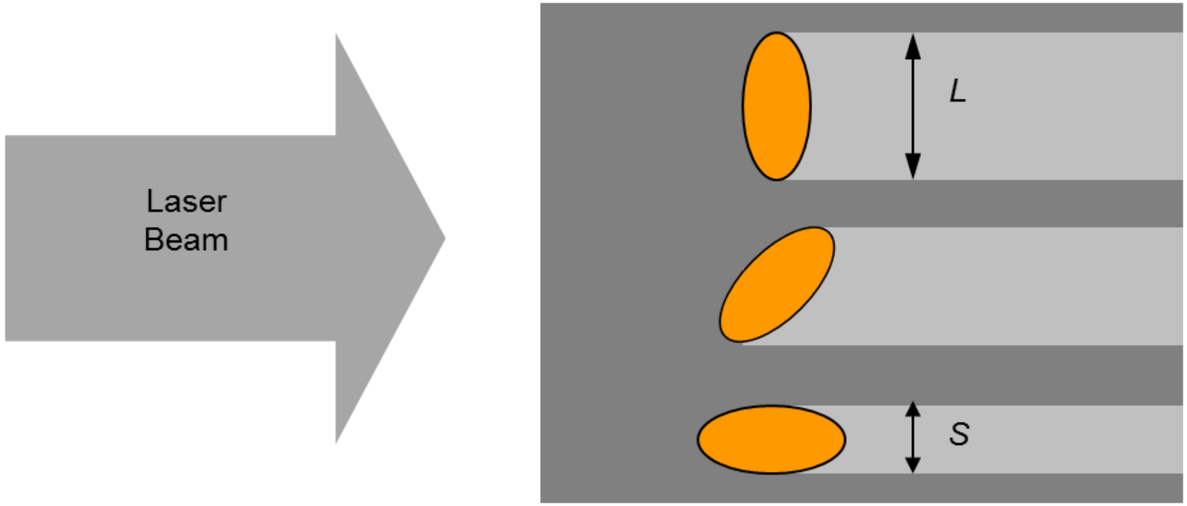


$$R = \frac{\sum (r_i / N)}{r_{max}}$$



Yang & Wei (2012): Géotechnique

Experiment: test material and particle characteristics

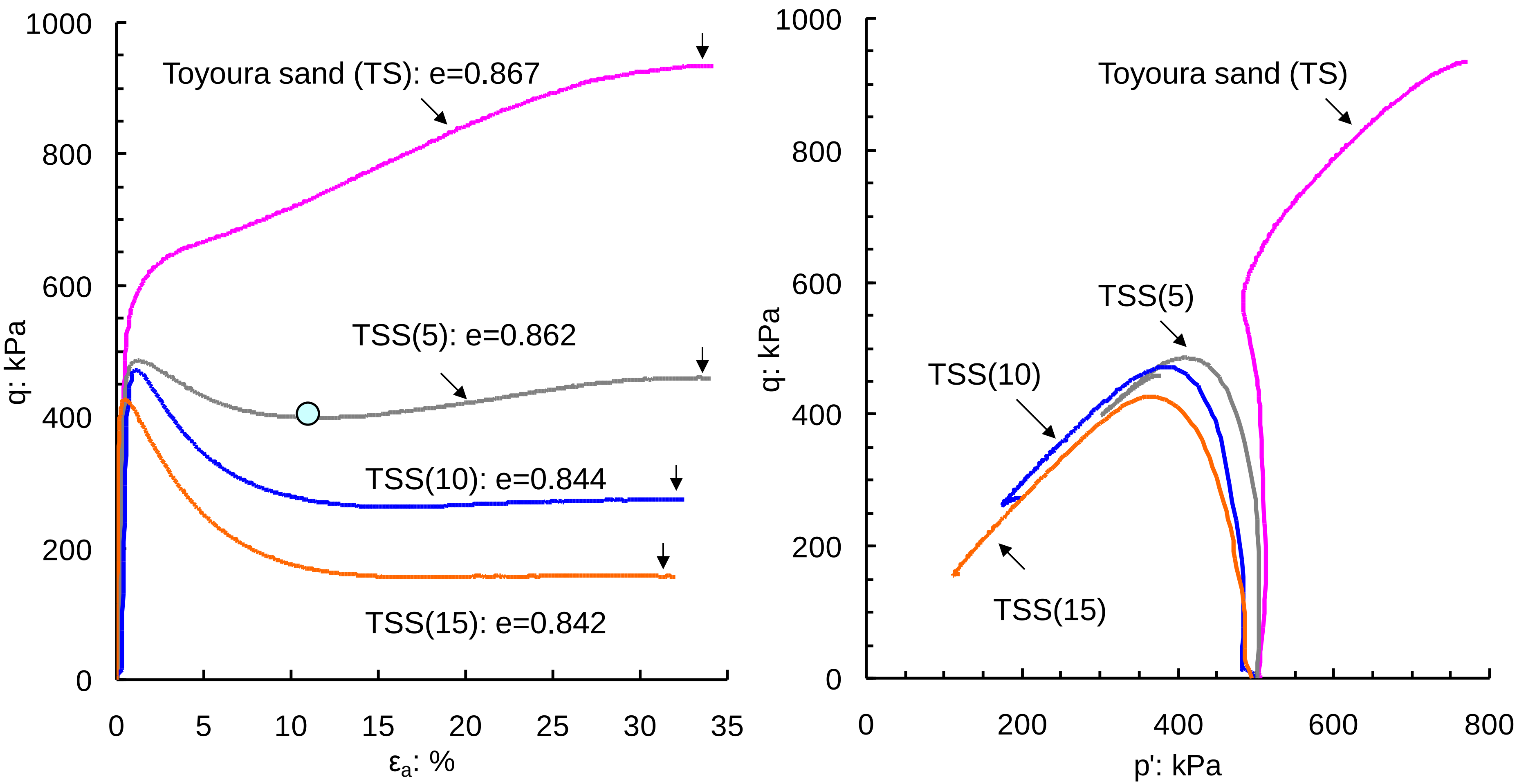


Laser Diffraction (LD) method for particle analysis

	Crushed silica	Glass bead
Aspect ratio, r_{JP}	2.597	~1.0
Flatness, r_E	1.113	0.995
Note: r_{JP}=L/S; r_E=D_{LD}/D_{stokes}		

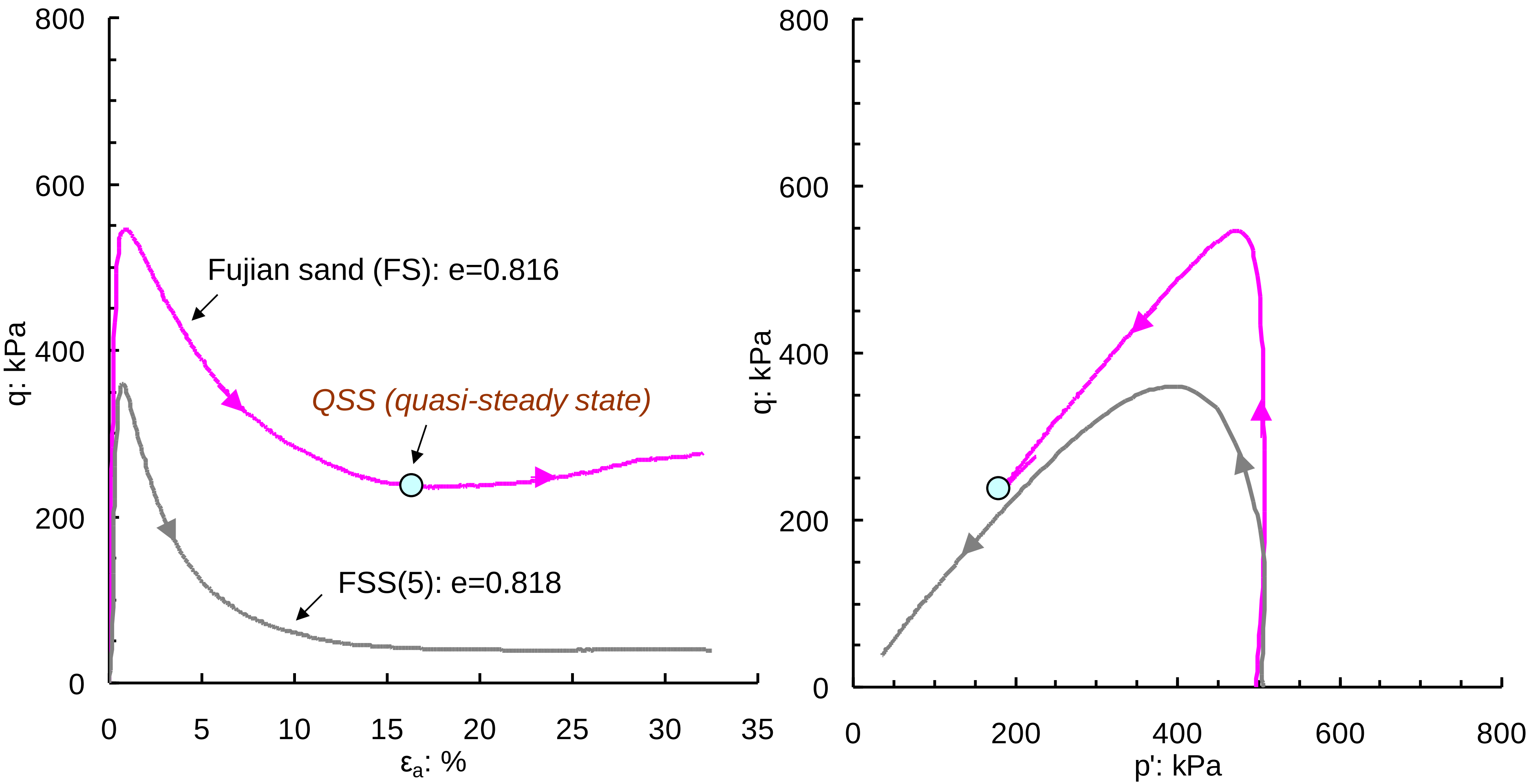
Yang & Wei (2012): Géotechnique

Experiment: overall shear behavior



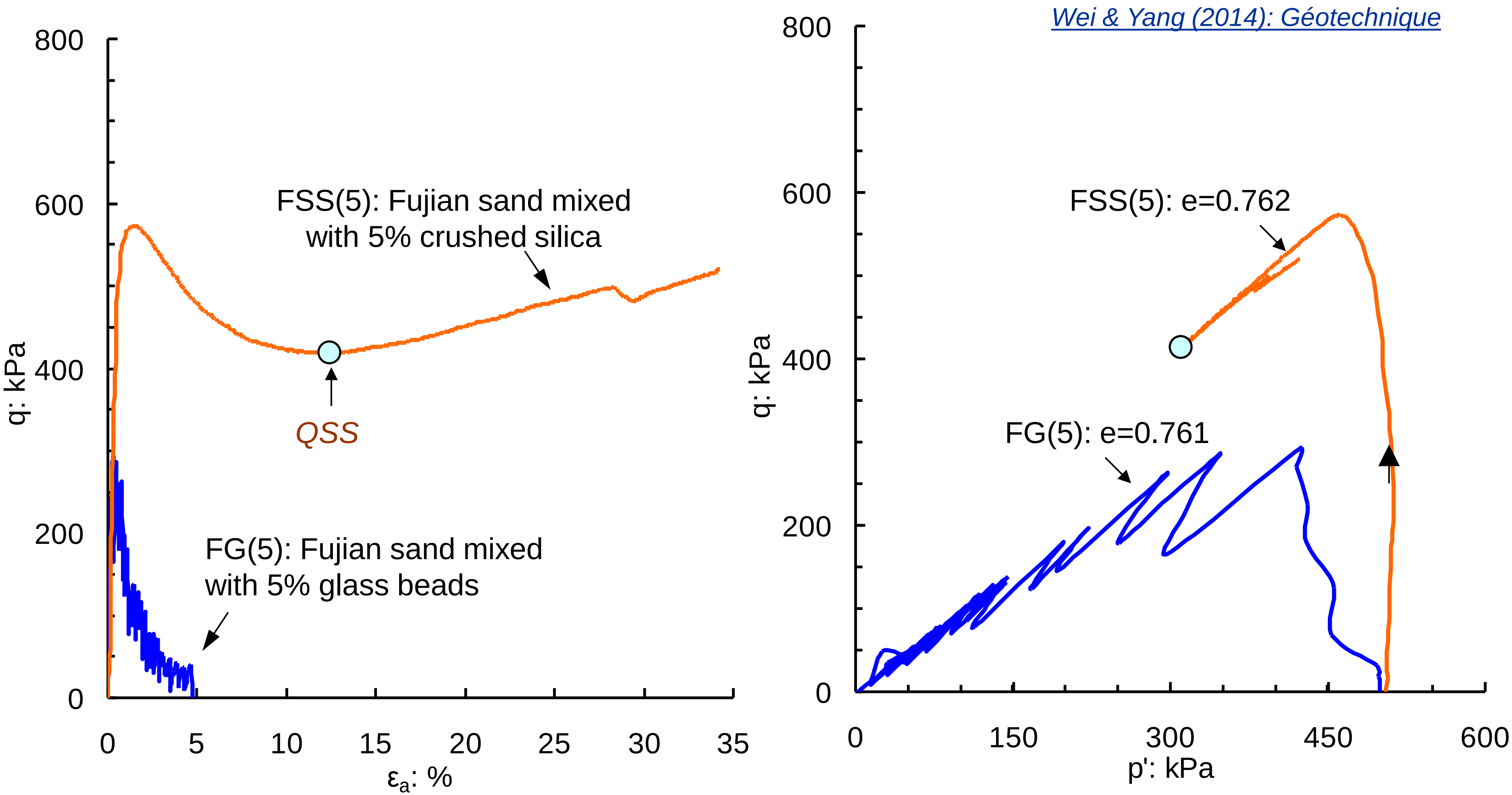
Undrained shear behavior of Toyoura sand modified by crushed silica fines

Experiment: overall shear behavior



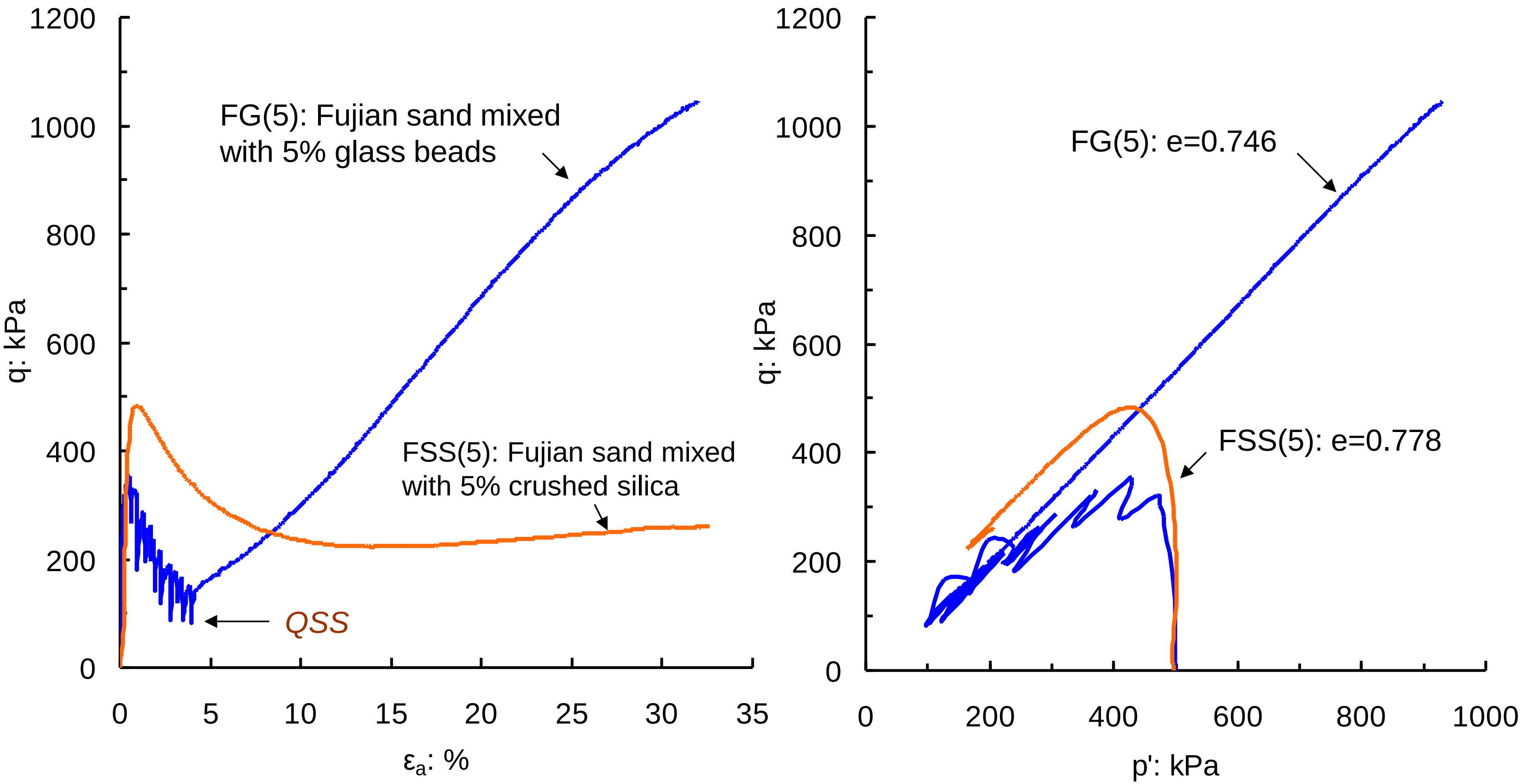
Undrained shear behavior of Fujian sand modified by crushed silica fines

Experiment: overall shear behavior



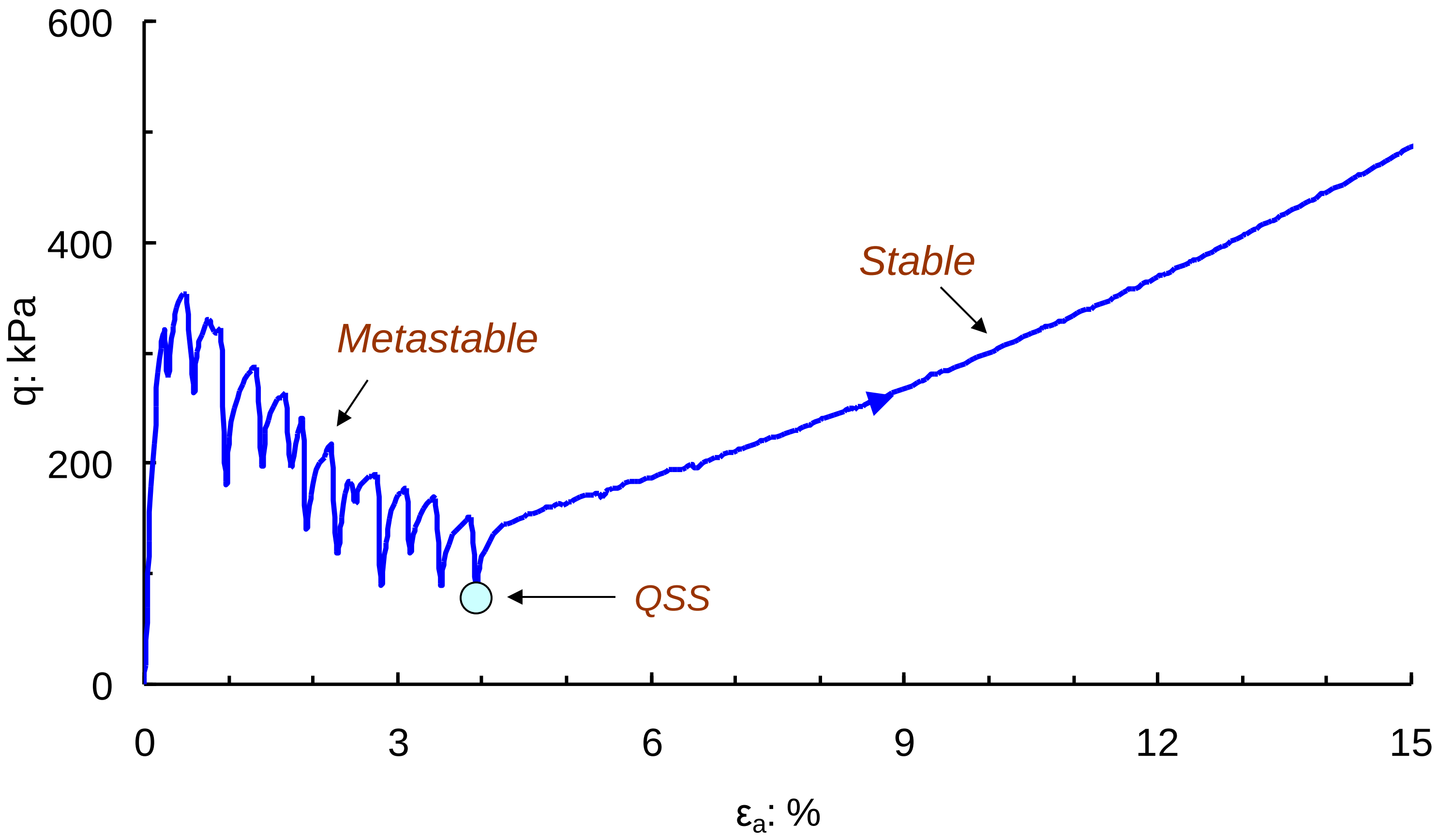
Role of grain shape

Wei & Yang (2014): Géotechnique



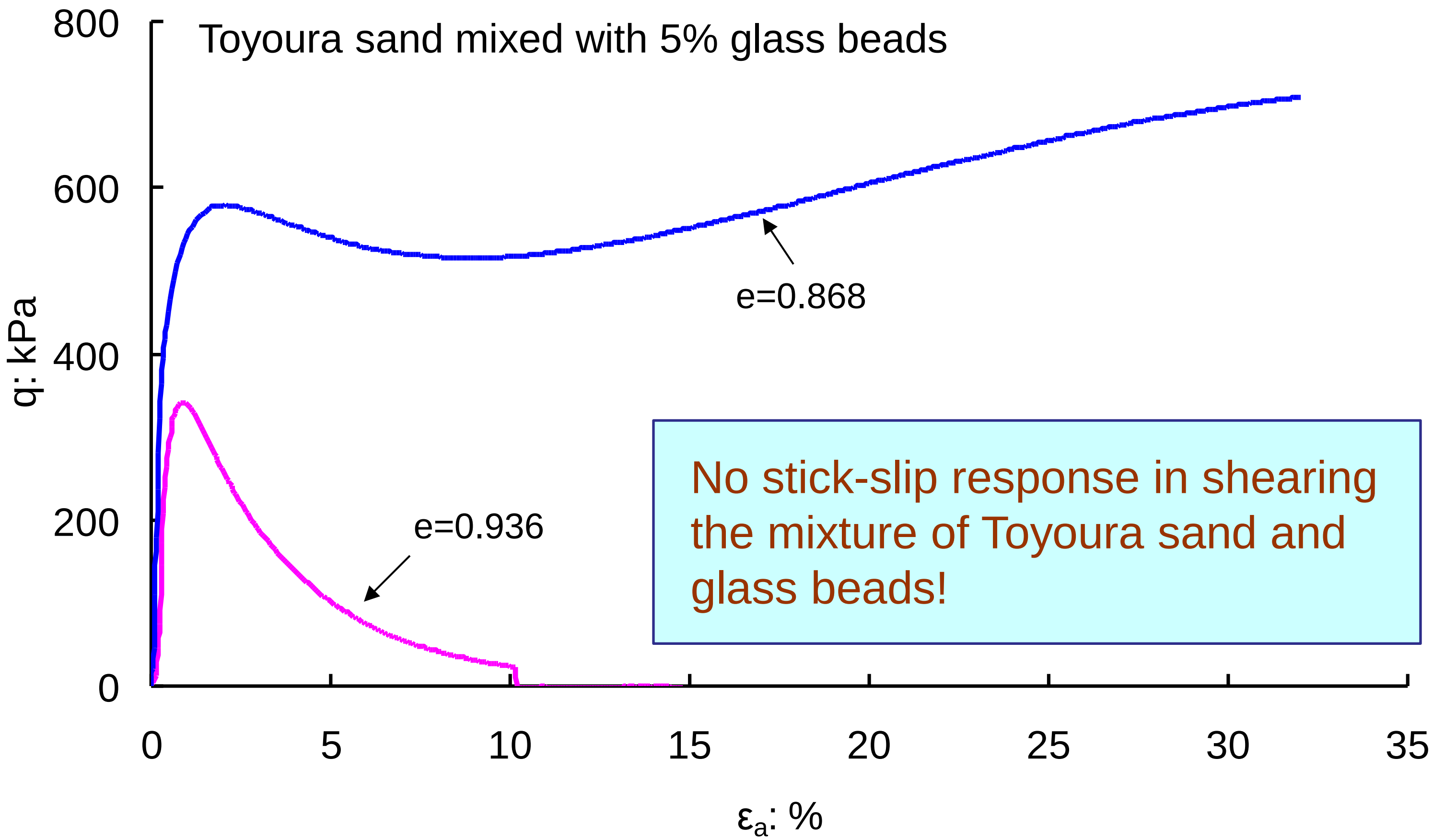
Experiment: overall shear behavior

[Wei & Yang (2014): Géotechnique]



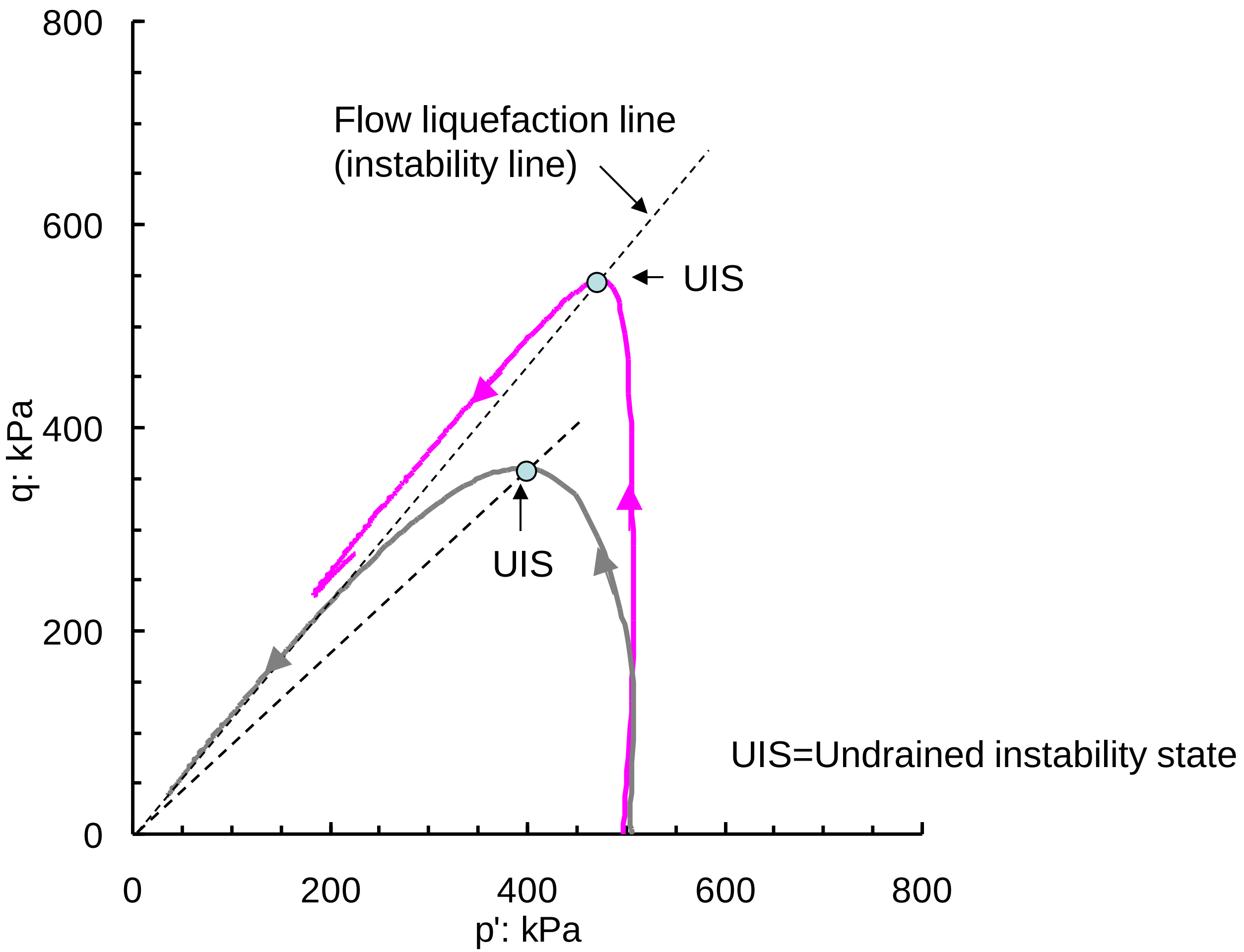
The first experimental evidence showing that QSS marks a change from a metastable to a stable microstructure

Experiment: overall shear behavior

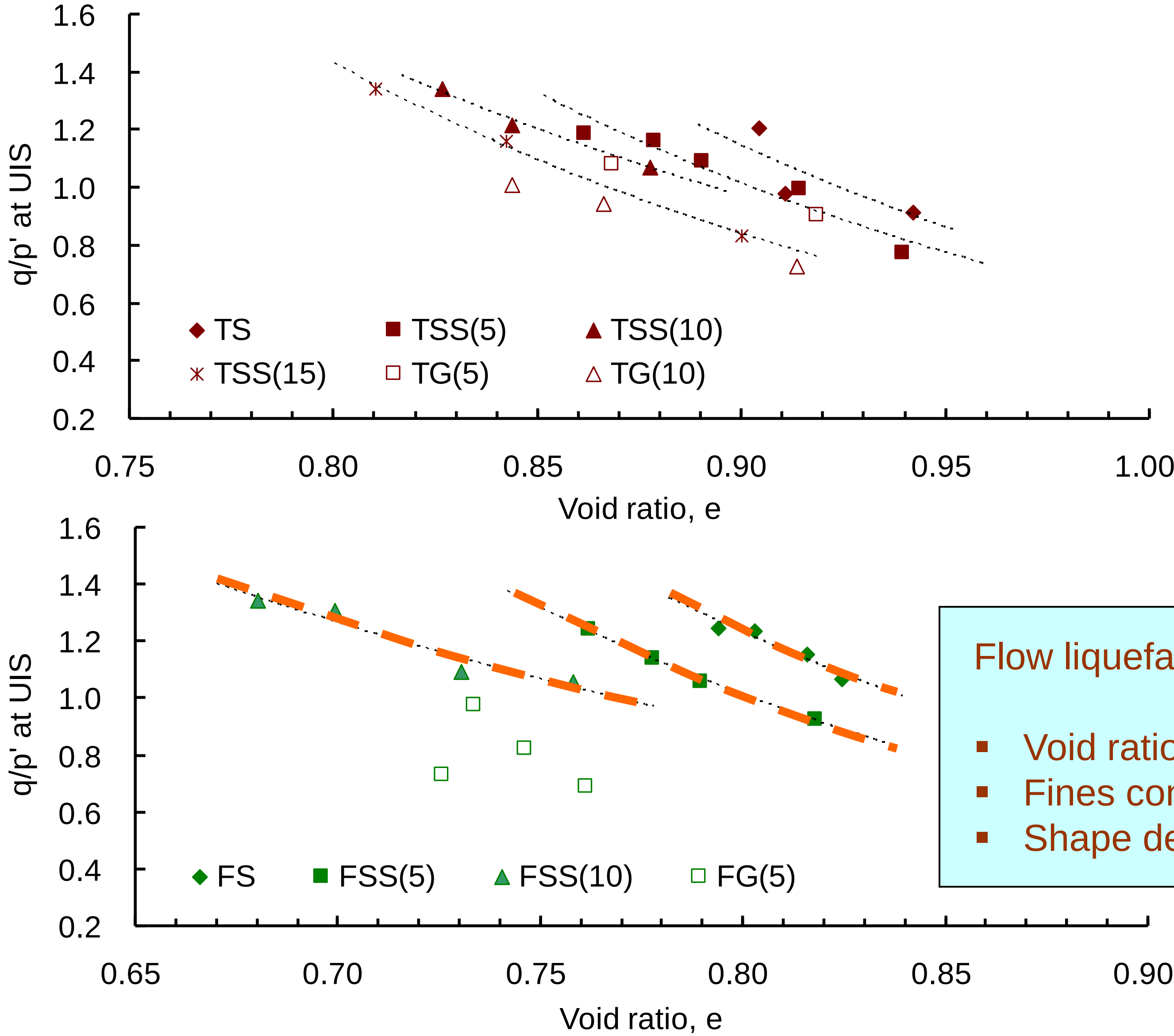


No stick-slip response in shearing the mixture of Toyoura sand and glass beads!

Experiment: onset of liquefaction



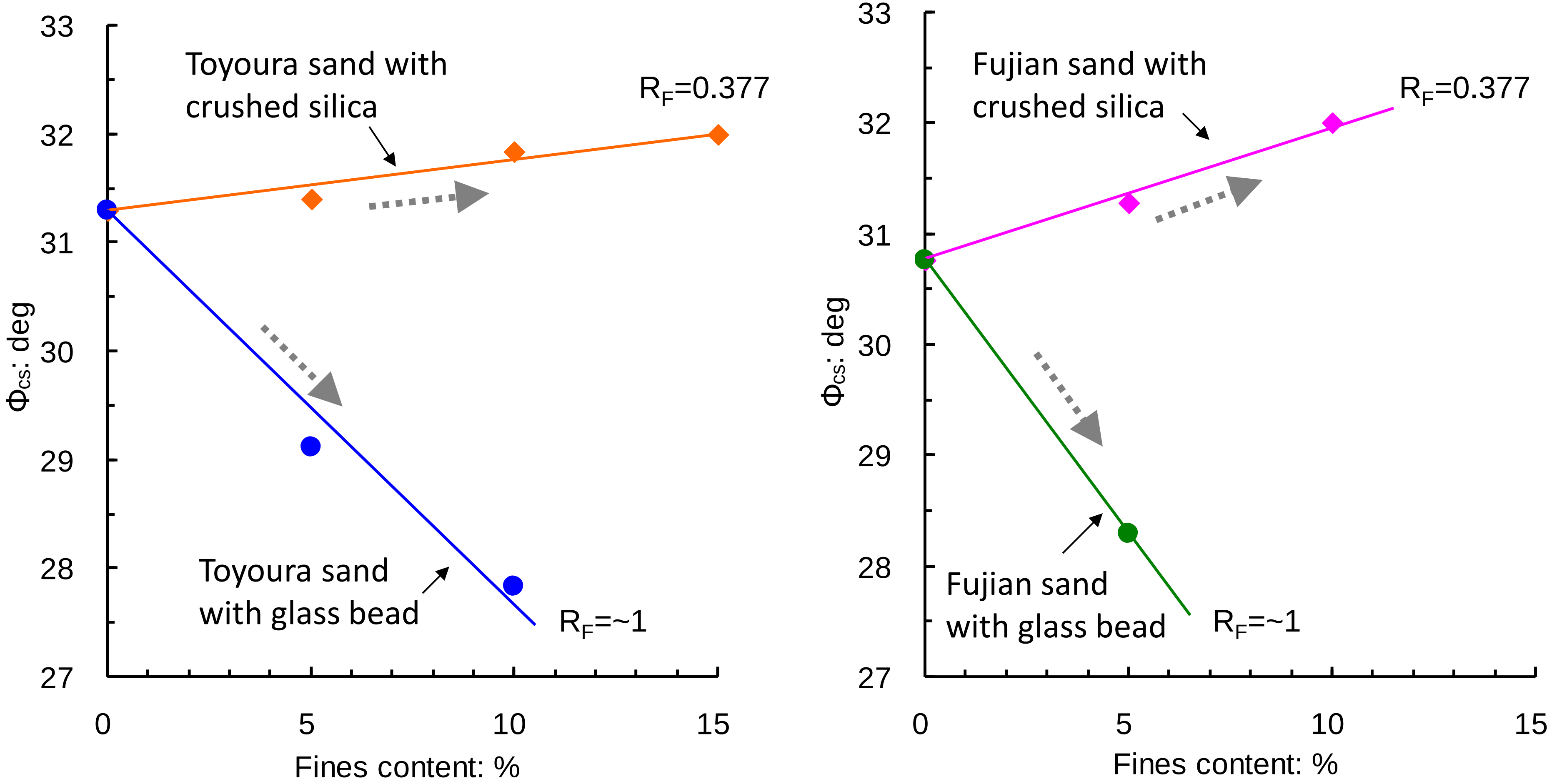
Confirmation of the concept of non-uniqueness of flow liquefaction line of Yang (2002)



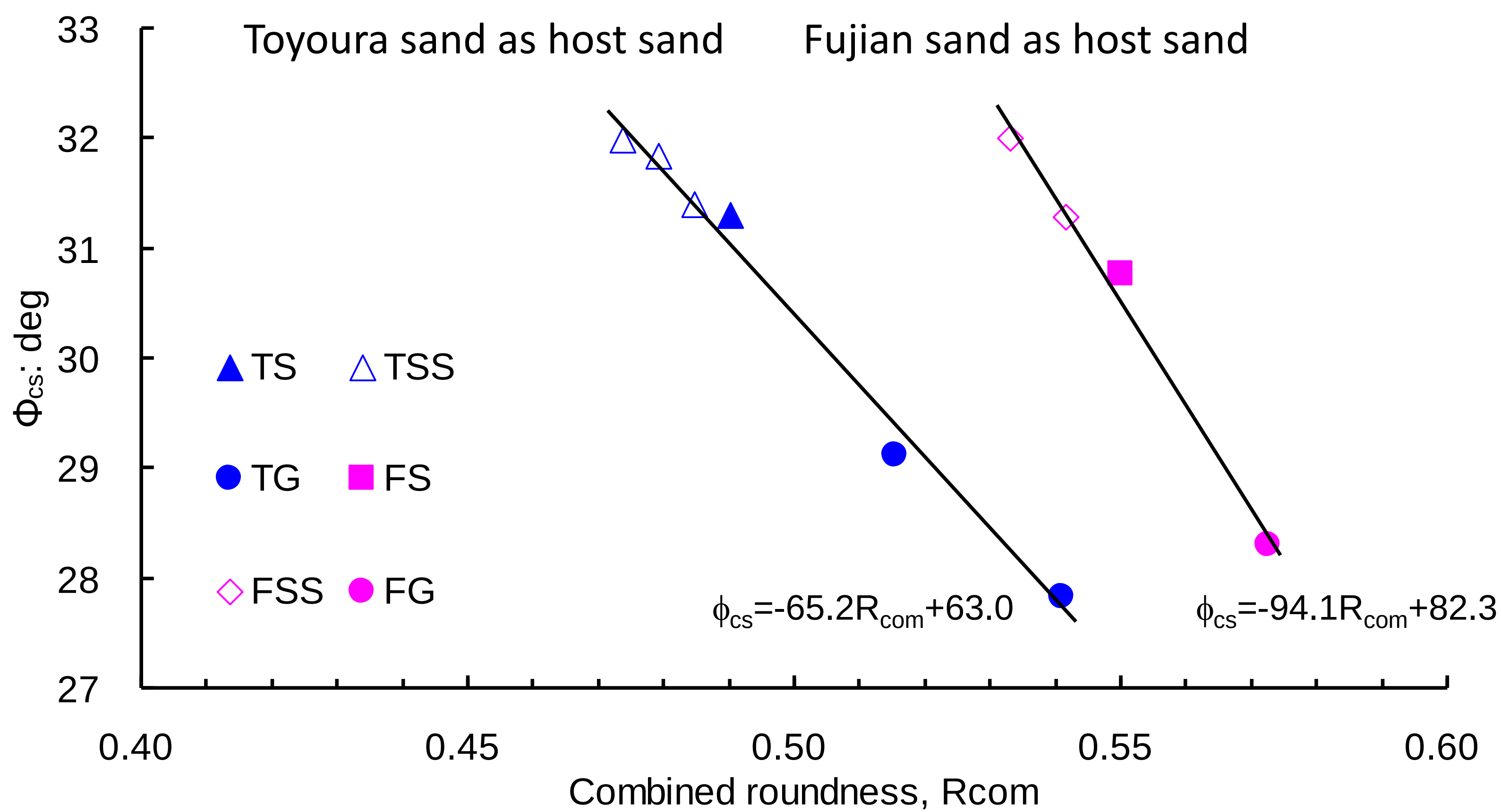
Flow liquefaction line is

- Void ratio dependent
- Fines content dependent
- Shape dependent

What about the friction angle at critical state (steady state)?



Experiment: critical state friction angle



Combined Roundness: $R_{com} = R_{HS}(1\text{-}FC) + R_F FC$

Yang & Wei (2012); Wei & Yang (2014)

Summary of key findings

- The addition of fines into a clean sand can result in an increase in strain softening, with the degree of softening increasing as higher percentages of fines are added.
- A mixed soil containing rounded fines tends to exhibit higher susceptibility to flow liquefaction than a mixed soil containing angular fines of the same percentage, and this tendency will become more evident if the host sand is also composed of rounded particles.
- The critical state friction angle of a mixed soil is affected not only by the shape of coarse particles but also by the shape of fine particles, and this shape effect is coupled with fines content. The new index, termed combined roundness, is useful to account for the coupled effects.

Related publications

- Wei, L.M. and Yang, J. (2014). On the role of grain shape in static liquefaction of sand-fines mixtures. *Géotechnique*, 64(9), 740-745.
- Yang, J. and Wei, L.M. (2012). Collapse of loose sand with the addition of fines: the role of particle shape. *Géotechnique*, 62(12), 1111-1125.
- Yang, J. and Dai, B.B. (2011). Is the quasi-steady state a real behaviour? - A micromechanical perspective. *Géotechnique*, 61(2), 175-184.
- Yang, J. (2002). Non-uniqueness of flow liquefaction line for loose sand. *Géotechnique*, 52(10), 757-760.

Thank You

More information: http://web.hku.hk/~junyang