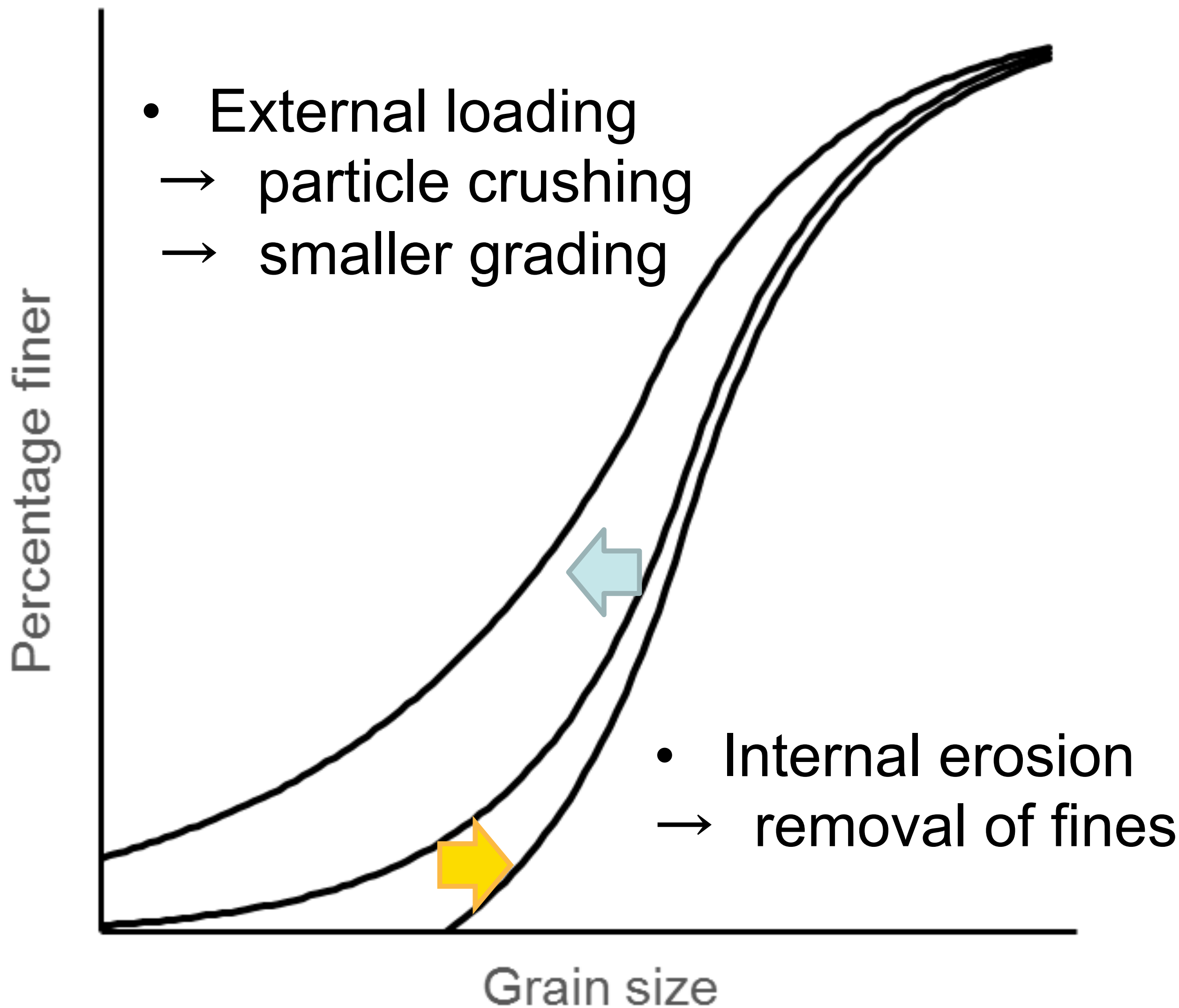
GEOMECHANICS OF CRUSHABLE MATERIALS WITH THE CHANGE OF GRADING

Yamaguchi University
Yukio NAKATA

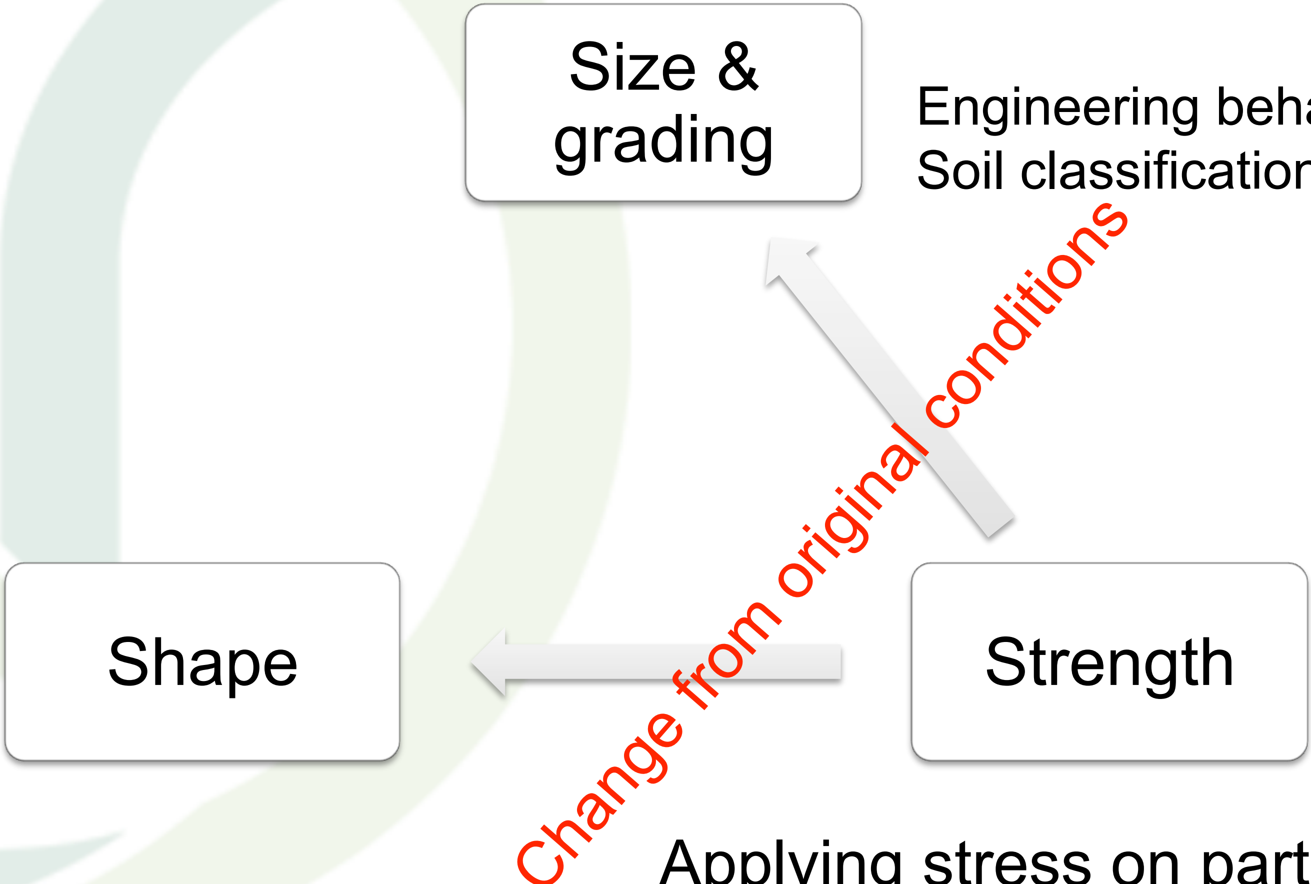
Change of grading



Presentation contents

- Introduction
  - Importance of particle crushing
  - Progress of research on crushing
- Contents
  - Mechanical behaviour accompanied by particle crushing
    - Experimental and numerical results will be introduced
    - Size dependency on crushing strength, its effect on mechanical behaviour will be examined experimentally
    - Mechanical behaviour will be normalized by crushing strength numerically
  - Mechanical behaviour after removal of grains
    - The grading change in internal erosion will be explained numerically
- Summary

Why particle crushing is important in Geomechanics?



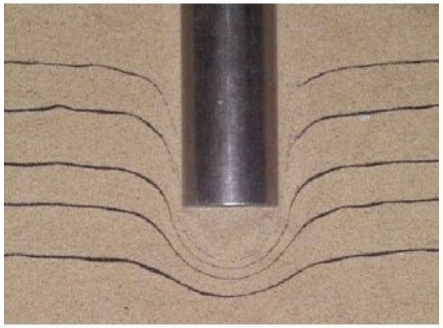
Engineering behaviour
Soil classification

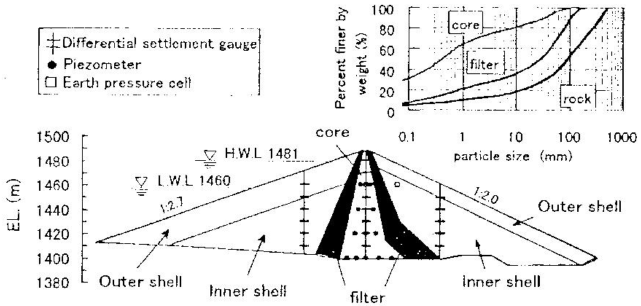
Density
&
Shear stiffness
and resistance

Applying stress on particle
> Crushing strength

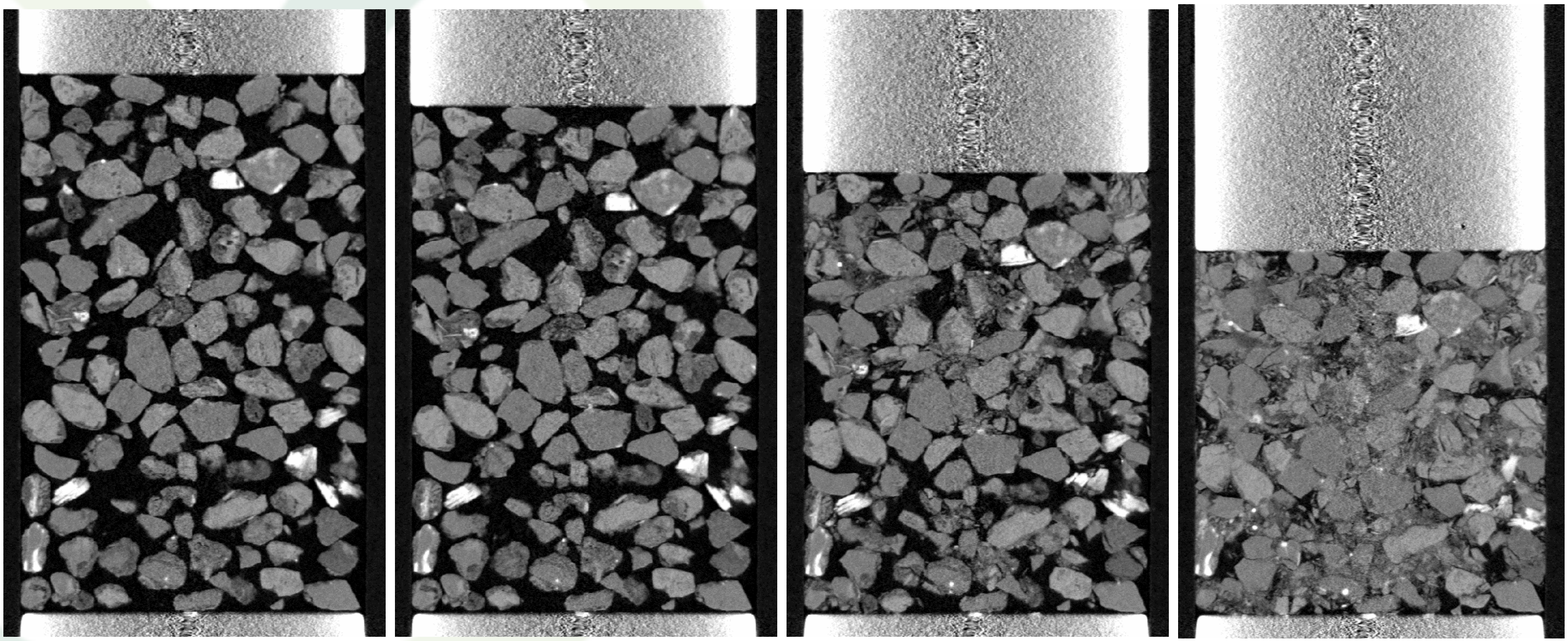
Where particle crushing occur?

- High stress conditions
  - the end of pile
  - the bottoms of high embankment and dam
- Weak and crushable grains
  - decomposed granite (feldspar and mica)
  - volcanic ashes (pumice)
  - carbonate sand (algae and shell fragments)





Progress of research on particle crushing
- Introduction of advanced observation technique

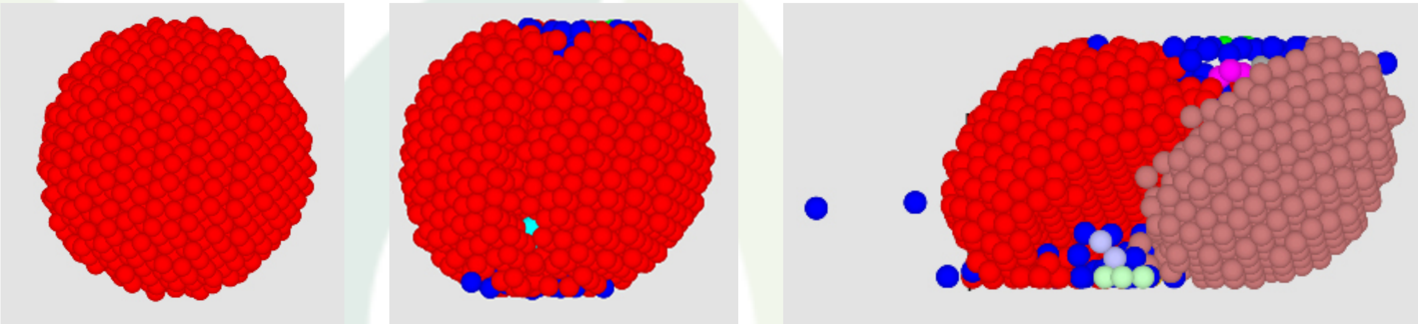


initial 2MPa(yield) 8MPa 40MPa

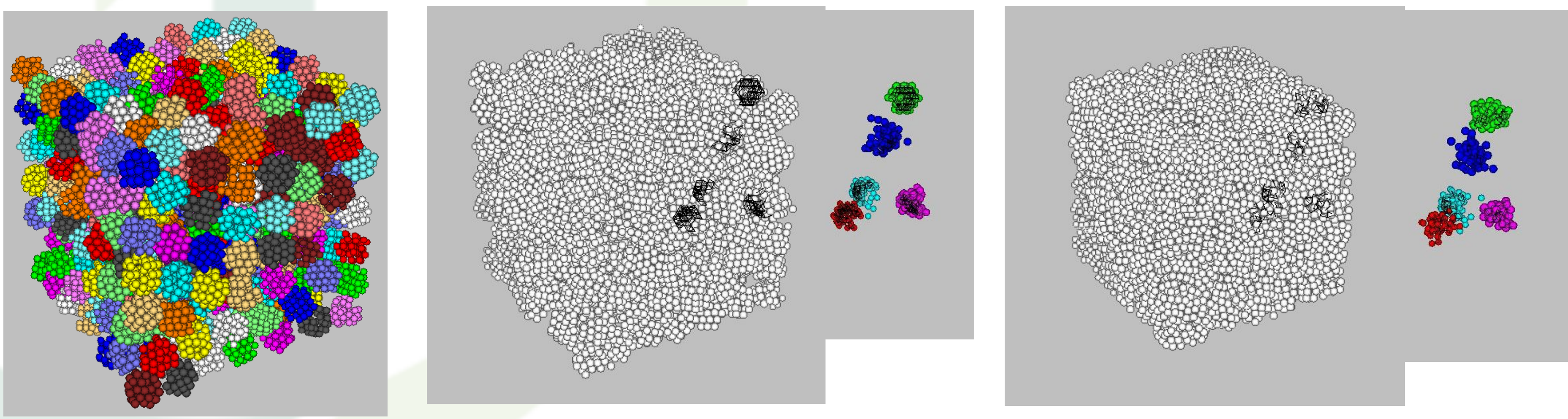
Observation during 1D compression using CT scanning

Scanned by T Matsushima

Progress of research on particle crushing
- Introduction of numerical simulation for understanding of micromechanics



Crushing for single grain (Robertoson & Bolton, 2001, McDowell & Harireche 2002a, 2002b)



Crushing in assembly of crushable grains (Cheng et al. 2003, 2004, Bolton, 2008)

Simulation for particle crushing using DEM

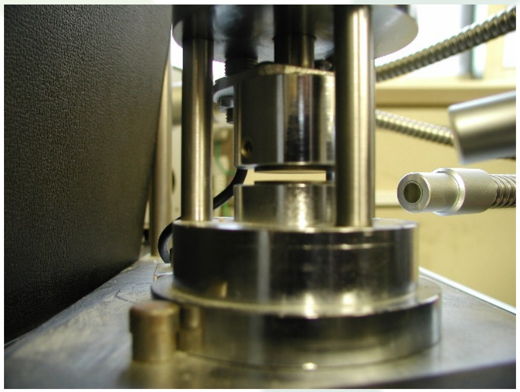
Experimental and numerical results will be introduced

Size dependency on crushing strength, its effect on mechanical behaviour will be examined experimentally

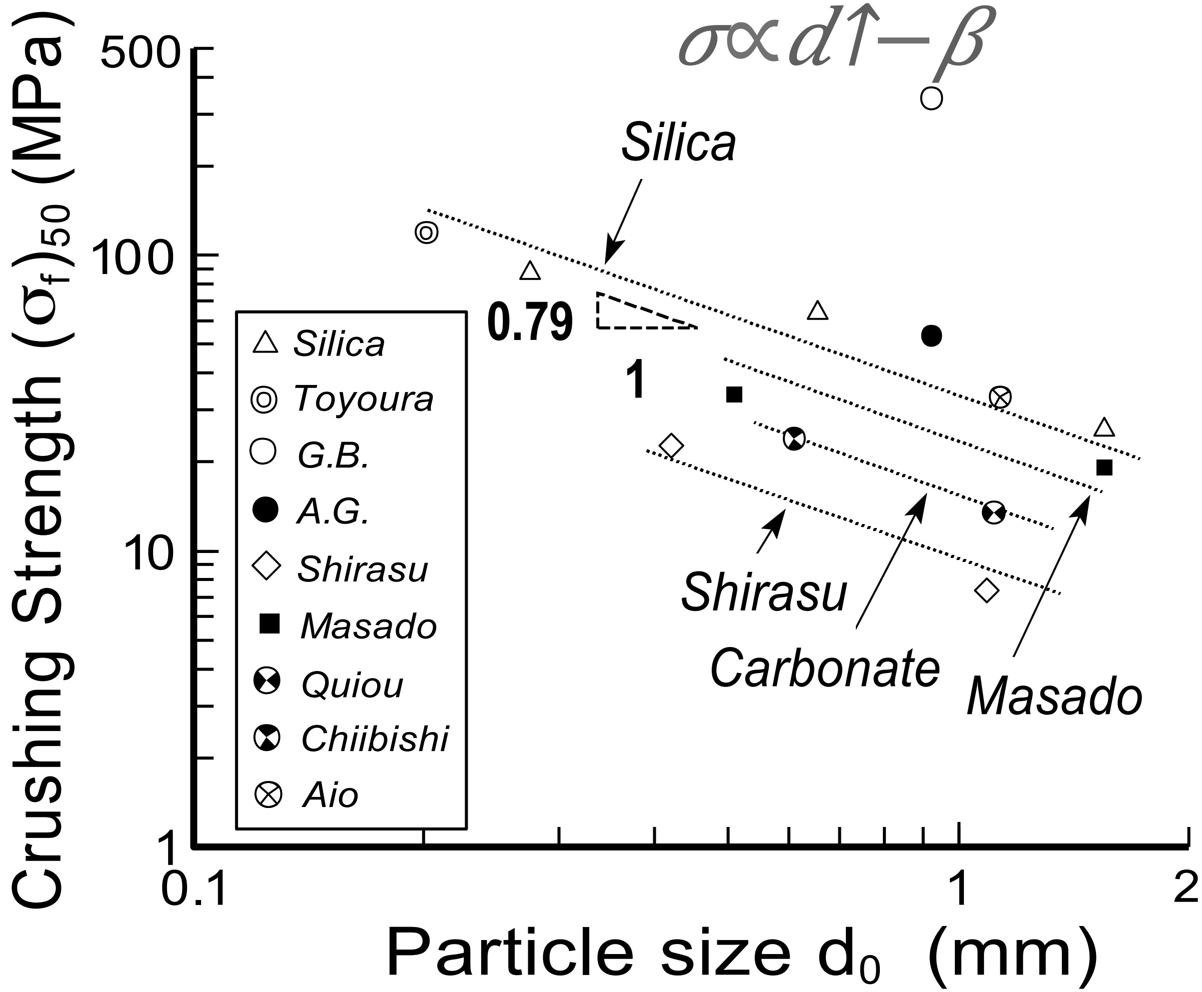
Mechanical behaviour will be normalized by crushing strength numerically

MECHANICAL BEHAVIOUR ACCOMPANIED BY PARTICLE CRUSHING

Crushing properties of single particle - Dependency on particle size of strength for geomaterials

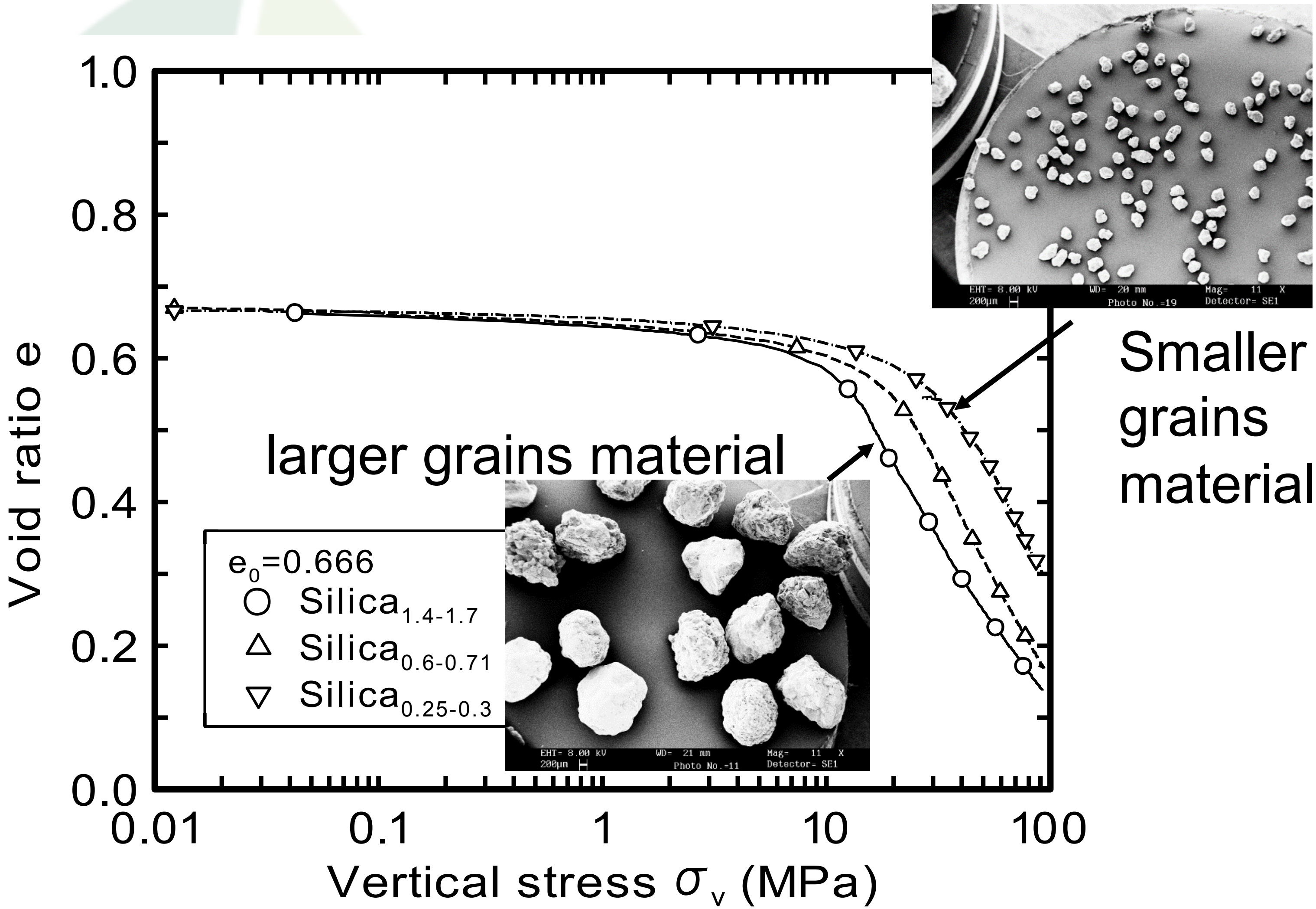


$\sigma \propto d^{-\beta}$



(Nakata et al. 1999 & 2001, Kato et al, 2001)

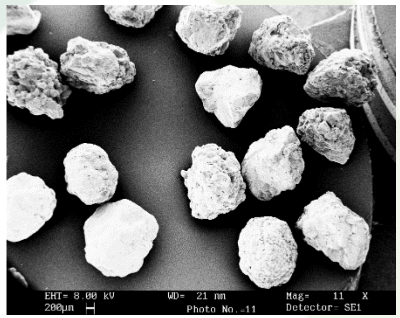
Compression behaviour depending on size

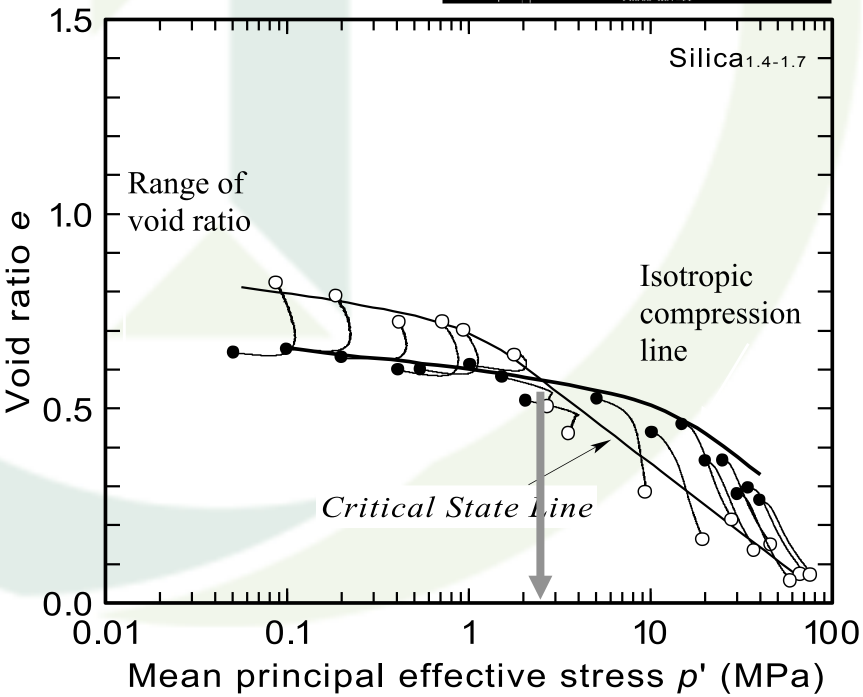


(Nakata et al. 2001)

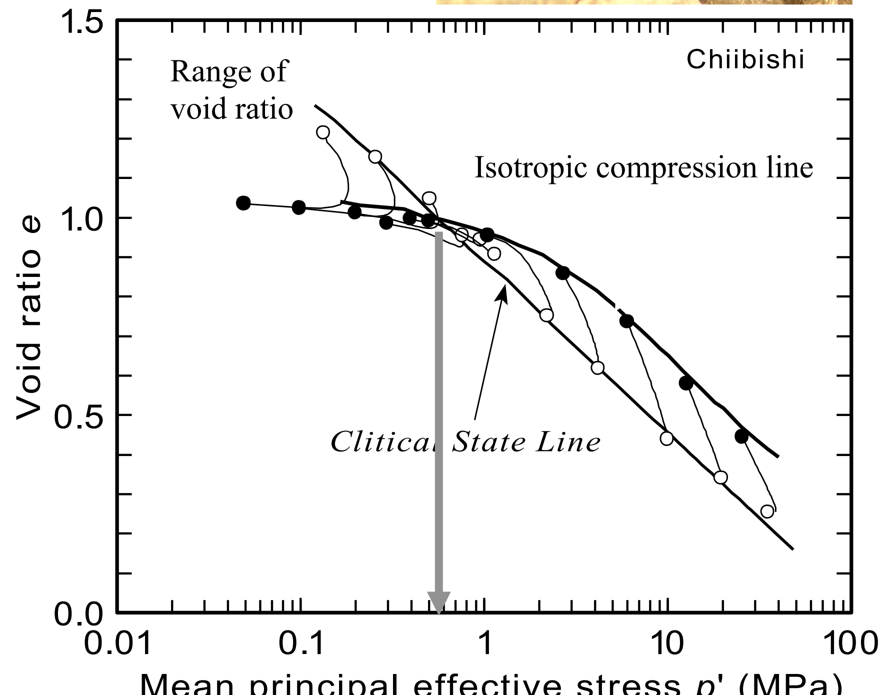
State path of isotropic compression and triaxial compression tests (50kPa-40MPa) for geomaterials

Silica sand





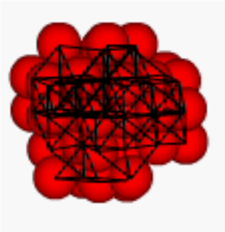
Carbonate sand (alga and shell fragments)



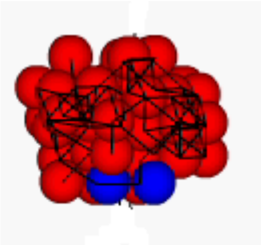
(Kato, et al. 2003)

A Modelling of Crushable grains by 3D-DEM

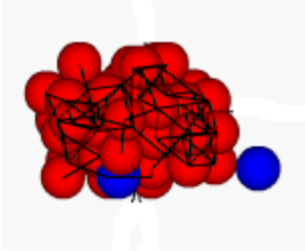
- Soil grain = group of balls
- Regularly packed balls of identical size (hexagonal close)



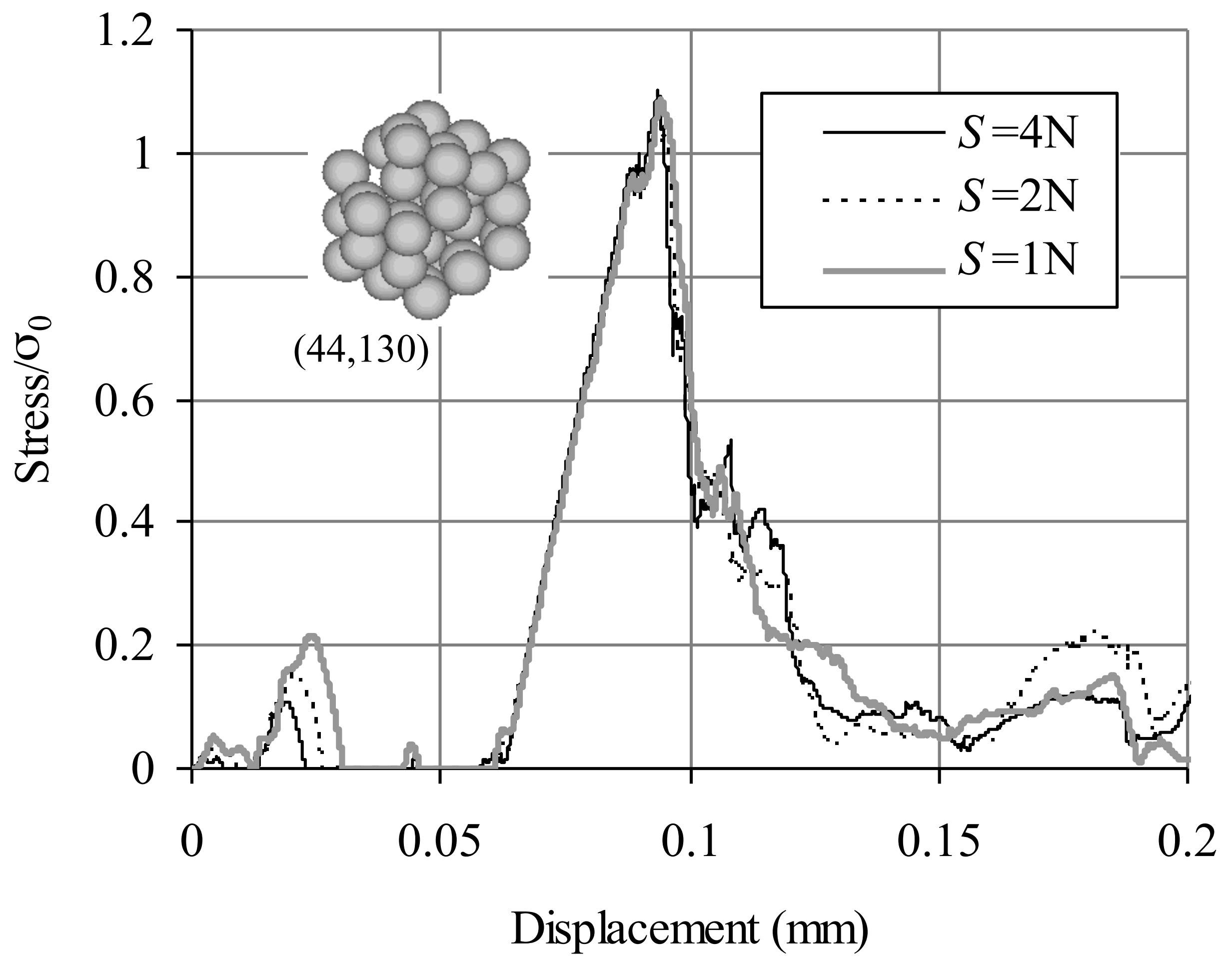
- Introducing the randomness
  - removing balls assuming the existence probability of 20%



- Bonded contacts with bond strength
  - If the magnitude of a force equals or exceeds the bond strength, the bond breaks



Simulation results of single particle crushing for grains with different strength



Normalized particle crushing behaviour

(Nakata et al, 2005)

Laboratory test simulations for crushable grains assembly

to understand the macro response for the assembly of the crushable grains

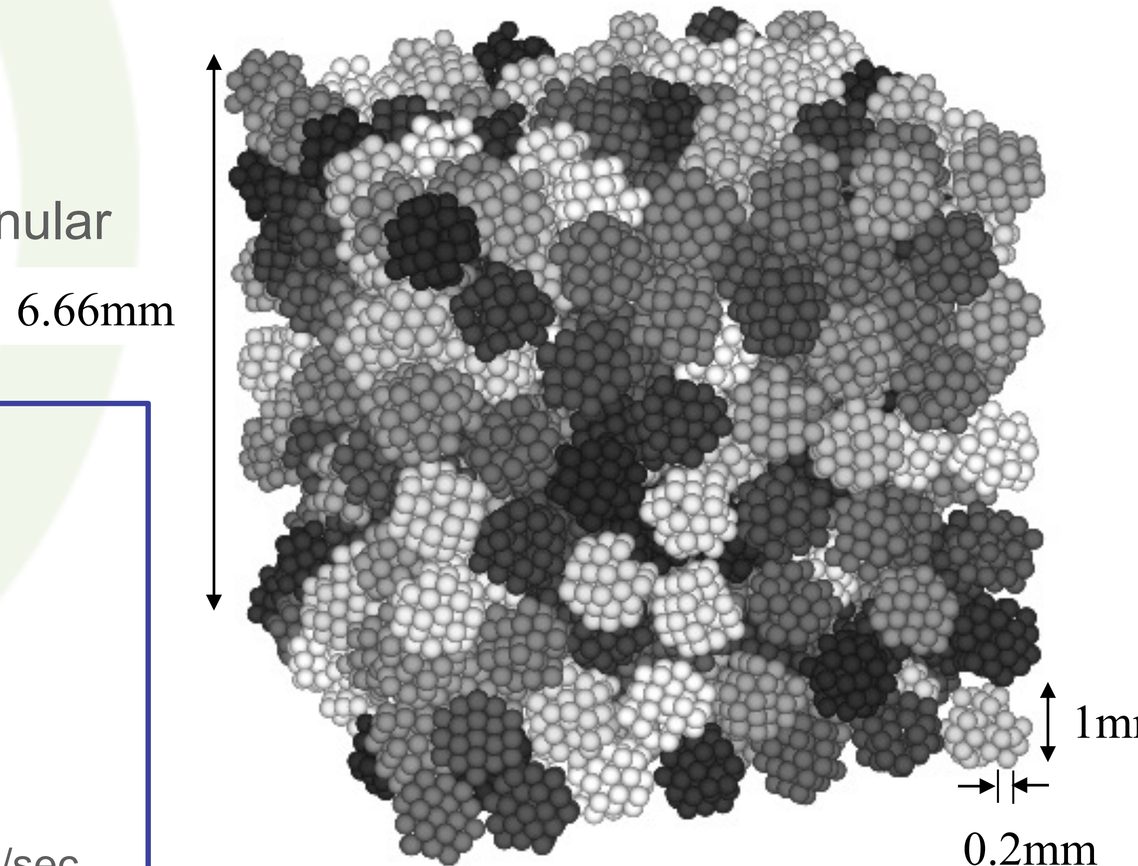
To simulate **both** the rearrangement and particle breaking mechanism!!! (granular nature & stress-level dependent)

Cubical assembly:

- $(6.66\ mm)^3$
- 378 grains
- 6 Frictionless walls

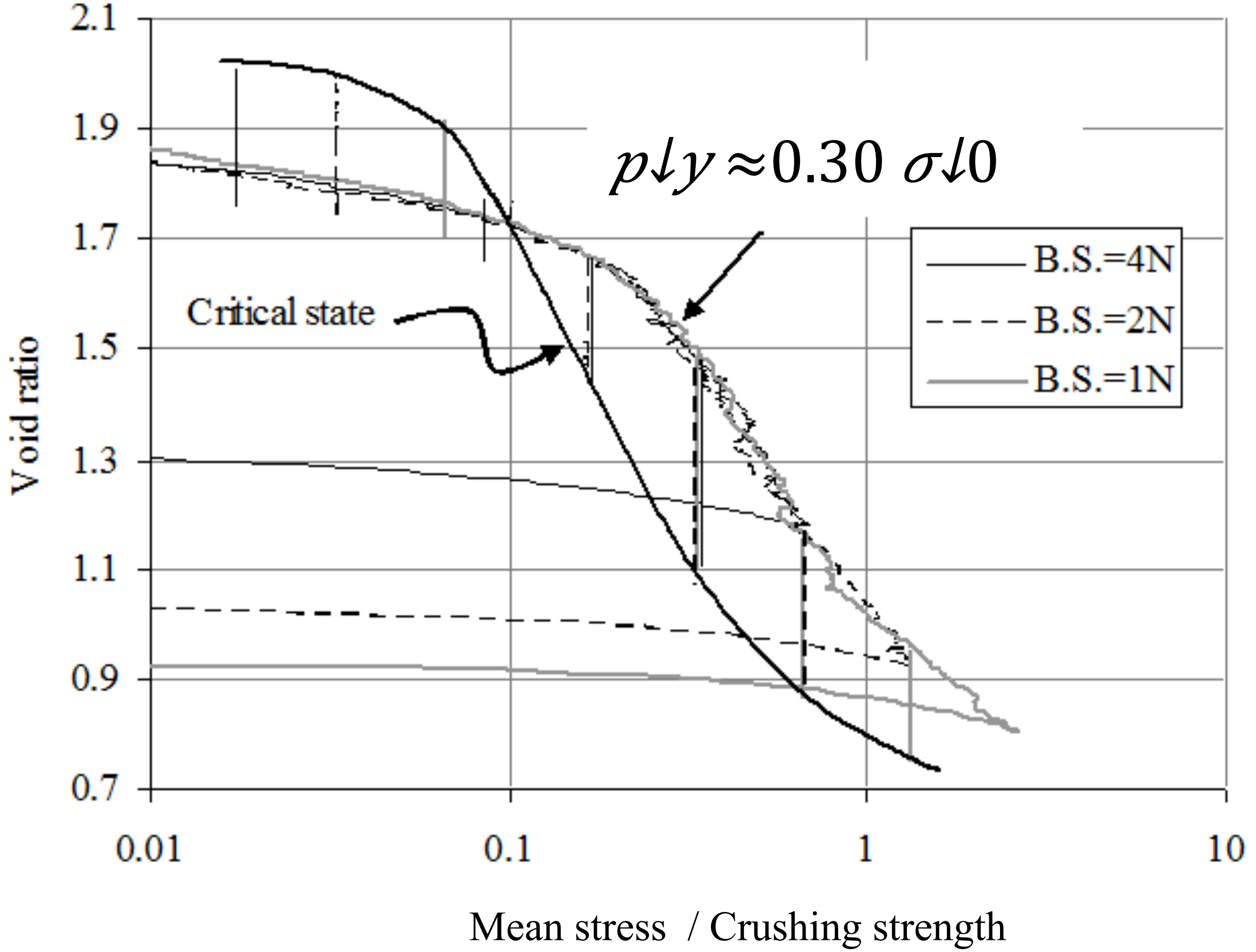
Test condition:

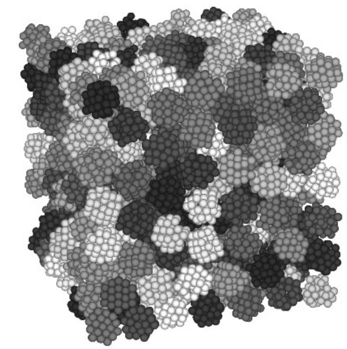
- Strain control method
- keeping wall speeds of 0.05m/sec



(Cheng et al. 2003, 2004, Bolton, 2008)

Simulation results on IC and TC for crushable grains assemblies with different strength

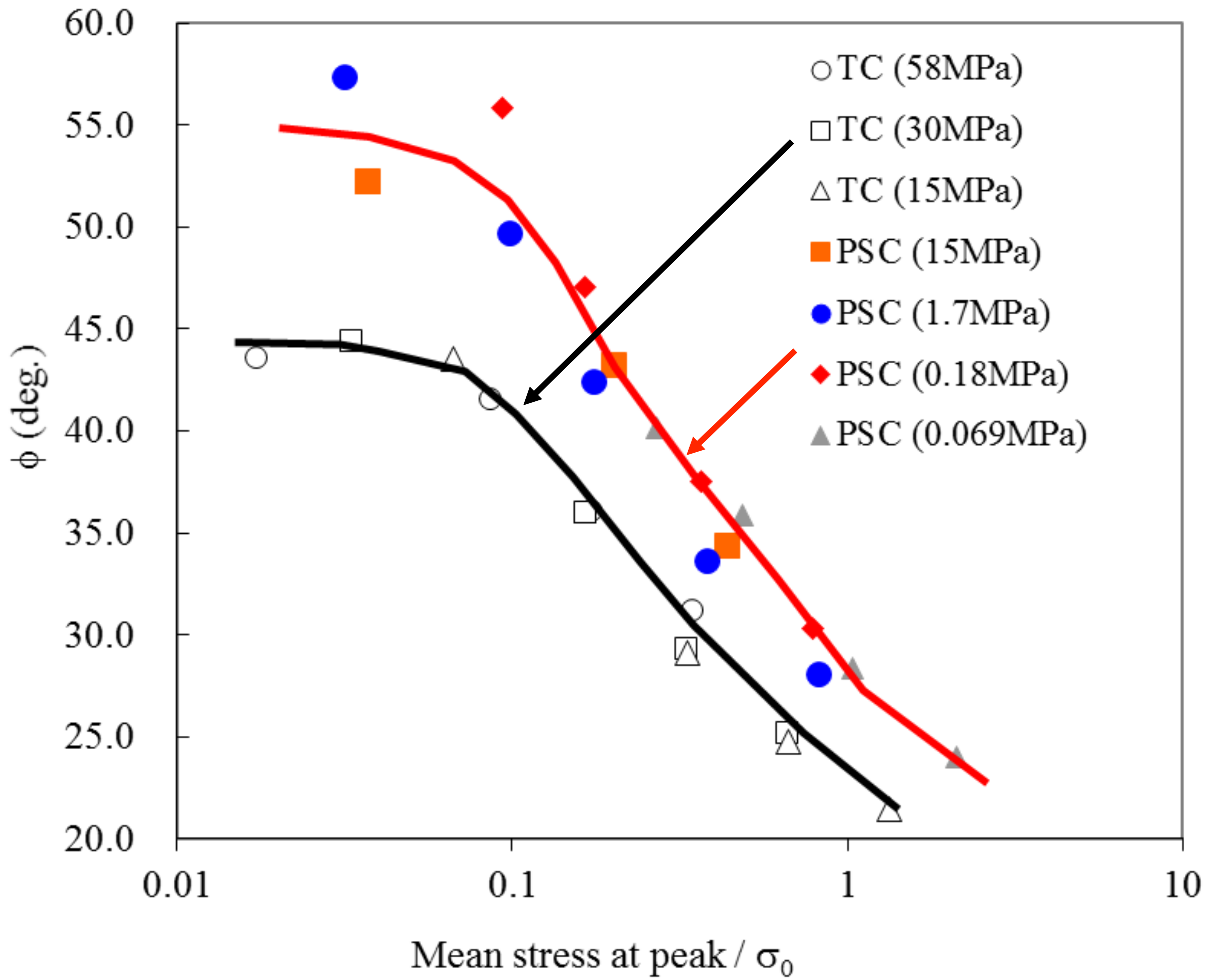


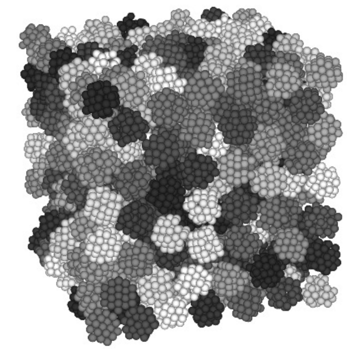


State path normalized by crushing strength

(Nakata et al, 2005)

Simulation results on stress dependency of shear resistance angle during TC and PSC

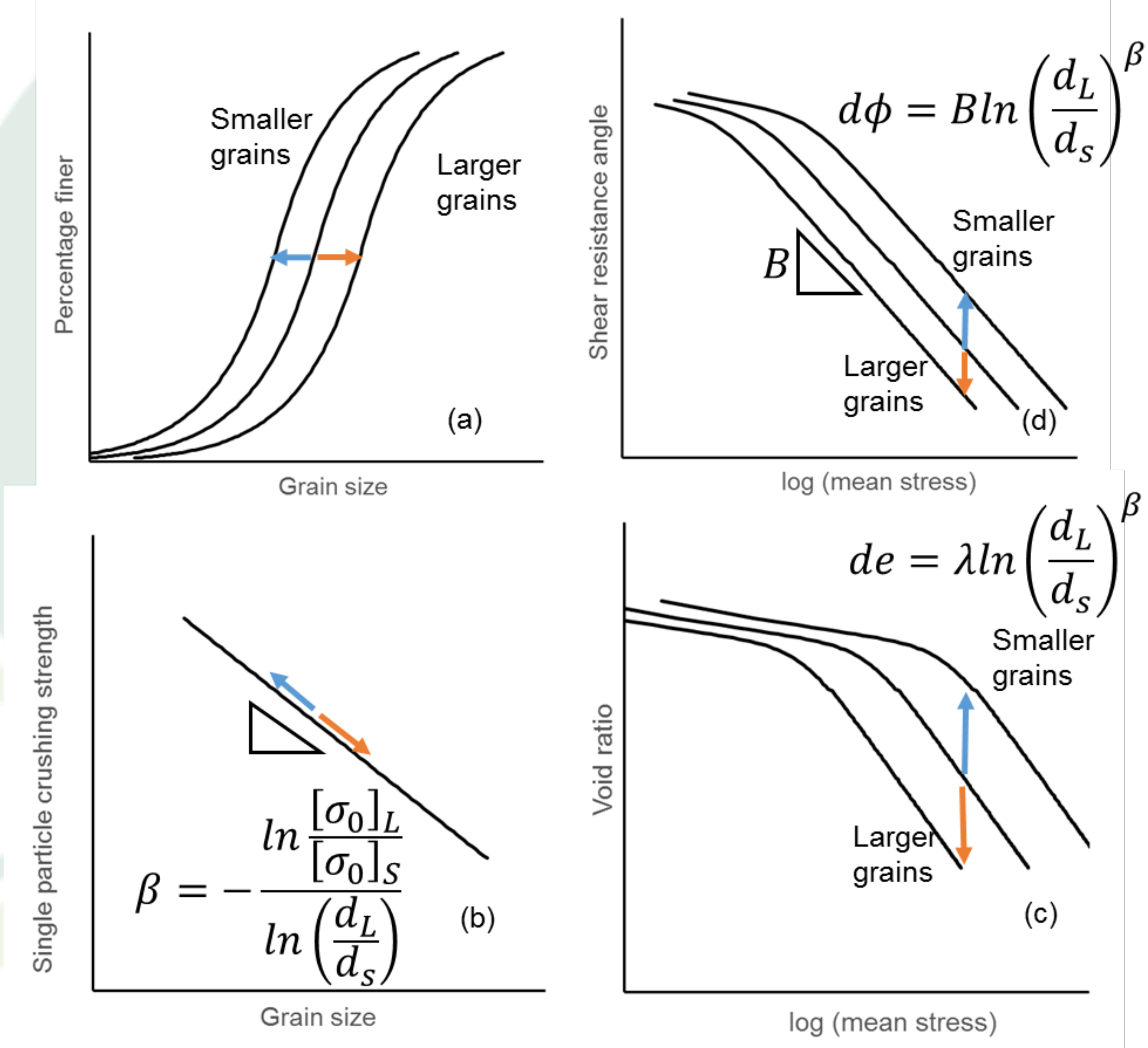




Pressure dependency normalized by crushing strength

(Nakata et al, 2005 & 2006)

Geomechanics of crushable materials depending on initial particle size (particle strength)



The grading change in internal erosion will be explained numerically

MECHANICAL BEHAVIOUR AFTER REMOVAL OF GRAINS

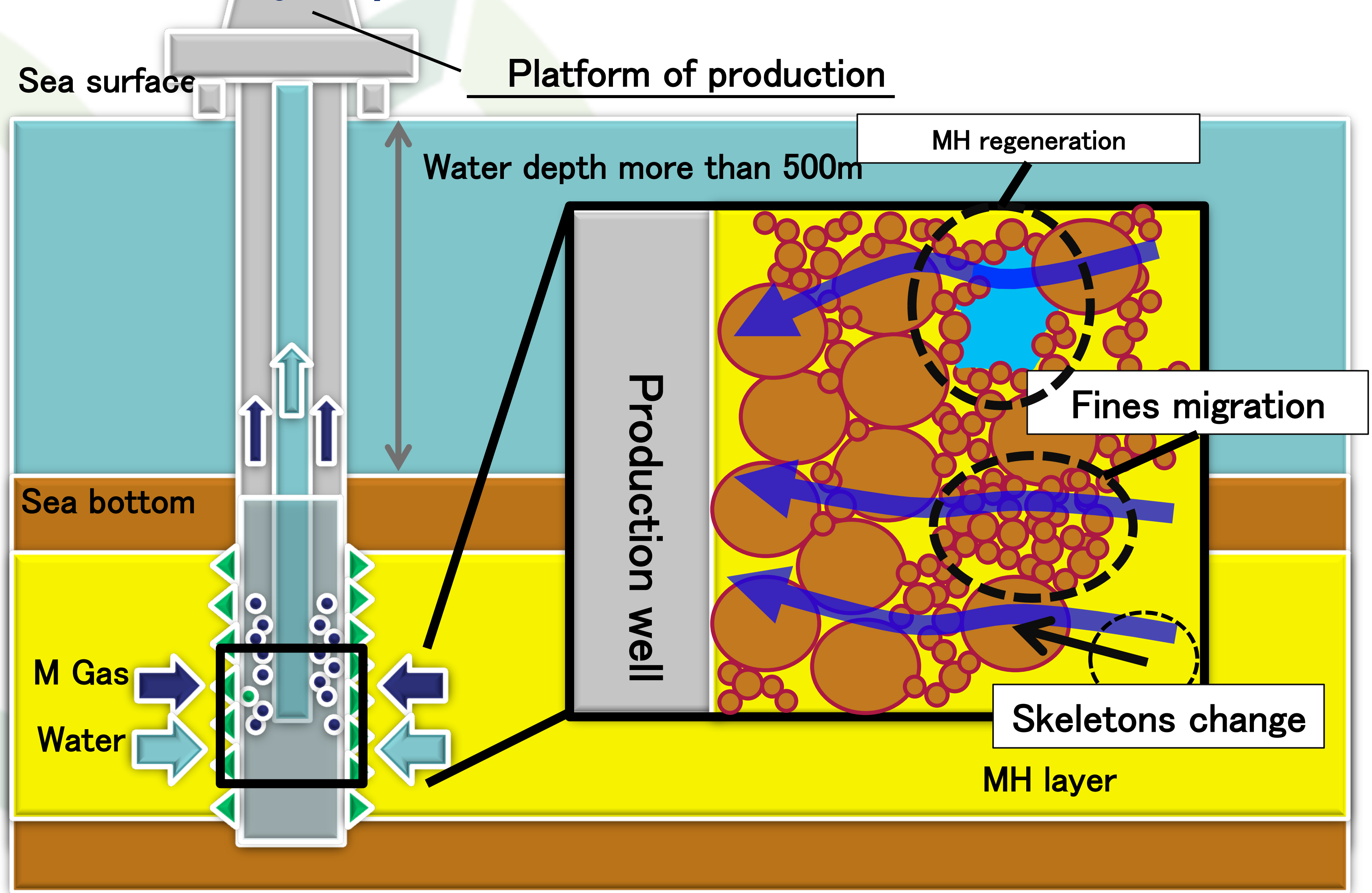
Fines removal due to internal erosion

- ■Particle flow out of a soil matrix at a higher permeation field
- ■Possible geotechnical situations
  - embankment
  - Fill dam
  - River dike
  - MH production

Internal erosion in road embankment

Removal of fines from drainage pipe

Geotechnical problem of MH production by depressurisation

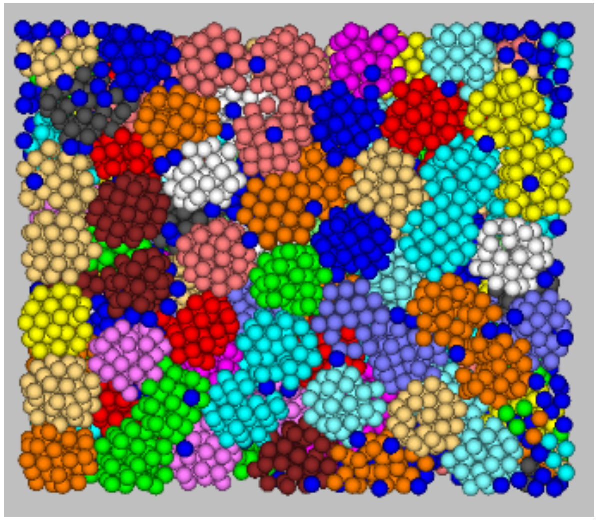


Geotechnical problems due to internal erosion

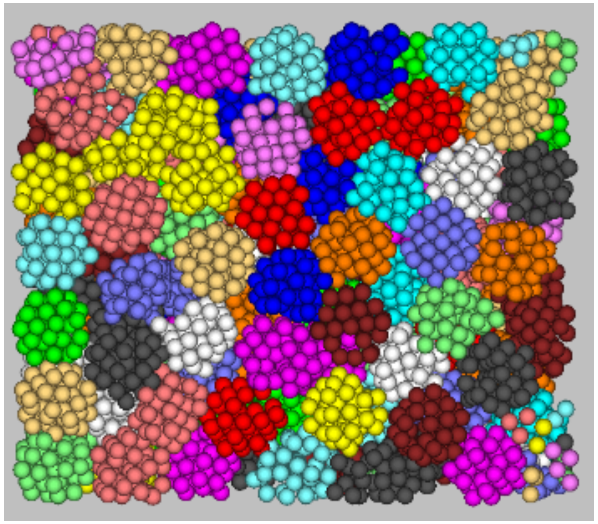
- Elevation of effective stress due to seepage
- Removal of fines

Numerical technique was employed to simulate the removal of small grains (a ball) (Wood & Maeda 2006)

1. Calculation of K_0
2. Removal of all smallest grains at five stress levels
3. Re-calculation keeping K_0
4. PSC calculation

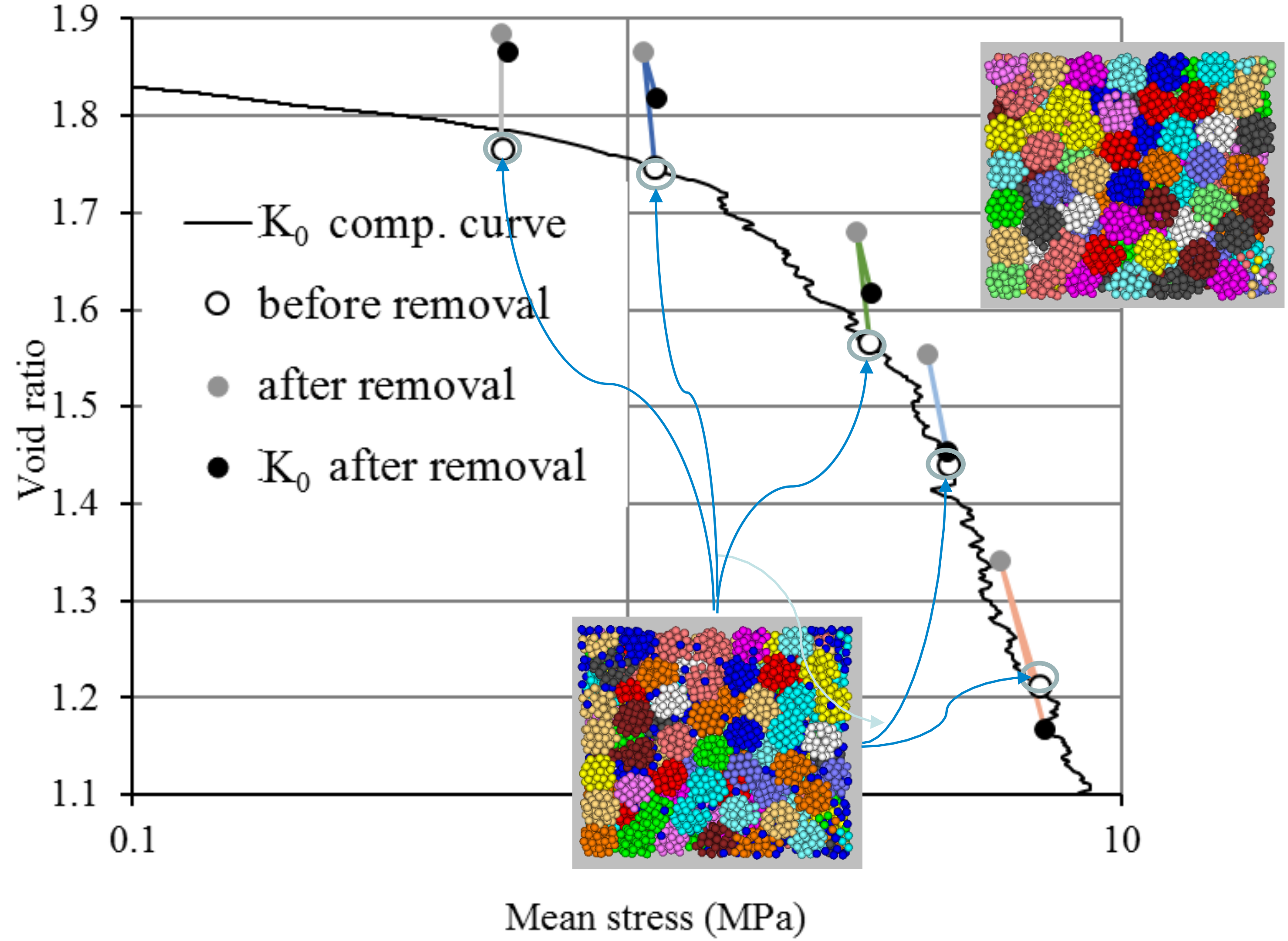


Before removal

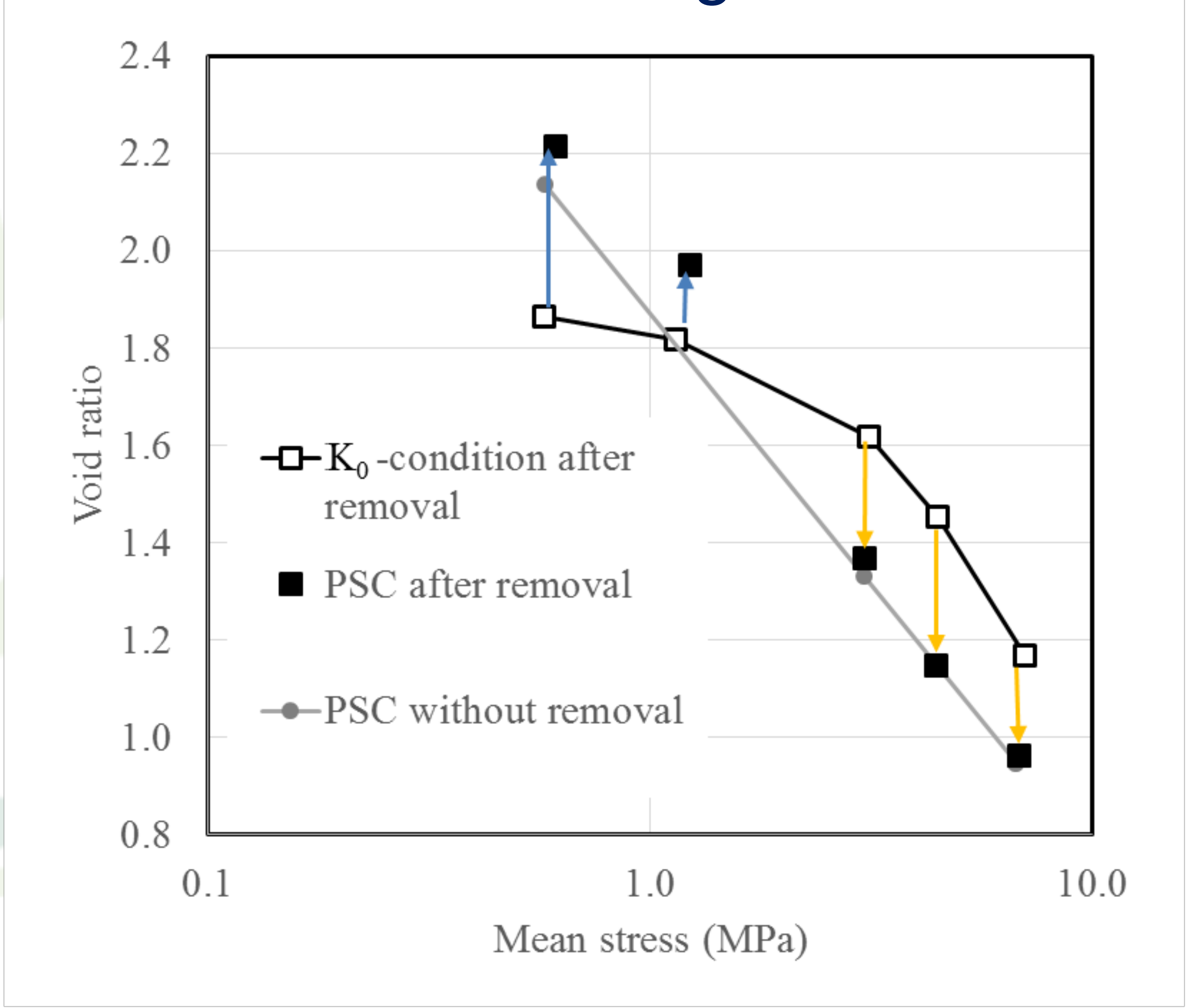


After removal

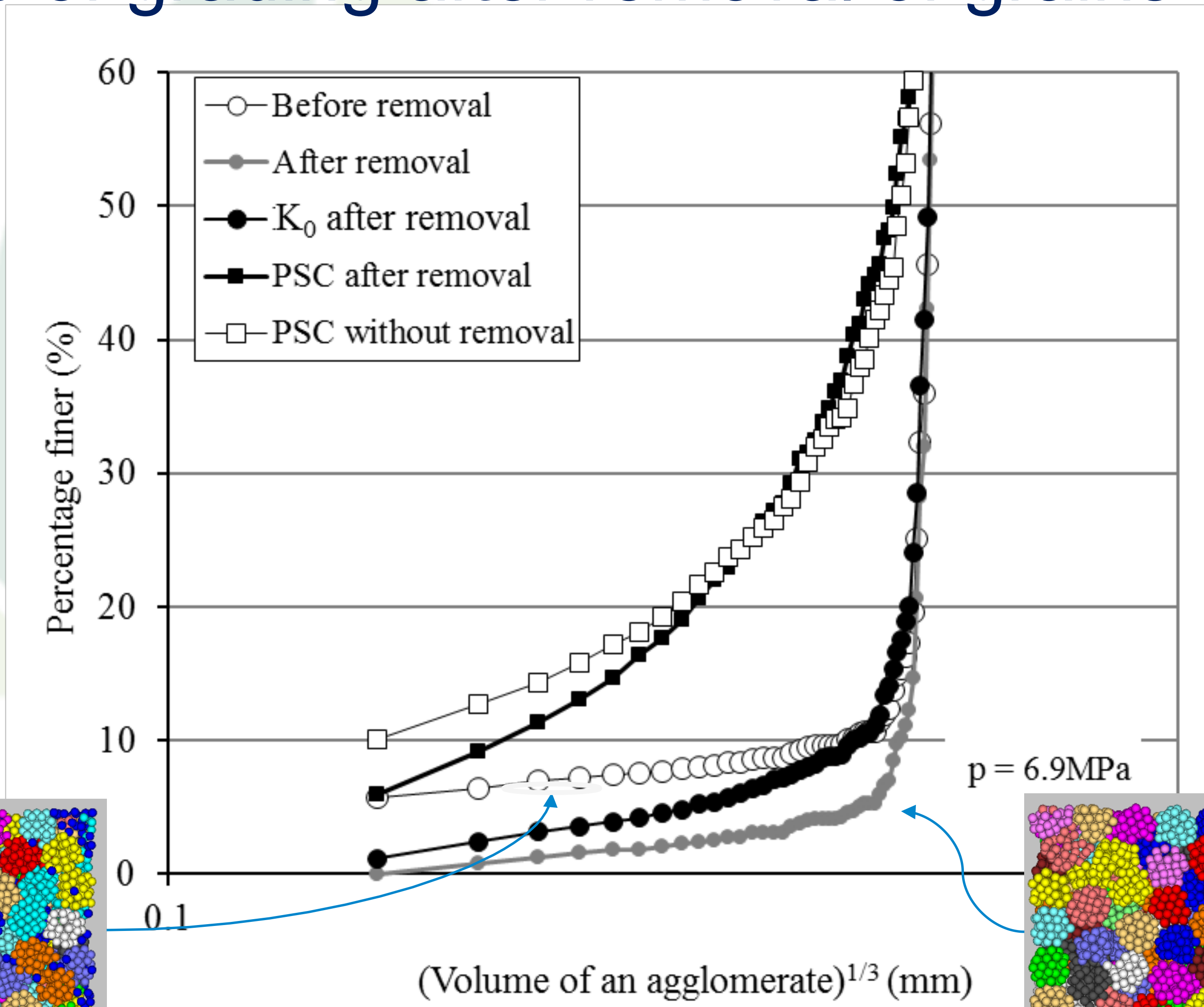
Variation of void ratio after removal of grains

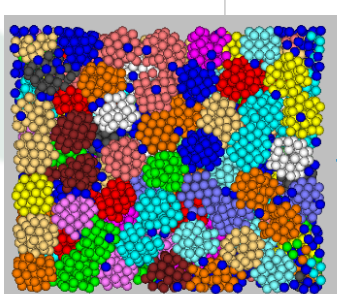


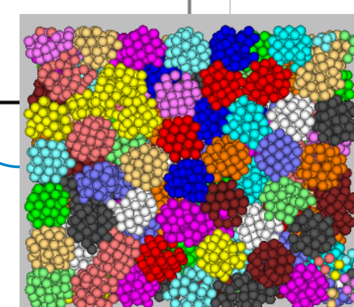
Variation of void ratio during PSC after removal



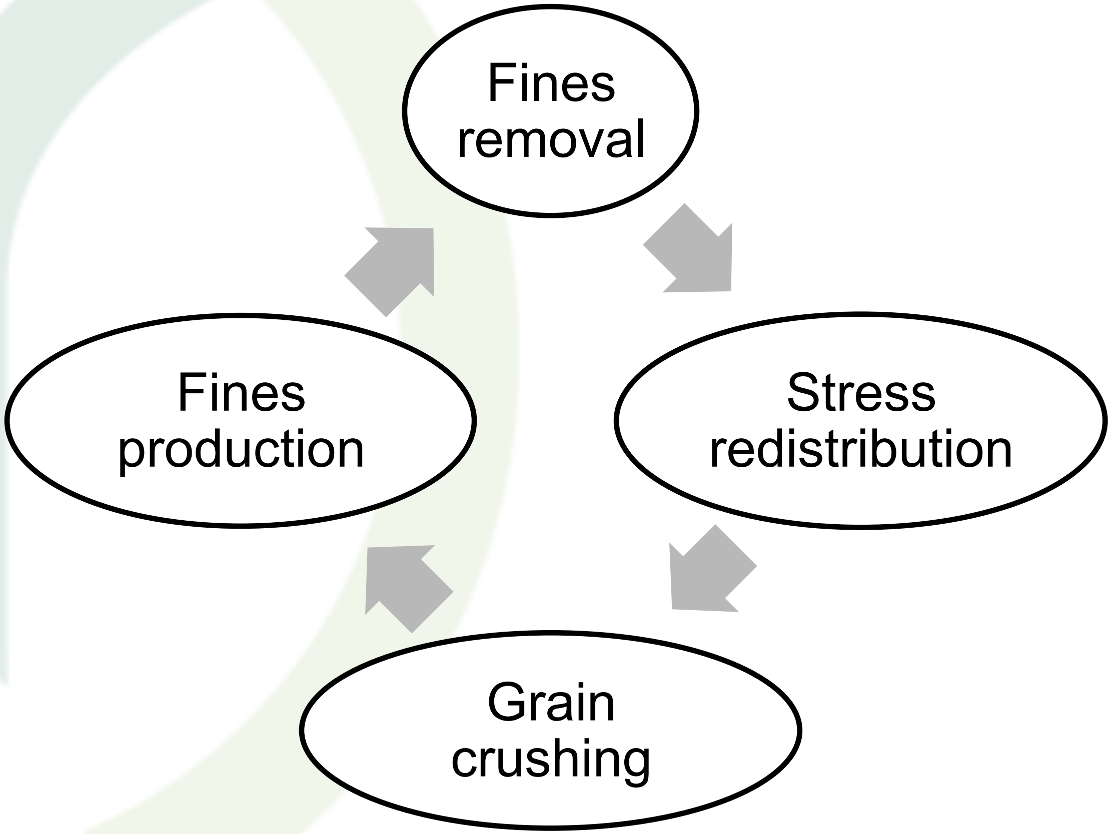
Change of grading after removal of grains







Possible situation during internal erosion



Chain reaction of fines removal and production

SUMMARY

Summary (1)

■Mechanical behaviour accompanied by particle crushing

- Size dependency on crushing strength was presented experimentally
- Mechanical behaviour were normalized by the crushing strength numerically
- Geomechanics depending on initial particle size was summarised

Summary (2)

■Mechanical behaviour after removal of grains

- The effects of removal was dependent on the stress level
- At higher stress, the K_0C and CS condition were closed to the original
- Chain reaction of fines removal and production would be expected

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