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Characteristics of soluble mixtures

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Outline

- **Geo-soluble mixtures**
  - Introduction
  - Testing
  - Numerical Modeling
  - Summary

Introduction

- Soil naturally contains grains of different mineral → dissolved
- Dissolution → change microstructure:
  - ↑ local void + permeability
  - influence the safety

St. Francis Dam Failure →

The small strain stiffness of soluble mixtures modeled by sand-salt mixtures with various salt volume fractions.

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Materials

Jumunjin Sand

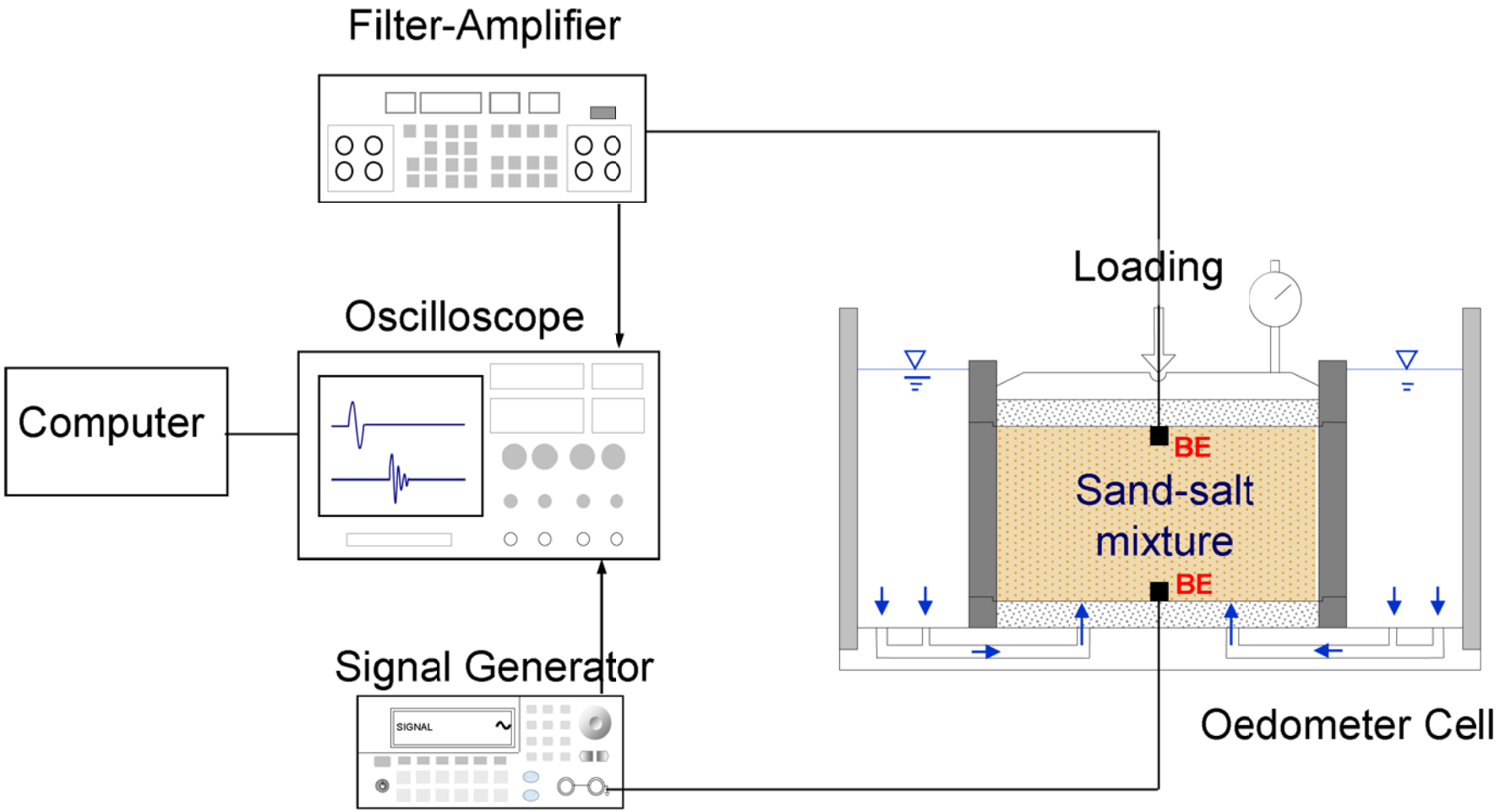
Salt

	G_s	D_{50} (mm)	S	R
Sand	2.62	0.36	0.65	0.7
Salt	2.16	0.25	0.73	0.27

- Mean grain size of sand particles $\approx$ 1.5 times larger than that of salt particle

Experimental setup

- The effect of dissolution – micro to macro mechanical behavior of mixtures – implementing S-wave measurement.
- BE – top cap & bottom plate

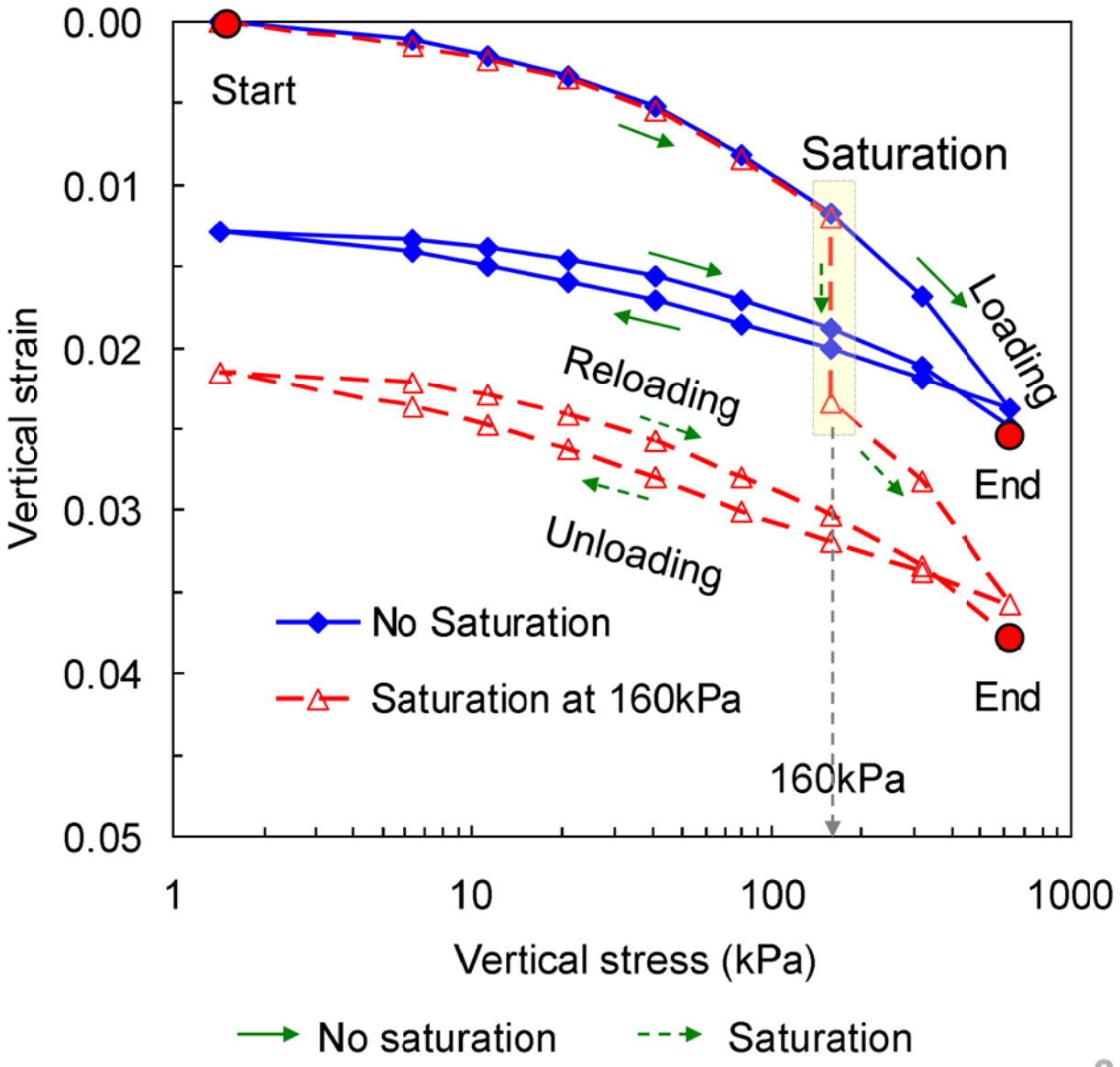


Test procedure

- Soluble mixtures – prepared different salt content- volume fraction
  - Salt fraction: sf = V_{salt}/V_{sand} (%)
  - Specimens with sf = 0, 2, 5, 7, & 10 %
  - 5 layers, tamping (same energy)
- 3 stages: loading – unloading – reloading with time interval:
  - Loading – unloading stage: 30 minutes
  - Saturation stage: 1000 minutes
- Stress for saturation: used NaCl 0.01 - different confining stresses
- Shear wave measurement: at the end of loading step

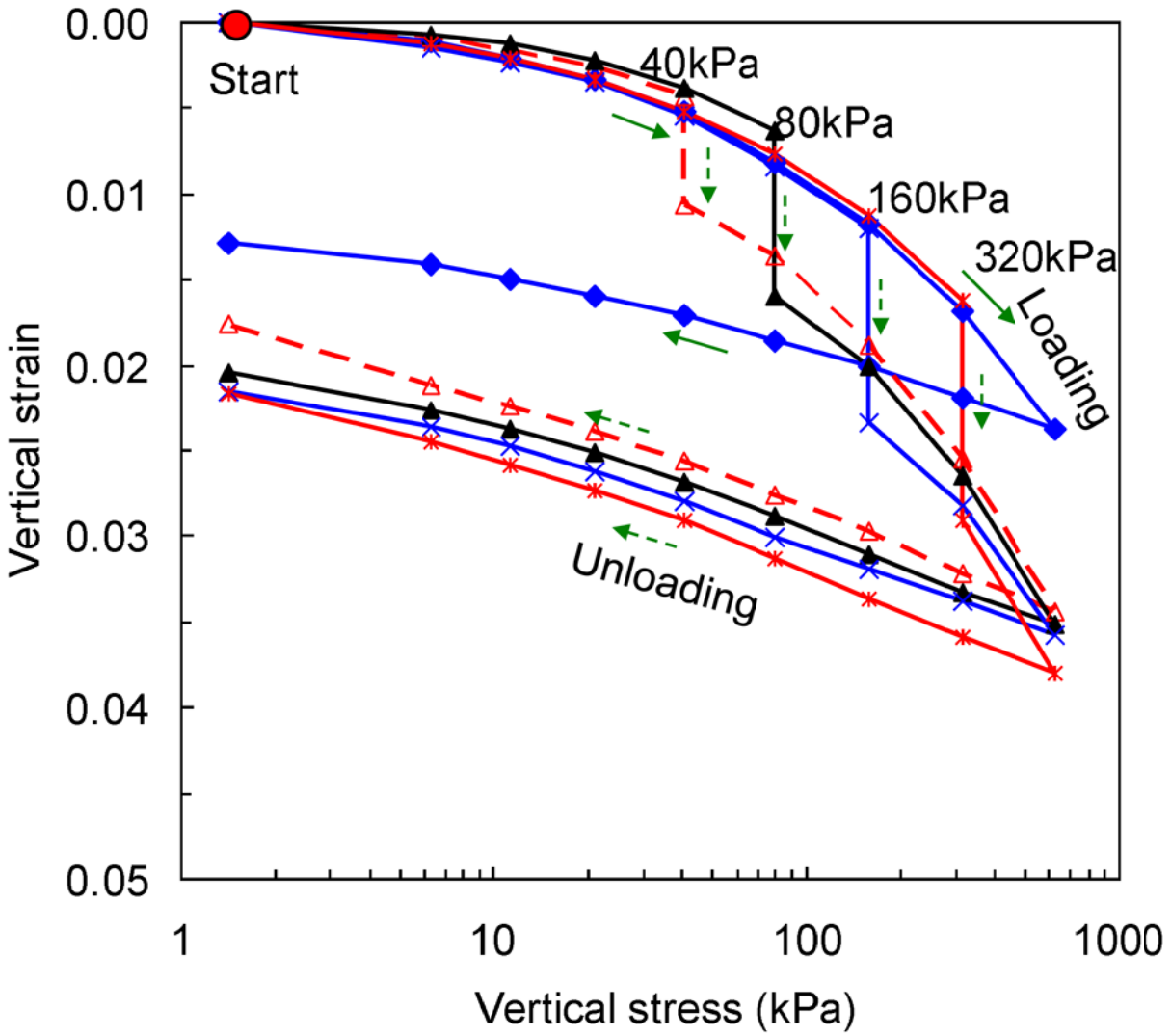
Vertical strain - Saturation

- Vertical strain of 2 mixtures with 10% initial salt fraction
- 1: no dissolved
- 2: dissolved at 160kPa
- Before saturation:
  - identical behavior
- After saturation:
  - ε_v ↑



Vertical strain – Different vertical stresses

- Vertical strain: mixtures 10% initial salt fraction – saturated – different stresses.
- Dissolved at various σ_v^s = 40 ~ 320kPa
- As the planed stress increase, the total vertical strain increase: $\sigma_v \uparrow$ $\varepsilon_v \uparrow$

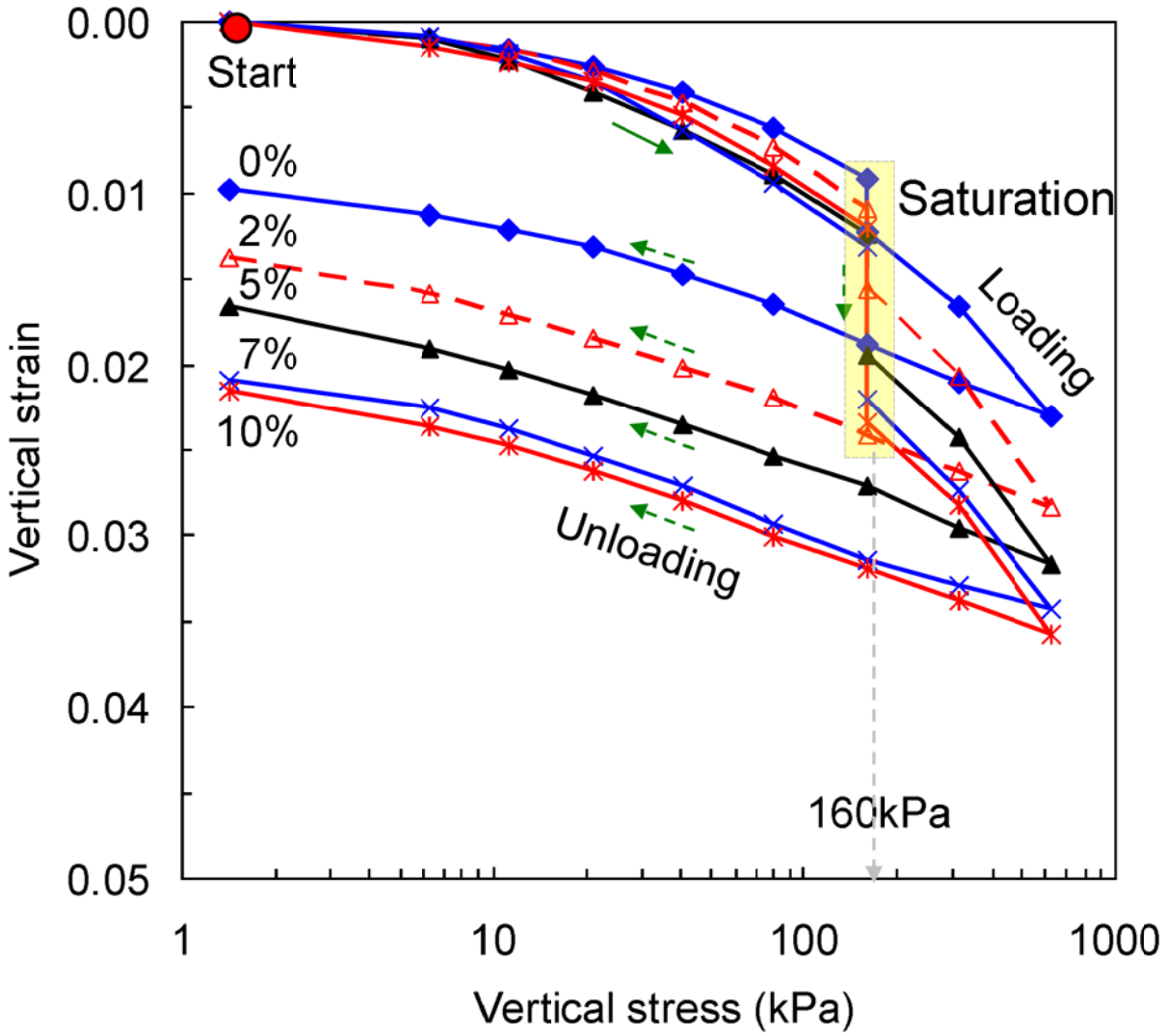


Vertical strain – Different salt fractions

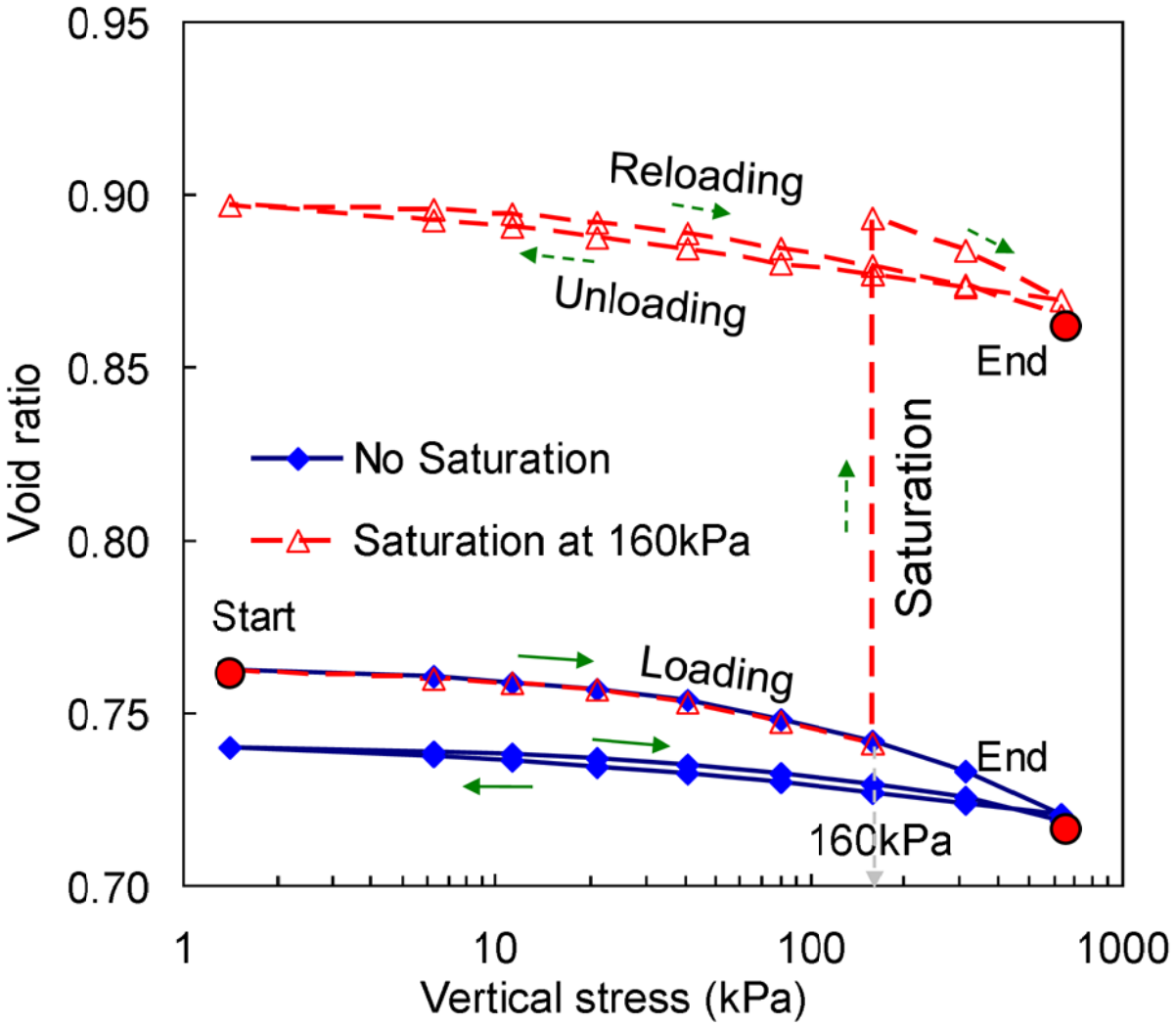
- Specimens: different initial sf: 0~10%
- Saturated at σ_v=160kPa
- sf ↑ ε_v ↑

∴ Total volume ↓ after dissolution

∴ Specimens seems to be getting stiffer

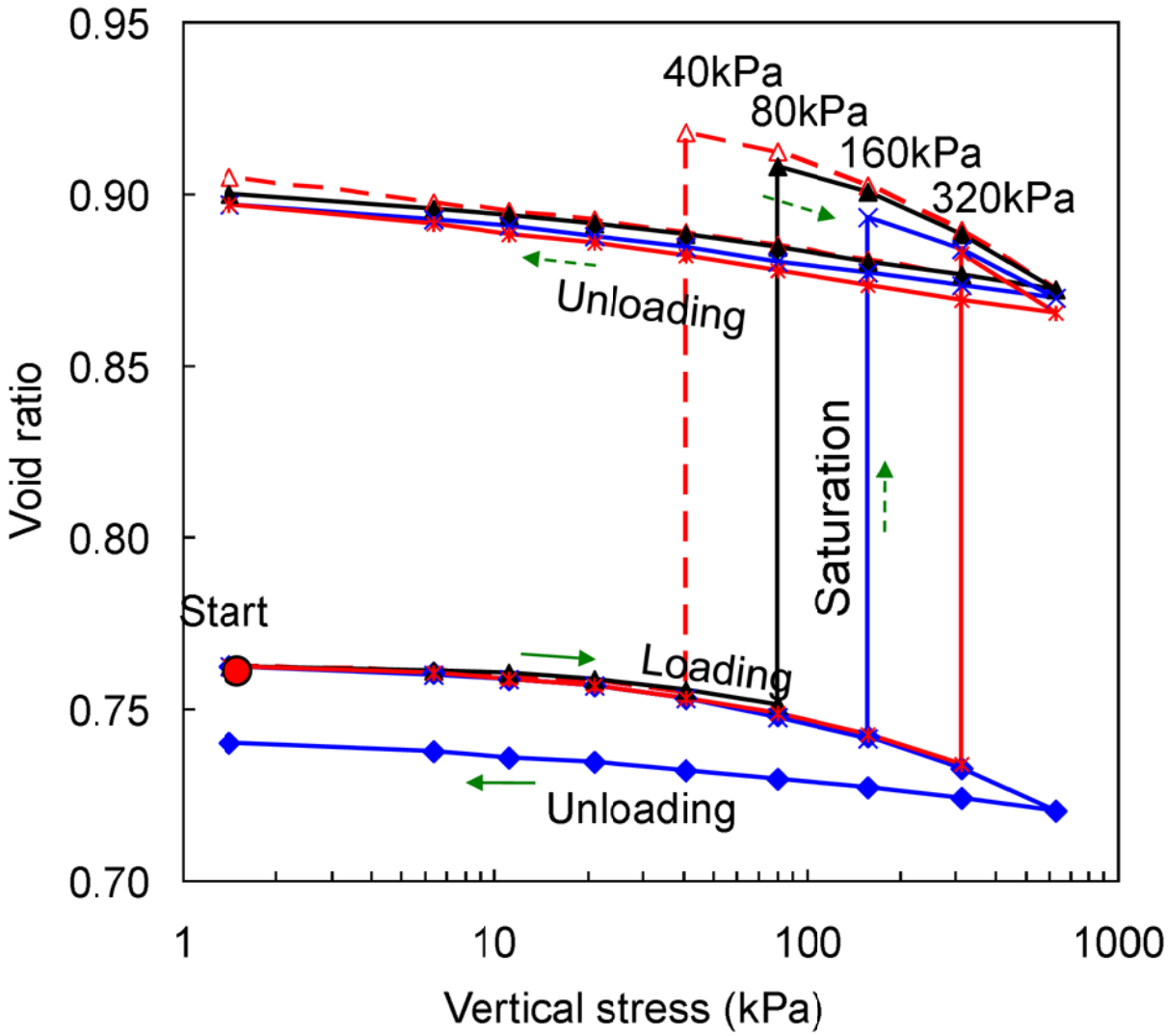


Void ratio – Saturation



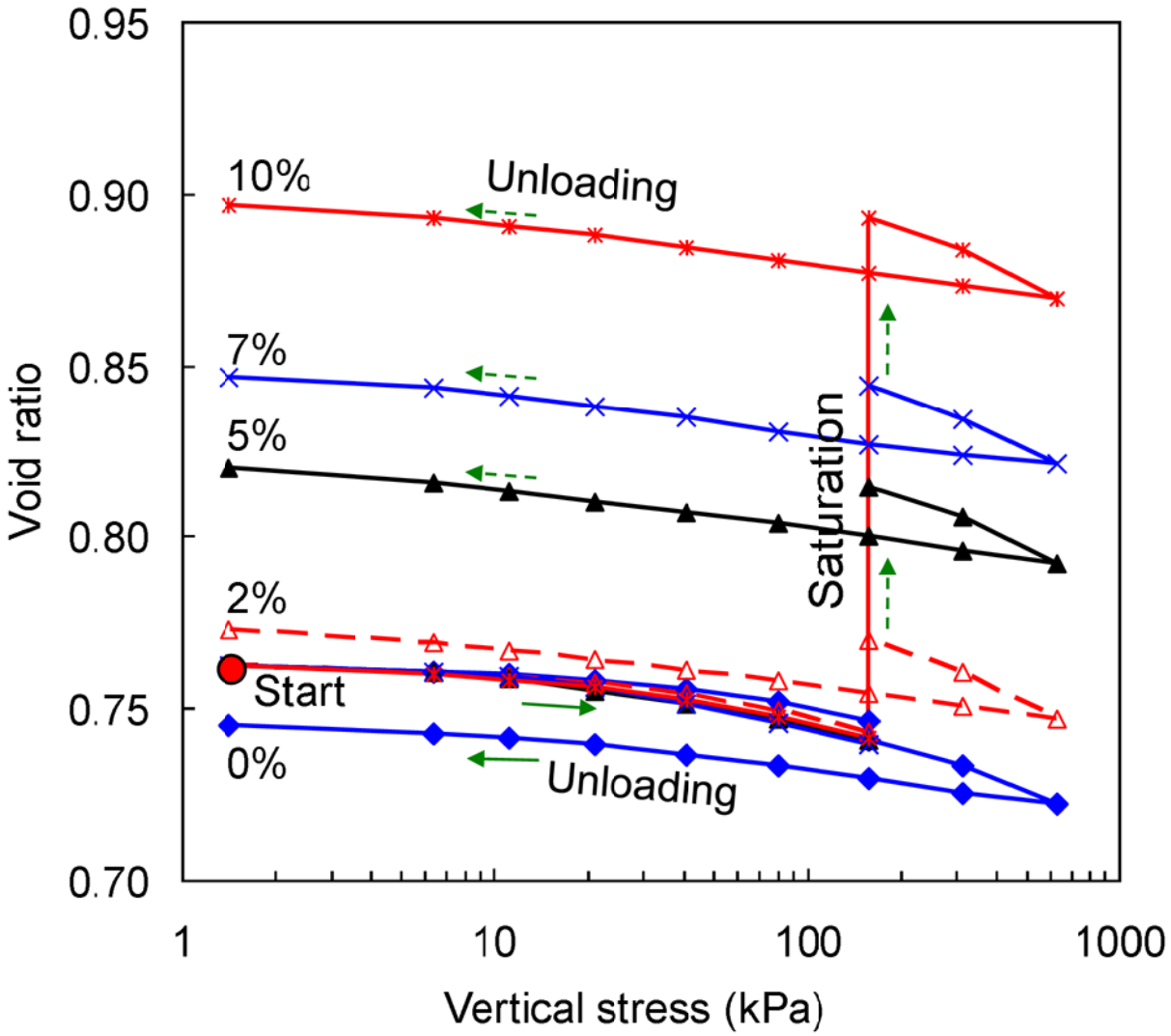
- Change of void ratio for 2 mixtures –10% sf
- 1: no dissolved
- 2: dissolved at 160kPa
- Before saturation:
  - Same behavior
- After saturation:
  - e ↑↑ ← dissolution of salt particles

Void ratio – Different vertical stresses



- Change of void ratio of the mixtures - 10% sf
- Saturated at different σ_v^s = 40~320kPa
- Before saturation:
  - Same behavior
- At saturated stress:
  - $\sigma_v \uparrow$ e $\downarrow$: lower saturated stress – higher void ratio

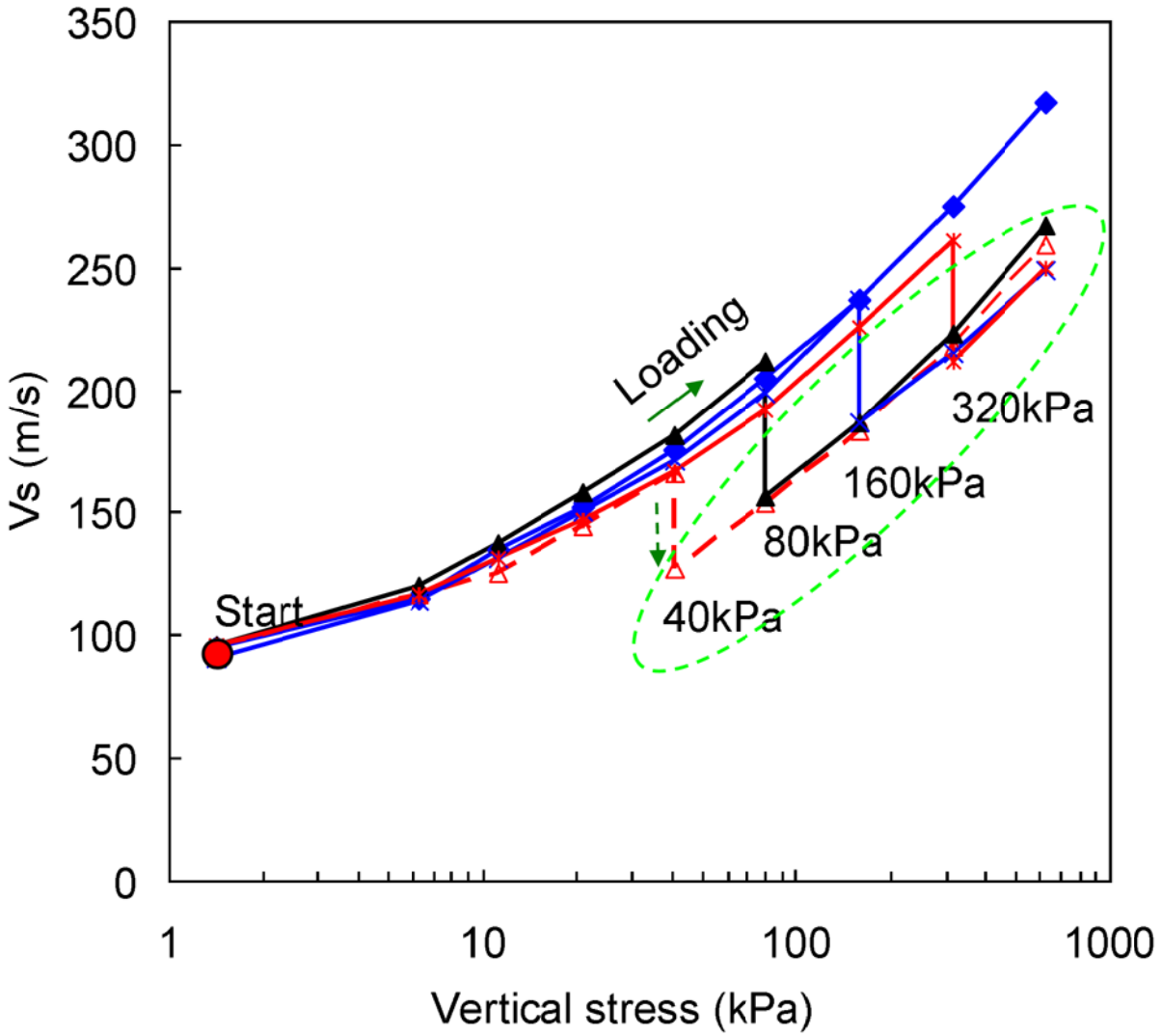
Void ratio - Different salt fractions



- Evolution of void ratio – mixtures - 0 ~ 10% sf
- Saturated: σ_v^s =160kPa
- Before saturation:
  - Same behavior
- At saturated stress:
  - sf↑ e ↑ : higher initial sf, higher void ratio
- Specimens getting loosen due to the dissolution

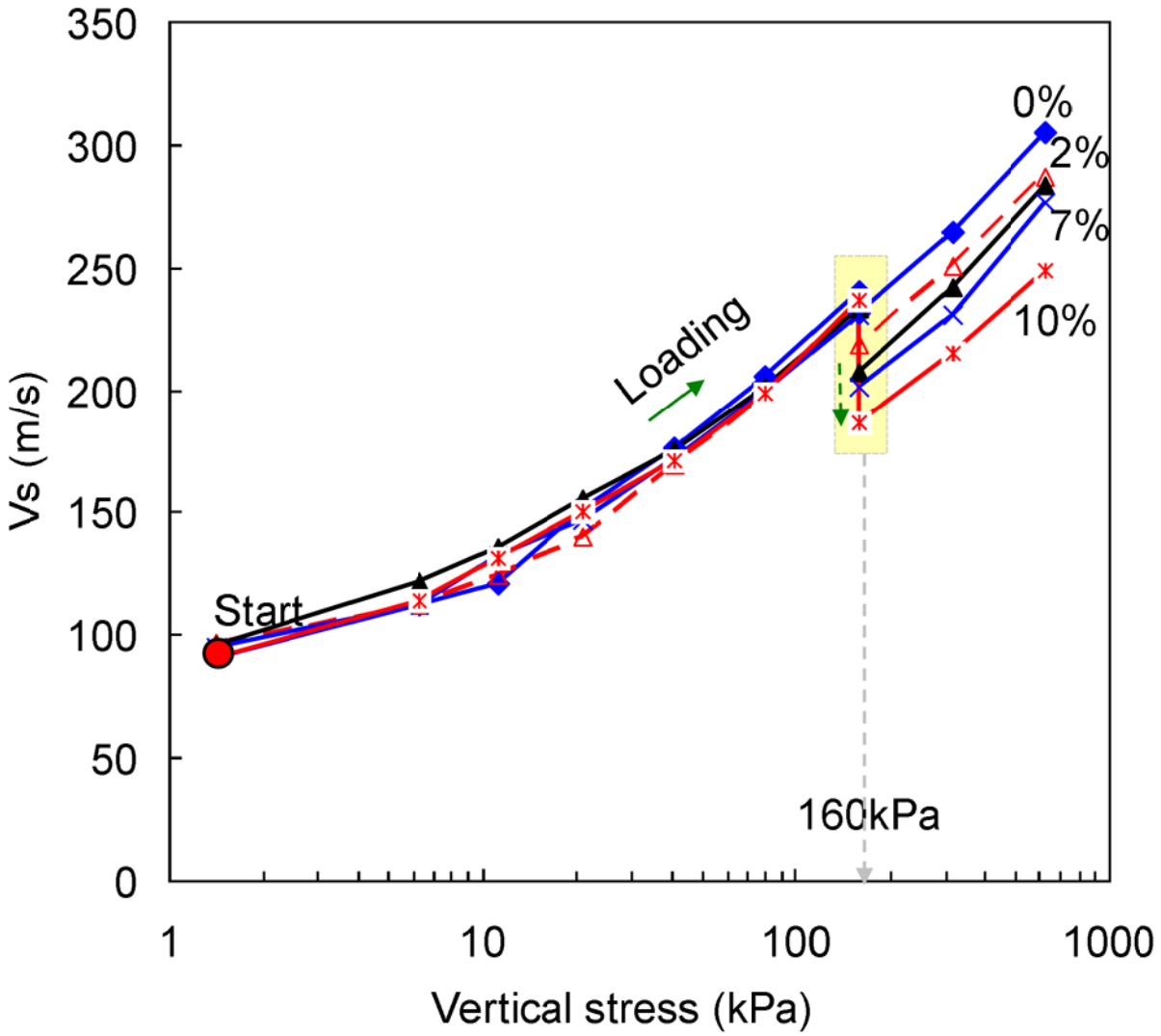
S-wave velocity - Different vertical stresses

- Shear wave velocities – specimens 10% initial sf
- Saturated at different σ_v^s = 40 ~ 320kPa
- V_s ↓ due to dissolution
- V_s after sat. collapses to 1 single line
- Vs ↓ about 26%~19% at σ_v^s = 40 ~ 320kPa



S-wave velocity – Different salt fractions

- Shear wave velocities - specimens: 0 ~ 10% initial sf
- Saturated at fixed σ_v^s :160kPa
- Decrement of V_s - proportional to the initial sf



Discussions

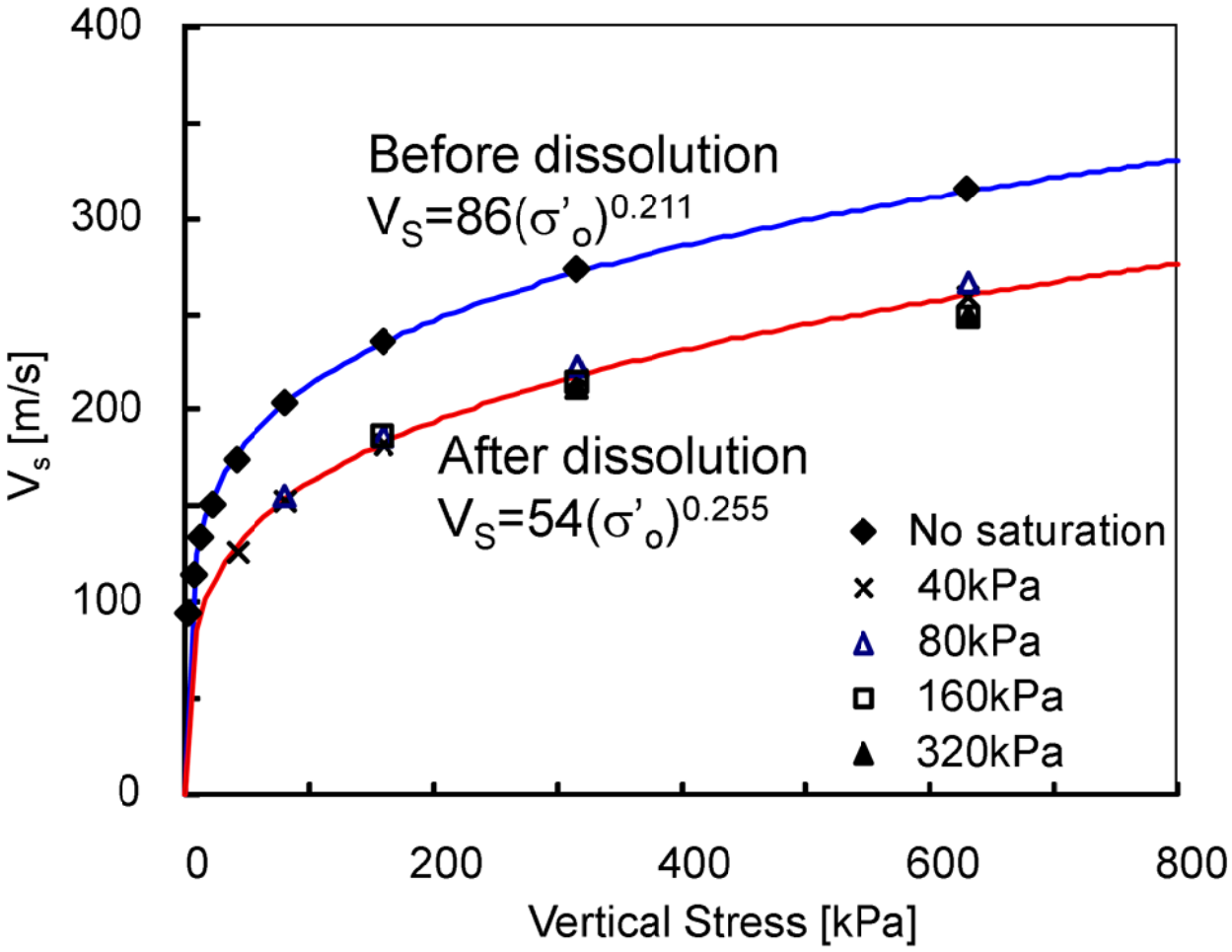
- Shear wave velocities can be expressed in term – effective stress

$$V_s = \alpha\left(\frac{\sigma'_0}{1kPa}\right)^{\beta} = \alpha\left(\frac{\sigma'_p + \sigma'_m}{2kPa}\right)^{\beta} = Af(e)\left(\frac{(1+K_o)\sigma'_p}{2kPa}\right)^{\beta}$$

  - σ'_p & σ'_m – effective stress in direction of wave propagation & of particle motion
  - α, β & A: experimentally determined
  - β: relates to contact behavior of media – size, structure, shape of particles
  - α: represents type of packing (porosity – coordination number), the properties of grain materials & fabric changes
  - $$f(e) = \frac{2.97 - e}{\sqrt{1+e}}$$ *(Hardin and Drnevich, 1972)*

Discussions

- Investigation of A & f(e) → mechanical behavior of mixtures after dissolution
- Shear wave velocity vs. σ' – specimens 10% sf → collapse 1 single line



- e ↑ ≈ 21%
- α: 86 → 54
- f(e) ↓ - 11%

∴ A ↓ - 30%

∴ A-factor ↓ implies a loss of the particle contact after dissolution.

→ β ↑ α ↓ - loosen specimens.

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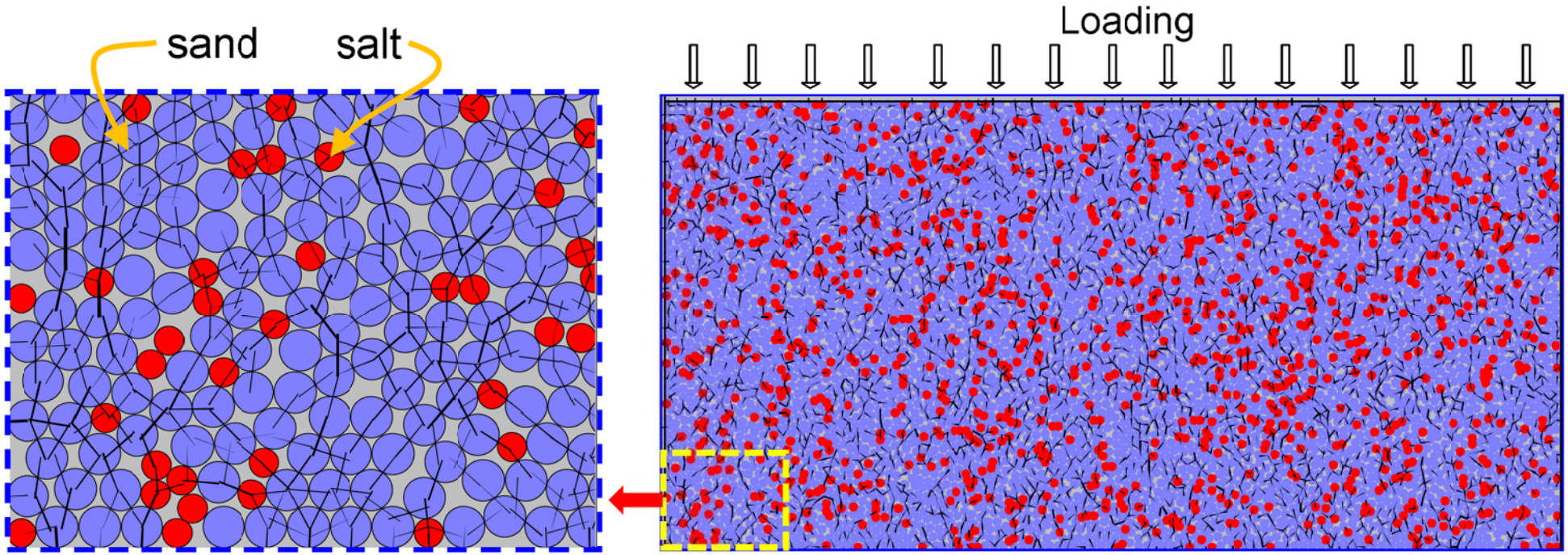
Sample Preparation

- DEM (PFC2D) used to modeling soluble mixtures in K_o loading condition

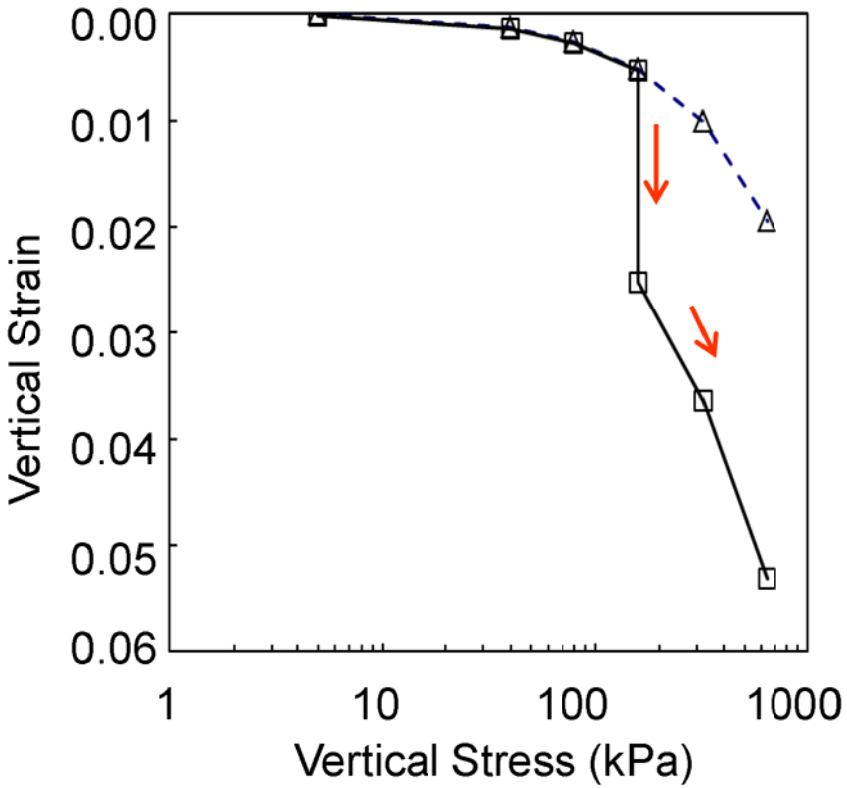


- d_{sand} =0.36mm , d_{salt} = 0.25mm
- $k_n = 10^8$ N/m , $k_s = 5 \times 10^7$ N/m
- ρ = 2650kg/m^3
- sf = 10%

- Simulation: created walls, generated particles, equilibrium state, consolidated to desired stress level: 160kPa
- Dissolved particles by slowly reducing radii of soluble particles : 0.9999

Stress – strain – Numerical simulation

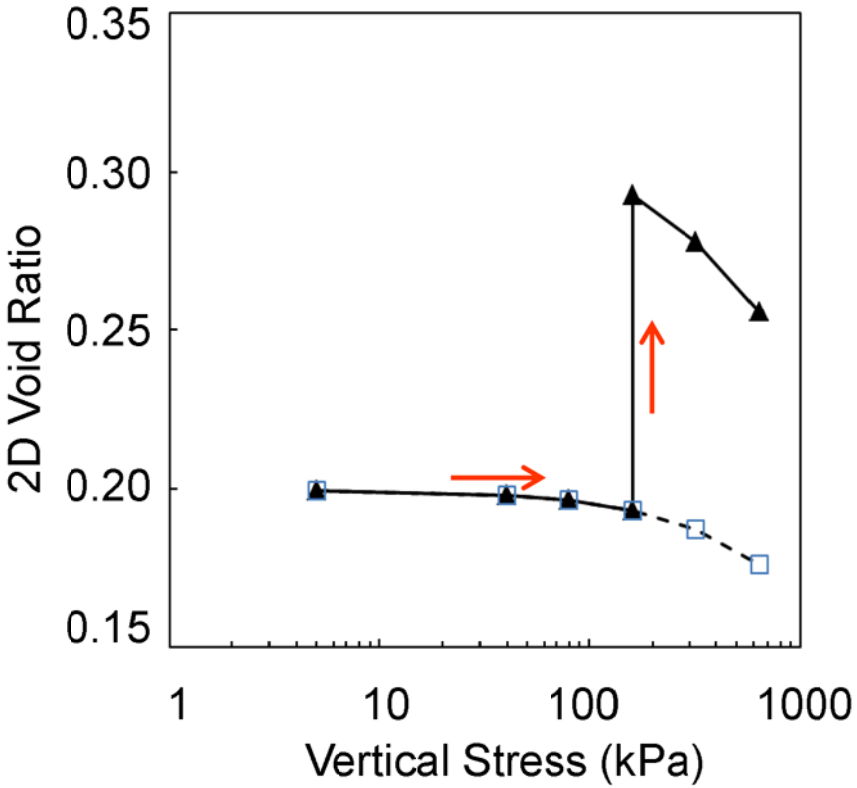
- **Stress – Strain**



- After saturation:
  - ε_v ↑

∴ Total volume ↓ after dissolution

- **Stress – Void ratio**

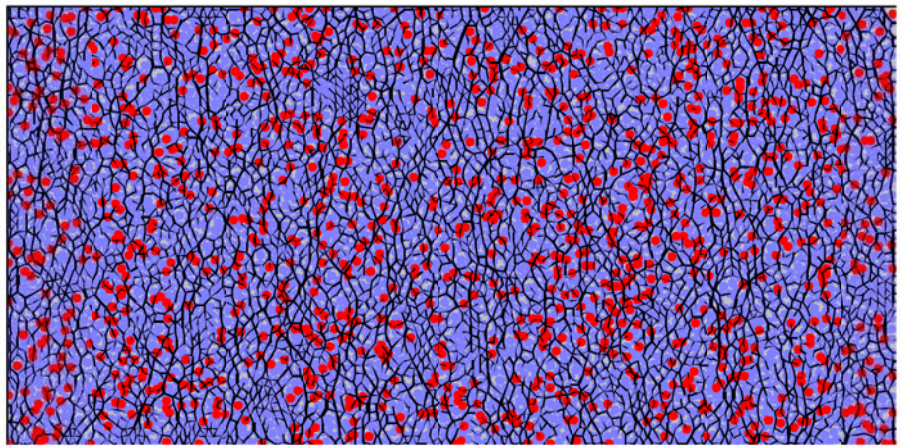


- After saturation:
  - e_{2D} ↑↑

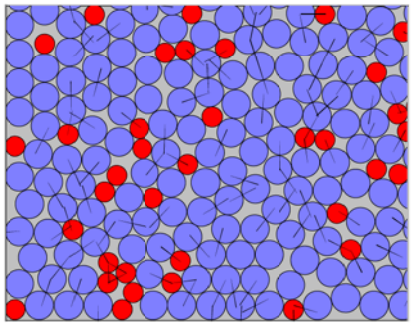
∴ Specimen getting loosen

Discussion – Fabric, force chain

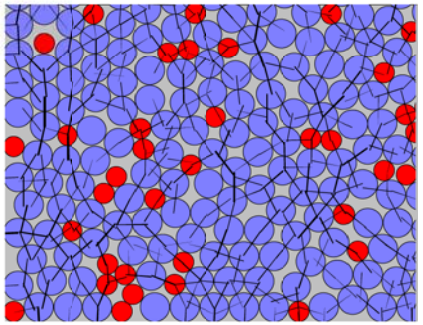
- No dissolution



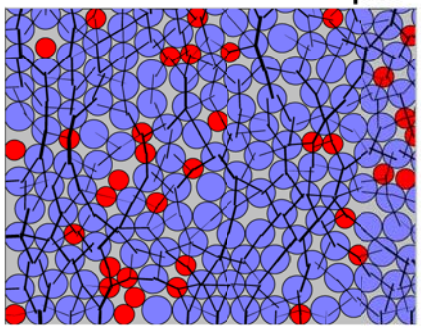
160Kpa



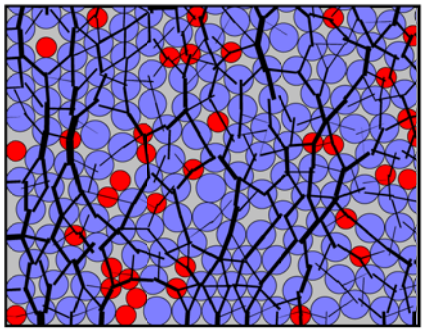
5Kpa



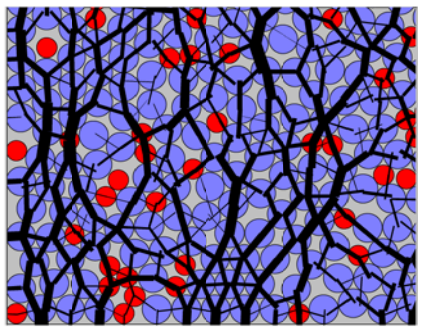
40Kpa



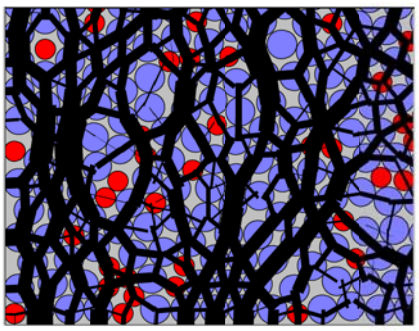
80Kpa



160Kpa



320Kpa

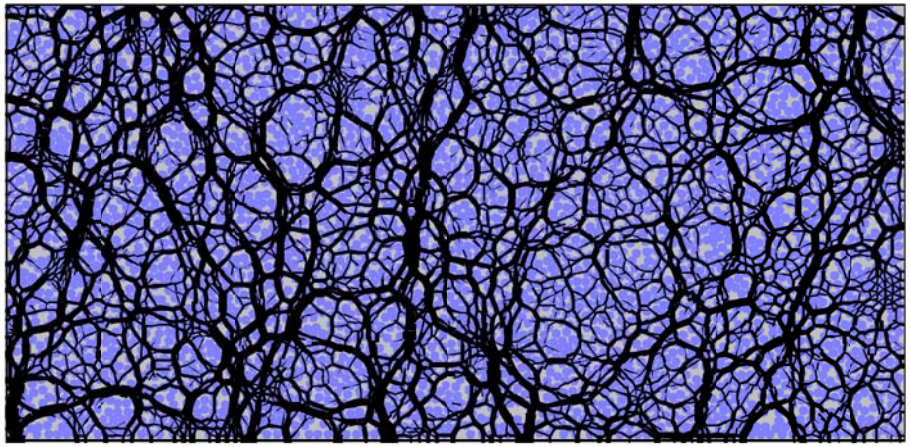


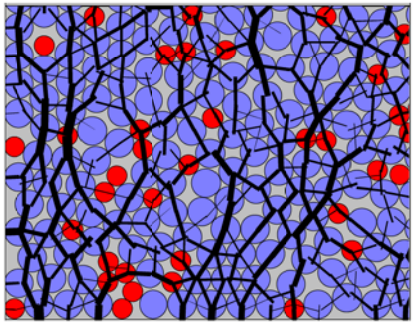
640Kpa

Discussion – Fabric, force chain

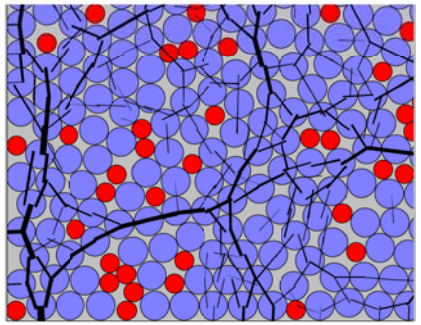
- Dissolution

160Kpa

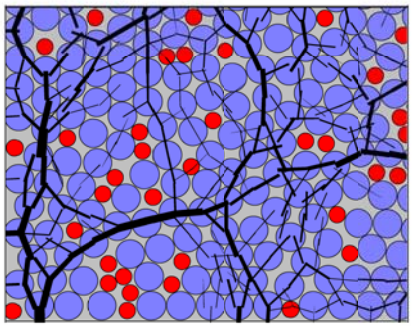




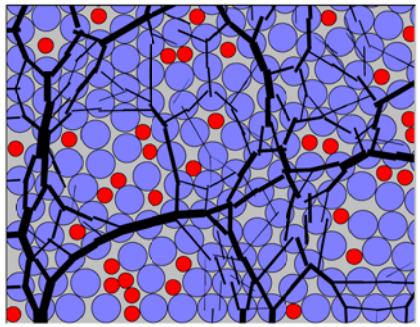
R/R_o = 1.0



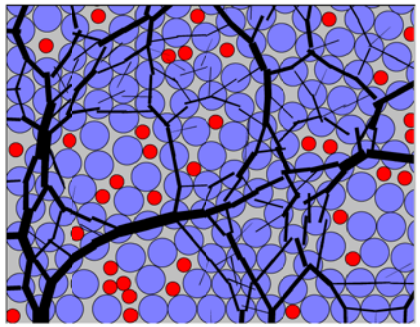
R/R_o = 0.9



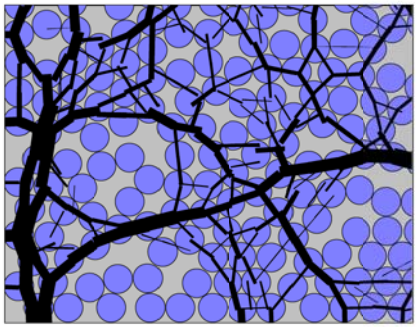
R/R_o = 0.82



R/R_o = 0.74



R/R_o = 0.67

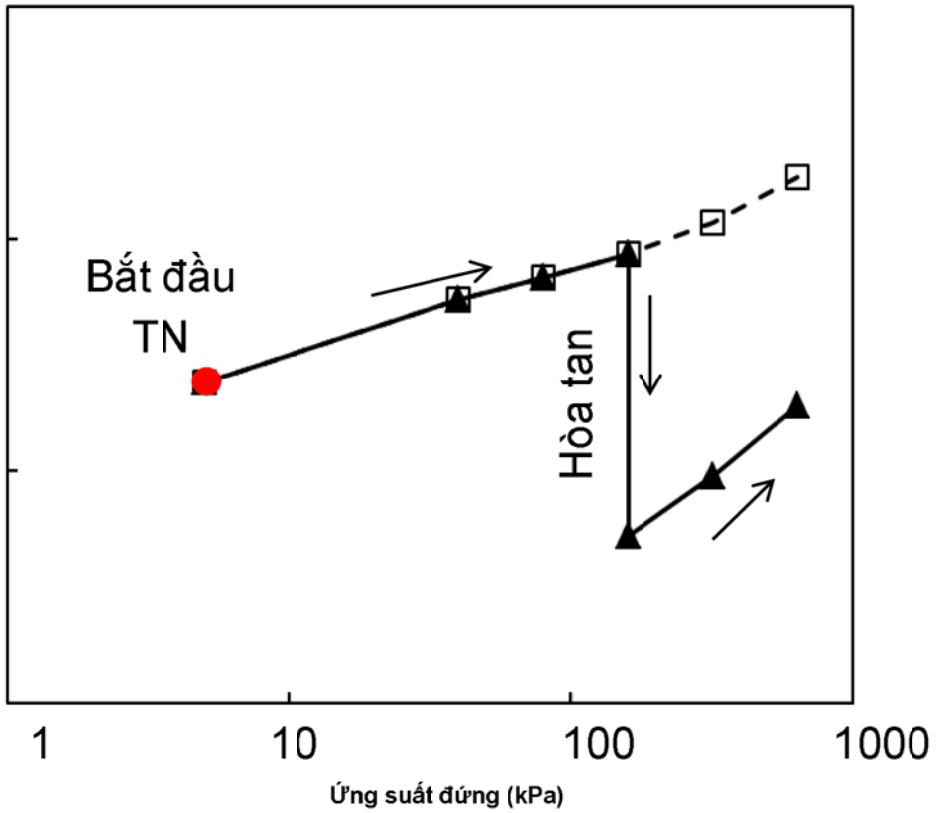


R/R_o = 0.0

Discussion – Coordination number

- Coordination Number

$$c = \frac{2M_{pp} + M_{pw}}{N}$$



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Summary - stiffness characteristics

- Artificial specimens : sand-salt with various salt fraction
- Experiments in conventional oedometer cell + BE
- After dissolution,
  - Vertical strain increases
  - Void ratio increases
  - Shear wave velocity decreases
- The changes is proportional with initial salt fraction
- Dissolution → increase of void ratio and reduce particle contact
- DEM simulations :
  - same trend as experiments
  - show inside process of the soluble mixtures