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Laboratory Investigation of Initiation and Development of Internal Erosion under Complex Stress States

D. S. Chang, Limin Zhang & T. H. Xu

The Hong Kong University of Science & Technology

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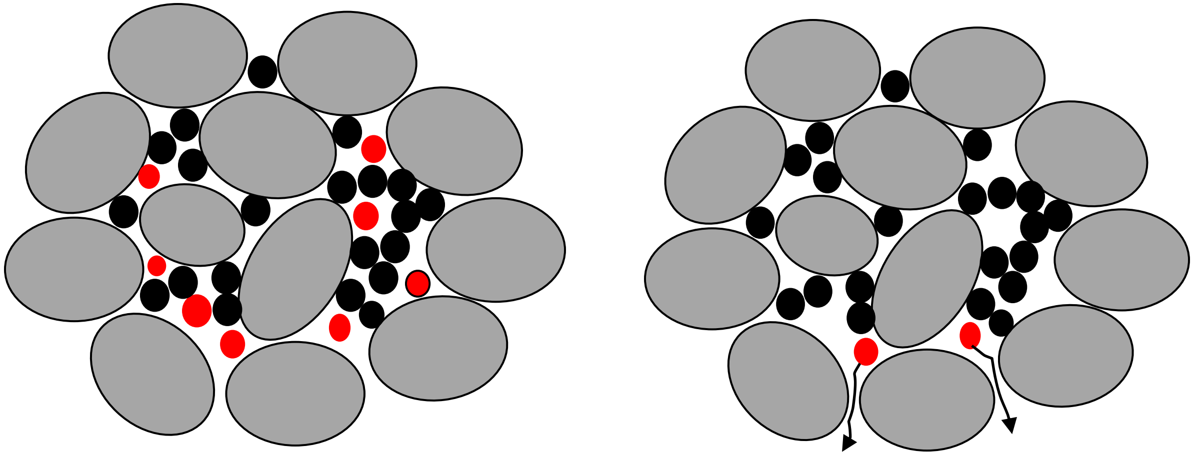
Outline

- Introduction
- Laboratory investigation of suffusion
  - Experimental program
  - Progression of internal erosion under different stress conditions
  - Critical hydraulic gradients
- Conclusions

Internal erosion

- Initiated by backward erosion, concentrated leak erosion, soil contact erosion, and suffusion
- Selective erosion of fine particles within the matrix of coarse soil particles under seepage flow



Control conditions of suffusion

- Geometric conditions (Potential of suffusion)
  - Grain-size distribution (USACE 1953; Istomina 1957; Kezdi 1979; Kenney and Lau 1985; Burenkova 1993; Honjo et al. 1996; Mao 2005; Li and Fannin 2008; Wan and Fell 2008)
  - Pore-size distribution (Indraratna et al. 2011)
  - Grain shape (Schuler 1994)
- Hydromechanical conditions (Onset of suffusion)
  - Critical hydraulic gradient (Terzaghi 1939; Wu 1980; Adel et al. 1988; Skempton and Brogan 1994, Mao et al. 2009; Li and Fannin 2011)
  - Stress state (Bendahmane et al. 2008; Moffat and Fannin 2011)
  - Relative density (Wan 2006)

Suffusion considering stress state

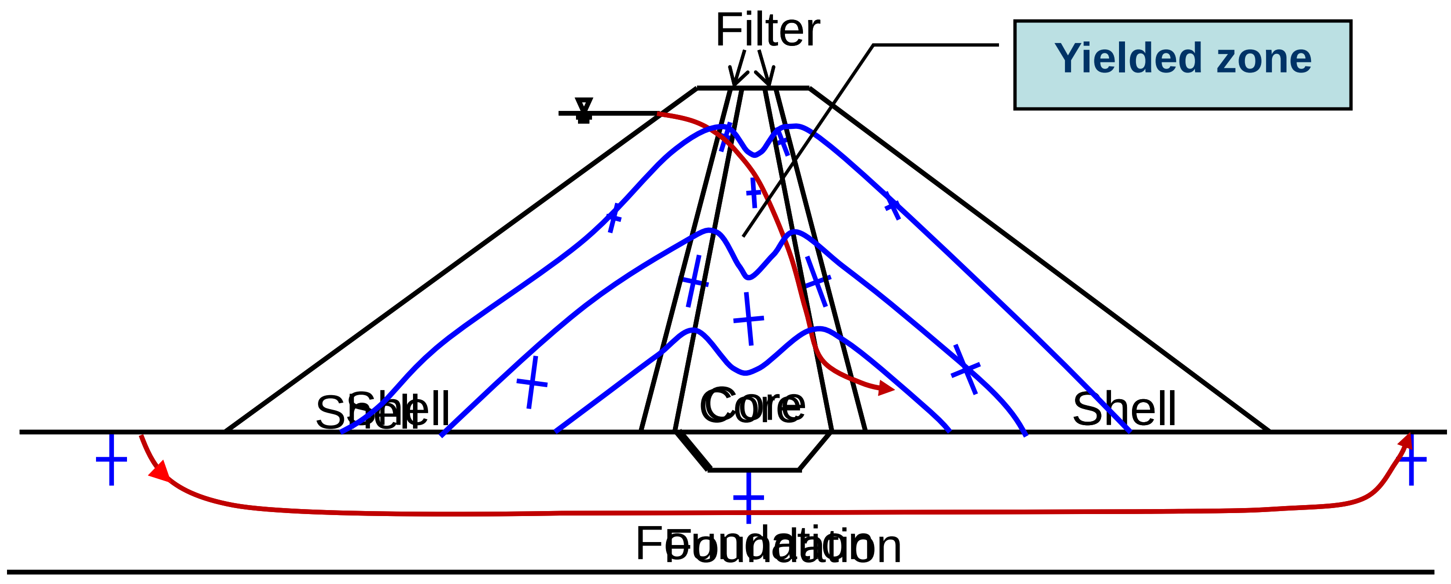
- **Simple stress states**

  Isotropic stress states:
  Bendahmane et al. (2008)

  K_0 stress states:
  Moffat and Fannin (2011)

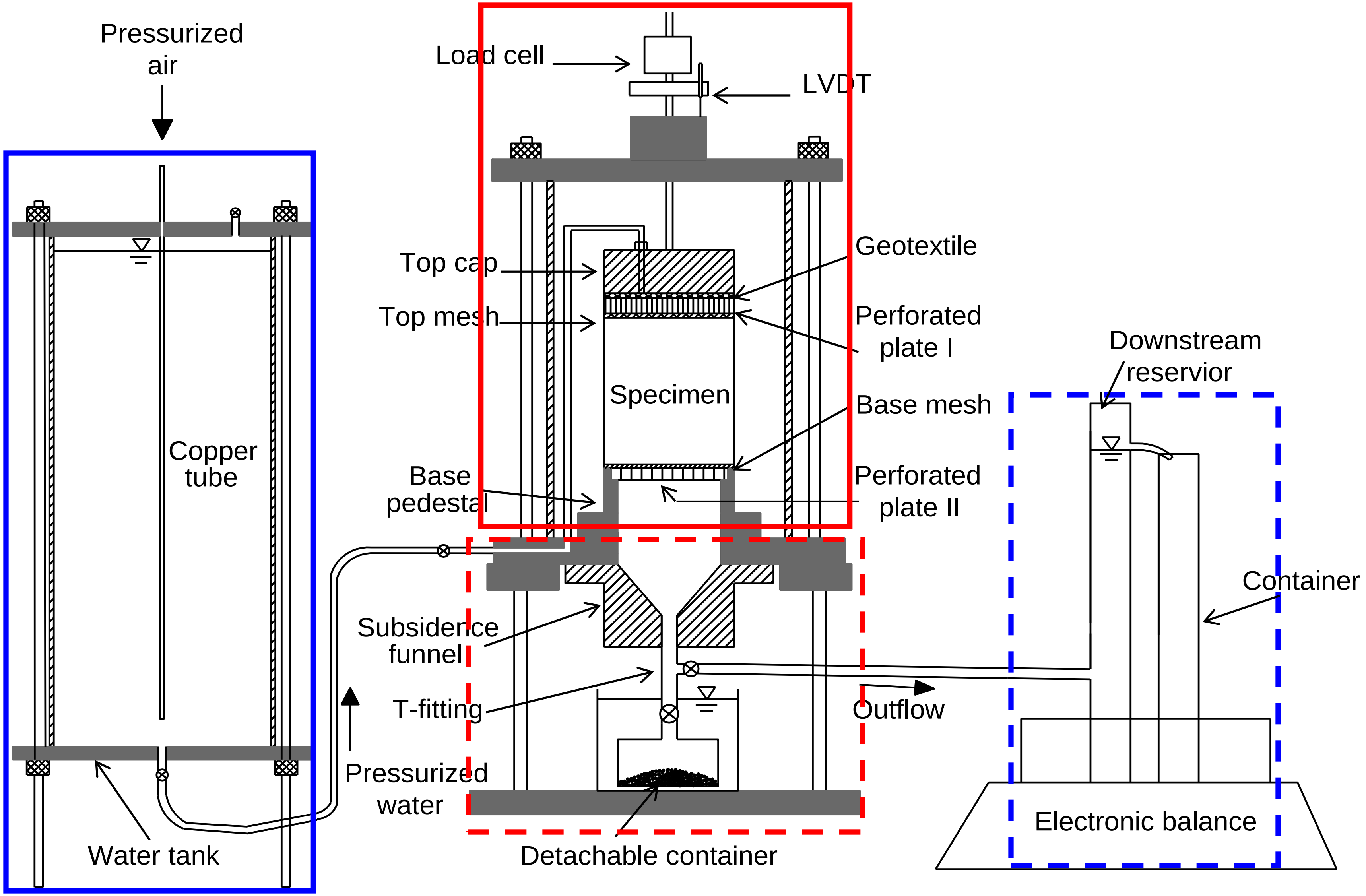
- **Complex stress states**

  This research



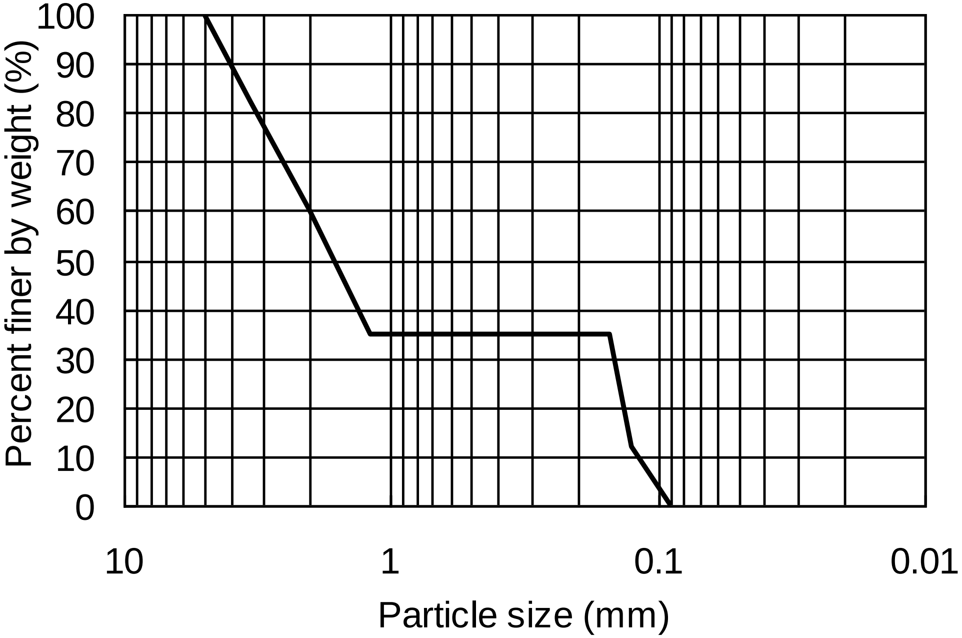
Suffusion process under complex stress states?

Testing apparatus



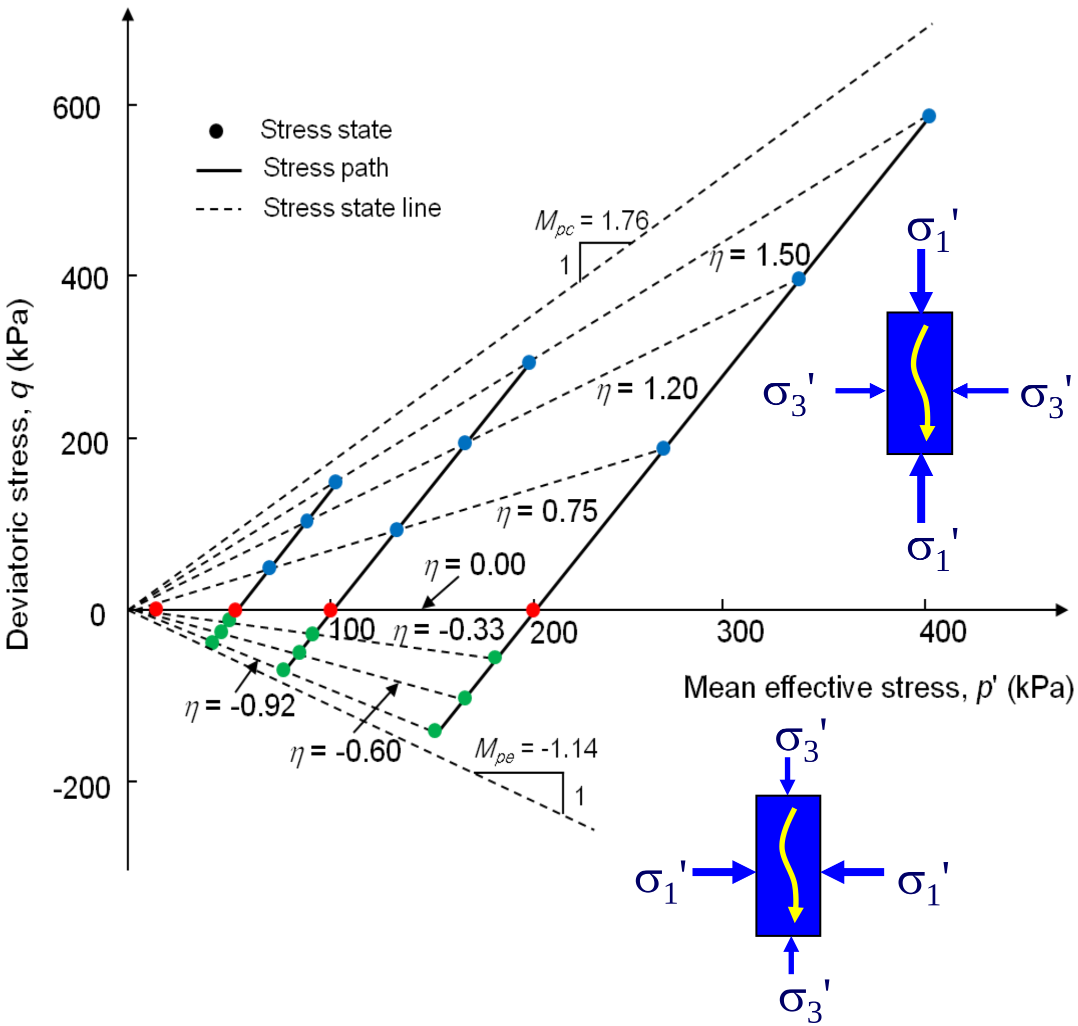
Testing material

- Mixture of Leighton Buzzard sand (fraction E) and completely decomposed granite (CDG)
- Internally unstable (Kezdi's criterion, Kenney and Lau's criterion, Fannin and Moffat's criterion)

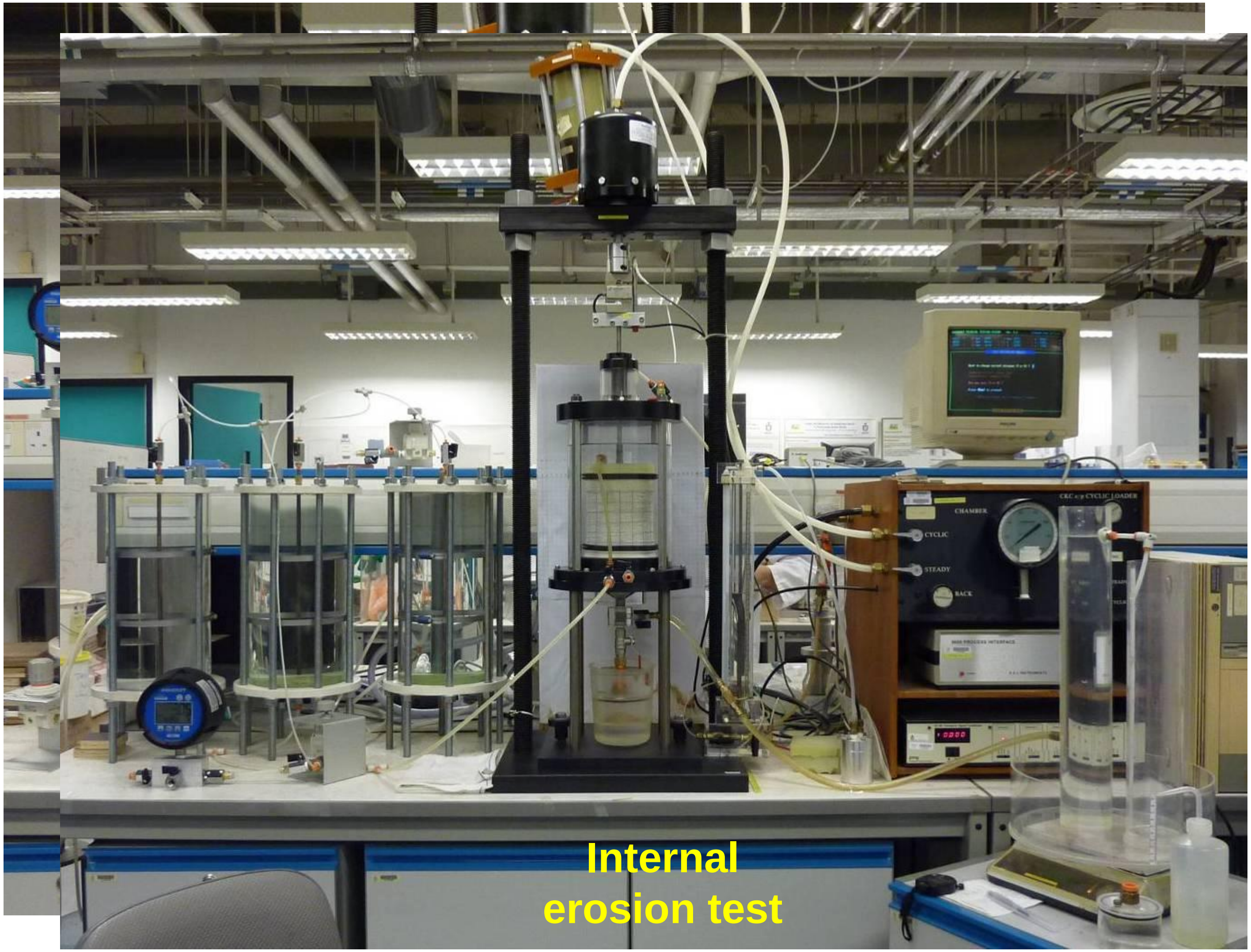


Testing program

- Complex stress states
  - Isotropic stress conditions (4 tests)
  - Triaxial compression stress conditions (9 tests)
  - Triaixal extension stress conditions (9 tests)

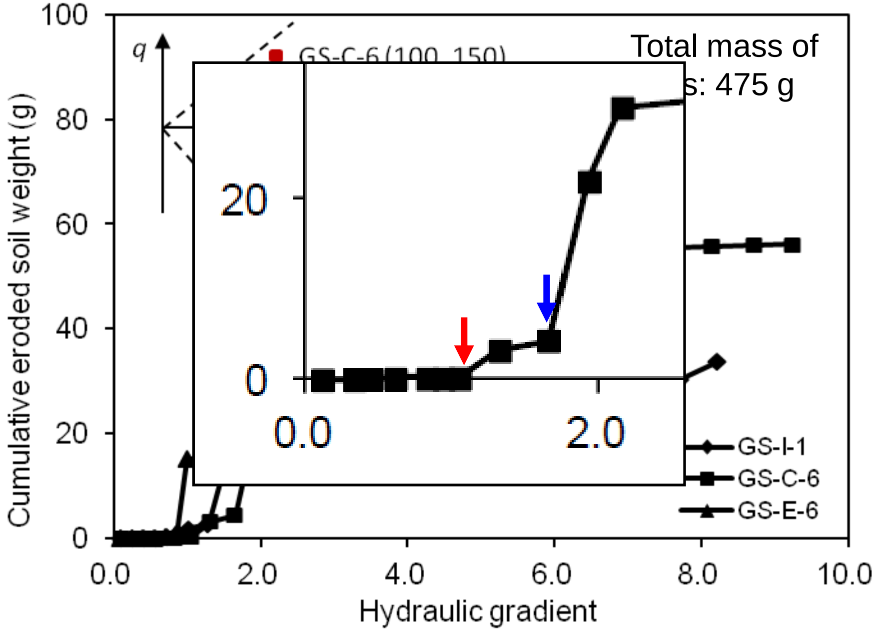


Testing procedures

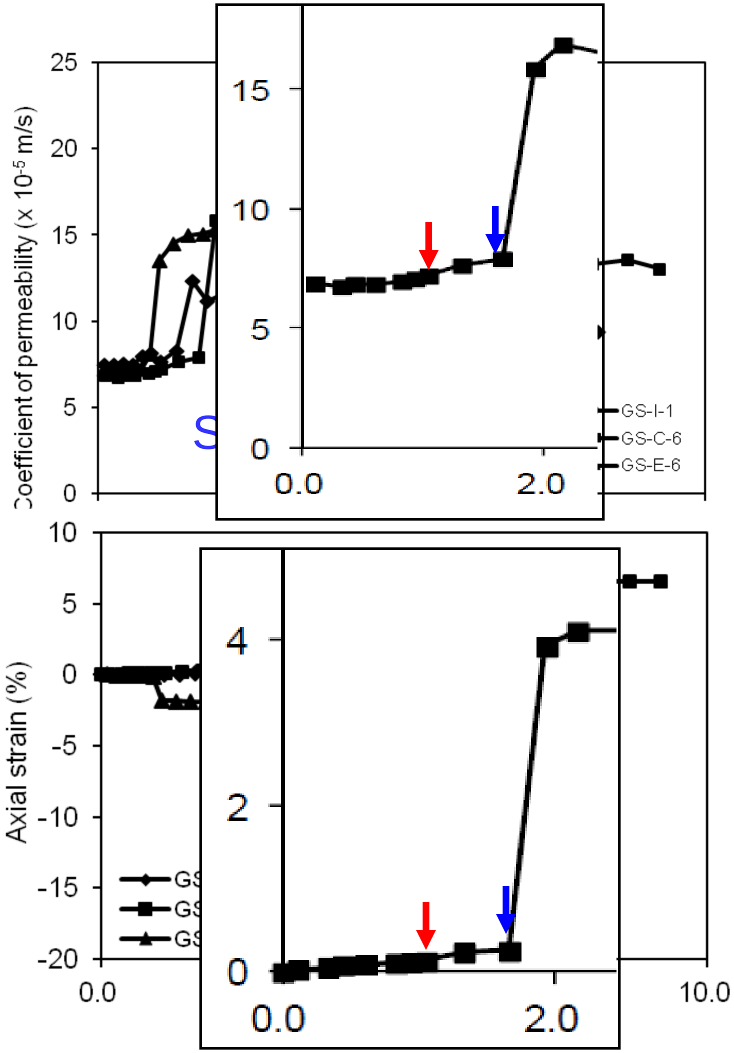


Progression of suffusion

- Specimens GS-I-1, GS-C-6, and GS-E-6 (under the same confining stress of 50 kPa)

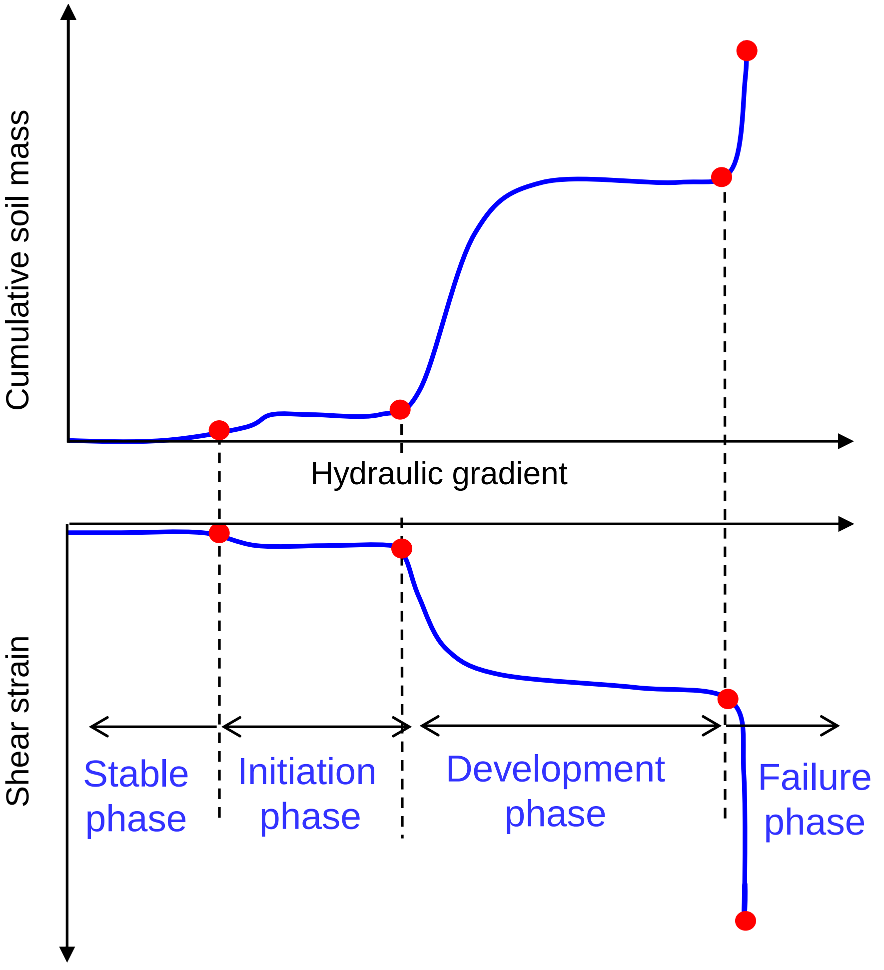


Cumulative eroded soil mass



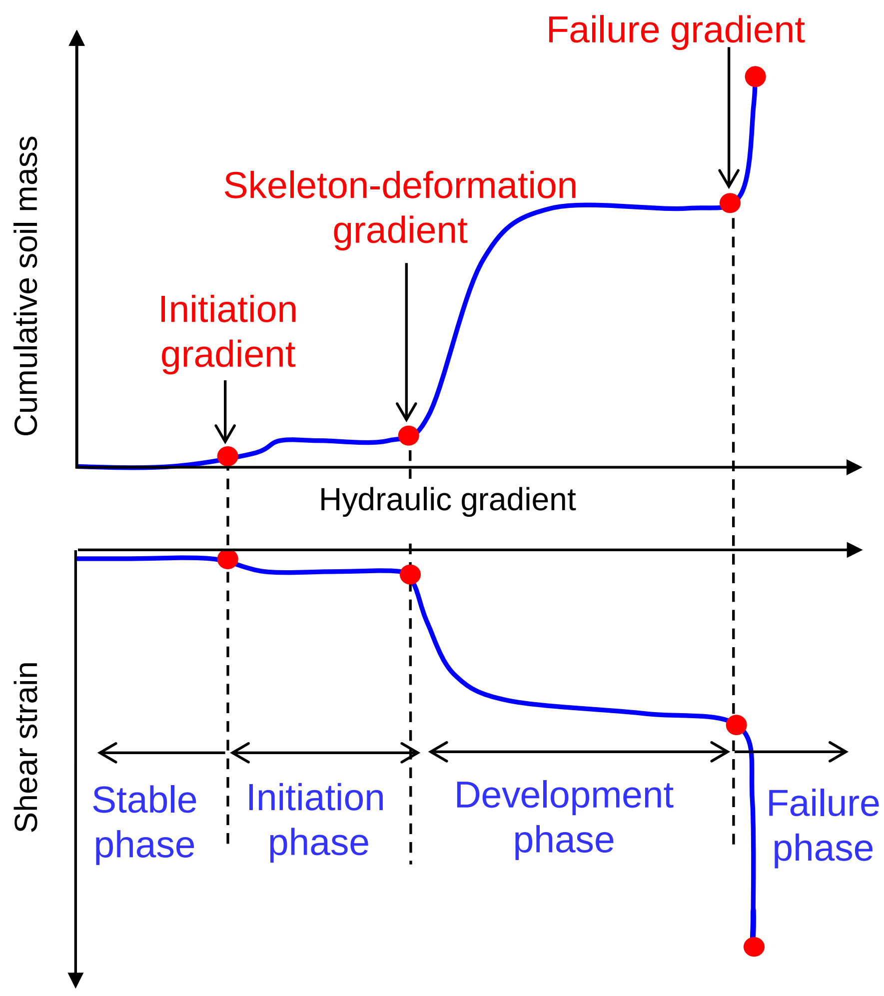
Four phases of suffusion

- Stable phase
  - Erosion is negligible and the specimen deformation is not visible
- Initiation phase
  - Some fine particles erode but the specimen deformation is limited
- Development phase
  - A large amount of fine particles is washed out and large specimen deformations occur
- Failure phase
  - Soil experiences shear failure due to excessive loss of fine particles and seepage-induced stress change

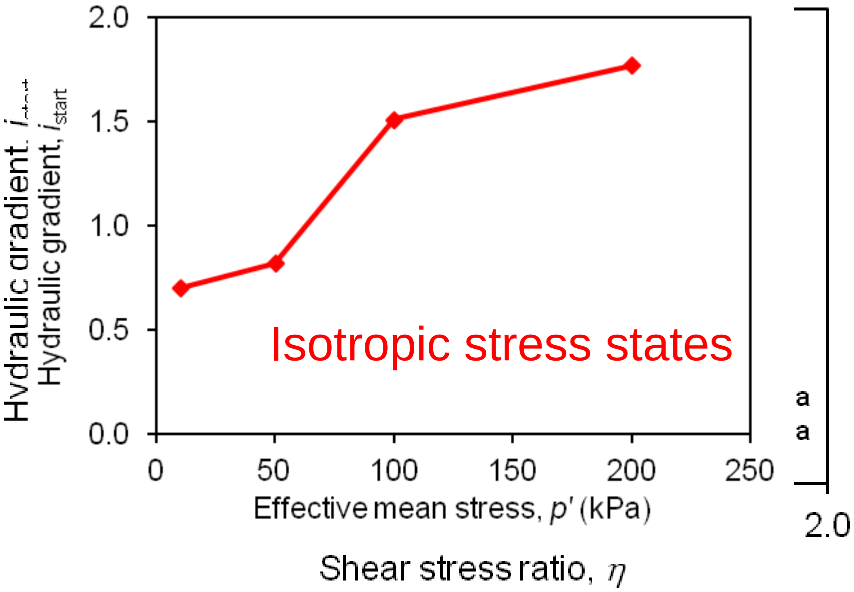


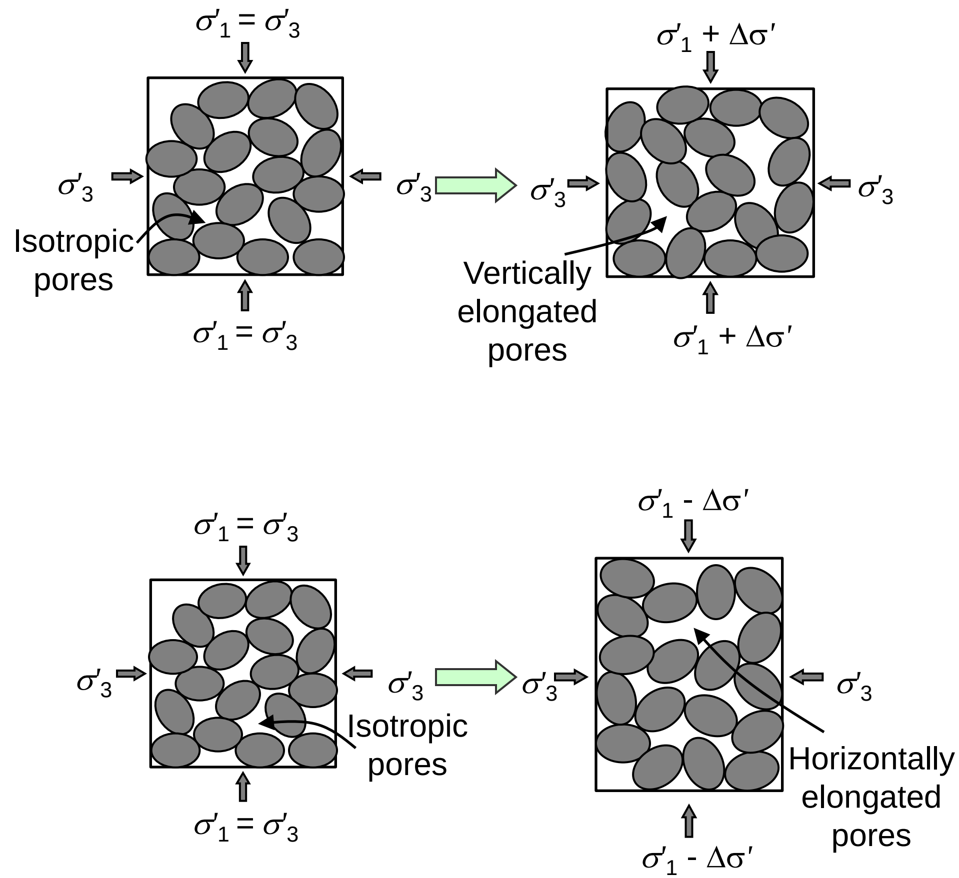
Definitions of critical hydraulic gradients

- Initiation hydraulic gradient, i_{start}
  - Initiation of internal erosion
- Skeleton-deformation gradient, i_{sd}
  - Sudden increases in eroded soil mass, permeability, and deformation
- Failure gradient, i_f
  - Very large deformation occurs and soil fails



Initiation hydraulic gradient under complex stress states

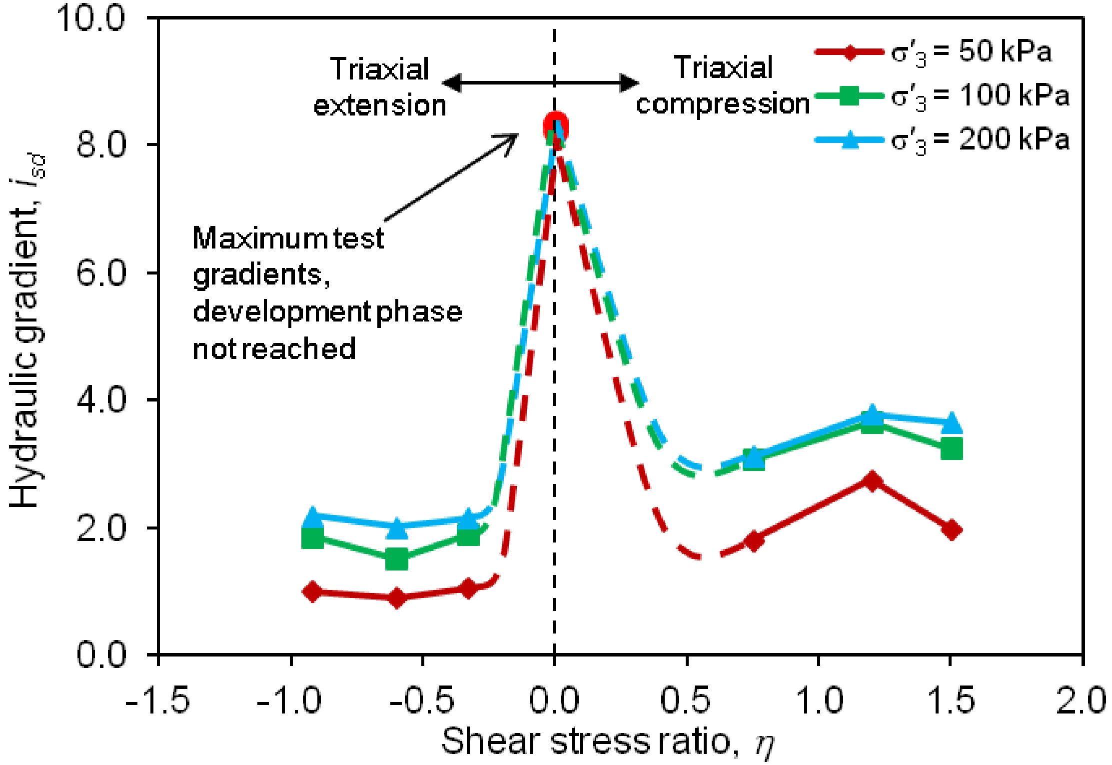




Under the same shear stress ratio, i_{start} increases with confining stress

TC: i_{start} increases with η first and then decreases
TE: little variations

Skeleton-deformation hydraulic gradient under complex stress states



- Under isotropic stress conditions: largest i_{sd} under the same confining stress
- Under compression stress conditions: i_{sd} first increases and then decreases
- Under extension stress conditions: Little variations

Conclusions

- The suffusion process can be divided into four phases: stable, initiation, development, and failure phase. Correspondingly, three critical hydraulic gradients are defined: initiation hydraulic gradient, skeleton-deformation hydraulic gradient, and failure hydraulic gradient..
- The initiation hydraulic gradient is mainly controlled by soil porosity and shear stress ratio. Under compression stress conditions, it increases with increasing stress ratio first and then decreases when the soil approaches shear failure.
- The skeleton-deformation hydraulic gradient is associated with buckling of the strong force chains within the soil due to the loss of lateral support by the fine particles. It is governed by the shear stress ratio and soil porosity. It is much larger under isotropic stress conditions than those under compression or extension stress conditions.

Thank you for your attention