Modelling the Behaviour of Soil Subjected to Internal Erosion

P.-Y. Hicher

Research Institute in Civil and Mechanical Engineering, UMR 6183 CNRS – Ecole Centrale de Nantes – University of Nantes
Outline

Micro-mechanical Model

Modeling of internal erosion

Behavior of eroded soils subjected to internal and external input loads

Summary
Micromechanical Approach

[Chang CS & Hicher PY (2005), *Int. J. Solids & Structures*]

Macro scale

![Micromechanical Approach Diagram](image)

Global stress-strain relation

\[ \Delta \sigma_{ij} = C_{ijkl} \Delta \varepsilon_{kl} \]

Inter-particle force-displacement relation

\[ \Delta f_i^\alpha = K_{ij}^\alpha \Delta \delta_j^\alpha \]

Localization & Homogenization

(Static method)

\[ \Delta u_{j,i} = A^{-1}_{ik} \sum_{\alpha=1}^{N} \Delta \delta_j^{\alpha} l_k^{\alpha} \]

Normal compression (elastic behavior)

Shear sliding [Coulomb-type]
Kinetic of extraction of the solid particles

Interparticle friction $\Phi_p$ depends on void ratio $e$ (interlocking of particles)

Loading parameter: \[ fe = \frac{m_{\text{extracted}}}{m_{\text{initial}}} \]

\[ (\Delta e)_{ex} = \frac{fe(1 + e_0)}{1 - fe} \]

\[ \tan \Phi_p = \left( \frac{e_c}{e} \right)^m \tan \Phi_\mu \]

Strain response → change in $e$

\[ \Delta e_{ij} = C_{ijkl} \Delta \varepsilon_{kl} \]
Induced mechanical responses

Increase of the porosity

Change from a dense/dilative behaviour to a loose/contractive behaviour

Triaxial compression pursued for intact samples after extraction

Induced deformations
under constant effective stresses

Influence of the deviatoric stress

Dense samples $e_0 = 0.3$
Induced mechanical responses

Increase of the porosity
Change from a dense/dilative behaviour to a loose/contractive behaviour

Triaxial compression pursued for intact samples after extraction

Stress-strain relationships without and with internal erosion under different initial stress conditions: (a) deviatoric stress versus axial strain and (b) volumetric strain versus axial strain (final hydraulic gradient =8.0).

Chang & Zhang, ASTM J., 2011
Instability due to internal erosion (1)

Internal erosion creates:

- Increase in void ratio
- Instability of the soil mass due to an increase in pore water pressure
- Erosion due to water seepage
Influence of pore water pressure increase

Constant – q tests on intact samples

Failure is obtained when the stress paths reach the plastic limit
Influence of pore water pressure increase - cont.

Failure is obtained before the critical state line.
An instable state is reached which corresponds to the vanishing of the second order work.
Instability due to internal erosion (2)

Impact of a fast external loading
such as shock, seismic loading...
Undrained triaxial tests

Dr = 60%

Unconditionally stable behavior
Dr = 30%
Existence of an unstable domain
Undrained triaxial tests

Dr = 0
Large domain of instability
Failure of a hydraulic dam

hydropower plant in Dychow (Poland)

Sliding by instability of part of the material constituting the embankment dam
The material responsible for the sliding is a silty sand subjected to internal erosion during a period of 60 years, which put it in a relative density as small as 15 to 20%.
Summary

The microstructural model can capture with reasonable accuracy the conditions of instability detected experimentally.

We focused here on the influence of the stress and strain paths, demonstrating that the conditions of instability can be reached far below the plastic limit.

The initial void ratio is an important parameter, which controls the amplitude of the unstable domain. Instability condition linked to internal erosion can occur due to the decrease of initial density during suffusion.

The numerical results appear to agree with observations made on embankment dams which underwent internal erosion, and in particular with the description of their modes of failure.
Thank you for your attention