Institut de Recherche en
Génie Civil et Mécanique

Centrale
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Modelling the Behaviour of Soil Subjected to Internal Erosion

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Outline

Micro-mechanical Model

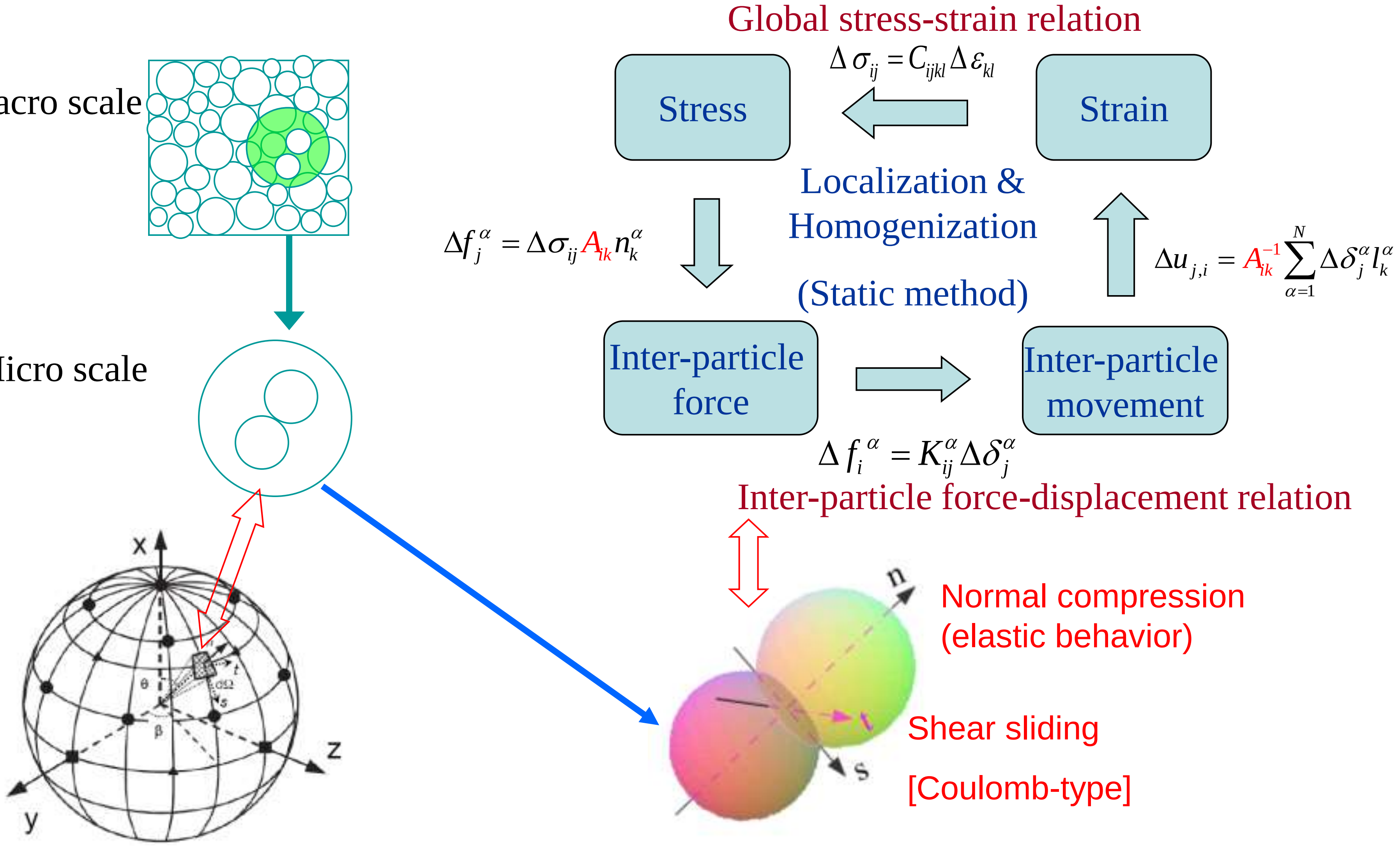
Modeling of internal erosion

Behavior of eroded soils subjected to internal and external input loads

Summary

Micromechanical Approach

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



Global stress-strain relation

$\Delta \sigma_{ij} = C_{ijkl} \Delta \varepsilon_{kl}$

Stress

Strain

Macro scale

Localization & Homogenization

(Static method)

$\Delta f_j^{\alpha} = \Delta \sigma_{ij} A_{ik} n_k^{\alpha}$

$\Delta u_{j,i} = A_{ik}^{-1} \sum_{\alpha=1}^{N} \Delta \delta_j^{\alpha} l_k^{\alpha}$

Micro scale

Inter-particle force

Inter-particle movement

$\Delta f_i^{\alpha} = K_{ij}^{\alpha} \Delta \delta_j^{\alpha}$

Inter-particle force-displacement relation

Normal compression (elastic behavior)

Shear sliding

[Coulomb-type]

Kinetic of extraction of the solid particles

Interparticle friction Φ_p depends on void ratio e (interlocking of particles)

Loading parameter: $fe = m_{extracted} / m_{initial}$

loading parameter

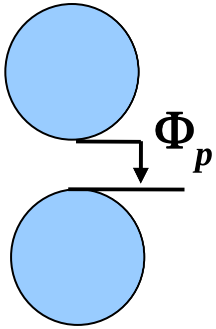
$$(\Delta e)_{ex} = \frac{fe(1+e_0)}{1-fe} \longrightarrow \tan\Phi_p = \left(\frac{e_c}{e}\right)^m \tan\Phi_\mu$$

Strain response

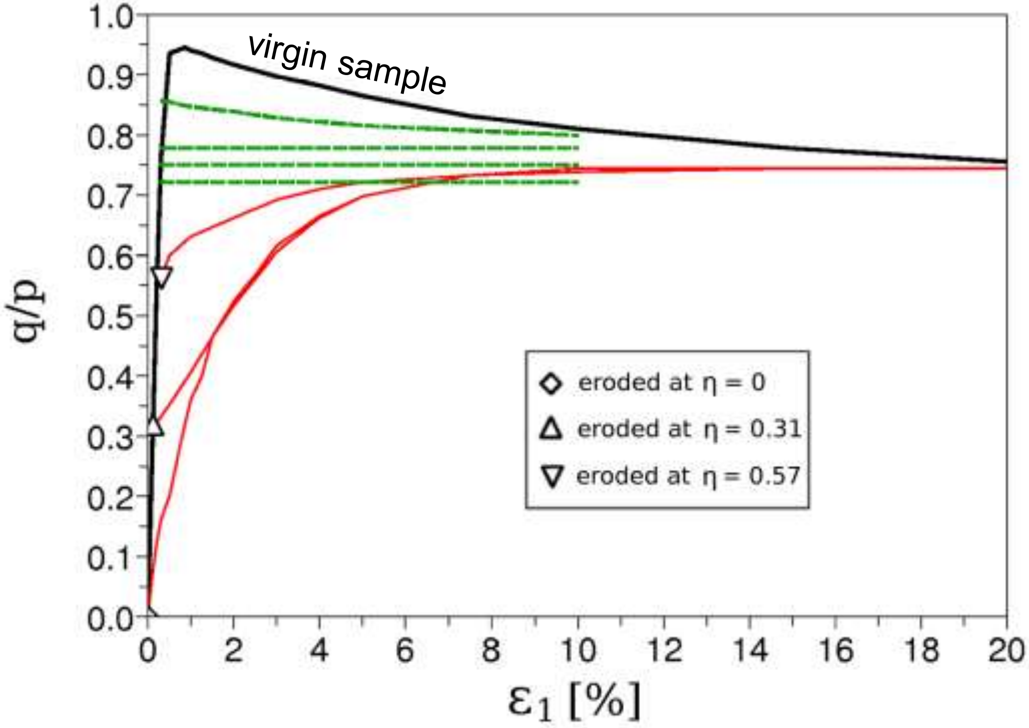
→ change in e

homogenization

$$\Delta\varepsilon_{ij} = C^{\alpha}_{ijkl}\Delta\sigma_{kl}$$



Induced mechanical responses

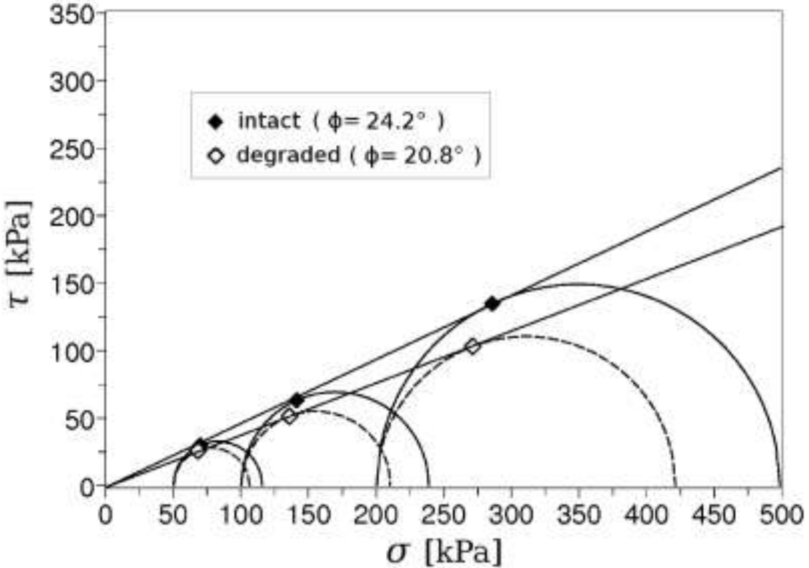


Triaxial compression pursued for intact samples after extraction

Increase of the porosity

↓

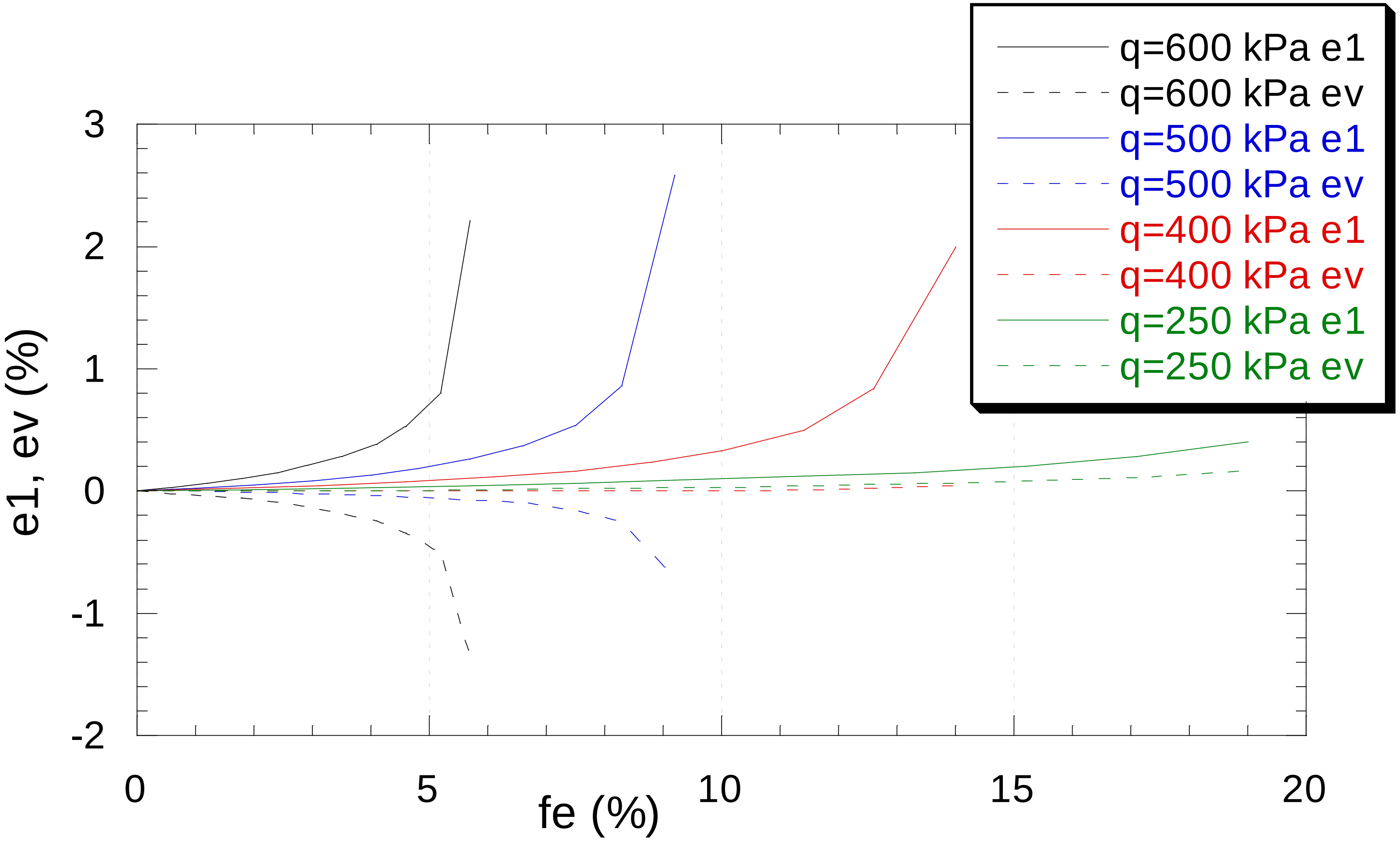
Change from a dense/dilative behaviour to a loose/contractive behaviour



Scholtes, L, Hicher, P.-Y., Sibille, L. CRAS Mécanique (2010)

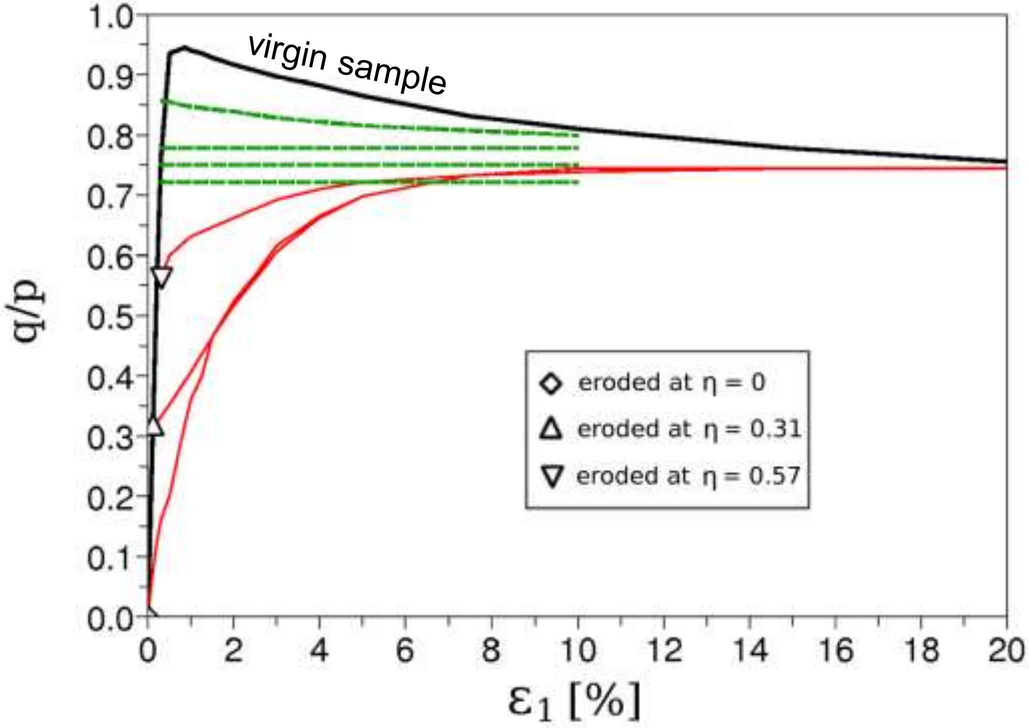
Induced deformations under constant effective stresses

Influence of the deviatoric stress



Dense samples $e_0 = 0.3$

Induced mechanical responses

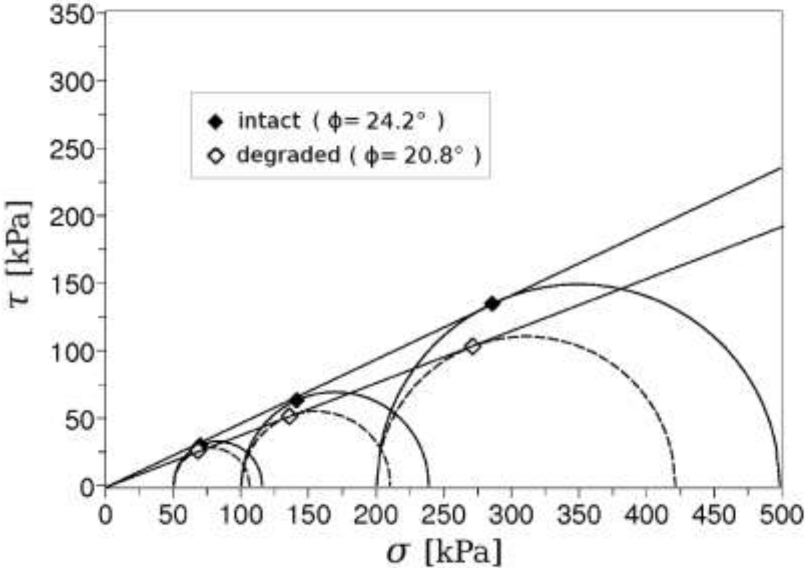


Increase of the porosity

↓

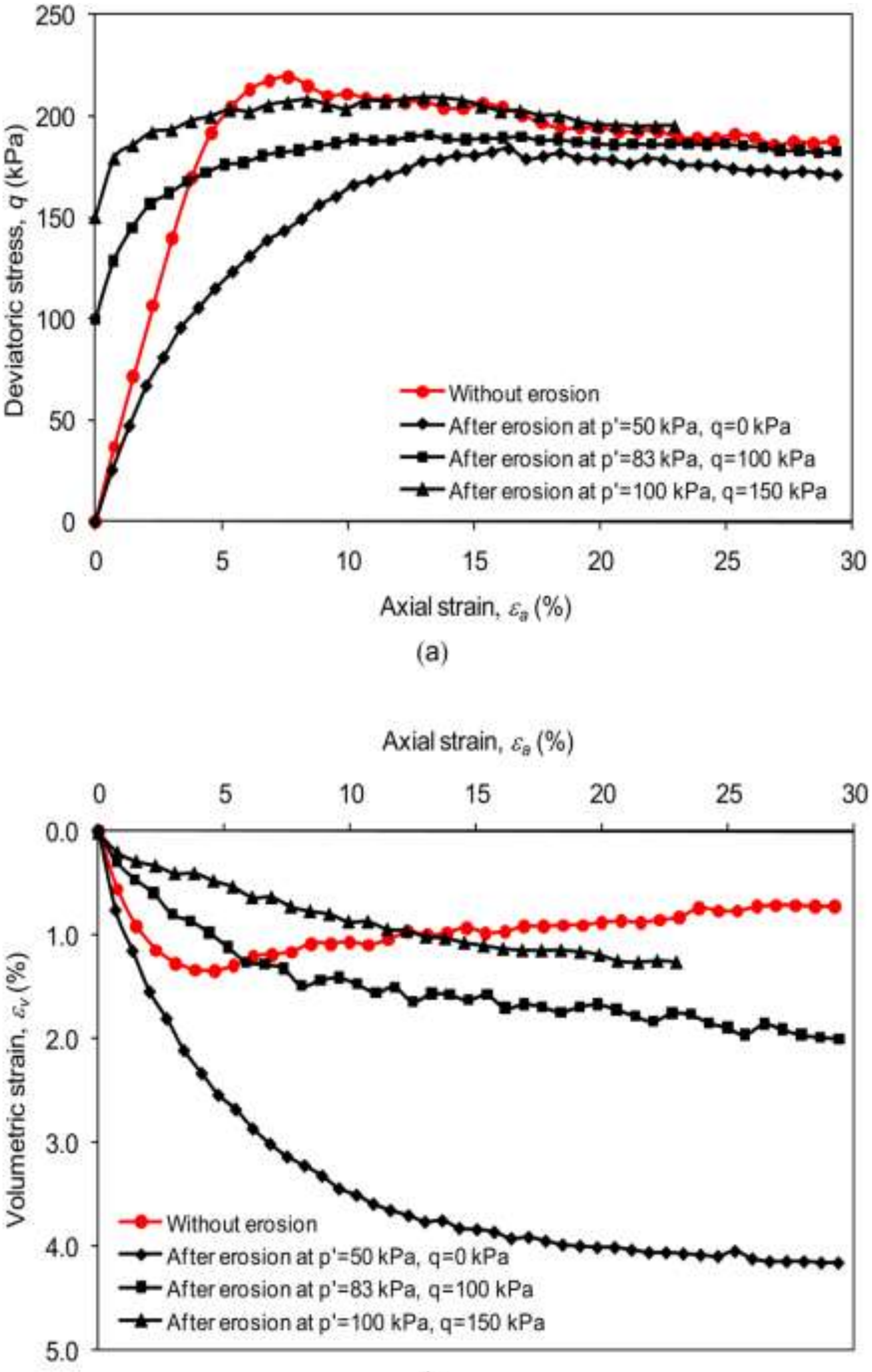
Change from a dense/dilative behaviour to a loose/contractive behaviour

Triaxial compression pursued for intact samples after extraction



Scholtes, L, Hicher, P.-Y., Sibille, L. CRAS Mécanique (2010)

Experimental results on silty sand



(a)

(b)

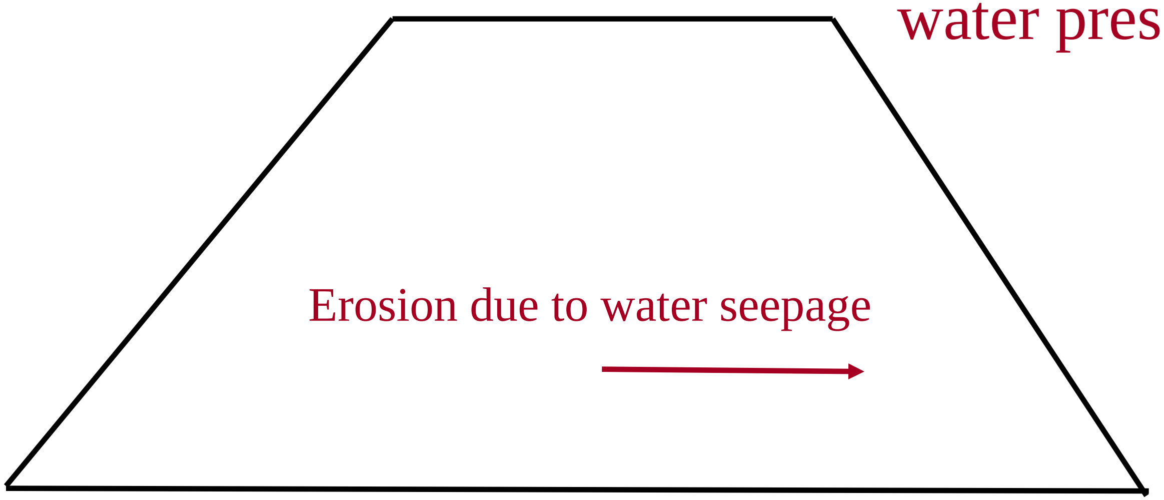
Stress-strain relationships without and with internal erosion under different initial stress conditions:
(a) deviatoric stress versus axial strain and
(b) volumetric strain versus axial strain (final hydraulic gradient =8.0).

Chang & Zhang, ASTM J., 2011

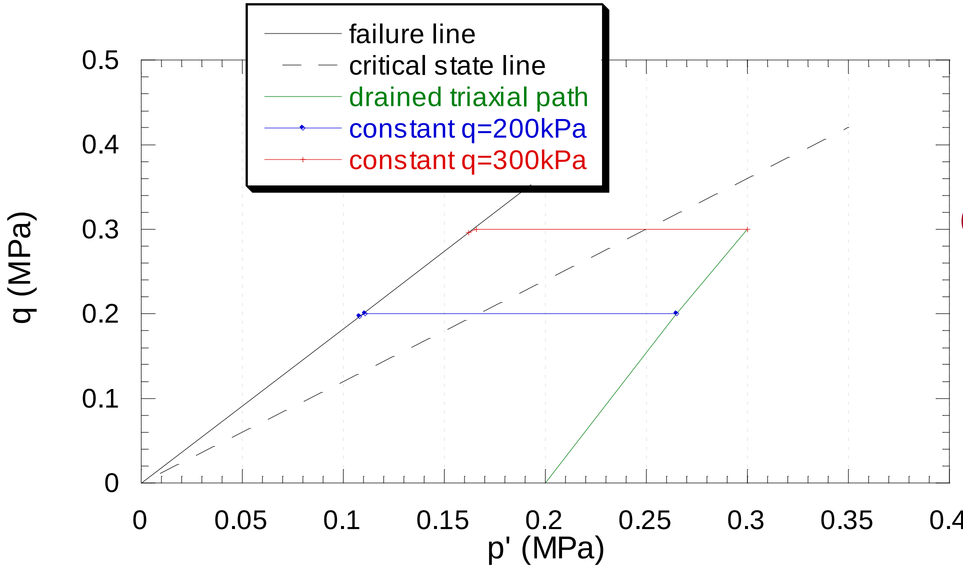
Instability due to internal erosion (1)

Internal erosion creates:

Increase in void ratio → Instability of the soil mass due to an increase in pore water pressure

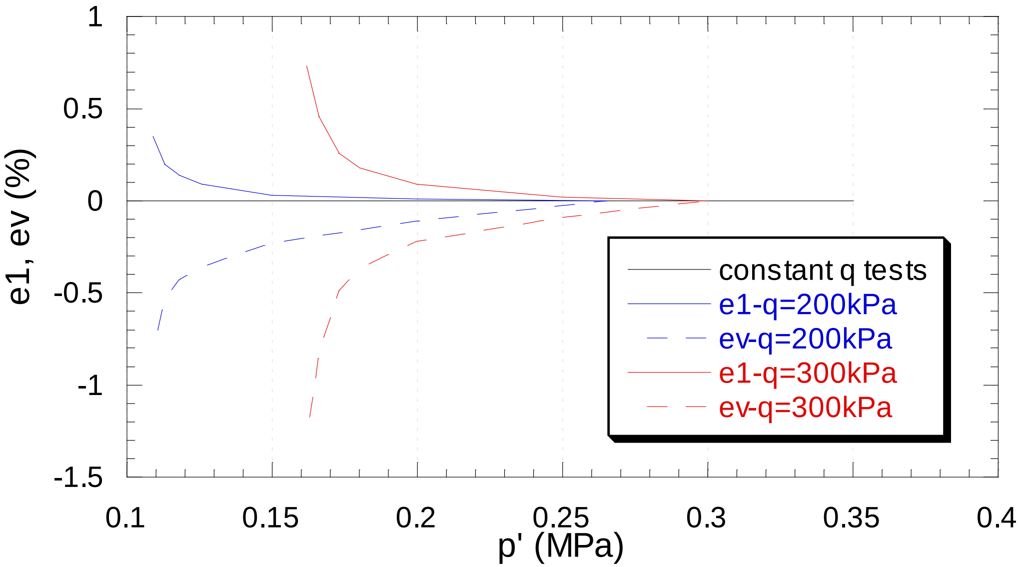


Influence of pore water pressure increase

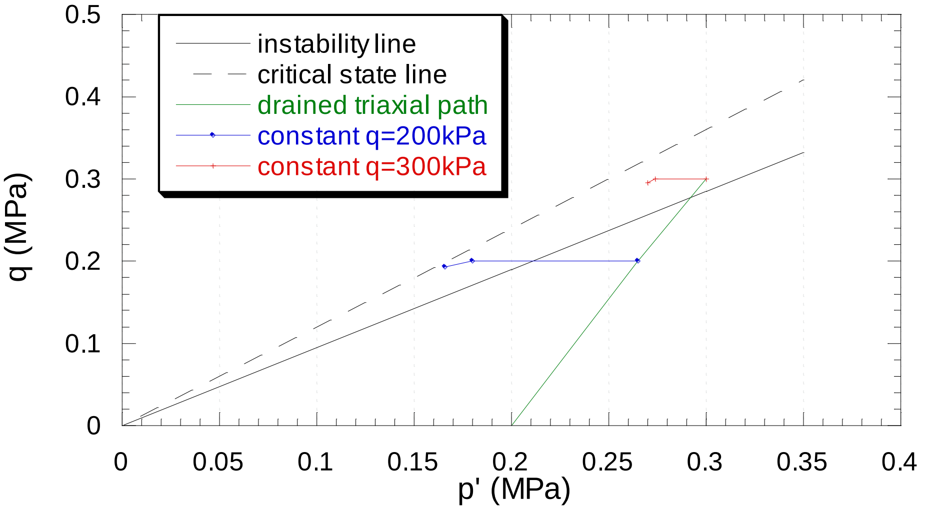


Constant – q tests on intact samples

Failure is obtained when the stress paths reach the plastic limit

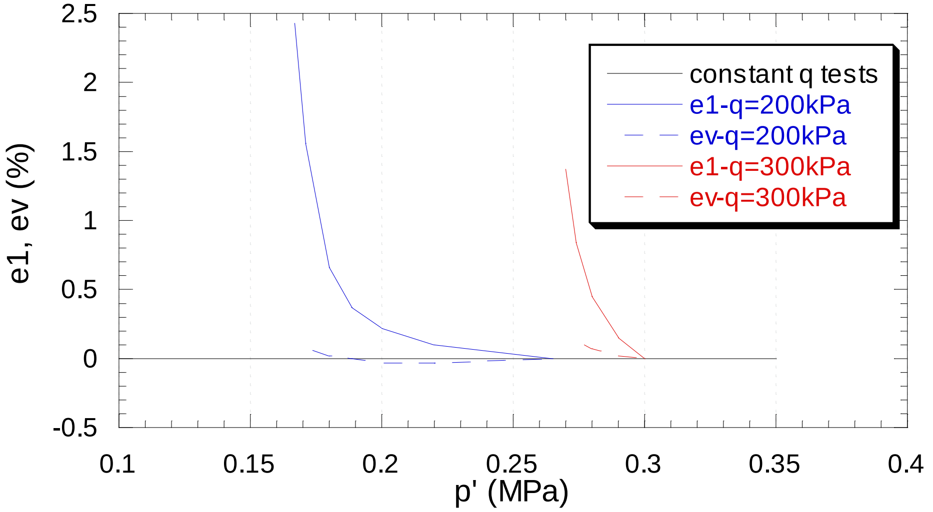


Influence of pore water pressure increase - cont.



Constant –q tests on eroded samples

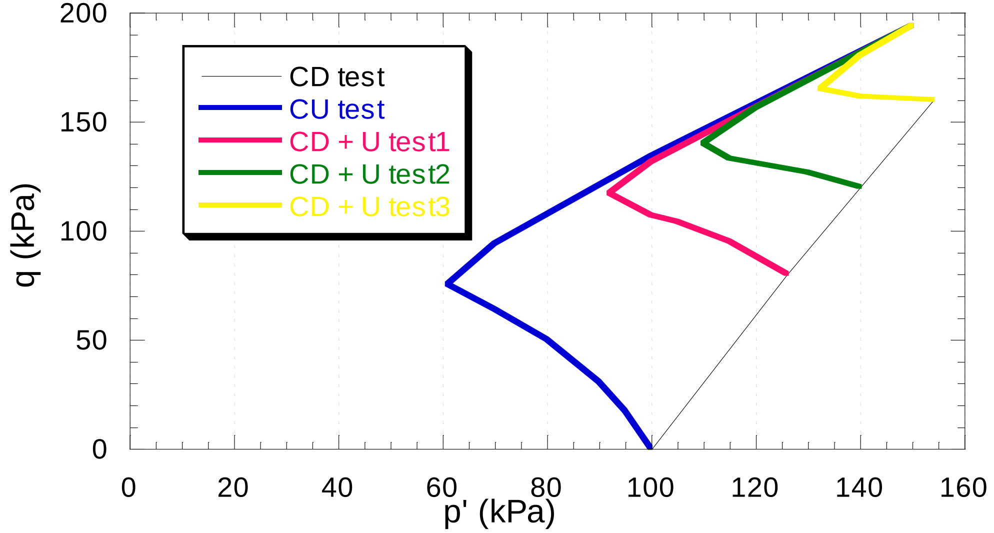
Failure is obtained before the critical state line.
An instable state is reached which corresponds to the vanishing of the second order work



Instability due to internal erosion (2)

Impact of a fast external loading

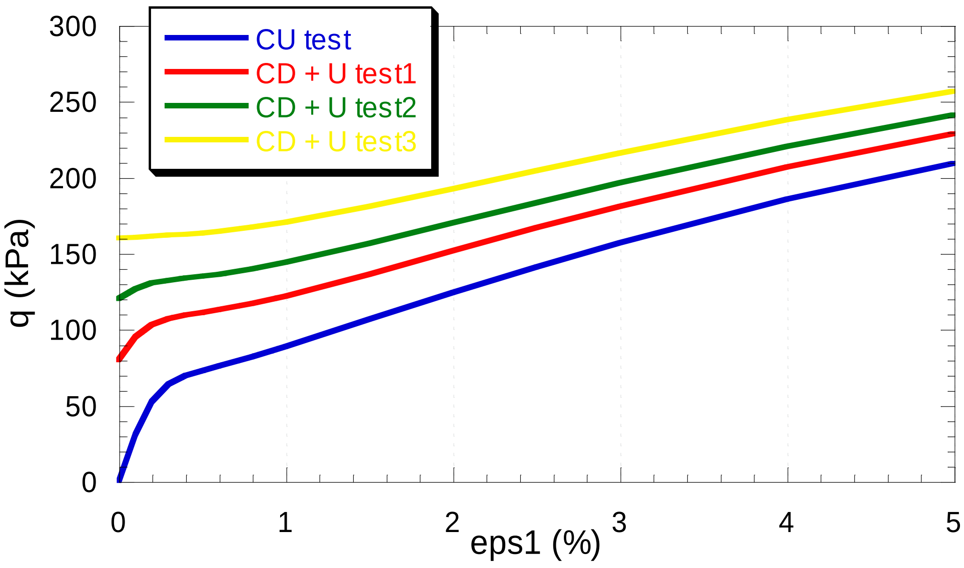
such as shock, seismic loading…

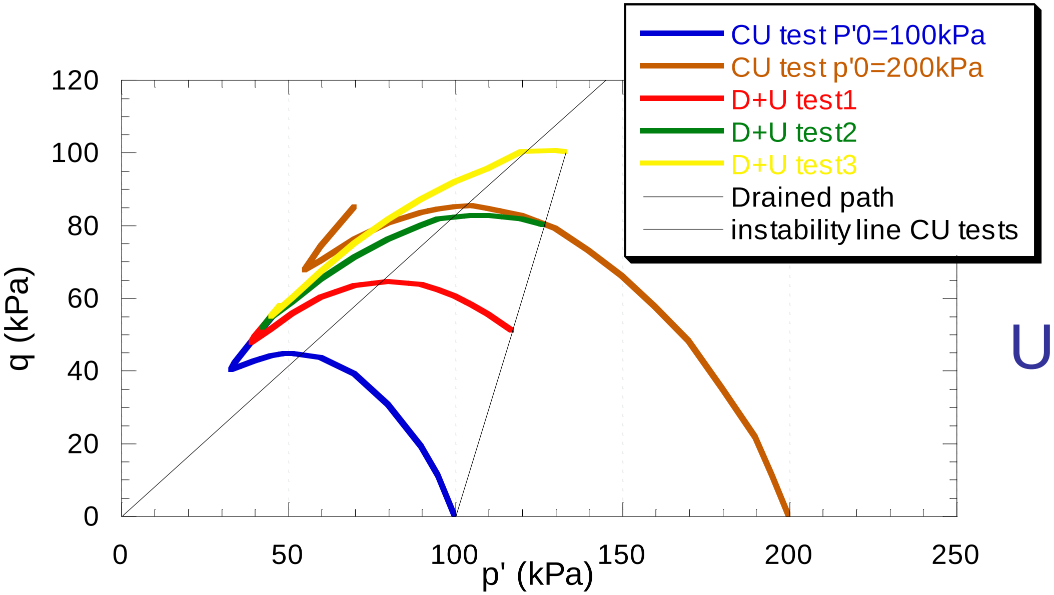


Undrained triaxial tests

Dr = 60%

Unconditionally stable behavior

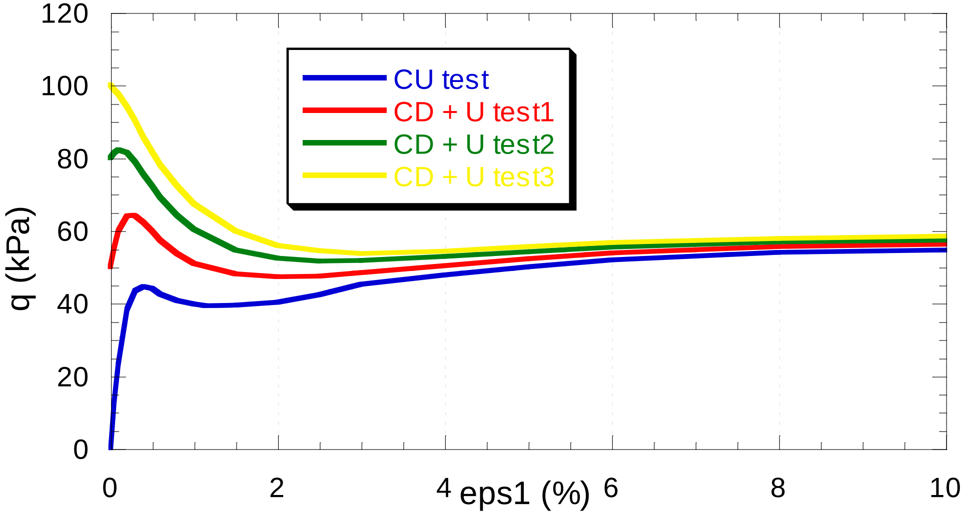


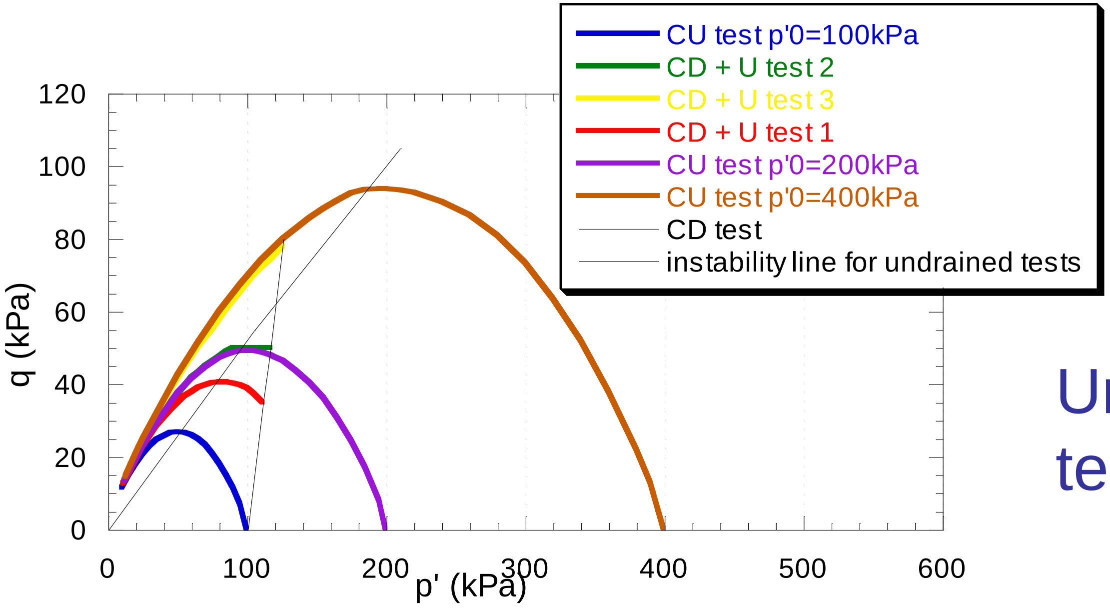


Undrained triaxial tests

Dr = 30%

Existence of an unstable domain

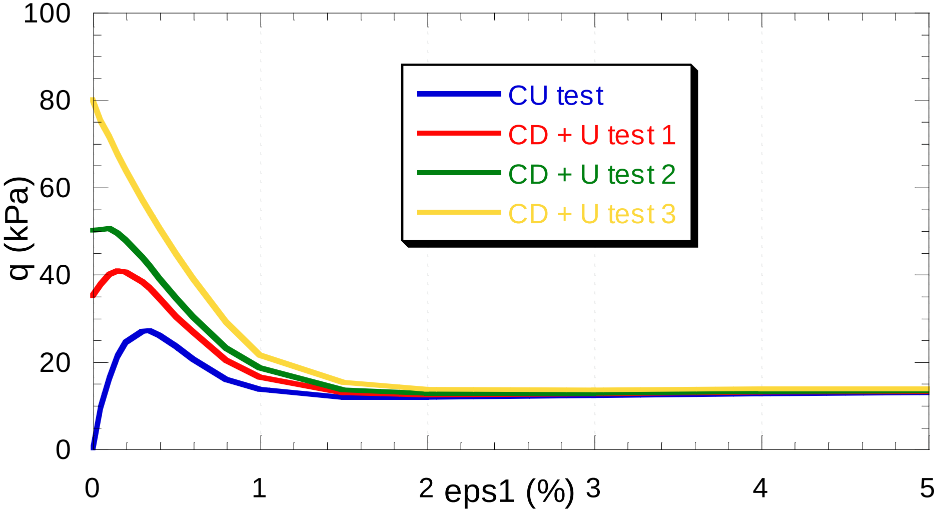




Undrained triaxial tests

Dr = 0

Large domain of instability



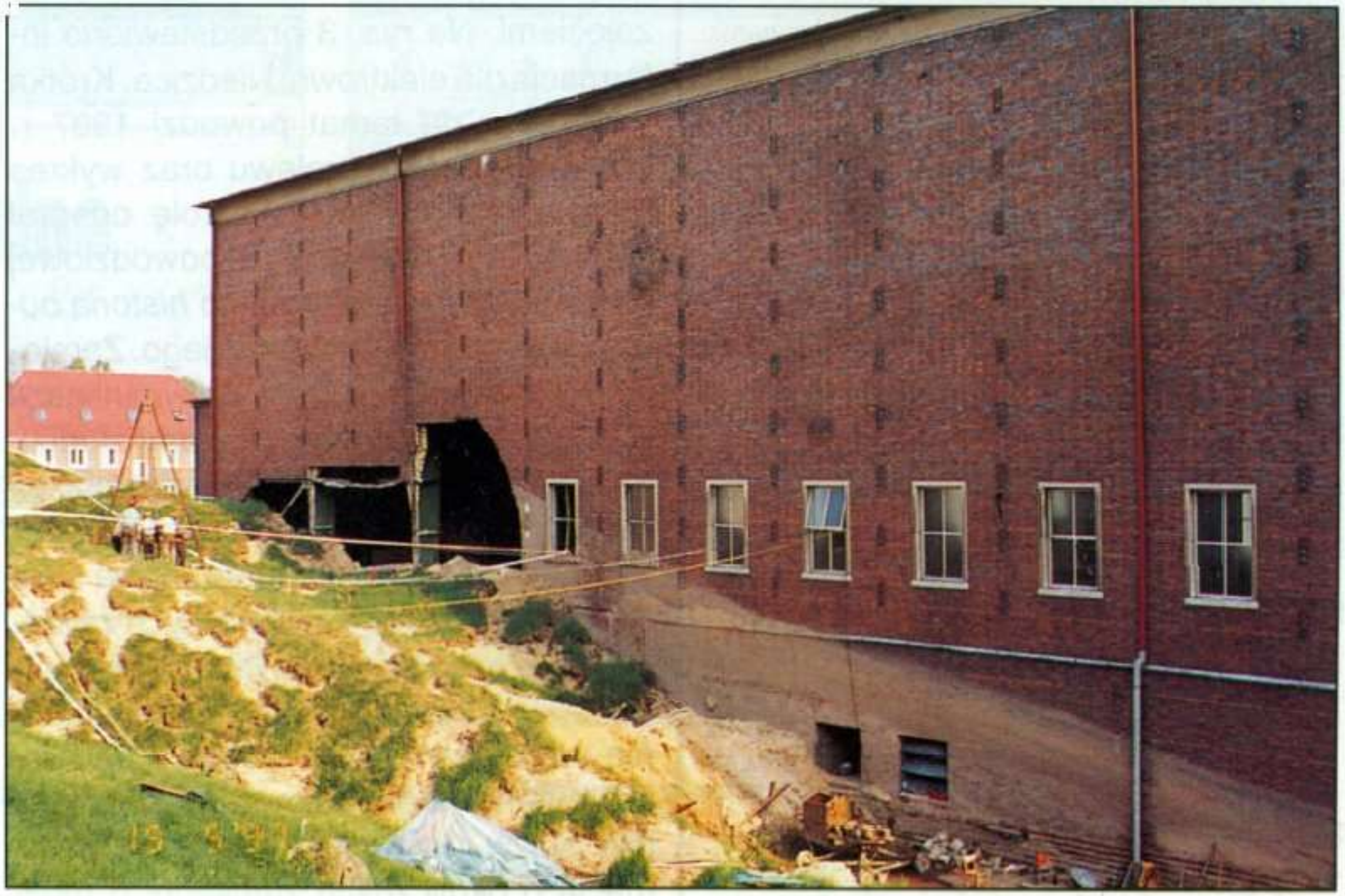
Failure of a hydraulic dam

Picture 1. View of the landslide, the cut road at the construction of the water inlet

hydropower plant in Dychow (Poland)

Picture 2. View at the landslide with shifted road and damaged brick wall of the machinery hall

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