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Presentazione del progetto MITIGO e dei primi risultati

Workshop del 4-5 Aprile 2022

Partner UniTN

Modellazione fisico-matematica dei fenomeni di rigonfiamento nei terreni della frana di Costa della Gaveta

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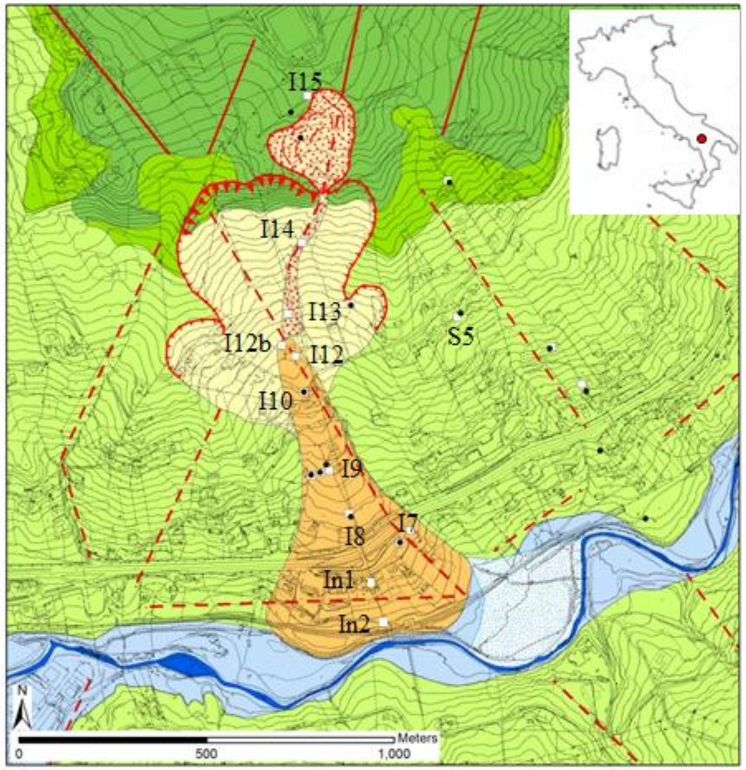
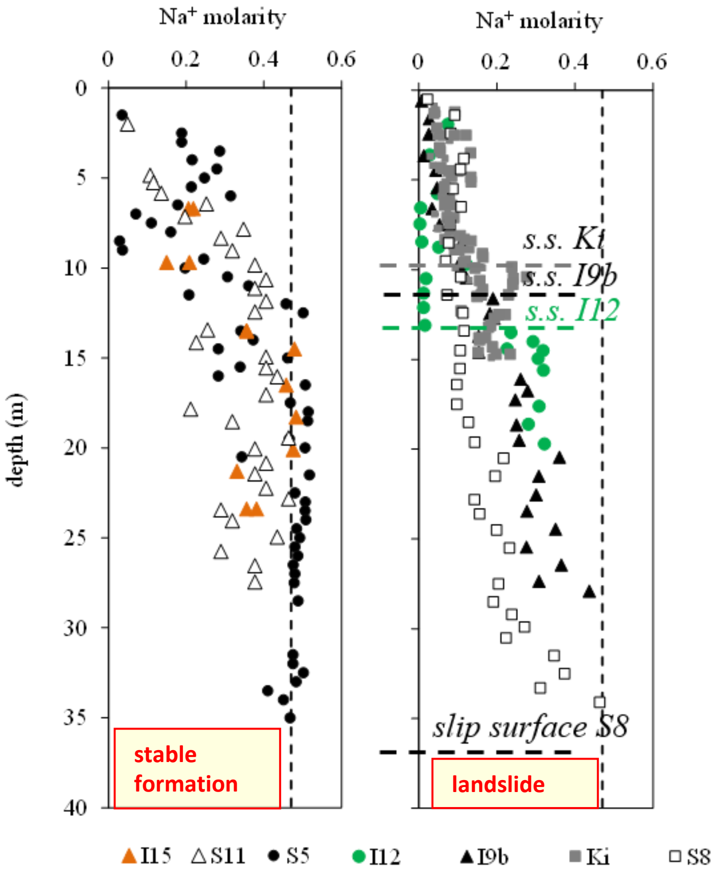
Motivation: Evaluation of the chemical effects on the slope stability

Tectonized Varicoloured Clays Costa della Gaveta (PZ)



Geological map (Di Maio et al., 2017)

The natural pore fluid is an aqueous ion solution

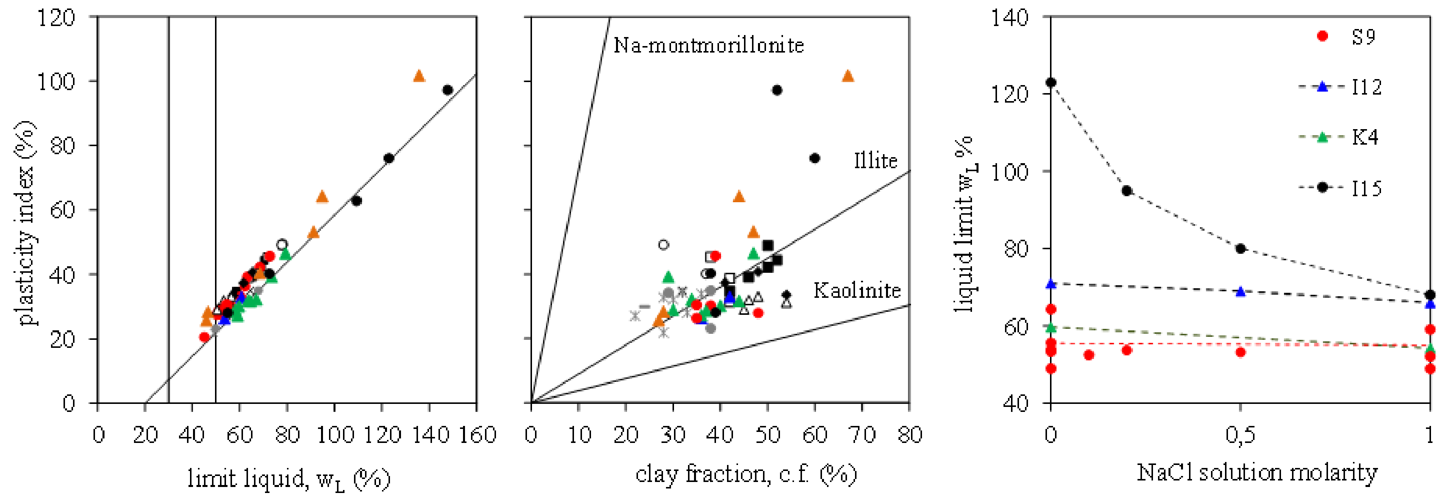


- The natural pore fluid solution at about 5-10 m depth in the stable formation, has a concentration very similar to seawater (0.45-0.5 mol Na^+) that decreases gradually towards the ground surface.
- In the landslide, the pore solution concentration is much lower.
- The concentration decrease is the effect of exposure to rain of these marine origin soil.

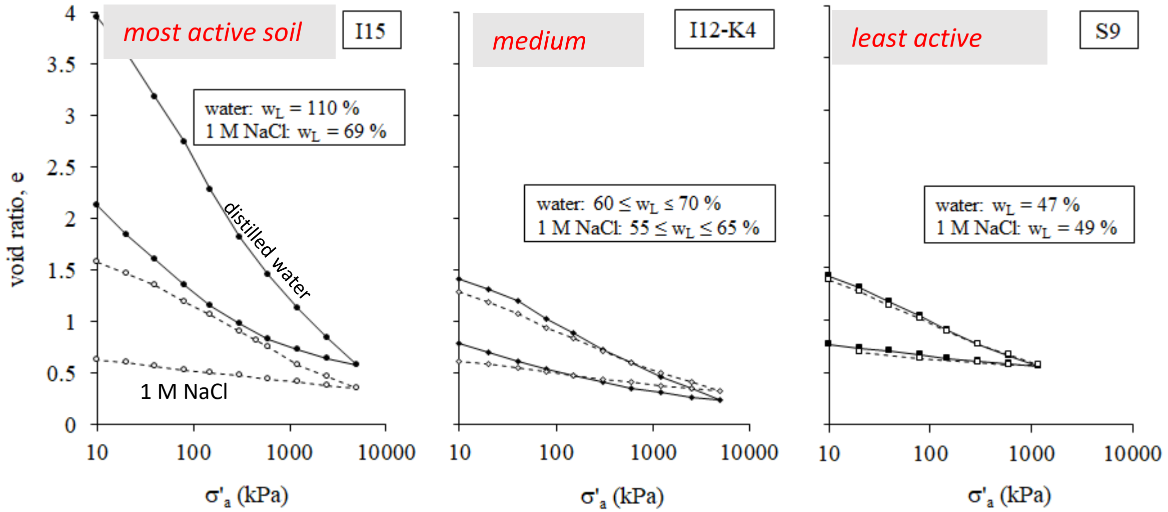
Motivazione

Motivation: Evaluation of the minimal chemical effects on the slope stability

The soil is characterized by wide ranges of plasticity and activity



Soil samples with different w_L were reconstituted with a concentrated salt solution and with distilled water and compressed in oedometric conditions

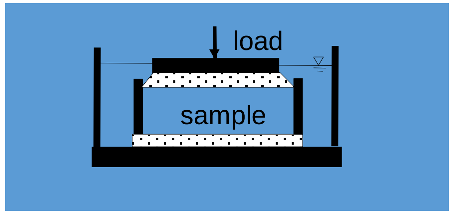


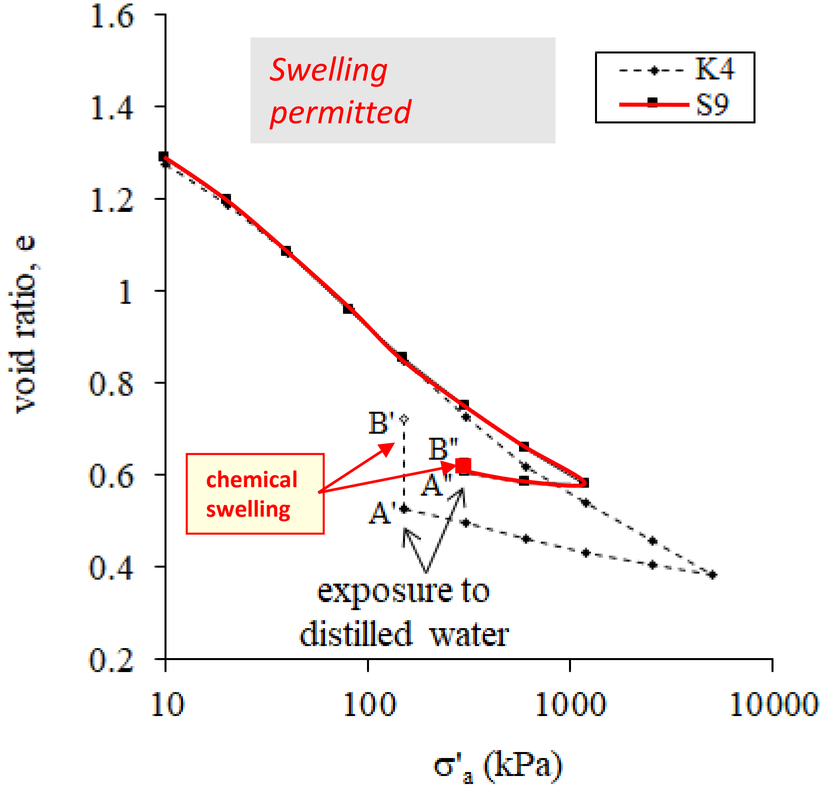
The influence of pore solution composition decreases dramatically with decreasing liquid limit

Motivazione

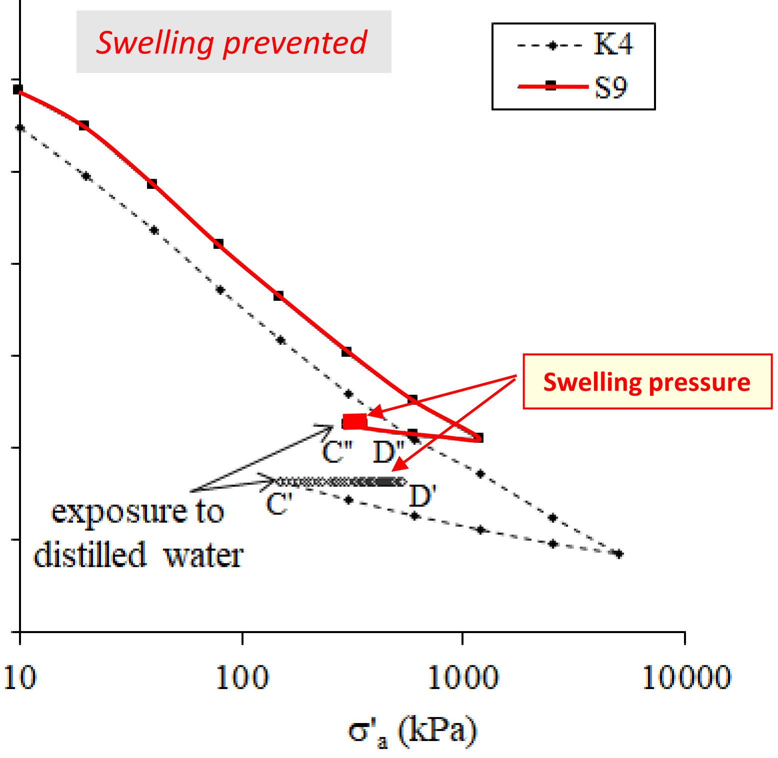
Motivation: Evaluation of the minimal chemical effects on the slope stability

- The chemically induced swelling was very large in the most plastic soil and negligible in the least plastic one.
- Swelling pressure too attained different values, however it was very large also in the least plastic soil.





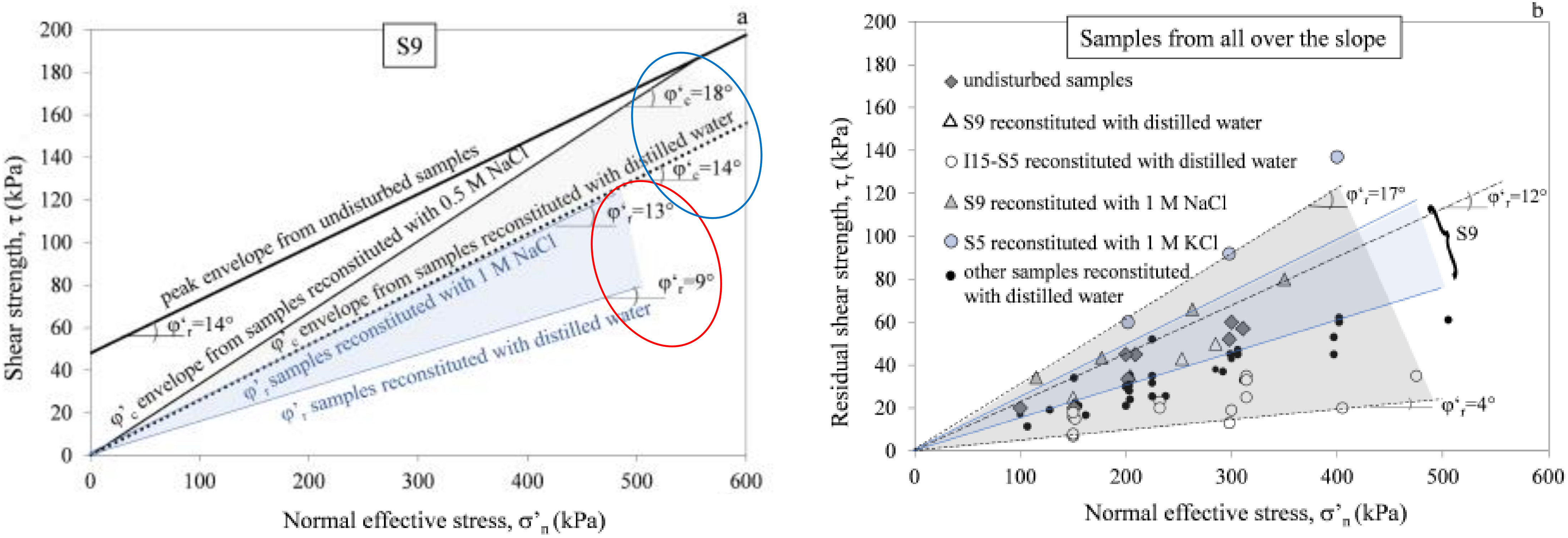
Free swelling test



Swelling pressure test

- Exposure to distilled water is known to decrease both critical state and residual friction angles
- To evaluate the minimal chemical effects on the slope stability, a constitutive model of clay- pore fluid interaction was calibrated - and the analysis was focused - on the material with the smallest chemo-mechanical response, S9.

Motivazione



- ➢ Grande effetto del fluido interstiziale sulla resistenza del campione
- ➢ Grande variabilità di angolo di resistenza in condizioni residue

Outline of presentation:

- Problem formulation and proposed 2D model
- Validation of the model with experimental oedometer tests on sample extracted from Costa della Gaveta Landslide (natural soil)
- Simplified analysis of the effect of swelling pressure on slope stability
- The case of an infinite slope
- The formulation of a new contact element
- Conclusions

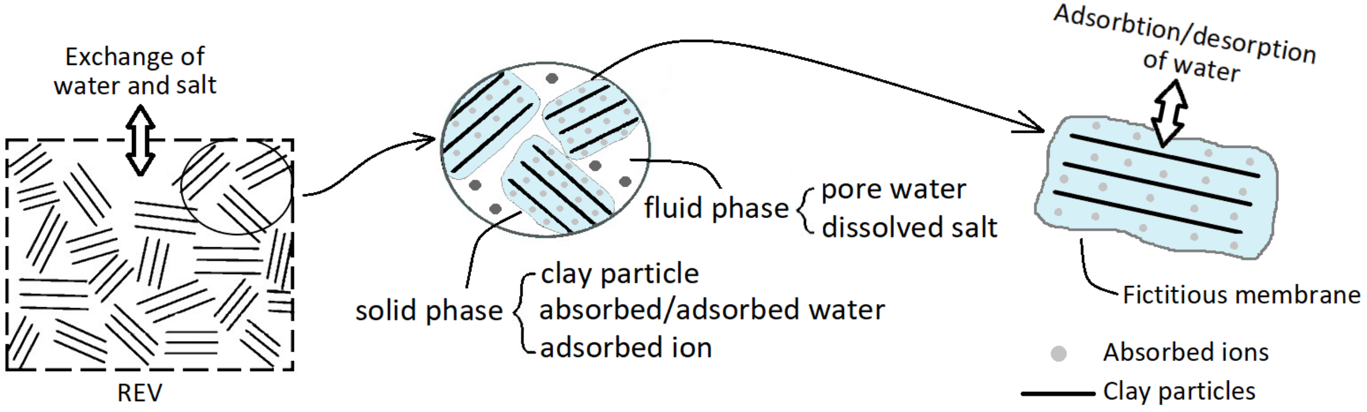
Sulle argille di minor attività !!!

Inquadramento del modello matematico

General framework of the model

Saturated clay is composed of 2 phases, each one consisting of several species:

- solid phase (S): clay particles (c) + absorbed water (w) +adsorbed ions (s)
- fluid phase (W): pore water (w) + hydrated ions (s)
- All species, except clay mineral, can be exchanged through the fictitious membrane (Loret et al 2002)

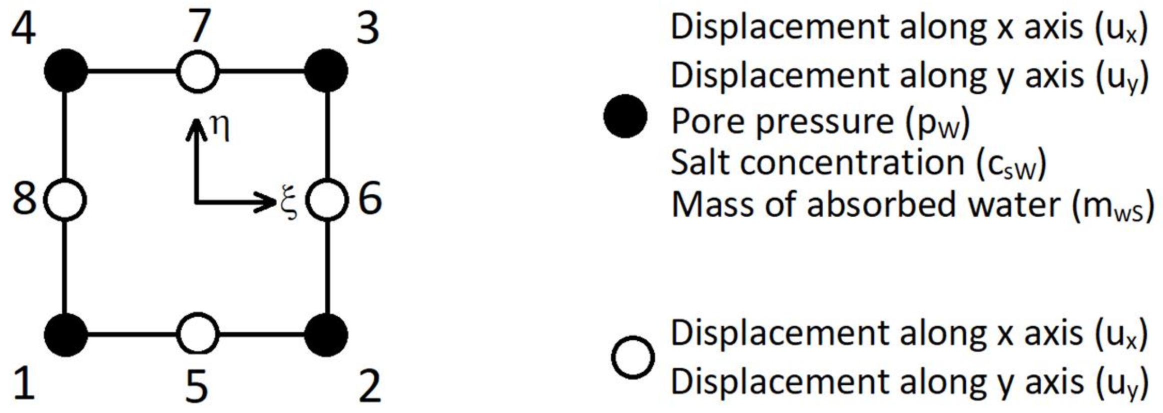


Representative elementary volume (REV) of two-phase porous medium

Balance equations:

- Momentum balance
- Mass balance of pore water in the fluid phase
- Mass balance of salt in the fluid phase
- Mass balance of absorbed water in the solid phase

Advection and osmotic efficiency have been taken into account, although their effects are negligible.



Proposed plain strain element implemented in user element subroutine of ABAQUS

New elastic energy as a polynomial

$$\psi(\varepsilon, m_{ws}) = \sum_i A_i \left[(trC + \varepsilon_s)^i + \xi_i \left(trC_D^2 + \frac{(trC + \varepsilon_s)^2}{3} \right)^{\frac{i}{2}} \right] +$$

$$+ \frac{RT}{M_w^M} \left(m_{ws} \log \left(\frac{m_{ws}/M_w^M}{m_{ws}/M_w^M + N_{cs}} \right) - M_w^M N_{cs} \log(m_{ws} + M_w^M N_{cs}) \right) + C m_{ws}$$

$C = B\varepsilon^e$

B is fabric tensor taking account of elastic anisotropy as: $\mathrm{tr}(B^2) = 3$

C_D deviatoric part

$\varepsilon_s(m_{ws}, \varepsilon^e)$

ξ_i is a function of Poisson's ratio

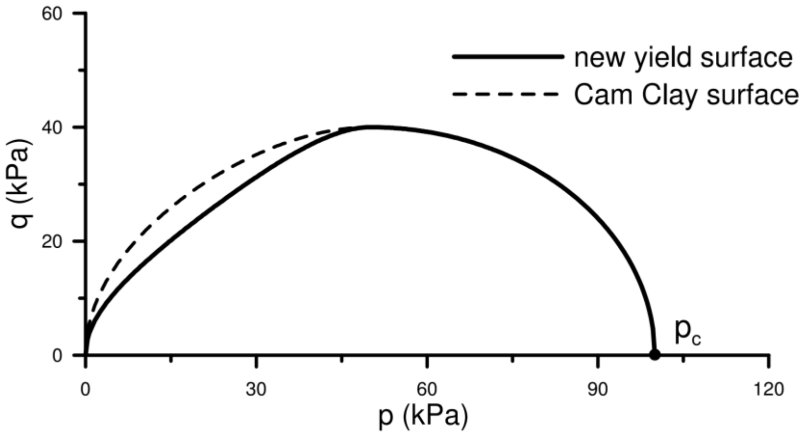
This elasticity law consideres the change of shear and volumetric stiffness depend of stress level and salt concentration

Yield surface

$$f = f(\bar{p}, q, \bar{\mu}_{ws}, tr\varepsilon^{pl}) = M^2 g^2 (\tilde{p}^2 - \tilde{p} p_c) + q^2$$

with g a function of Lode angle

New yield function gives a smaller peak strength for highly overconsolidated clays, which leads to a better agreement with the experimental results.

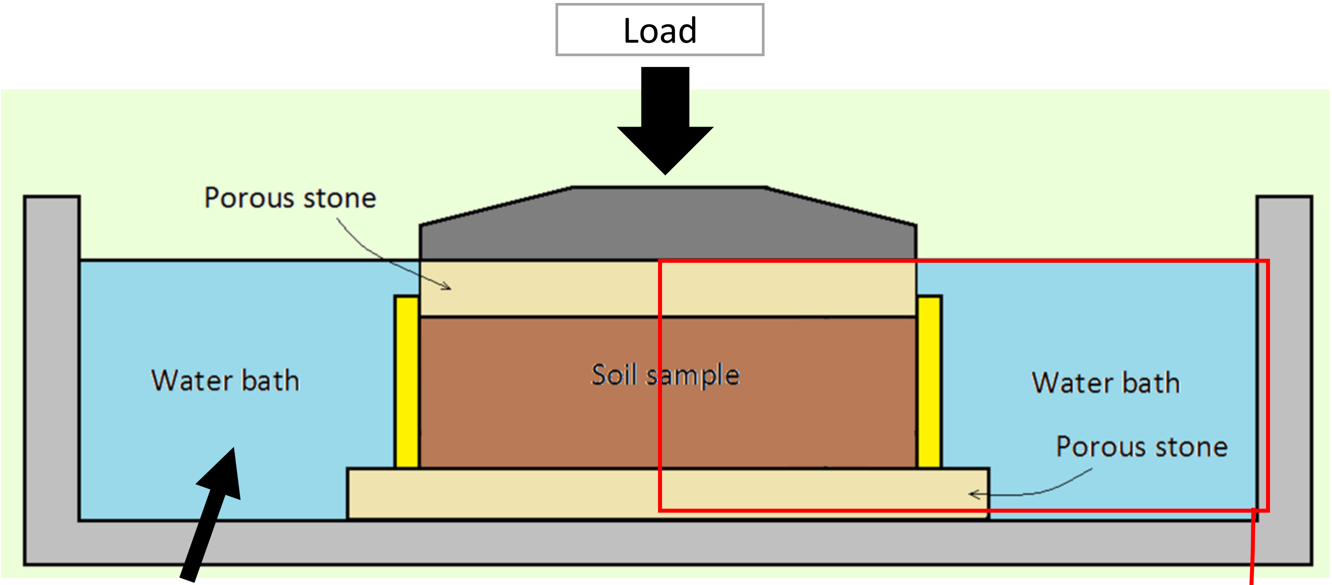


Experimental oedometer tests

Prepared sample with distilled water or 1 mol/l of NaCl

Mechanical load up to a certain value

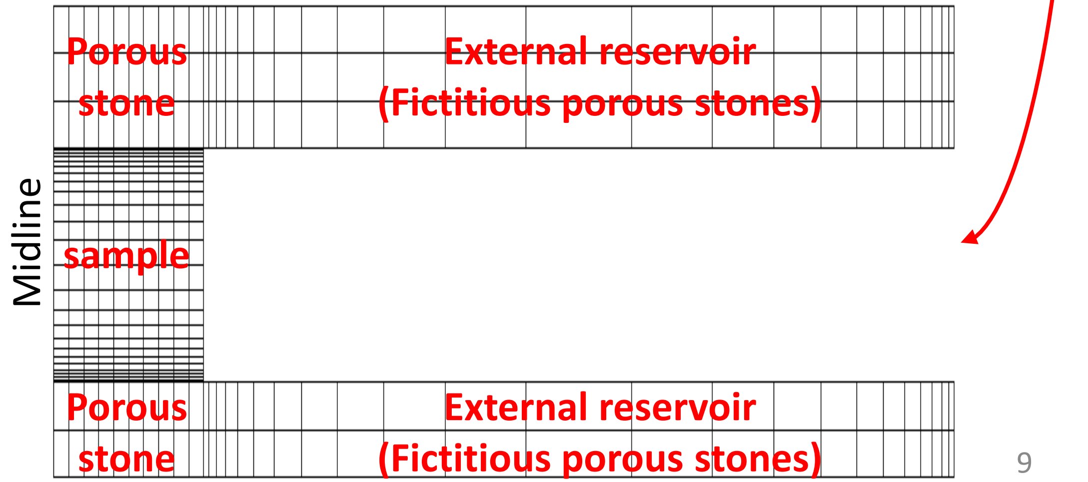
Replacement of salty water with distilled water



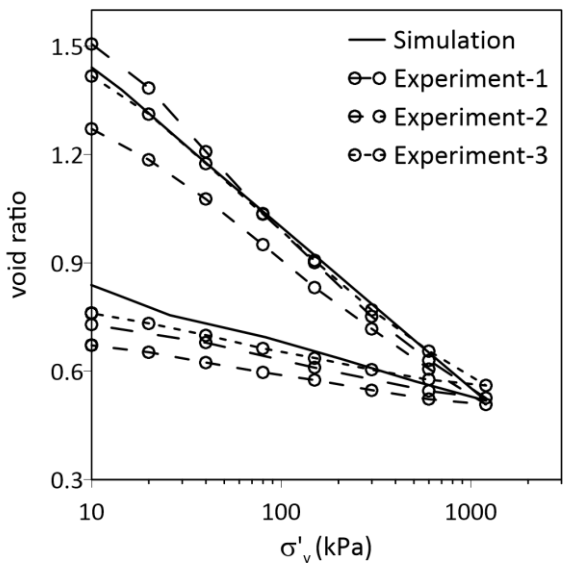
Initial solution is similar to the specimen (1 mol/l)

Finite element simulation of oedometer test

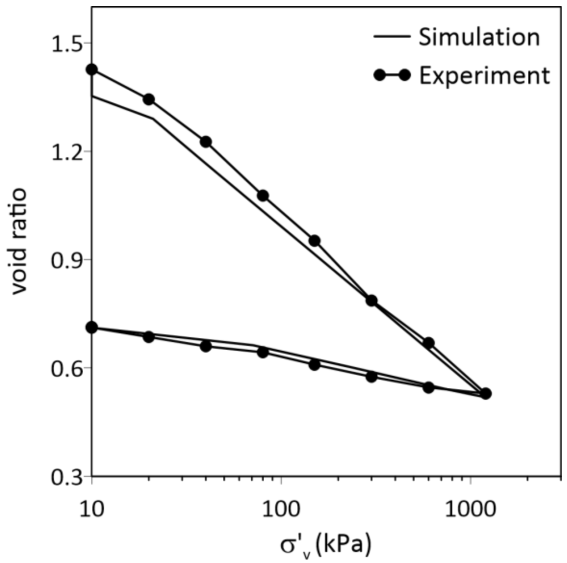
The dimension of the fictitious porous stones (external reservoir) has been computed such that the ratio among the pore volumes of the sample, of the porous stones and of the external cell fluid is preserved.



Calibration of the model

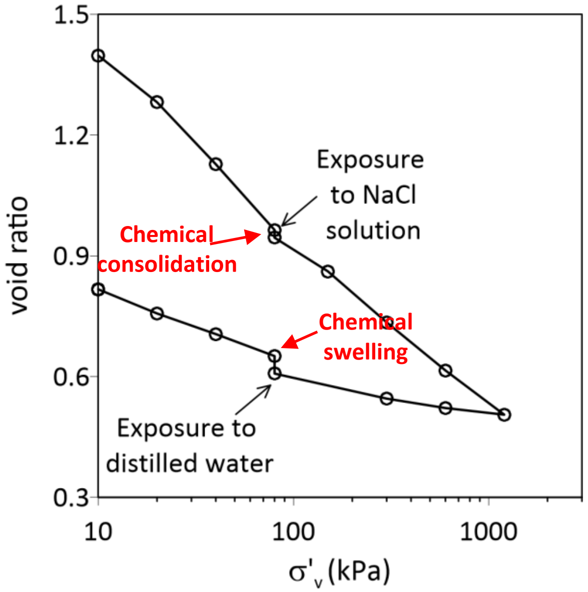


Sample prepared with distilled water

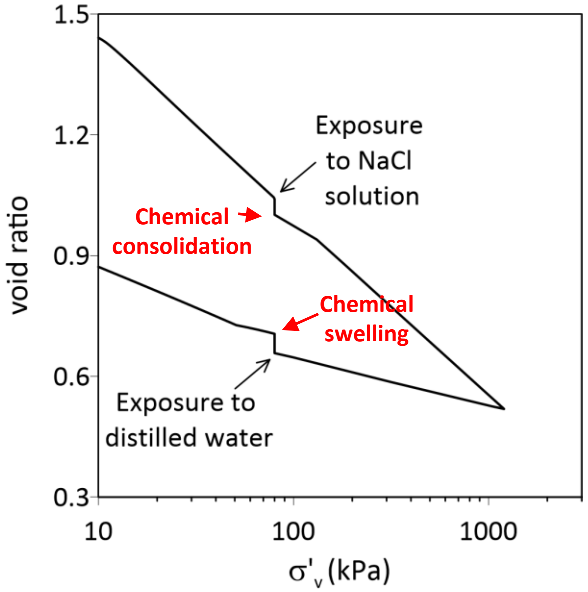


Sample prepared with 1 mol/l NaCl

Sample prepared with distilled water



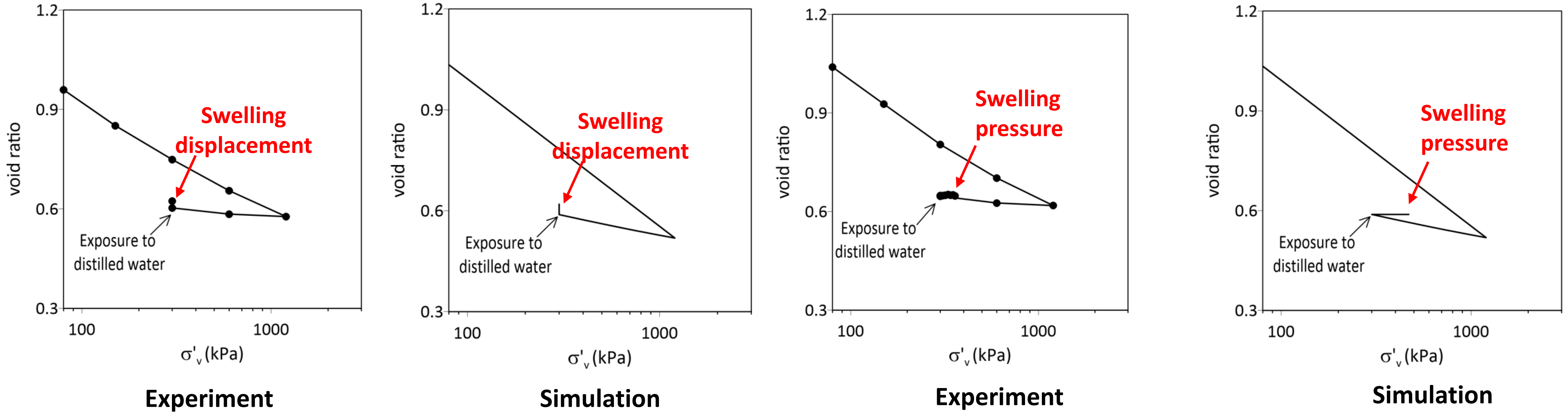
Experiment



Simulation

Swelling and swelling pressure of the sample prepared with 1 mol/l of NaCl

Free swelling test | **Swelling pressure test**



Although the amount of swelling displacement is negligible, the amount of swelling pressure is significant.

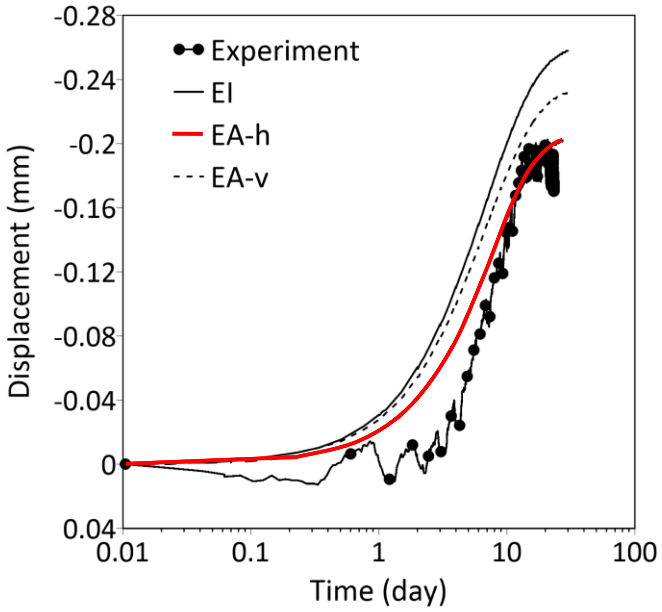
Simulazioni del modello

Effect of fabric tensor (governing elastic anisotropy) on swelling behavior

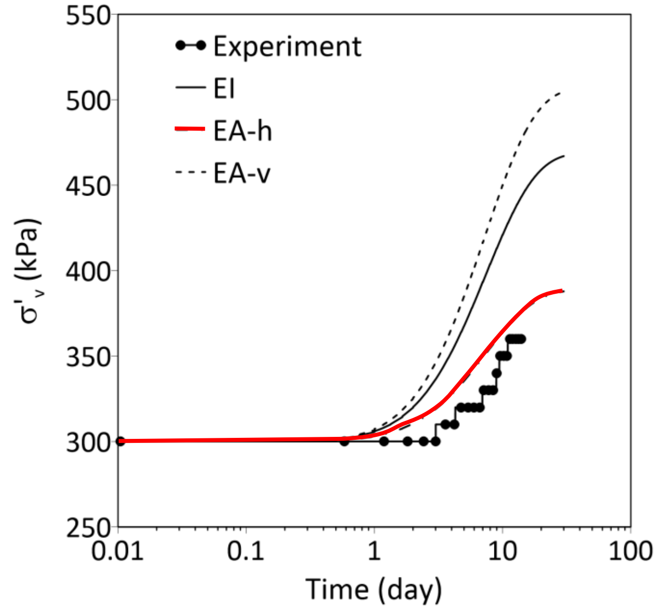
Elastic isotropy of fabric tensor **(EI)**: $B_{11} = B_{22} = B_{33} = 1$
Elastic anisotropy of fabric tensor with larger components in vertical direction **(EA-v)**: $B_{22} = 1.2, B_{11} = B_{33} = 0.883$
Elastic anisotropy of fabric tensor with larger components in horizontal direction **(EA-h)**:$B_{22} = 0.596, B_{11} = B_{33} = 1.15$

- The simulation results of swelling displacement and swelling pressure are more compatible with the experiment when the horizontal components of elastic anisotropy of fabric tensor are larger (EA-h)

We need further experimental data on anisotropy of these clays for better understanding these aspects



Swelling displacement



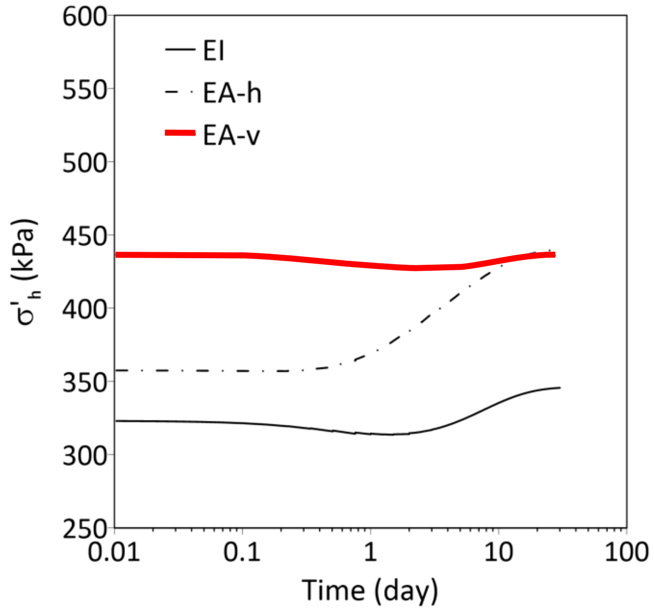
Swelling pressure

Effect of fabric tensor anisotropy on horizontal stress

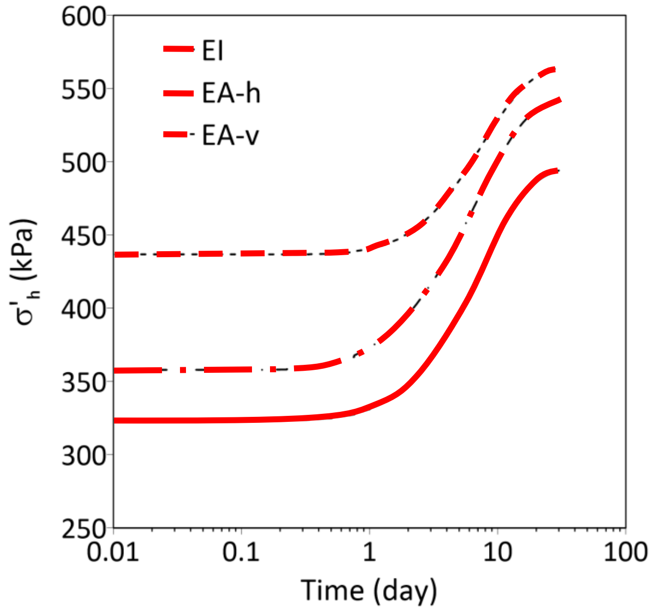
Elastic isotropy of fabric tensor **(EI)**: $B_{11} = B_{22} = B_{33} = 1$
Elastic anisotropy of fabric tensor with larger components in vertical direction **(EA-v)**: $B_{22} = 1.2, B_{11} = B_{33} = 0.883$
Elastic anisotropy of fabric tensor with larger components in horizontal direction **(EA-h)**:$B_{22} = 0.596, B_{11} = B_{33} = 1.15$

- In free swelling test, the increase of horizontal stress is small and is negligible if the vertical stiffness is larger than the horizontal one.
- In swelling pressure test, the horizontal stress increases significantly for all cases of elastic anisotropy.

Need for further experimental data !!



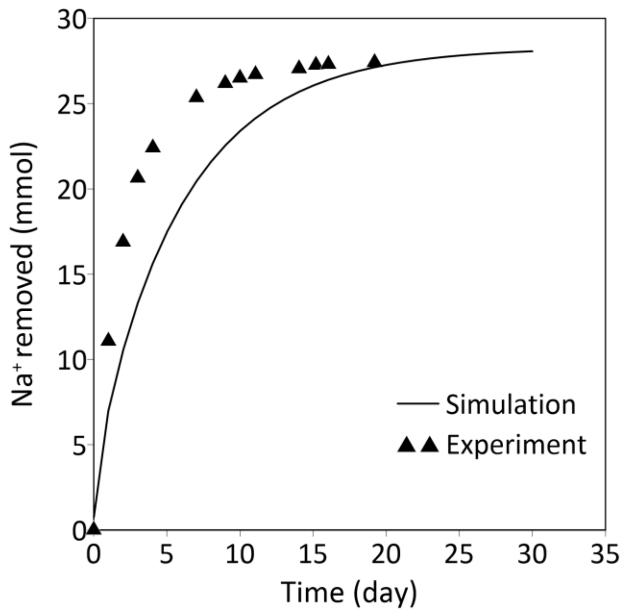
Free swelling test



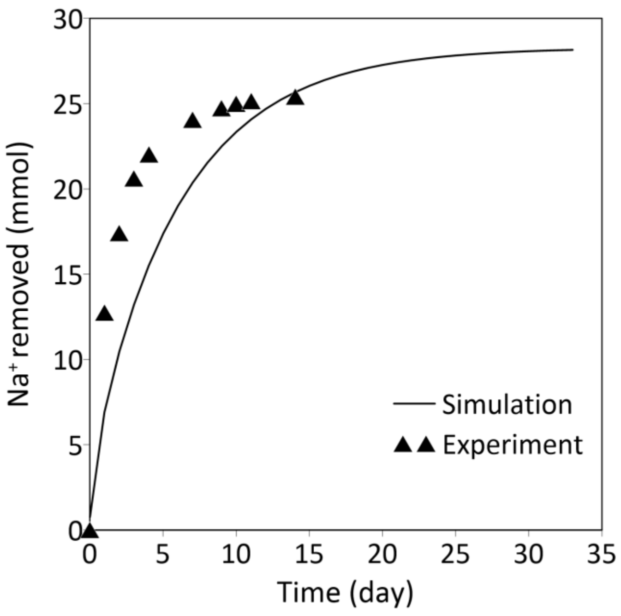
Swelling pressure test

Removed ions by time from an overconsolidated sample with vertical stress equal to 300 kPa

- In the experiment the removal of ion is faster than simulation at the beginning of exposure to distilled water.
- The time of swelling in the simulation is longer than the experiment in both swelling displacement and swelling pressure tests.



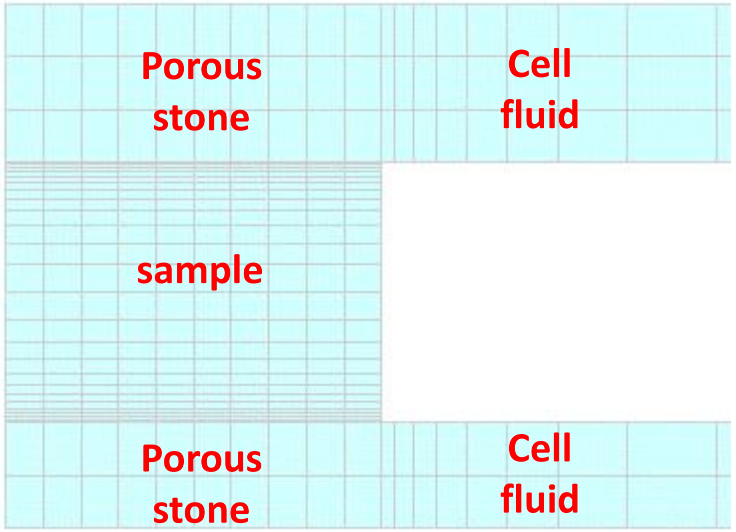
Free swelling test

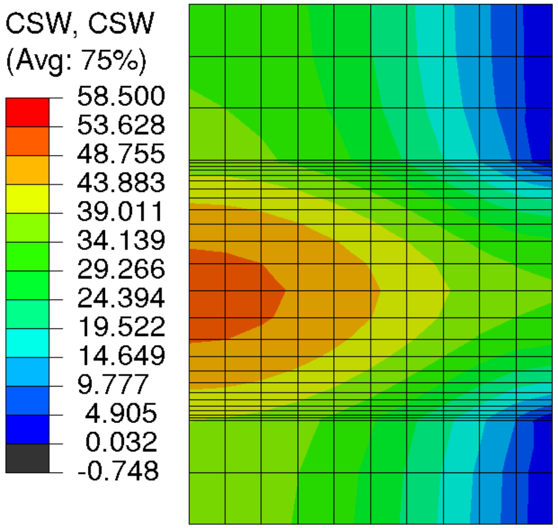


Swelling pressure test

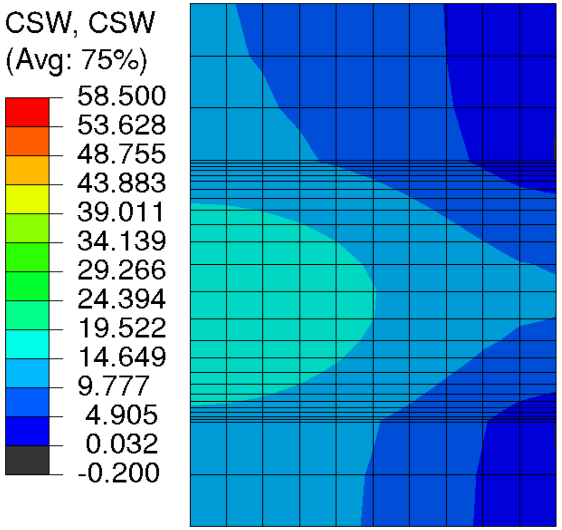
Simulazioni del modello

Salt concentration inside the sample and porous stones during different time of free swelling test





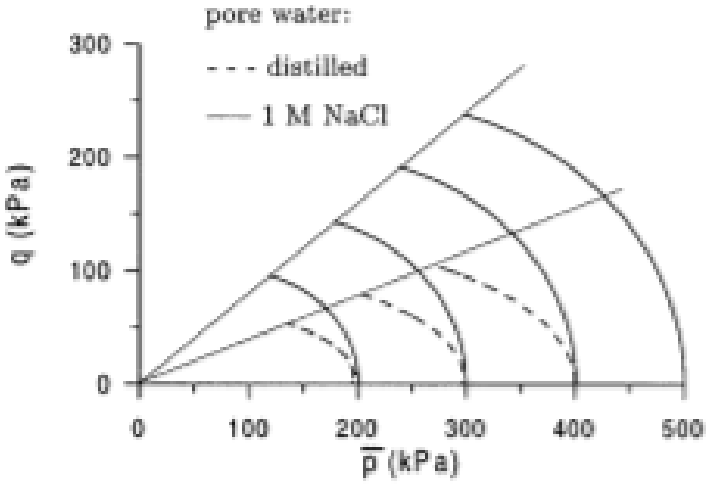
Beginning of 4th day



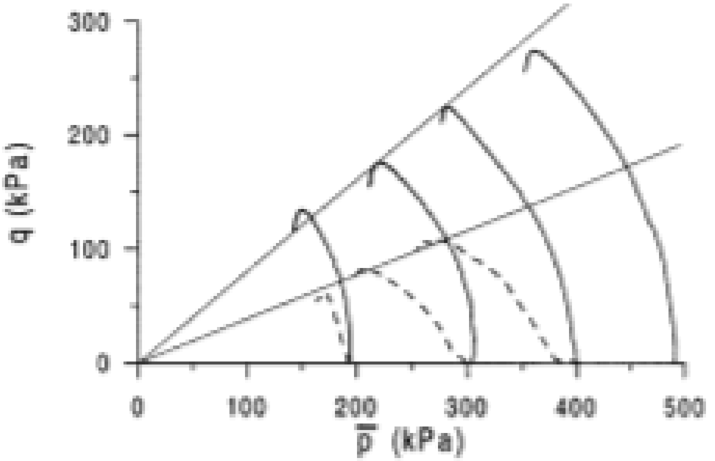
Beginning of 11th day

Initial salt concentration is equal to $1\ mol/l = 58.5\ kg/m^3$.
The salt diffuses out of the sample inducing a counter flux of water, entering into the sample, due to swelling.

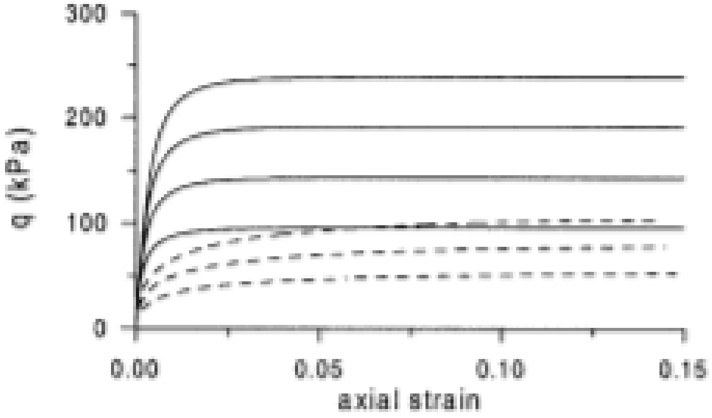
Simulazioni del modello



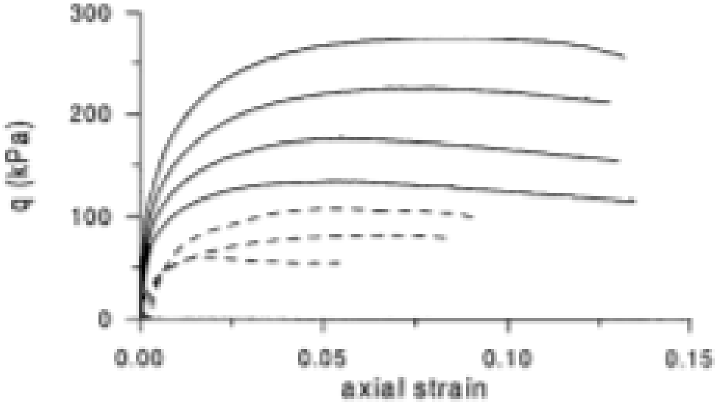
(a) Model simulations.



(b) Experimental data.



(c) Model simulations.

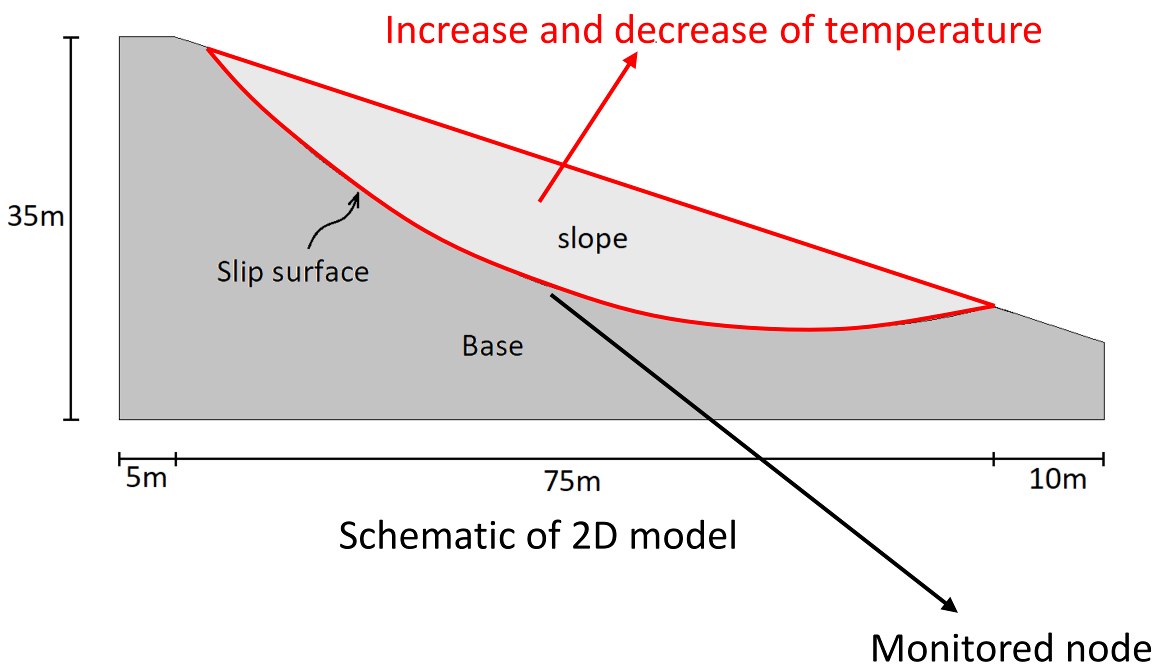


(d) Experimental data.

Effect of swelling on landslide displacement

Effect of swelling on landslide displacement in a slope with a preexisting slip surface

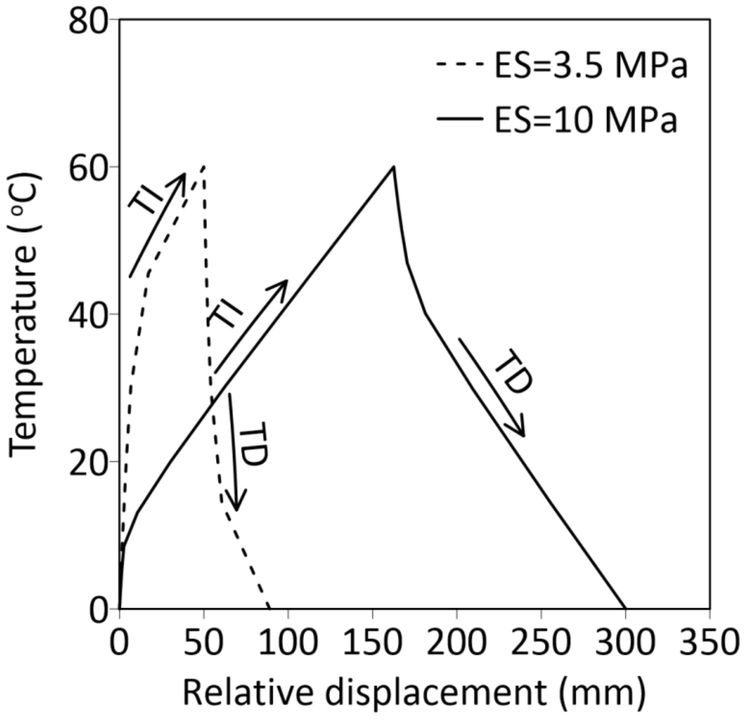
- Simple model with single phase materials
- The chemical induced volumetric strain is simulated with a temperature variation
- The increase of temperature causes the expansion of the material, thus mimicking the exposure of soil to distilled water.
- The decrease of temperature causes the contraction of the material, thus mimicking the exposure of soil to salt.
- The stiffness of the soil has been evaluated based on the swelling pressure and the tangent oedometric modulus
- Two values of friction angle for the stable soil and along the slip surface equal to 16° (slope failure) and 22° (far from slope failure)
- The change of friction angle due to variation of salt concentration has been neglected.



Schematic of 2D model

Displacement of a node at the middle of the slope

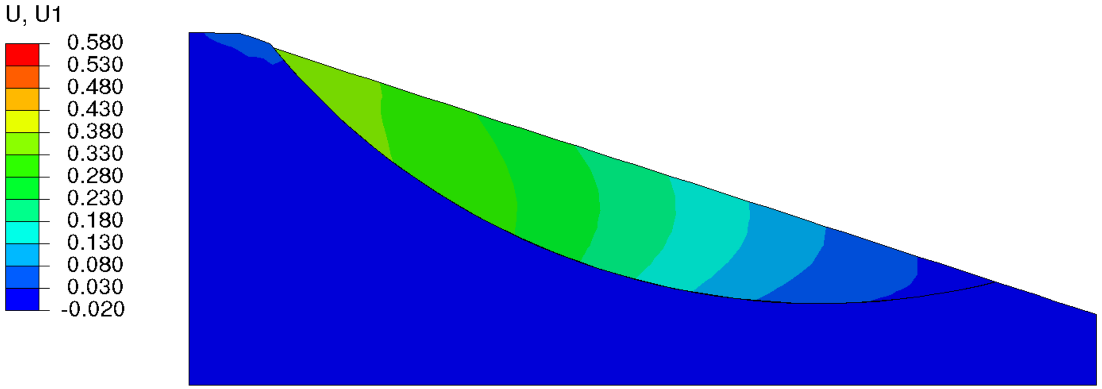
- Temperature increase (TI) mimics the exposure to distilled water
- temperature decrease (TD) mimics the exposure to salt solution
- The increase and subsequent decrease of temperature (simulating exposure to water and subsequent exposure to salt) lead to a residual displacement.
- Swelling leads to an increase of horizontal stresses in the slope and to irreversible displacement along the slip surface.
- The displacements leads friction angle to decrease towards residual value.
- Friction angle decreases by exposure of soil to distilled water



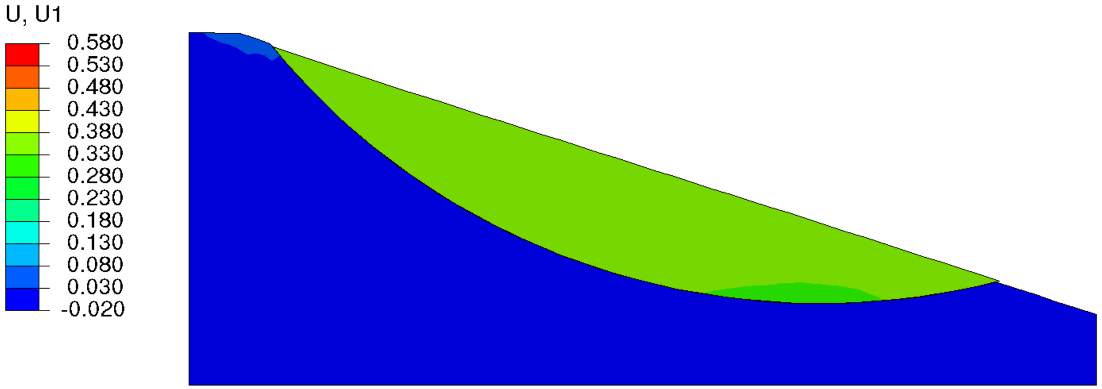
Friction angle along the failure surface= 16°

Effetti su un pendio

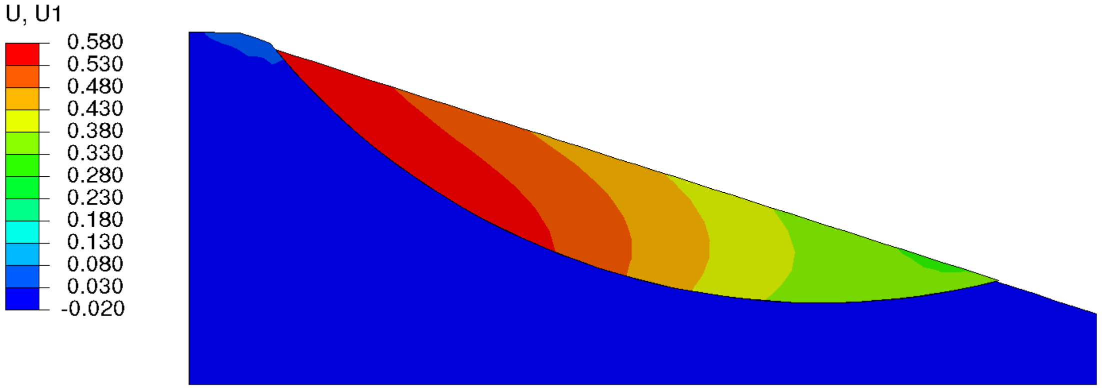
Displacement of the slope



Gravity
Maximum displacement at the top of the slope

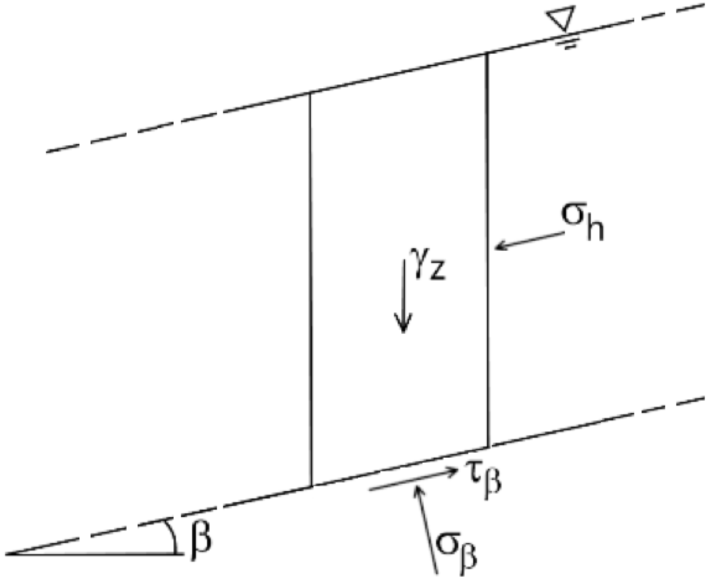


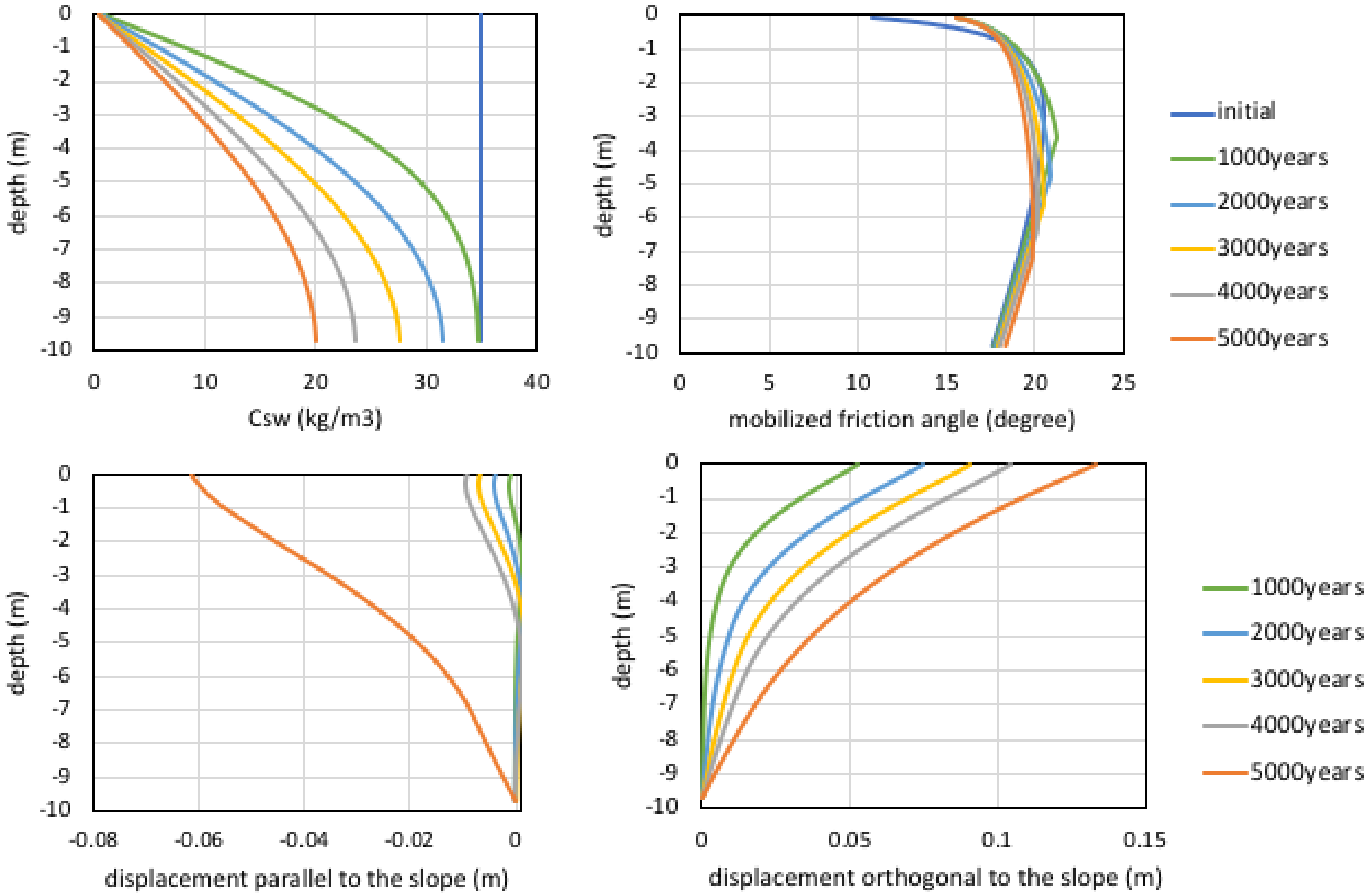
Decrease of salt concentration in the slope induces movement of the slope along the slip surface



Increase of salt concentration in the slope
increases of displacement of the slope specially at top

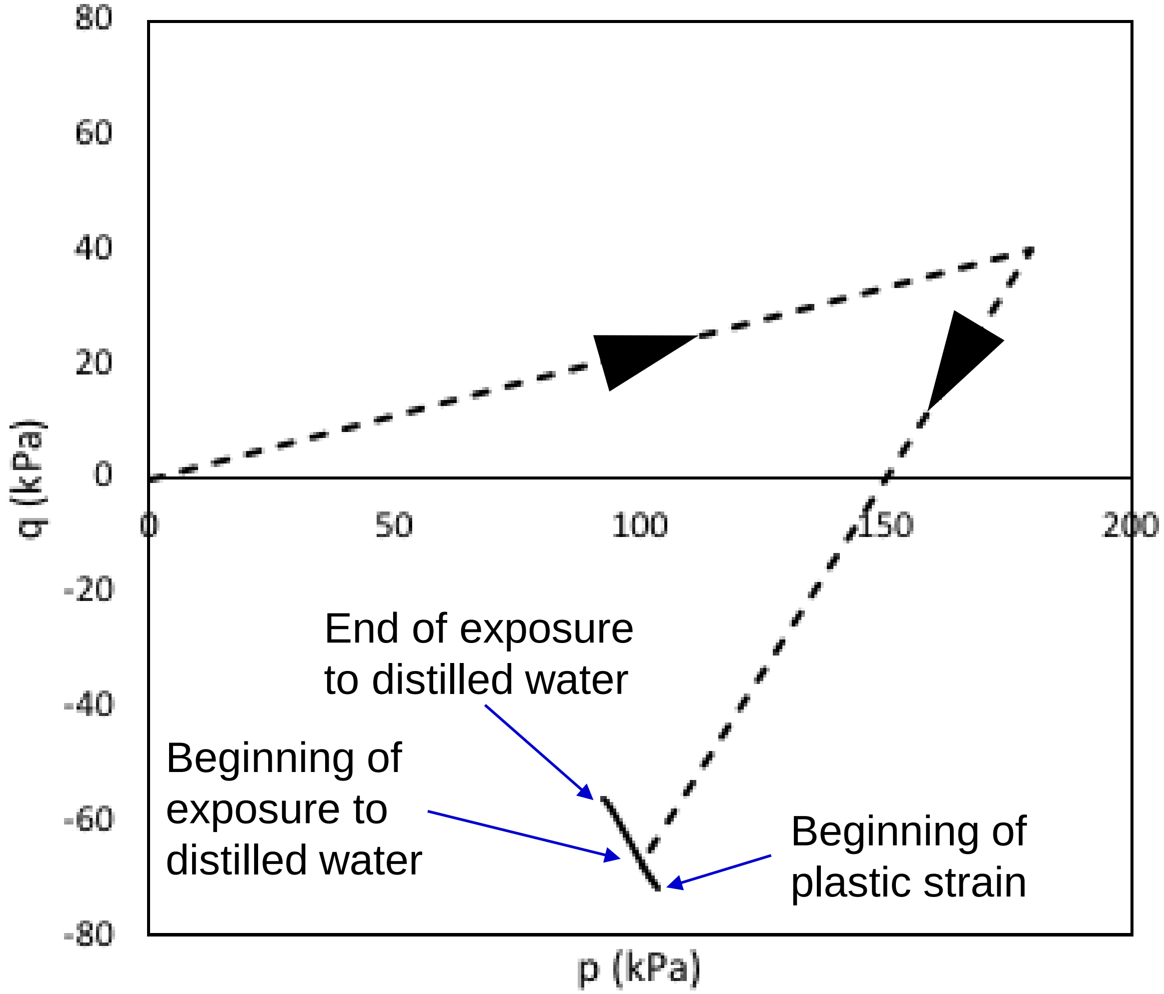
Infinite slope with 10 m depth

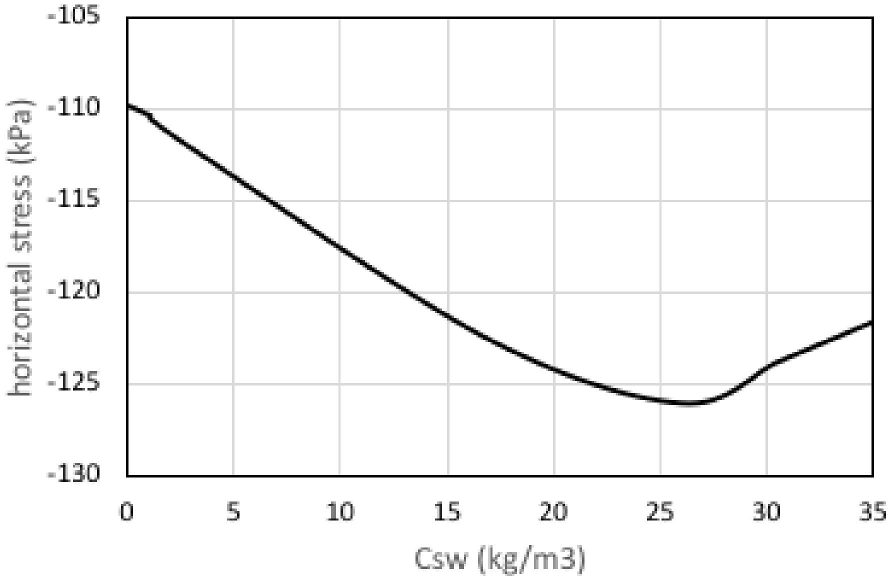


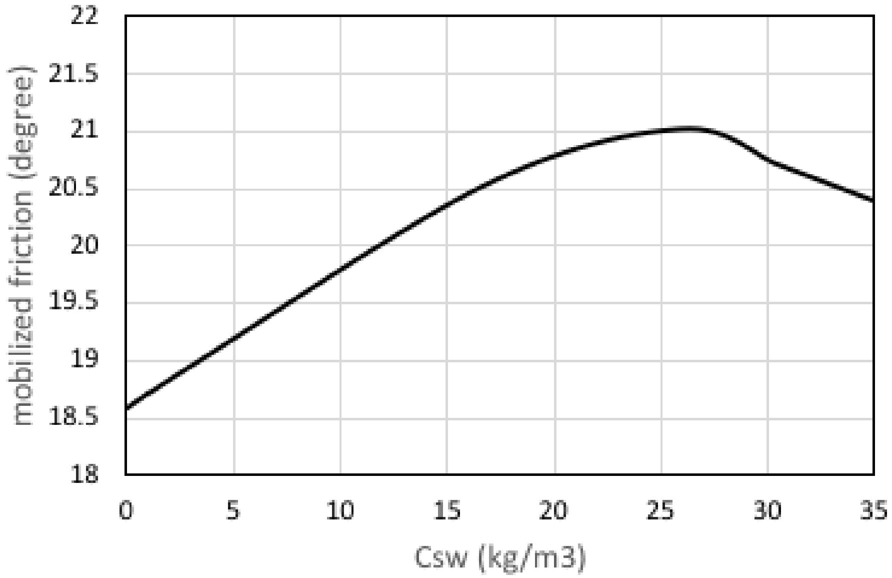


Displacements;
Negative→downward

Results of the element at 5m depth



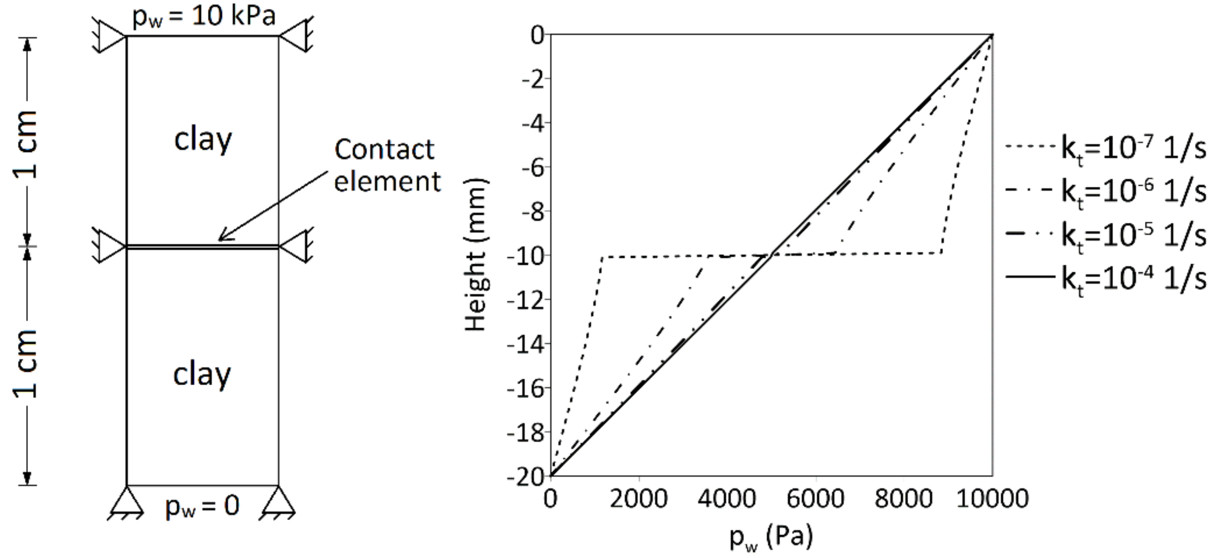




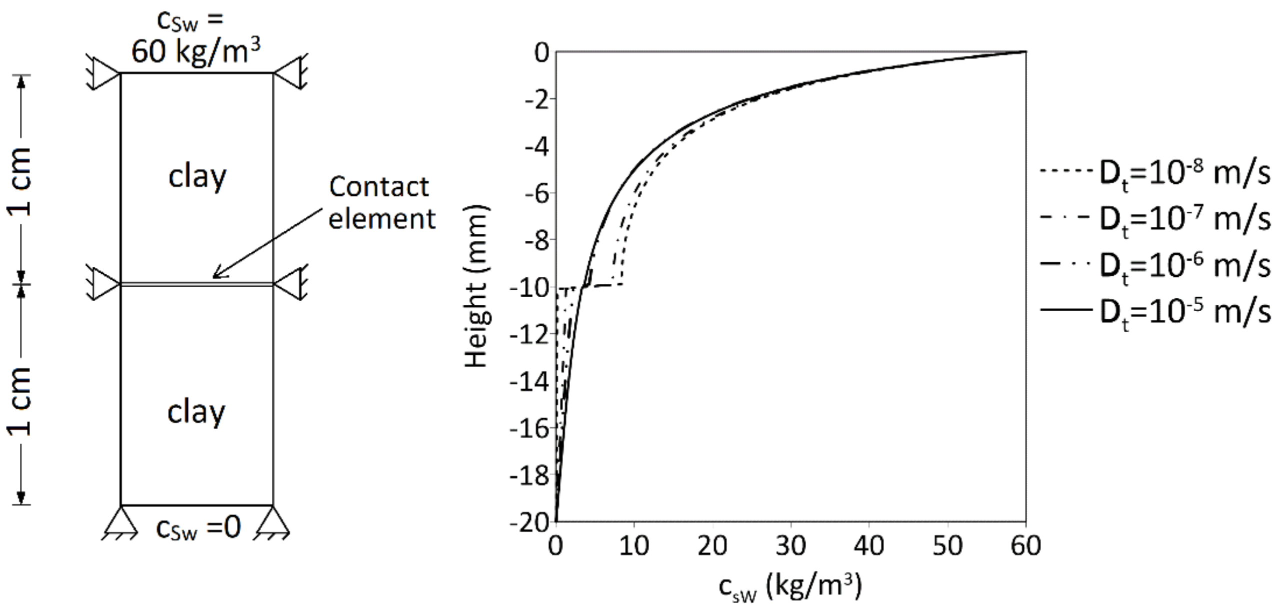
Implementazione di un nuovo elemento di contatto per simulare la superficie di scorrimento

(effetti legati alla velocità di deformazione e alle variazioni di concentrazione salina)

Flow of water and diffusion of salt in the normal direction of contact element

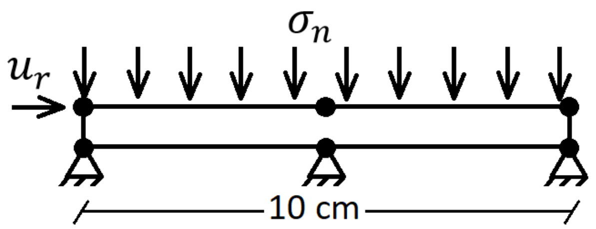


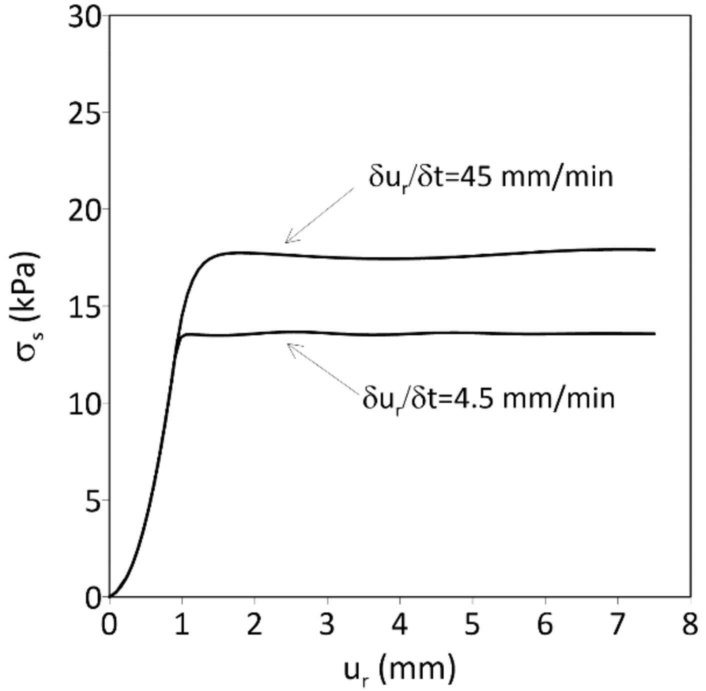
Vertical flux of water when different values of hydraulic conductivity k_t are considered for the contact element



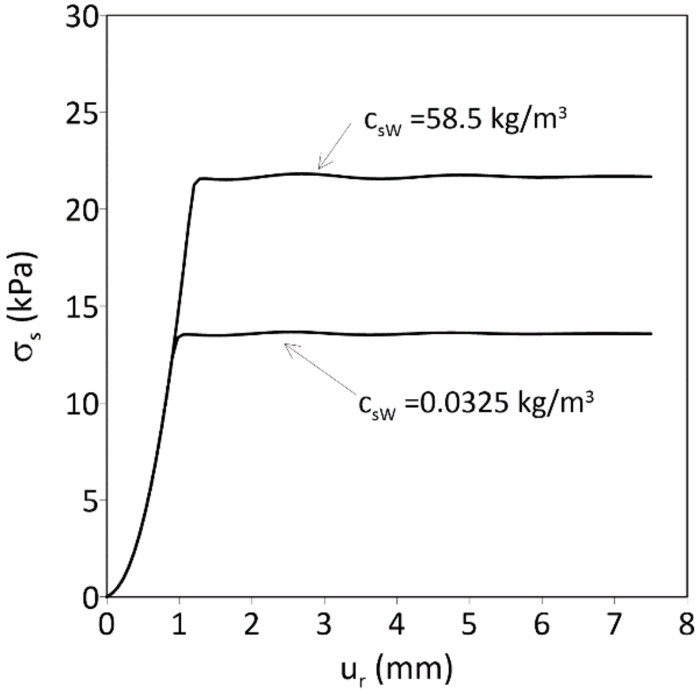
Vertical diffusion of salt when different values of and diffusion coefficient D_t are considered for the contact element

Effects of displacement rate and salt concentration on the mechanical behaviour

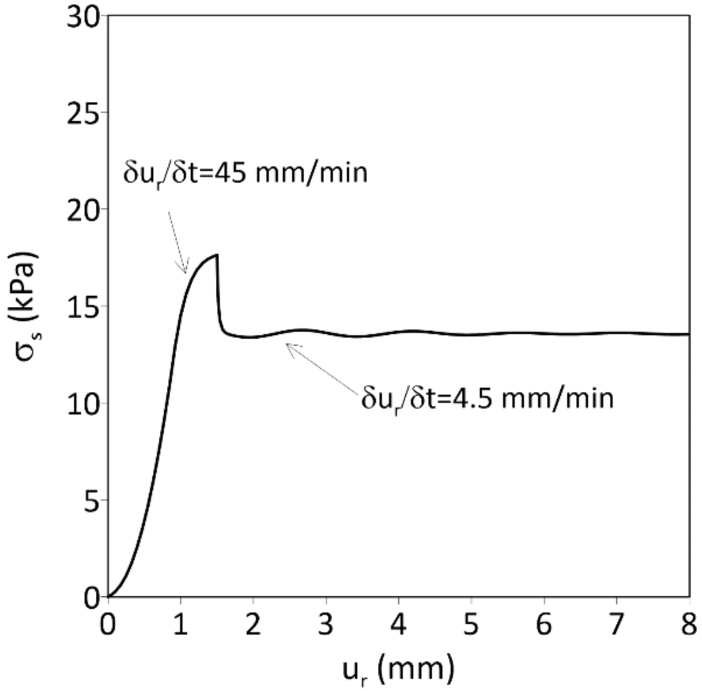




Effect of displacement rate

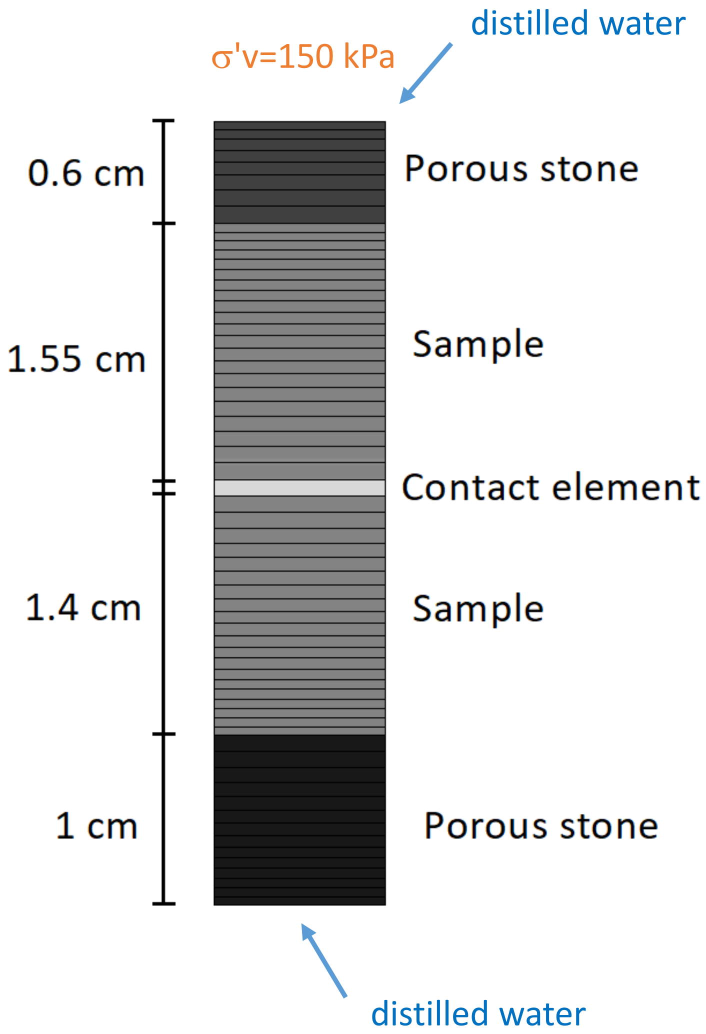


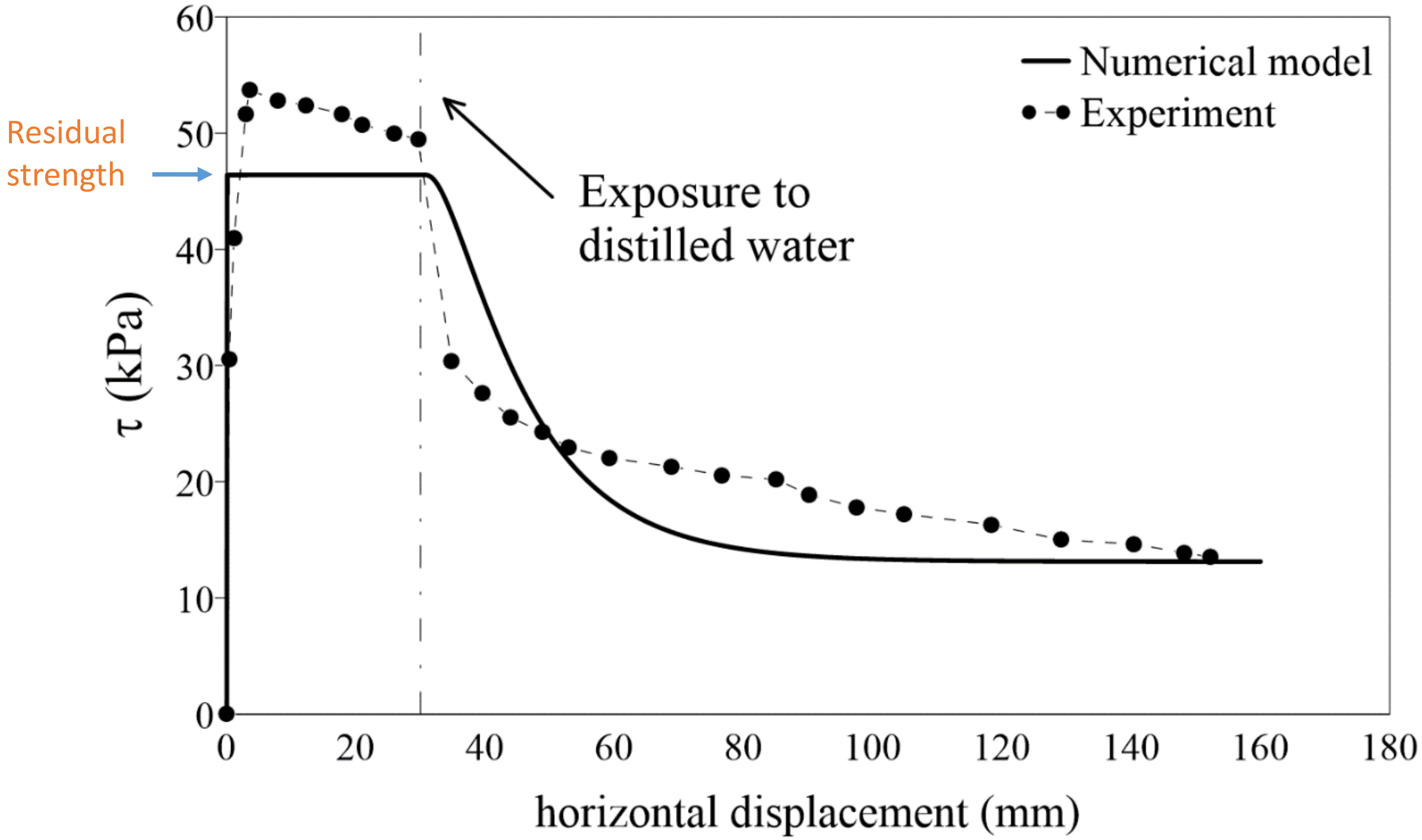
Effect of salt concentration



Effect of a change of displacement rate

Direct shear test and the effect of salt solution on the shear strength (Ponza bentonite)





90 days

(Di Maio & Scaringi 2016)

Sviluppi futuri

- Simulazione 2D dei fenomeni chemo-meccanici nel pendio
- Simulazione del campo prove con i pali di KCl
- implementazione dello scambio ionico (?)

GRAZIE PER L’ATTENTIONE !!!