Hydro – Mechanical Coupling in Saturated and Unsaturated Soils and it Consequences on the Electrical Behaviour

Gabriele Della Vecchia, Renato Maria Cosentini, Sebastiano Foti, Guido Musso
Structural and Geotechnical Engineering Dep., Politecnico di Torino, Torino, 10129, Italy

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Introduction

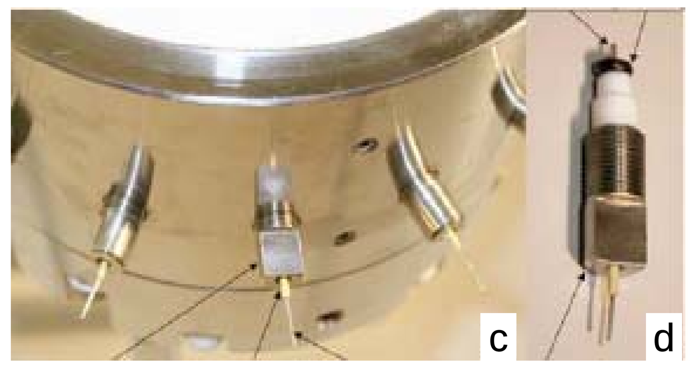
The present work deals with the hydro-mechanical coupled effects occurring in saturated and unsaturated soils and the consequences on the electrical conductivity of the material. The experimental results obtained under controlled conditions in laboratory tests are compared with numerical simulations aimed at improving the understanding of actual physical processes.

Experimental set-up

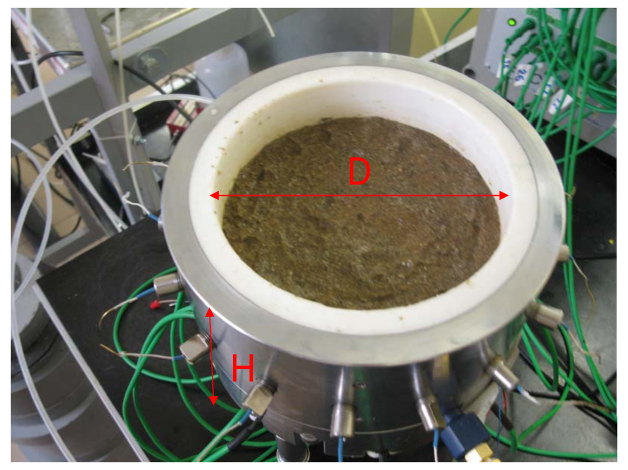
An oedometer cell, which allows for 3D electric tomography and seismic wave velocity measurements, has been used in the investigation (Comina et al., 2008).

ERT- Oedometer cell (a) external view of the cell and loading system and (b) view of metallic confining ring and insulating internal material.

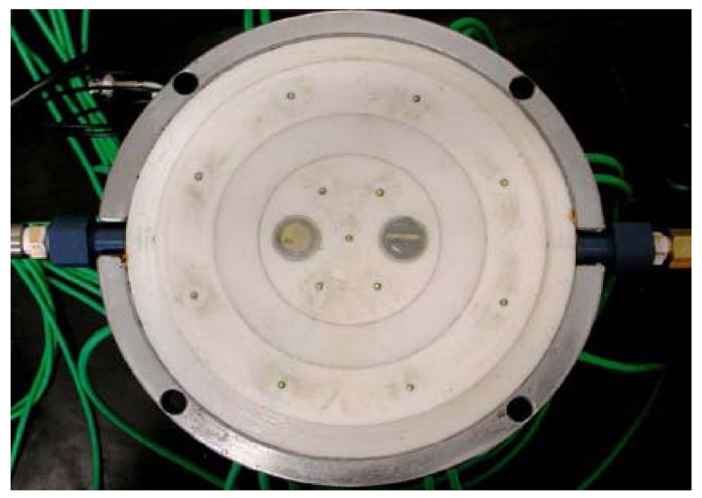
Cell characteristics			
	Sidewall	Top cap	Bottom cap
Electrodes	16	13	13



Electrode connection: (c) Overall view of the circumferential ring and (d) detail of a single electrode

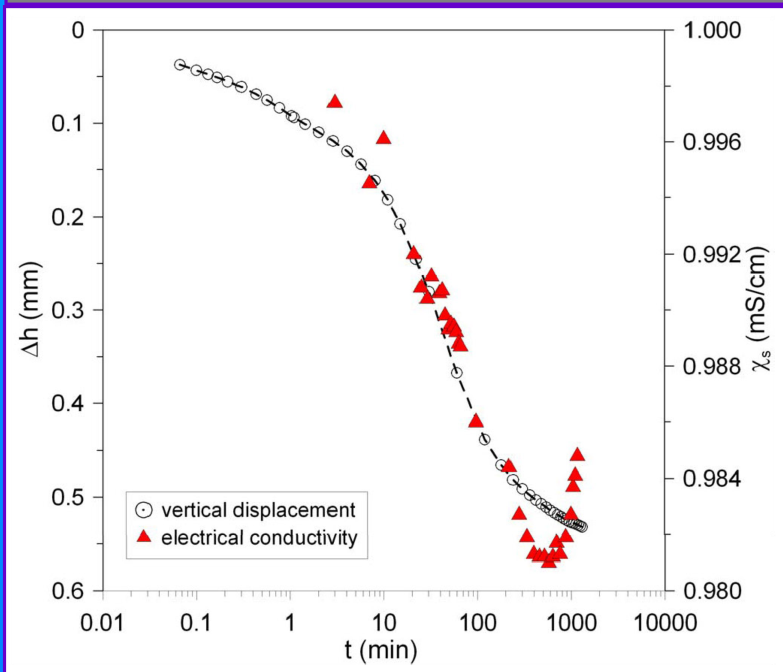


Cell dimensions		Sample dimensions	
D [cm]	H [cm]	D [cm]	H [cm]
13	6	13	4



Drainage of both caps. Equivalent hydraulic conductivity is about $6x10^{-6}$ m/s.

Experimental results



Consolidation test

Oedometer test run on a preconsolidated (100 kPa) kaolin sample.

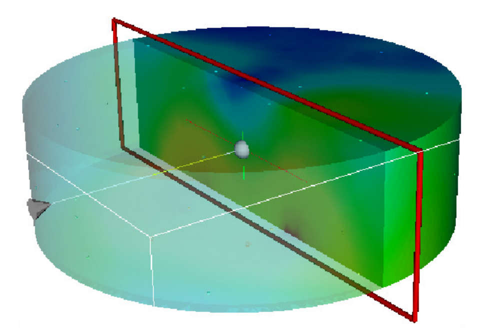
Time evolution of the vertical settlement and of the average electrical conductivity after application of load increment of 25 kPa

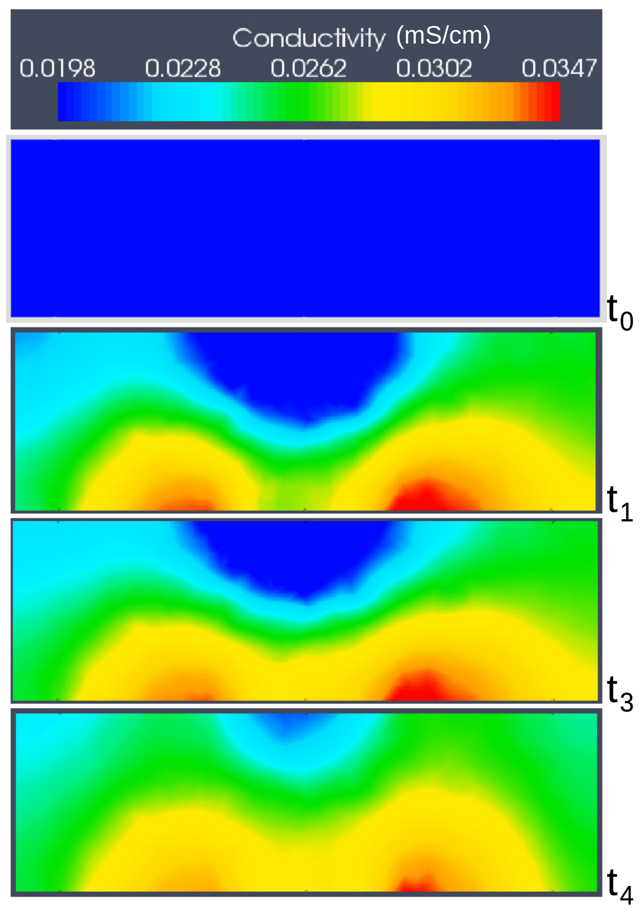
Imbibition test

Experiment performed on a silty sand.

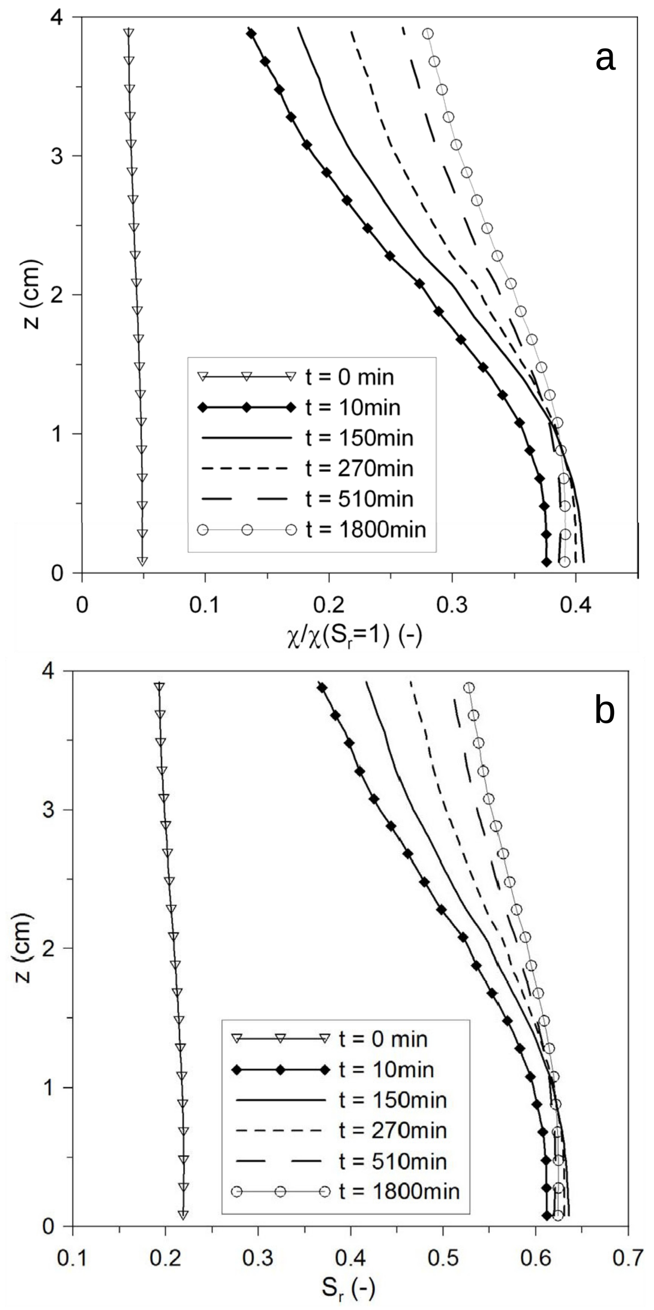
Initial condition of sample	
Technique	moist-tamping
ρ_d (g/cm^3)	1.49
Porosity	0.45
S_r	0.20

Test phases	
Homogenization	12^h
Imbibition	V = 90 cm^3 in 40''
Monitoring	ERT technique





Tomographic reconstructions of a radial section of the sample for:
t_0= 0'' (before drainage opening)
t_1 = 600''
t_2 = 6600''
t_3 = 180000''



Normalized conductivity (a) and distribution of local water saturation (b) along the vertical axis of symmetry

Governing equations

Coupled system of equations describing the hydro-mechanical response

- *Saturated porous medium*

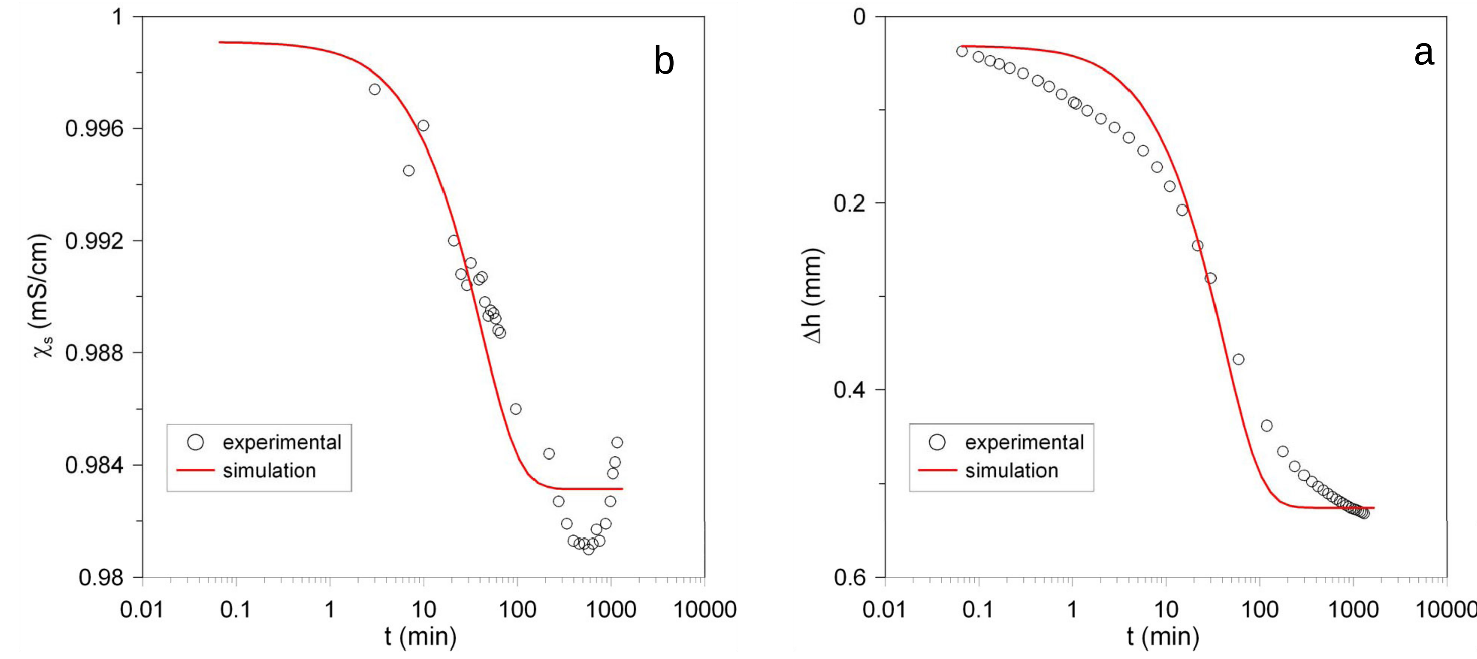
Mass balance equation	Equilibrium equation	effective stress	Darcy's law	Constitutive equation
$\frac{\partial(n\rho_w)}{\partial t}+\nabla\cdot(\rho_w\mathbf{q}_w)=0$	$\nabla\cdot(\boldsymbol{\sigma})+\mathbf{b}=0$	$\boldsymbol{\sigma}'=\boldsymbol{\sigma}-u_w\mathbf{I}$	$\mathbf{q}_w=-\mathbf{k}_w\nabla h=-\mathbf{k}_w\nabla\left(z+\frac{u_w}{\rho_w g}\right)$	$\rho_w=f(u_w)$

- *Unsaturated porous medium*

Mass balance equation	Equilibrium equation	effective stress	Darcy's law	Constitutive equation
$\frac{\partial(nS_r\rho_w)}{\partial t}+\nabla\cdot(\rho_w\mathbf{q}_w)=0$ $\frac{\partial(n(1-S_r)\rho_a)}{\partial t}+\nabla\cdot(\rho_a\mathbf{q}_a)=0$	$\nabla\cdot(\boldsymbol{\sigma})+\mathbf{b}=0$	$\boldsymbol{\sigma}=\sigma-u_a\mathbf{I}+S_r(u_a-u_w)$	$\mathbf{q}_w=-\mathbf{k}_w(S_r)\nabla\left(z+\frac{u_w}{\rho_w g}\right)$ $\mathbf{q}_a=-\mathbf{k}_a(S_r)\nabla\left(z+\frac{u_a}{\rho_a g}\right)$	$\rho_w=f_w(u_w)$ $\rho_a=f_a(u_a)$ $S_r=g(u_a-u_w)$

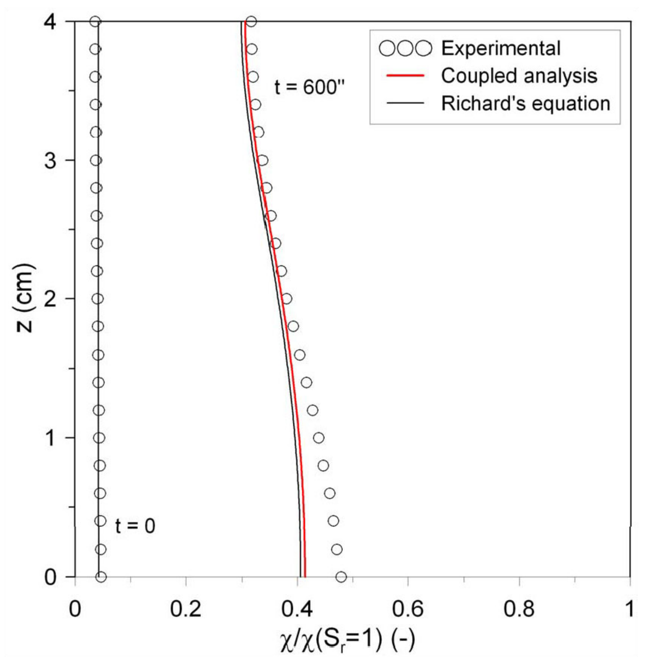
Simulation

Consolidation simulation



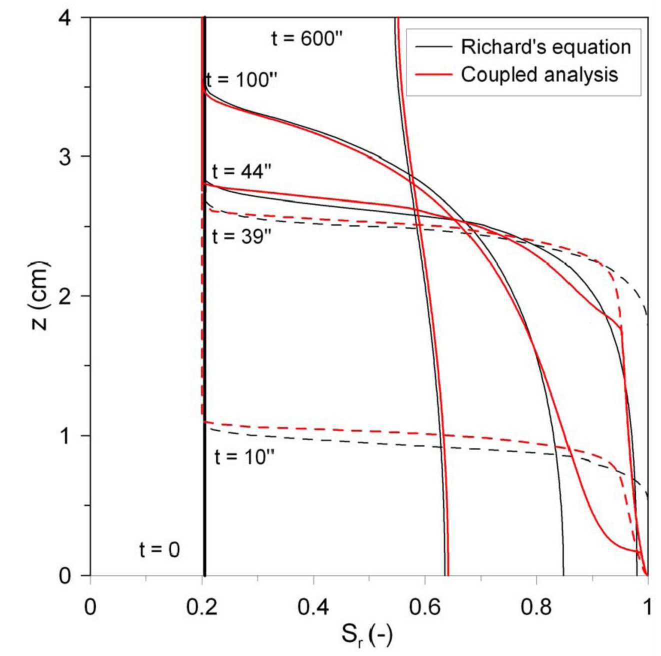
Time evolution of vertical displacement (a) and the normalized electrical conductivity (b) during consolidation stage

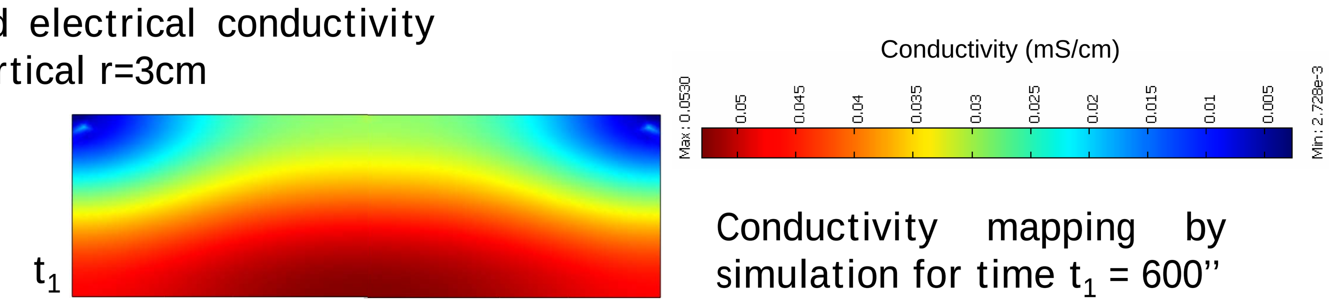
Imbibition simulation



Comparison between experimental data, single fluid simulation and coupled analysis in term of normalized electrical conductivity along a vertical r=3cm

Time evolution of the degree of saturation along the vertical corresponding to r = 3 cm





Conductivity mapping by simulation for time t_1 = 600''

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Further Information

gabriele.dellavecchia@polito.it
sebastiano.foti@polito.it
renato.cosentini@polito.it
guido.musso@polito.it

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