Material susceptibility to suffusion: from a hydro mechanical characterization to the numerical simulation

Marot D., Bendahmane F., Gelet R., Nguyen N.S., Sibille L.
Guihéneuf L., Leroy L., Fournol D.
Le V.T., Rochim A., Tran D.M., Zhang L., Zhong C.

UNIVERSITÉ DE NANTES

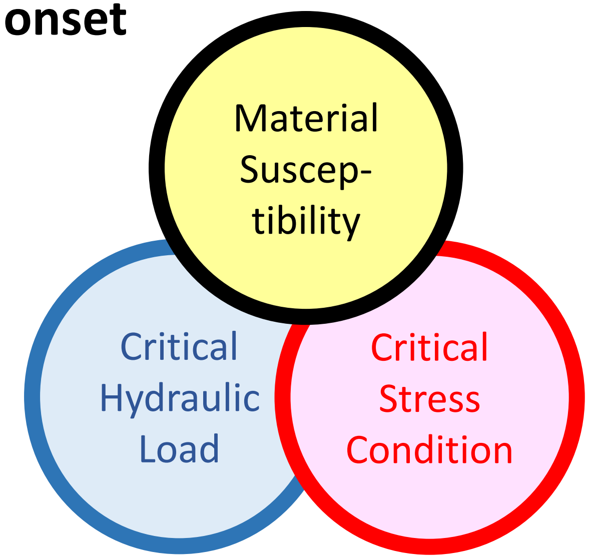
Institut de Recherche en Génie Civil et Mécanique

UMR CNRS 6183

VAL IN BTP CAPACITÉS

Main conditions for suffusion onset

Venn diagram
(Garner & Fannin, 2010)



- size of the fine particles < size of the constrictions
- volume of fine particles < volume of voids
- flow velocity must be high enough

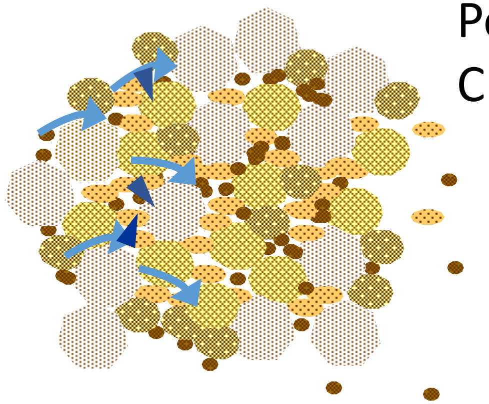
(Fell & Fry, 2013)

Whole development, complex process

Detachment

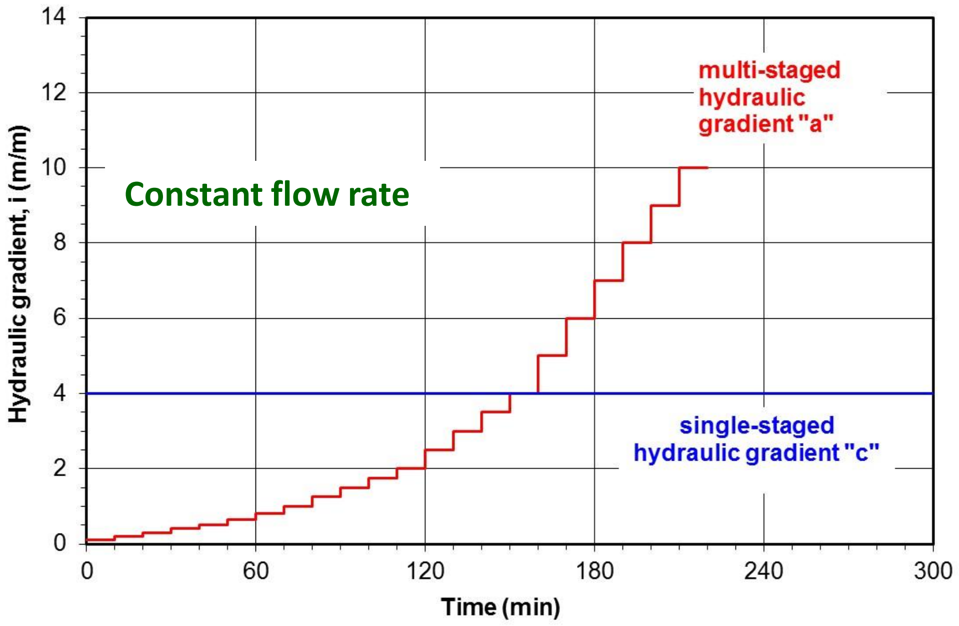
Possible filtration
Changes of porosity

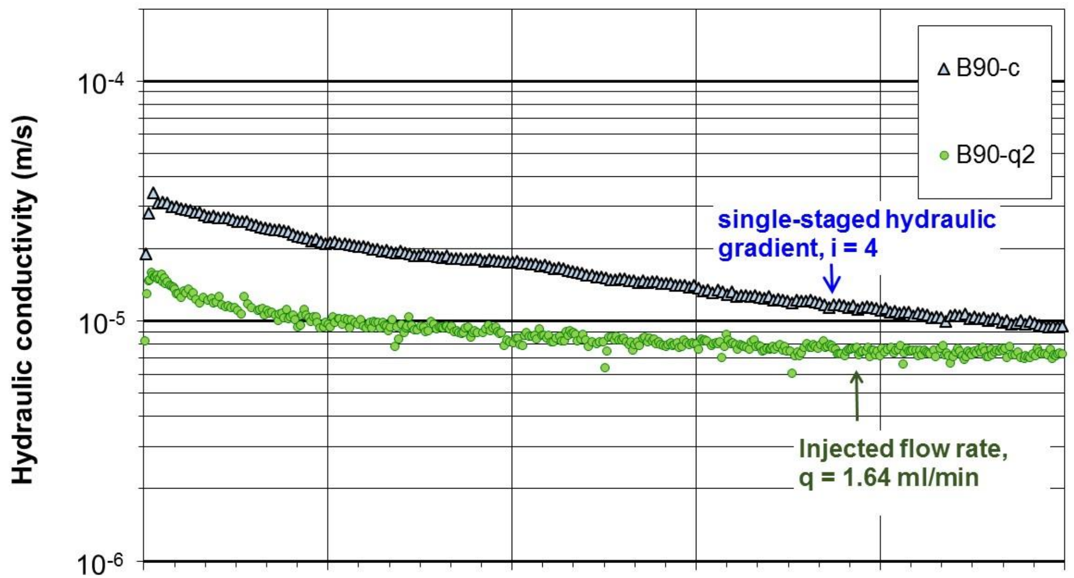
Changes of flow and interstitial pressure

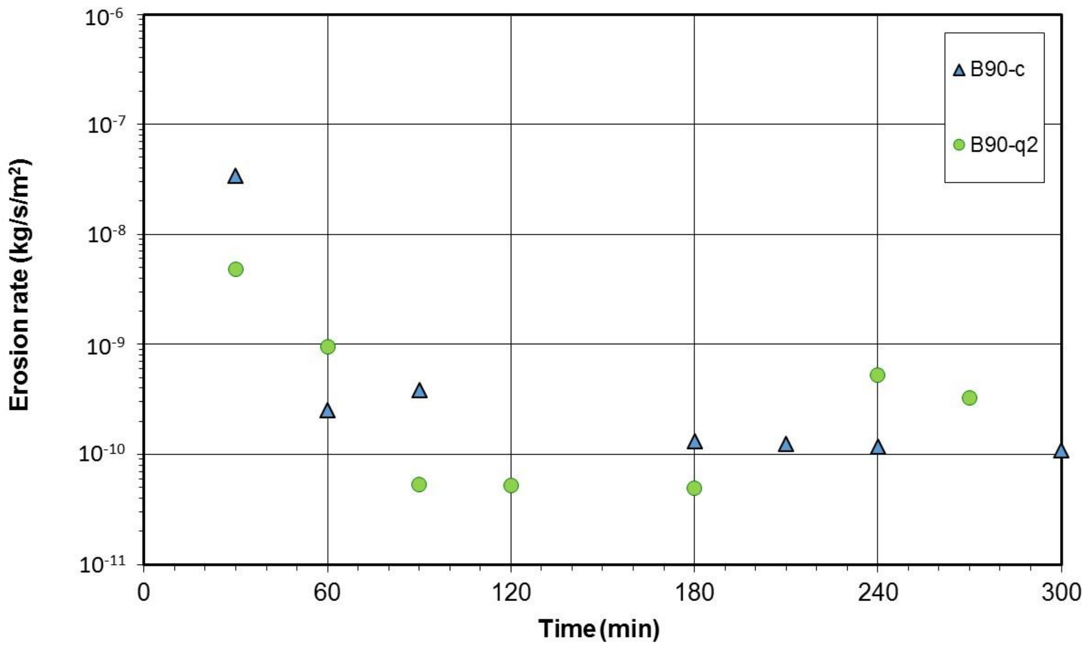


Transport

➔ Hydraulic loading & soil responses coupled

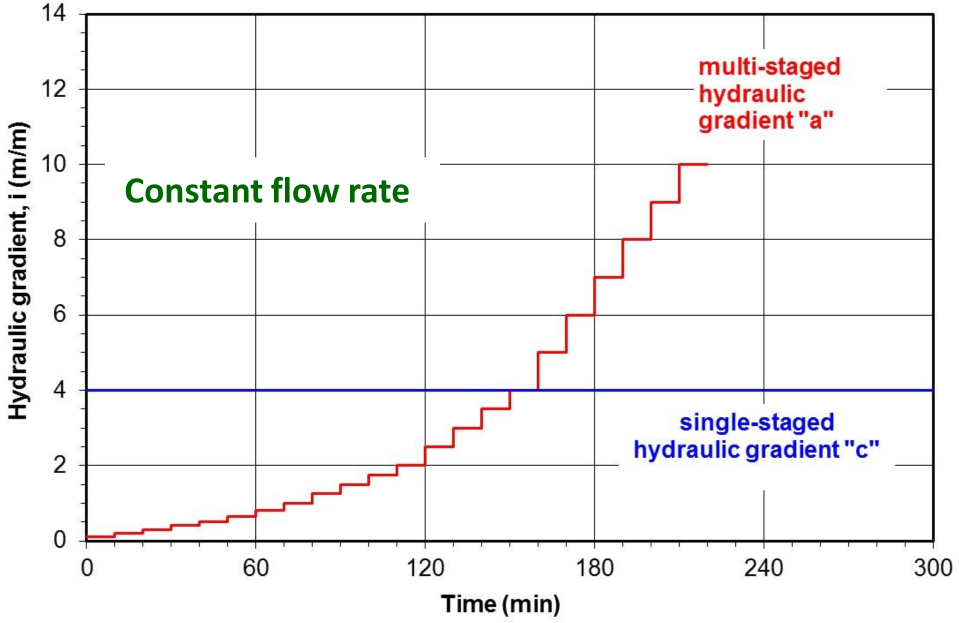


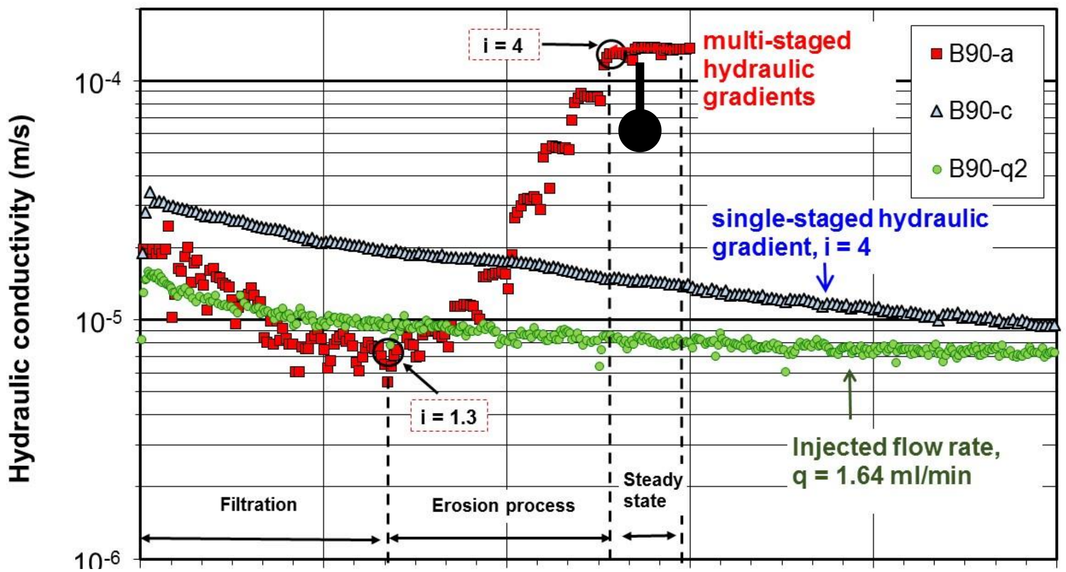




Skempton & Brogan‘s approach

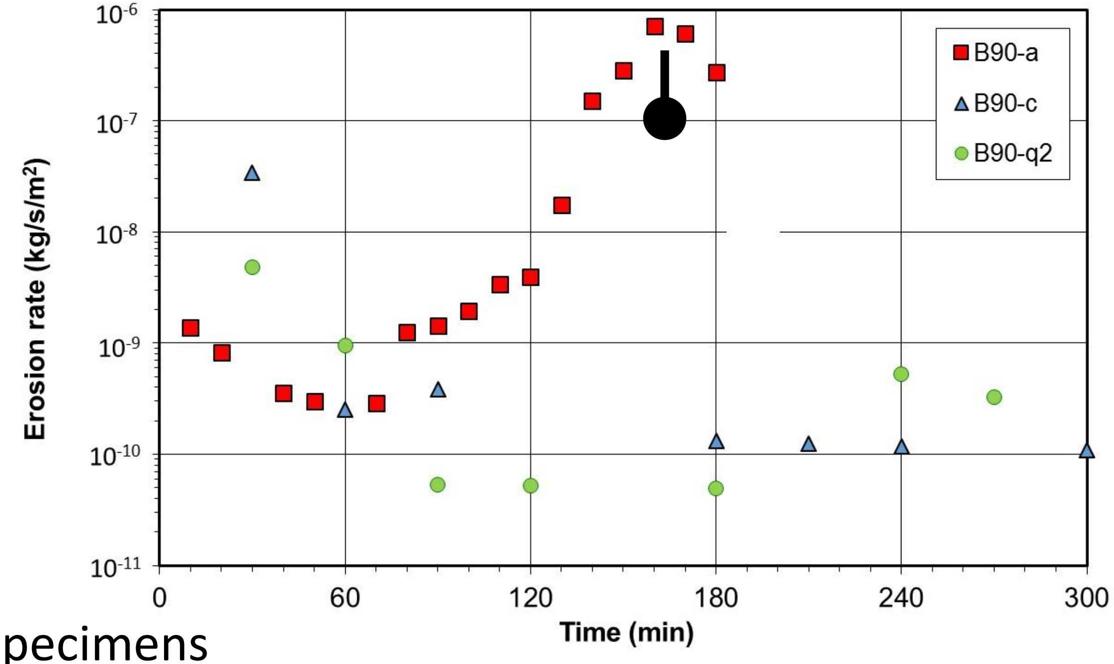
➔ No initiation of suffusion





To prevent an underestimation of the erodibility

➔ Test under **multi-staged hydraulic gradients**

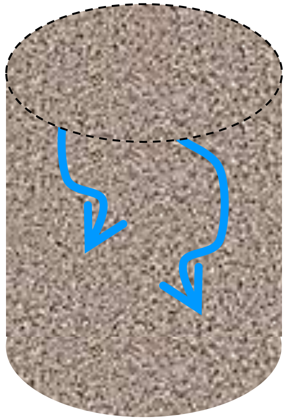


Stable state ➔ eroded state

Mechanical behavior of non eroded / eroded specimens

Different suffusion developments according to the applied hydraulic loading path

➔ how to **model** the hydraulic loading ?

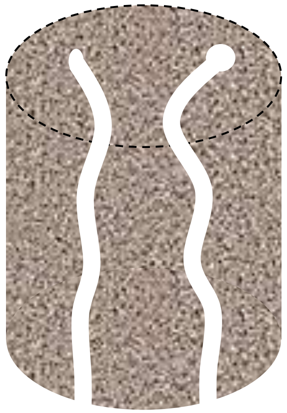


Constant hydraulic gradient i

Auto filtration

➔ low velocity and low erosion

So **velocity** could model the hydraulic load



Constant velocity v

Preferential flow paths

➔ Low i and low erosion

➔ **Same velocity but different rates of erosion**

➔ **v, i**: **both** have to be considered by the **power**

Analogy: current and electric voltage

Both are used to model the electrical bias

by the computation of the **power**

No expended **energy** ➔ no expended €

Energy based method

Power expended by interstitial seepage flow which can induce suffusion
power transferred from fluid to solid particles: negligible

Sibille et al., (2015). Internal erosion in granular media: direct numerical simulations and energy interpretation. Hydrological Processes, Vol. 29, Issue 9, 2149-2163)

$$\boxed{P_{flow} = (\gamma_w \Delta z + \Delta P)\ Q} = \gamma_w \Delta h\ Q$$

Hydraulic loading path

Expended energy

$$\boxed{E_{flow} = \sum P(t)\ \Delta t}$$

At the stable state

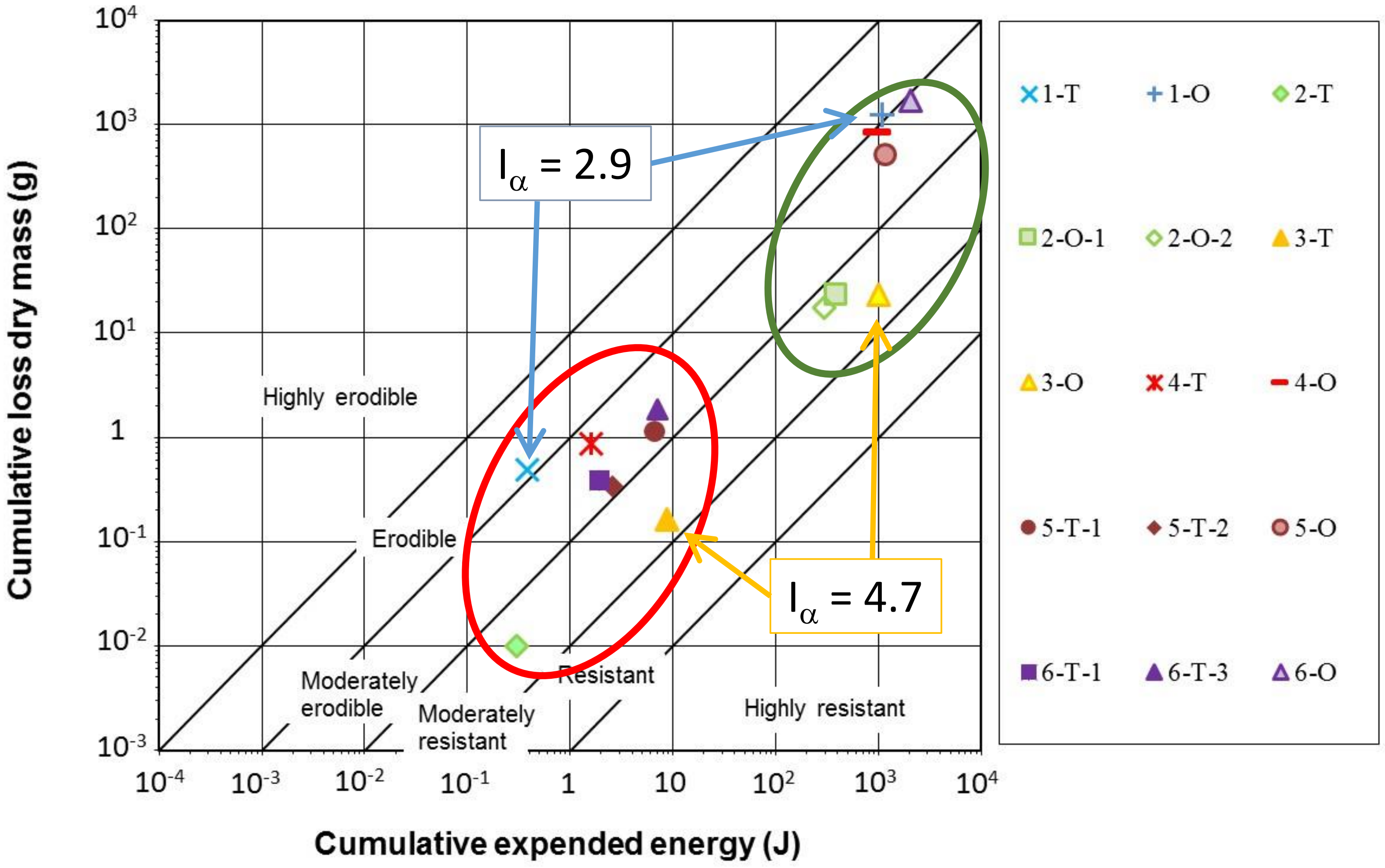
Erosion resistance index

$$\boxed{I_\alpha = -\log_{10}\left(\frac{\text{Eroded dry mass}}{E_{flow}}\right)} \Rightarrow \text{Soil's property}$$

Marot D., Rochim A., Nguyen H.H., Bendahmane F., Sibille L. (2016). Assessing the susceptibility of gap graded soils to internal erosion: proposition of a new experimental methodology. Nat. Hazards, 83(1): 365-388. DOI 10.1007/s11069-016-2319-8.

Triaxial erodimeter: specimen length 50-100mm

Oedopermeameter: specimen length 250-450mm



Zhong C. et al. (2018). Comparison of erodimeters and interpretative methods for suffusion susceptibility characterization. Journal of Geotechnical and Geoenvironmental Engineering (ASCE), 144(9): 04018067.

➔ I_α appears **intrinsic**, at the time and spatial scales tested in laboratory

9 physical parameters easy to measure ➔ estimation of I_α

➔ optimization of soil characterization

Le V.T. et al. (2018).
Suffusion susceptibility investigation by energy based method and statistical analysis
Canadian Geotechnical Journal. 55(1), pp 57-68

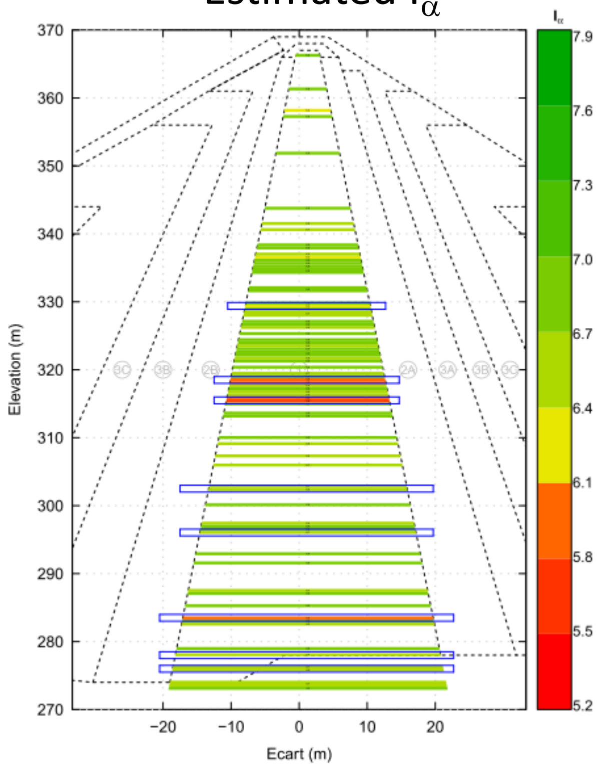
Localization of « weaker » zones in relative

8 zones have a larger suffusion potential in relative to the rest of the structure

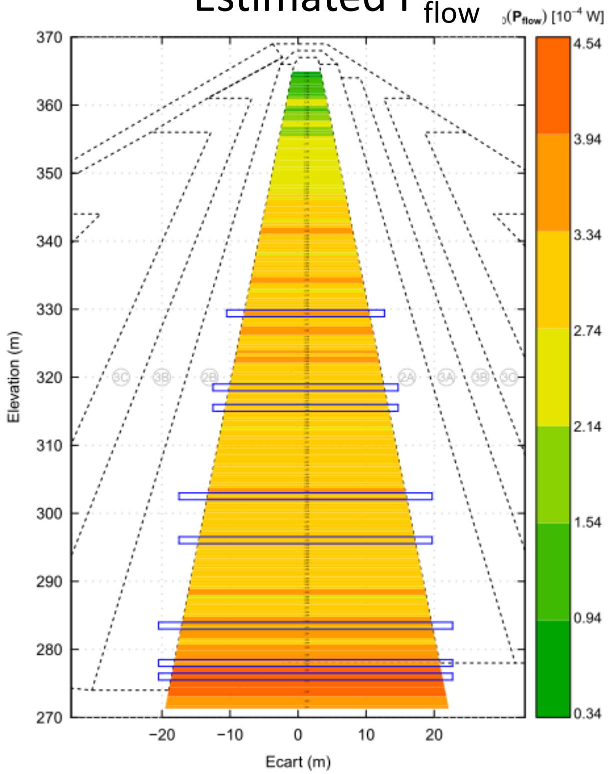
$$I_\alpha < 6{,}95 \text{ and } P_{flow} > 1.4\ 10^{-3}\ \text{W}$$

Zhang et al. (2018). A method to assess the suffusion susceptibility of core soils in zoned dams based on construction data. European Journal of Environmental and Civil Engineering, 23(5), pp 626-644

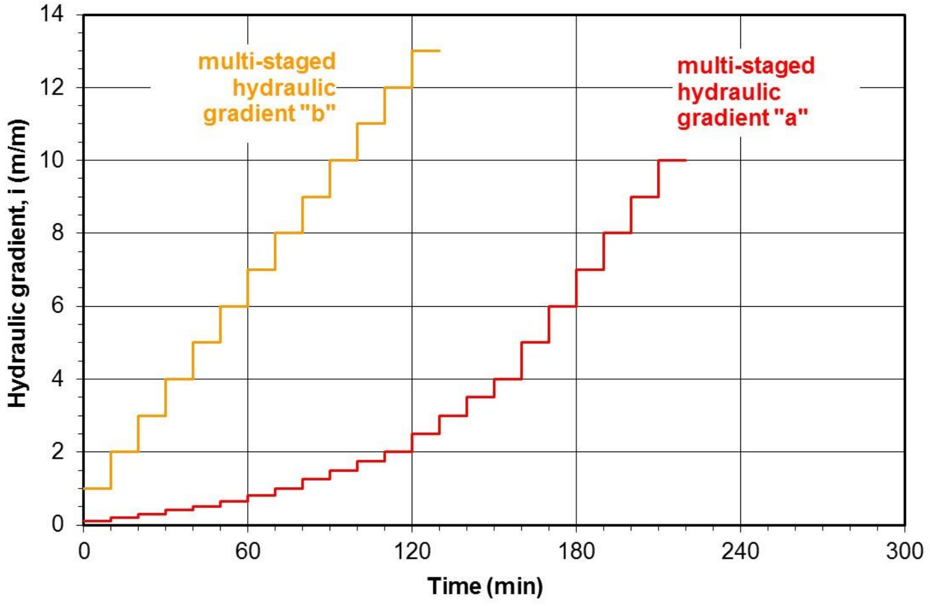
Estimated I_α

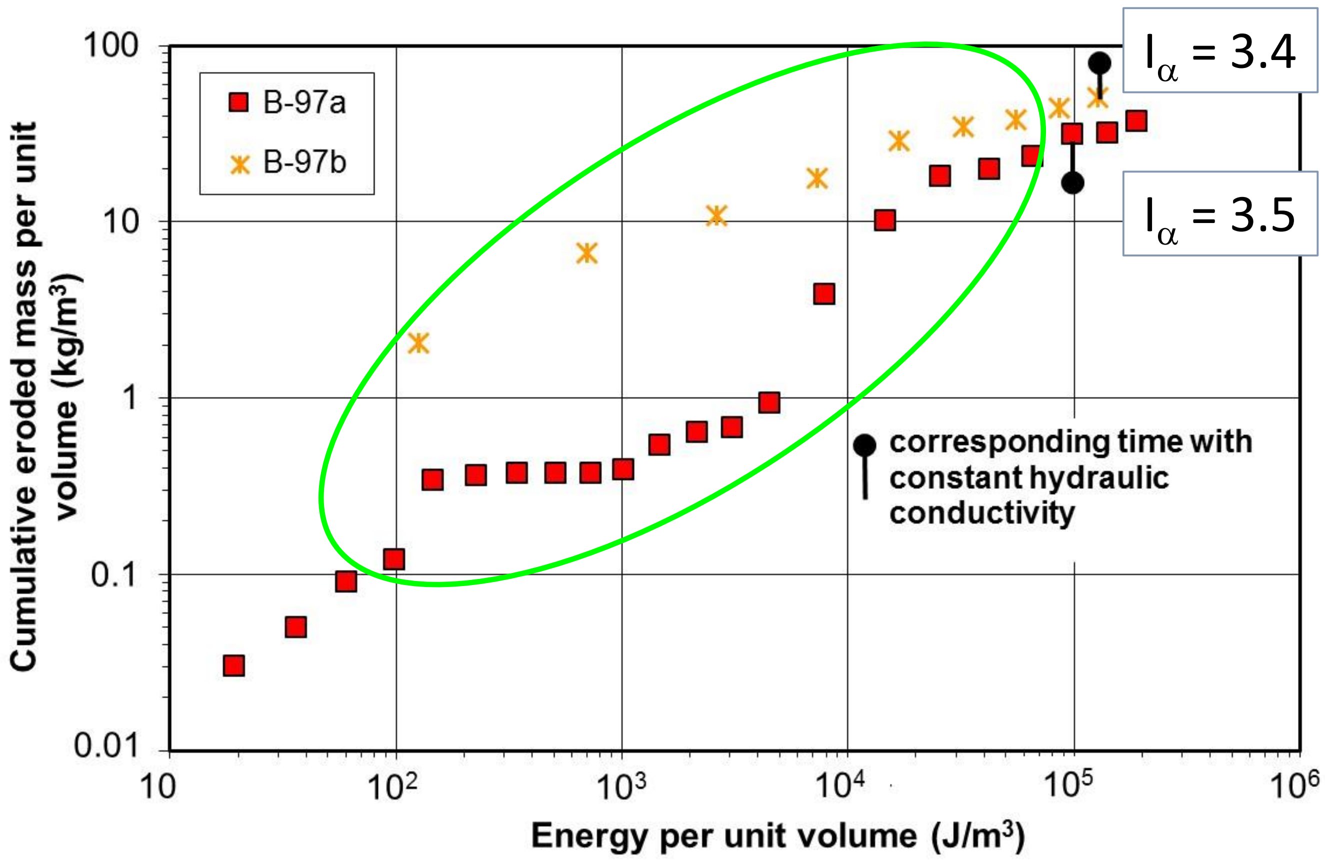


Estimated P_{flow}



At a given time,
no information about the kinetics





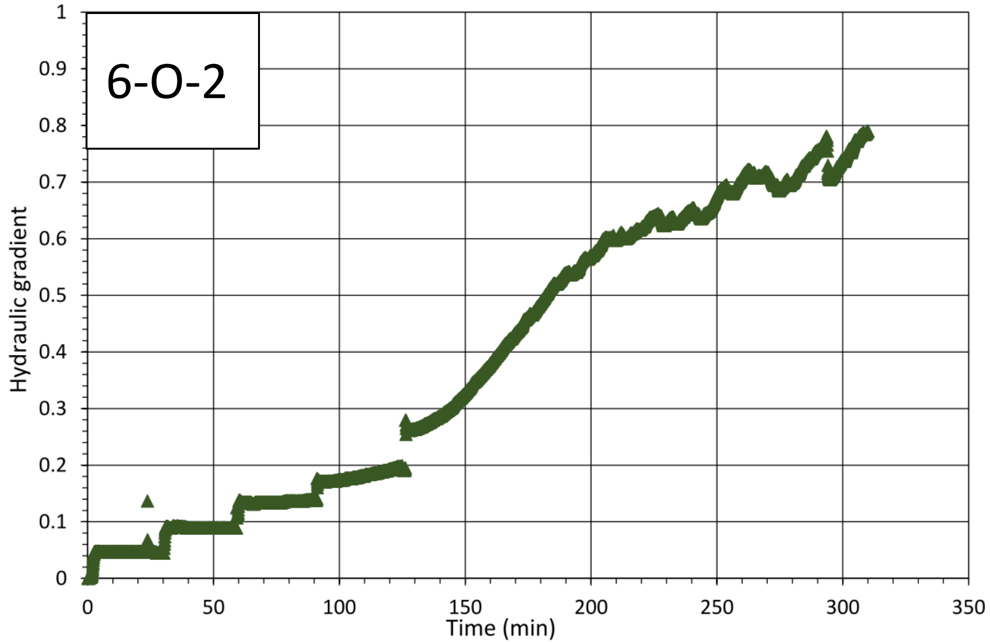
For the kinetics: erosion law

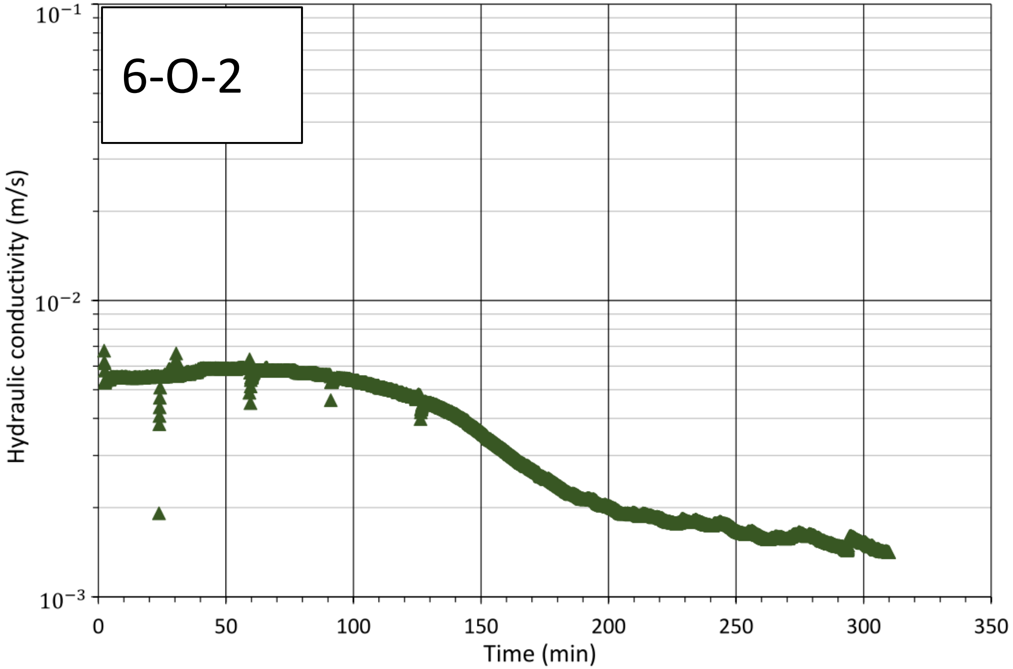
$$\frac{\bar{m}_{cum}(t) - \bar{m}_{sat}}{\bar{m}_{max} - \bar{m}_{sat}} = \left(\frac{\bar{E}_{cum}(t)}{\bar{E}_{max}}\right)^{b(t)}$$

- $\bar{m}_{max}$ and $\bar{E}_{max}$ are constants
- $\bar{m}_{sat}$ is an initial value
- $b(t)$ is a parameter that describes the kinetics
- $b(t) < 1$: rapid suffusion
- $b(t) > 1$: slow suffusion

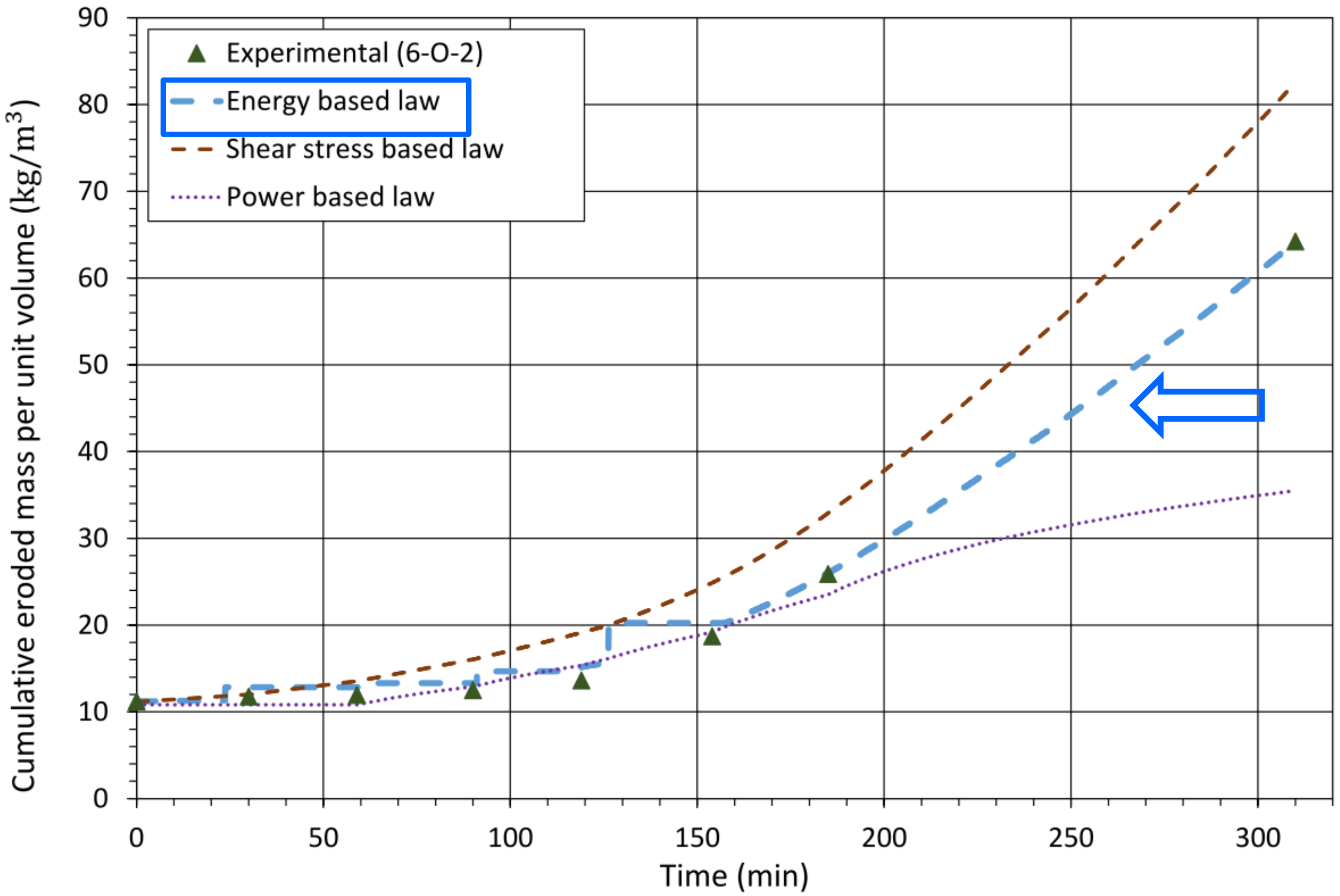
$$\bar{m}_{max} = 10^{-I_\alpha}\,\bar{E}_{max}$$

$$b(t, t_{smoothed}) = \frac{\bar{P}_{smoothed}(t, t_{smoothed})}{\bar{P}_{flow}(t)}$$



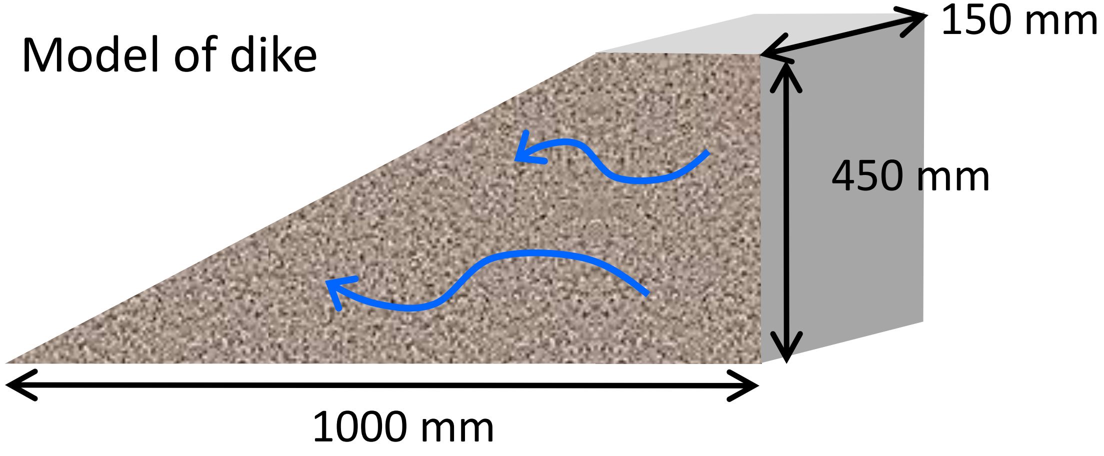


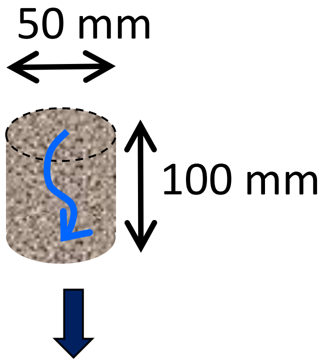
Time evolution of eroded mass



Kodieh et al. (2020). A study of suffusion kinetics inspired from experimental data: comparison of three different approaches. Acta Geotechnica. DOI: 10.1007/s11440-020-01016-5

Model of dike

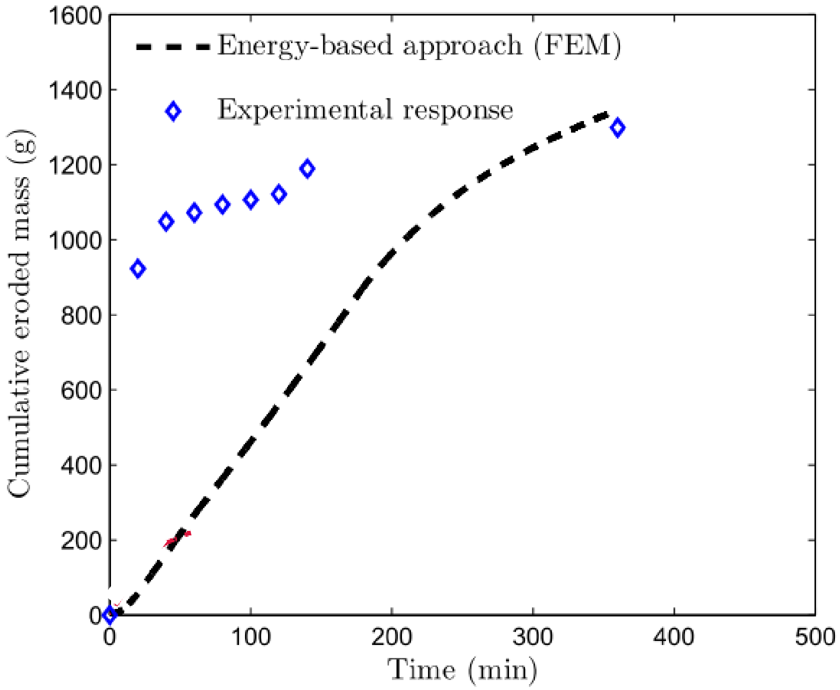




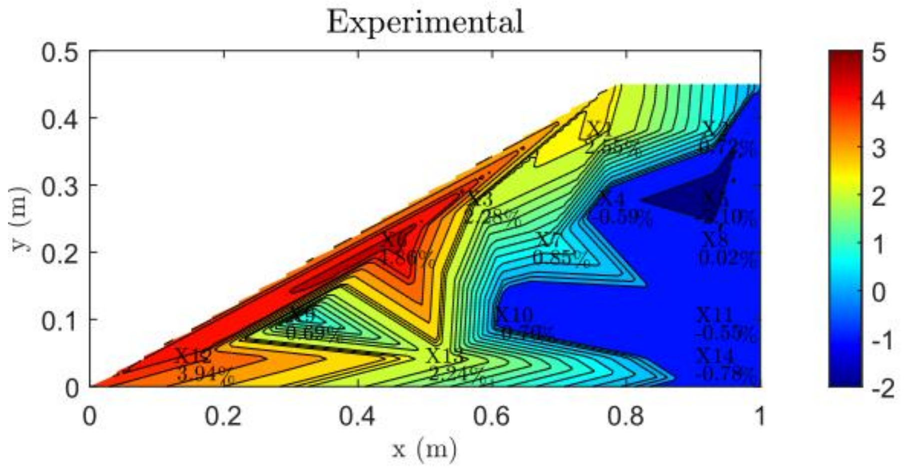
Soil's properties

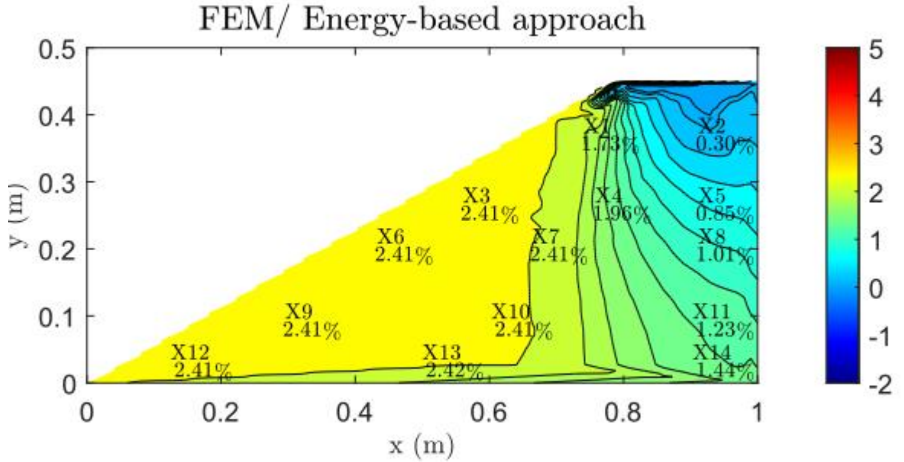
FEM

Time evolution of cumulative eroded mass



Spatial distribution of the variation of the percentage of fines after suffusion



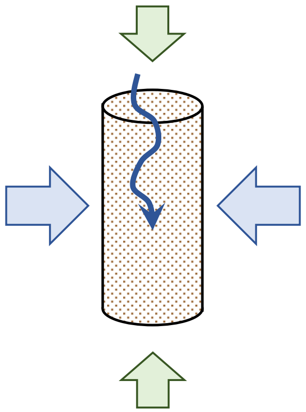


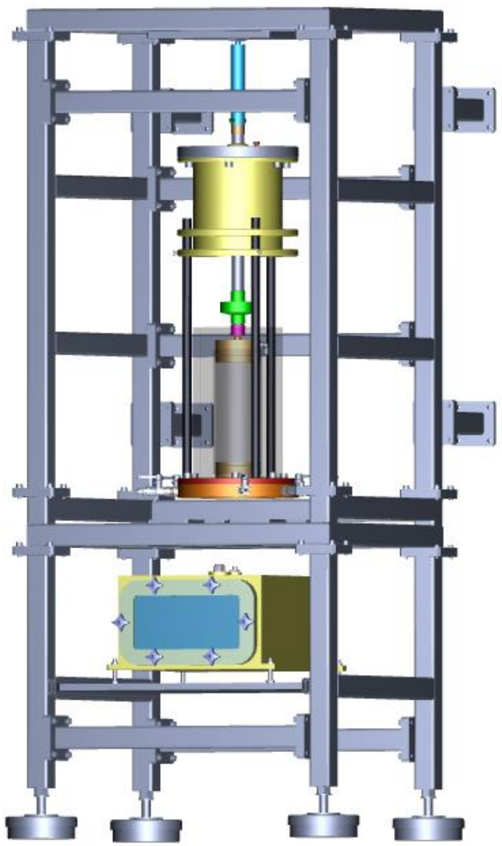
Gelet et al. (submitted). Analysis of suffusion in cohesionless soils: model, experiments and simulations in partnership with

J.R. Courivaud F. Landstorfer

Influence of hydraulic loadings

which reflect better on-site hydraulic loadings





Influence of mechanical states

Soil's mechanical behavior

Numerical part: presentation of Q. Rousseau

Experimental benchmark

in partnership with J. Fannin

Acknowledgments

Thank you for your attention

Acknowledgments for providing financial support for our research

EDF CIH | Verbund | IMS Risques Naturels | Région Pays de la Loire | European Commission

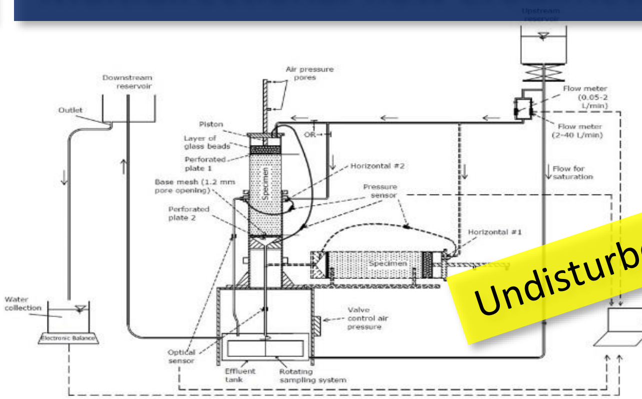
Bach Khoa Da Nang | Université Libanaise | Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation

Contact: didier.marot@univ-nantes.fr

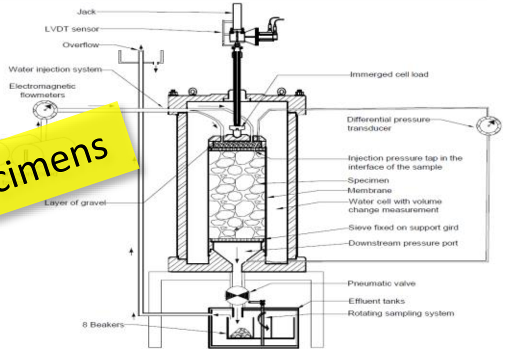
Triaxial erodimeter

Oedopermeameter

Multidirectional flow erodimeter



Large triaxial erodimeter



Undisturbed specimens

Jet Erosion Test