INTERNAL EROSION PHENOMENA IN EMBANKMENT DAMS

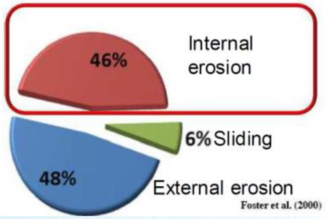
Basis for facilitating numerical modelling

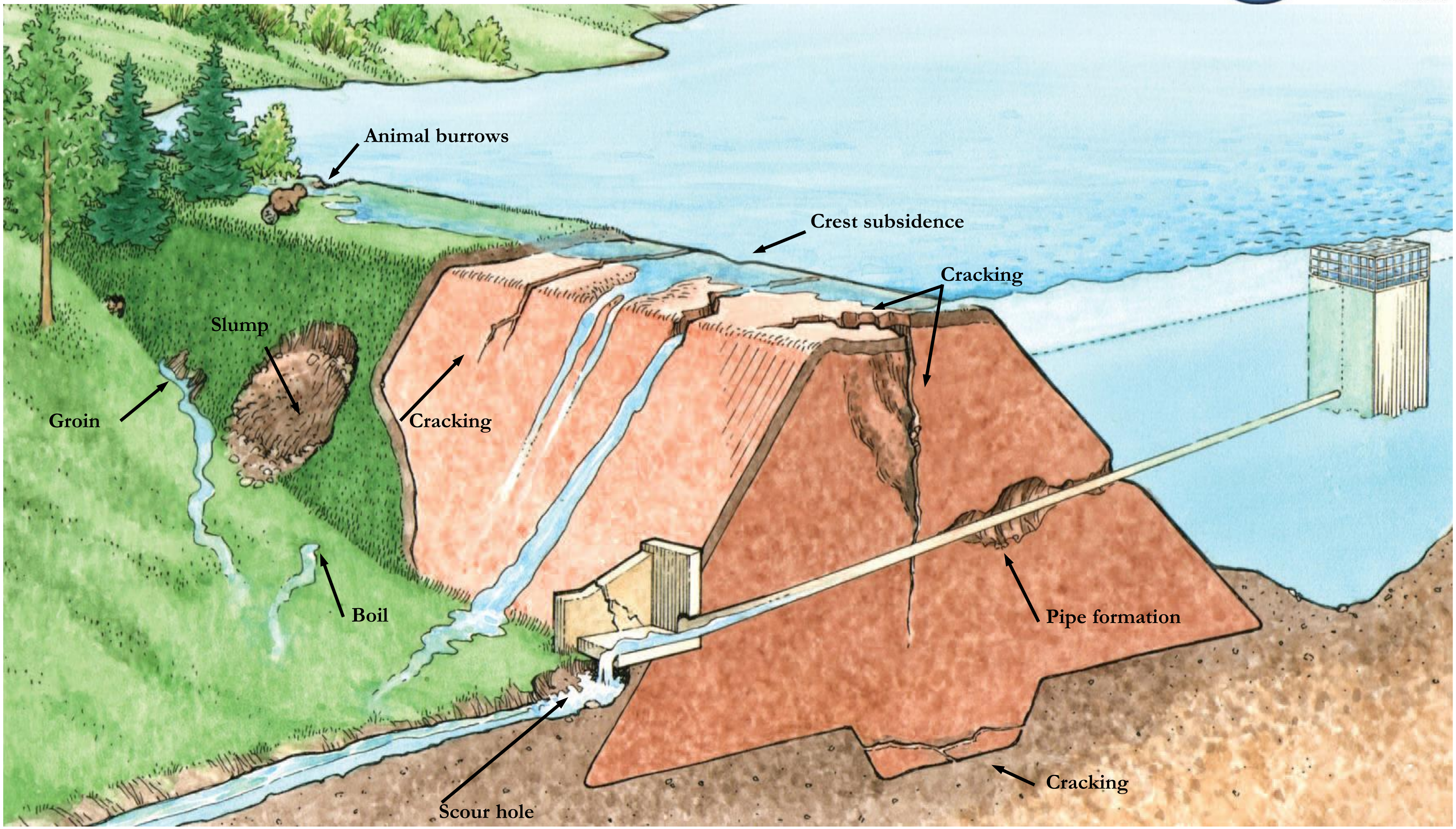
Swedcold Temadag
25 of October 2016

FARZAD FERDOS

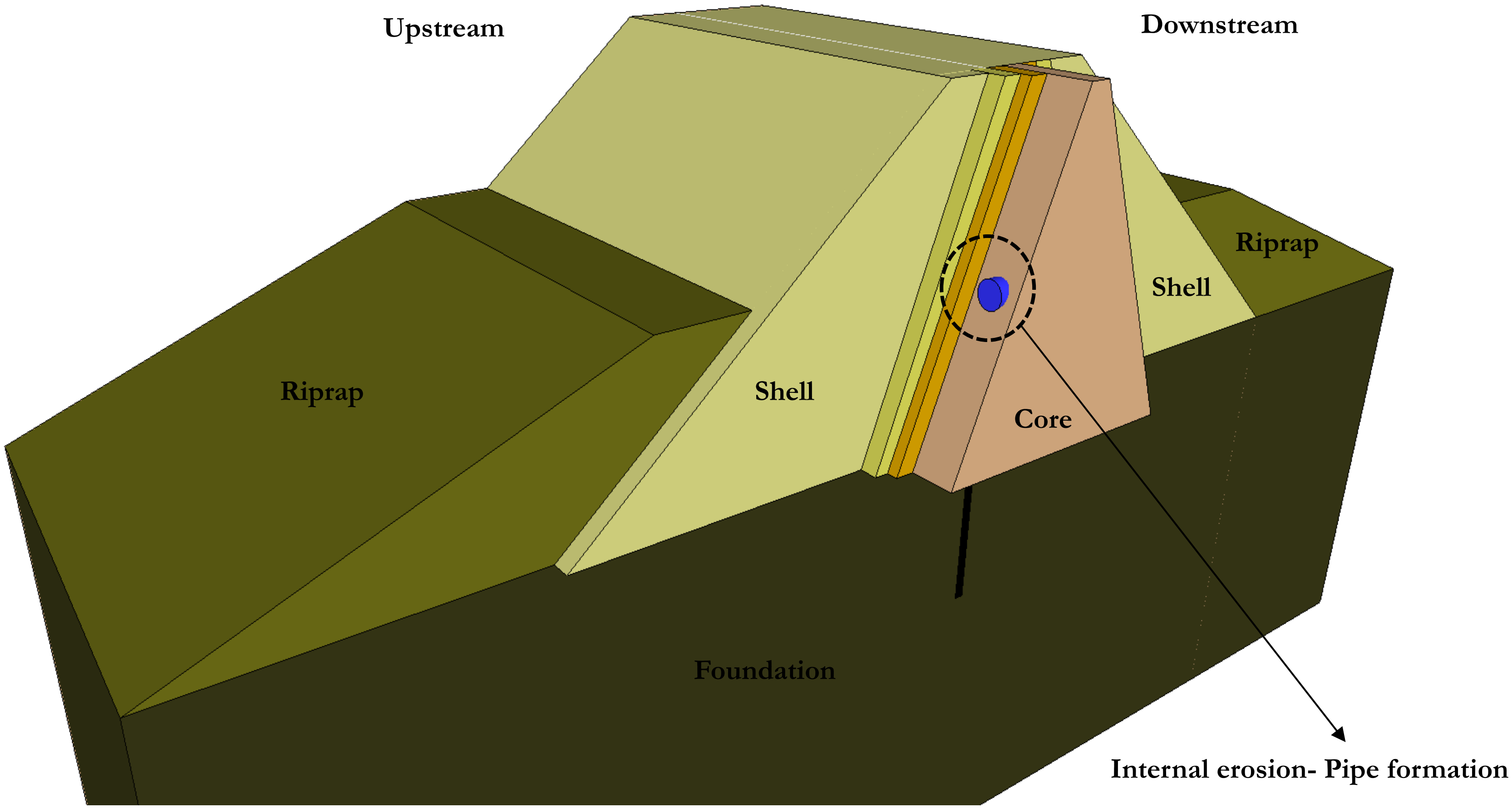
Failure of Teton Dam on June 5, 1976

Erosion is the main cause of failure of earth structures such as embankment dams, dykes and levees.

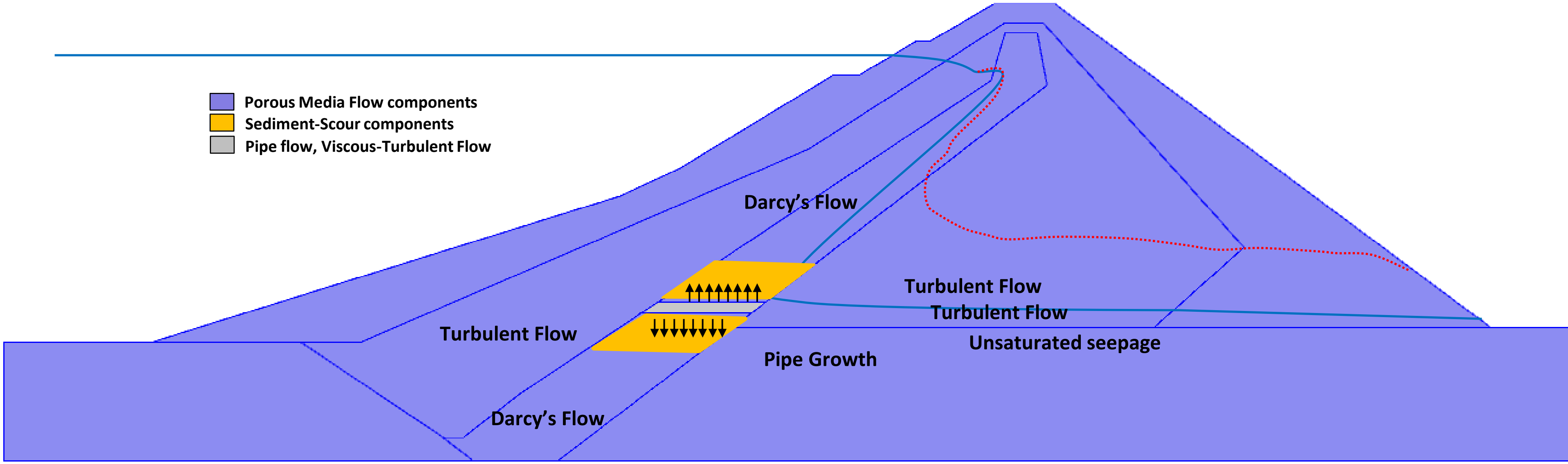


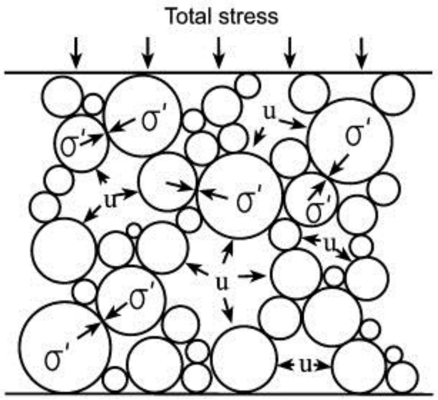


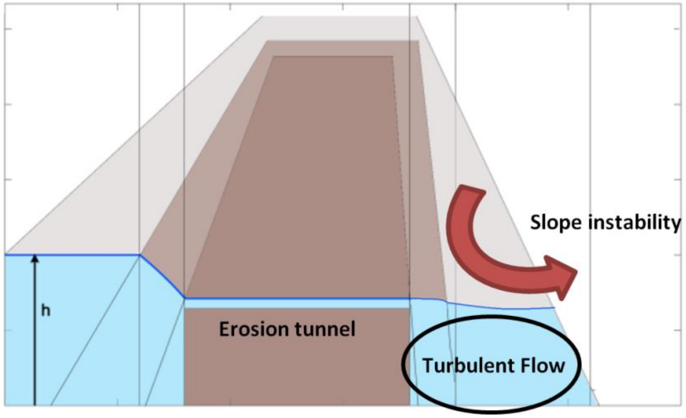
Large zoned embankment dam breach due to internal erosion



Numerical modelling of a zoned embankment dam undergoing internal erosion.





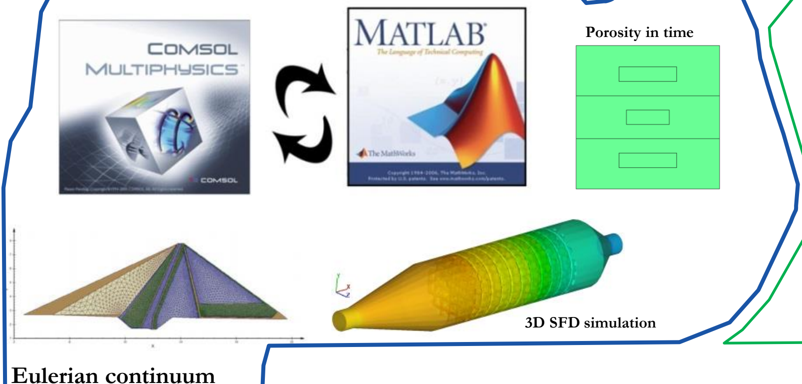


PhD project in Hydraulic Structures

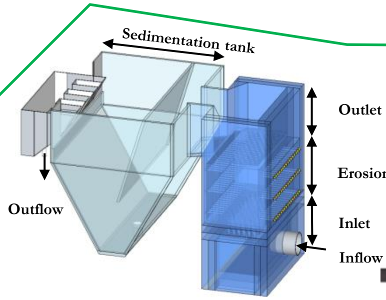
Phase I A thorough study of the hydraulic behaviour of coarse rockfill material subjected to heavy and turbulent throughflow conditions.

Phase II Explore ways in which internal erosion processes and their development in porous material can be numerically modelled for engineering purposes.

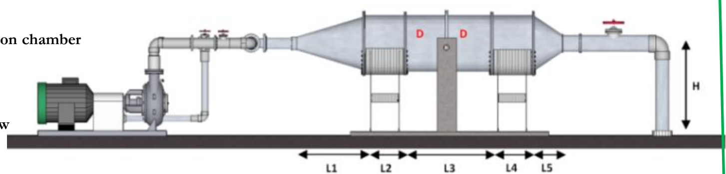
Numerical approach



Experimental approach



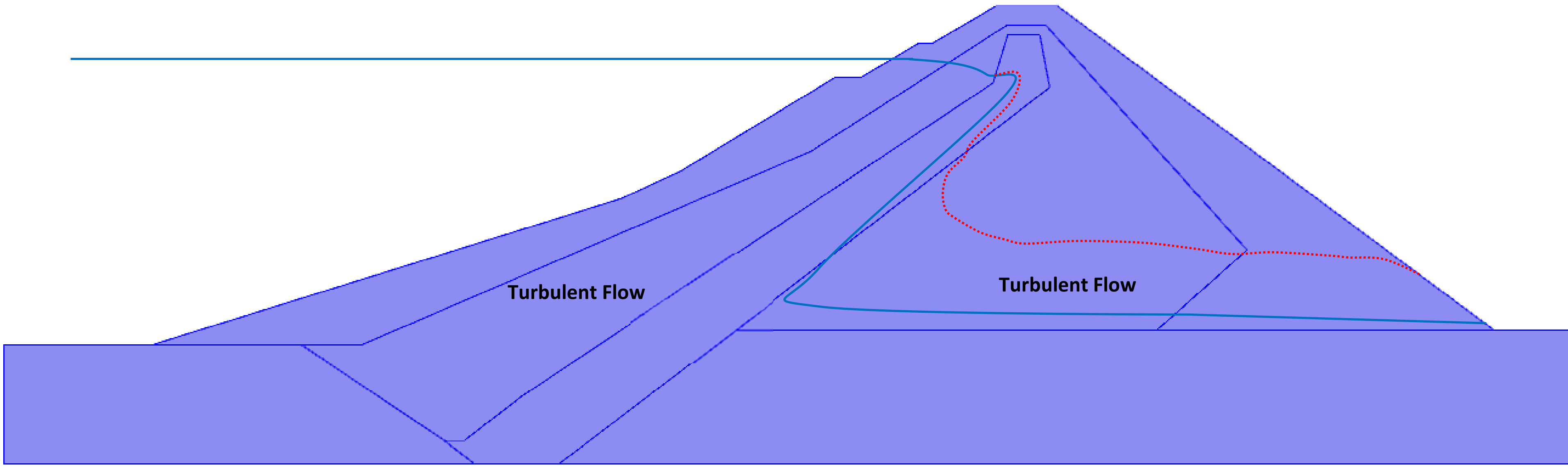
Planned for Part II



L_1 m	L_2 m	L_3 m	L_4 m	L_5 m	L_{total} m	H m	D m
1.5	0.5	2.0	0.5	0.5	5.0	1.0	1.0

Completed in Part I

Phase I Study of the hydraulic behaviour of coarse rockfill material subjected to heavy and turbulent throughflow conditions.



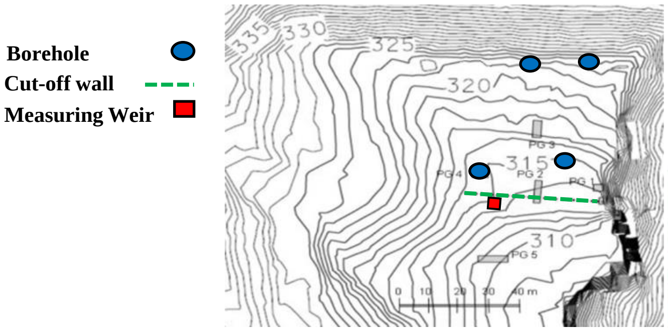
A systematic and confident understanding of the throughflow is crucial for the design, safety assessment and erosion protection of the dams and to decrease their risk of failure.

Numerical modelling → Flow behaviour needs to be understood

Material properties and governing equations for turbulent throughflow (Constitutive law)

Throughflow properties of coarse rockfill material were studied by means of :

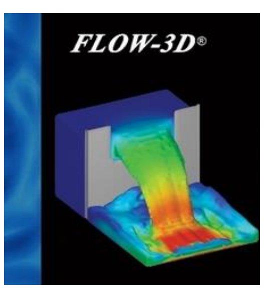
1. Analysing field pumping test data from Trängslet rockfill dam.

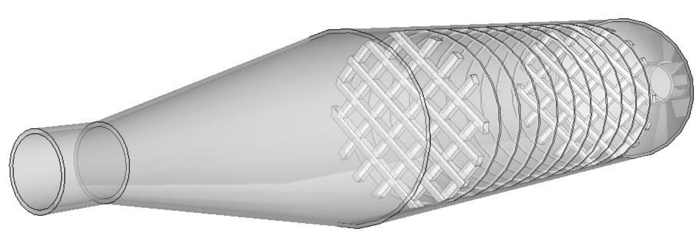


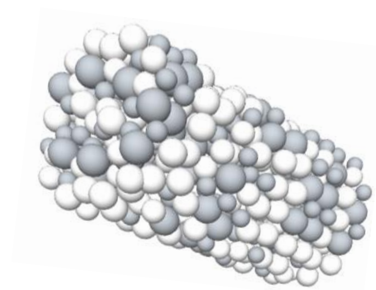
2 field tests (2008 and 2010) done by SWECO

2. Constructing a large-scale apparatus (permeameter)and doing extensive laboratory tests.

3. Simulating 3D models for fluid flow through coarse materials, resembling the ones used in the laboratory experiments, by using the Flow-3D software.

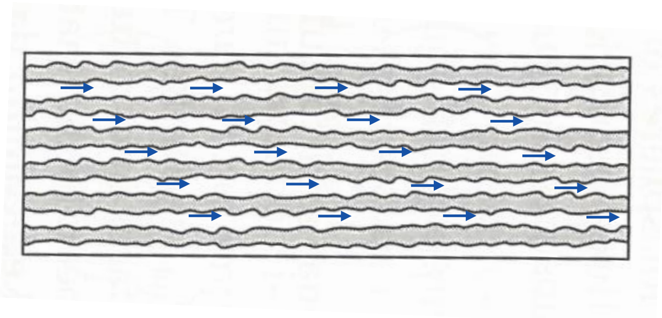




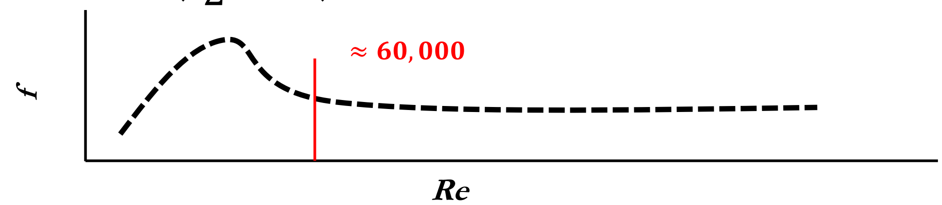


Friction Factors:

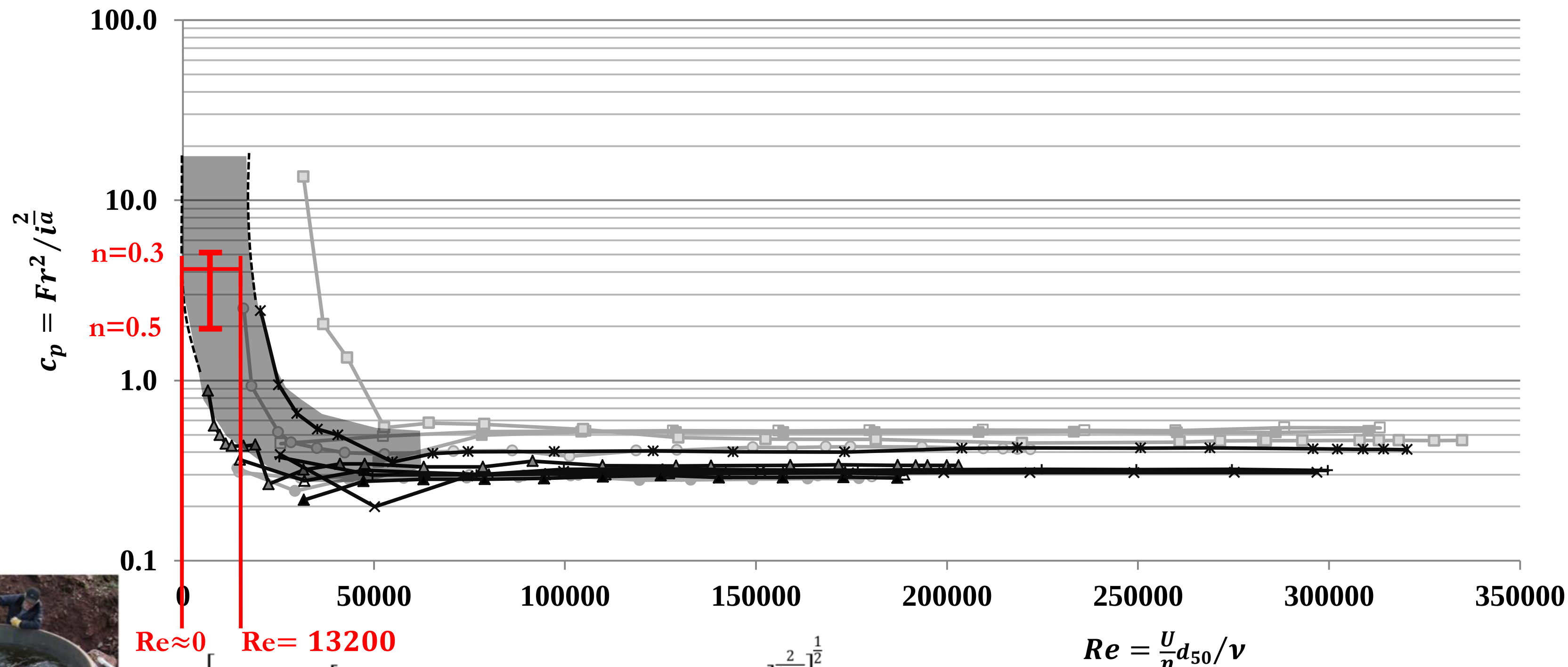
Reynolds number dependency of the friction factors was observed for high Re numbers!



$$f = \frac{1}{4}\left(\frac{D_p}{L}\right)\left(\frac{P_0 - P_L}{\frac{1}{2}\rho v_0^2}\right) \quad where \quad P_0 - P_L = \frac{1}{2}\rho\langle v^2\rangle\left(\frac{L}{R_h}\right) f_{tube}$$



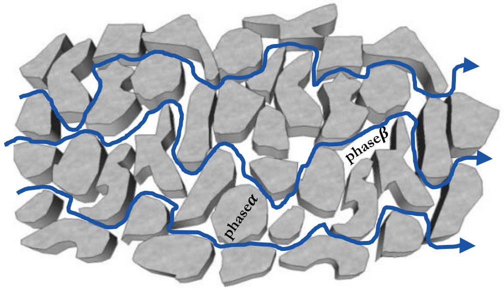
Flow Laws:



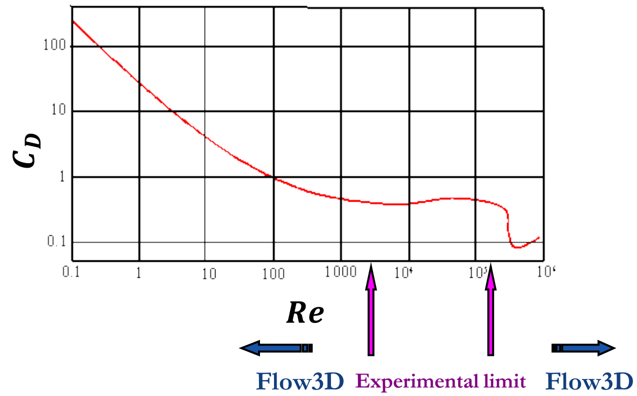
$$h_L(r) = \left[\frac{Q}{\pi k}\ln\left(\frac{r_c}{r}\right) + \left[\left[h_0^{(1+a)} + \acute{b}\left(\frac{Q}{2\pi}\right)^{a}\left(\frac{1+a}{1-a}\right)\left(\left(\frac{r_c}{r_{well}}\right)^{(1-a)} - 1\right)\right]\right]^{\frac{2}{1+a}}\right]^{\frac{1}{2}}$$

$$k = 0.1027\, m/s \quad a = 1.729 \quad \acute{b} = 5.095$$

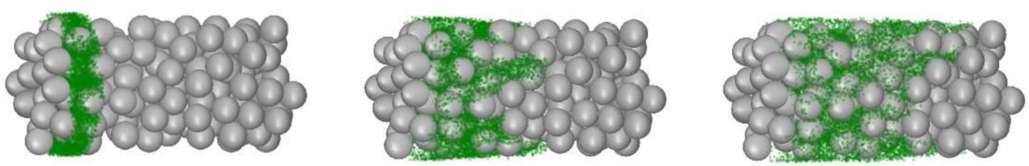
Numerical experimentation:



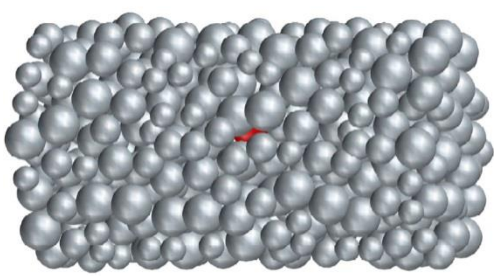
- Study beyond the experimental limits (Re number)

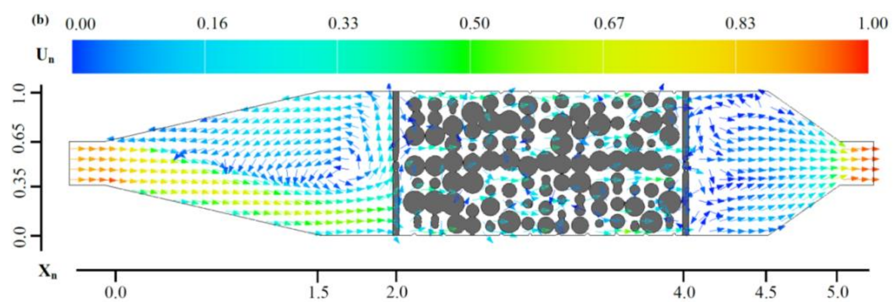


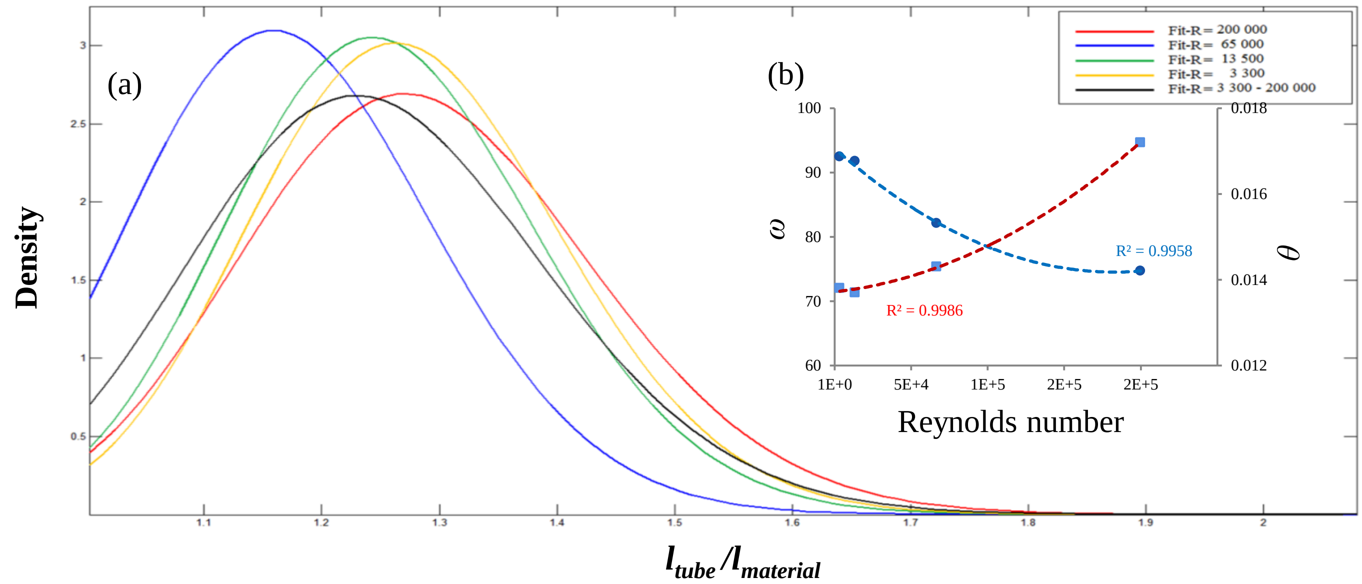
- Particle-path tracking

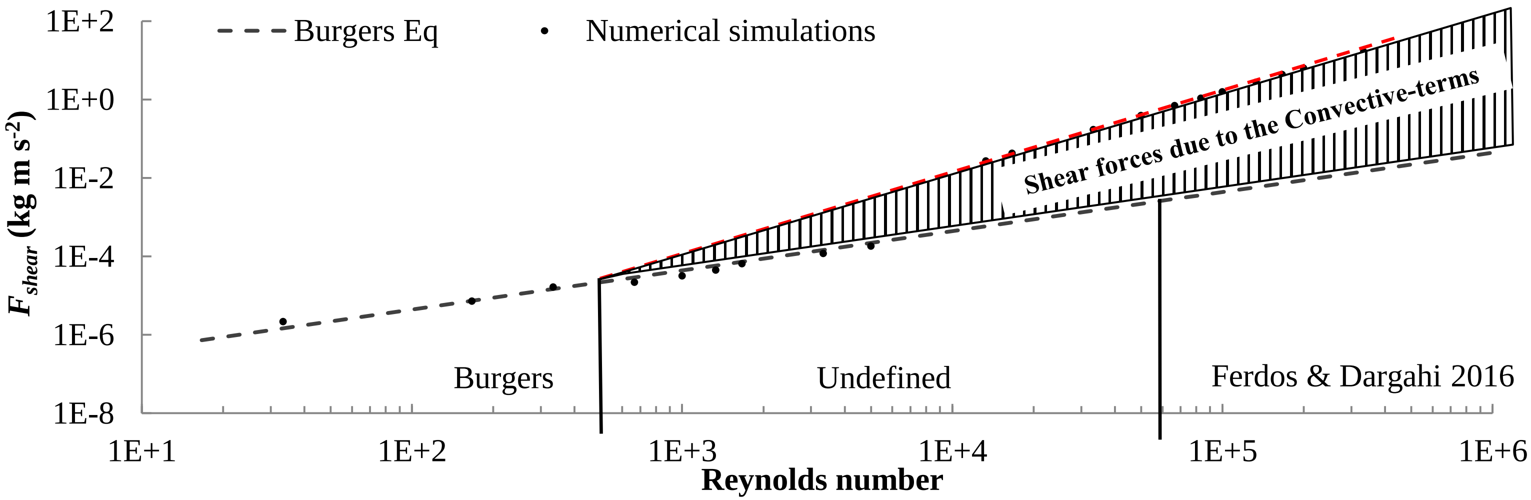


- Studying the force balance within the porous media :

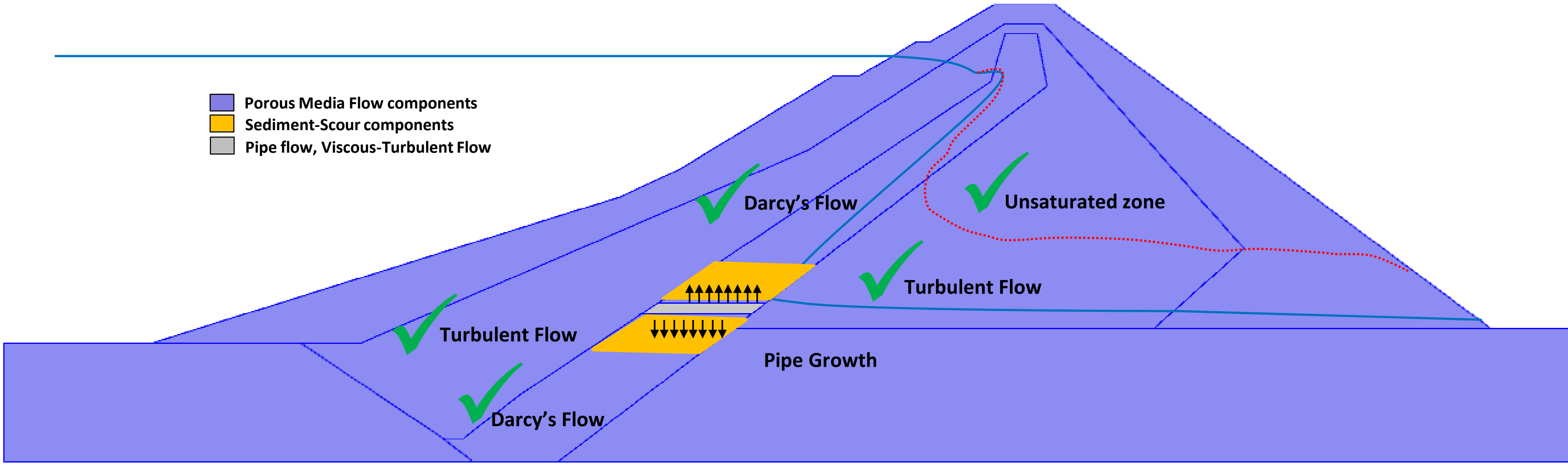




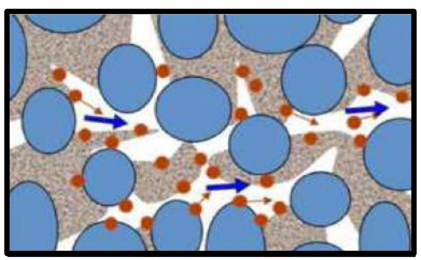




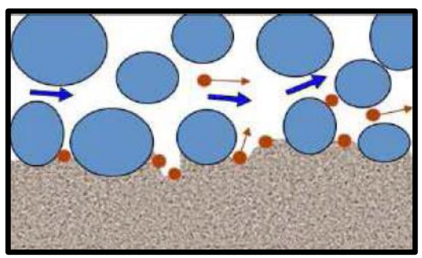
$$F = 6\pi\mu_{eff} RU\left[1+(\lambda_I+\lambda_{II})S/\forall\right] + T_D\rho U^2\left[(\lambda_I+\lambda_{II})S^{\frac{2}{3}}\right]$$



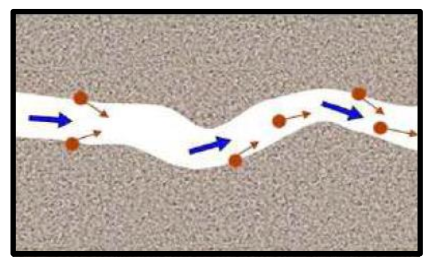
Phase II Explore ways in which internal erosion processes and their development in porous material can be numerically modelled for engineering purposes.



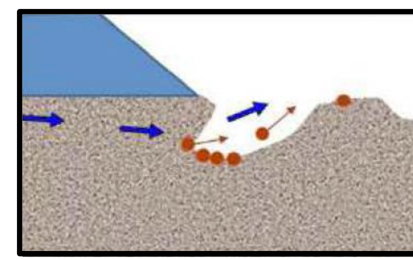
Suffusion and granulometric instability



Contact erosion between two soil layers



Concentrated leak erosion



Backward piping erosion

- ✓ Understand the mechanisms
- ✓ Facilitate numerical modelling

Suffusion and the concentrated leak erosion mechanisms were studied by means of:

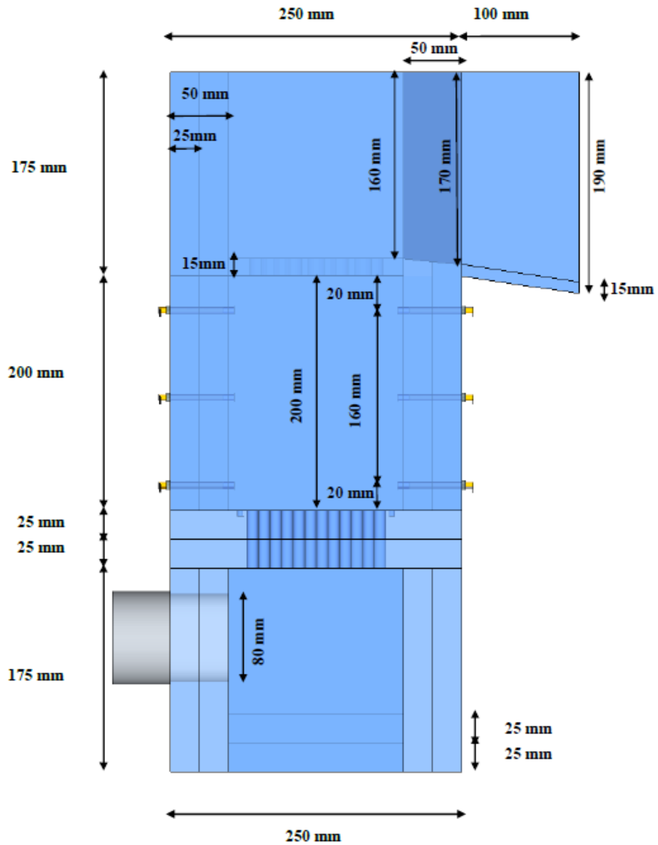
1. Conducting laboratory experiments

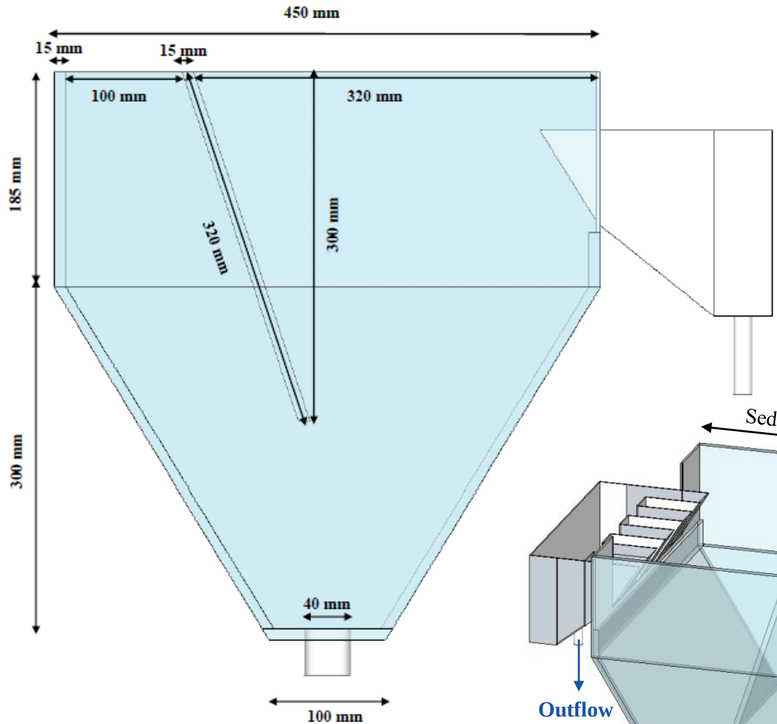
2. Developing a theoretical framework to facilitate continuum-based numerical modelling.

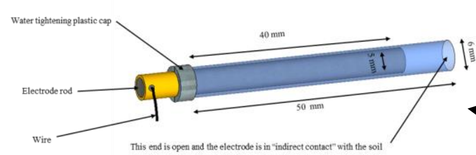
3. Definition of constitutive law of erosion whereby the initiation of material instability "erosion initiation", as well as the continuation of the phenomenon "mass removal rate" are accounted for.

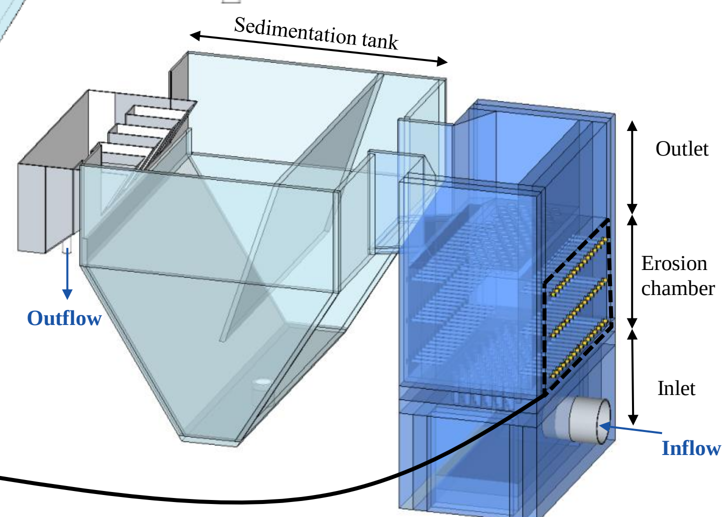
Laboratory studies on internal erosion

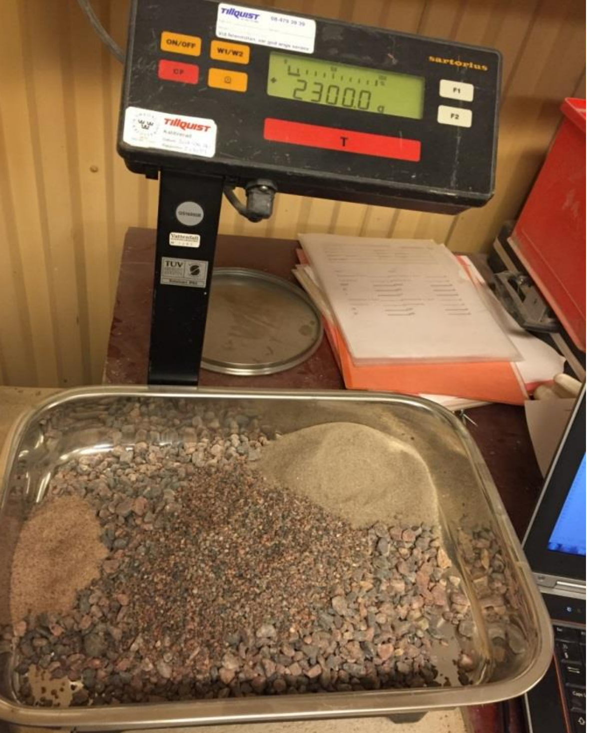
Side view











Tests for Suffusion mechanism:

Soil-A mixture of Skempton and Brogan (1994)

Initiation tests
(2 repetitions)

Type A
(constant hydraulic loading)

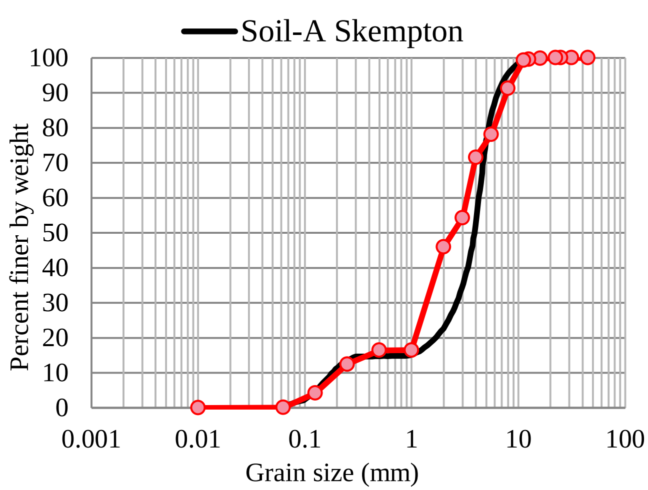
Type B
(constant material matrix)

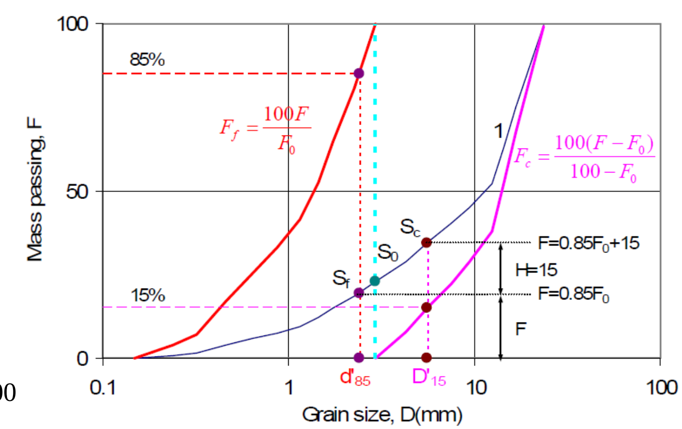
0 kPa mechanical loading

10 kPa mechanical loading

25 kPa mechanical loading

50 kPa mechanical loading



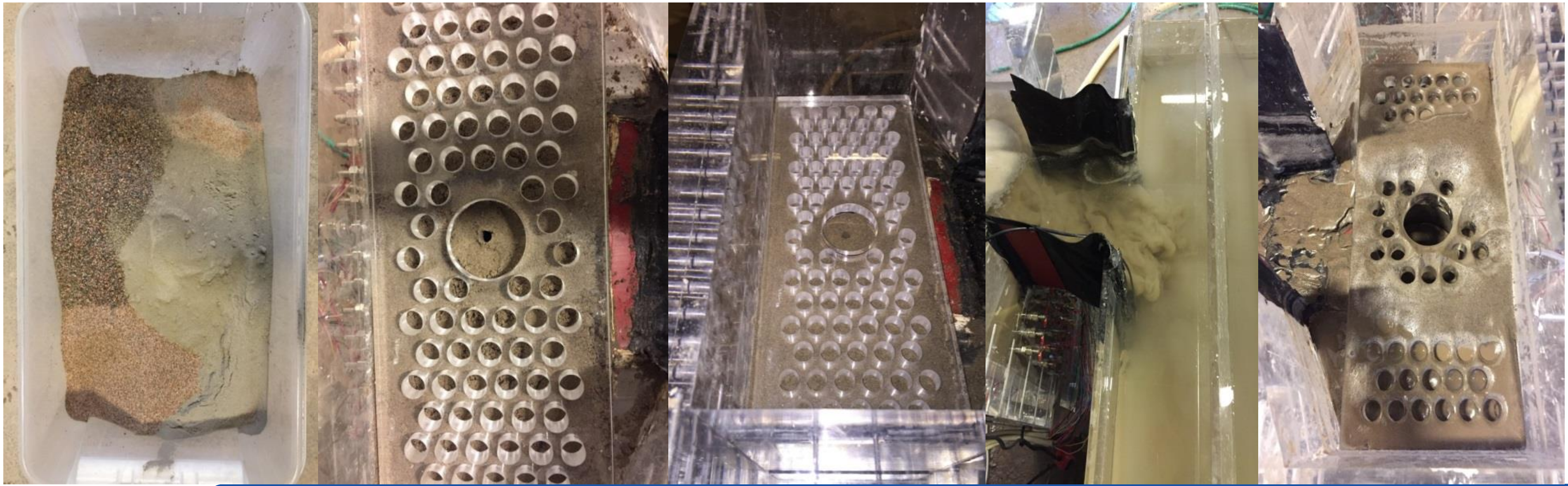


Conducted tests for Concentrated leak mechanism:

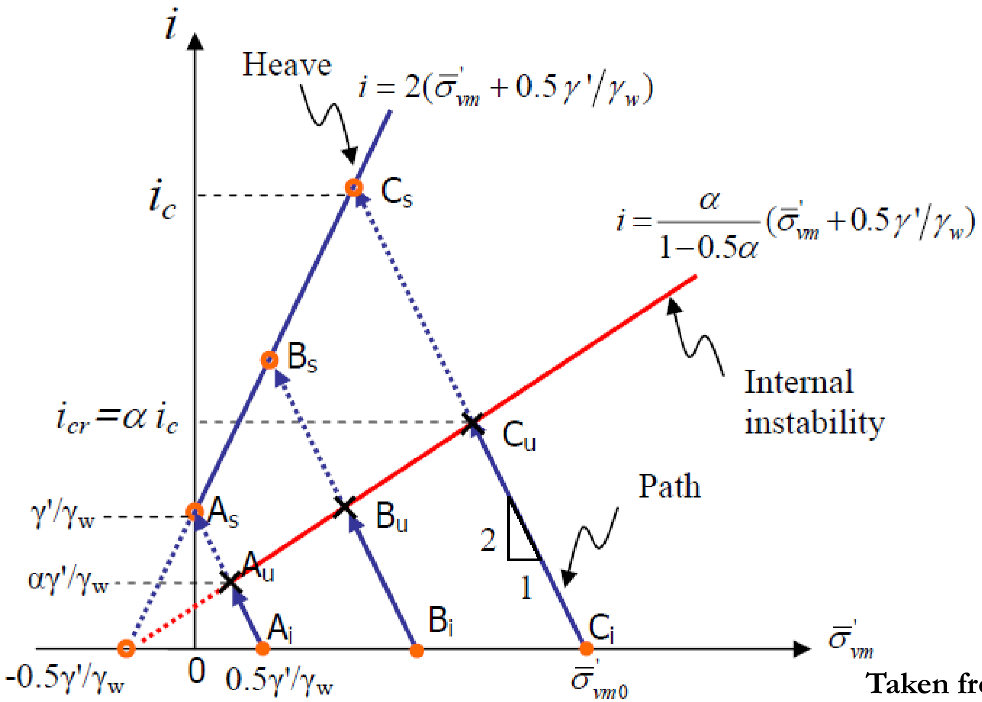
Silty clay core material of Teton dam in Idaho, U.S.A.

Concentrated leak (HET):

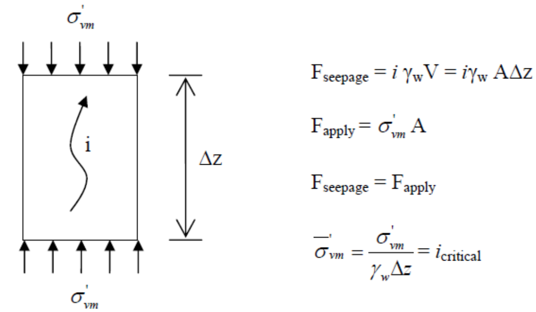
- HET - 0 : 0 mechanical loading (4 repetitions)
- HET -25 : 25 kPa m.loading
- HET -50 : 50 kPa m.loading
- HET -75 : 75 kPa m.loading
- HET -100 : 100 kPa m.loading



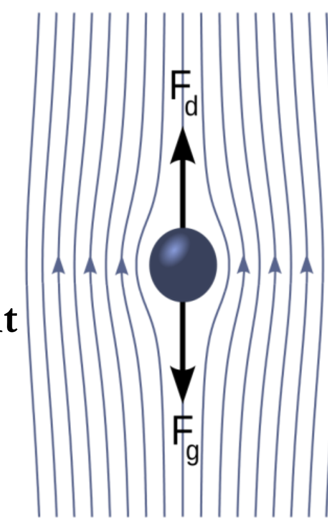
Hydromechanical Envelope model:



Taken from Li, 2006.



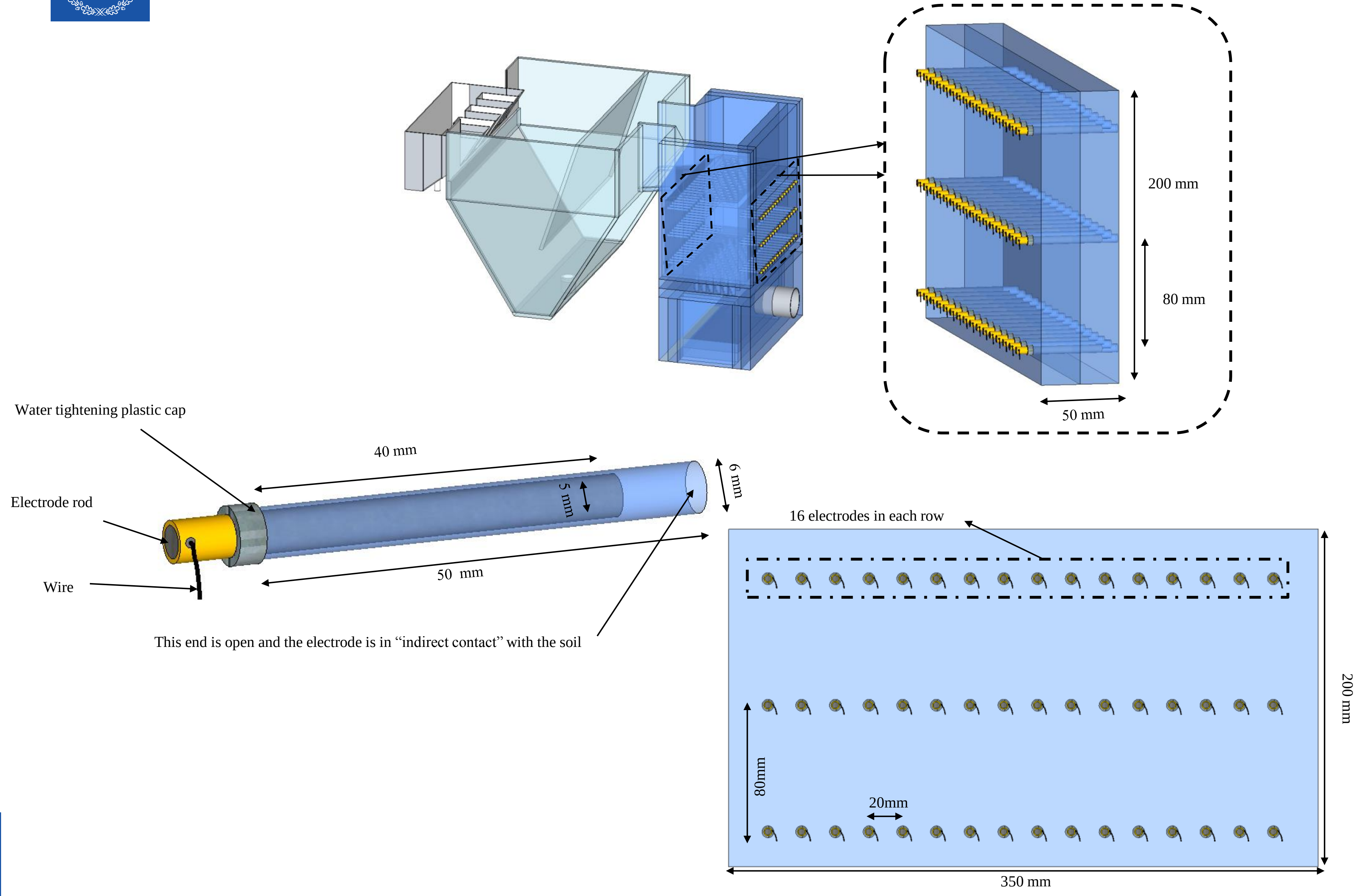
Definition and physical nature of normalized effective stress



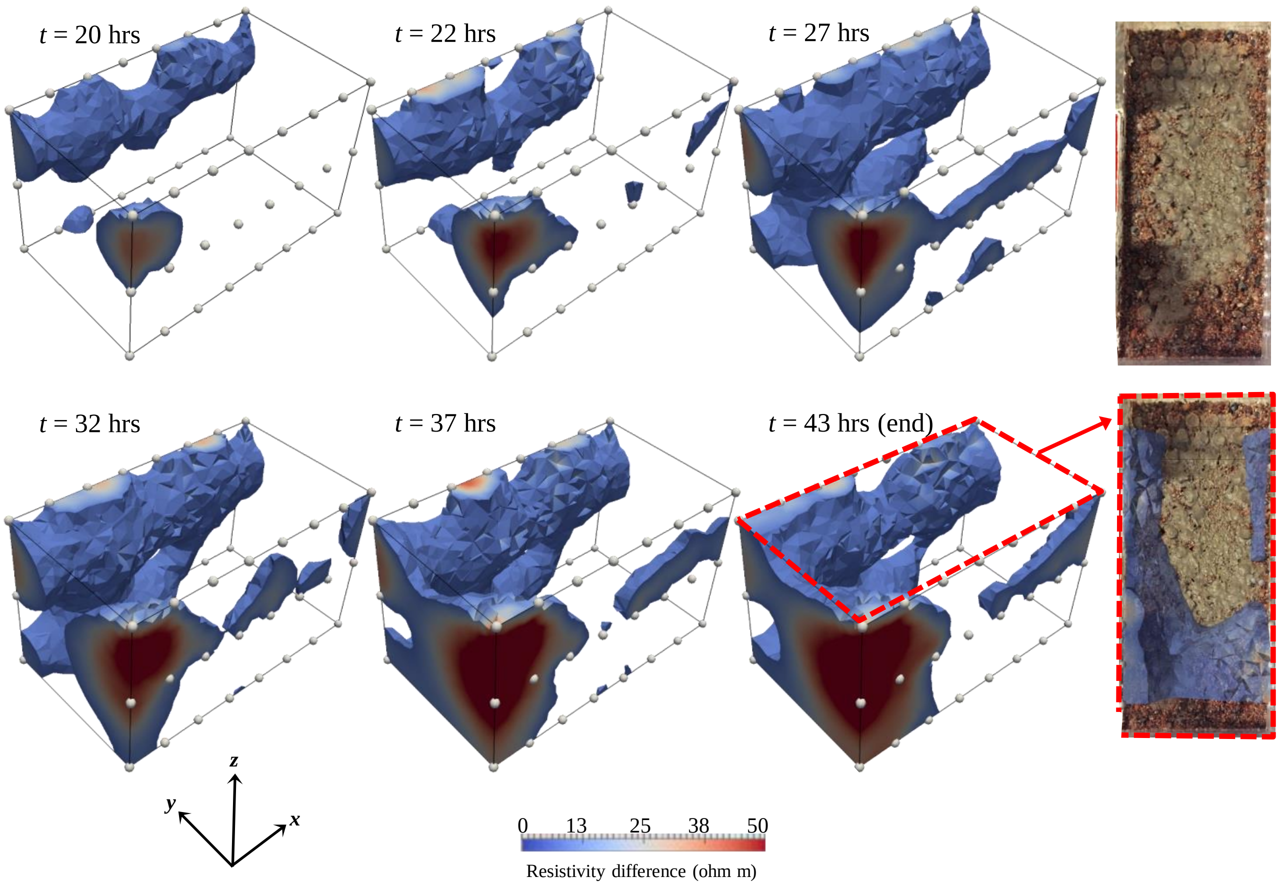
Modification is needed to get the flow-induced shear forces in to account

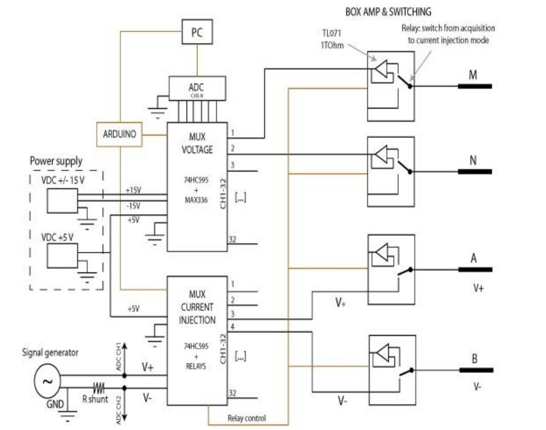
Otherwise the stress reduction factors cannot be explained.

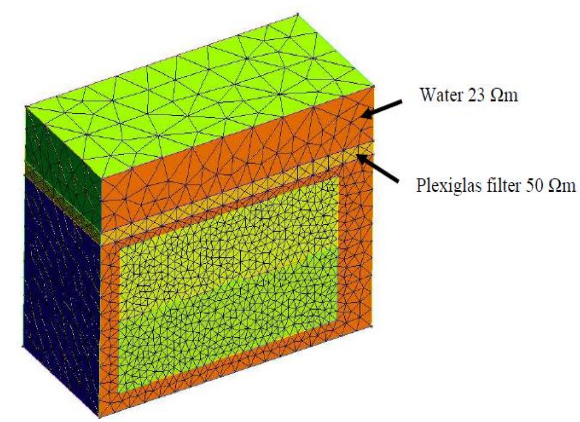
3D resistivity tomography studies



3D resistivity change due to suffusion process



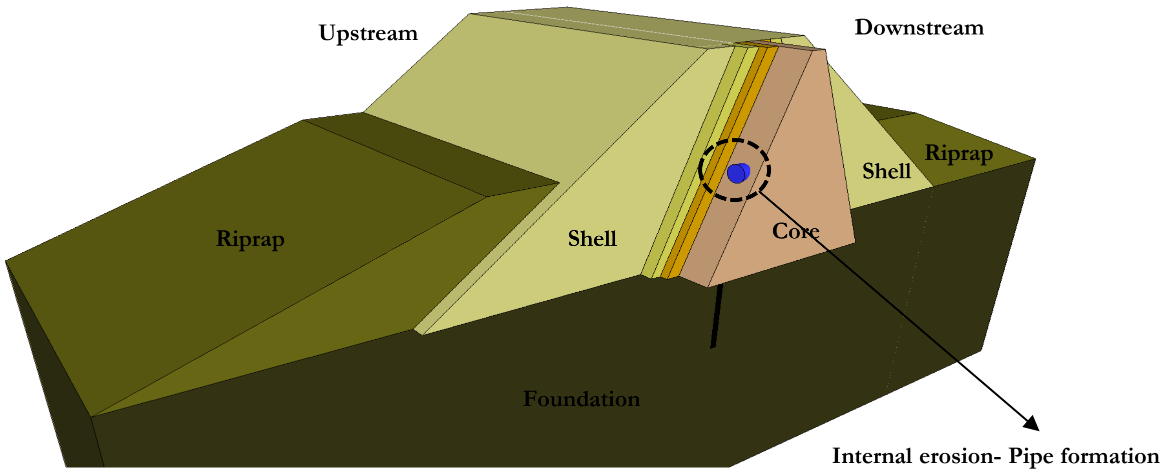




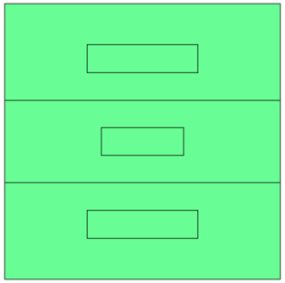
This resistivity change can be translated to porosity change in media due to internal erosion.

Conclusion remarks:

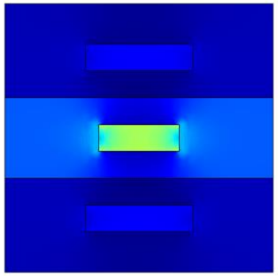
Adopting the findings from the two aforementioned continuum based work enables modelling the internal erosion phenomena in embankment dams from initiation until the failure.

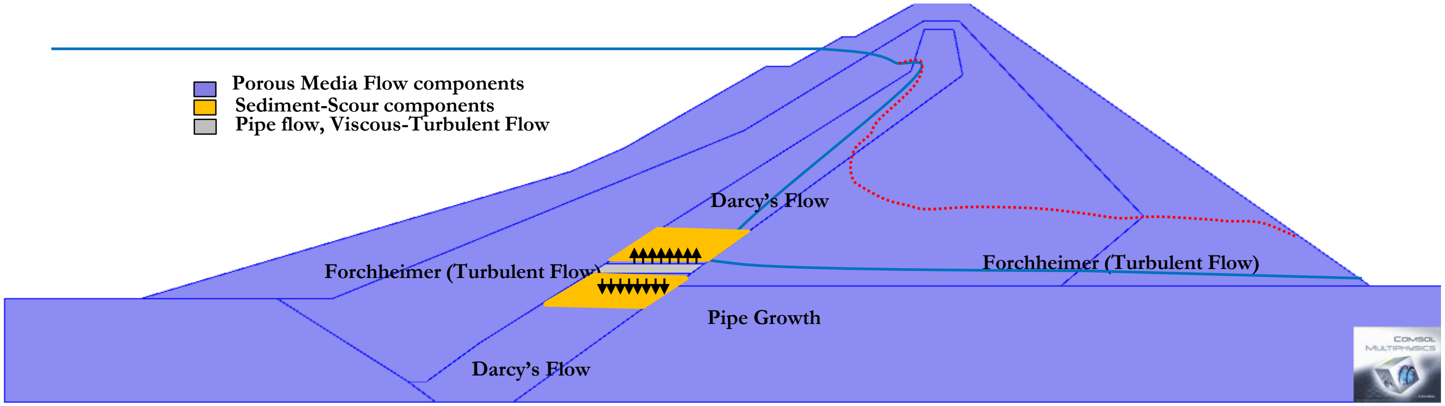


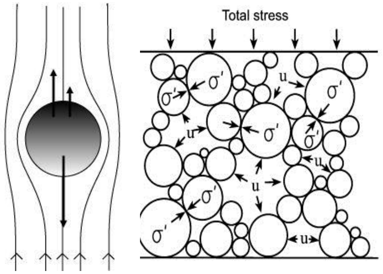
Material's Porosity in time



Velocity magnitude in time







Public PhD defense

INTERNAL EROSION PHENOMENA IN EMBANKMENT DAMS:

Throughflow and internal erosion mechanisms

Location:

Kollegiesalen, Brinellvägen 8, KTH Royal Institute of Technology

Time:

Friday November 4 at 9:00 AM.

Welcome!

THANK YOU FOR YOUR ATTENTION!