LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

Research Perspectives in Embankment Dams at LNEC

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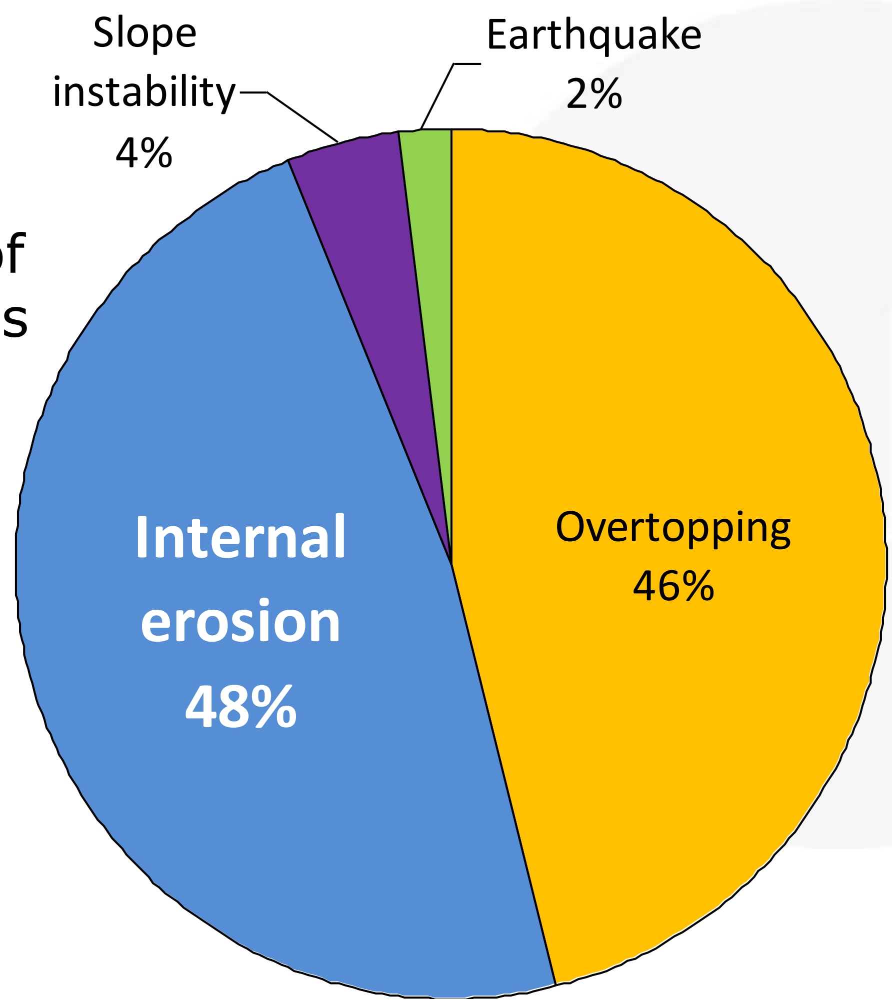
Summary

> The influence of upstream zones in the limitation of the progression of internal erosion in zoned dams

> Self-hardening slurry walls design and quality control

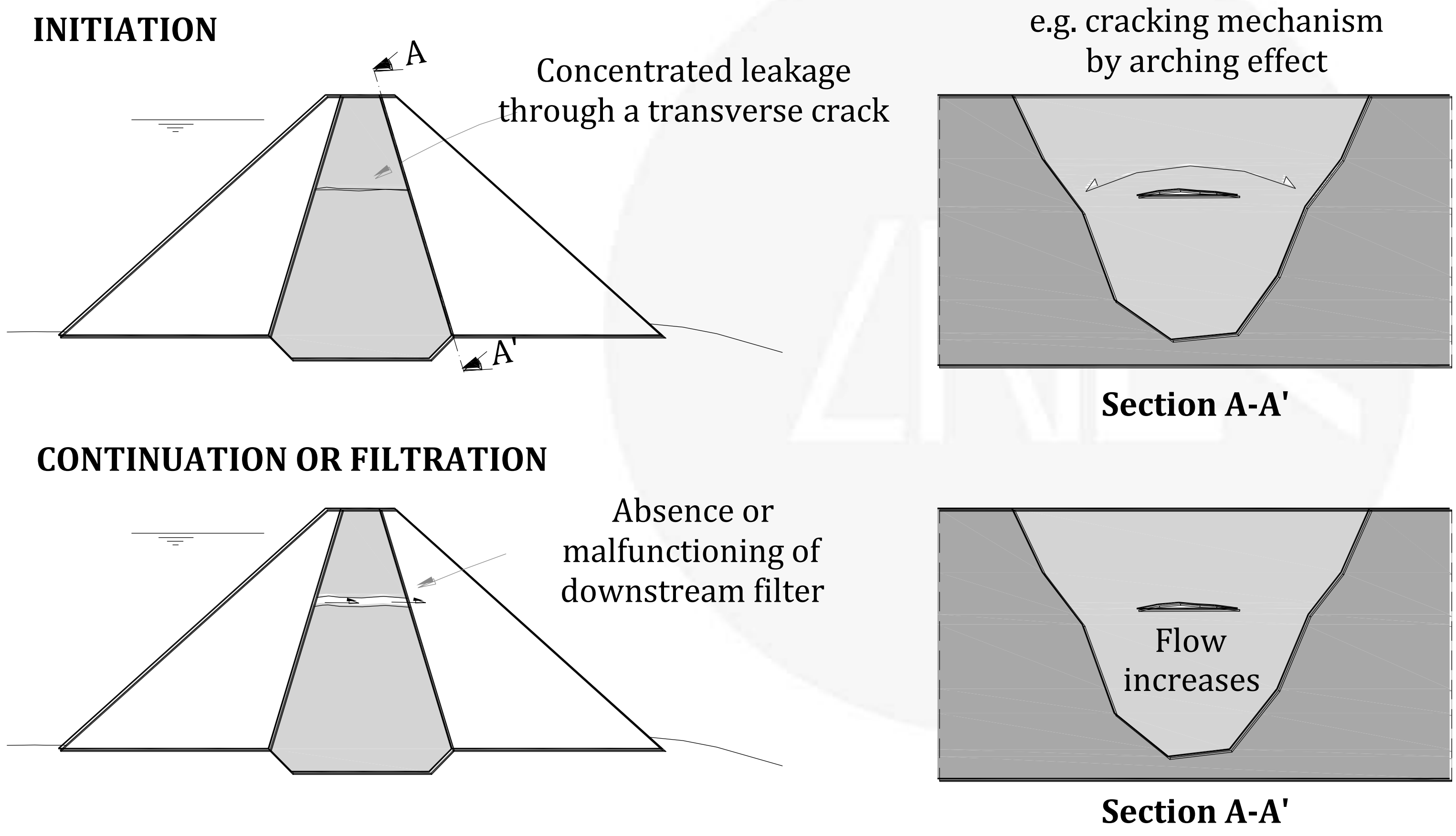
Importance of internal erosion to dam safety

Overall statistics of embankment dams failures



Source: Foster, Fell e Spannagle (2000)

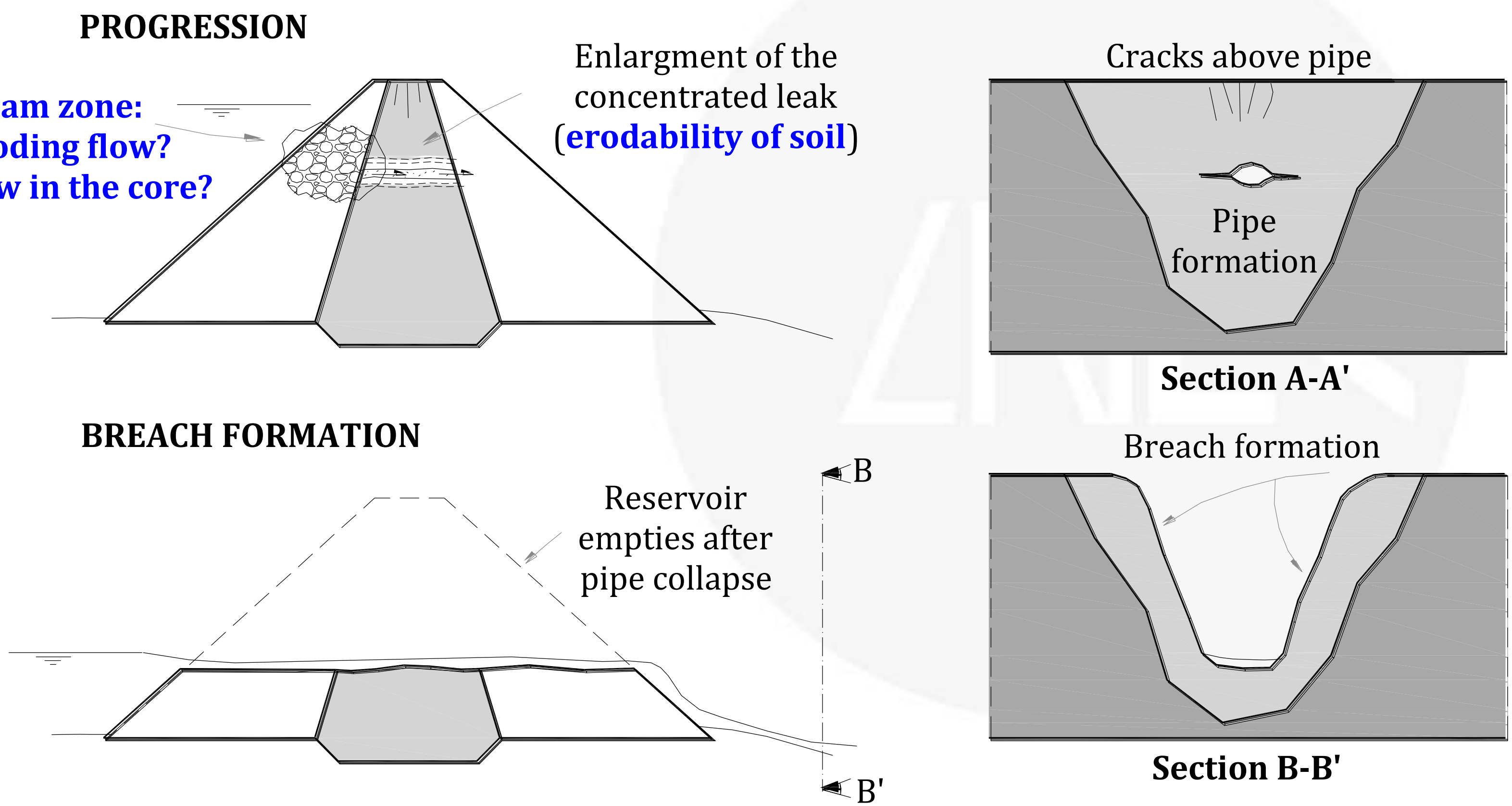
Internal erosion process leading to failure



Internal erosion process leading to failure (cont)

Does the upstream zone:

- **Limits the eroding flow?**
- **fills in the flaw in the core?**



Progression of internal erosion to piping

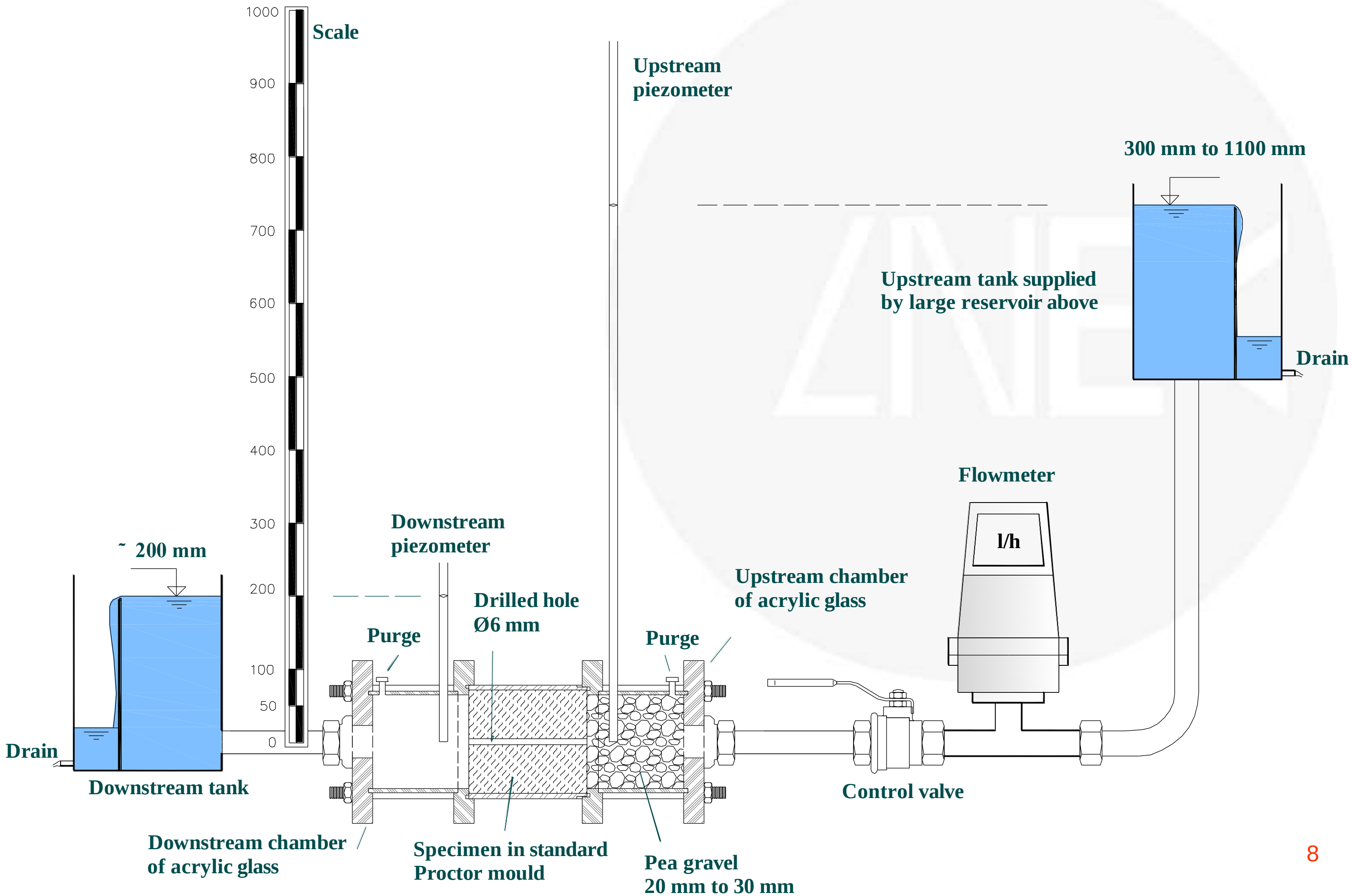
Tunbridge Dam, Tasmânia, Australia, 11/28/2008
Source: Jeffery Farrar (2008)

Progression of internal erosion to piping

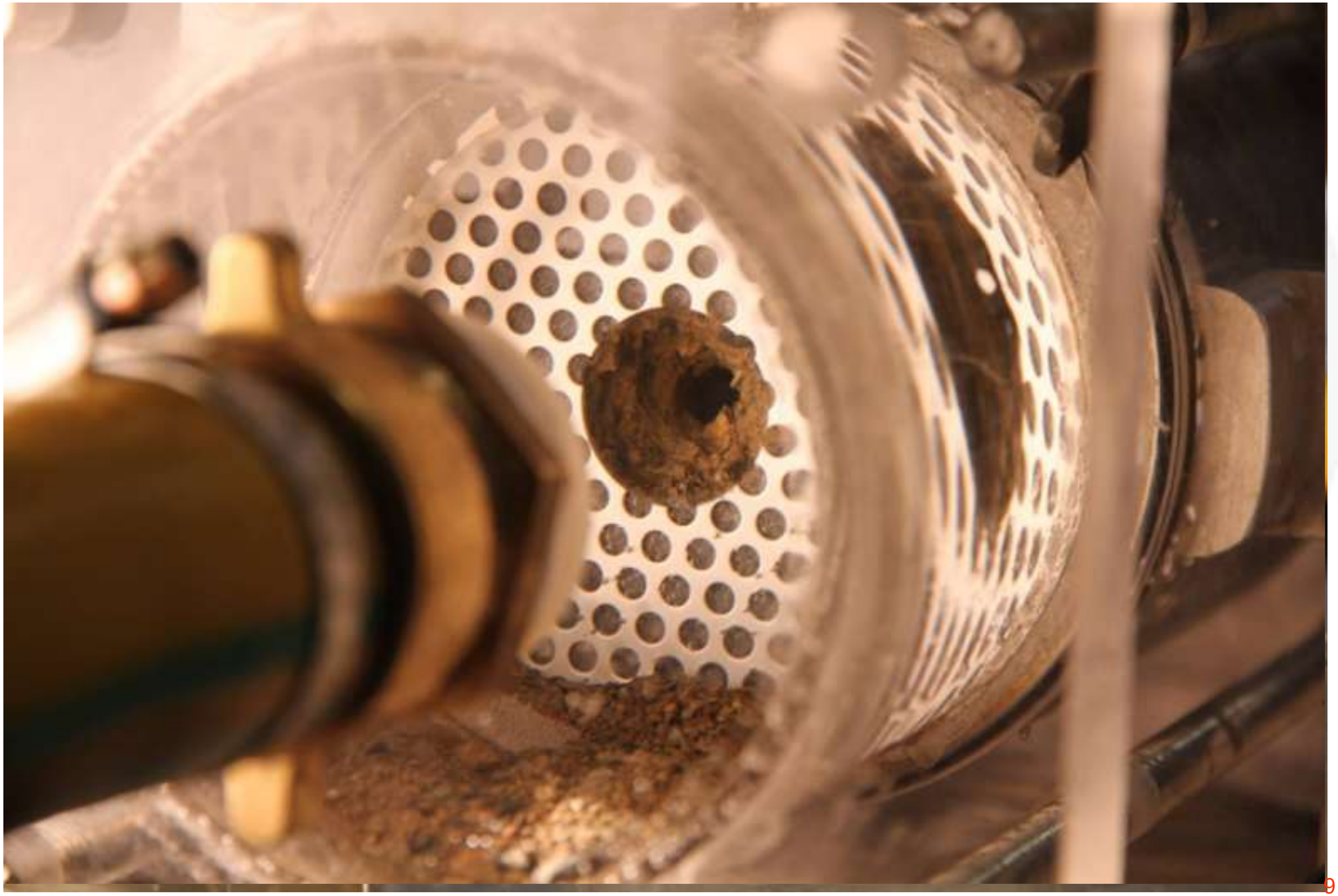
Source: Hanson e Hunt (USDA, 2007)

Erodability of soils in concentrated leaks

> Hole Erosion Test (HET)

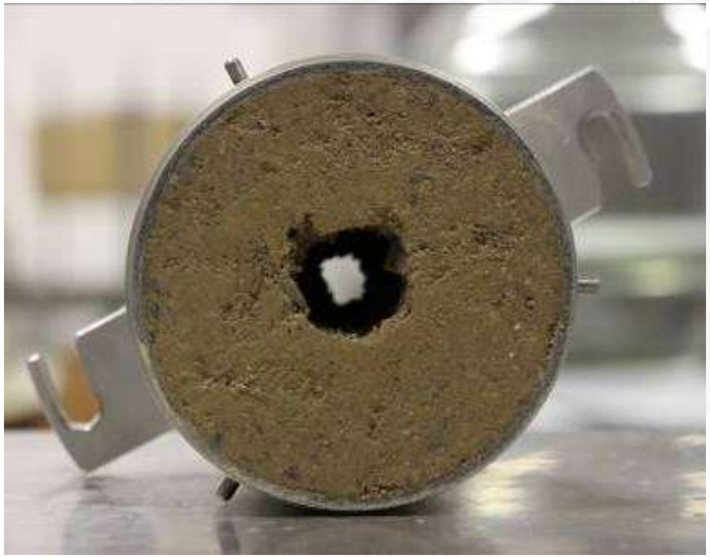


Hole Erosion Test (HET) during test



Hole Erosion Test

> **Axial hole at the end of a test**

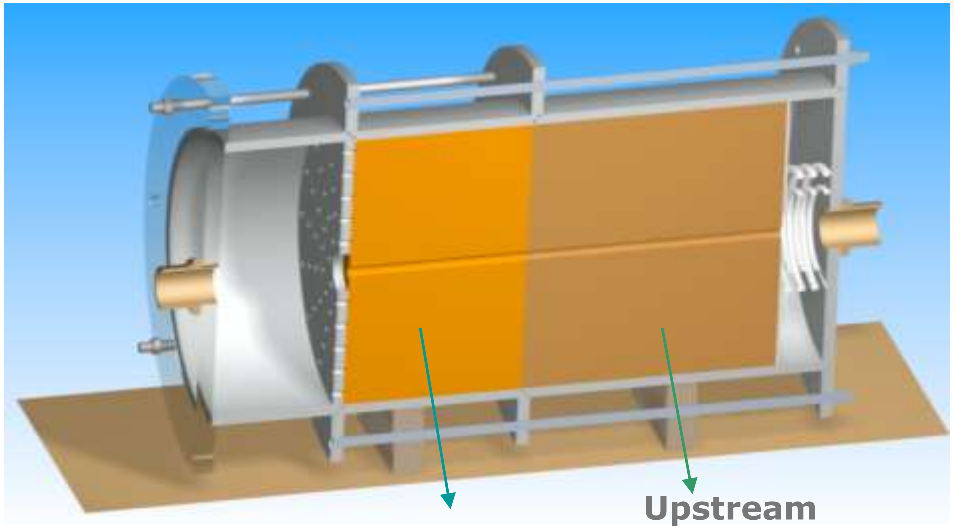




Limitation of progression of piping

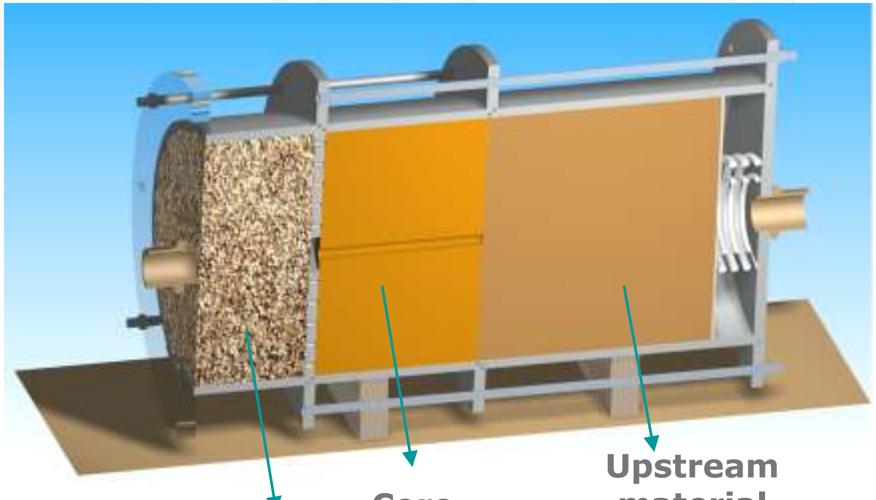
Influence of the presence of upstream zones

- Flow restriction action
- Crack-filling action

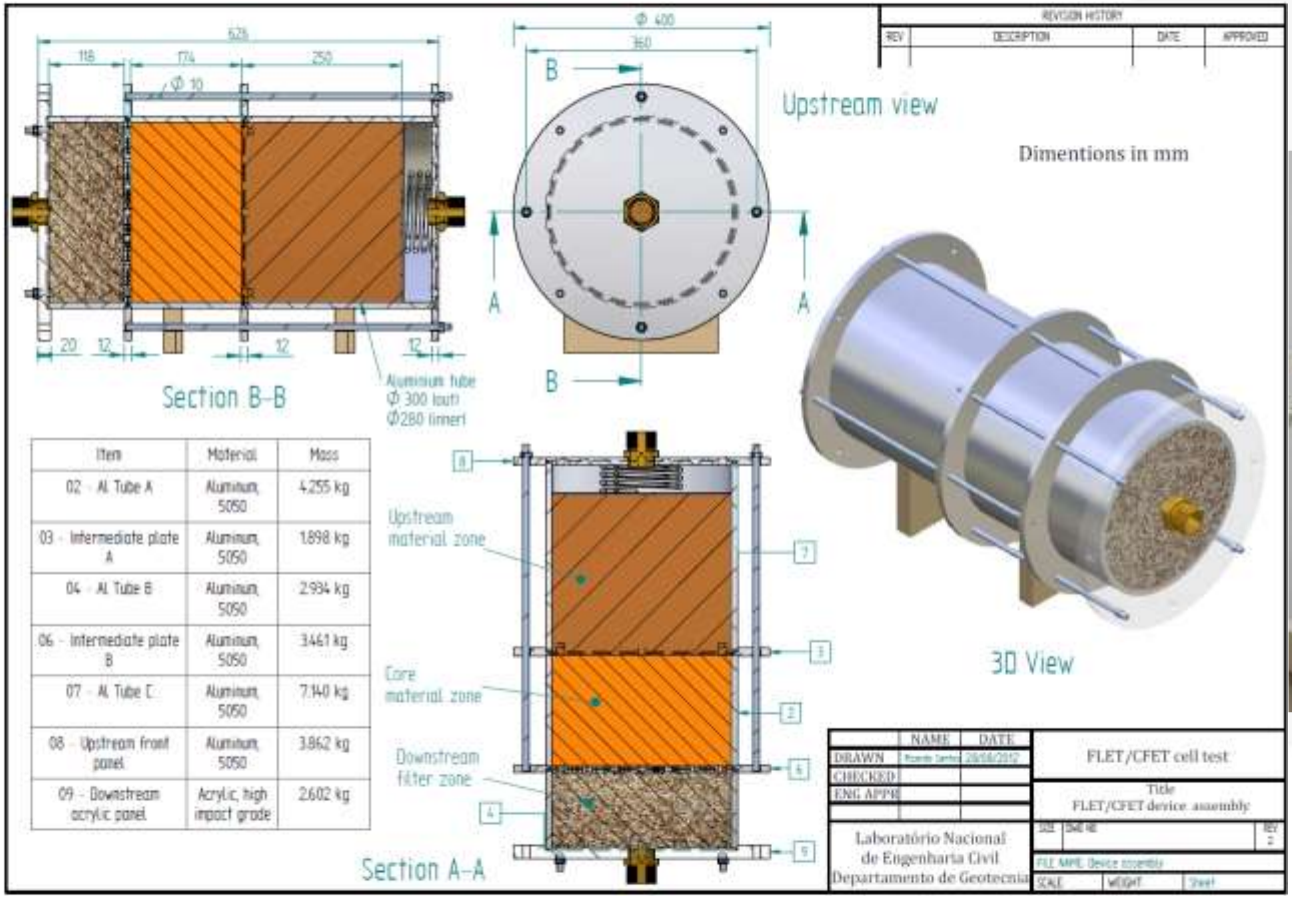
Flow Limitation Erosion Test (FLET)



Crack-Filling Erosion Test (CFET)

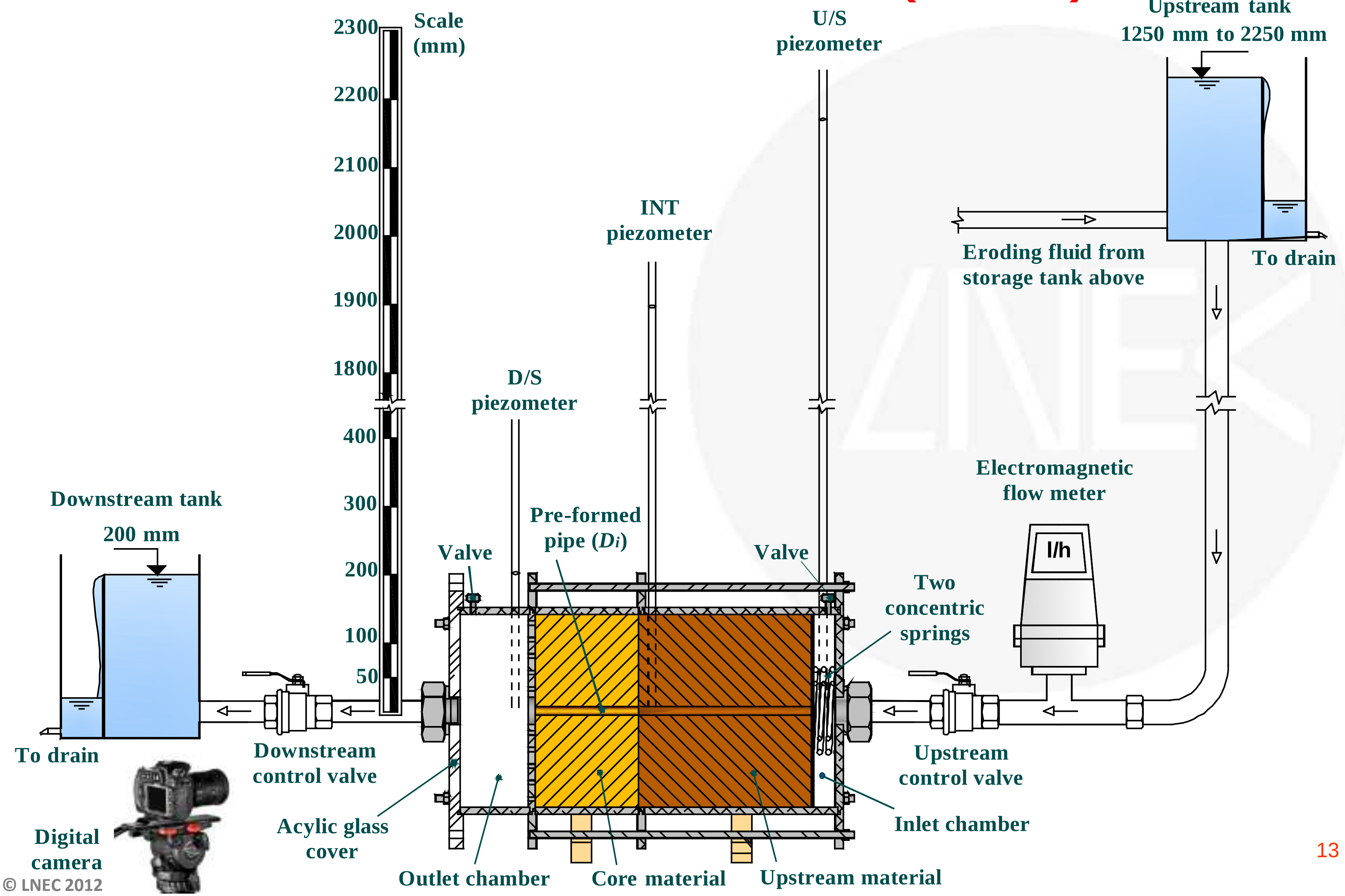


Test cell developed at LNEC for FLET and CFET



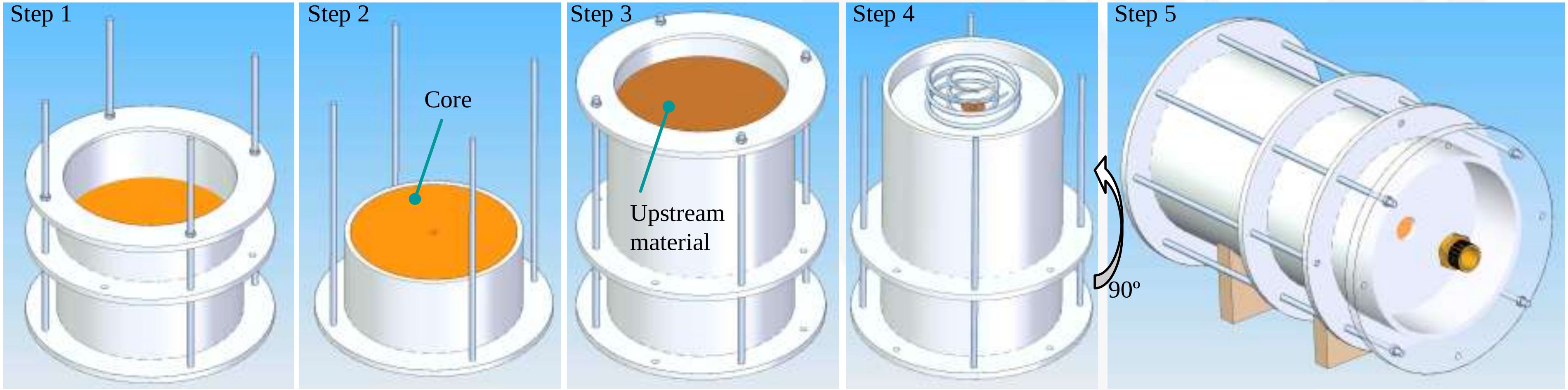
Item	Material	Mass
02 - Al Tube A	Aluminum 5050	4.255 kg
03 - Intermediate plate A	Aluminum 5050	1.898 kg
04 - Al Tube B	Aluminum 5050	2.934 kg
06 - Intermediate plate B	Aluminum 5050	3.461 kg
07 - Al Tube C	Aluminum 5050	7.140 kg
08 - Upstream front panel	Aluminum 5050	3.862 kg
09 - Downstream acrylic panel	Acrylic, high impact grade	2.602 kg

Flow Limitation Erosion Test (FLET)

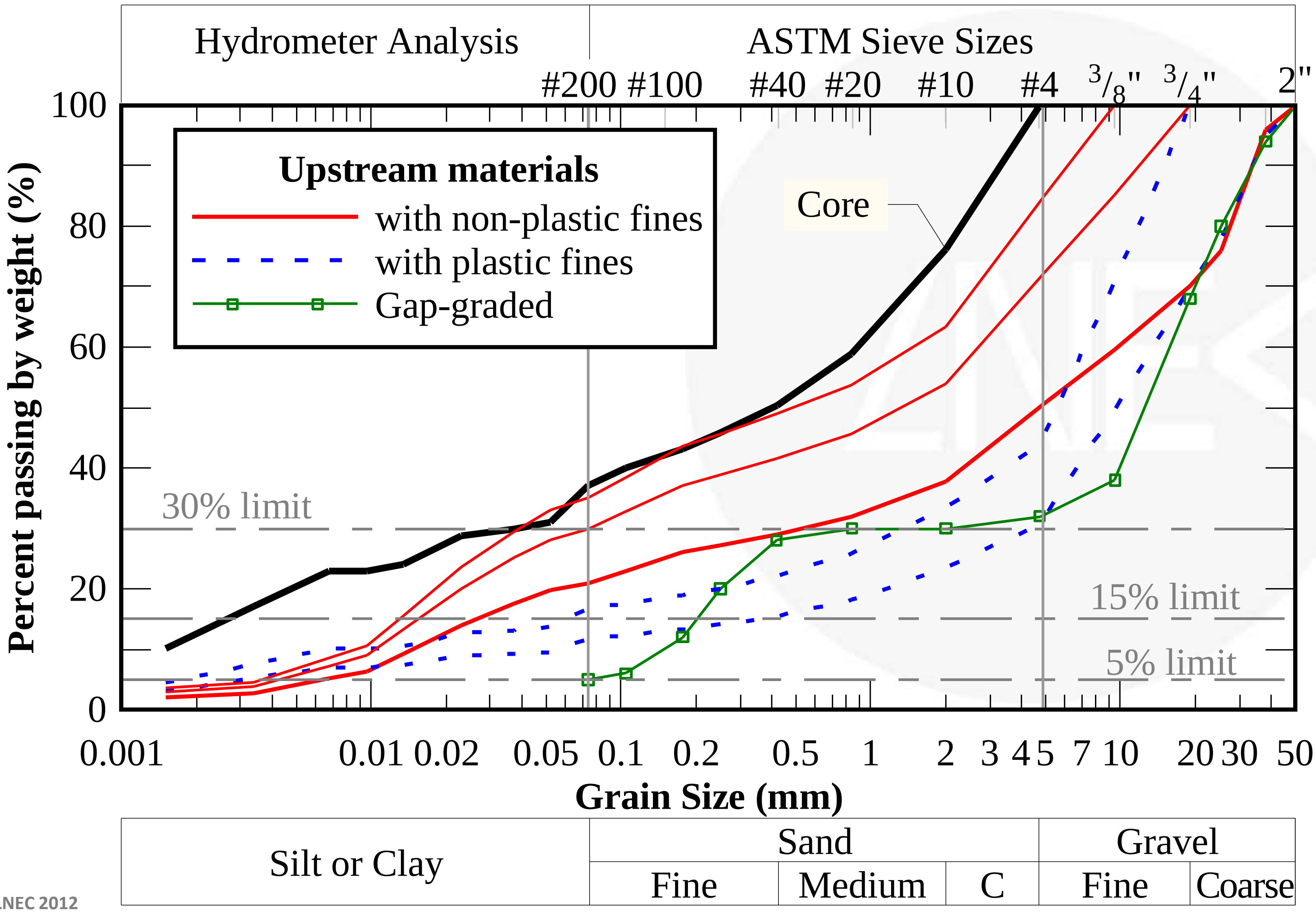


Flow Limitation Erosion Test

> Steps for assembly of test cell and specimen preparation

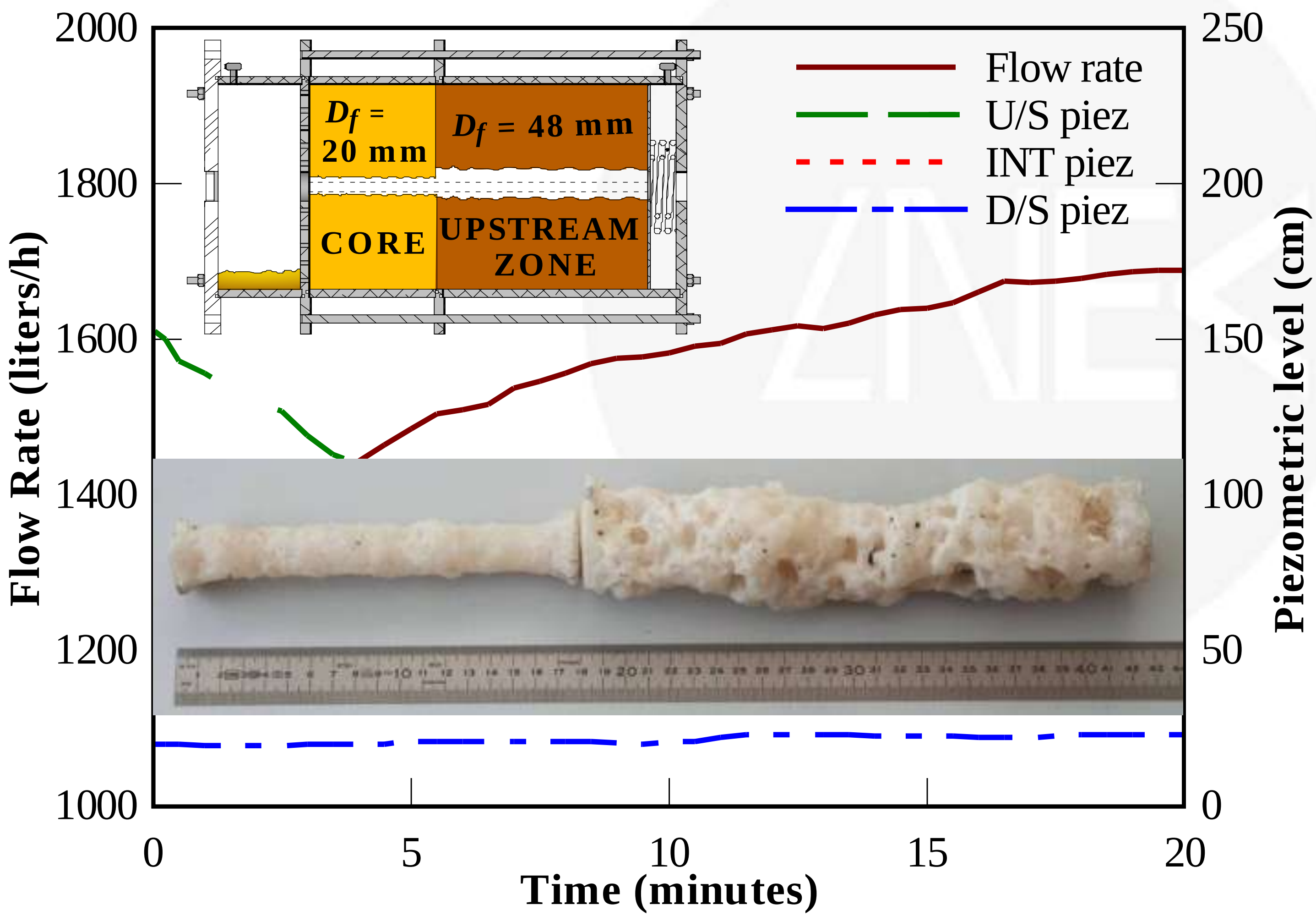


Upstream materials tested in the FLET



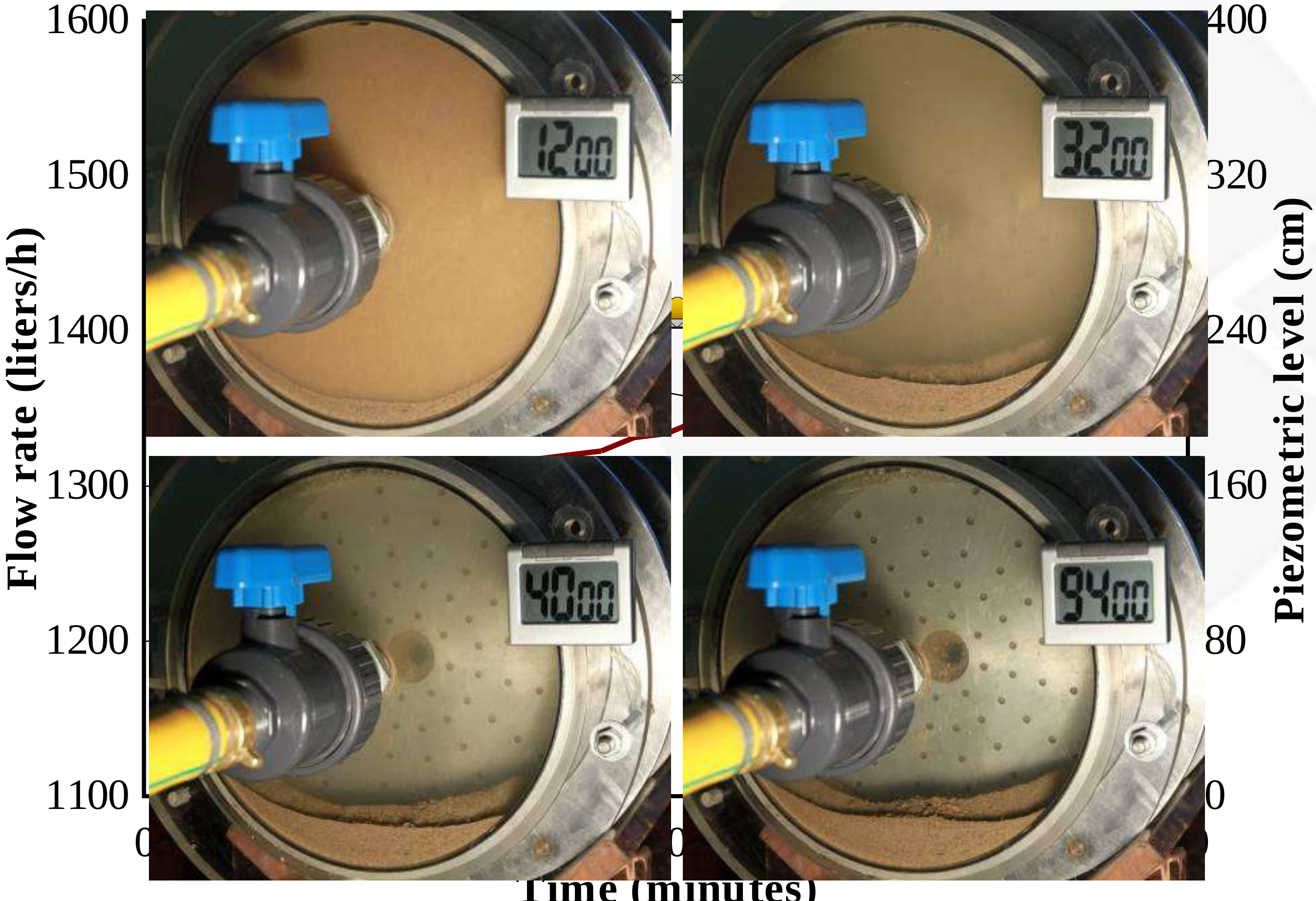
Some results of carried out FLET's at LNEC

> Progression of erosion without flow restriction



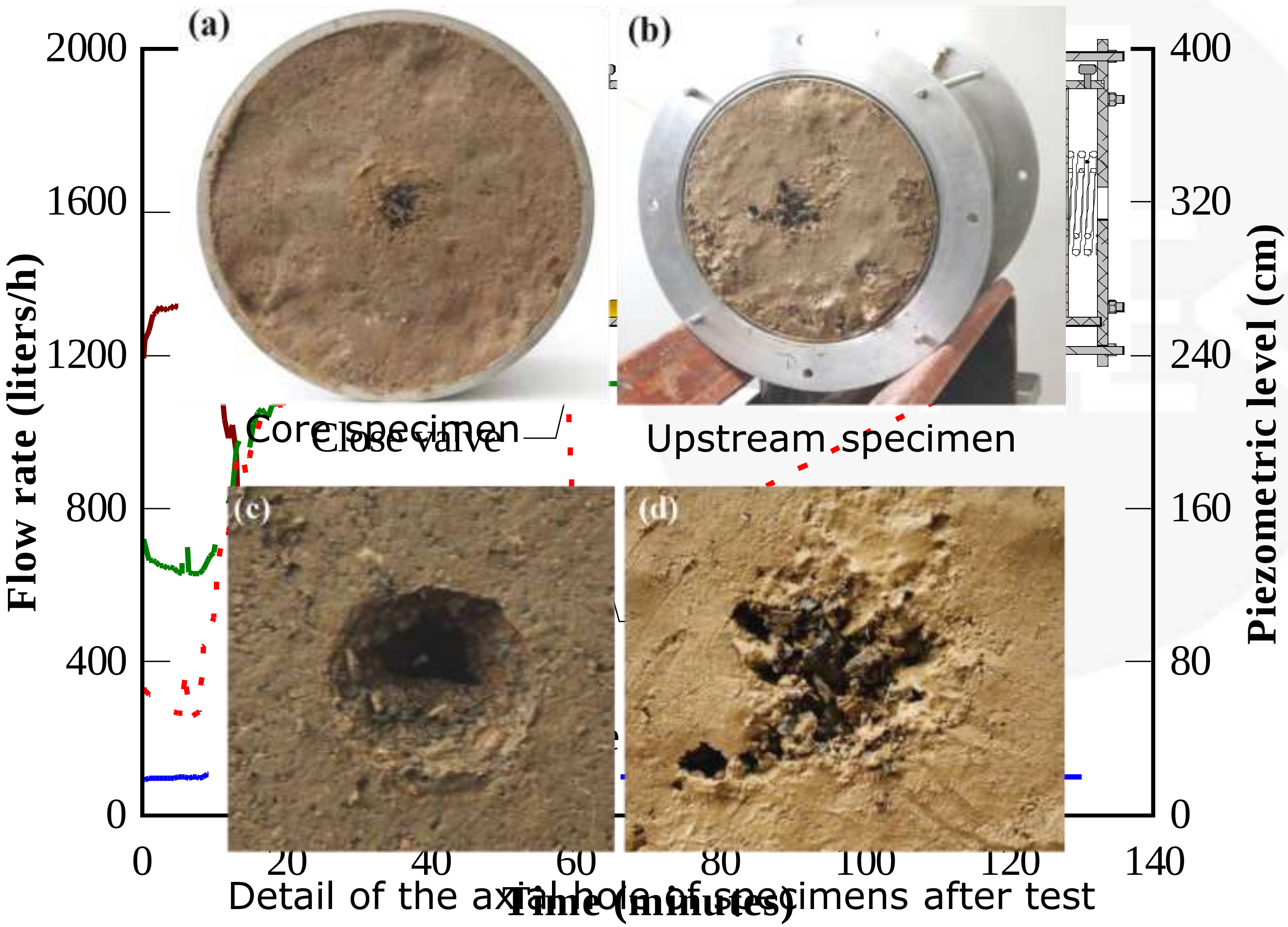
Some results of carried out FLET's at LNEC

> Flow restriction due to non-erodible upstream material



Some results of carried out FLET's at LNEC

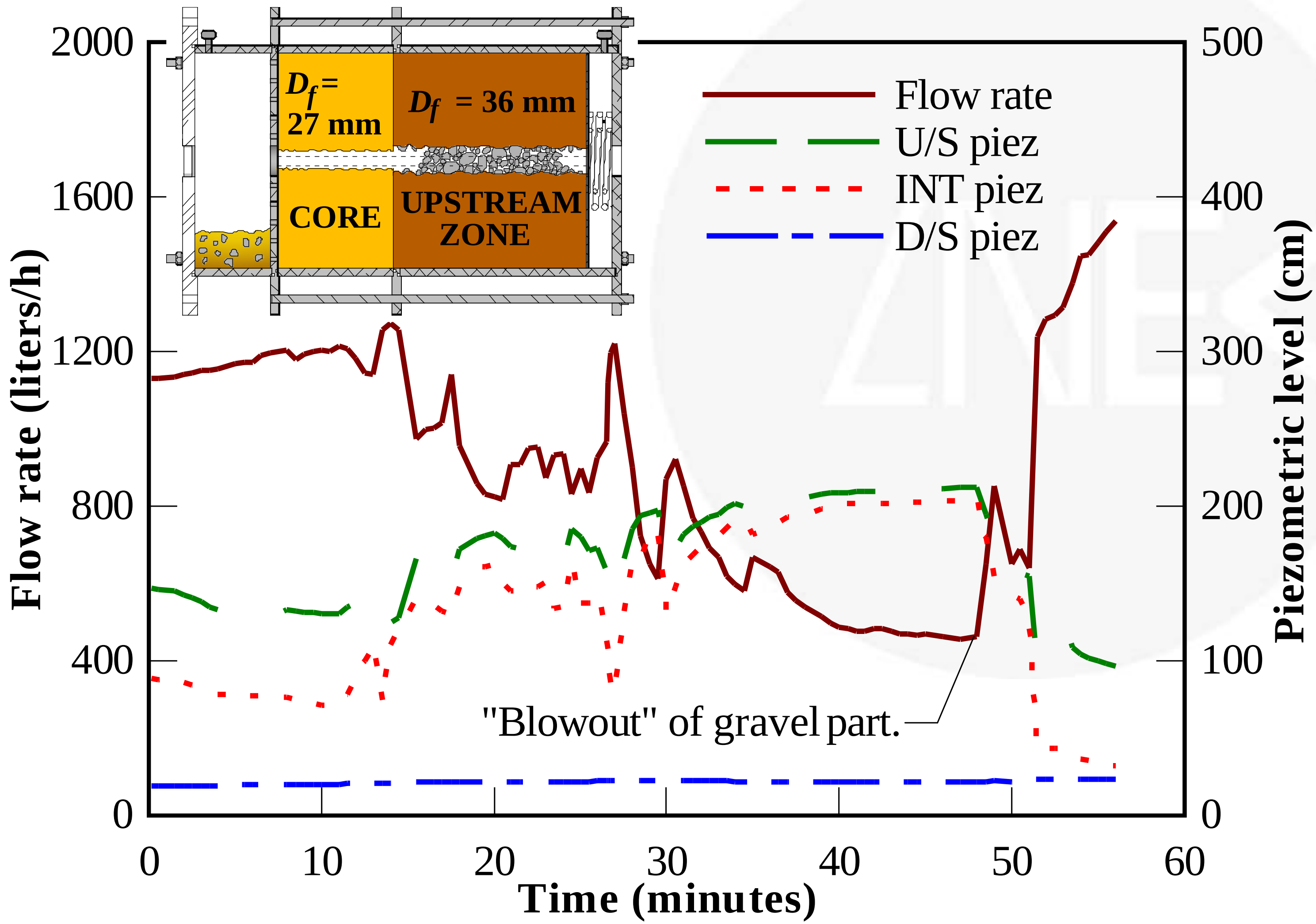
> **Flow rate stops completely (self-healing ability)**



Detail of the axial hole of specimens after test

Some results of carried out FLET's at LNEC

> Erosion process slows down during a period

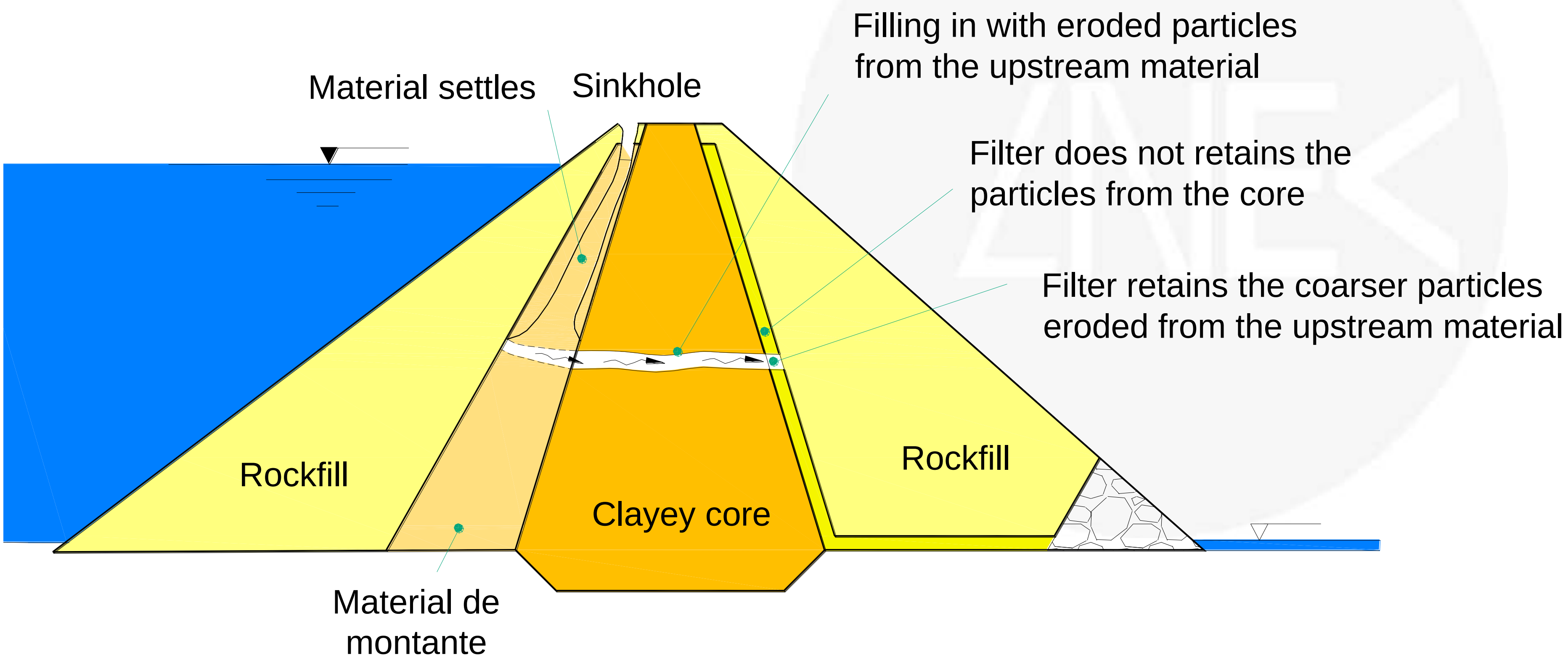


Major outcomes of carried out FLET's

- The performed tests showed that the *FLET* allows the evaluation of the flow restriction action by an upstream material, that is, if the piping process in the core stops, slows down or progresses.
- The flow restriction action is strongly influenced by some characteristics of the upstream materials, including the *fines and gravel contents*, as well as the *plastic nature of the fines*.
- The *compaction water content* of the upstream material affects strongly the progression of piping erosion.
- The non-plastic fines of soils compacted to the dry side tends to erode more rapidly, leaving unbounded the gravel particles with potential to initiate a self-healing mechanism at the interface or inside the core sample.

Crack-Filling Erosion Test (CFET)

> Conceptual model of Crack-filling action mechanism



Crack-Filling Erosion Test (CFET)

> Example of sinkhole formation at the embankment crest

WAC Bennett Dam | Canadá

Source: Steve Garner, BCHydro (2007)

Embankment height=186 m | Length= 2 km
Electricity production= 13 biliões kWh/ano

Crack-Filling Erosion Test (CFET)

> Placement of the filter layer

> CFET setup ready to test

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Crack-Filling Erosion Test (CFET)

> **Crack-filling of the axial hole on the core with an uniform fine sand**

Crack-Filling Erosion Test (CFET)

> Crack-filling of the axial hole on the core with an uniform fine sand

Major outcomes of preliminary CFET's

- The preliminary tests showed that the CFET is suitable for the evaluation of the crack-filling action by granular upstream materials.
- The filter layer has an important role in the crack filling action, by retaining some of the particles that are washed in from the upstream material.
- The potential benefits of crack filling action arise from the compatibility between the particle sizes of the upstream material and those of the downstream filter.
- Tests are currently underway examining the crack-filling action due to the presence of several types of coarse grained upstream materials (obtained by blending some fines, and sand and gravel particles).

SELF-HARDENING SLURRY WALLS DESIGN AND QUALITY CONTROL

INTRODUCTION

> Objectives

- A comprehensive literature review.
- Characterization of the factors involved in self-hardening slurry behaviour during construction and in the long term performance.
- Definition of numerical models for analysis and interpretation of the slurry wall behaviour.
- Definition of design principles.
- Proposal of a quality control and performance evaluation methodology.

DESCRIPTION SELF-HARDENING SLURRY CUT-OFF WALL

- A self-hardening slurry cut-off wall is a non--structural underground wall that serves as a barrier to the horizontal flow of water and other fluids.
- It is constructed with the aid of a viscous stabilizing fluid known as slurry. Usually, cement-bentonite slurries are used.
- In Europe, self-hardening slurries walls have been used since 1960, particularly in seepage control applications.
- In Portugal, the technology was first applied in 1978, in the remedial works of the Roxo Dam.

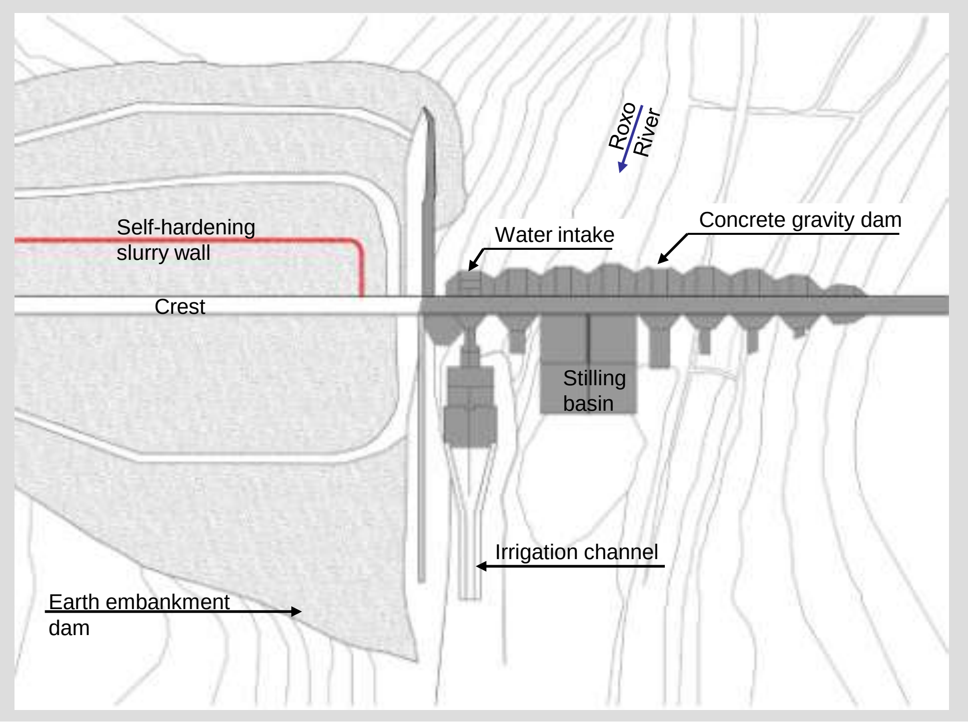
APPLICATIONS

- Main applications of the technology.
- Construction procedures.

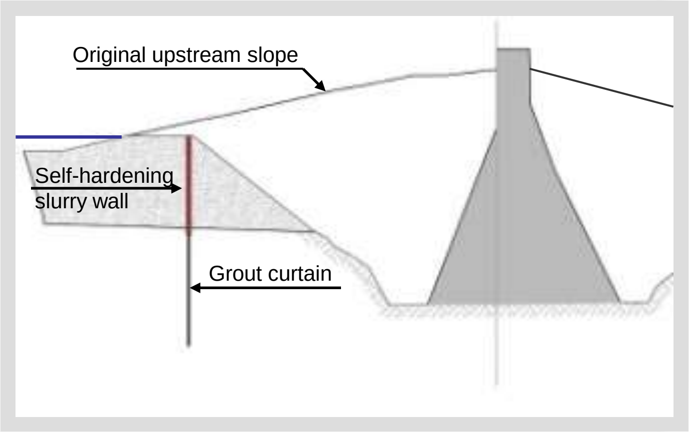
- Excavation dewatering.
- Reduction of seepage through embankments or water storage structures.
- Reduction of seepage of ponds and lakes.
- Subsurface dams or groundwater reservoir.
- Isolation or maintenance of water tables.
- Containment of solid and liquid wastes.
- Seismic cut-off.

APPLICATIONS

> Roxo Dam



Plan



Cross-section

Cut-off wall characteristics:	
Wall length:	190 m
Maximum depth:	16.8 m
Width:	0,6 m

Jan. 1977

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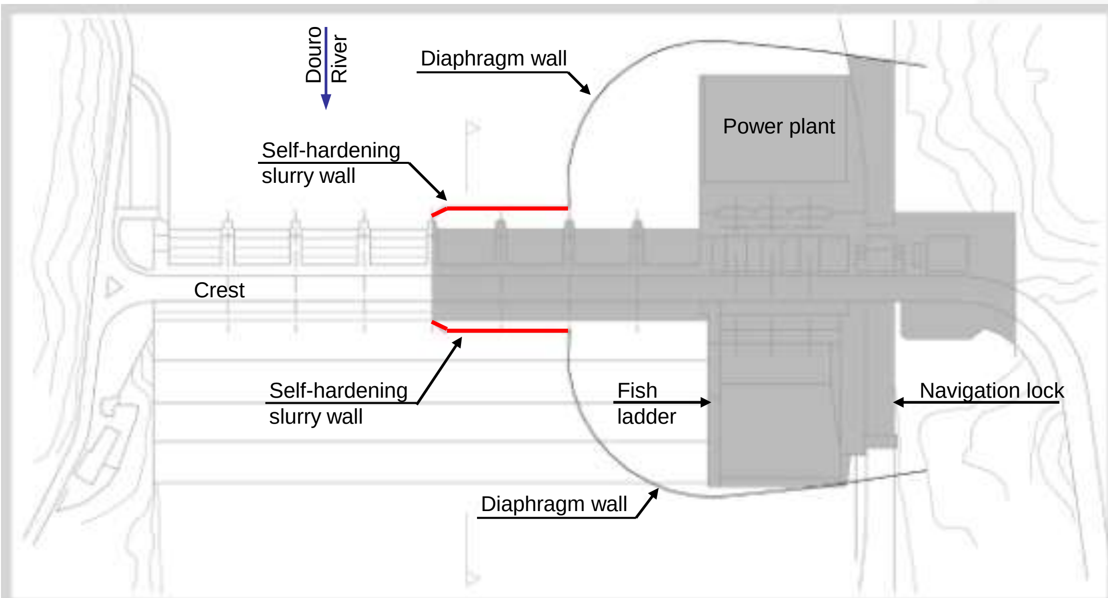
Parede auto-endurecedora - Abril 1978

Maio 1978

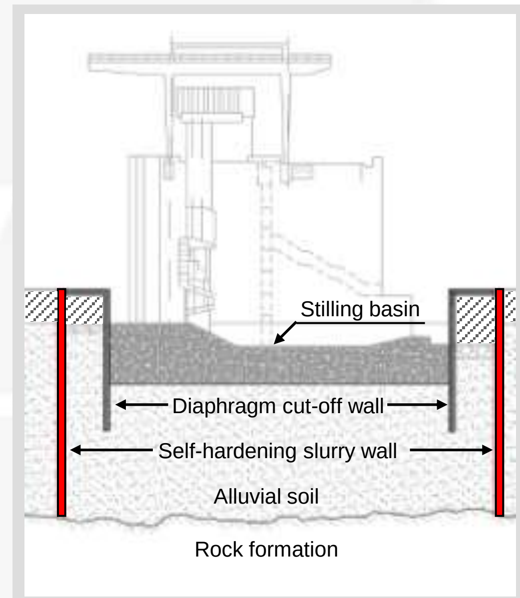
Agosto 1980

APPLICATIONS

> Crestuma-Lever Dam



Plan

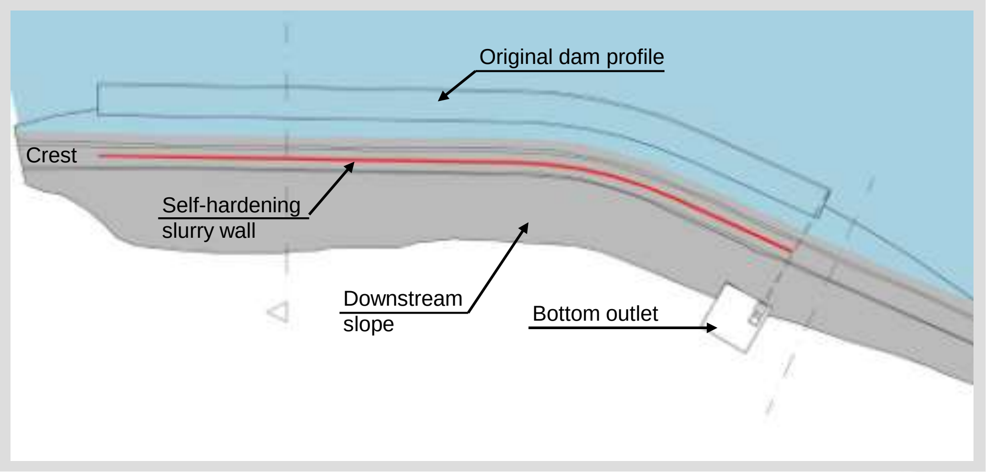


Cross-section

Cut-off wall characteristics:	
Wall area:	5 600 m^2
Maximum depth:	40 m
Width:	0,8 m

APPLICATIONS

> Águas Industriais Dam



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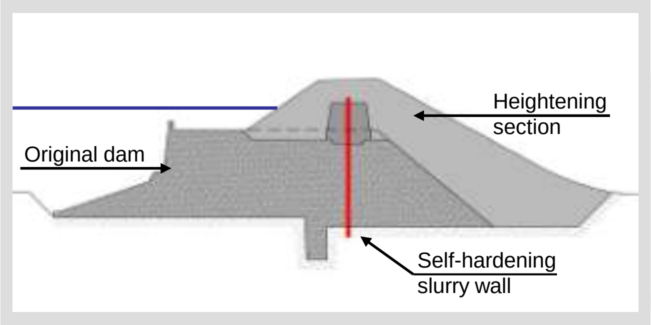


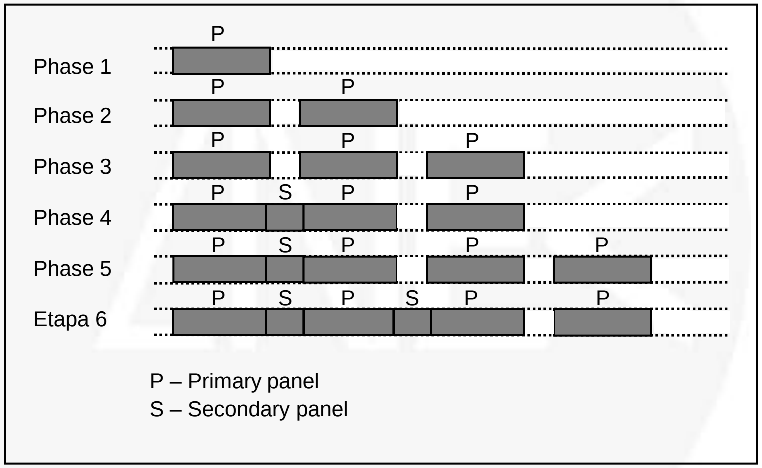
Cross-section

Cut-off wall characteristics:	
Wall length:	175 m
Maximum depth:	14 m
Width:	0,4 m

APPLICATIONS

- > Main applications of the technology.
- > Construction procedures.

- Alternating panel method.

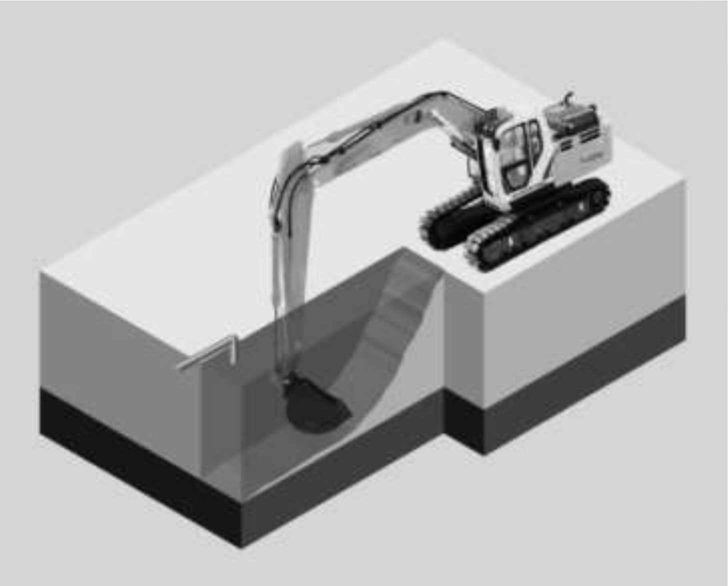


APPLICATIONS

> Main applications of the technology.

> Construction procedures.

- Alternating panel method.
- Continuous trenching method.



APPLICATIONS

- > Main applications of the technology.
- > Construction procedures.
  - Alternating panel method.
  - Continuous trenching method.
  - Structural diaphragm wall traditional method.

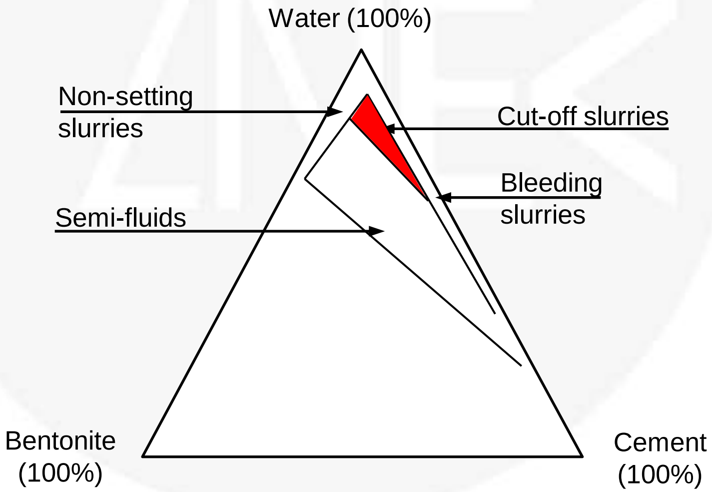
SELF-HARDENING SLURRY CHARACTERIZATION

> Self-hardening slurry features.

> Self-hardening slurry composition.

> Chemical reactions between water, cement and bentonite.

- Water: 1 m^3
- Cementitious material: 100 to 350 kg
- Bentonite: 30 to 60 kg



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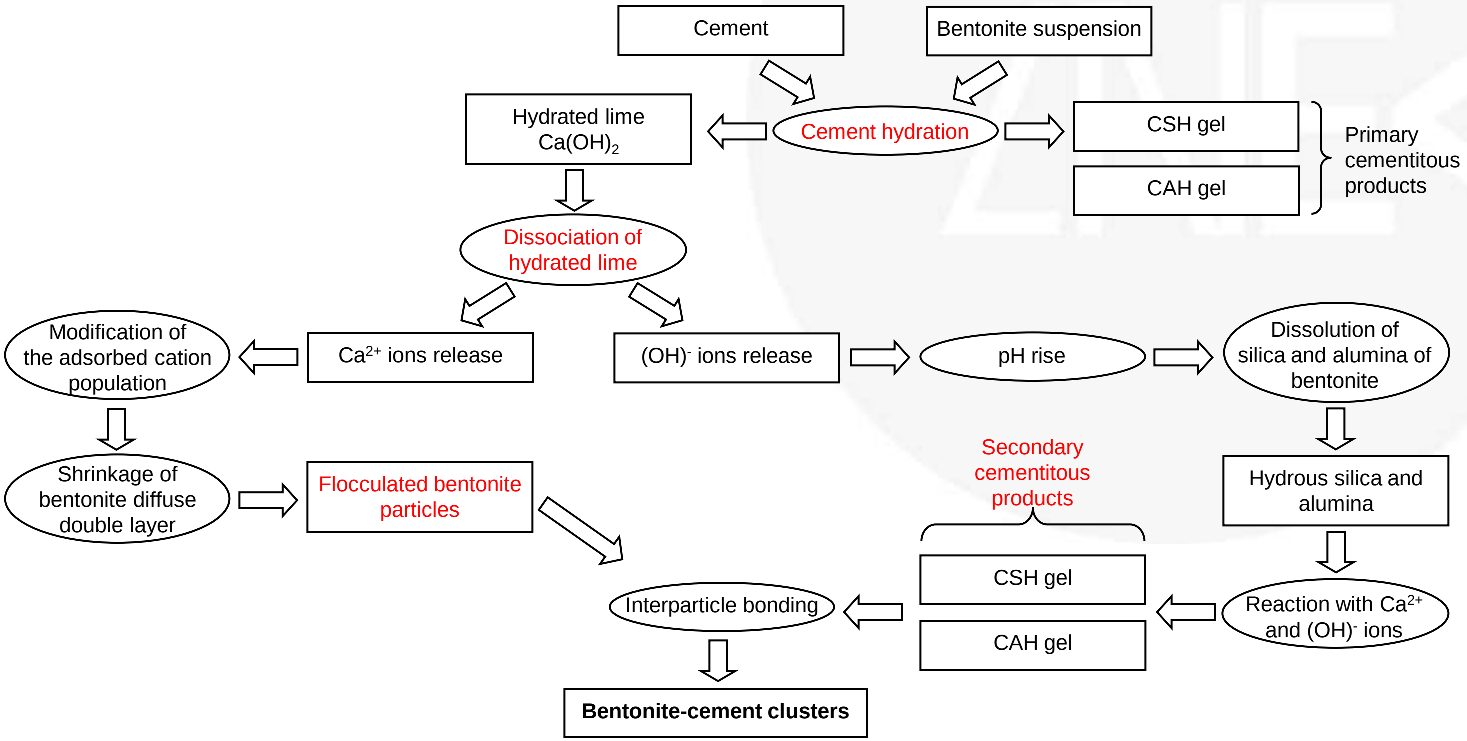

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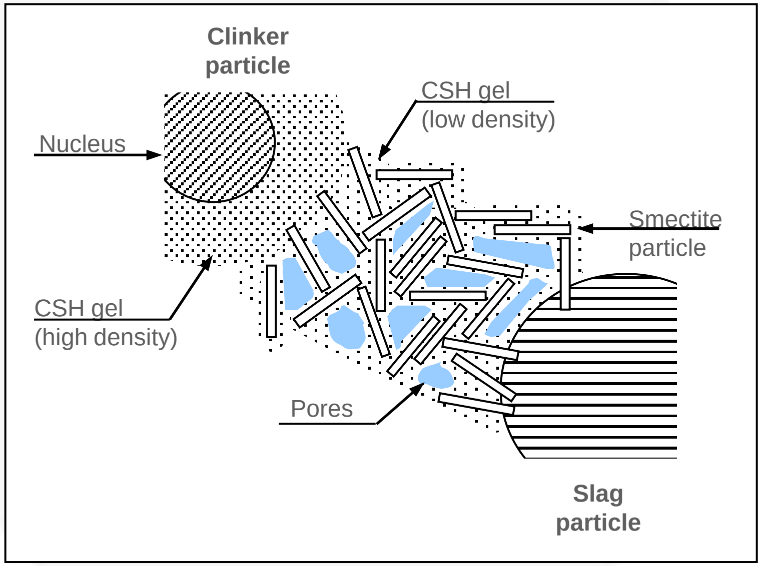
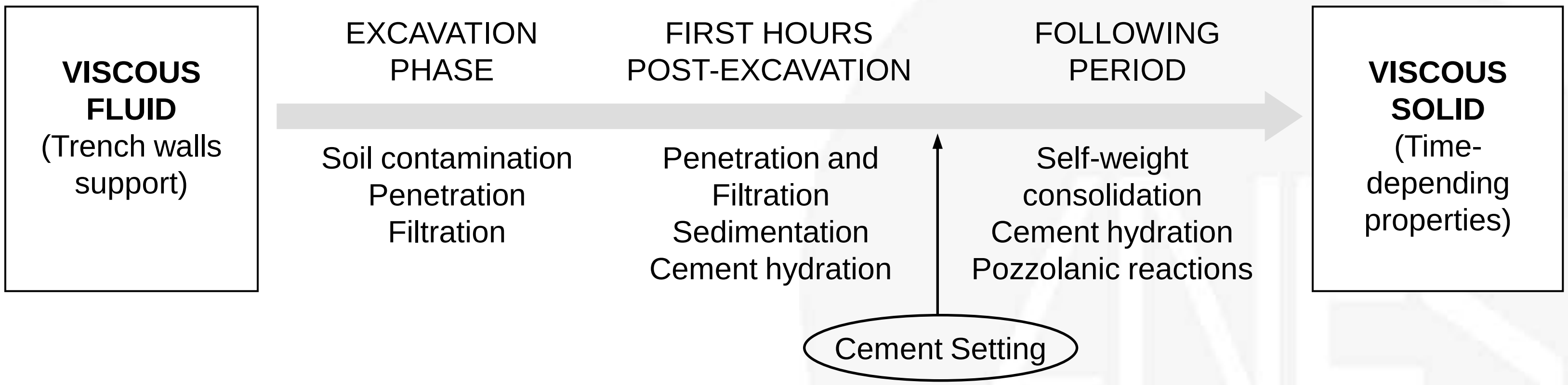


Bentonite-cement cluster

PROCESSES INVOLVED IN THE FORMATION OF THE CUT-OFF WALL MATERIAL



EXPERIMENTAL WORK

> Objectives.

- Identify and quantify the influence of the slurry composition, and mixing procedures upon the rheological behaviour of the fresh slurry.
- Identify and quantify the influence of the slurry composition, spoil contamination, curing time and surcharge loads upon the physical, mechanical and hydraulic behaviour of the hardened slurry.

EXPERIMENTAL WORK

> Experimental work description:

- Rheological characterization of self--hardening slurries.
- Characterization of the “cake” formed by filtration.
- Bleeding evolution of self-hardening slurries.
- Physical characterization of hardened slurry samples.
- Compressibility and threshold stress of hardened slurry samples.
- Strength and deformability of hardened slurry samples.
- Permeability of hardened slurry samples.

Marsh funnel and cup

Slurry composition	Marsh viscosity
35 kg bent. + 150 kg cement	47 s
35 kg bent. + 200 kg cement	49 s
50 kg bent. + 200 kg cement	105 s

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Fann viscometer

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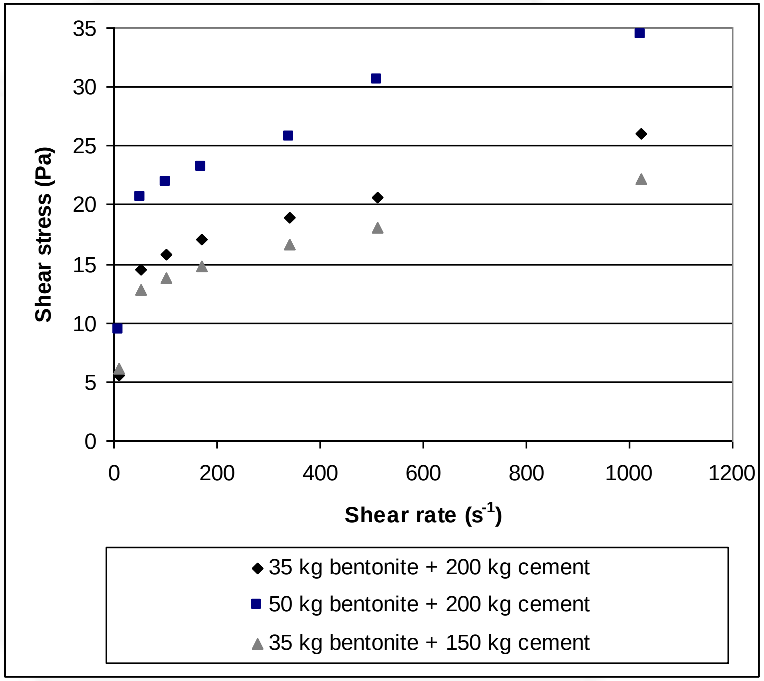

Slurry composition	Viscosity	Gel strength
35 kg bent. + 150 kg cement	8.0 cP	4.1 Pa
35 kg bent. + 200 kg cement	9.5 cP	4.6 Pa
50 kg bent. + 200 kg cement	12.5 cP	5.1 Pa

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Filter press

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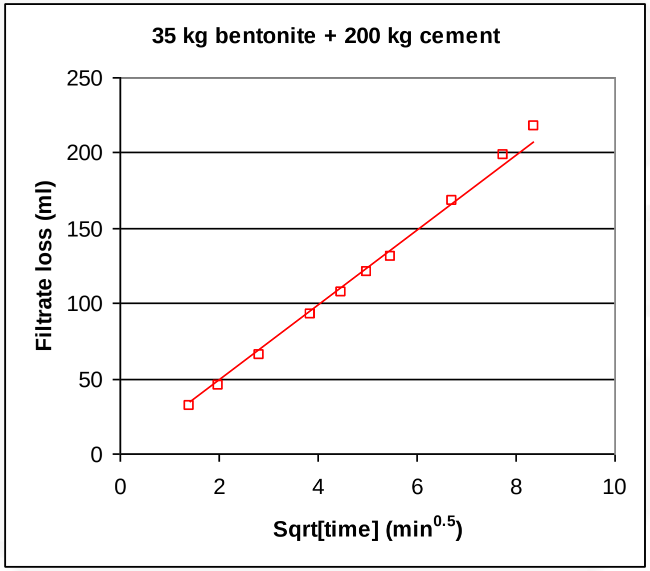

- "Cake" permeability: 1.7×10^{-8} m/s
- "Cake" unit mass: 1240 kg/m^3
- "Cake" water content: 122%
- "Cake" void ratio: 3.0

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Composition	Bleeding
35 kg bent. + 150 kg cement:	6%
35 kg bent. + 200 kg cement:	5 to 6%
50 kg bent. + 200 kg cement:	2%

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Slurry composition	Unit mass (average)
35 kg bent. + 150 kg cement	1145 kg/m^3
35 kg bent. + 200 kg cement	1155 kg/m^3
50 kg bent. + 200 kg cement	1165 kg/m^3

	Water content
35 kg bent. + 150 kg cement	395 to 445%
35 kg bent. + 200 kg cement	305 to 350%
50 kg bent. + 200 kg cement	300 to 325%

	w_L	IP
35 kg bent. + 150 kg cement	128%	22%
35 kg bent. + 200 kg cement	151%	38%

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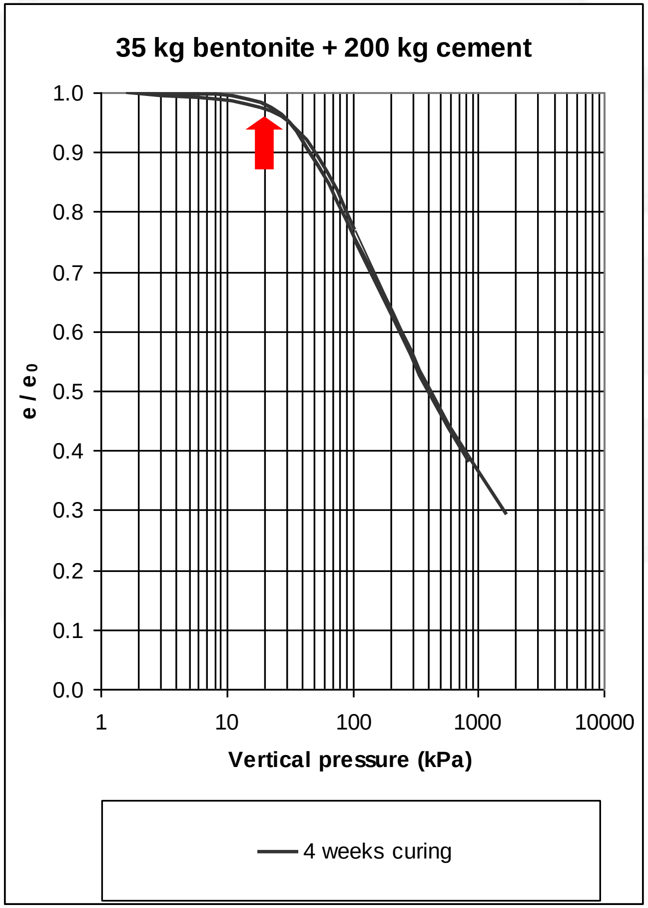

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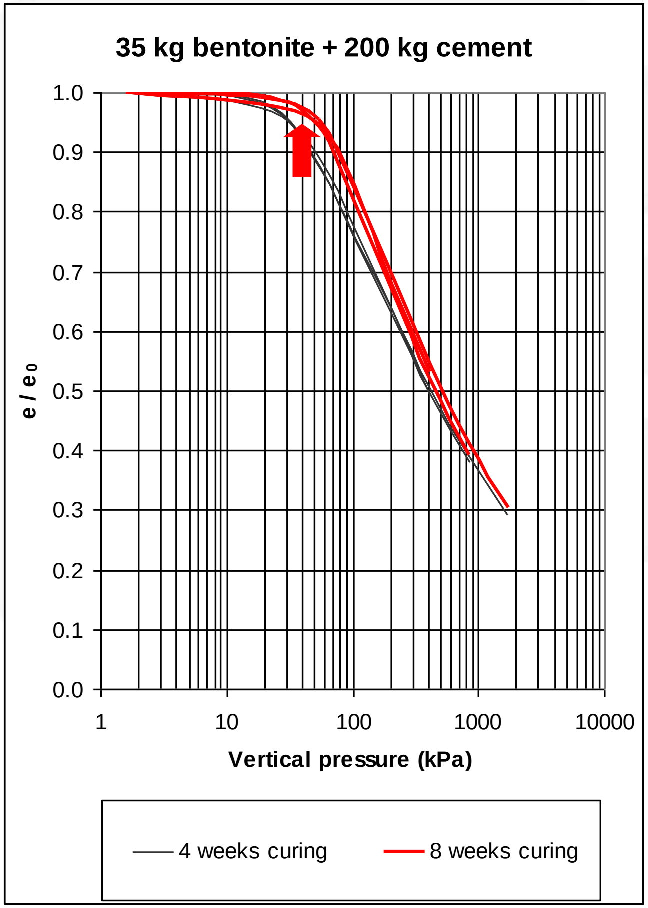

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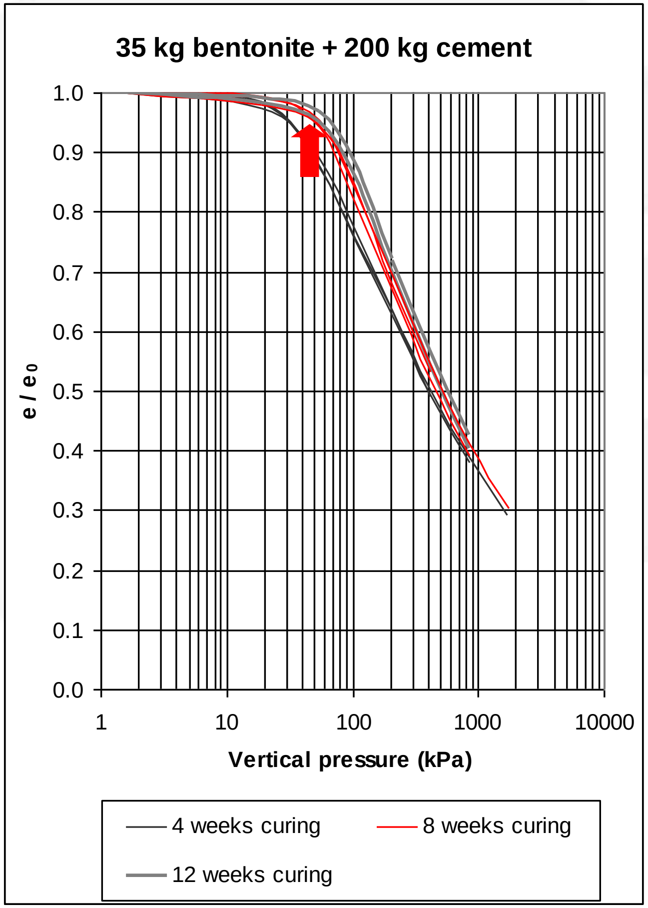

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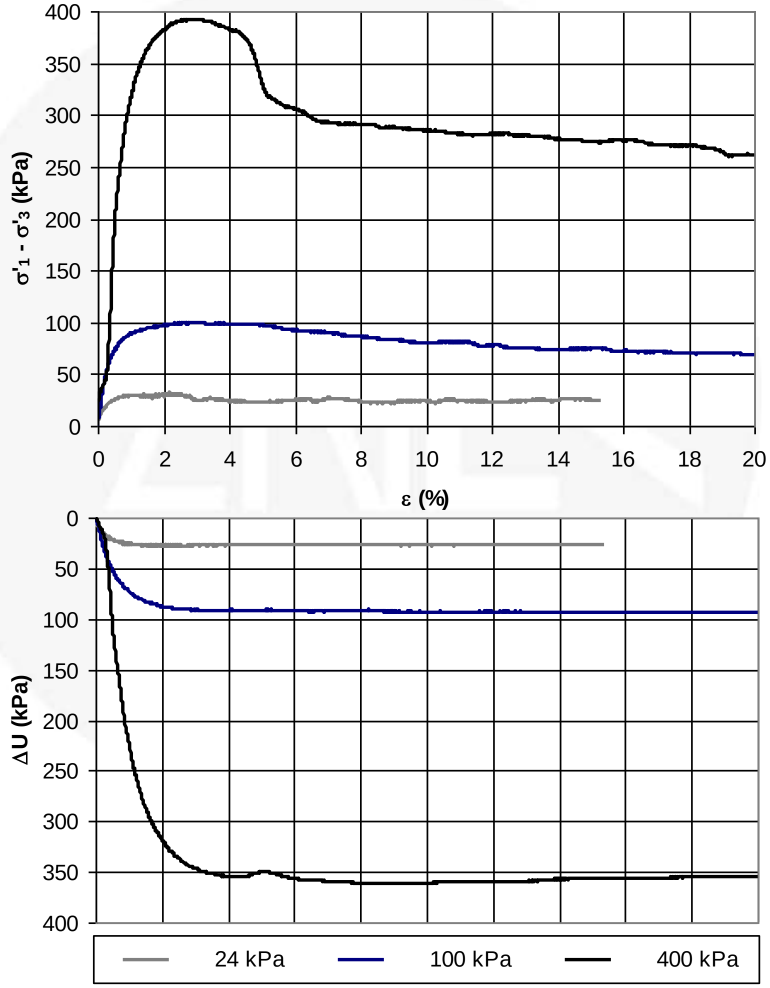

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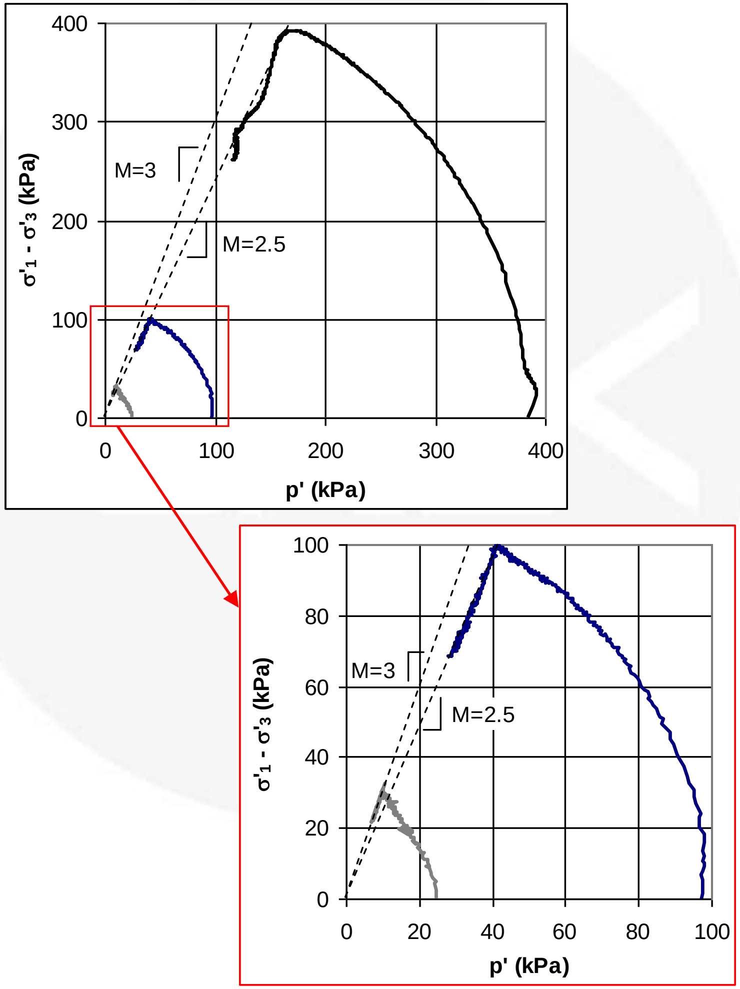

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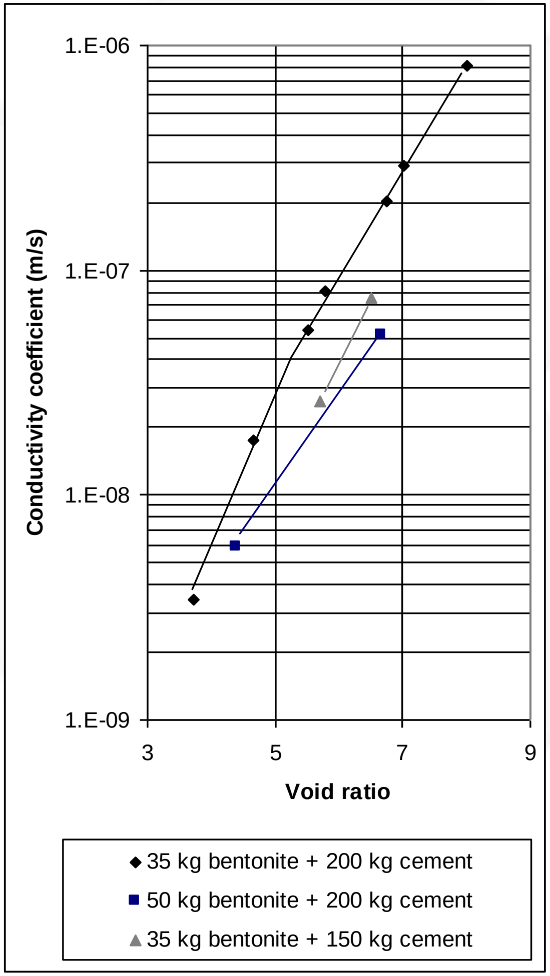

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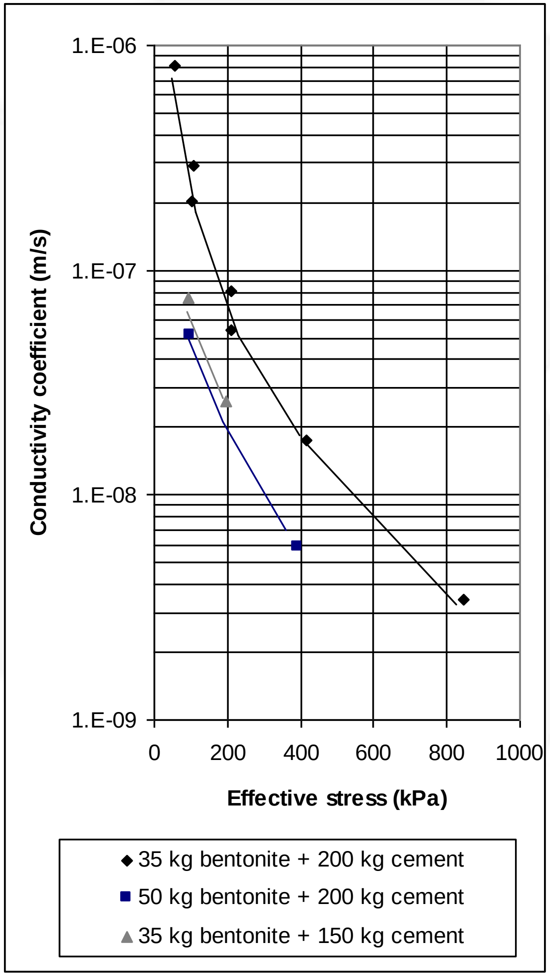

FUTURE RESEARCH

- Feasibility study regarding the use of piezocone penetration tests for assessing the integrity of self-hardening slurry cut-off walls, but also for determining permeability, strength and compressibility of the slurry "*in situ*".
- Feasibility study regarding the use of geophysical tests in assessing the integrity of self-hardening slurry cut-off walls and also in the characterization of its permeability.
- Sedimentation and self-weight consolidation analysis of self-hardening slurries using a consolidation column equipped with a gamma densimeter.
- Detailed study concerning the influence of slurry setting upon the development of slurry filtration, penetration and sedimentation processes.

LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

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