Bulletin Cemented Soil Dams
Properties of cemented soils

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Bulletin CSD : Table of content

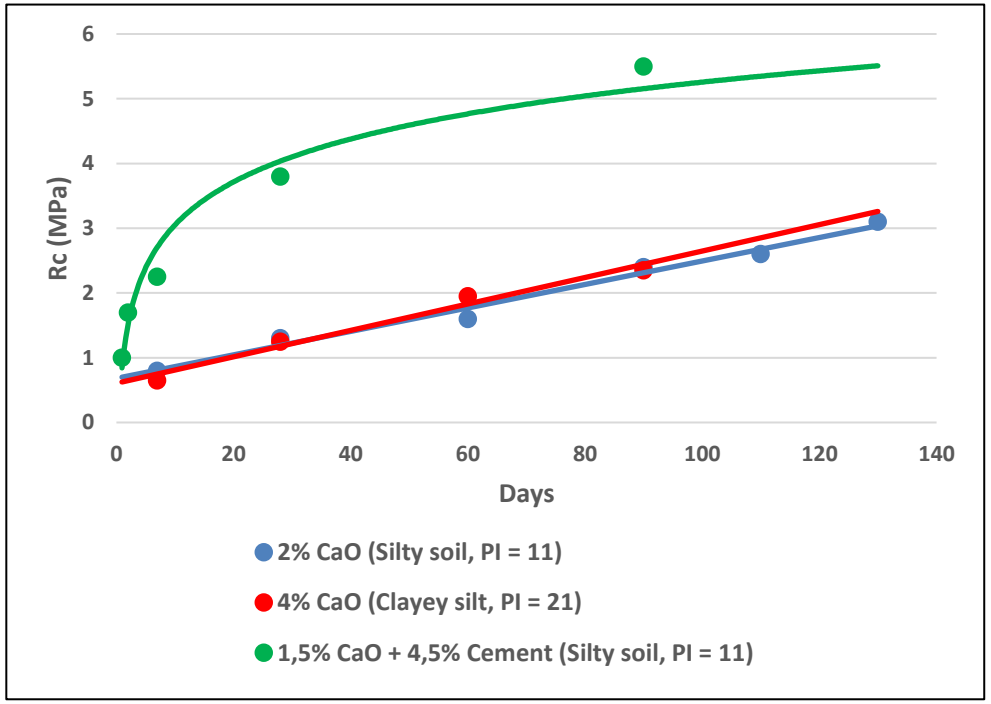
Purpose of Chapter 5 of the bulletin

- Chapter 5 recollects for more than 30 pages the properties of the cemented materials which have been reporded in the litterature or illustrated from examples and experiments. i.e.:
  - Mechanical performances and rheological behavior: UCS, Tensile strength, elastic and plastic deformations, compressibility, erosion resistance, behavior as regard to cracking;
  - Permeability and Hydraulic performances of the treated soil;
  - Long term resistance from external agressions.
- Performance of cemented soils depends on several parameters:
  - *binder (type and dosage),*
  - *soil (particle size distribution, fine content, clay content, activity and mineralogy, water content, etc),*
  - *density after compaction, curing time and temperature...*

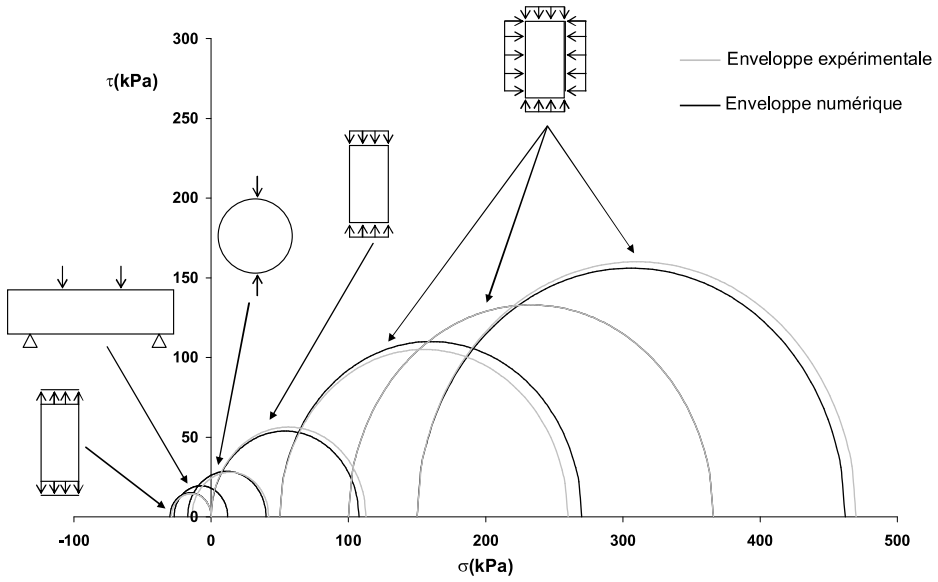
The data presented in the bulletin have been collected from a very large documentation (more than 200) published all over the world

Unconfined Compression Test

- Mechanical improvement of soil resistance is commonly measured by the UCS test.
- Example is given showing increase of strength for two types of soils treated with lime and cement.
- There are a lot of examples of silty clays and clayey soils treated particularly with lime which show significative increase of strength, even if this increase may take time (sometimes over one year), even with high plasticity clays)
- UCS is often taken as a key parameter to govern other mechanical performances of the soil (tensile strength, elastic modulus)



Determination of tensile properties



(from Abdelkhader Ammeri thesis -2009)

- Tensile strength is a significant parameter for road design
- This is also the case for concrete dam designers.

Soil failure envelopes from usual tests are shown on this schematic diagram:

- Triaxial test,
- Unconfined Compression Test,
- Tensile tests : splitting test (R_{it}-Brazilian test), flexural test and direct tensile test (R_t)
- Results obtained: R_{it}/UCS = 0,10 to 0,11

and: R_t = 0.8 R_{it} from european experience .

Examples of elastic modulus versus UCS

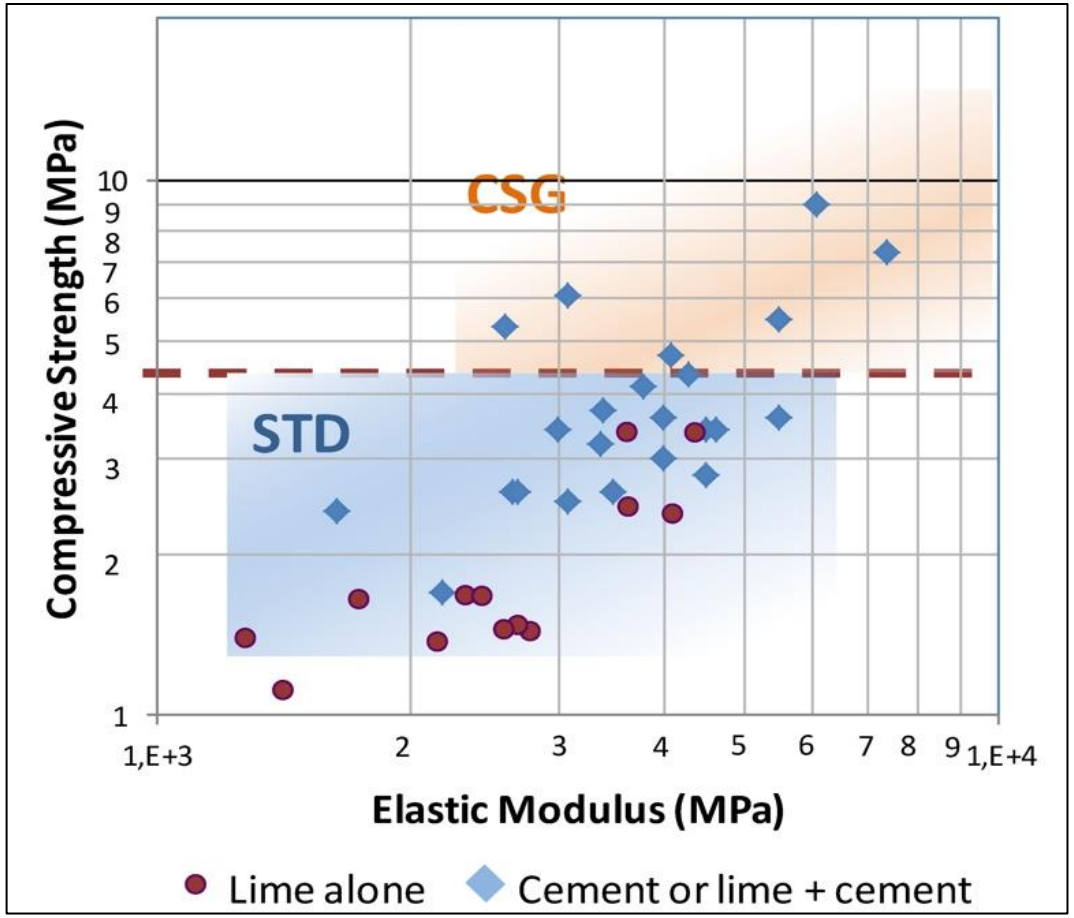
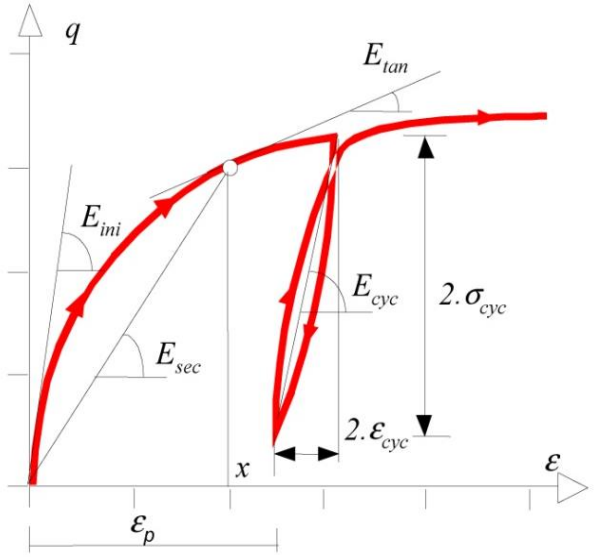
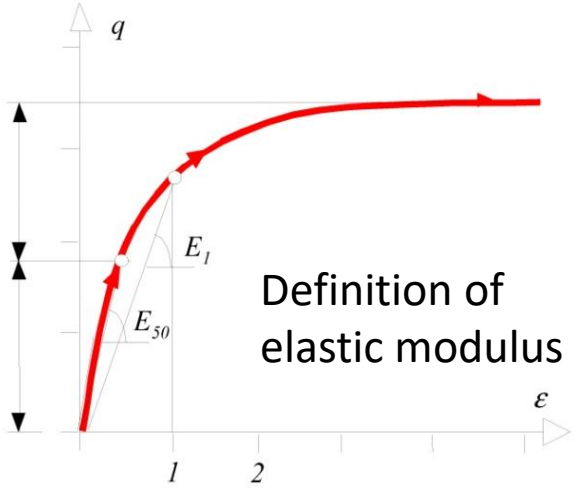


Diagram from French data base on road pavement.

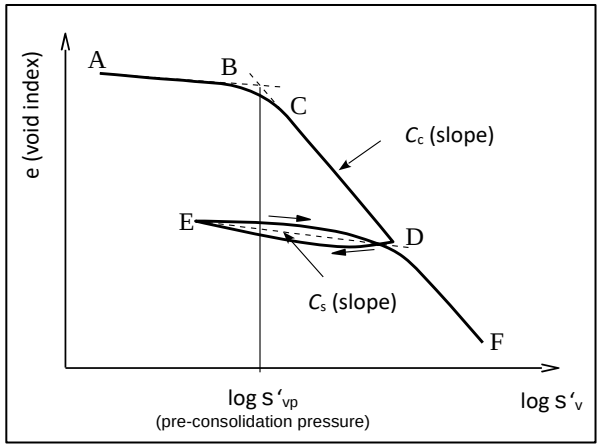
the usual ratio of Elastic modulus versus UCS of 10^3 is also obtained with soil treated either by lime alone or by lime+cement.

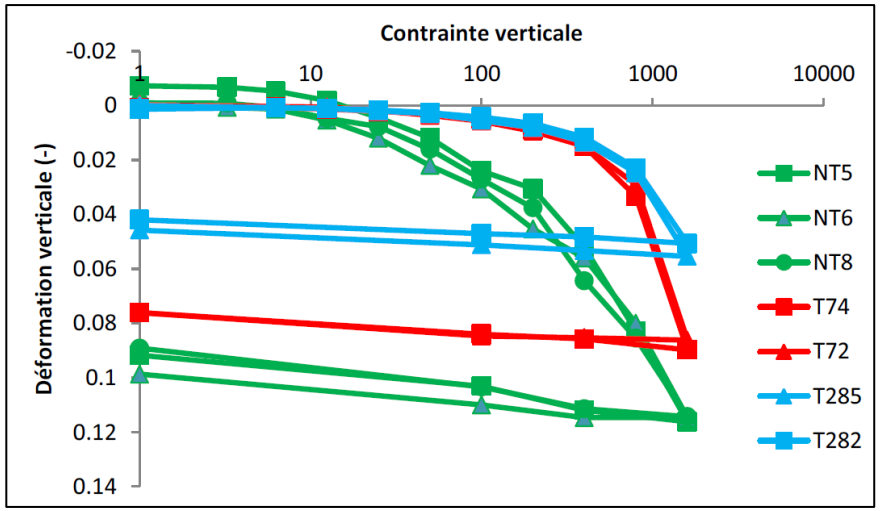




Definition of elastic modulus

Plastic deformations of treated soils





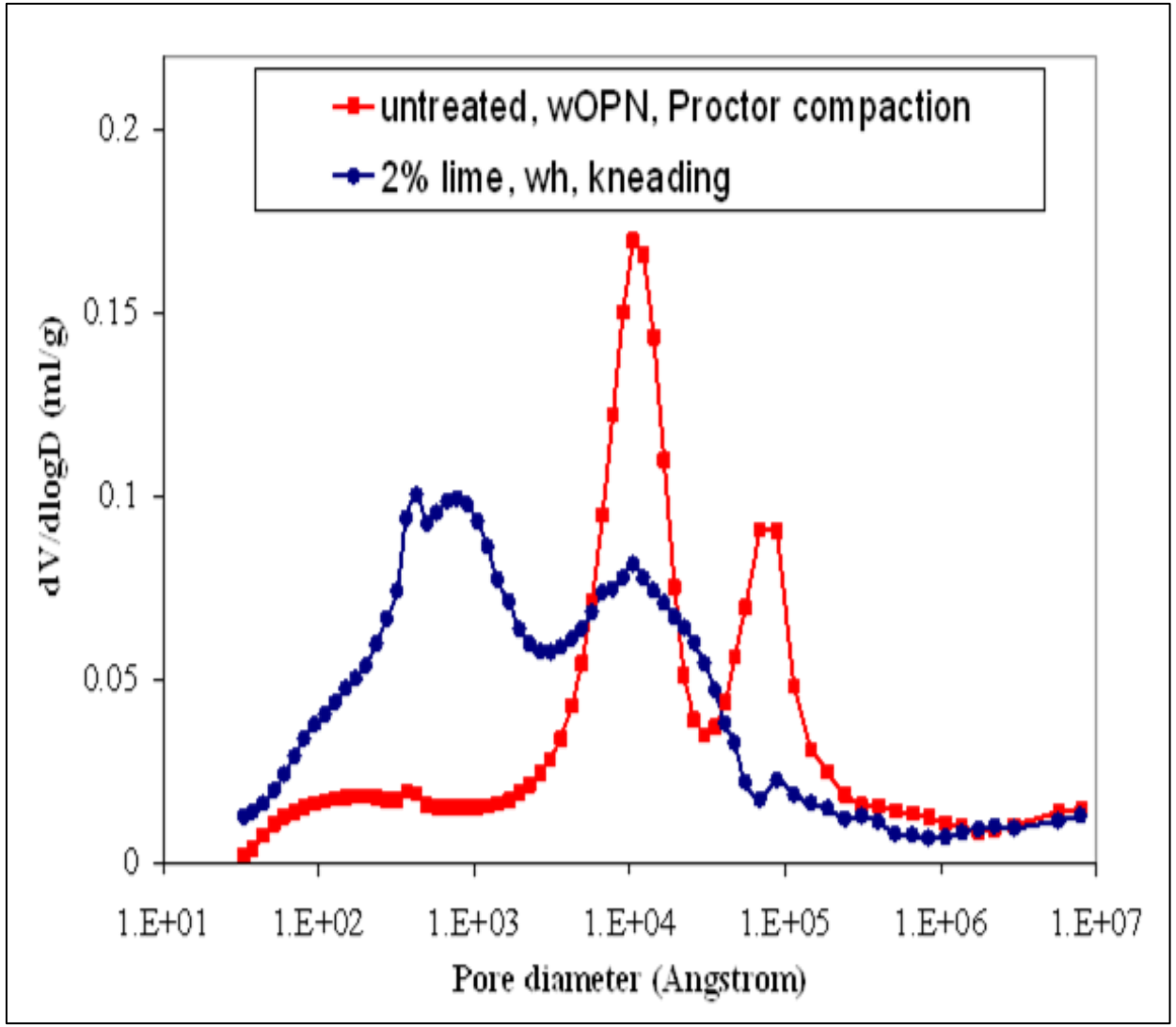
- DigueElite French research program (2015-2017) and other publications are reported in the bulletin.
- Major conclusions:
  - treatment causes significant increase in isotropic elastic stiffness and yield strength,
  - the threshold becomes much greater than the stresses generally encountered in small hydraulic structures (i.e 200 to 300 kPa)

Permeability of treated soils

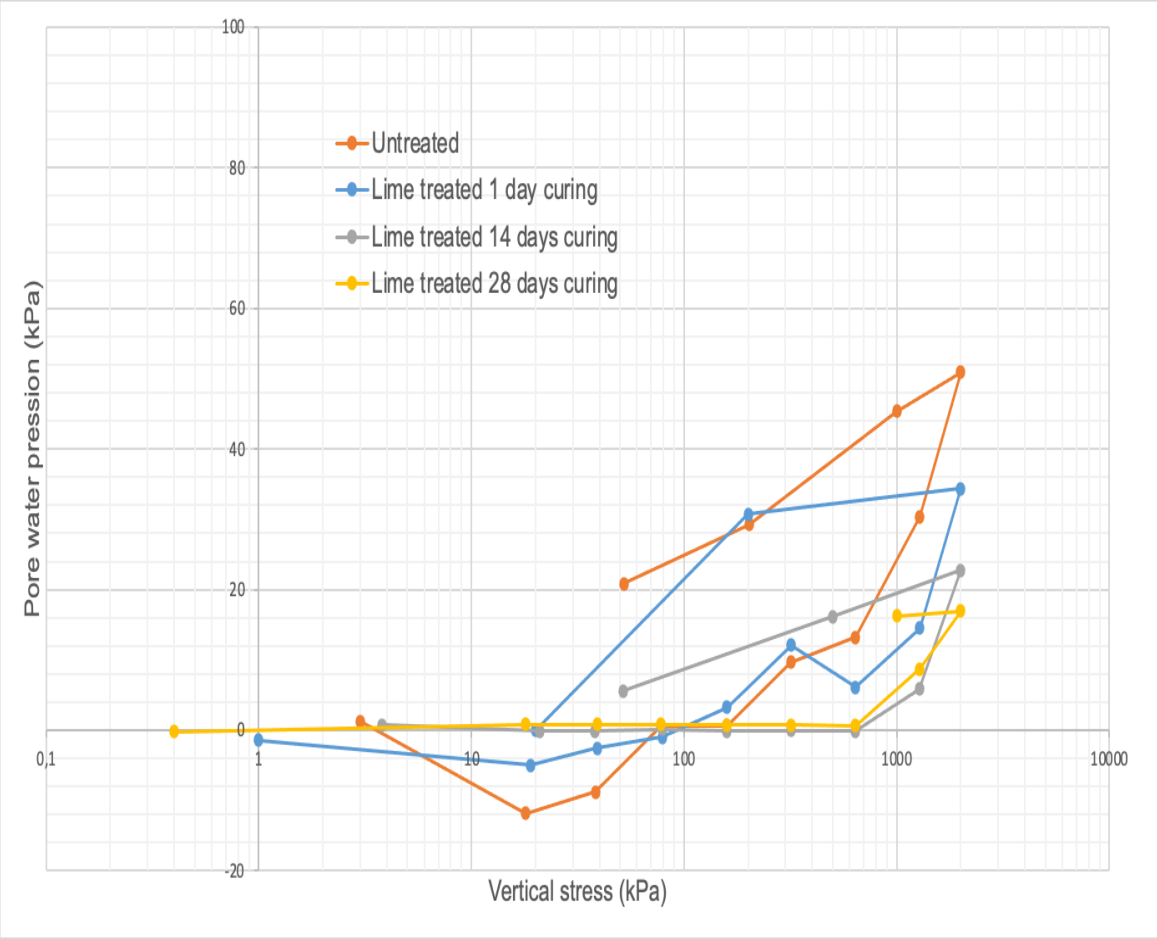
- Permeability of cemented soil depends on the way it has been compacted:
  - compacted with kneading effect
  - on the wet side of the OMC (1.05 to 1.15 OMC), with saturation ratio <95%,

  then the permeability will be similar or even less than the permeability of the natural soil.

- Explanation:
  - New pore size distribution within the structure of the soil after treatment.



Pore pressure development



- Pore pressure development in the body of an embankment depends:
  - on the degree of saturation and compressibility of the compacted soil
  - on the coefficient of consolidation (evolving with time) and construction progress rate.
- Workshop organised by the French Committee (CFBR) 2016-2018)
  - including extensive laboratory tests
  - numerical associated modelling of a 30m high CS Dam construction

leads to the conclusion that insignificant development of pore pressure within the treated soil is recorded when σ_v <1 Mpa, provided Sr<90%

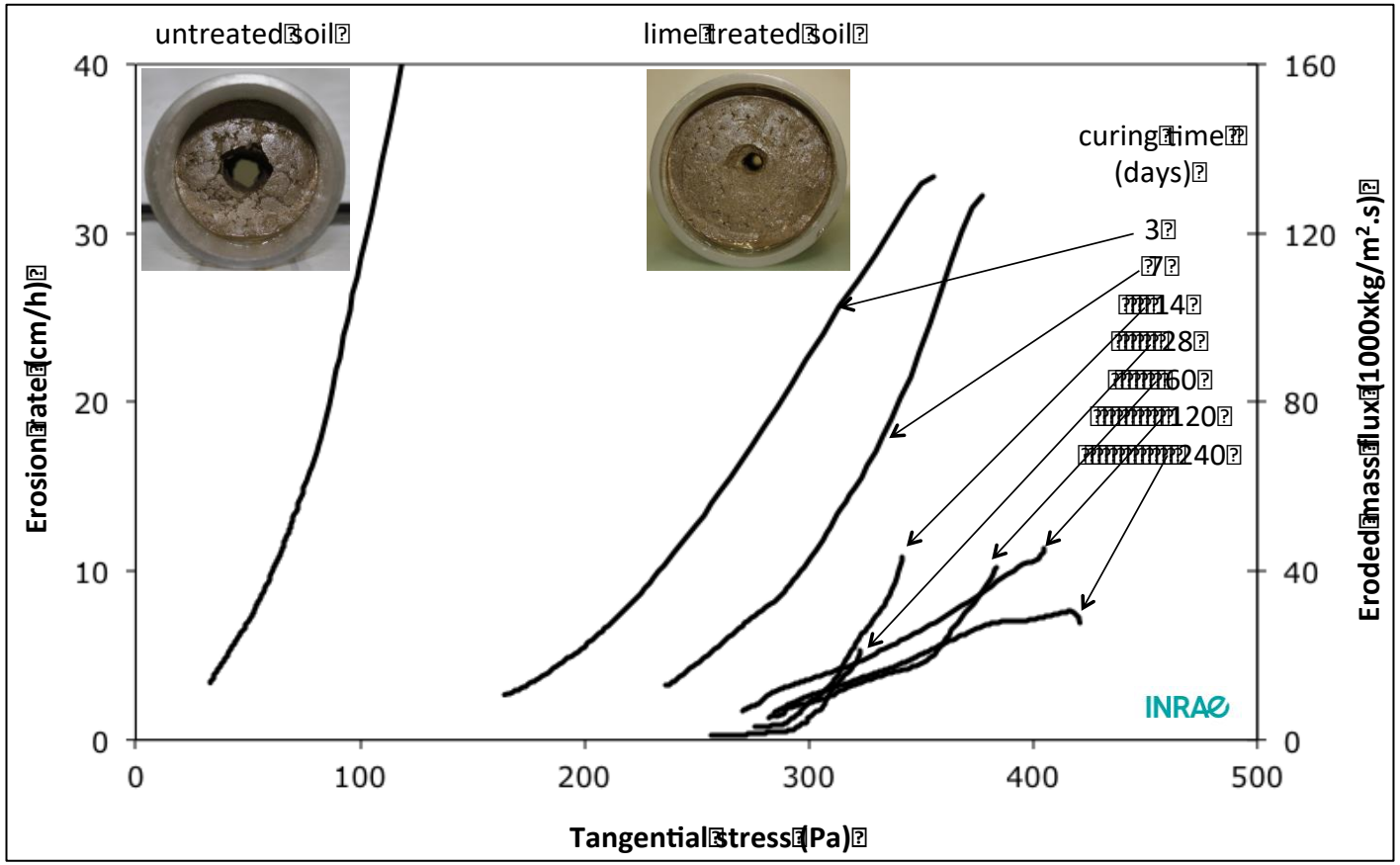
- *Internal erosion*

➢ Internal erosion is subject of ICOLD bulletin 164

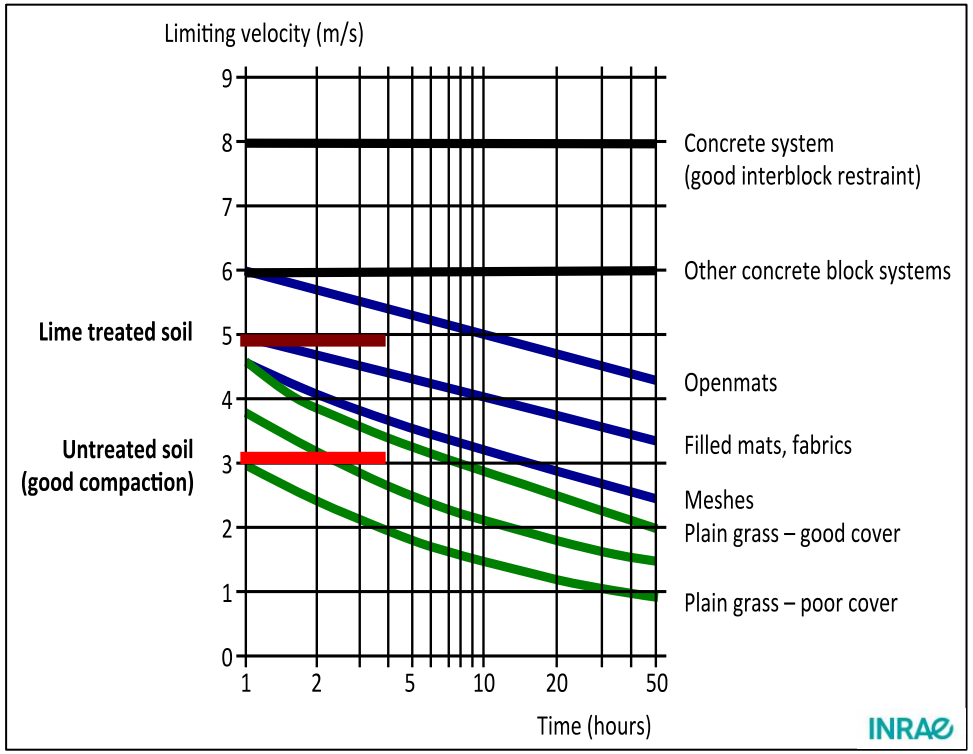
➢ Hole Erosion Test (HET) is the laboratory test allowing to assess the performance of the material

➢ Critical stress (erosion threshold) multiplied by 6 to 10

➢ Erosion index increases with time, when the treated soil improves its resistance



- *External erosion*



- Important property in relation with the performance of treated soils as regard to overtopping and overflowing of hydraulic structures.
- Full scale models developed to analyse the performance: DigueElite research program (award of innovation in Vienna 26th Congress), in the South of France for the SYMADREM construction and rehabilitation of levees, in China for the Heilongjiang Pangtoupao levee.
- But also with lived experiences of overflowing like on the crest of the cofferdam Pannecière in France
- and also with the construction of a dam in Burkina Faso designed to be able to resist to limited overflows.

Other properties developed in chapter 5 of the bulletin

Sediment dredging of the Friant Kern canal during maintenance operations in 2010
The picture shows by itself erosion resistance of the lime treated section

- Behavior improvement of dispersive clays
  - Numerous examples of repairs of dams and levees, and also treated material used as protection layer for the core of high dams in USA and in Swaziland.
- Long term behavior and resistance to weather
  - Numerous examples of a good behavior of hydraulic structures. The most emblematic example: the Friant-Kern canal
- Cracking of treated soil and self-healing
  - Cracking within the stiffer cemented material is to be controlled, as for all other embankment. However, a self-healing capacity of the cemented material to allow restoration of the monolith.

Thank you for your attention