SOIL MIX
Belgian research activities

SOIL MIX PROJECT – IWT 080736

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Topics

1. Introduction

2. Purposes of the SOIL MIX Project

3. Test results
   - 3.1 Mechanical characterization
   - 3.2 Durability
   - 3.3 Permeability
   - 3.4 “Steel-soil mix” adherence

4. Perspectives

1. Introduction

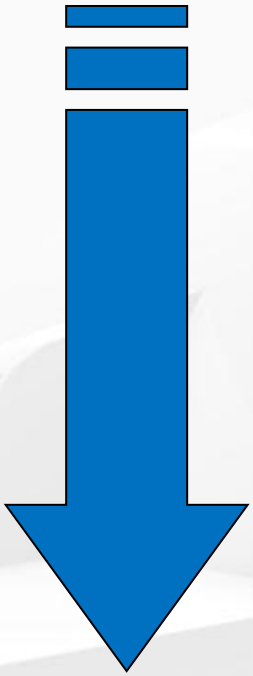
- Since 2003
  - Laboratory testing
    - Unconfined compressive strength (UCS)
    - Elastic modulus (E)
- Research project "Retaining structure" (2007-2013)
  - Berlin walls, secant piles walls, diaphragm walls, ...
  - Deep Soil Mix walls (DSM)
    - Quality assessment procedure – development of guidelines
- New project "SOIL MIX" (2009-2013)
  - SOIL MIX – IWT 080736
    - BBRI, ABEF, KULeuven

→ permanent use and bearing capacity

2. Purposes of the SOIL MIX Project

Current application of SOIL MIX

Temporary retaining structure



Gaps:

1. Mechanical characteristics
2. Durability
3. Permeability
4. 'Steel – soil mix adherence'

Intended application

Foundations – bearing capacity
Permanent retaining structures

3. Test results

3.1 Mechanical characterization

Sampling

- Boring
- Transport
- Conservation conditions

Analysis of soil inclusions in the soil mix

Density

- Test procedure and results

Unconfined compressive strength(UCS)

Elastic modulus (E)

Tensile splitting strength (T)

⇒ *Guidelines have to be provided*

3. Test results

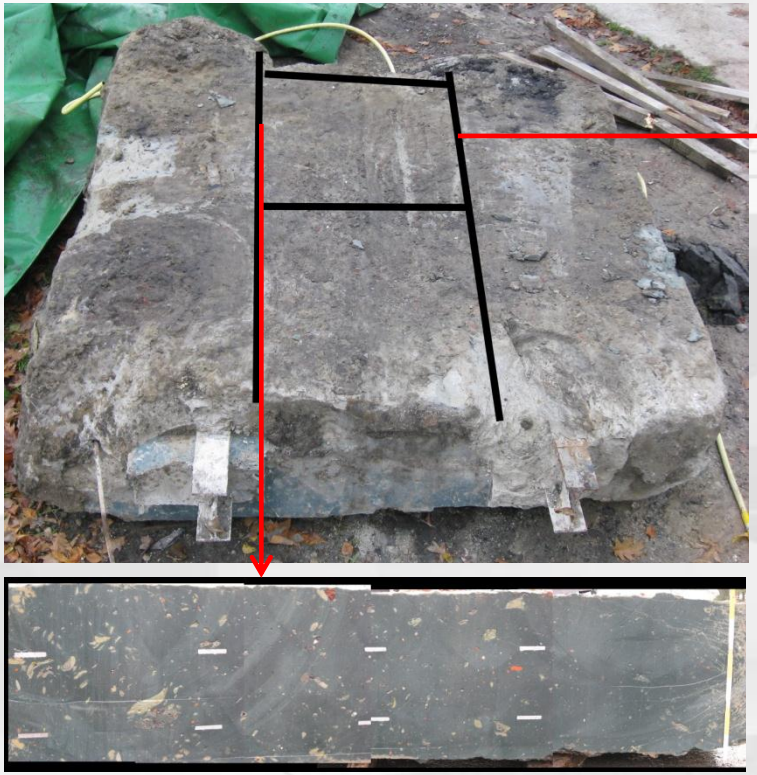
3.1 Mechanical characterization

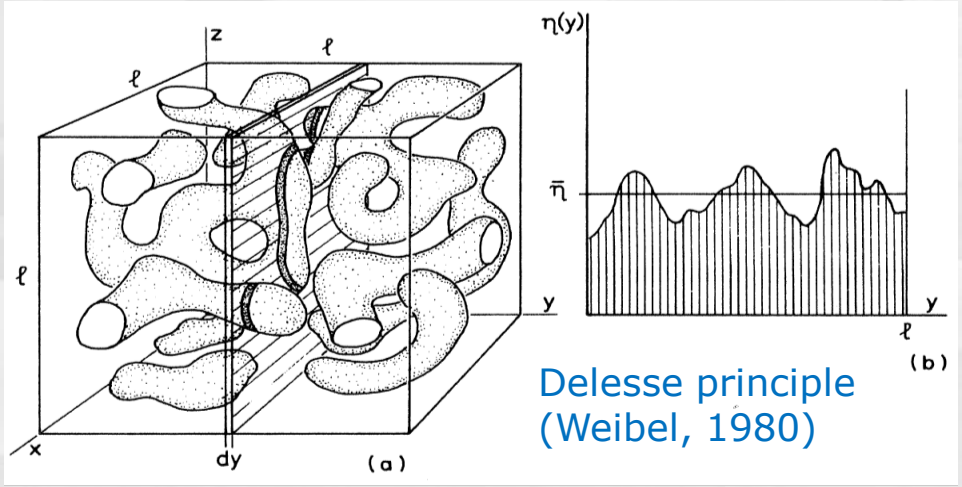
Soil inclusion analysis

Soil or soft inclusions into the mix

Sawn column/panel: surface analysis

Surface % ⟶ Volume % (Weibel, 1980)





Delesse principle (Weibel, 1980)

3. Test results

3.1 Mechanical characterization

Soil inclusion analysis

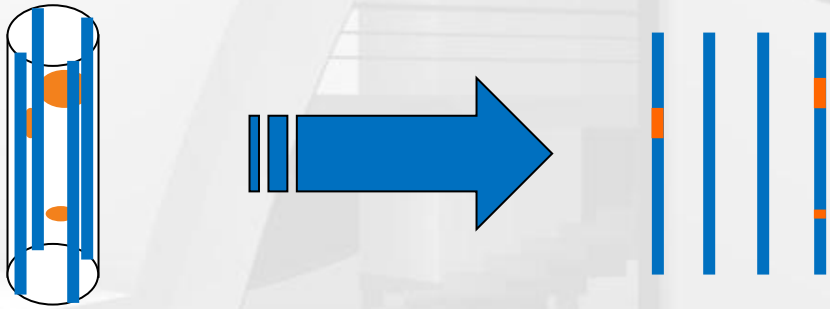
Soil or soft inclusions into the mix

Sawn column/panel: surface analysis

Surface % ⟶ Volume % (Weibel, 1980)

Cores: line analysis

Line % ⟶ Volume % (Weibel, 1980)



→ Inclusion percentage

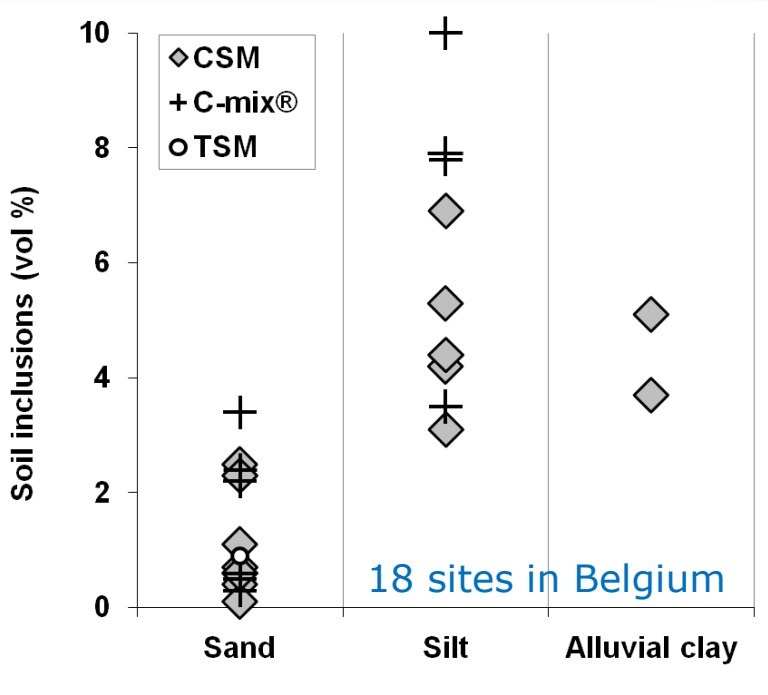
- **"Soil mix: influence of soil inclusions on structural behaviour" in ECSMGE – Athens 2011**
- **"Deep Mixing Technology in Belgium: Execution of Retaining Walls and Design Properties of Deep Mixed Material" in Grouting and Deep Mixing conference – New-Orleans 2012**

3. Test results

3.1 Mechanical characterization

Soil inclusion analysis

Soil or soft inclusions into the mix



Tertiary and quaternary sands: [0 à 3.5%]

Silty soils or alluvial clays: [3 à 10%]

Clayey soils with organic material (peat)
tertiary (overconsolidated) clays → 35%

- "Soil mix: influence of soil inclusions on structural behaviour" in ECSMGE – Athens 2011
- "Deep Mixing Technology in Belgium: Execution of Retaining Walls and Design Properties of Deep Mixed Material" in Grouting and Deep Mixing conference – New-Orleans 2012

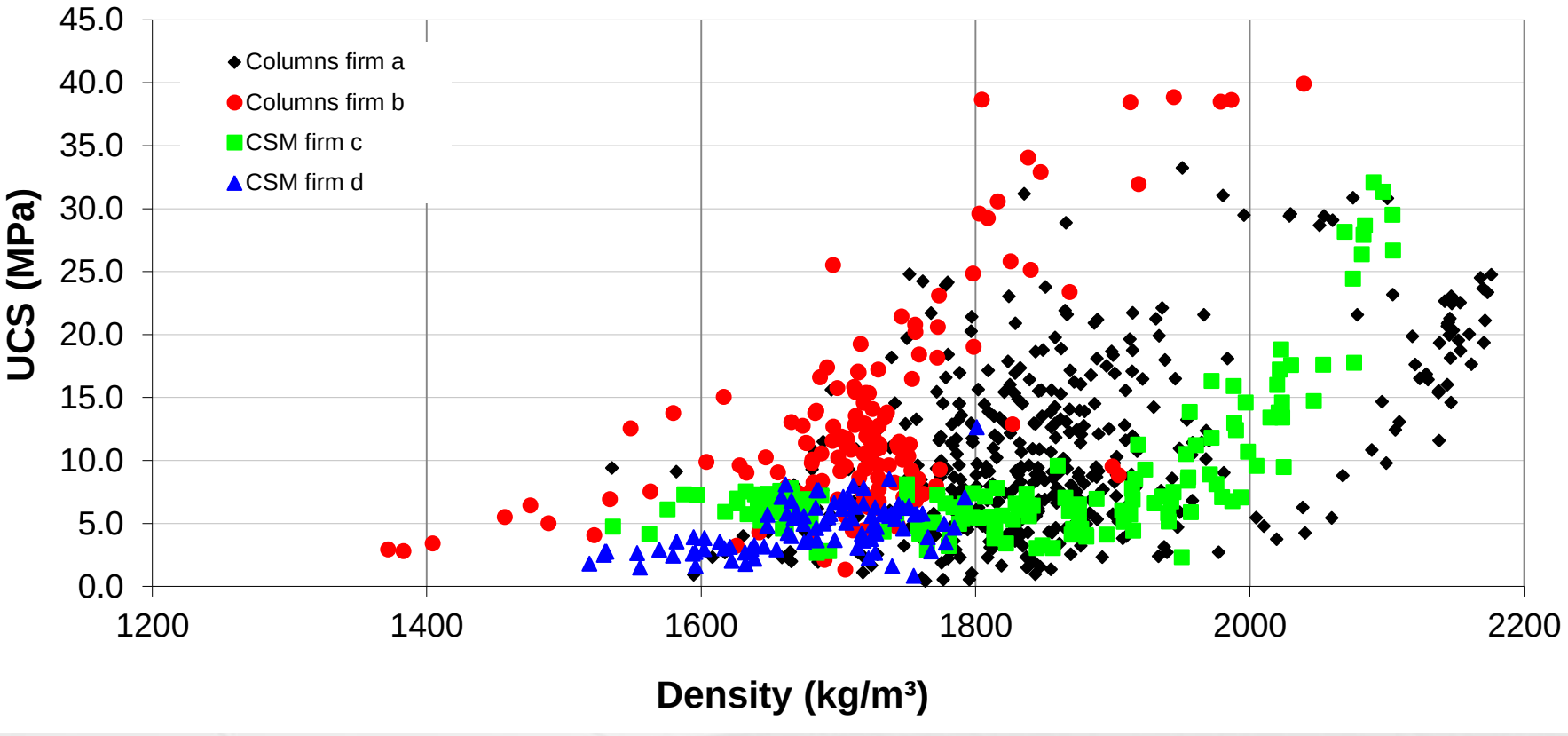
3. Test results

3.1 Mechanical characterization

Unconfined compressive strength (UCS)

Density – UCS

22 sites in Belgium
(clay - silt - sand)



Influence of the density?

3. Test results

3.1 Mechanical characterization

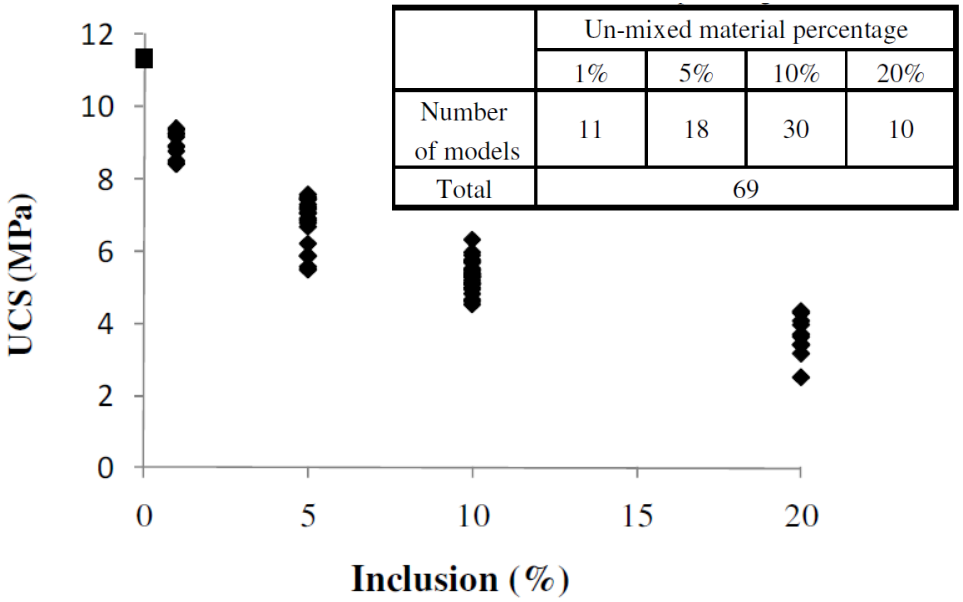
Soil inclusion influence – numerical simulations

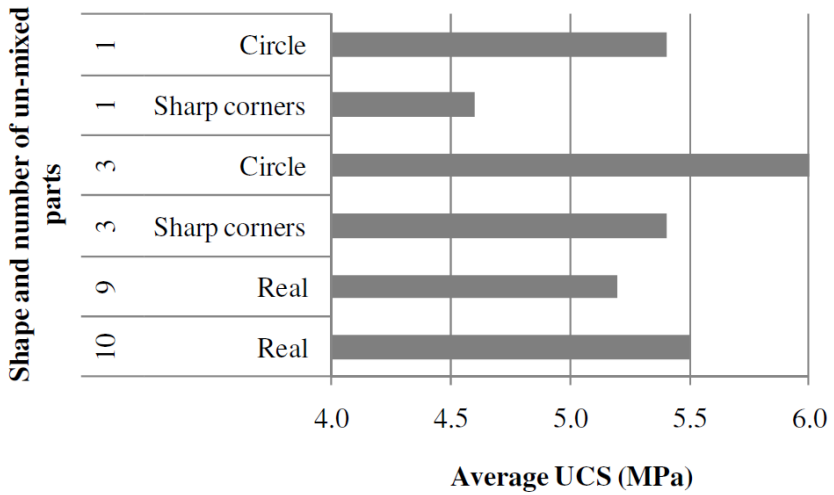
→ Unconfined compressive strength (UCS)

Calibration: soil mix block (large scale - 1.2 x 0.55 x 0.55m)

- "Plastic Numerical elasto-plastic simulations of soil mix: Study of the effect of inclusions", research report, KUL (2011)

	Un-mixed material percentage			
	1%	5%	10%	20%
Number of models	11	18	30	10
Total	69			





In a later phase, **discontinuous simulations** are planned, so that individual fracture growth can be investigated.

3. Test results

3.1 Mechanical characterization

Soil mix block (large scale)

- "Uniaxial Compression Test on Large Soil Mix Block (Knokke site)", rapport de recherche interne, KUL (2011)
- "Rock mechanical tests on core samples from soil mix block (site of Knokke)", research report, KUL (2011)

CSM – Knokke – sand

52.9cm × 60.9cm × 124.0cm

The UCS-value is 8.3 MPa.

At 50% of the peak strength, E_t = 13.6 GPa and E_S = 16.0 GPa.

Cores with a diameter of 113 mm, drilled inside the block after testing, resulted in an average UCS value of 11.9 MPa.

No significant decrease is observed when the sample is about 5 times larger. For typical rock material, one would expect a reduction by a factor 2 or 3. The reason why this is not observed is probably the fact that the **soil mix material is relatively more homogeneous than most rocks**.

Not many macro-fractures are observed

3. Test results

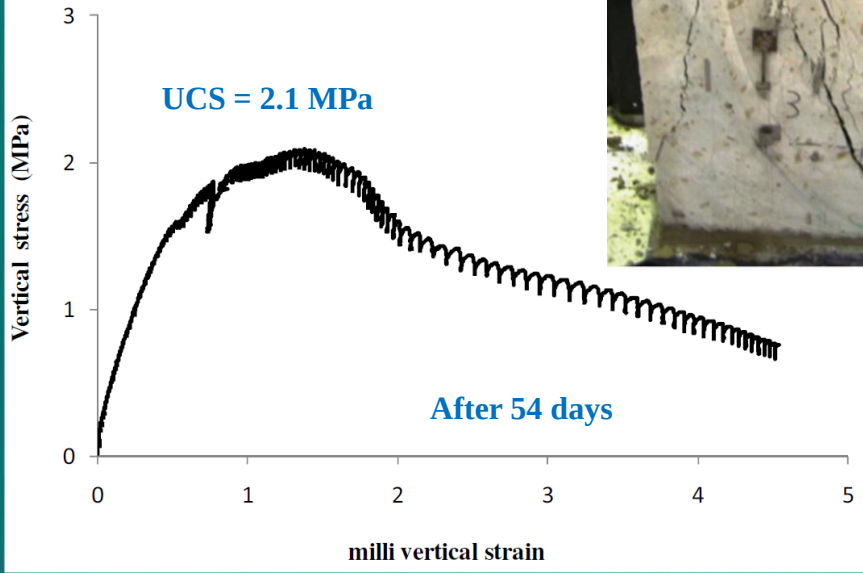
3.1 Mechanical characterization

Soil mix block (large scale)

- **"Uniaxial Compression Test on Large Soil Mix Block (Knokke site)", rapport de recherche interne, KUL (2011)**
- **"Rock mechanical tests on core samples from soil mix block (site of Knokke)", rapport de recherche interne, KUL (2011)**

CSM – Wetteren – remolded soil (sand/silt)

54.9cm × 48.4cm × 89.9cm



UCS-value is 2.1 MPa.

At 50% of the peak strength:
E_t = 2.9 GPa and E_s = 3.3 GPa.

Cores with a diameter of 113 mm, drilled inside the block after testing, resulted in a average UCS value of 4 MPa → a decrease of about a factor 2.

In comparison to Knokke, the reduction is larger, but the material was also much more heterogeneous than in Knokke.

The reduction is more similar as what one would expect for typical rock material, i.e. a reduction by a factor 2 or 3.

3. Test results

3.1 Mechanical characterization

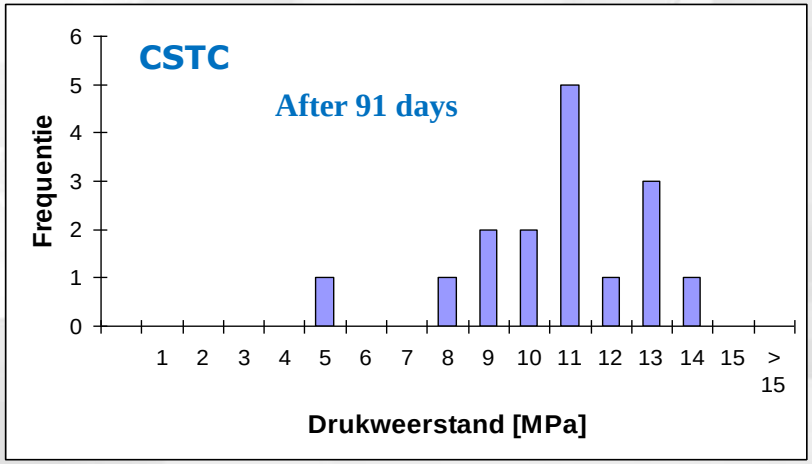
Test on soil mix block (large scale)

→ Characteristic UCS-value

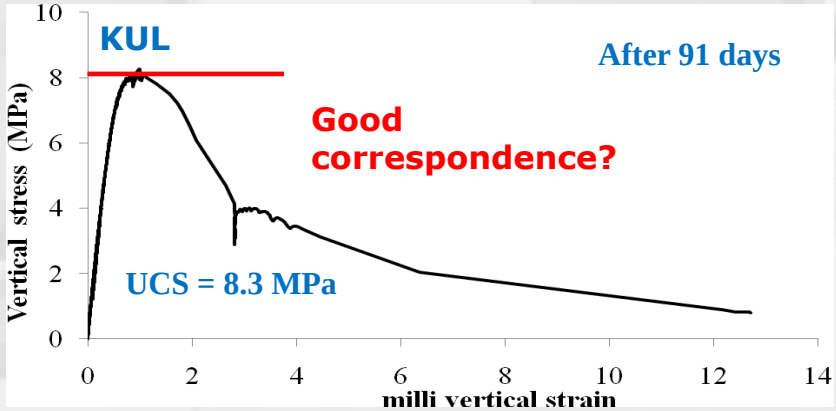
- "Deep Mixing Technology in Belgium: Execution of Retaining Walls and Design Properties of Deep Mixed Material" in Grouting and Deep Mixing conference – New-Orleans 2012

Histogram of UCS-values [MPa] from cored samples of Knokke panel

Characteristic UCS-value = 7.0 MPa*next slide
Lognormal distribution*next slide



Curve ε-σ for the Knokke block (large scale)

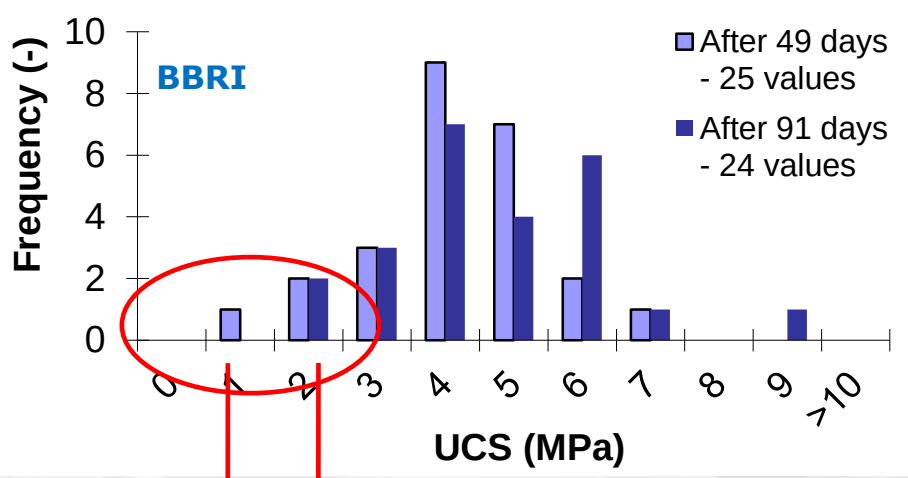


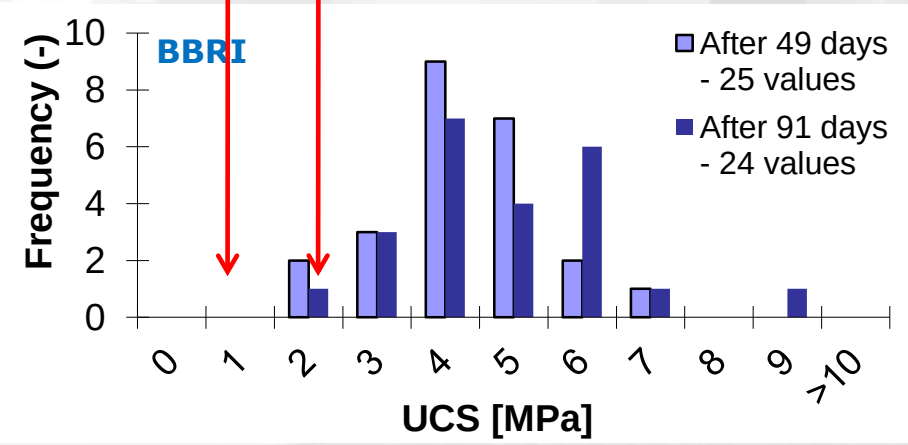
3. Test results

3.1 Mechanical characterization

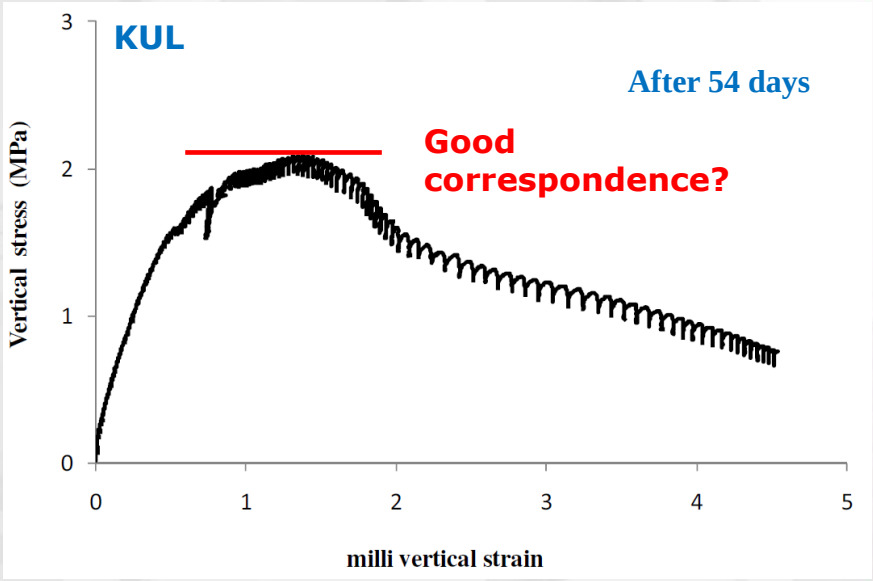
Test on soil mix block (large scale)

→ Characteristic UCS-value





Curve ε-σ for the Wetteren block (large scale)



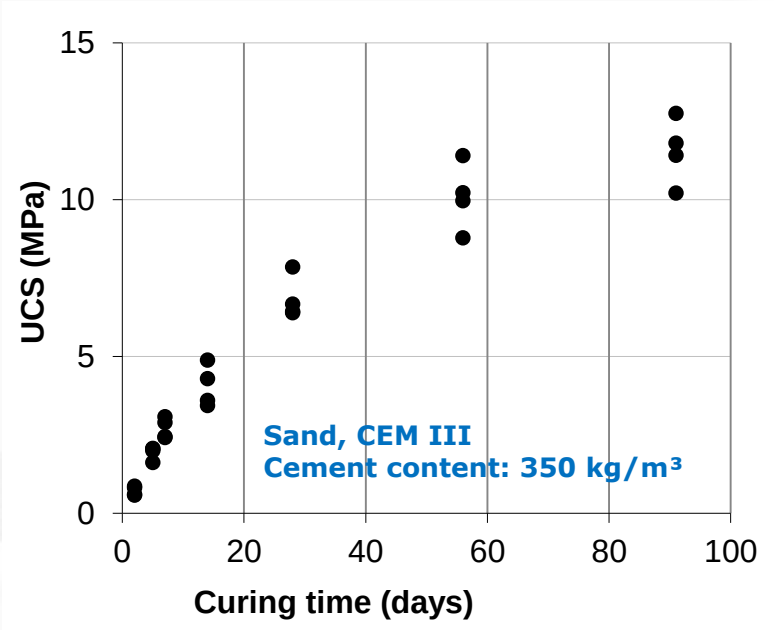
Representativeness of the cores:
Samples with inclusions
> 1/6 D are excluded

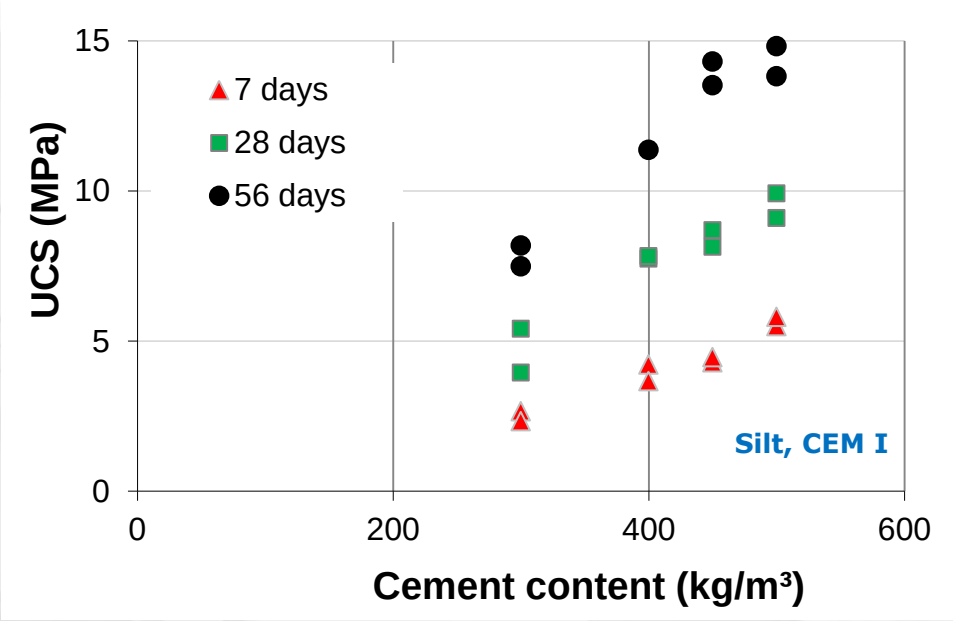
After 49 days : 1.7 → 2.5 MPa
After 91 days : 2.4 → 2.7 MPa

3. Test results

3.1 Mechanical characterization

UCS – curing time





EN 1992-1-1

$$UCS_m(t) = \beta_{cc}(t)\, UCS_m$$

$$\beta_{cc}(t) = \exp\left(s\left(1 - \sqrt{\frac{28}{t}}\right)\right)$$

t = curing time (days)
s = empirical parameter [-] → Soil type, W/C, Cement type

CSM : 0,96 <s<0,99
CVR : 1.28<s<1.71

"SOIL MIX walls as retaining structures – critical analysis of the material design parameters" in Geotechnical Challenges in Megacities Conference – Moscow 2010

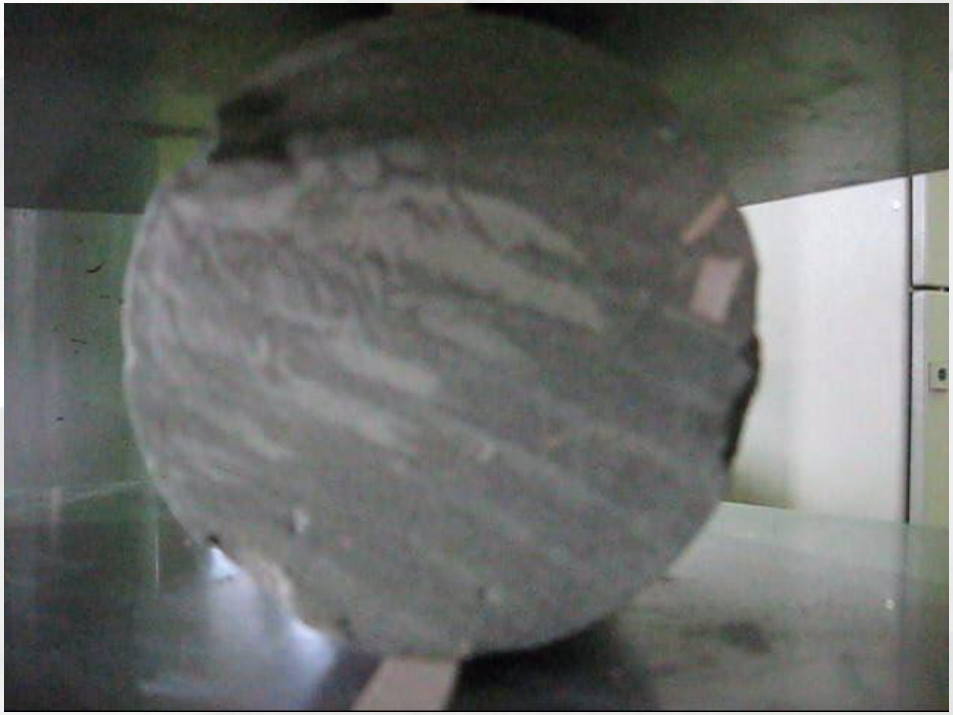
3. Test results

3.1 Mechanical characterization

Tensile splitting strength

NBN EN 12390-6 Testing hardened concrete - Part 6: Tensile splitting strength of test specimens

Sample diameter (D) = 100 mm ± 15% (113 mm)
Sample length (L) = 1 D

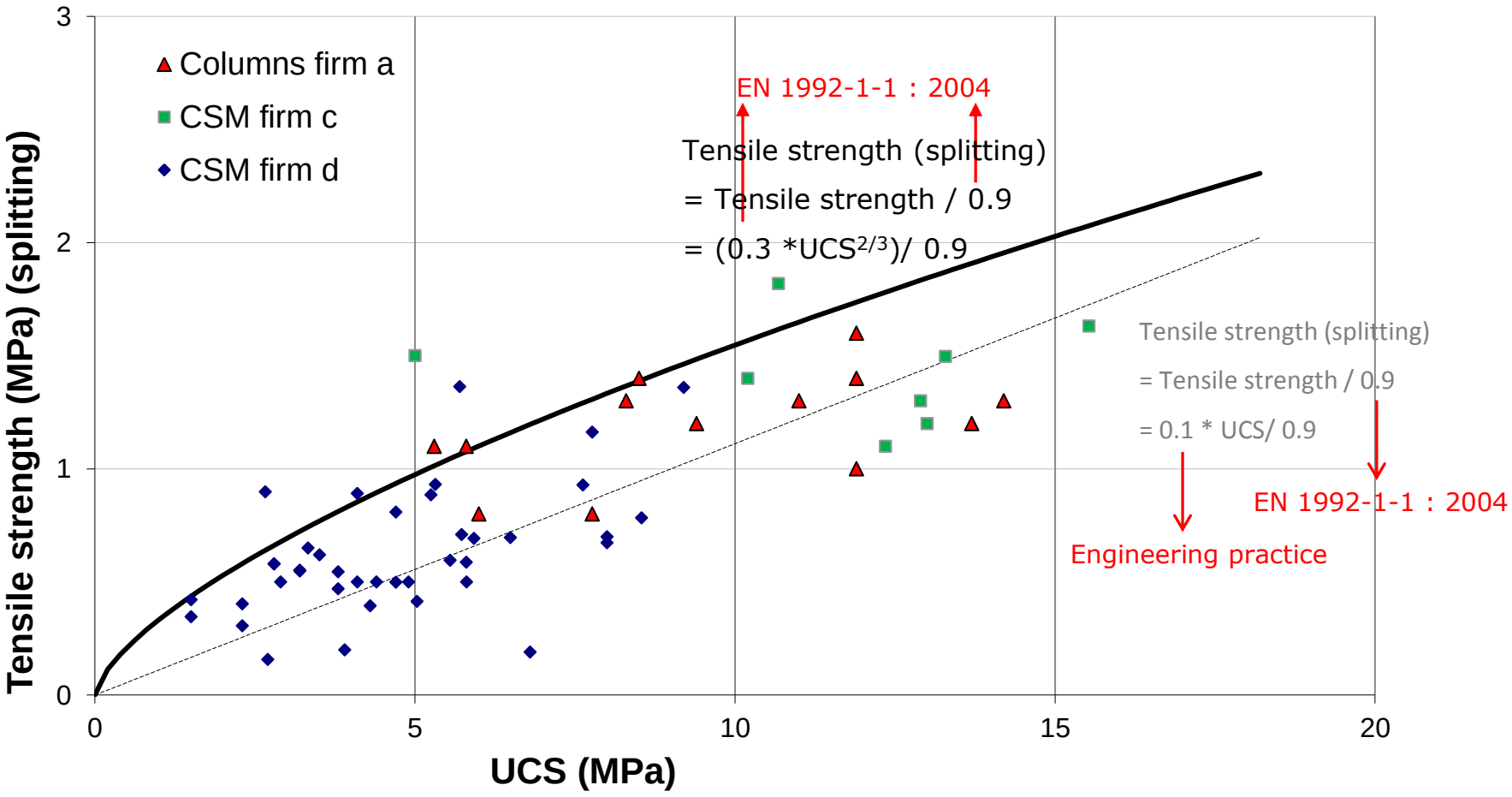


3. Test results

3.1 Mechanical characterization

Tensile splitting strength

9 sites in Belgium



3. Test results

3.2 Durability

Topics:

- Mechanical characteristics:
  - UCS, E, T in function of the time
  - Creep
    Type of soil, σ, T°, cement type, humidity (RH), W/C

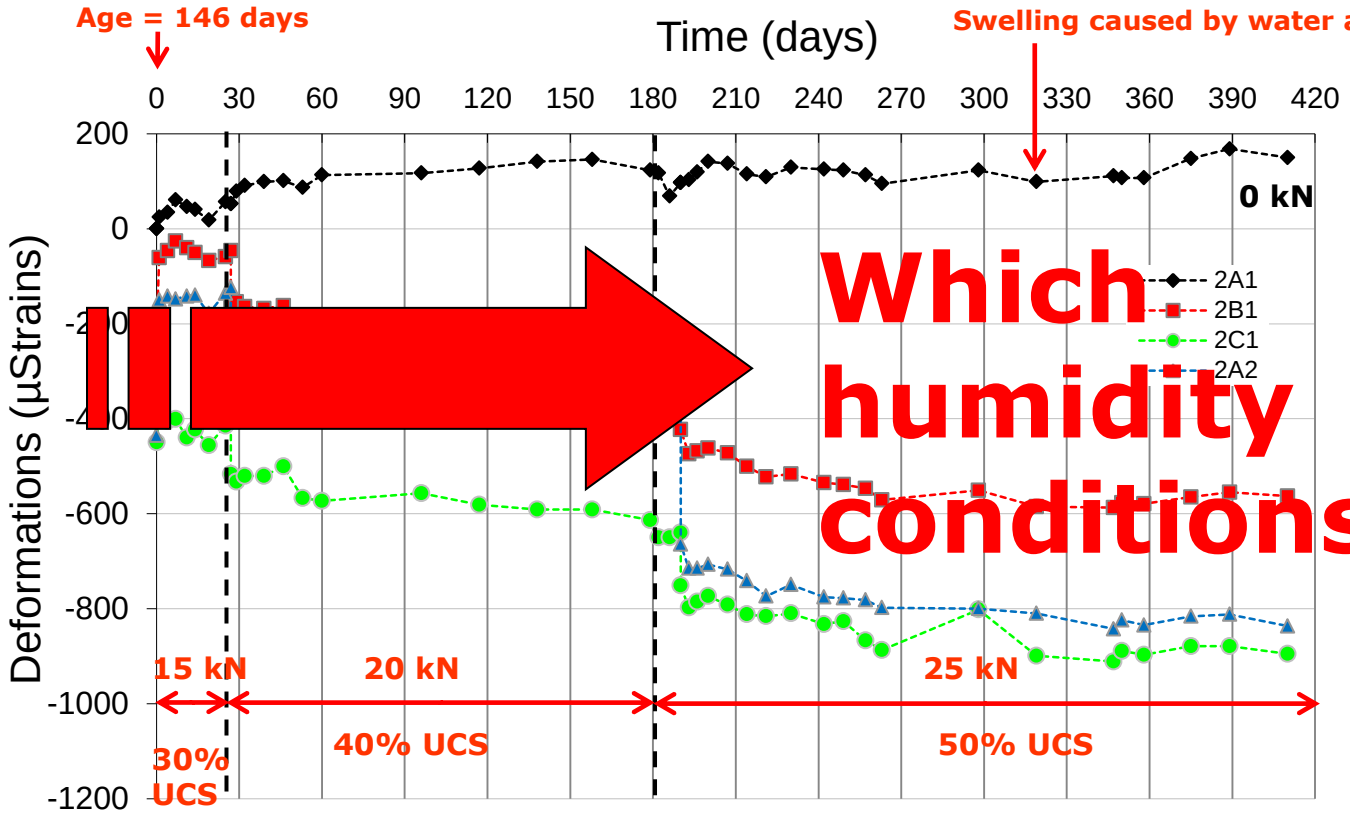
- Influence of environment:
  - Degradation related to air-exposure
    Humidity, porosity, pH and carbonation in function of the time
  - Corrosion – carbonation
    Air-exposure or above the ground water
  - Setting and hardening in polluted soils and in saltwater
    Internal and/or external pollution
  - Corrosion – pollution
    Chlorides

3. Test results

3.2 Durability

Creep

Under water (T=20±4°C)



CSM – Leuven

Tertiary sand

UCS = 5.9 MPa

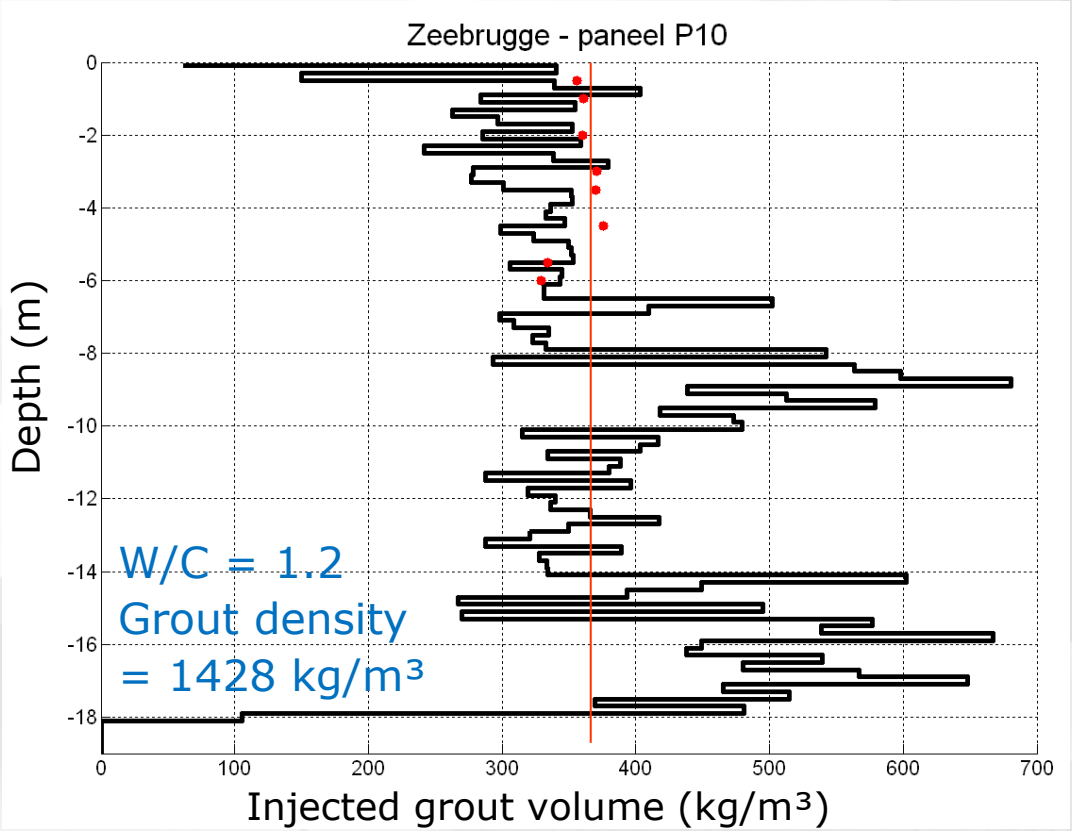
3. Test results

3.2 Durability

Cement content

Chemical determination: SiO_2, CaO, CO_2 and insoluble residue

CSM – Zeebrugge – quaternary sand



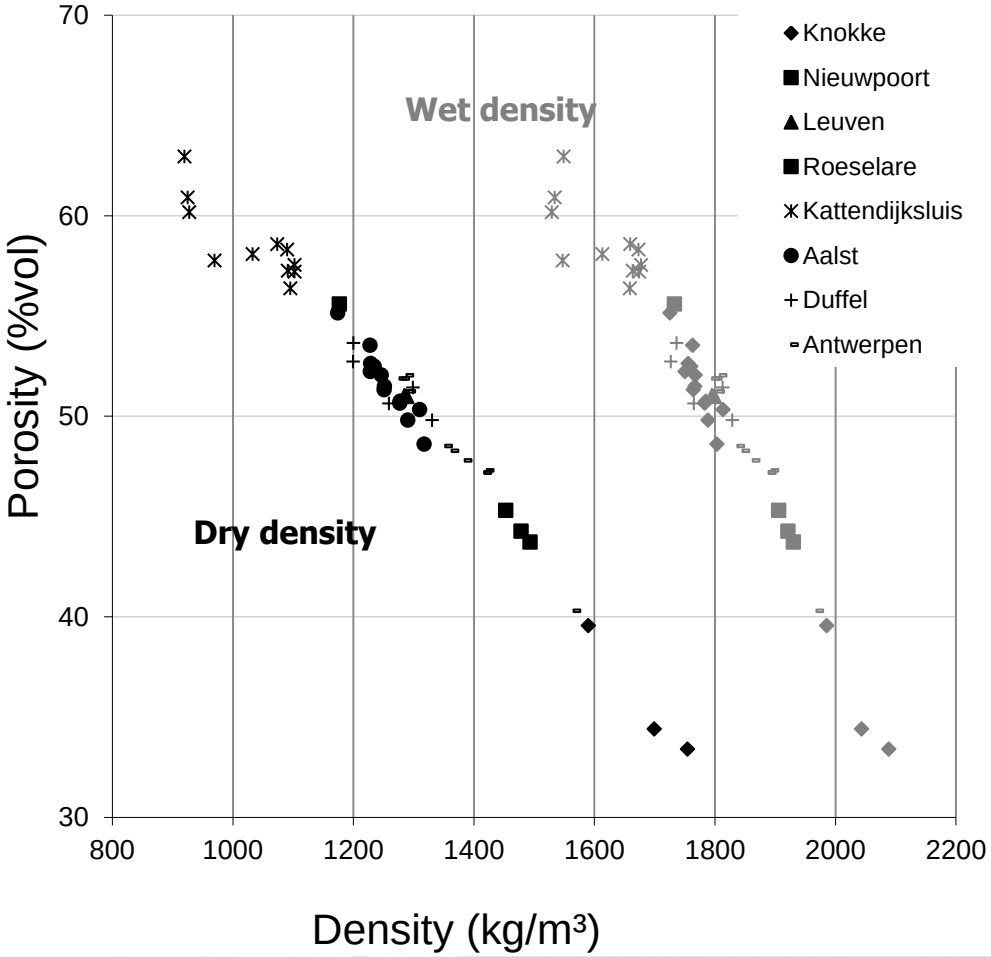
- Parameters:
  - W/C
  - Grout density
- Cement content:
  - Injection volume <-> return?

3. Test results

3.2 Durability

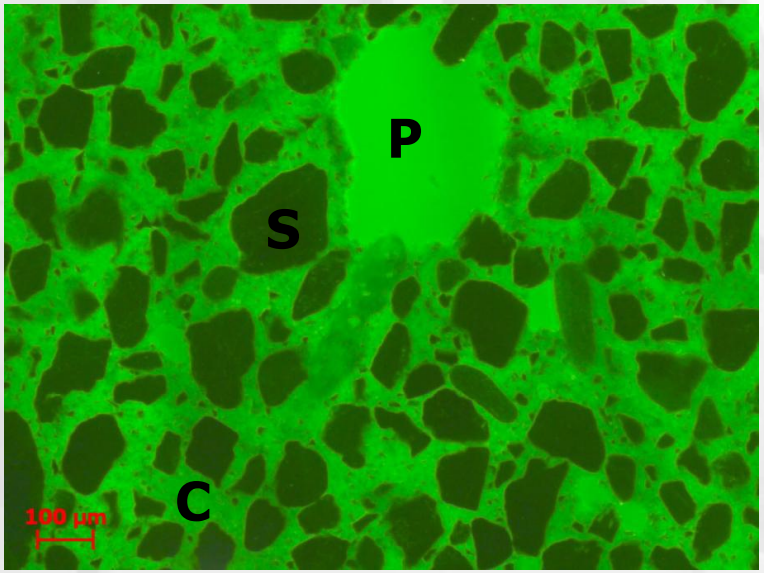
Porosity NBN B15-215

Soil mix between 30 and 65 vol%



Microscopic analysis (thin films) – fluorescent light (LM 3445)

"Microporosity" of cement



P = pore, S = sand, C = porous cement

→ High capillary porosity (high W/C)

→ High creep for RH = 60%

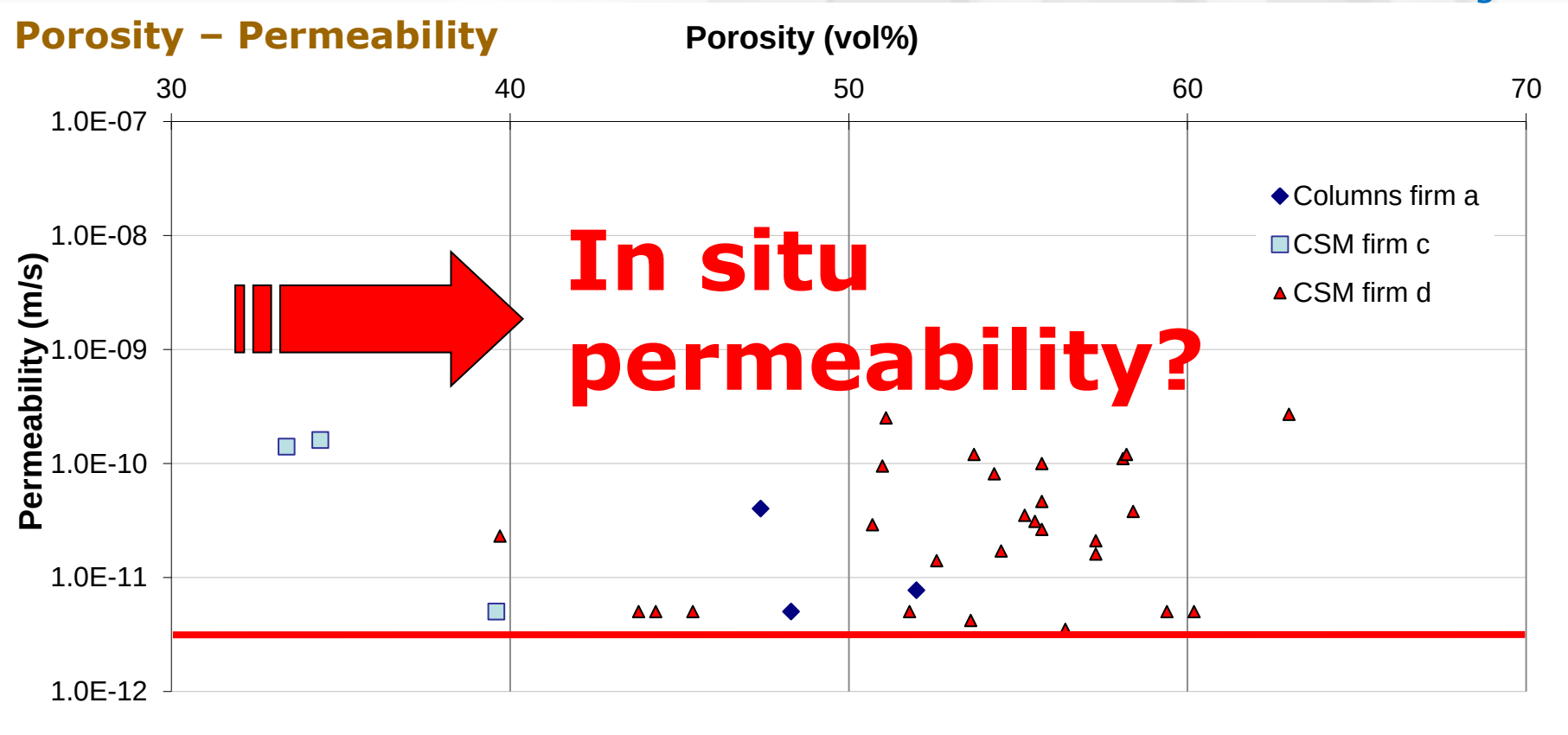
3. Test results

3.3 Permeability

Permeability

DIN 18130-1 Laboratory tests for determining the coefficient of permeability of soil

9 sites in Belgium



3. Test results

3.4 'Steel-soil mix' adherence

In situ pull-out tests (inspired by NBN EN 15184)

CSM – Leuven – sand

5. Perspectives of the SOIL MIX – IWT 080736 project

Temporary retaining structure – permanent – bearing capacity

Mechanical characterization:
- Sampling
- UCS, E, T
- Curing time
- Inclusion analysis
  → Laboratory tests >< gaps

+ Tests on blocks (large scale)
  Representativeness of the cores (inclusion >1/6D) ?
  → Characteristic UCS-value

Durability :
Mechanical characterization:
- UCS, E, T = f(t)
- Cement content
- Porosity

+ Creep tests
  → Minimal humidity condition ?

Influence of the environment:
- Degradation ?
- Pollution/Saltwater ?
- Corrosion ?
- Freeze/thaw ?

Permeability
→ Laboratory tests >< gaps
→ In situ permeability?

'Steel-soil mix' adherence:
+ In situ tests

Bending tests?
NDT (sonic, sclerometer,…) ?
SLT?

5. Perspectives of the SOIL MIX – IWT 080736 project

3 papers describing the results of the SOIL MIX – IWT 080736 project:

SOIL MIX walls as retaining structures – Belgian practice

SOIL MIX walls as retaining structures – mechanical characterization

Mechanical characterization of SOIL MIX material – procedure description

www.bbri.be/go/IS-GI-2012