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8IMC_223

Observation of the failure mechanism of brick masonry doublets with cement and lime mortars by microfocus X-ray computed tomography

HENDRICKX R.; BRUYNINCKX K.;
SCHUEREMANS L.; KERCKHOFS G.;
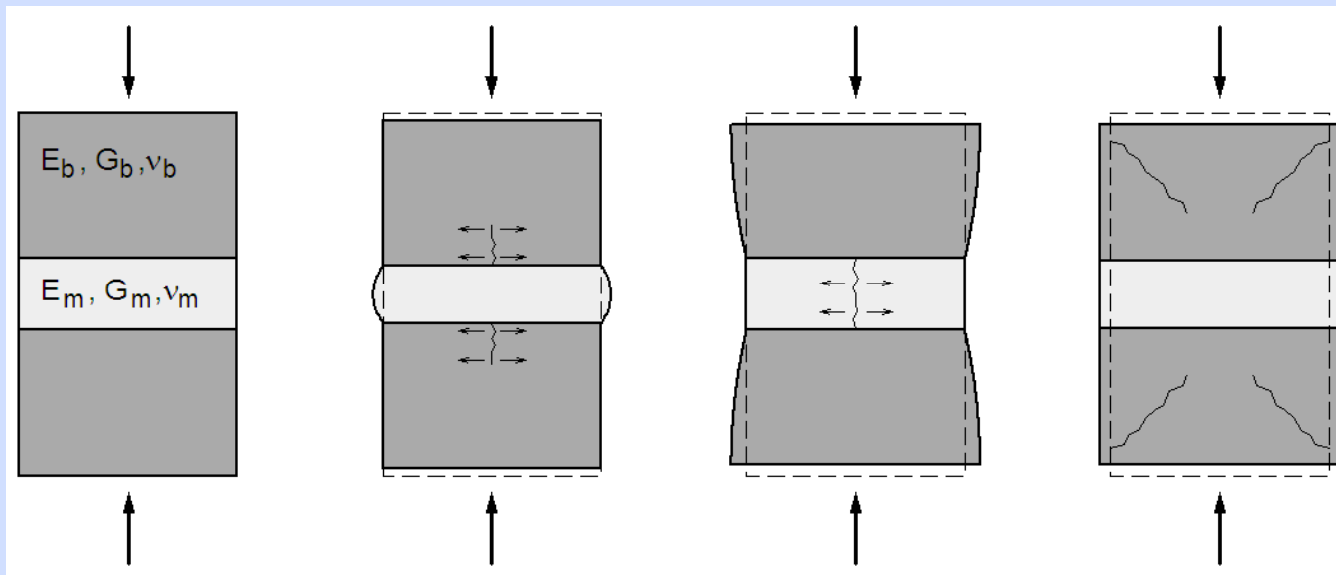VERSTRYNGE E.; WEVERS M.;
VAN BALEN K.

July 5th, 2010 at Hilton Hotel

Introduction: failure modes of masonry

Uniaxial compression leads to failure of mode I, i.e. formation of internal shear planes due to tensile cracking (Lourenço 1996).
Different failure modes according to Hilsdorf 1969:

- if the brick's stiffness is higher than the mortar's stiffness, the mortar will tend to expand more laterally, which causes tensile stress in the brick;

- if the mortar's stiffness is higher than the brick's stiffness, the brick will tend to expand more laterally, which causes tensile stress in the mortar;

- if stiffnesses are comparable, a homogeneous behaviour is expected, with typically the formation of conical shear planes.

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Introduction: failure of mortar

Dependent on the ratio between horizontal and vertical stresses
(Hayen 2004)

- Stress coefficient κ: $$\kappa = \sigma_{vert} \Big/ \sigma_{hor}$$

- for $\kappa < 0.25$ the tensile-shear mechanism is dominant
- for $\kappa > 0.25$ the pore collapse mechanism was dominant

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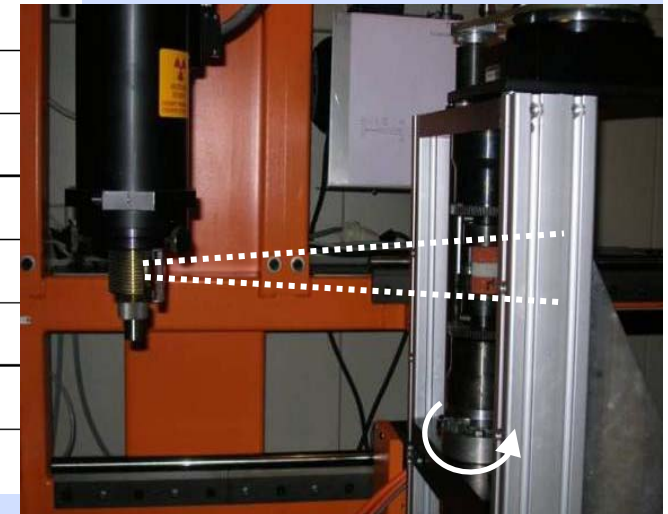# Introduction: microfocus computed tomography (CT) combined with compression

- Cylindrical object placed between source and detector
- Images taken every rotation step of 1°, over 180°
- Reconstruction of horizontal slices from the raw data.
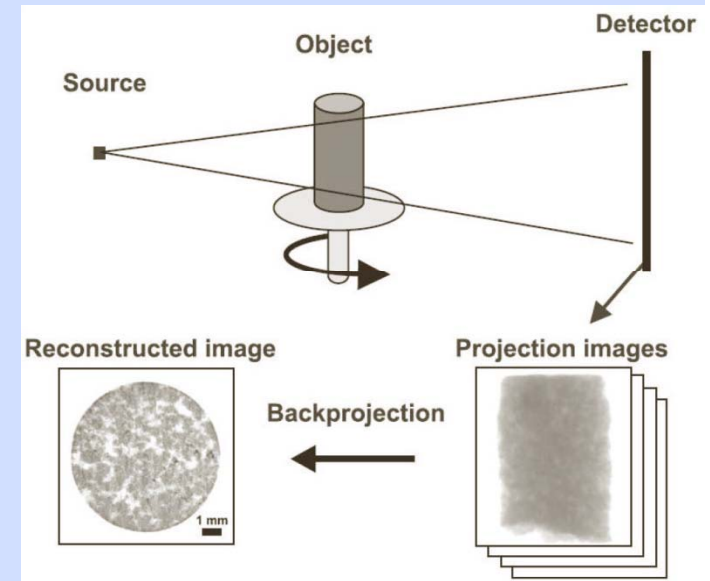
size (m)	brick	mortar	visualisation technique		
10^{-9}					
		gel pores			
10^{-6}	pores	cap. pores / micro-cracks		synchrotron CT	nanoCT
	pores	binder particles			
		air bubbles			
10^{-3}	inclusions	sand grains	μCT		
	constr. element	constr. element			

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Materials

The brick: "Spaans Rood" by Wienerberger

- compressive strength 10.2 MPa on cylinders, 8.9 MPa on doublets (NBN B24-201)
- Young's modulus 1095 MPa
- dynamic Young's modulus (ultrasound propagation) 3730 MPa
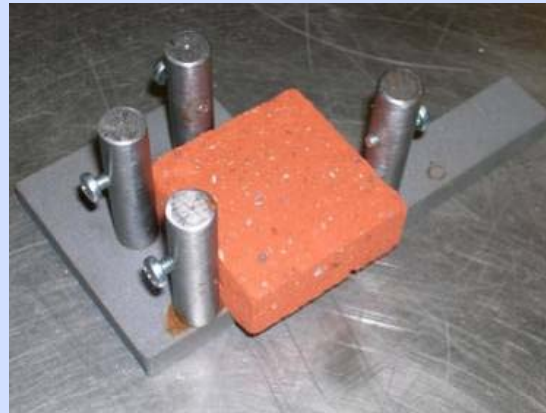- porosity 28.1%;

The mortars: 5 different types were selected

	Lime hydrate un-carbonated	Lime hydrate carbonated	Hydraulic lime	Lime-cement	Cement
Composition					
Binder/sand ratio (kg/kg)	0.127	0.127	0.212	0.212	0.247
Water/binder ratio (kg/kg)	1.810	1.810	1.102	1.019	0.907
Mechanical properties					
$f_{c,m}$ (MPa)	0.81	2.22	1.37	10.88	29.48
$E_{dyn,m}$ (MPa)	3244	5449	2573	11182	21997
ρ (kg/m³)	1671	1722	1861	1841	2016
$f_{t,flex,m}$ (MPa)	0.37	0.83	0.49	3.19	8.05

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Sample preparation

Accessory device

Step 1: brick bottom layer

Step 2: hybrid mortar layer

Step 3: parallel brick top layer

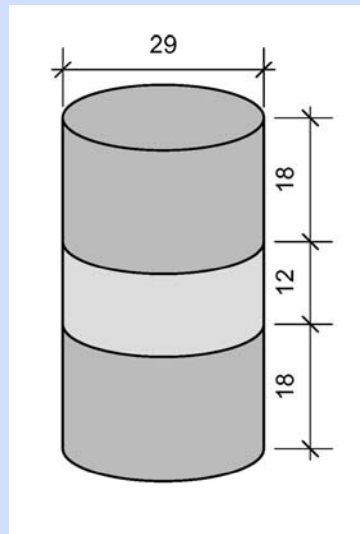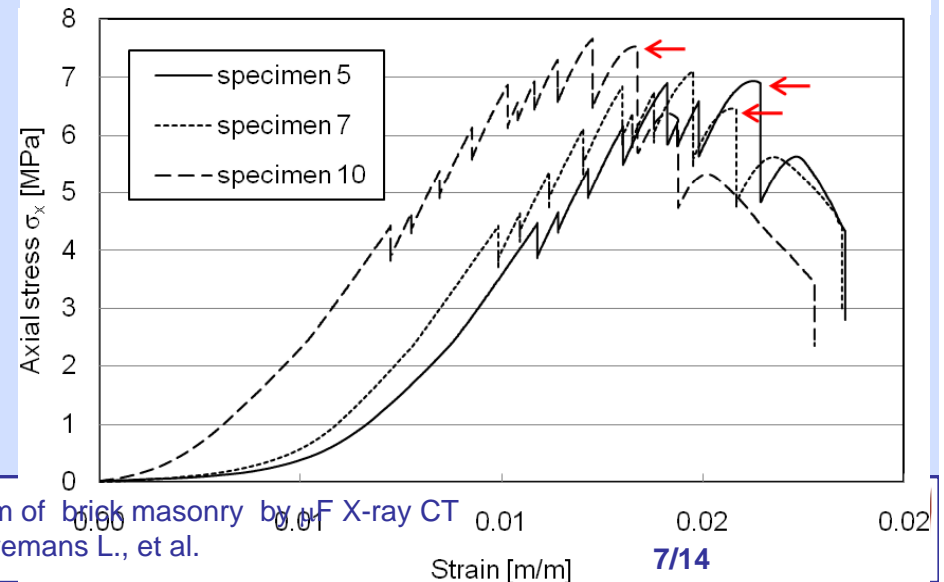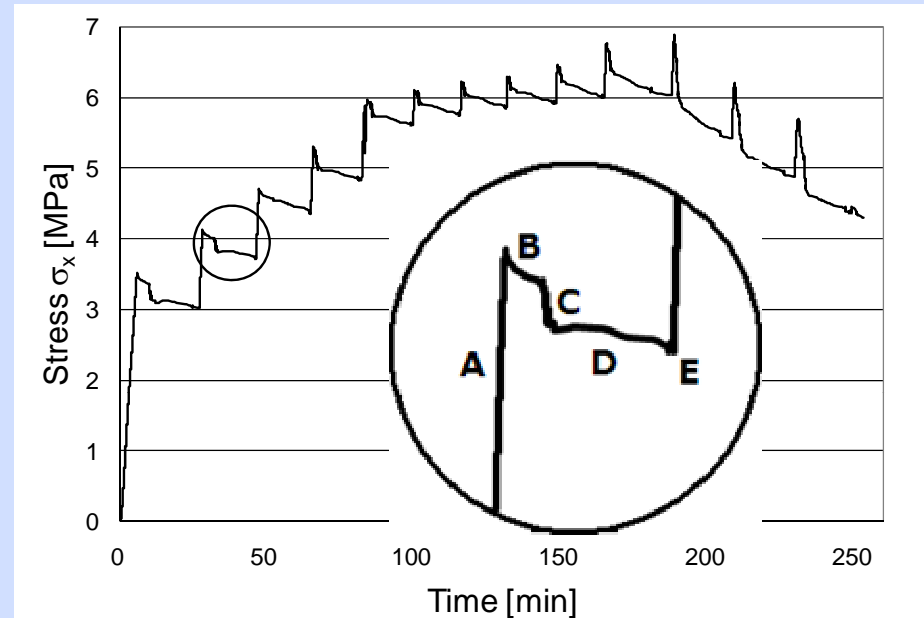Step 4: sample before core drilling

Test sample – d=29mm – h=48 mm

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Testing procedure

- Preliminary determination of compressive strength of specimens
- procedure in steps, rate-controlled but fixed at determined stress-levels
- each step has 5 stages
- data acquisition during stage D
- importance of relaxation after fixing the displacement during each step
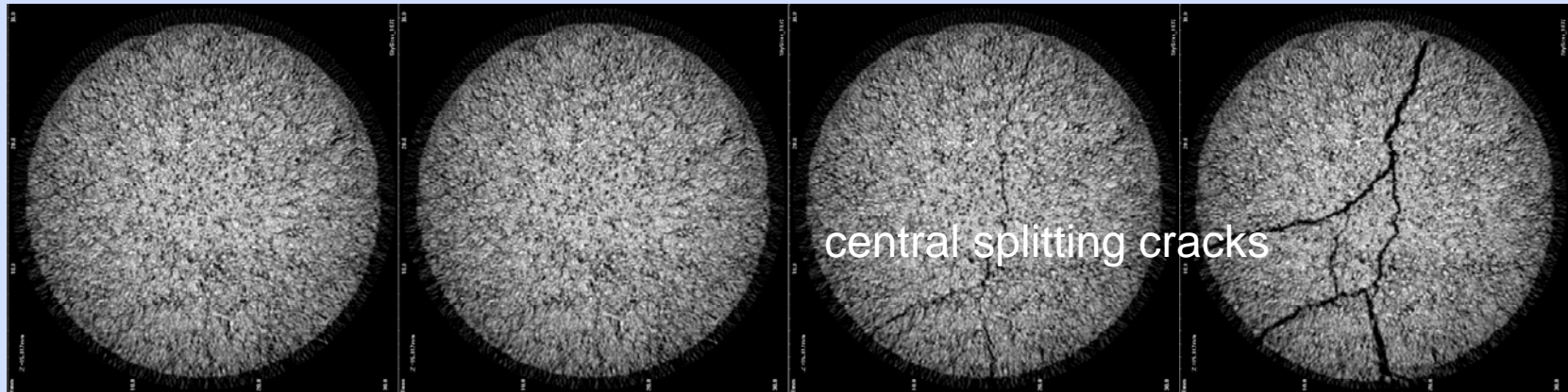
specimen geometry

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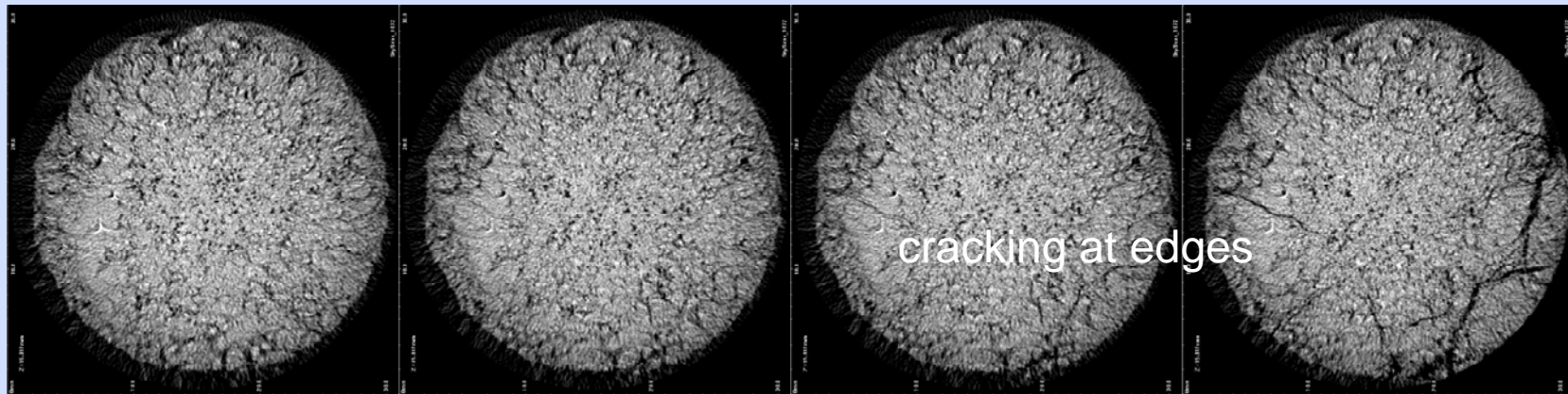
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Results and data treatment: horizontal slices

First processed data consists of horizontal slices, that can be stacked
to 3D images or vertical sections

central splitting cracks

4 load steps in specimen with cement mortar: section through symmetry plane

cracking at edges

4 load steps in specimen with hydraulic lime mortar

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Results: cement mortar and lime-cement mortar
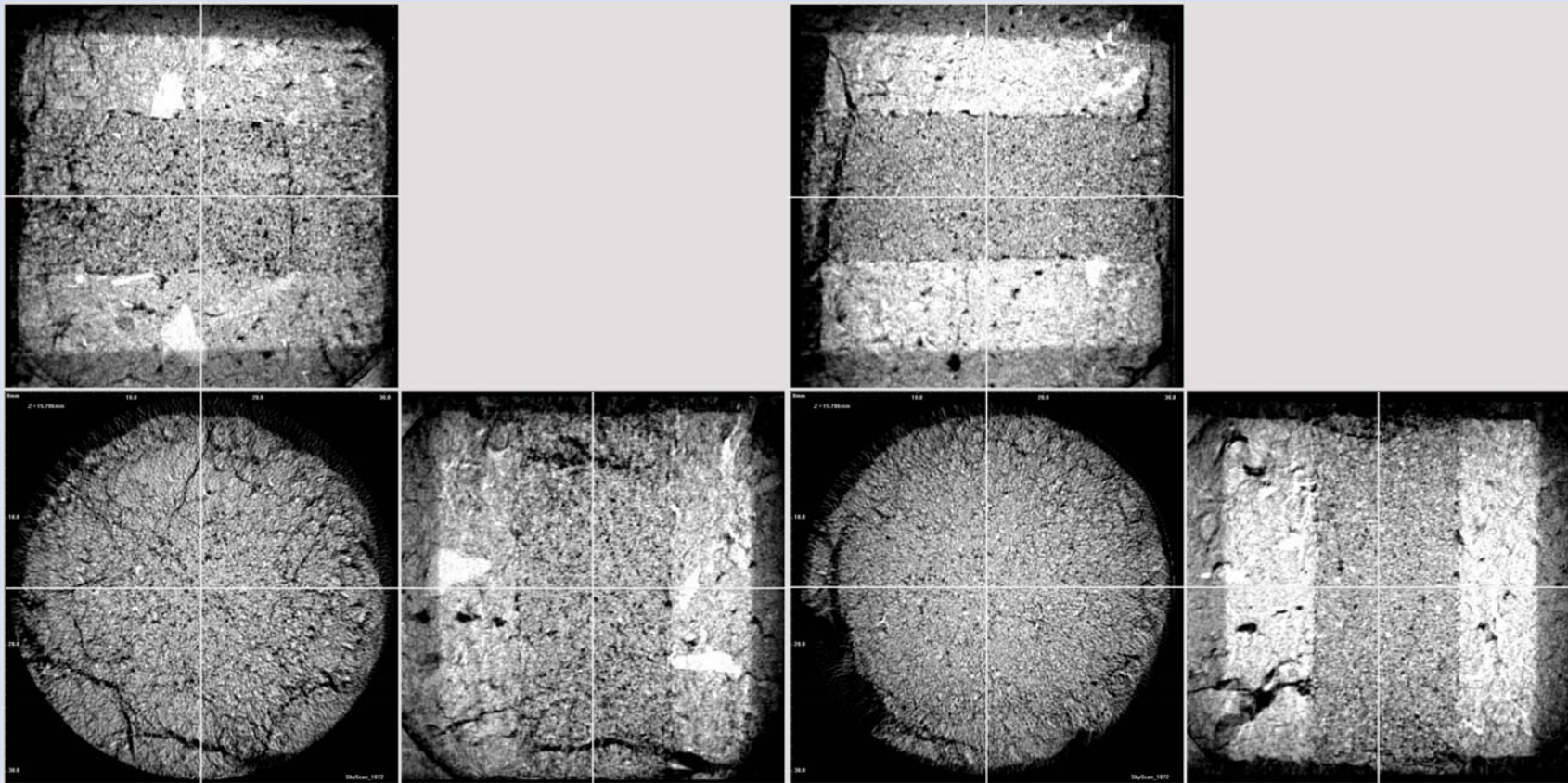
Stack of slices used to produce 3 orthogonal sections
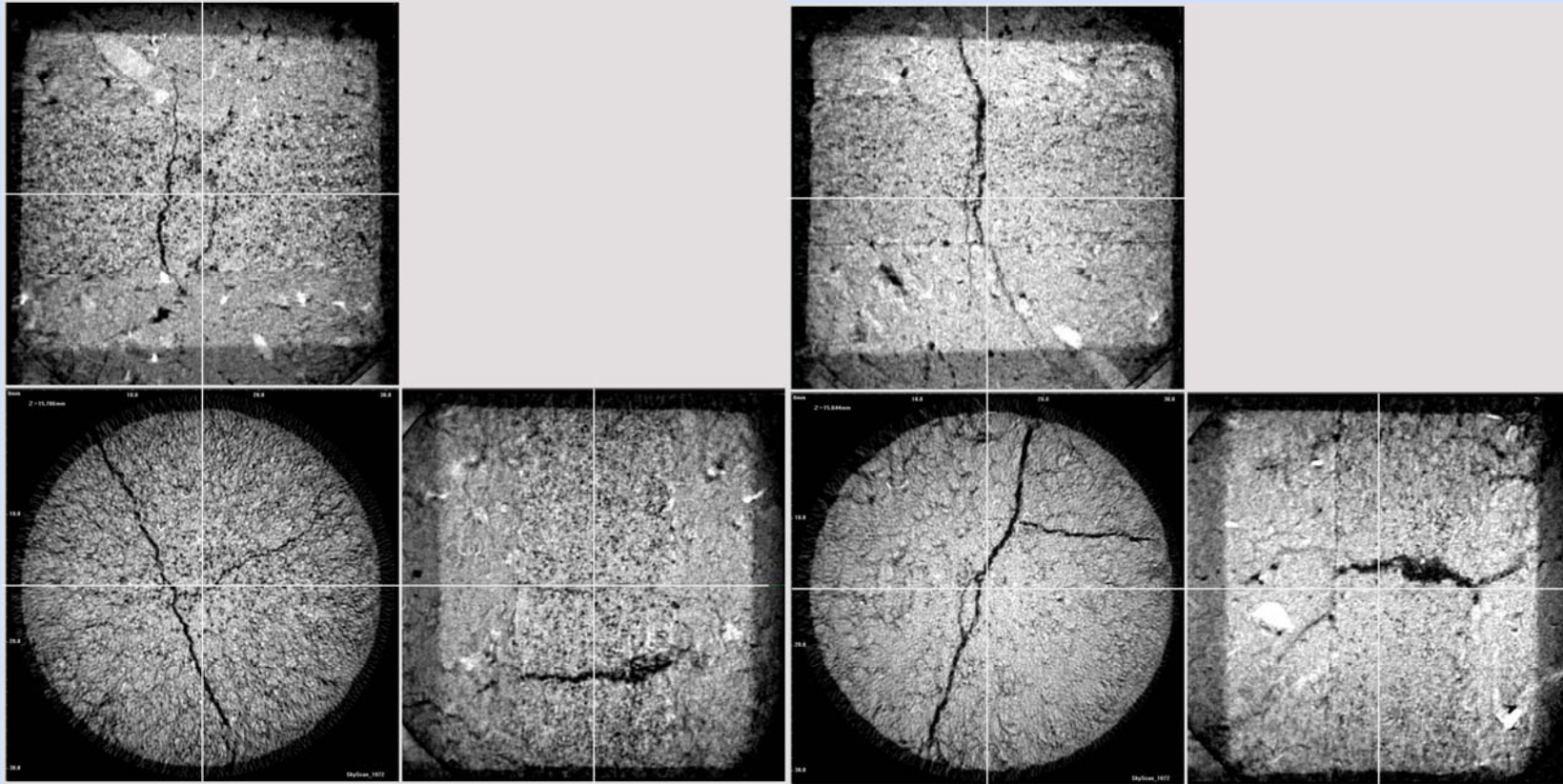
Cement mortar specimen 7.

Lime- cement mortar specimen 6.

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Results: hydraulic lime mortar and uncarbonated lime hydrate mortar

Hydraulic lime mortar specimen 7.　　　　Uncarbonated lime hydrate mortar specimen 9.

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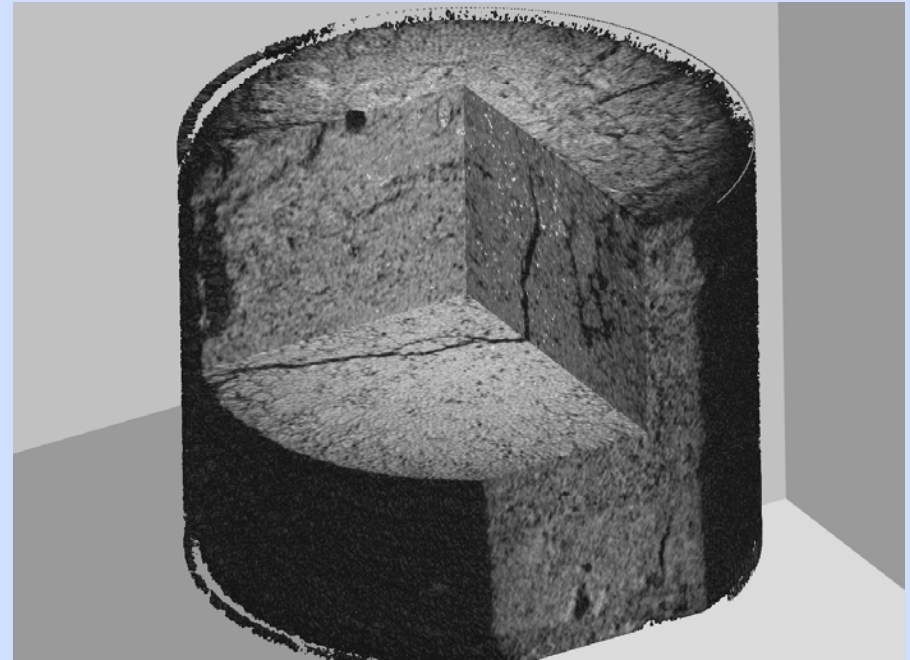
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Results: carbonated lime mortar and 3D rendering
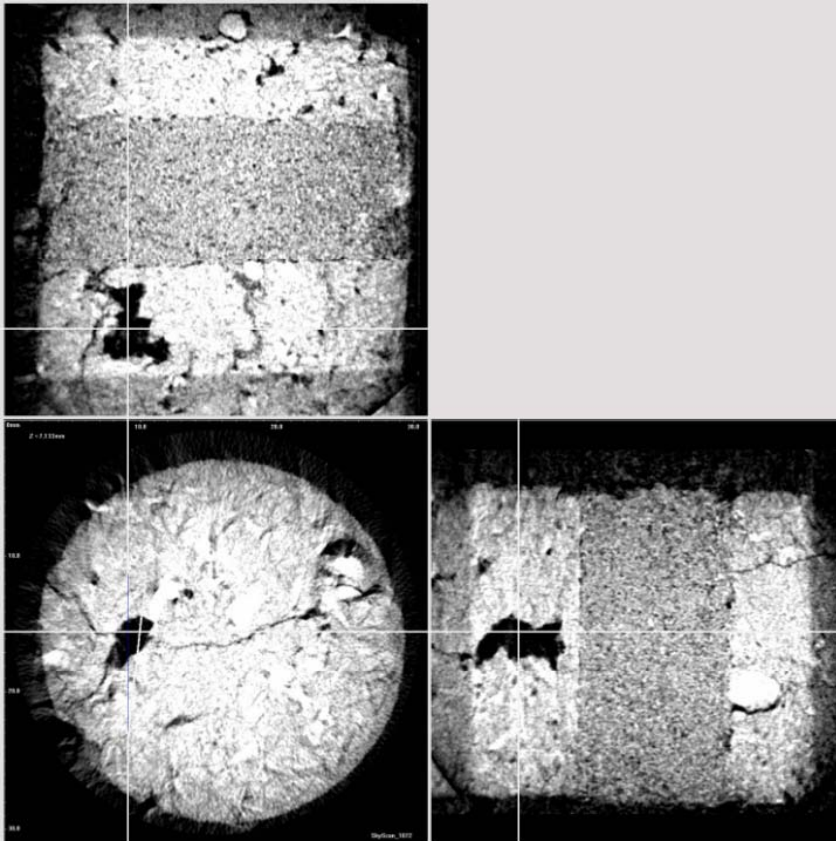
Carbonated lime hydrate mortar specimen 3.

3D rendering of lime-cement mortar specimen 6.

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Quantitative analysis

- Can we distinguish compaction of the materials through quantitative analysis of attenuated radiation?
- Beer's law for attenuation of X-rays:

$$\frac{I_t}{I_0} = \exp(-\mu d)$$

$$\mu = -\frac{1}{d}\ln\left(\frac{I_t}{I_0}\right)$$

Experimental determination of attenuation coefficients from known thickness d and incident/transmitted intensities (I_0 and I_t):

	Lime hydrate un-carbonated	Lime hydrate carbonated	Hydraulic lime	Lime-cement	Cement
μ_{mortar} [1/m]	59.1	59.1	60.0	58.3	68.9
μ_{brick} [1/m]	70.8	70.3	69.6	69.3	71.1

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Quantitative analysis

- Average value of attenuation in mortar taken from central area in the slice of the symmetry plane.
- Plotted as a function of increasing normal stress.
- Unclear evolution for the high strenght mortars.
- Clear increase for uncarbonated lime mortar and hydraulic lime mortar, indicates compaction.
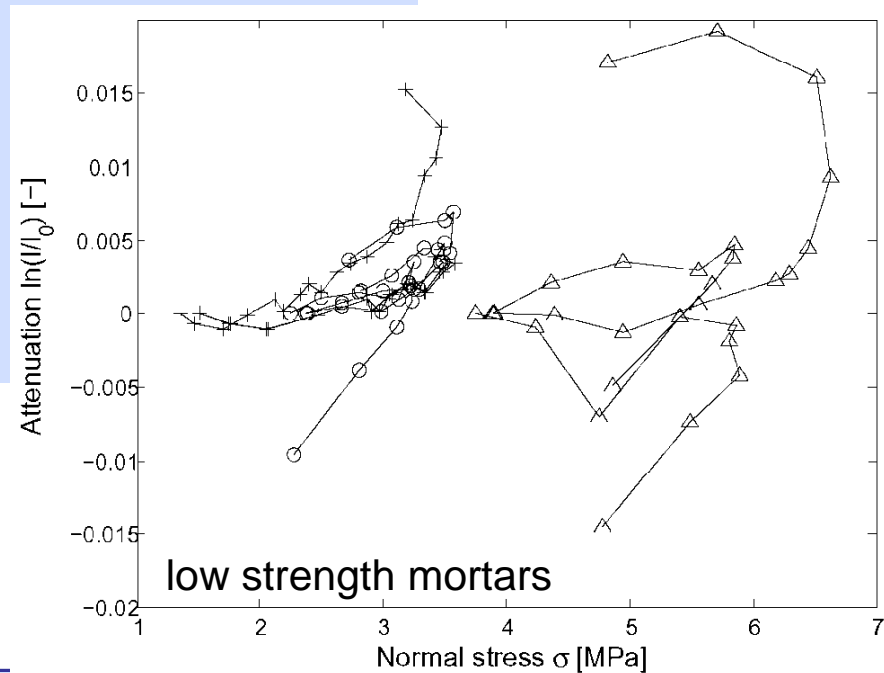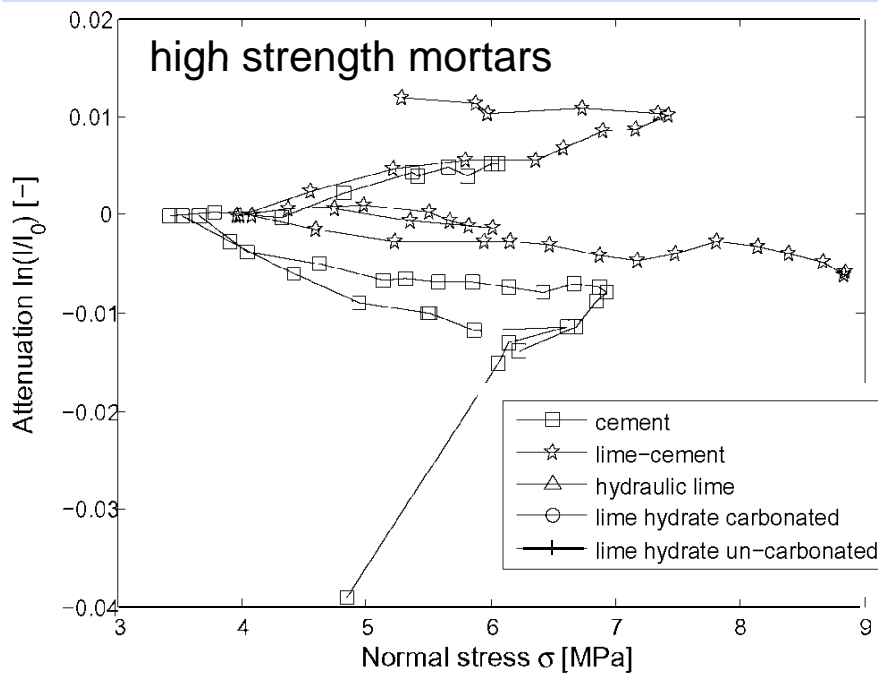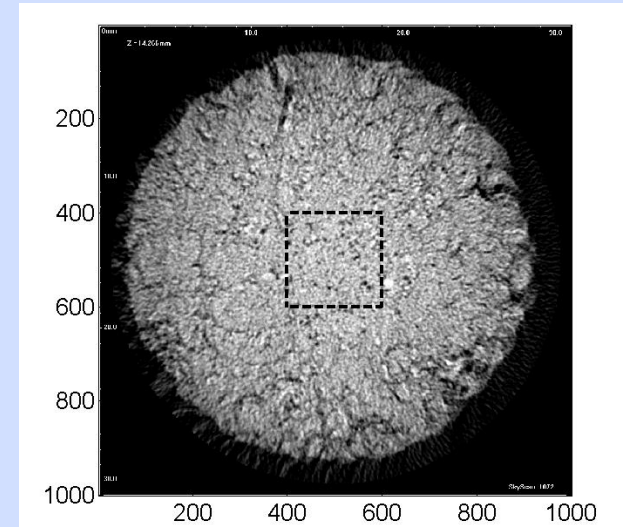
Conclusions

- Technique of CT combined with loading is feasible for masonry, although labour-intensive and requiring meticulous specimen preparation.

- The resolution for micro-CT provides macro- and meso-crack information, but misses the micron-scale, which is essential for crack initiation.

- Spatial resolution can however be improved when decreasing the field of view, but then the overview of the three elements is lost.

- Observations confirm the classical hypotheses of masonry failure. The link between the observed failure and stiffness ratios was clearly established.

- Compaction of low strength mortars – assumed to occur due to pore collapse - could be quantified.

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