Mechanical constitutive behaviour of masonry using digital image correlation

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Context

INTRODUCTION AND MOTIVATION

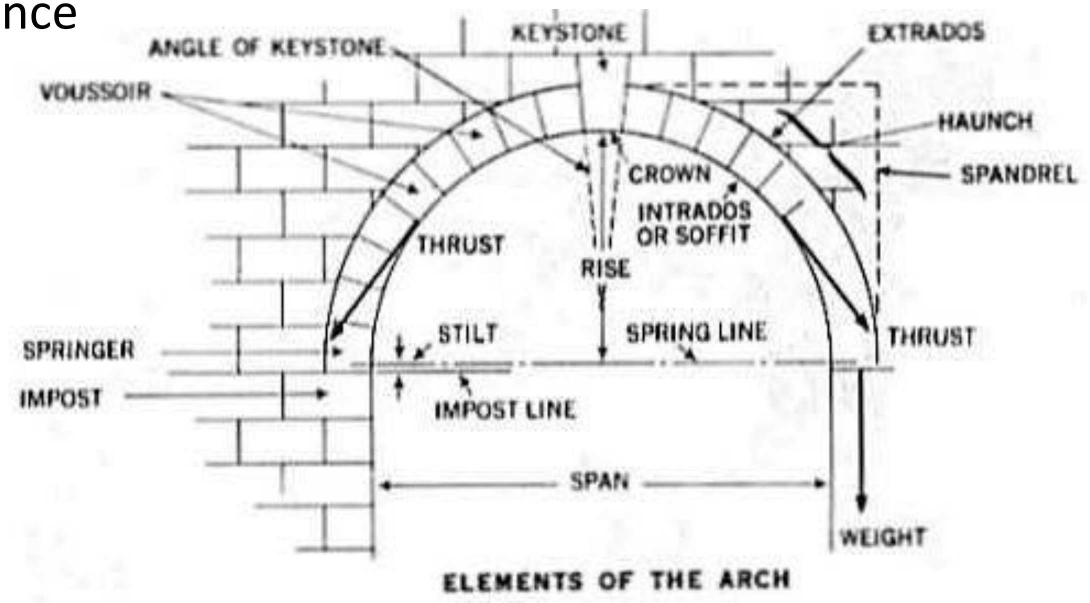
EXPERIMENTAL WORK ON MASONRY

CONCLUSIONS AND PERSPECTIVES

Definition and history of masonry arches

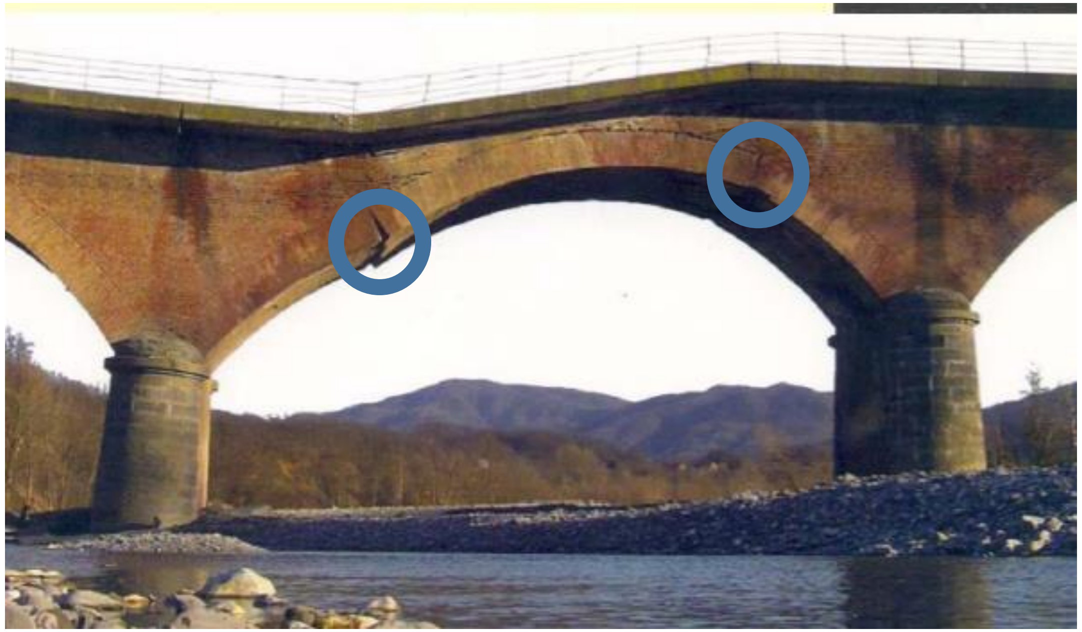
- A masonry arch is a curved structural element that spans an opening.
- It can sustain loads solely by virtue of compressions.

UNESCO world heritage sites
-Amphitheatre of El Jem, Tunisia
- Pont du Gard, France



Problematic of thesis subject

Many masonry structures have suffered from the accumulated effects of material degradation, aging, overloading, and foundation settlements.



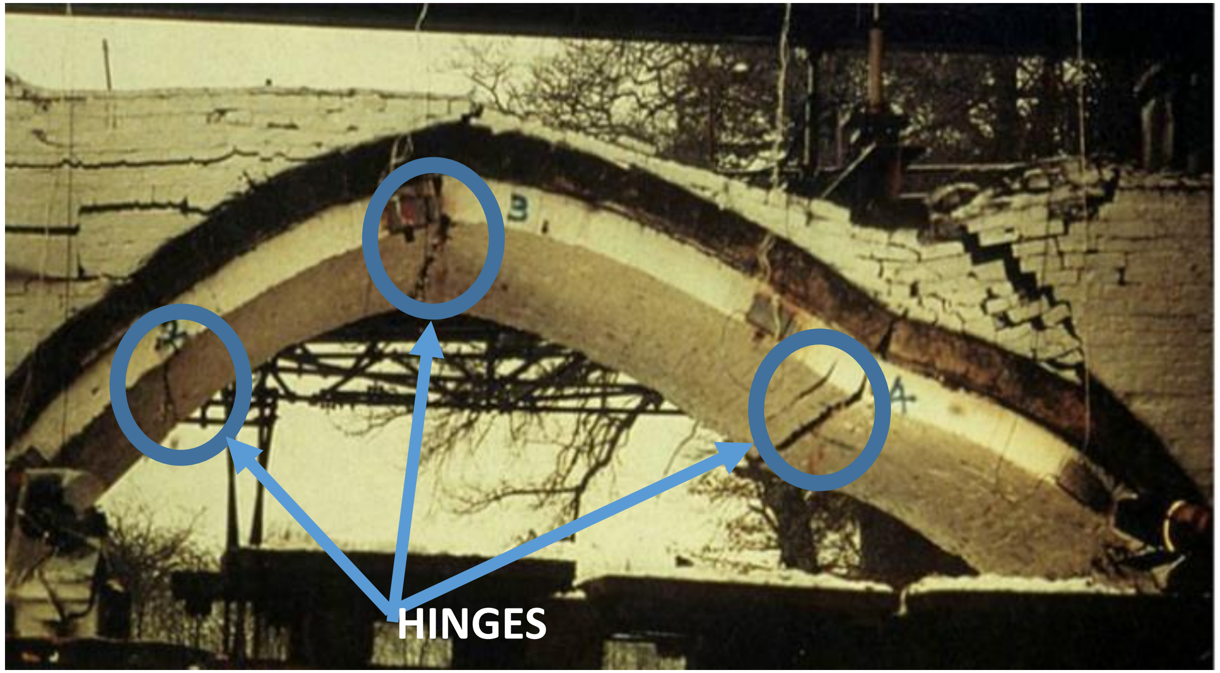
Road bridge Arquata

Pedestrian bridge Peru

The preservation of these structures requires the definition of an efficient requalification method
There are still many parameters lacking in literature for better experimental characterization of masonry structures in view of numerical modeling

Problematic of thesis subject

FEM allows the analysis of structural behavior in service and ultimate load states
the obtained results depends on the quality of input parameters and boundary conditions.



The Prestwood bridge

the approaches require a precise definition of the constitutive laws under all loading conditions
Damage to follow the degradation of the bearing capacity until the failure.

Literature review

The use of PWM tools (strain gauges, LVDT's, transponders) for displacement and strain measurement

Coupling LVDT's along the axis of loading of the specimen. This method gives an idea of the constitutive behavior but remains difficult to integrate

Thaickavil et al. 2018

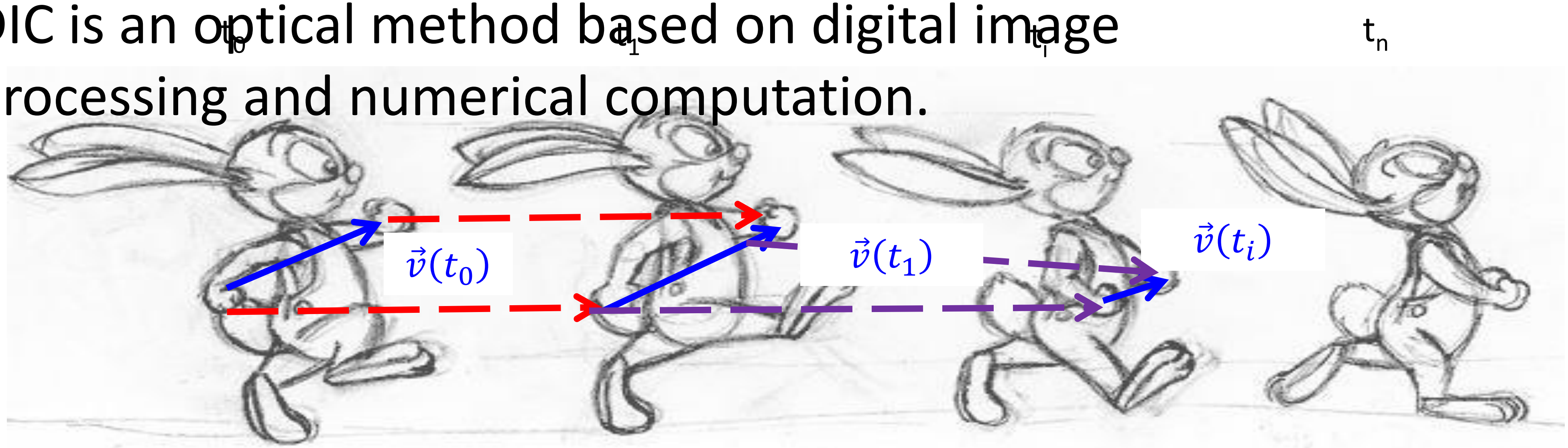
Ricamato et al. 2007

Thamboo et al. 2019

Domède et al. 2009

Definition of digital image correlation

DIC is an optical method based on digital image processing and numerical computation.

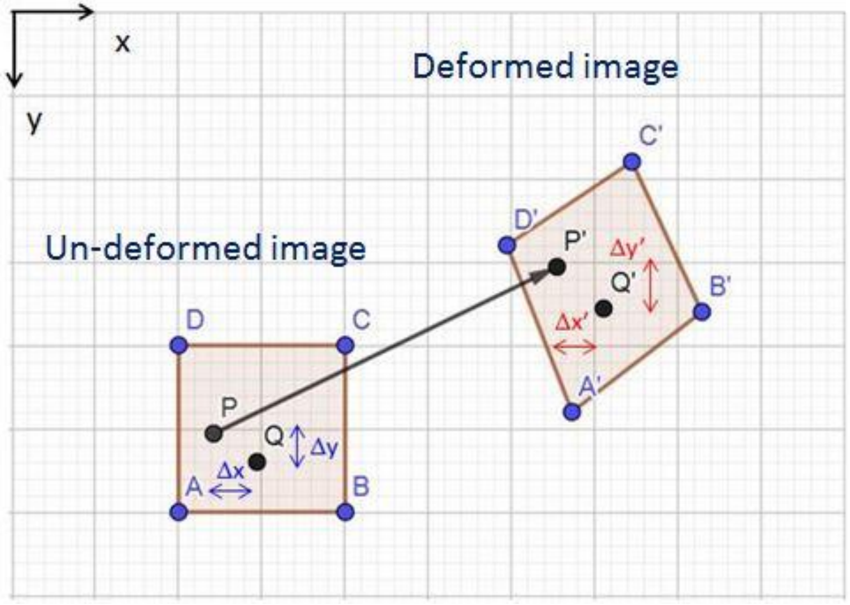


1 sec 24 images

1 sec 25 images

1 sec 50 images

DIC computation technique



Principle.

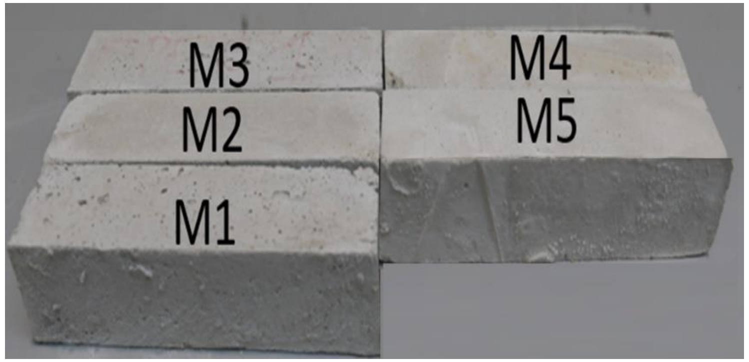
- Uses stochastic patterns in the reference stage to compute evolution of motion
- Compares digital image of the specimen's surface in the un-deformed(reference) stage with the deformed state.

$$[E]=\frac{1}{2}\left([F]^T[F]-[I]\right)$$

E: Green-Lagrange strain tensor
F: Deformation Gradient tensor
I: Unit tensor

Materials and specimens

CEM-I 52.5 N CE CP2 NF and EN 459-1 NHL 5



Mortar specimen

f_b =39 MPa

f_b =90 MPa

Fired clay bricks

Components (g/cm^3)	Mortar's compositions				
	Mortar -M1	Mortar-M2	Mortar-M3	Mortar-M4	Mortar-M5
Cement	500	350	250	150	0
Lime	0	150	250	350	500
Water	275	325	350	350	350
Sand	1387	1336	1132	1312	1312
W/B ratio	0.55	0.65	0.7	0.7	0.7
f_j (MPa)	50	38	22	16.5	3.5

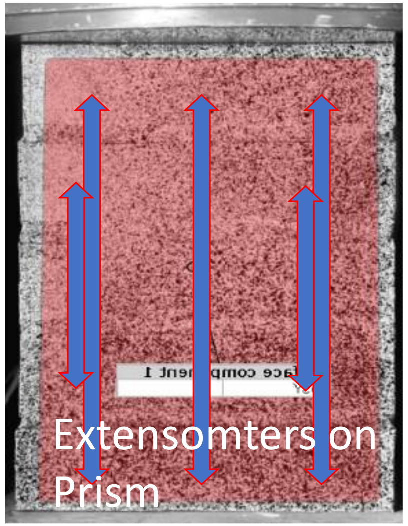
Experimental campaign

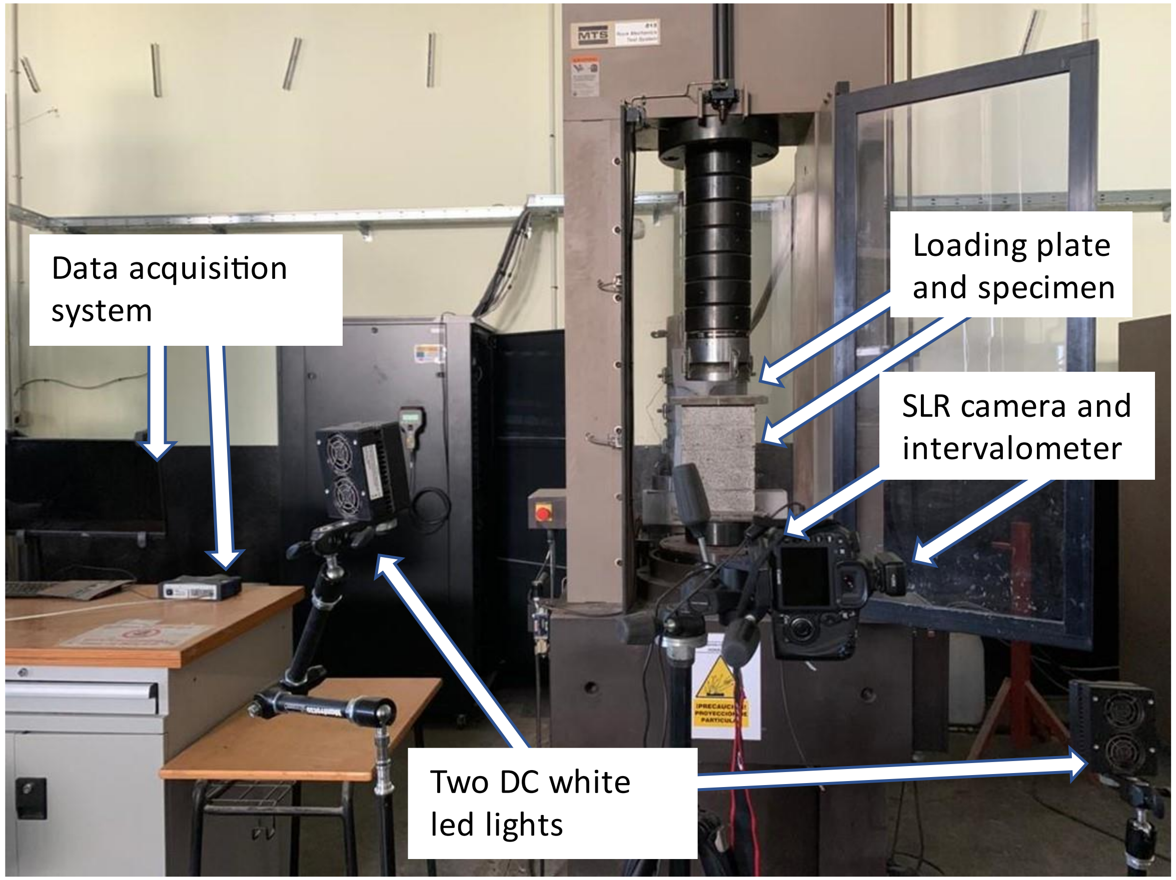
Prisms under construction

Specimen	Material	Dimension (mm^3)	Test Type	Specimen tested
Masonry Prism MP1	fired clay brick	50x100x220	Compressive monotonic test	20
			Compressive loading-unloading test	15
Masonry Prism MP2	fired clay brick	60x110x230	Compressive monotonic test	20
			Compressive loading-unloading test	15

Specimens during for curing

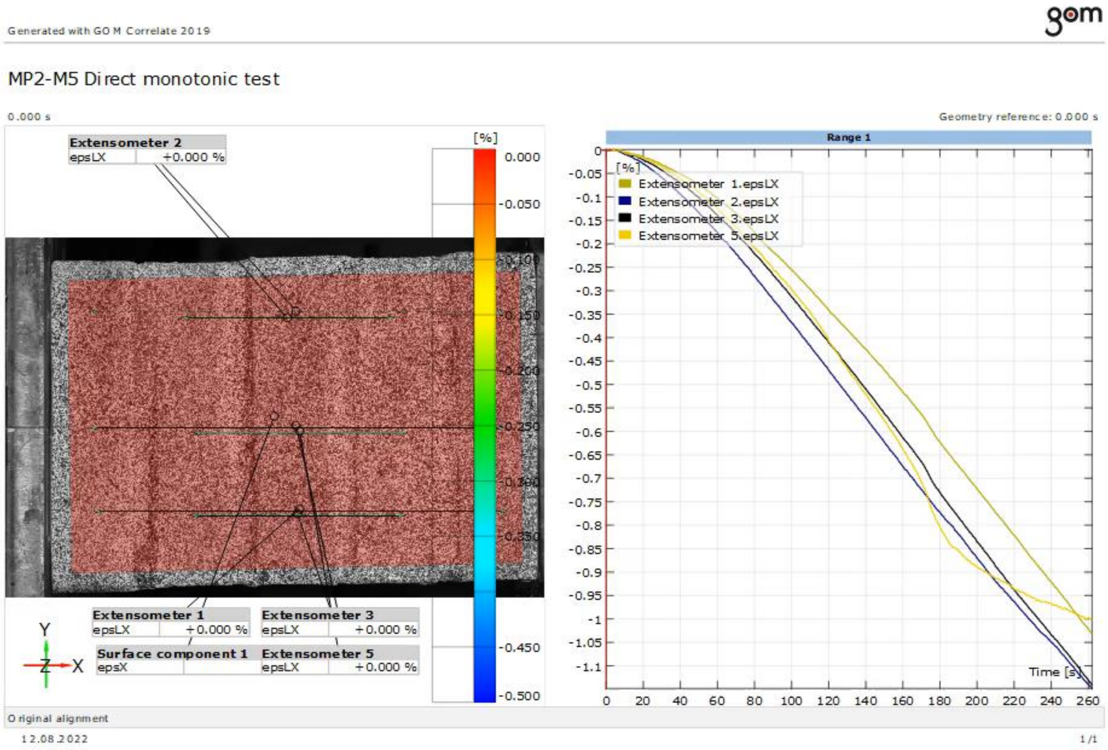
Experimental setup

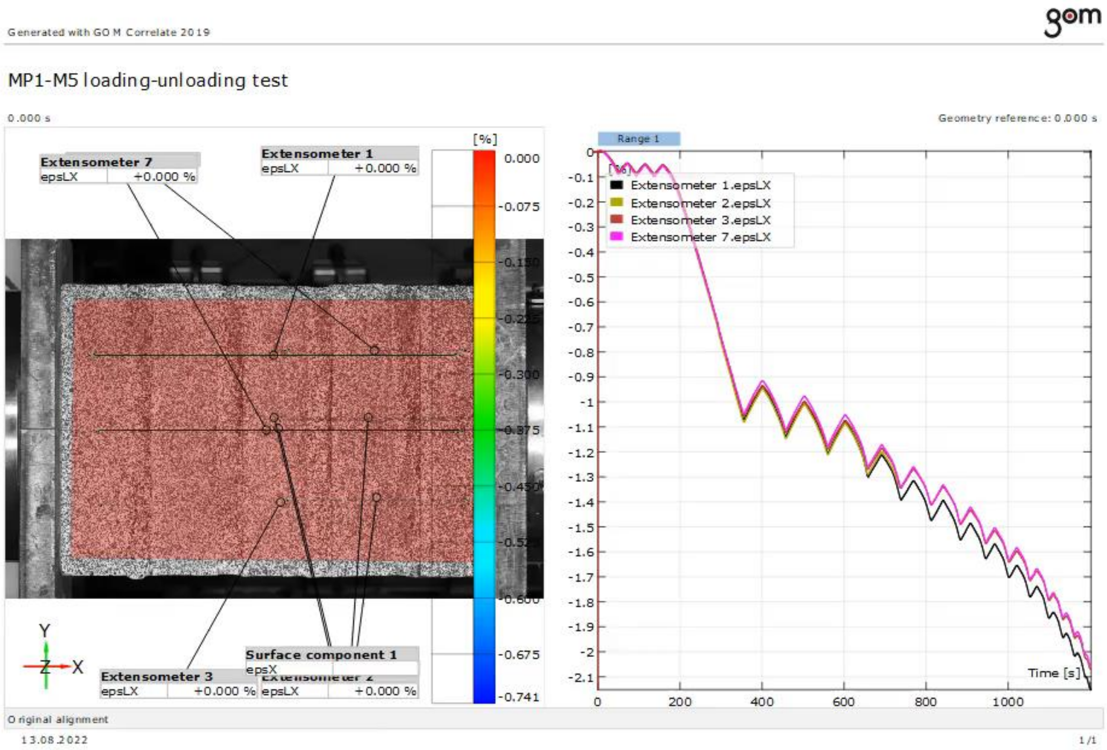




Masonry prism experimental setup

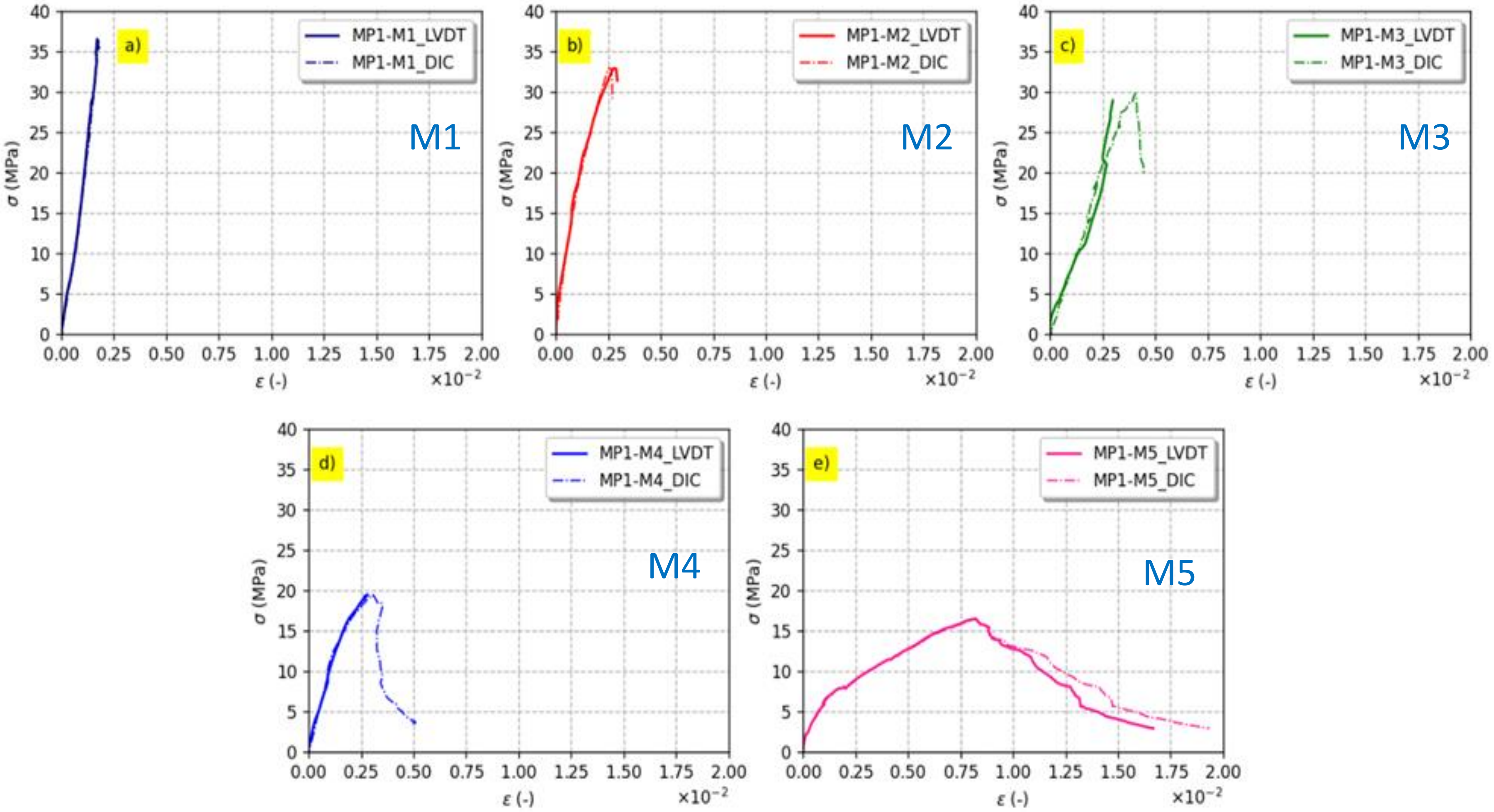
Post processing of masonry prisms

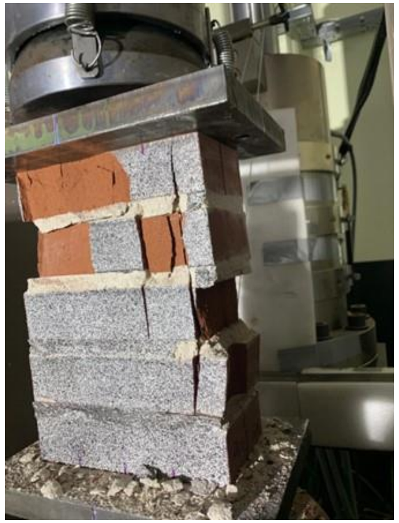




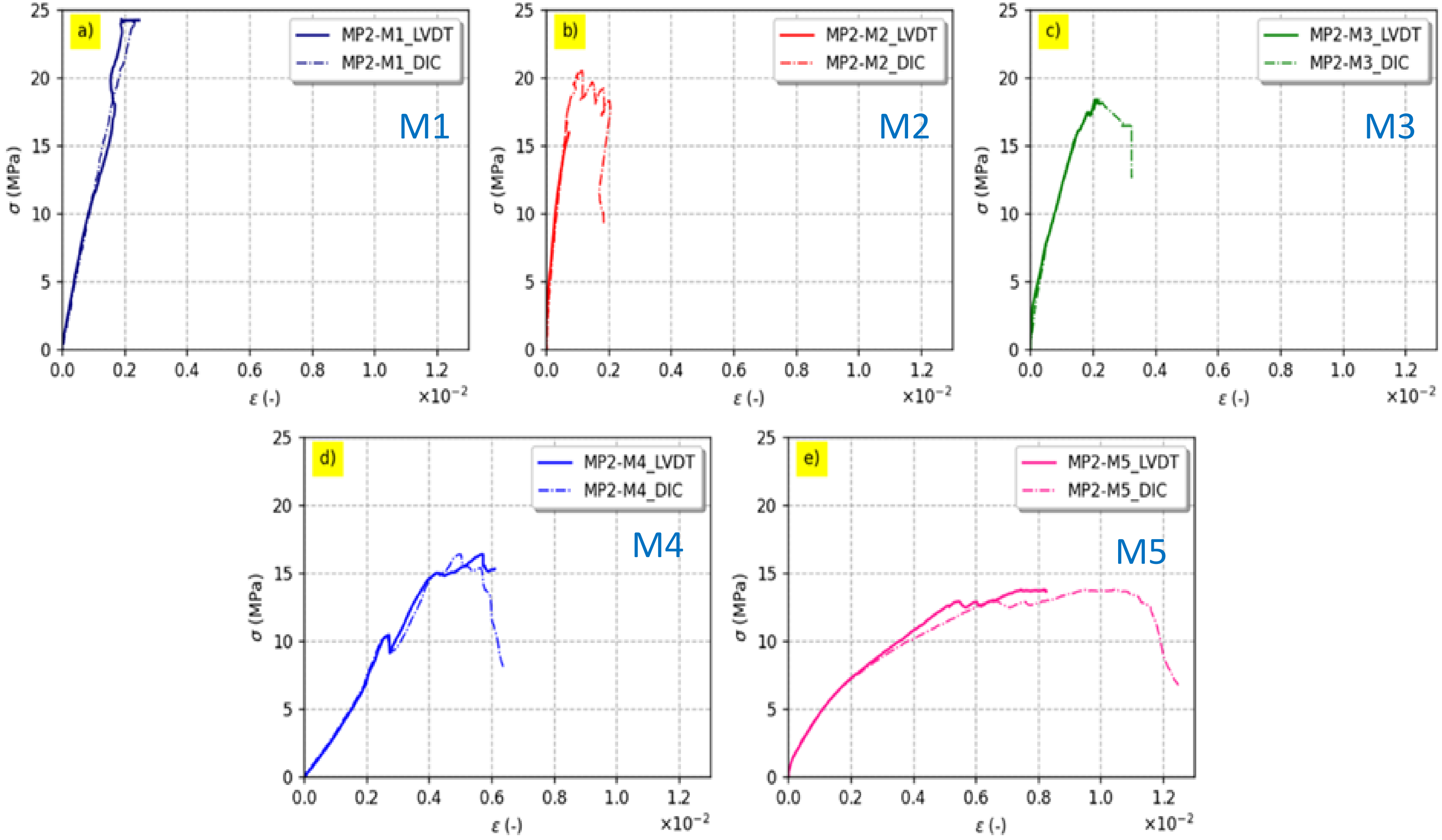
Images taken at 1Hz and 0.5Hz

Stress-strain curve MP1 (Monotonic loading)

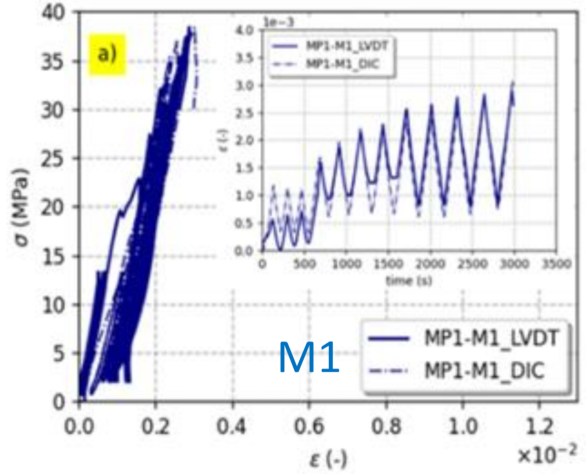


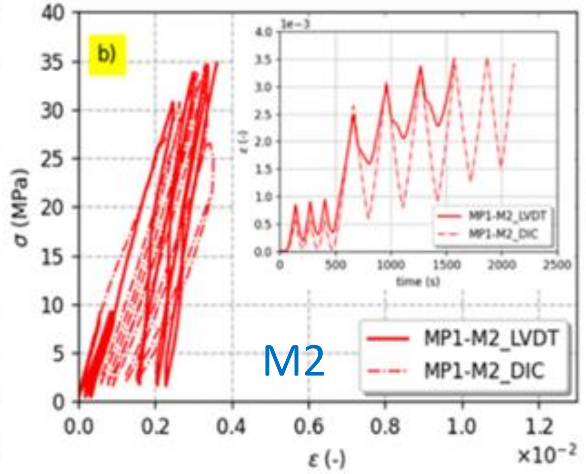


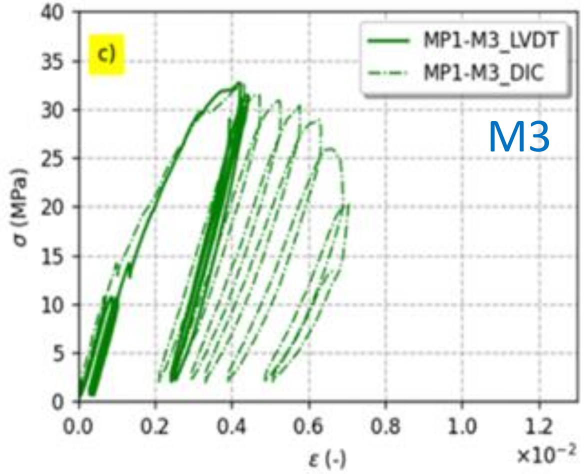
Stress-strain curve MP2 (Monotonic loading)

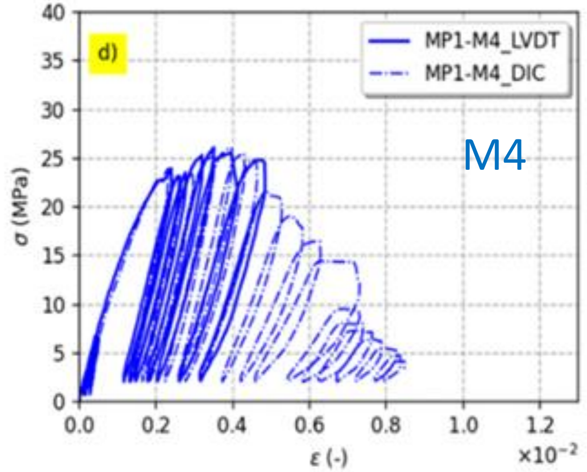


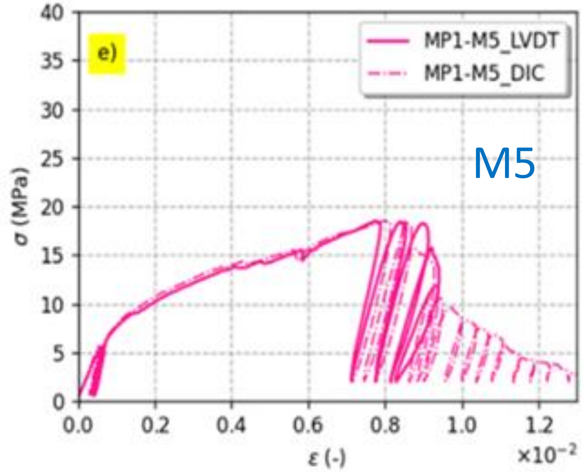
Stress-strain curve MP1 (Cyclic loading)





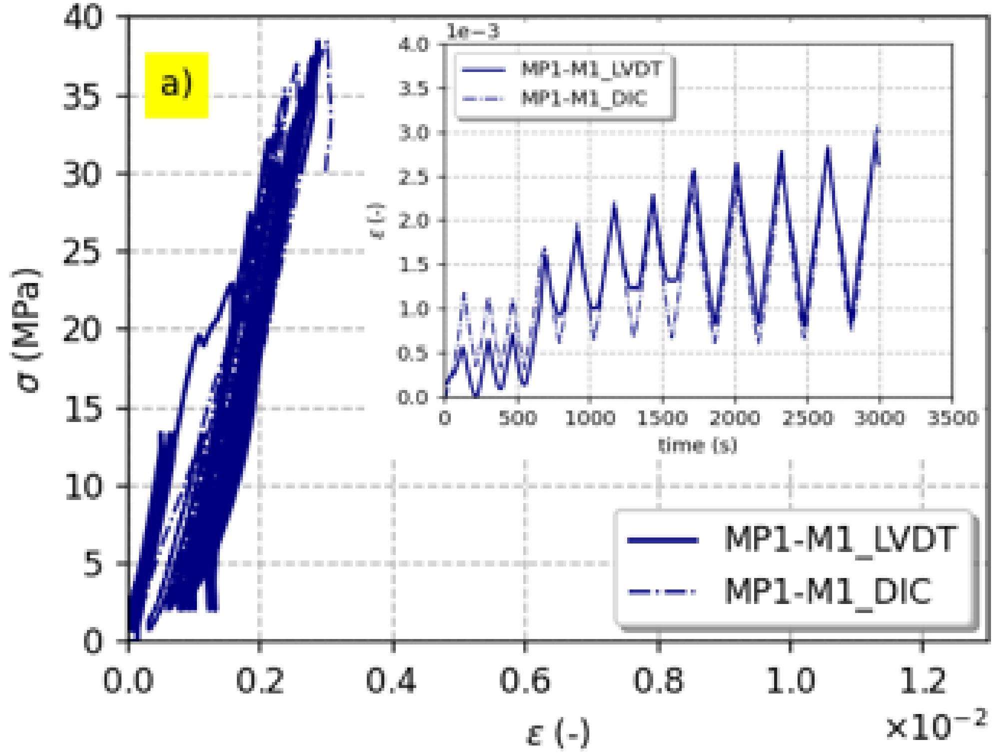


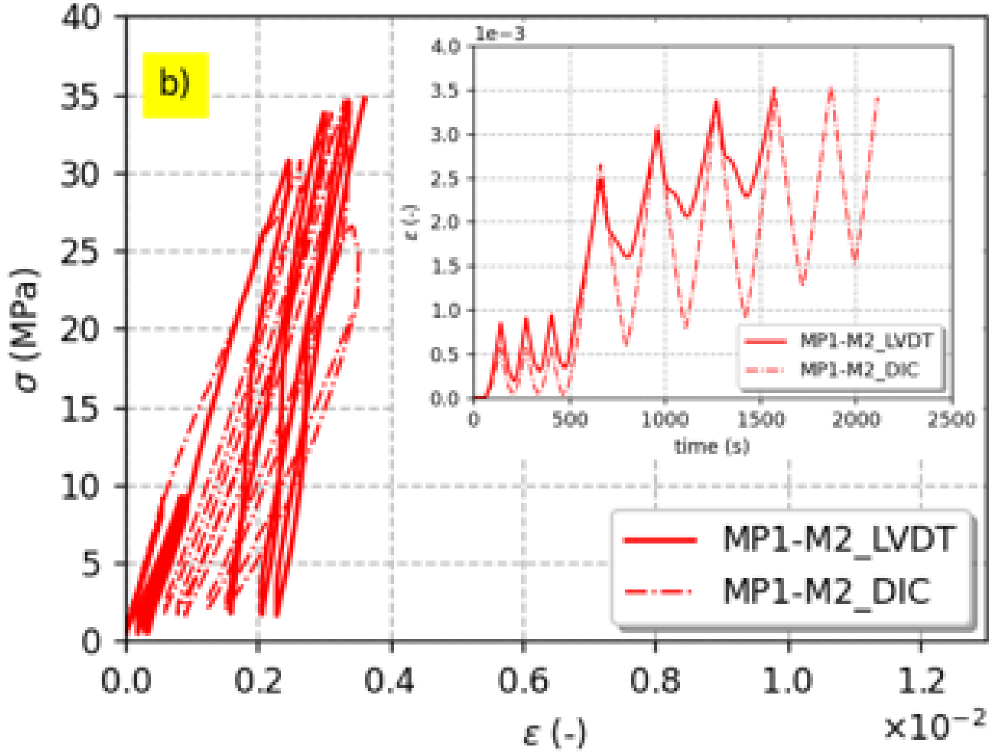




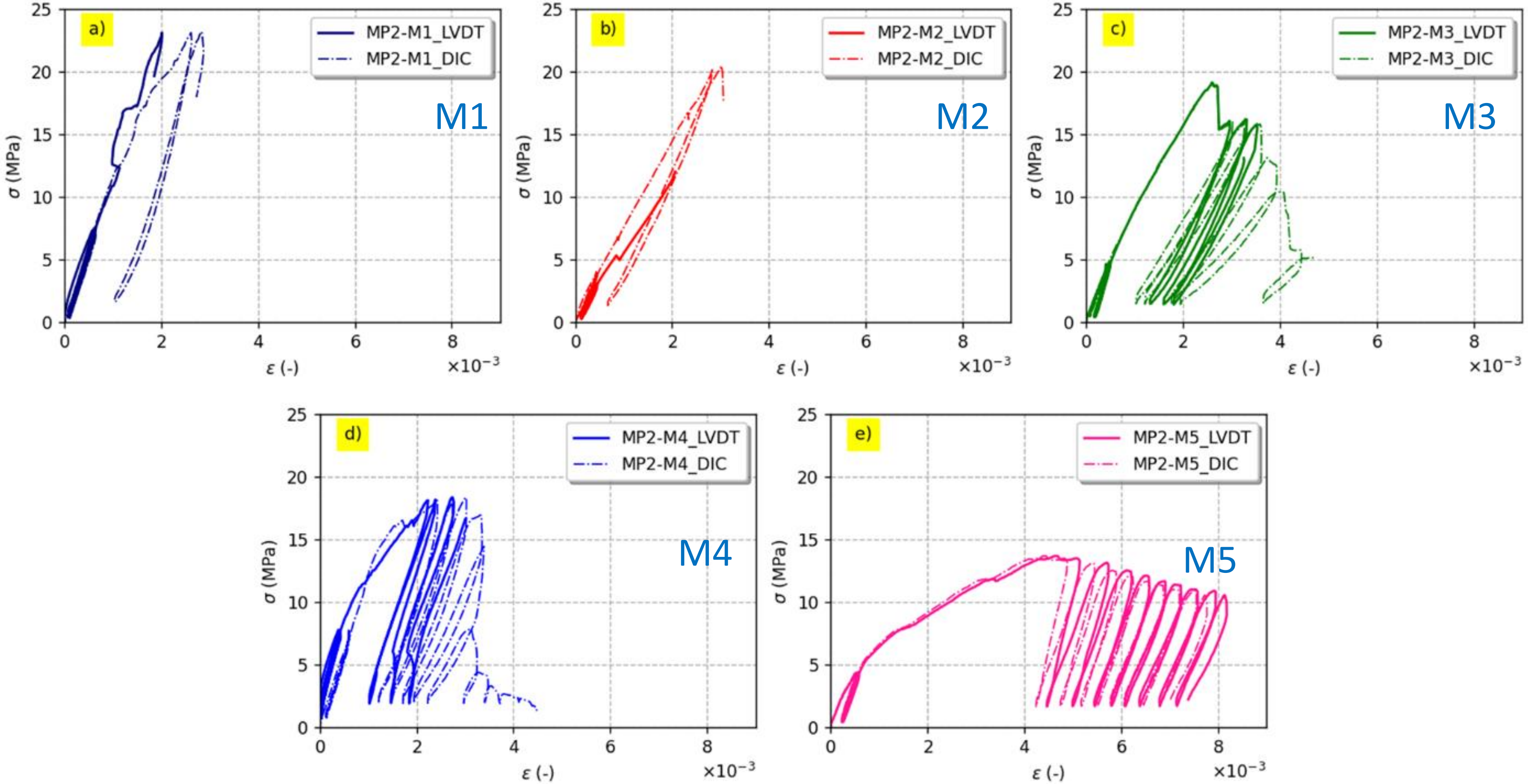
Specimen after test

Stress-strain curve MP1 (Cyclic loading)



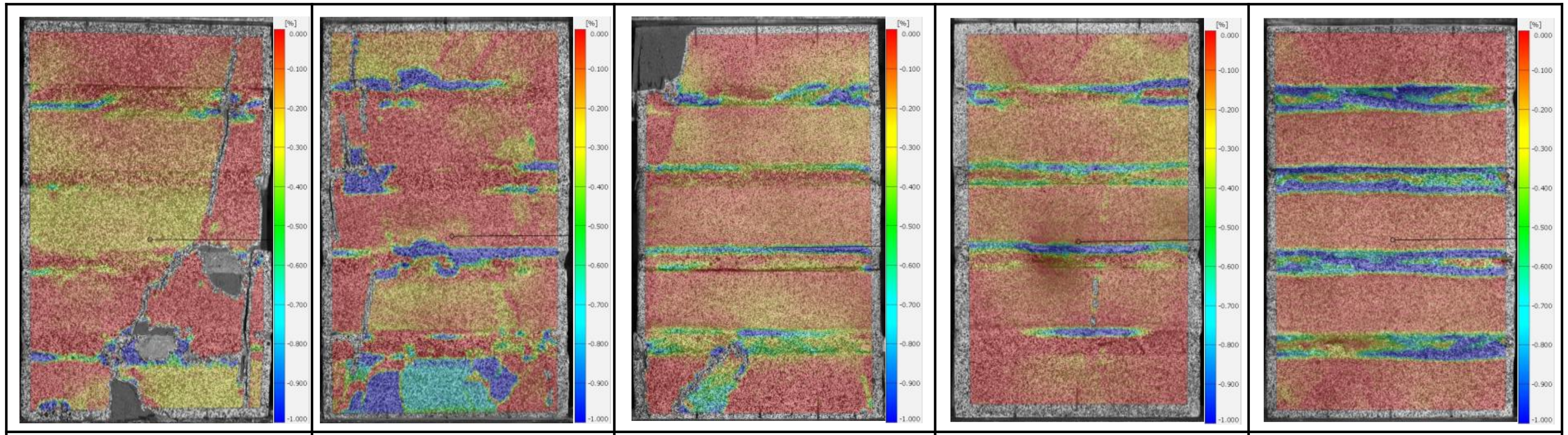


Stress-strain curve masonry MP2 (Cyclic loading)

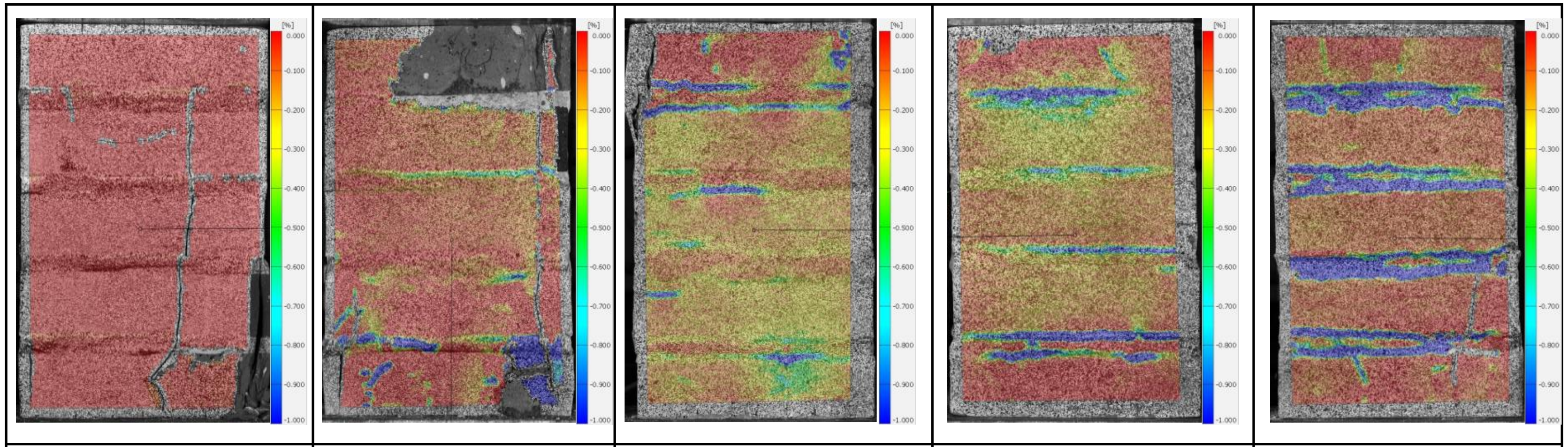


Specimen after test

Axial strain visualization at 90% of peak stress



a) MP1-M1	b) MP1-M2	c) MP1-M3	d) MP1-M4	e) MP1-M5



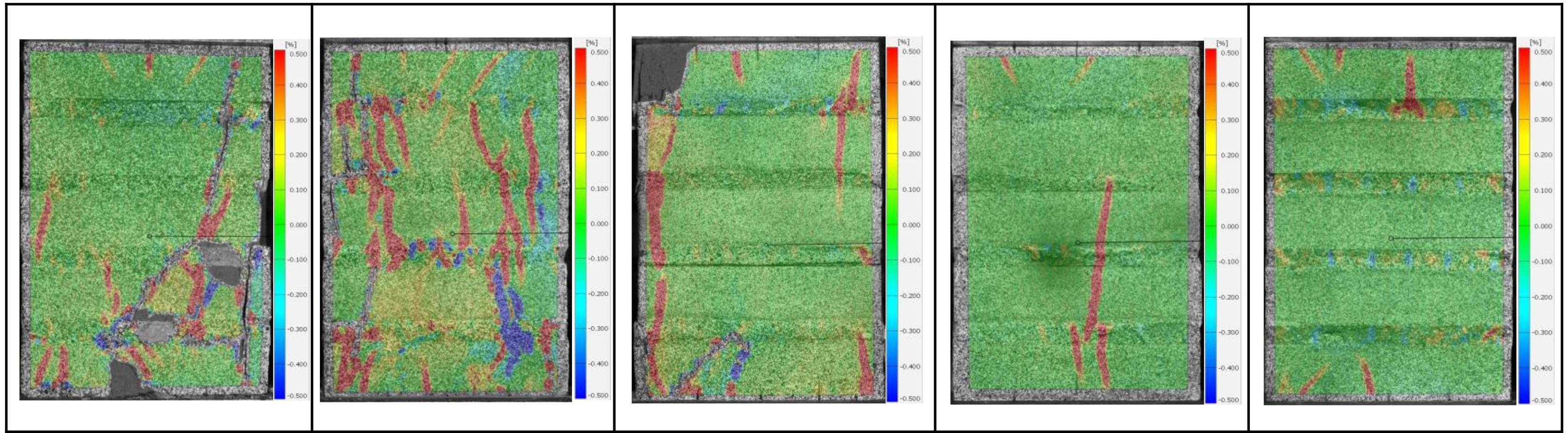
a) MP2-M1	b) MP2-M2	c) MP2-M3	d) MP2-M4	e) MP2-M5

- Spalling with higher cement ratio
- Spalling and strain localisation on cement-lime specimen
- Localisation of strains at joints with increase in lime contents

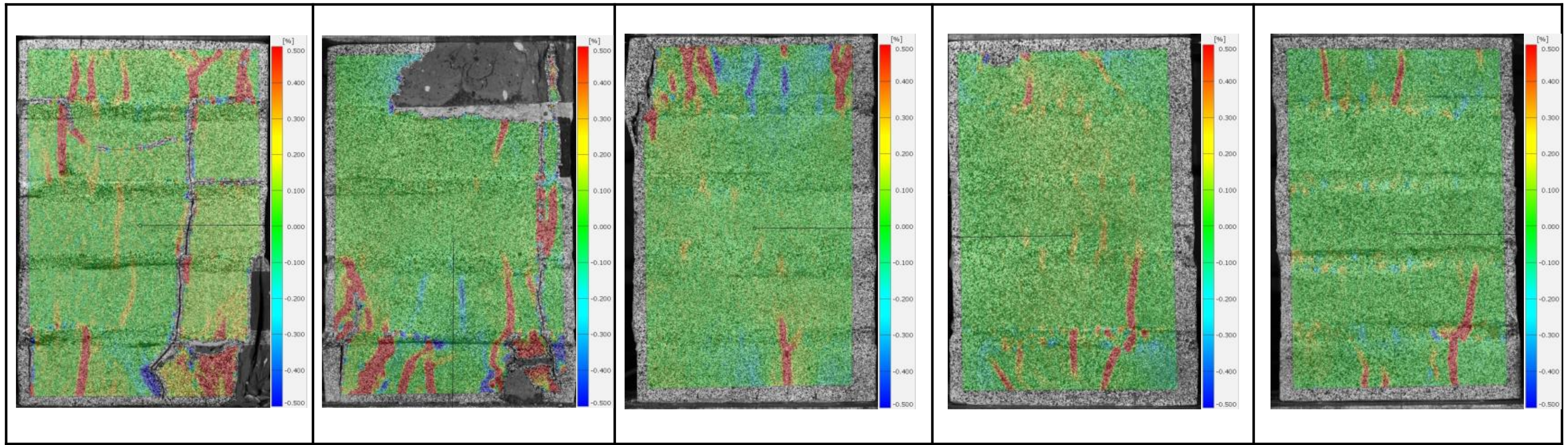
<u>Mortar constituents</u>

- M1-Cement 100% and lime 0%
- M2-Cement 70% and lime 30%
- M3-Cement 50% and lime 50%
- M4-Cement 30% and lime 70%
- M5-Cement 0% and lime 100%

Lateral strain visualization at 90% of peak stress



a) MP1-M1	b) MP1-M2	c) MP1-M3	d) MP1-M4	e) MP1-M5



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- M3-Cement 50% and lime 50%
- M4-Cement 30% and lime 70%
- M5-Cement 0% and lime 100%

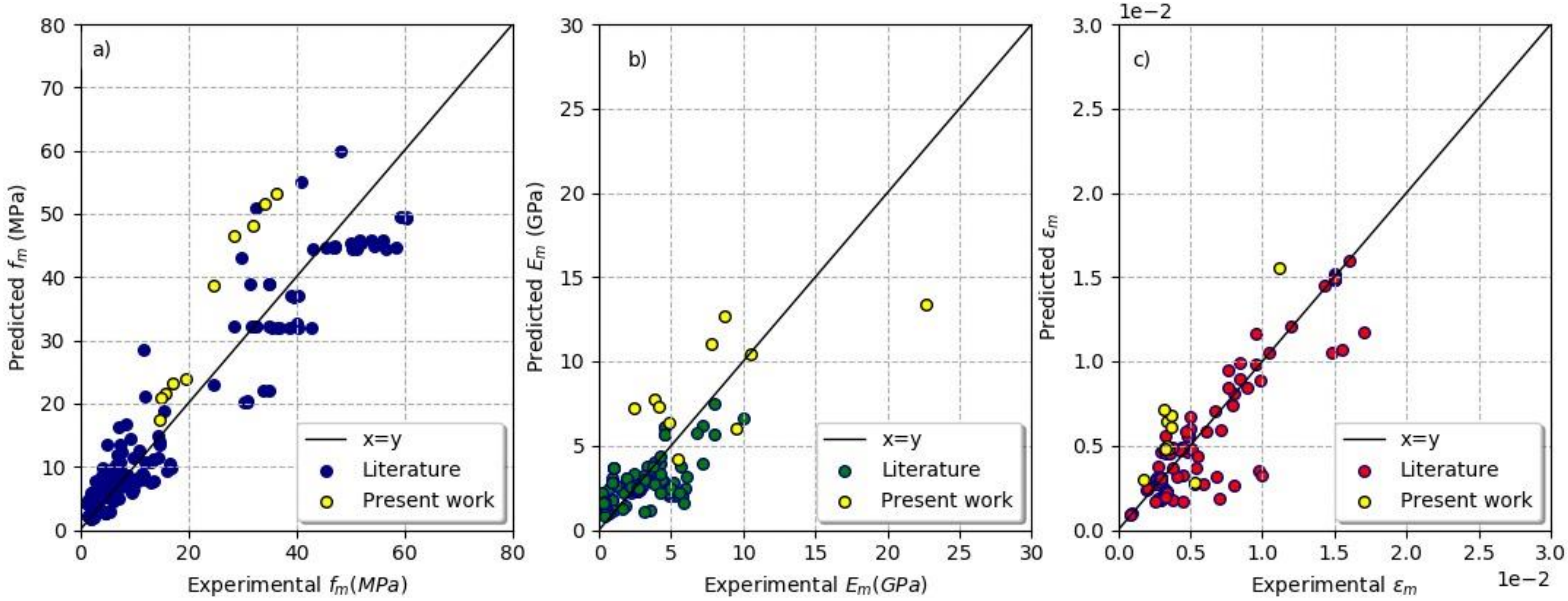
Summary of mechanical properties on prisms

Specimen	MP1-M1	MP1-M2	MP1-M3	MP1-M4	MP1-M5	MP2-M1	MP2-M2	MP3-M3	MP4-M4	MP5-M5
f_m (MPa)	36.57	32.97	28.95	19.51	16.50	24.31	20.51	18.42	16.40	13.78
$\varepsilon_{m\text{-}LVDT}$ (‰)	1.71	2.76	2.97	2.81	8.14	1.89	1.22	2.13	5.73	8.18
$\varepsilon_{m\text{-}DIC}$ (‰)	1.77	2.53	3.79	3.05	8.18	2.27	1.12	2.22	5.02	10.4
$E_{m\text{-}LVDT}$ (GPa)	17.89	14.58	8.13	8.66	4.09	12.25	24.97	11.17	8.66	4.17
$E_{m\text{-}DIC}$ (GPa)	17.33	14.17	7.74	9.12	4.68	11.63	25.17	12.52	9.12	3.61

f_m : Max compressive strength
$E_{m\text{-}LVDT}$: Elastic modulus measured with LVDT
$E_{m\text{-}DIC}$: Elastic modulus measured with DIC
$\varepsilon_{m\text{-}LVDT}$:Peak strain measured with LVDT
$\varepsilon_{m\text{-}DIC}$:Peak strain measured with DIC

- MP1 higher f_m
- Reduction of E_m and increase of ε_m with reduction of f_m except MP1-M4 and MP2-M2
- Max difference of 20% between both techniques

Present work and data-base comparison



$f_m = 0.09 f_b^{0.32} f_j^{1.22}$ $f_b \leq 20MPa$ **R^2=0.91**
$f_m = 1.90 f_b^{0.06} f_j^{0.79}$ $f_b > 20MPa$ **R^2=0.87**

234 data points

$E_m = 320 f_b^{0.63} f_j^{0.23}$ **R^2=0.56**

157 data points

$\varepsilon_m = \frac{0.48 f_m}{f_j^{0.06} E_m^{0.84}}$ **R^2=0.79**

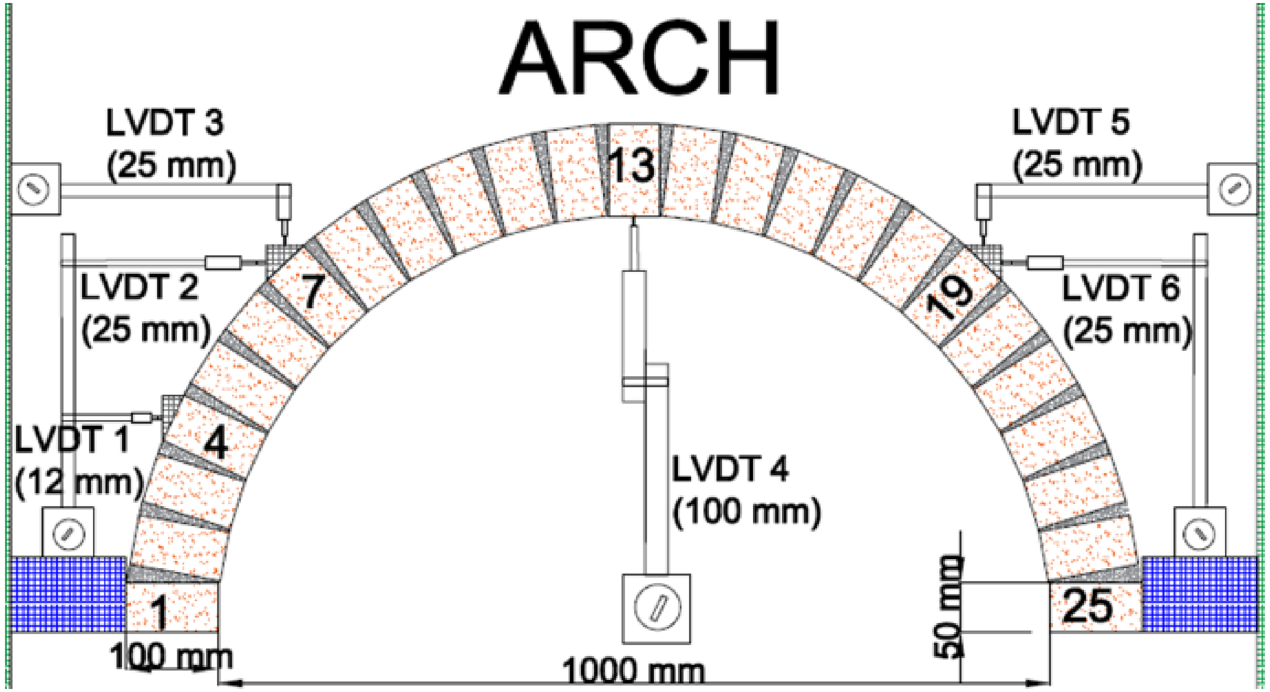
141 data points

Masonry arches

Formwork

After construction

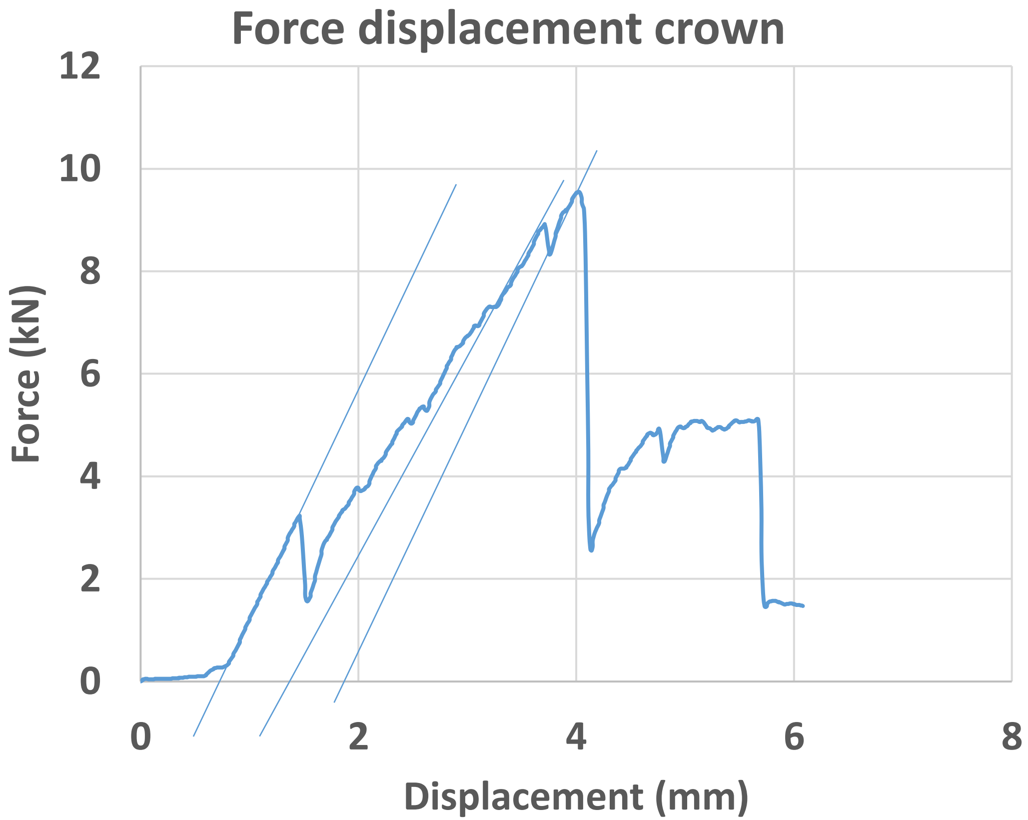
Curing of masonry arches

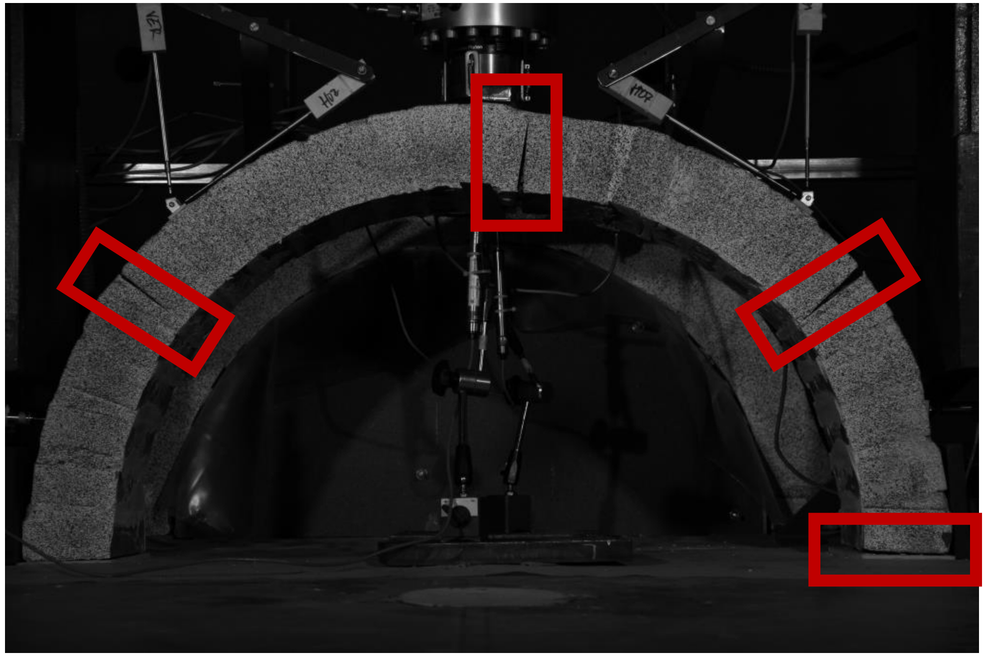


Experimental setup

Static analysis on masonry arches

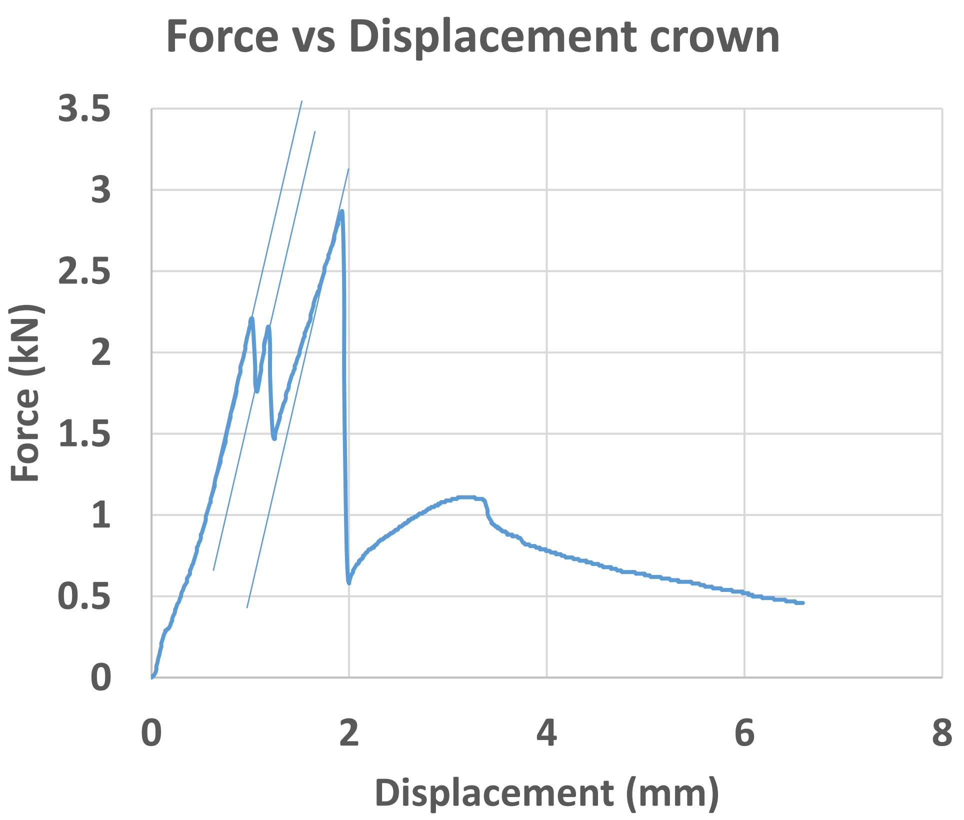
Masonry arch with 100% cement (1st Analysis)

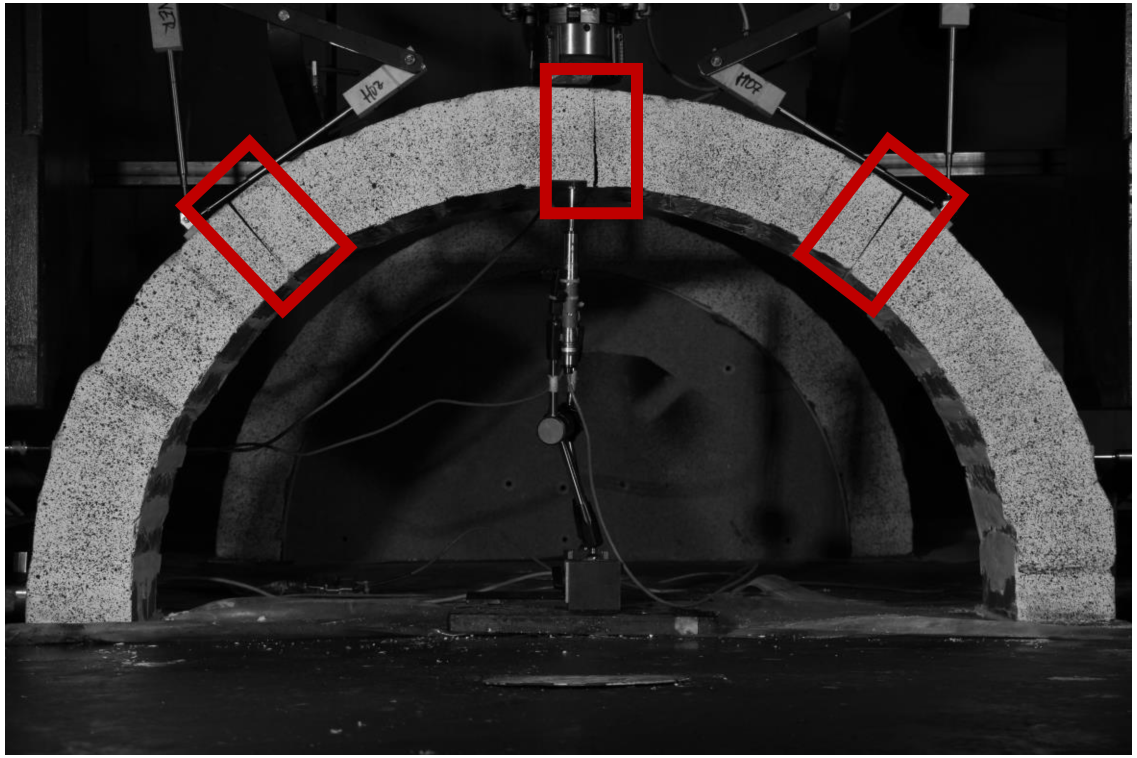




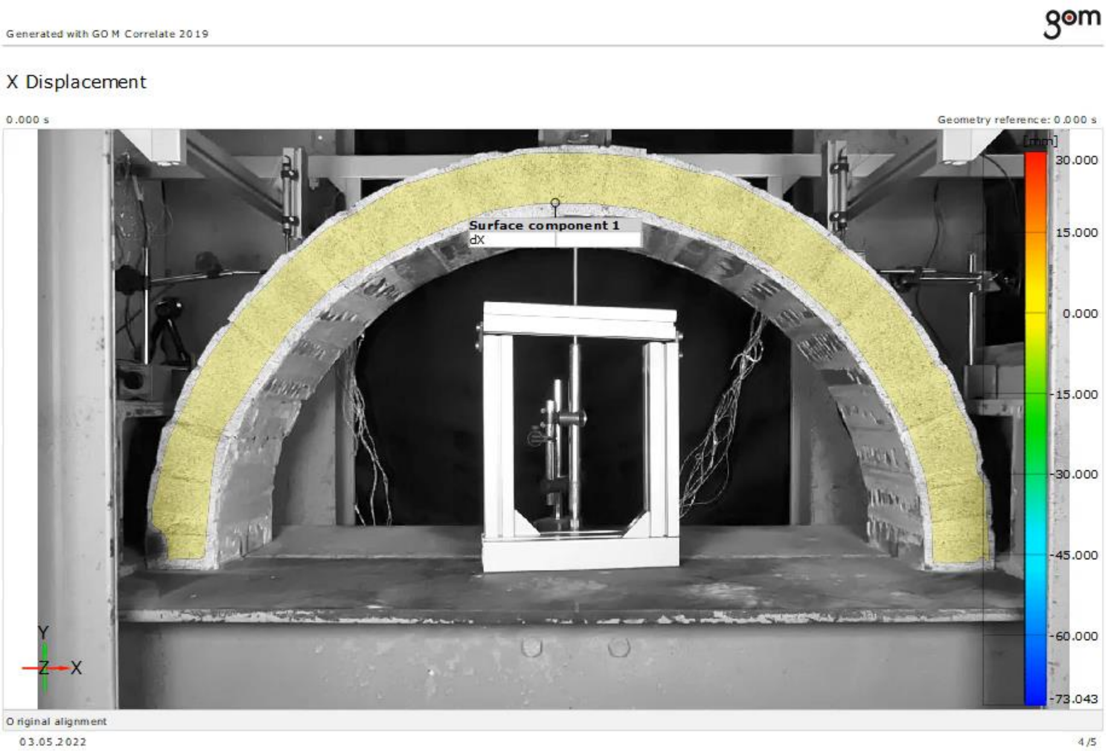
Static analysis on masonry arches

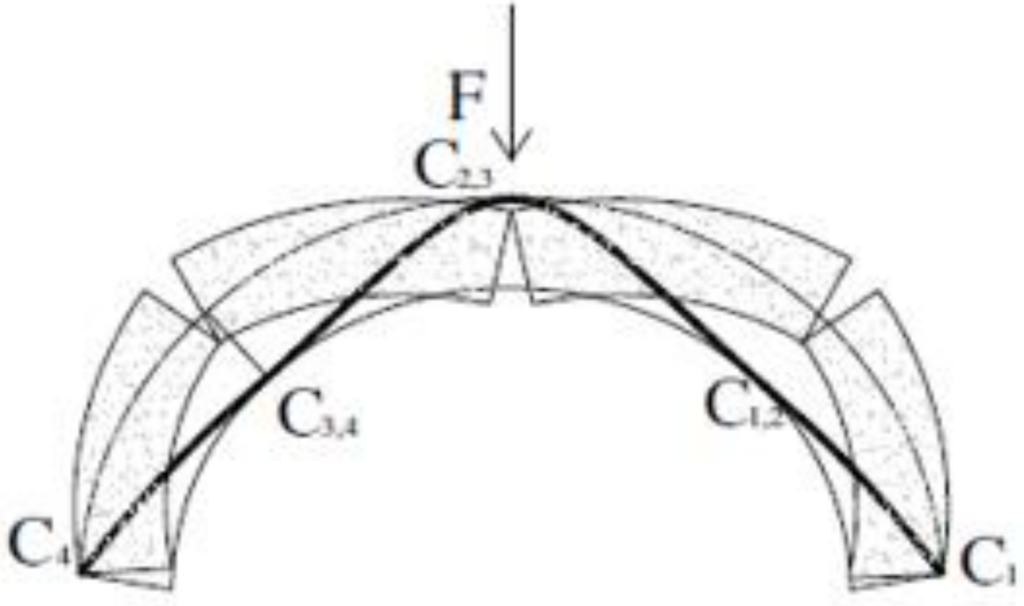
Masonry arch with 100% lime (1st Analysis)





Static analysis on masonry arches

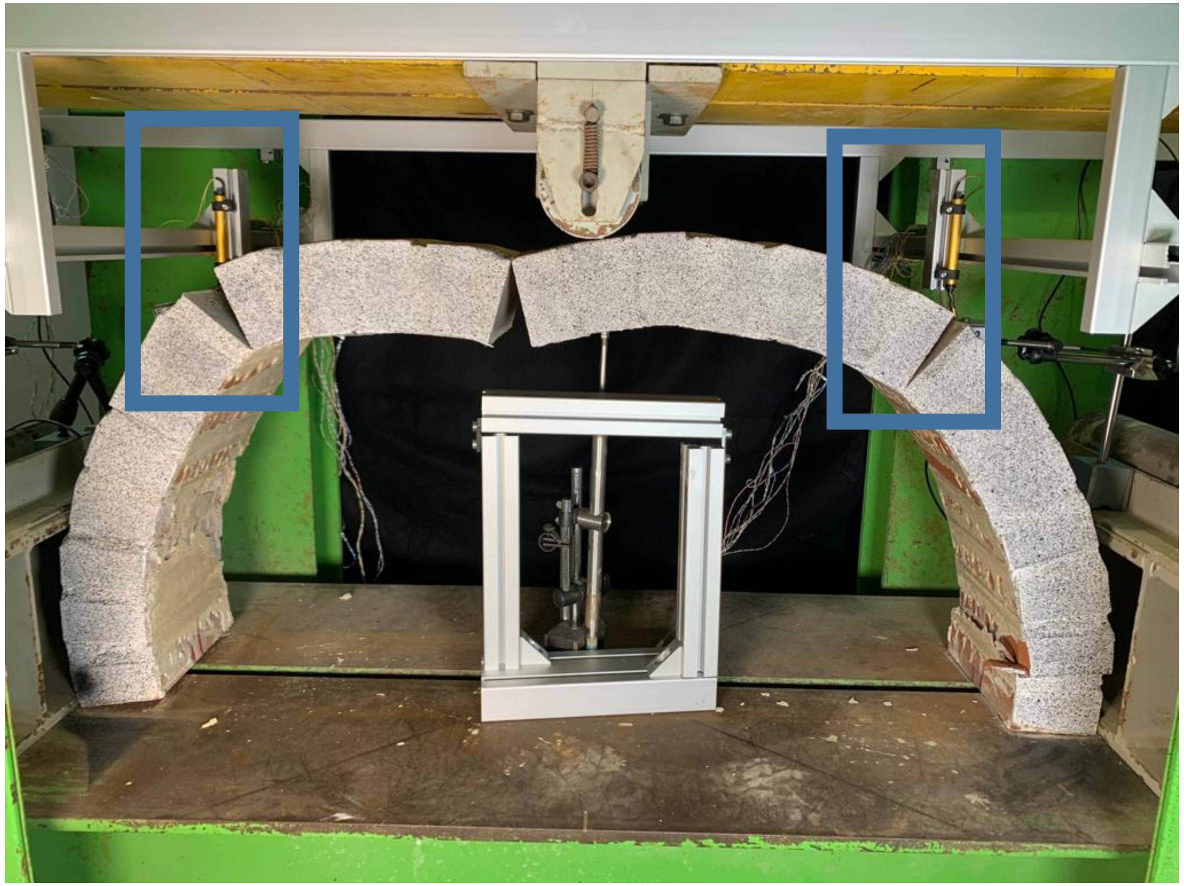


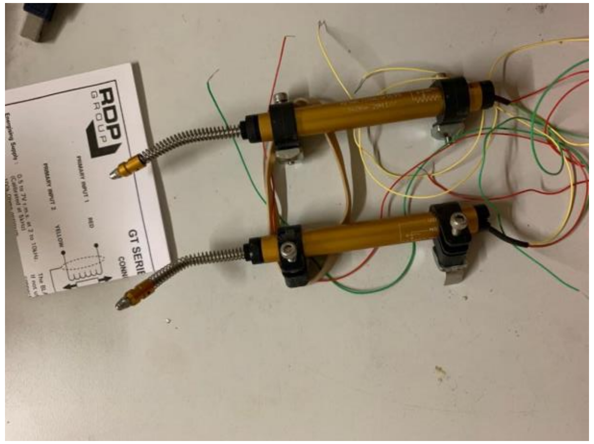


Heyman et al.

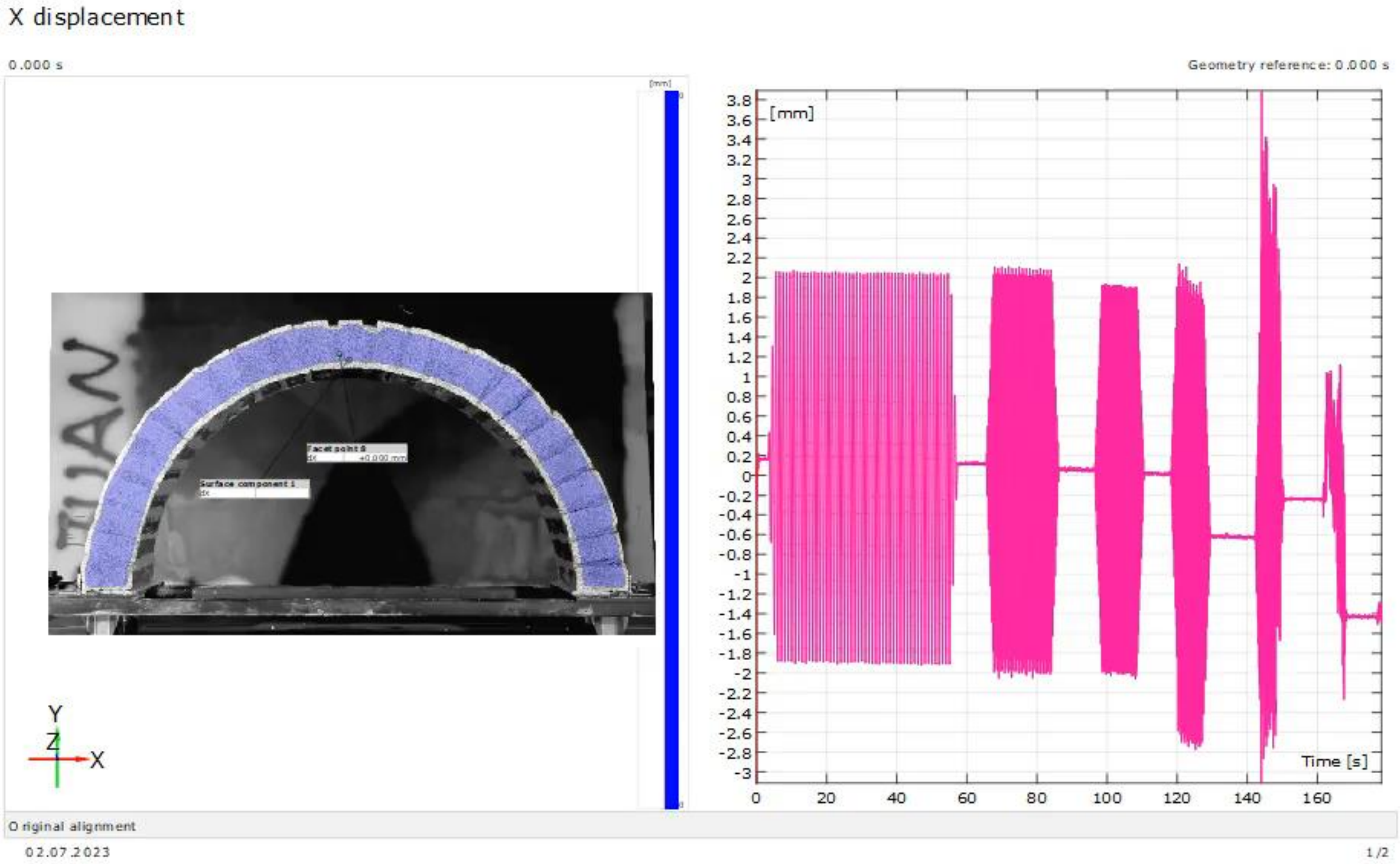
Max X-displacement = 31mm at brick 7

Static analysis on masonry arches





Pseudo-dynamic analysis on masonry arches



Properties

Images at 25 Hz
Sine tapered wave
50% of static pre-load
Frequency (1,3,5,7,10,13)
50 cycles
Displacement ±2mm and ±1.5 mm
Acceleration 2m/s2

Conclusions

1. Possibility to characterise the full-scale behaviour of material.
2. Strong influence of masonry joint strength on masonry compressive strength
3. Proposition of new analytical equations for mechanical properties.
4. Possibility to characterise historical monuments where essential data is not available.

Perspectives

- Automate DIC with artificial intelligence
- Characterisation of damage evolution in masonry arches with proposed models for numerical modelling
- Validation of DIC technique in masonry arches under dynamic behaviour
- Proposition of analytical model for damage analysis of masonry arches

Scientific publications

1. Strain measurement using digital image correlation by I BELLO et al. (FIB Conference paper 2021)

2. Constitutive behaviour of masonry prisms using a full-field measurement technique by I BELLO et al. (Structures journal 2022)

3. Characterization of Concrete Behavior Under Cyclic Loading Using 2D Digital Image Correlation by I BELLO et al. (Building Engineering 2023)

4. Complete stress-strain analysis of masonry prisms under compressive loading-unloading cycles through Digital Image Correlation by I BELLO et al. (2nd Peer Review Engineering Structures 2023)

5. Non-contact measurement of concrete under loading-unloading splitting test by I BELLO et al. (Accepted in International Journal of Masonry Research and Innovation 2023)

THANK YOU FOR YOUR ATTENTION

Questions and discussion!

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