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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE SEISMIC RESPONSE OF CONFINED MASONRY WALLS

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Content

Background and motivation

- Masonry structures have been and continue to be common practice in construction worldwide.
- Masonry is still one of the most commonly used building materials throughout the Balkans.

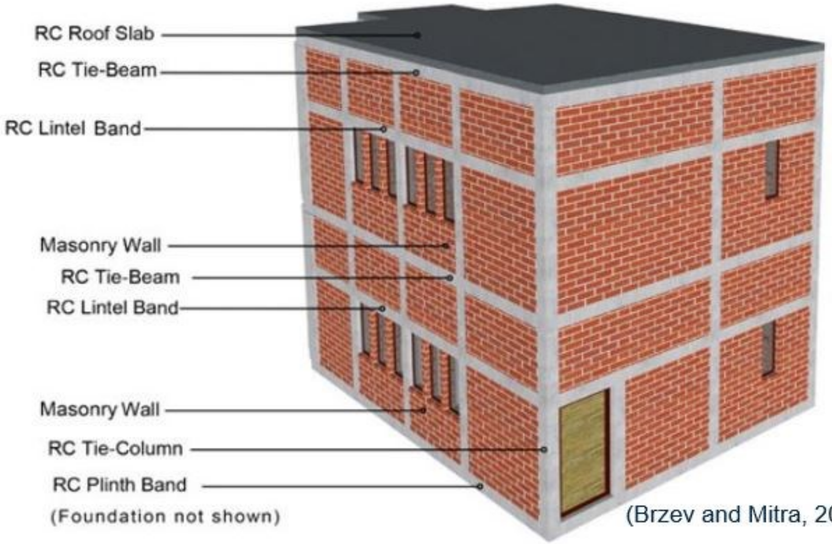
Slovenia

- From 2006 to 2020, 47% of the newly constructed buildings were masonry buildings! (GURS, 2021)
- Unreinforced masonry (URM) vs. Confined masonry (CM)
- URM construction – poor seismic performance in recent earthquakes (Croatia, Italy, Albania, Serbia, Slovenia).
- CM is an attractive, affordable, and cost-effective construction system for building low- to mid-rise masonry buildings in earthquake-prone regions.
- CM buildings - both in urban and rural areas of Slovenia (40% of the entire housing stock in Slovenia).

Background and motivation

- CM construction offers several advantages over seismically vulnerable URM buildings due to its superior seismic performance in recent major earthquakes.
- CM has features of both technologies (URM and RC frame with masonry infill)!
- Load-bearing masonry walls in CM buildings are confined by small-sized RC columns and beams (tie-columns & tie-beams).
- Tie-columns play a crucial role in improving seismic response!
- Providing lateral support to the walls; increasing walls’ displacement capacity, ductility, and energy dissipation capacity.

CM house under construction in Slovenia (Lutman and Tomaževič, 2002)



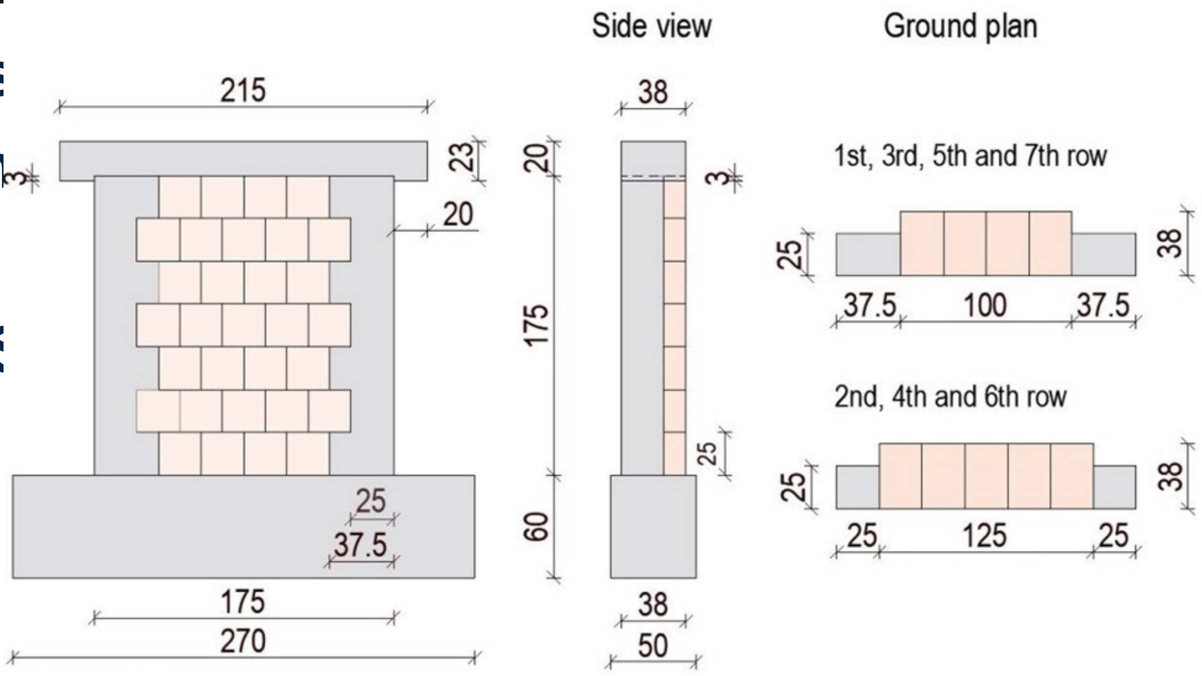
(Brzev and Mitra, 2018)

Introduction

- Most research on CM is based on experimental testing of walls.
- The finite element method-based approaches can be divided into three groups: detailed micro model, simplified micro model and macro model.
- Simplified micro-modelling approach was used in order to simulate the seismic response of CM walls (Krtinić et al., 2023).
- The one of the objectives is to develop a reliable 3D FE model that can capture the effect of partial confinement and interaction between masonry and RC tie-columns!

Experimental tests

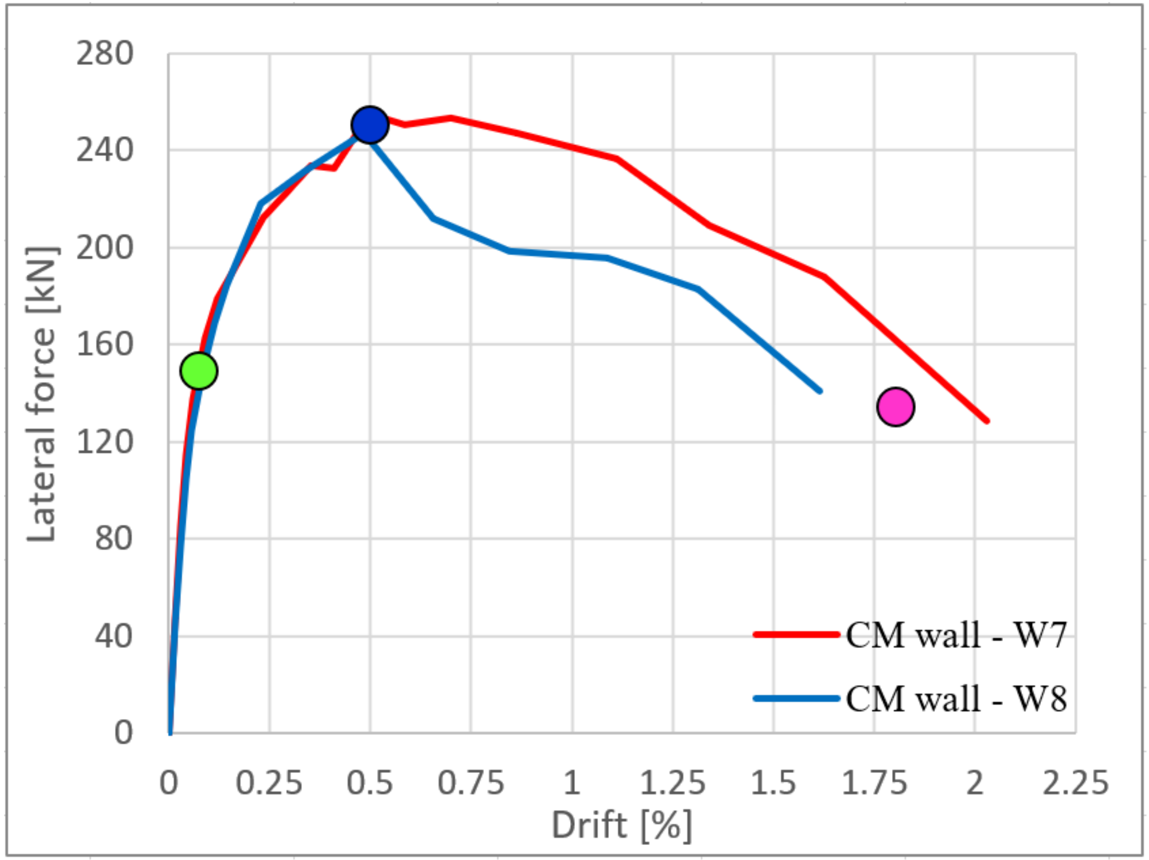
- The seismic response of modern CM walls - specimens W7, W8
- Modern hollow clay masonry blocks (units 250x249x380 mm)
- The cavities of modern blocks are filled with thermal insulation.
- Polyurethane (PU) glue instead of thin-bed mortar
- The final thickness of the bed joints
- Perfect overlapping of units (0.5 len
- RC tie-columns – 25x25 cm
- Longitudinal reinforcement 4 Ø14, S



Experimental tests

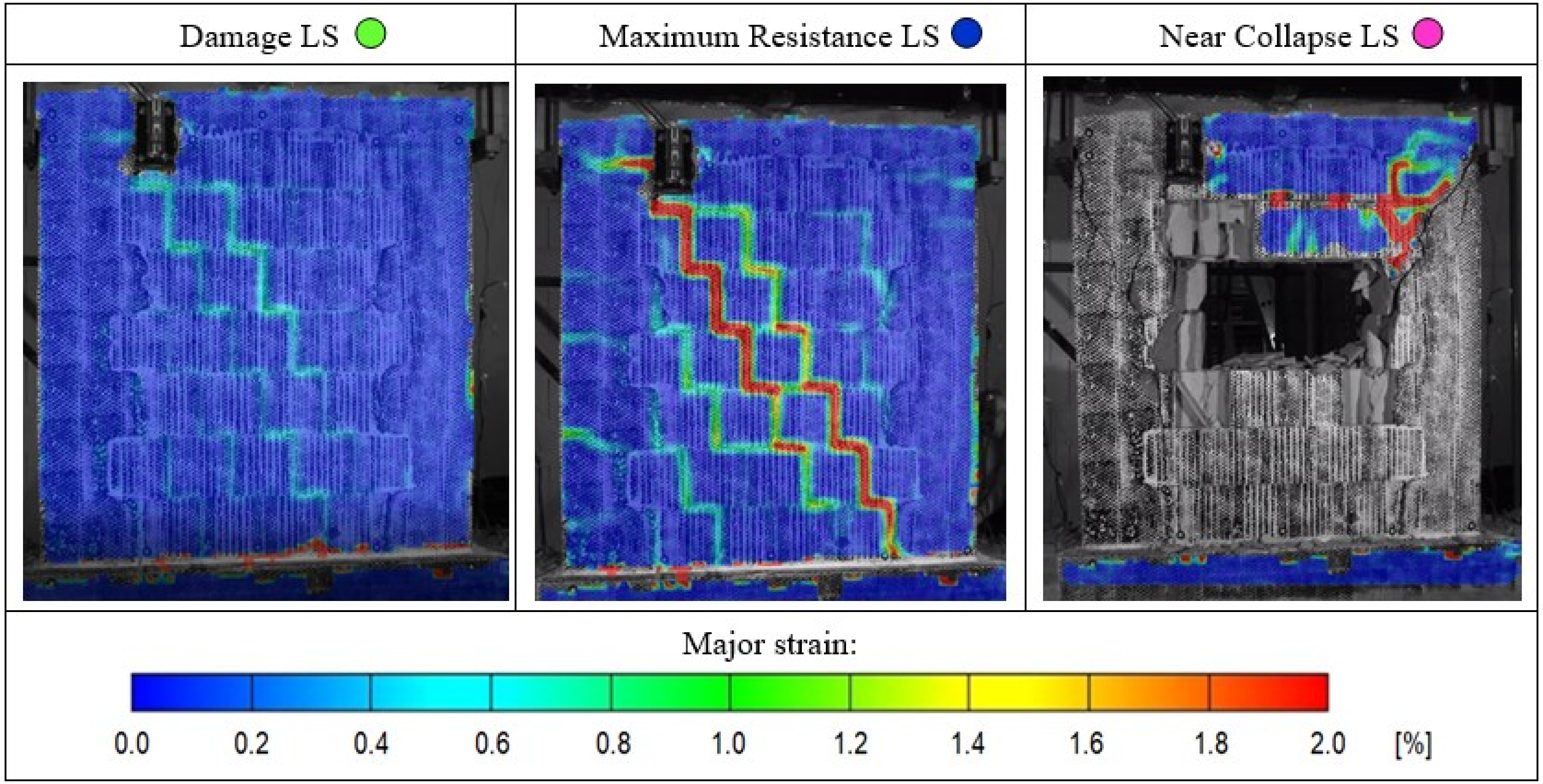
- Experimental results
- Based on exp. envelope curves, three limit states were defined:

1) Damage LS
2) Maximum resistance LS
3) Near collapse LS



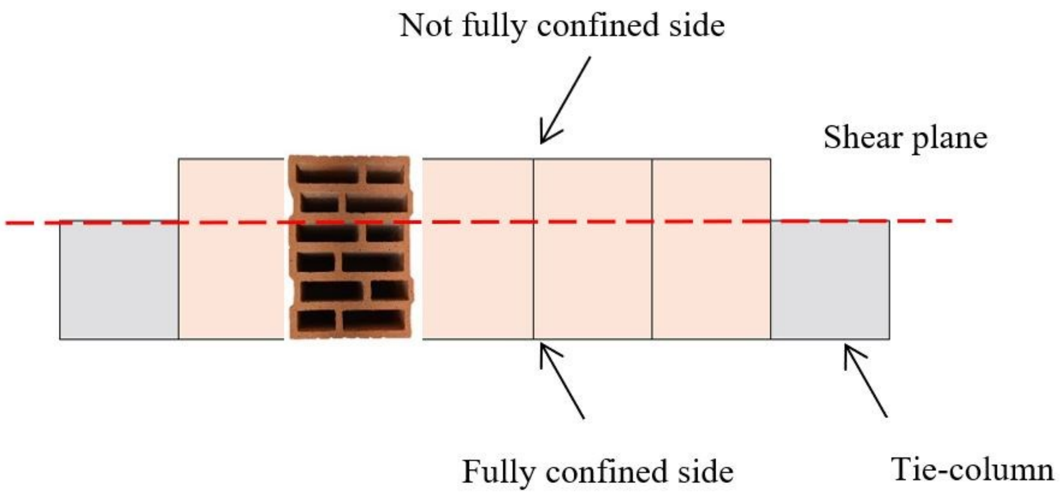
Experimental tests

- For each of the LSs, the strain fields were measured using DIC!
- The major strain fields of tested specimen W8



Experimental tests

- Experimental results
- An interesting phenomenon was observed during the tests.
- The protruding part of the masonry developed damage rather early and started to sheared off!
- Not fully confined side begins to crack and damage along a shear plane.



Experimental tests

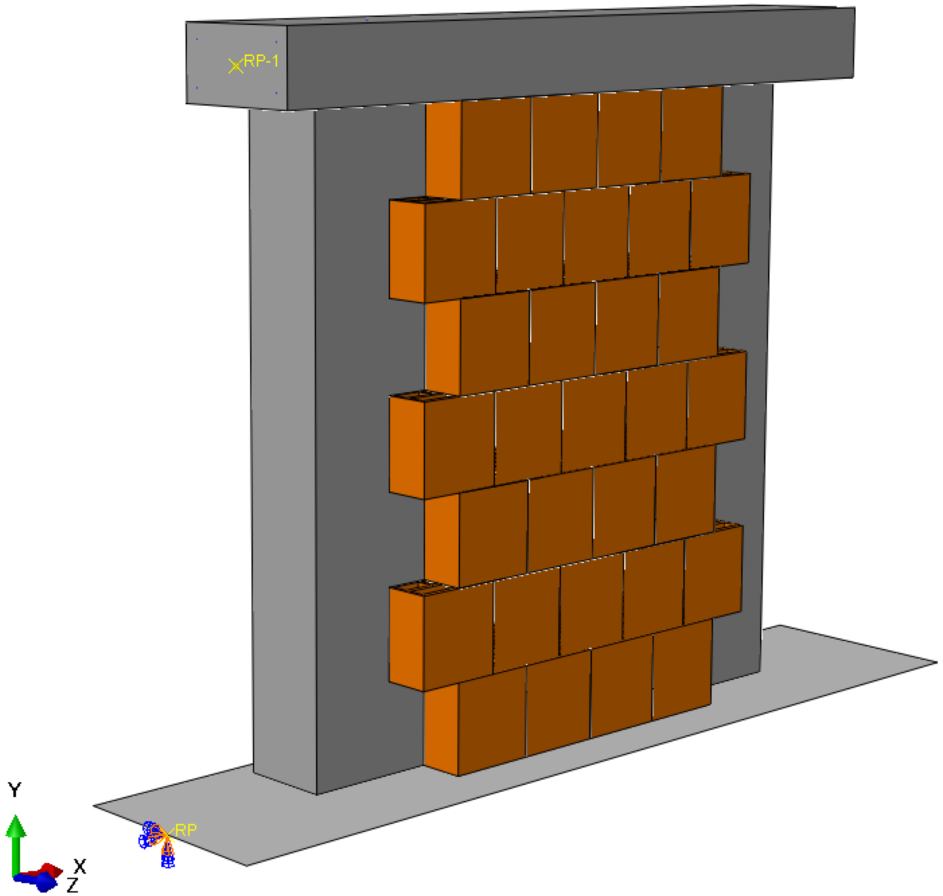
- At a drift of about 0.5% – The protruding parts of the units were damaged!
- At a drift of 1.3% – The protruding parts completely sheared off!

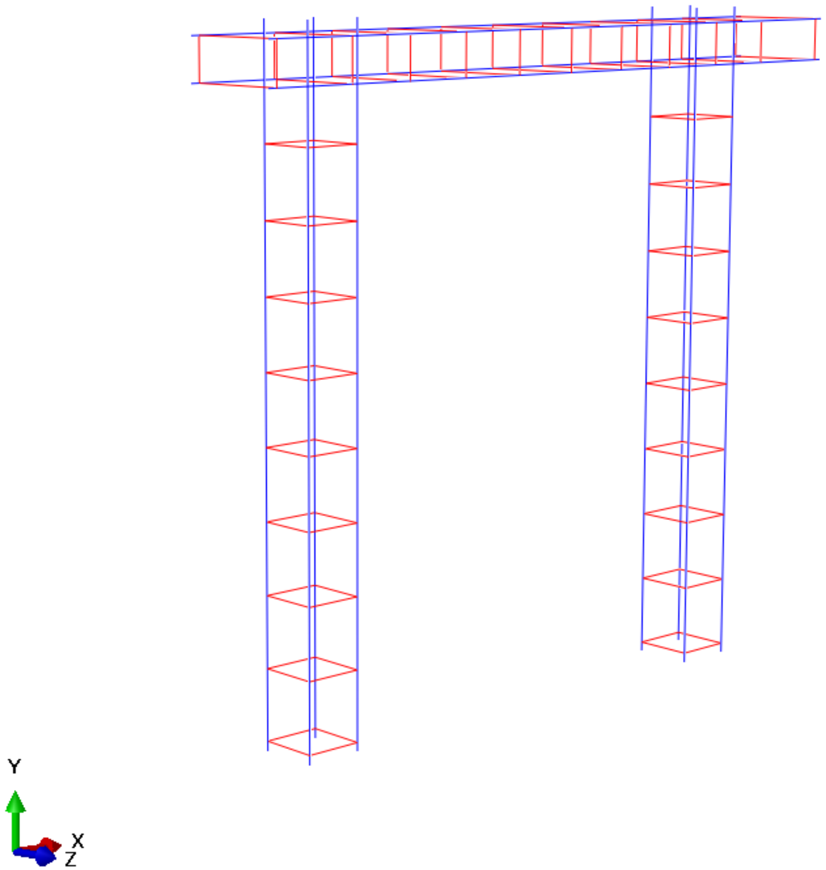
Numerical simulations of CM walls

- Description of the numerical models
- <u>Abaqus software</u>
- The CM wall is modelled using the actual geometry of full-scale specimens!
- Foundation - discrete rigid plate in order to reduce computational costs.
- RC tie-elements and masonry units - C3D8R
- Longitudinal reinforcement bars and stirrups - T3D2
- Interaction concrete – reinforcement - "Embedded Constraint"
- Fixed BC - bottom surface of the bottom beam

Numerical simulations of CM walls

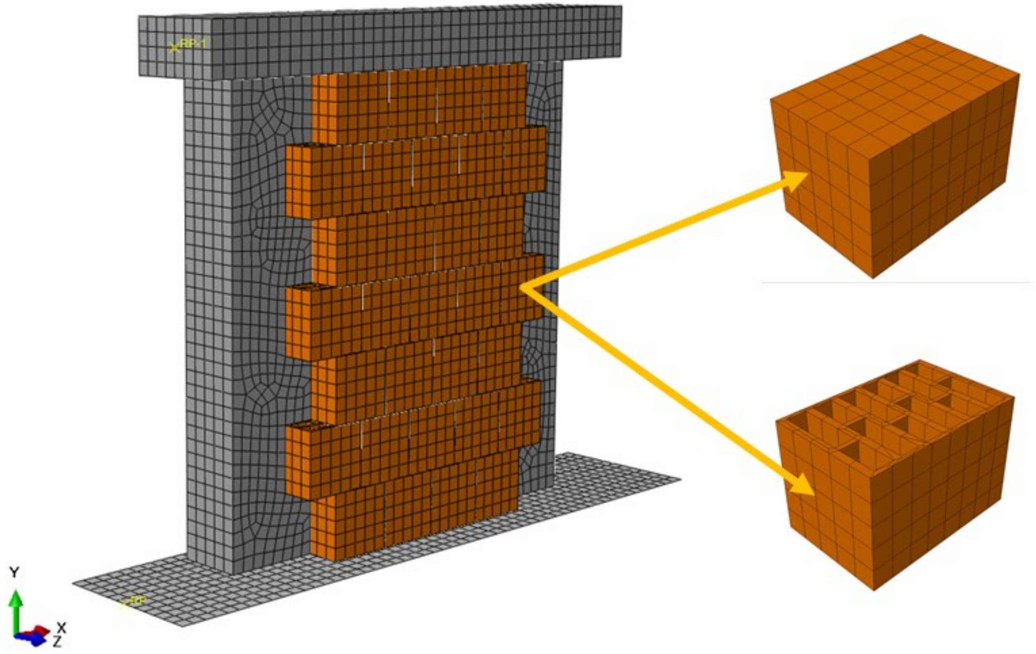
○ **Description of the numerical models**





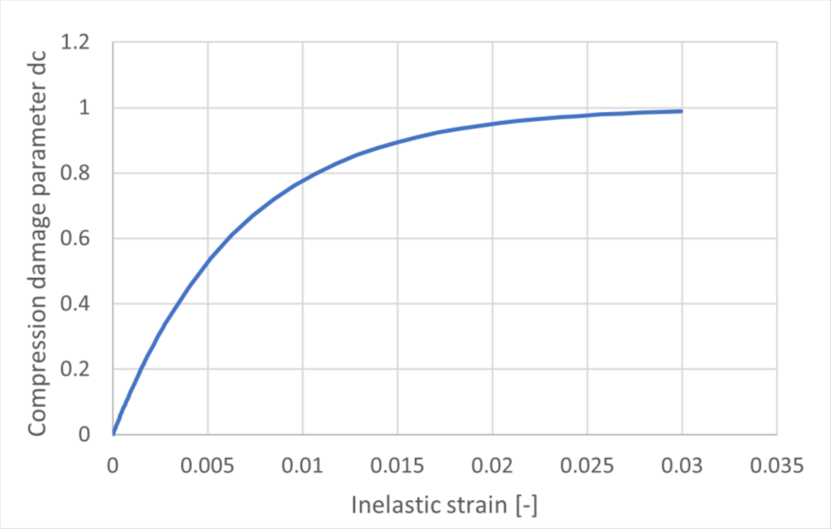
Numerical simulations of CM walls

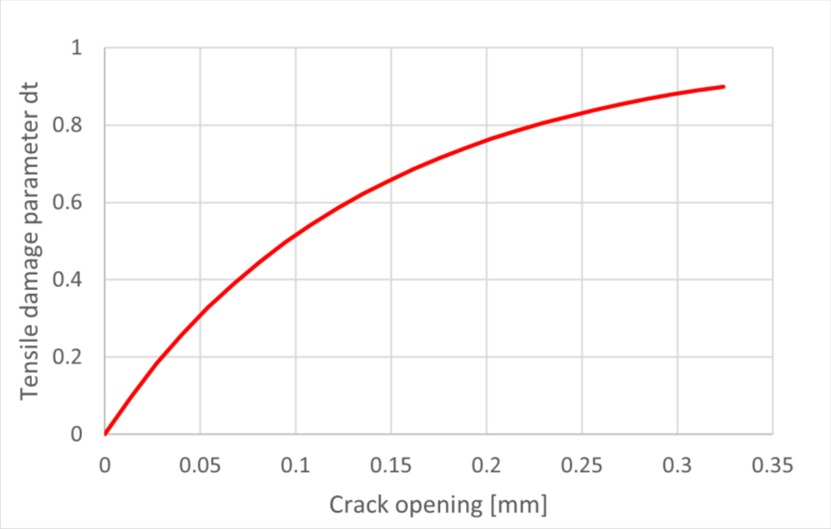
- **Numerical simulations were performed in two steps, using progressively more detailed models.**
- **Hollow clay blocks were modelled in two ways – two 3D models!**
- **First numerical model - masonry units as solid elements (without holes)**
- **Second numerical model - masonry units were modelled according to their actual geometry (with webs, shells and holes)**



Numerical simulations of CM walls

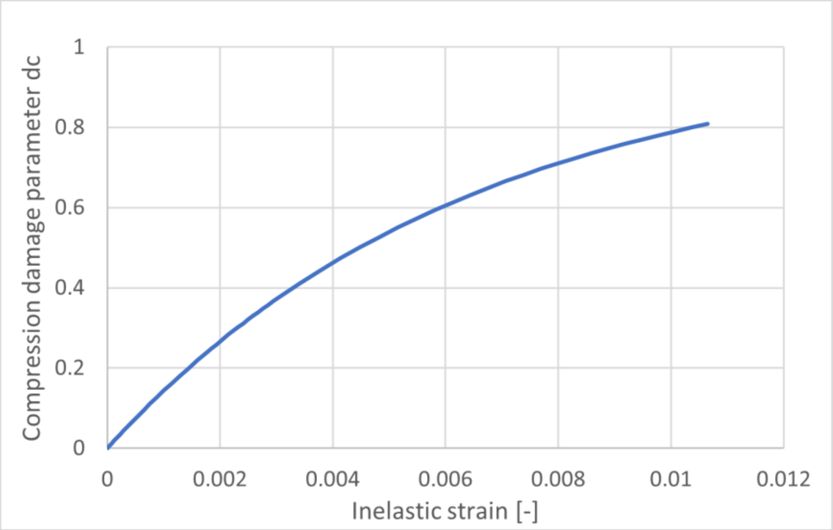
- <u>**Material model for concrete**</u>
- **Concrete Damaged Plasticity (CDP) model**
- **Compressive behaviour – stress-strain curve (Eurocode 2)**
- **Tensile behaviour – stress-displacement curve**
- **Damage curves for concrete under compression and tension**

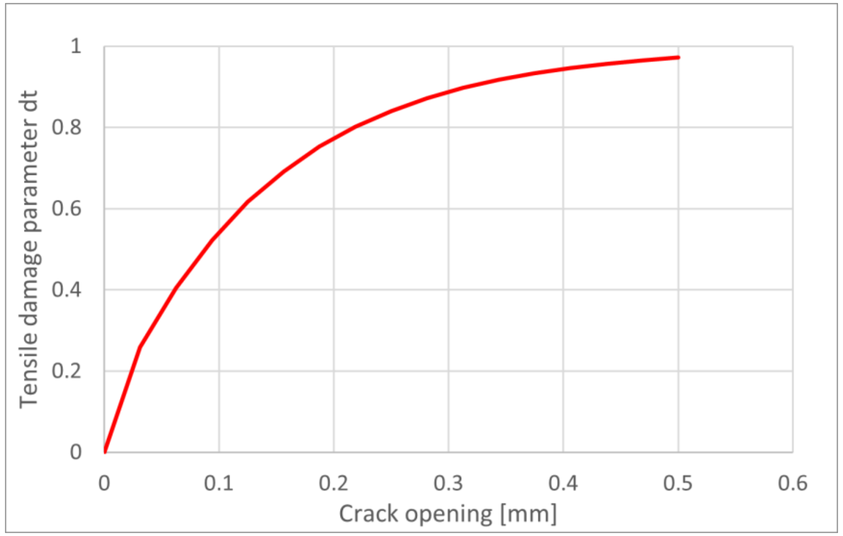




Numerical simulations of CM walls

- **Material model for masonry units**
- Concrete Damaged Plasticity (CDP) model
- For definition of stress-strain curves, the approach from Stavridis and Shing (2010) is used with the slight modification.
- The damage curves were generated in the same way as for concrete (FE model 1).
- For FE model 2 are generated in the same way just using different ultimate strain!





Numerical simulations of CM walls

- **Interaction between concrete and masonry units**
- **The contact interface between the units, as well as joints between the RC ties and masonry units - general contact with the specified interaction properties!**

1) global property assignment to all elements that are in contact (frictional coefficient - 0.57)

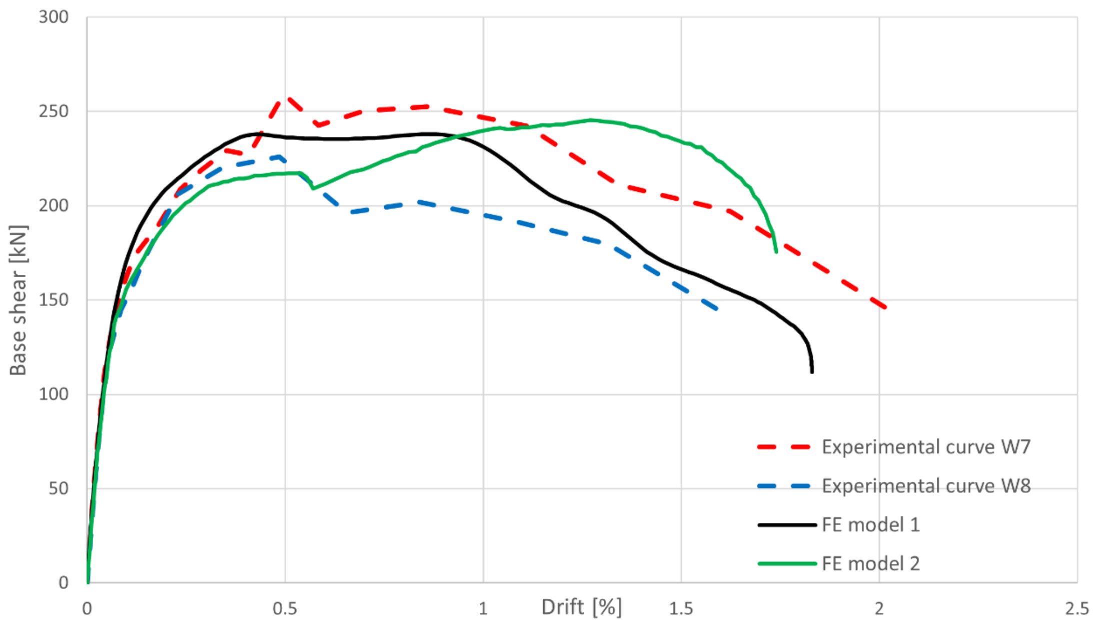
2) individual contact property to represent bed-joint behaviour (Surface-based cohesive behaviour)

- **Overview of values adopted for defining interaction properties for both numerical models are shown in the paper.**

Numerical simulations of CM walls

- **The results of numerical simulations (<u>in terms of the capacity curve</u>)**

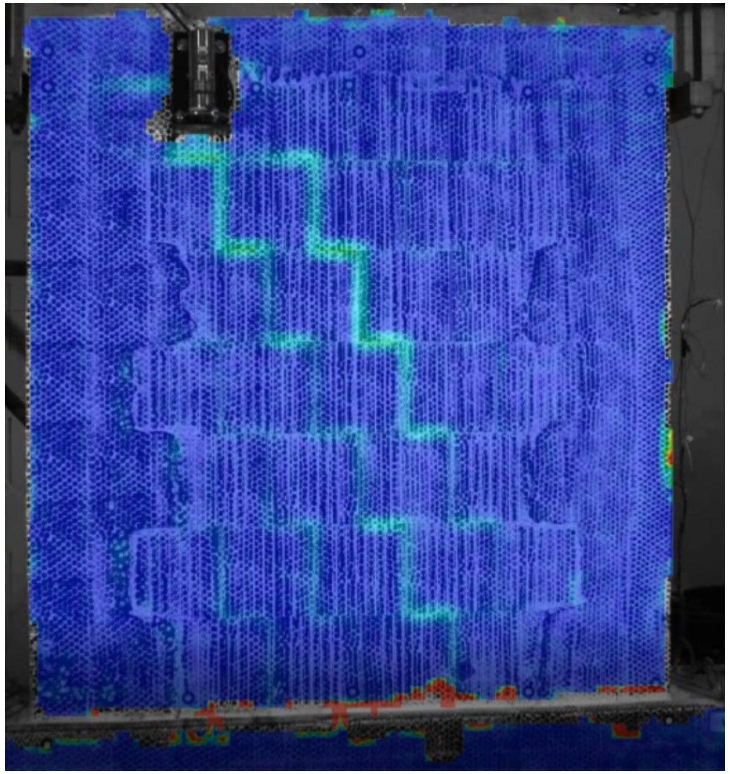
	Damage LS		Max. Resist. LS		Near Collapse LS	
	F [kN]	*Φ* [%]	*F* [kN]	*Φ* [%]	*F* [kN]	*Φ* [%]
Experiment W7	162.7	0.09	259.0	0.54	128.8	2.03
Experiment W8	151.0	0.085	247.0	0.49	140.9	1.62
Simulation M1	160.14	0.083	237.94	0.48	113.78	1.83
Difference W7/M1 [%]	-1.57	-7.78	-8.13	-11.11	-11.66	-9.85
Difference W8/M1 [%]	+5.71	-2.35	-3.67	-2.04	-19.25	+11.48
Simulation M2	155.70	0.092	217.31	0.53	169.42	1.74
Difference W7/M2 [%]	-4.30	+2.17	-16.10	-1.85	+26.58	-14.29
Difference W8/M2 [%]	+3.02	+7.61	-12.02	-7.55	+19.68	-6.90

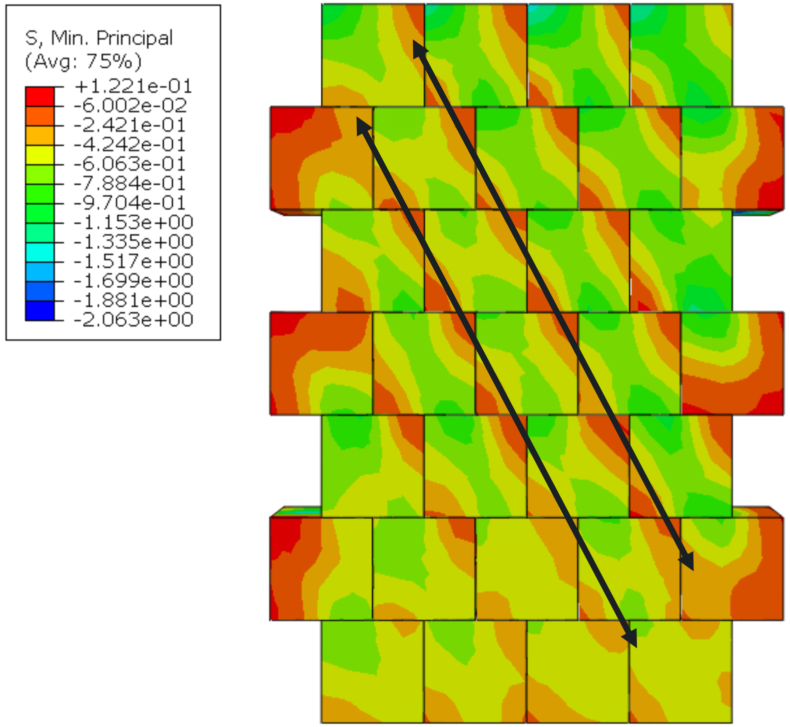


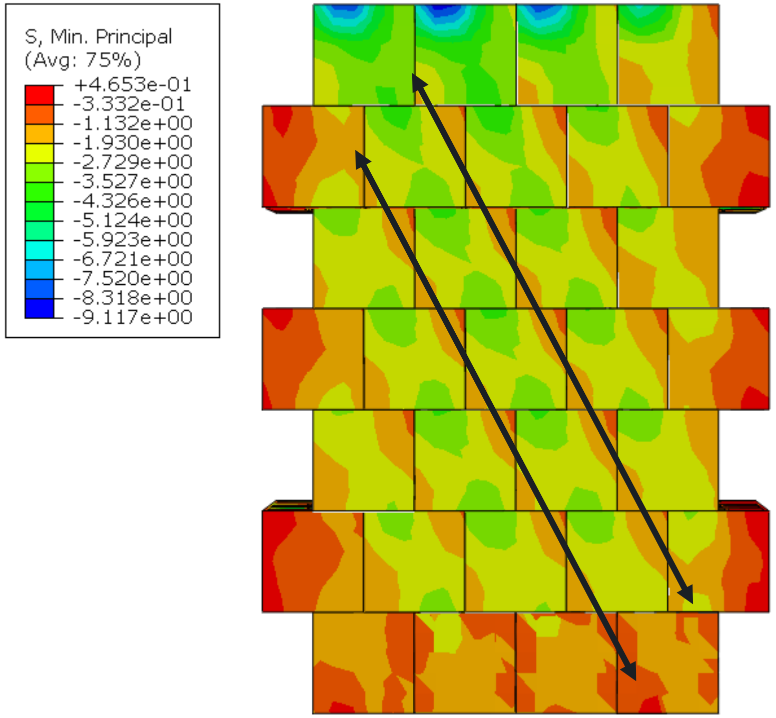
- **FE model 1 (black curve) – quite good alignment with the exp. envelope curve**
- **FE model 2 (green curve) - somewhat worse alignment of response curves**
- **In simulation M2, the difference in forces when the maximum peak capacity is reached is about 15% (underestimated)!**
- **The base shear force continues to increase with increasing drift (not observed in the experiment).**

Numerical simulations of CM walls

- The results of numerical simulations (stress distribution at LS)
- Damage LS (specimen W8) - lightly visible stepped diagonal cracks
- In the FE models 1 and 2 - similar propagation of diagonal struts!
- Each diagonal strut's width equals approximately half of the clay block length.

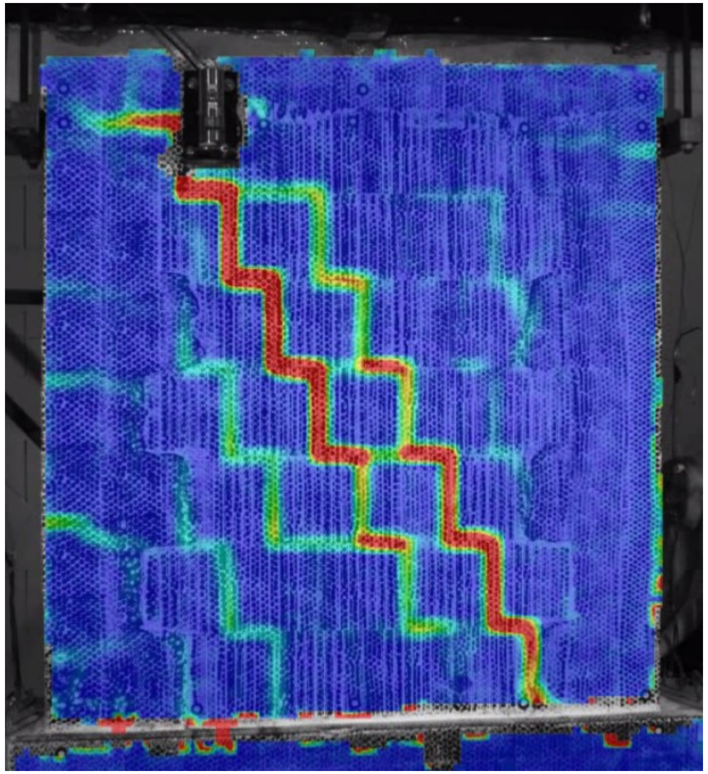


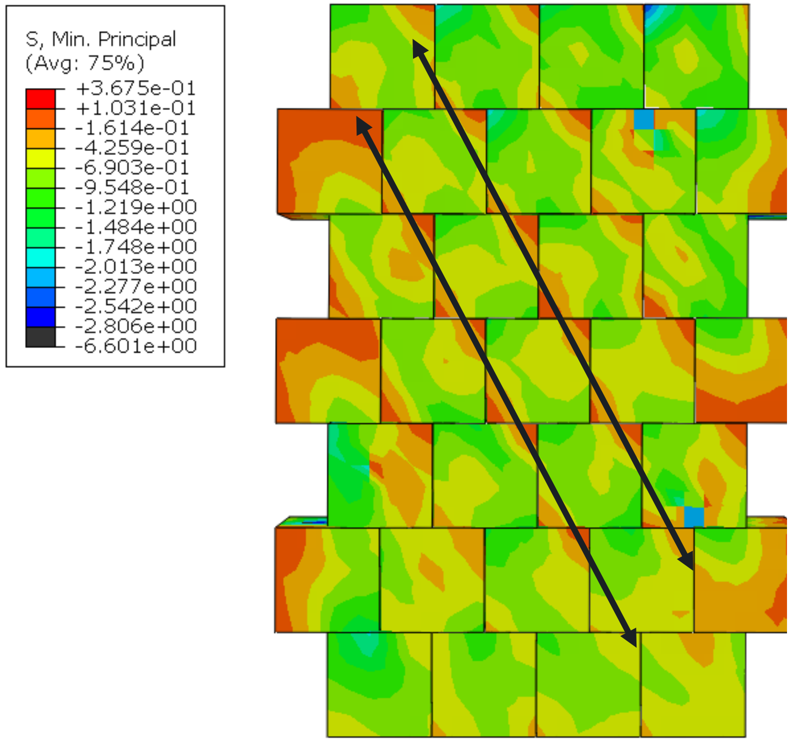


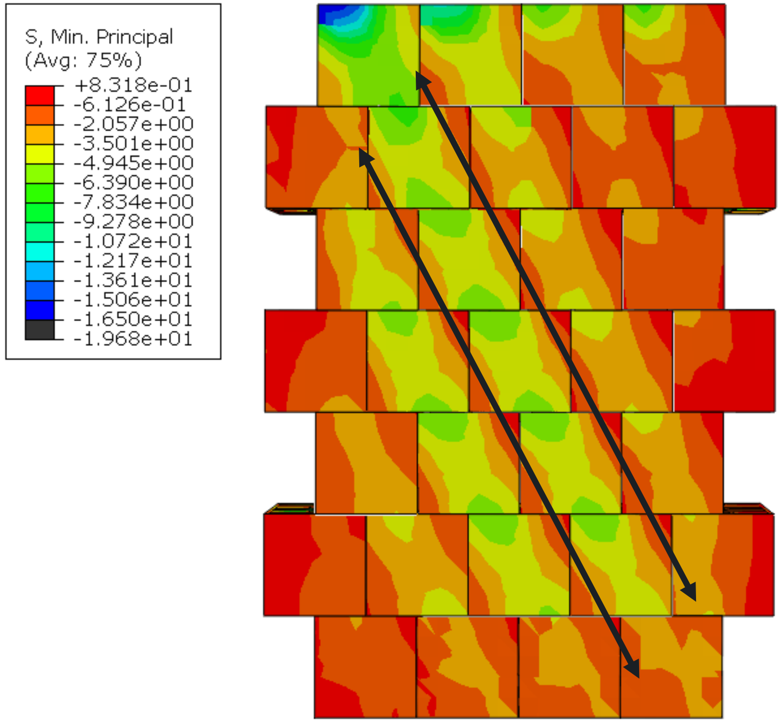


Numerical simulations of CM walls

- The results of numerical simulations (stress distribution at LS)
- Max. Resistance LS (specimen W8) - diagonal stepped cracks clearly pronounced
- In the FE models 1 and 2 - similar distribution of diagonal struts!

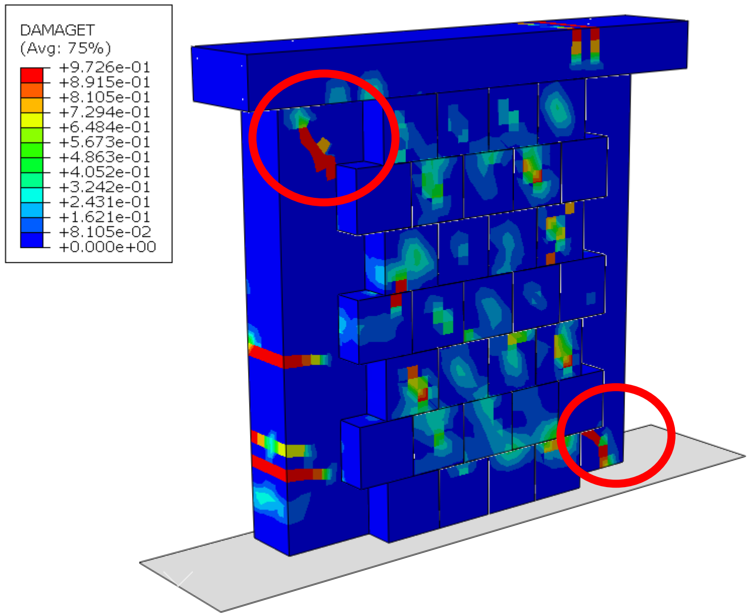


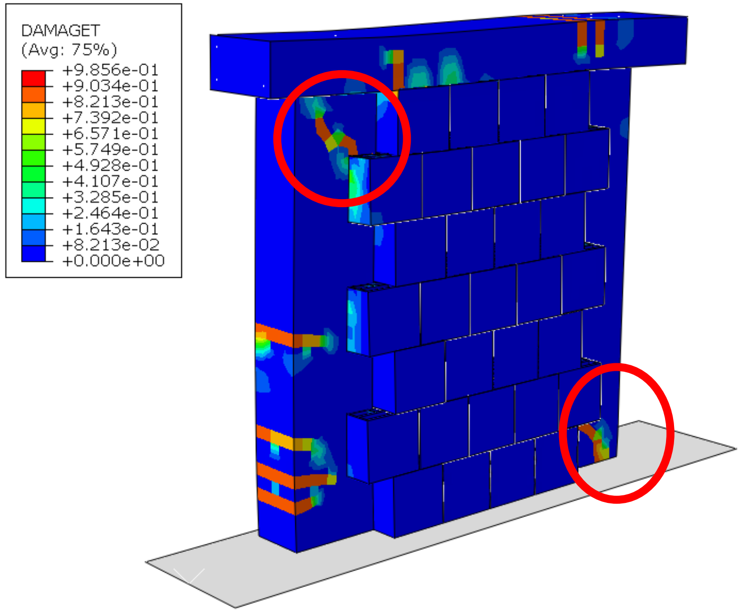




Numerical simulations of CM walls

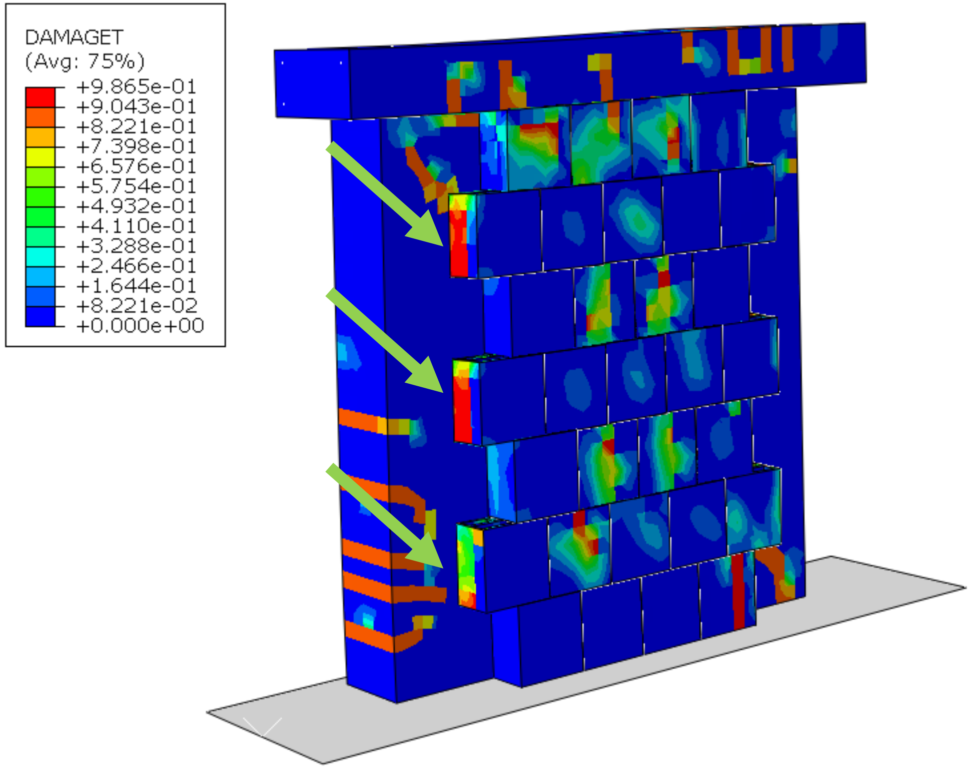
- The results of numerical simulations (<u>damage distribution at LS</u>)
- Horizontal cracks in tie-columns appear along the entire height of the tie-column.
- At a drift of about 0.5%, the damage in the tie-columns becomes concentrated in shear cracks! → **Shear failure in the CM wall**
- FE model 1 - blocks suffer more damage and there are more tensile cracks
- FE model 2 - first visible cracks occur in RC tie-columns, while the blocks remain practically undamaged





Numerical simulations of CM walls

- The results of numerical simulations (shear-off effect)
- The difference in thickness creates stress concentrations and damage to the protruding parts of the CM wall.
- This effect could successfully be modelled using FE model 2 with actual block geometry!



Conclusions

- The results of experimental shear compression tests on two full-scale CM walls were presented.
- In the tests it was observed that because the walls are thick and tie-columns are narrower than the masonry, the protruding part of masonry shears off.
- The seismic response and the shearing off phenomenon were modelled using detailed 3D FE models in Abaqus software (two approaches were employed)

1. FE model 1 replicates global response very well. However, it is not capable of replicating the shearing off phenomenon.
2. The more refined model (FE model 2) is less successful in replicating global response, especially in the post-peak response. The shear-off effect could be simulated!
3. 3D detailed FE model - able to replicate the behaviour of modern CM walls
4. The recommended 3D FE models should be verified and improved by additional experiments and additional numerical simulations in the future!

Conclusions

THANK YOU FOR YOUR ATTENTION!

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