Nonlinear Computational Homogenization Experiments

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Introduction: A multi-scale computational homogenization method for masonry structures, is presented. COMSOL is used for the simulation of a non-linear masonry RVE, for an extensive number of loading steps and loading paths.

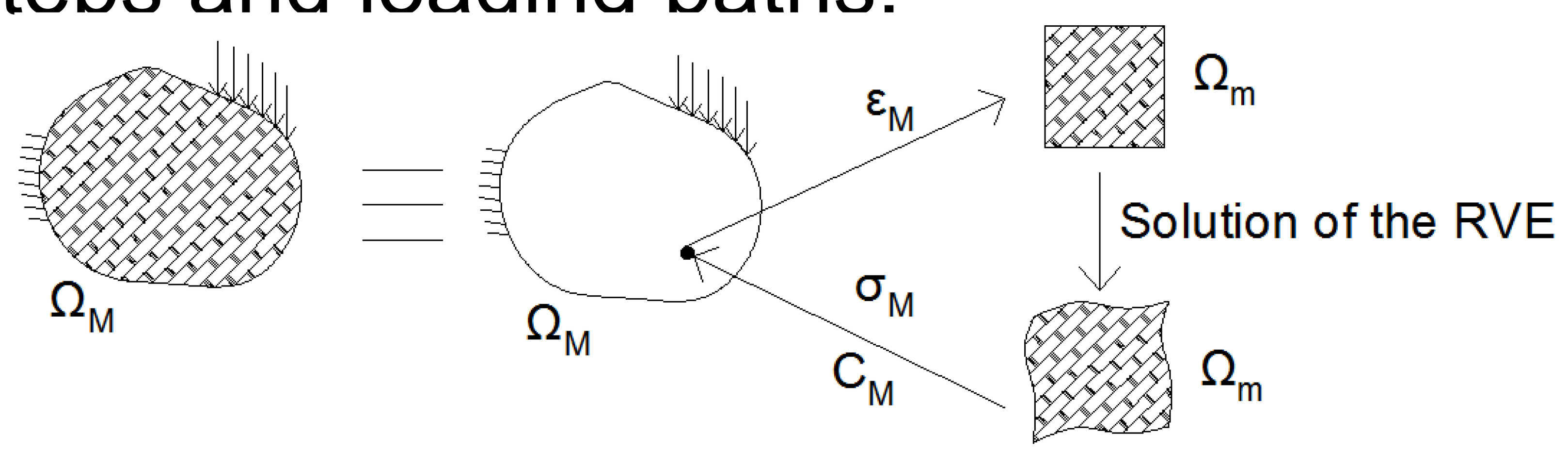

Figure 1. Multi-scale computational homogenization

Computational Methods:

Steps of the concept:

a) Creation of a non-linear masonry RVE with COMSOL.

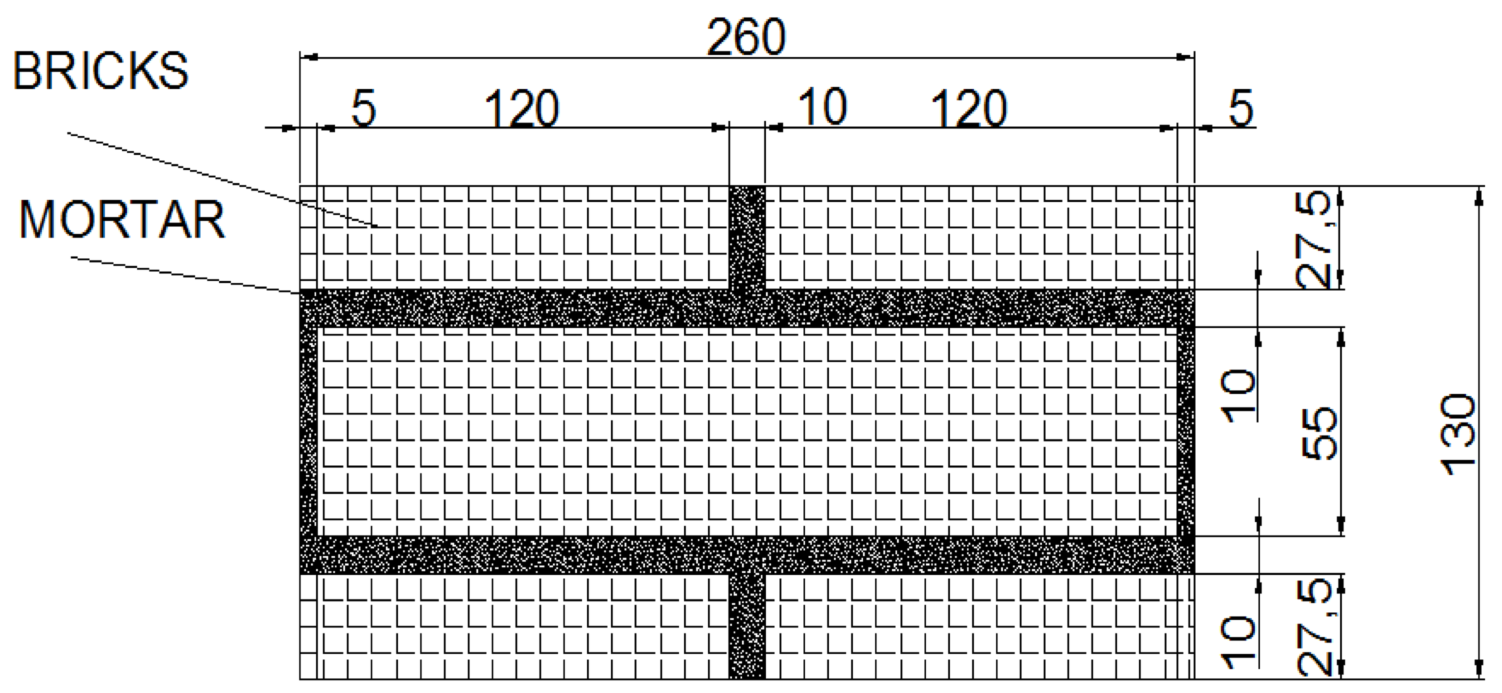

Figure 2. The masonry RVE

b) Plane stress parametric analysis.

c) Linear boundary conditions are the RVE loading.

$$\mathbf{u}|_{\partial V_m} = \boldsymbol{\epsilon}^M \mathbf{x}$$

d) Average stress-strain estimation is calculated, with the subdomain integration, postprocessing capability of COMSOL.

$$< \epsilon >_{V_m} = \frac{1}{V_m} \int_{V_m} \epsilon^m dV_m, \quad < \boldsymbol{\sigma} >_{V_m} = \frac{1}{V_m} \int_{V_m} \boldsymbol{\sigma}^m dV_m$$

e) Estimation of tangent stiffness, by applying 3 test incremental loadings in each loading path and level.

$$[\delta \boldsymbol{\epsilon}^M] = [\delta \boldsymbol{\epsilon}_1^M \quad \delta \boldsymbol{\epsilon}_2^M \quad \delta \boldsymbol{\epsilon}_3^M]$$

$$[\delta \boldsymbol{\sigma}^M] = [\delta \boldsymbol{\sigma}_1^M \quad \delta \boldsymbol{\sigma}_2^M \quad \delta \boldsymbol{\sigma}_3^M]$$

$$[\delta \boldsymbol{\sigma}^M] = \mathbf{C}^M [\delta \boldsymbol{\epsilon}^M] \Rightarrow \mathbf{C}^M = [\delta \boldsymbol{\sigma}^M][\delta \boldsymbol{\epsilon}^M]^{-1}$$

f) Incorporation of the stress-stiffness databases in computational homogenization model in MATLAB (FEM^2).

g) Comparison of the results with direct heterogeneous macroscopic models (using ABAQUS and MARC).

Results:

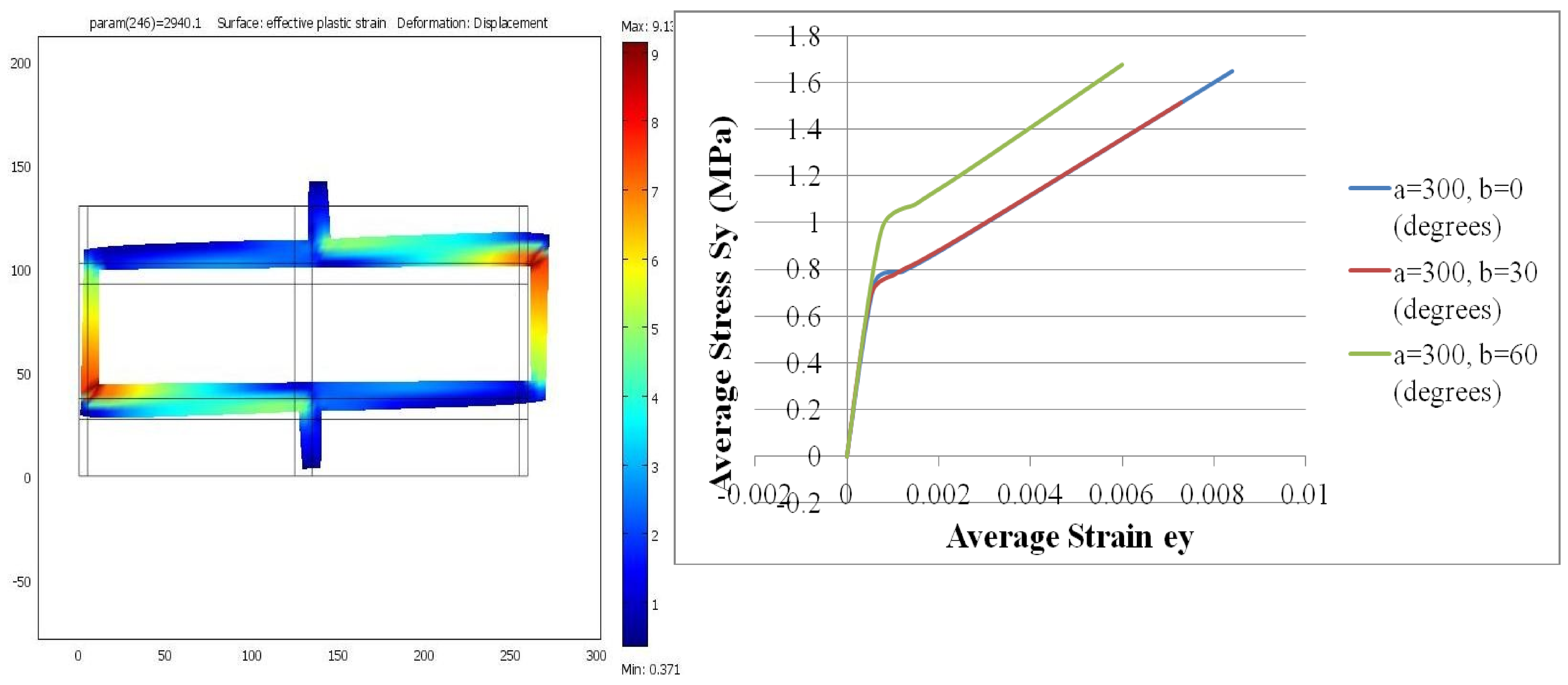

Figure 3. Effective plastic strain of the RVE – Stress-strain diagrams

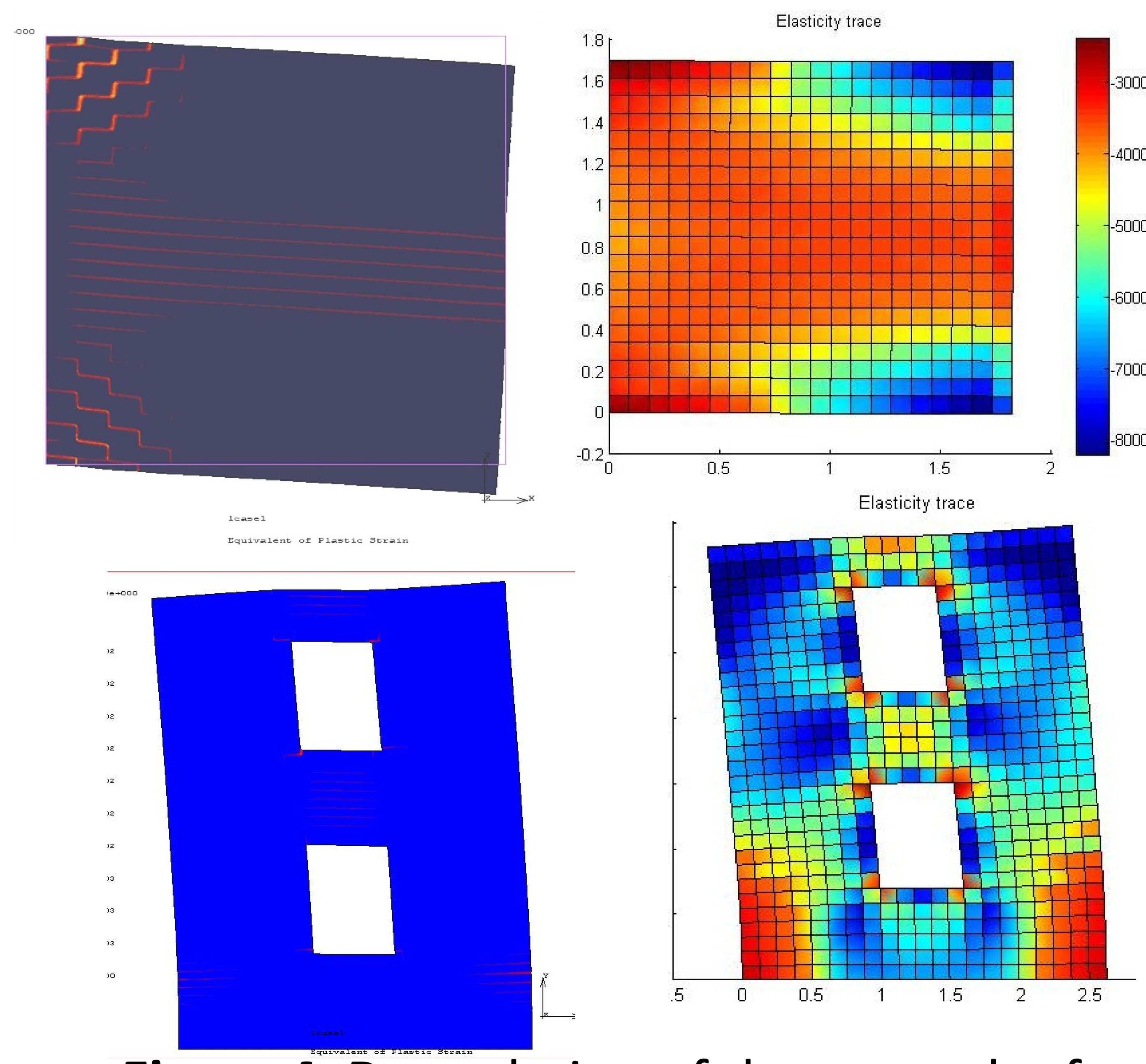

Figure 4. Degradation of the strength of big macroscopic masonry walls

Conclusions:

-The method works well.

- Agreement with direct macro analysis.

References:

1. Leftheris, B., Sapounaki, A., Stavroulaki, M.E., Stavroulakis, G.E., Computational Mechanics for Herritage Structures, WIT Press (2006)
2. Drosopoulos, G.A., Wriggers, P., Stavroulakis, G.E., Contact Analysis in Multi-Scale Computational Homogenization, CFRAC Conference proceedings, Prague (2013)