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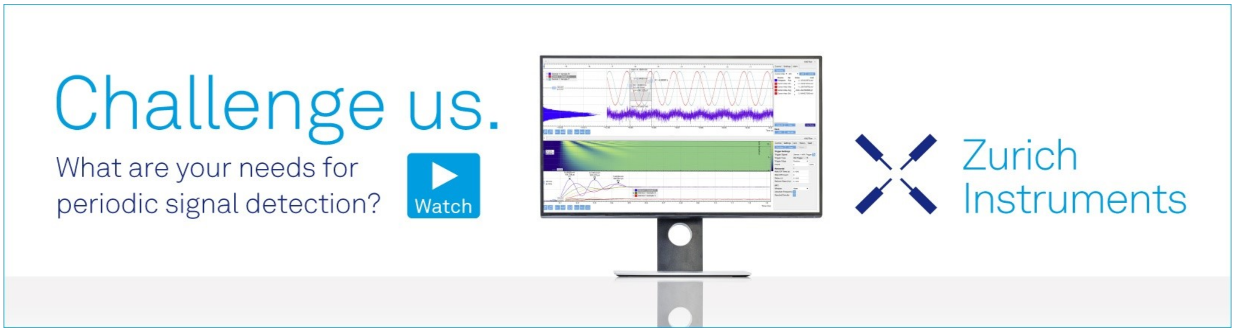

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Fast Discrete Homogenization Approach for the Analysis under Out-Of-Plane Loads of Unreinforced and TRM Reinforced Masonry Panels

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Abstract. A novel discretized homogenization strategy has been developed in order to deal with the analysis of masonry structures. In particular, unreinforced and TRM reinforced masonry panels have been simulated under out-of-plane-loads. The proposed method provides several advantages when compared with the already existing homogenization approaches. Bricks and mortar have been substituted by elastic cells linked by homogenized interfaces where the non-linear properties are lumped. Such interfaces are modeled as 8-noded 3D bricks along with a Concrete Damage Plasticity model, already available in Abaqus. In fact, the implementation at a structural level of the homogenized properties results faster and easier, leading to major competitiveness and even ensuring the coupling of the in-plane and out-of-plane actions. The proposed strategy has been tested and validated by comparison with experimental references available in the literature and numerical references, provided by the authors, based on a micro-modeling approach. The results are highly satisfactory in the prediction of the damage pattern and of the global behavior of the analyzed masonry panels.

INTRODUCTION

In the last years, several approaches have been developed in order to face with numerical analyses of masonry structures. The composite nature of such structures, made of bricks/stones and mortar, is a source of complication in the numerical procedure. These difficulties are furtherly increased when a reinforcing system is applied to the masonry structure in order to reduce its seismic vulnerability. A strengthening approach that has been applied more and more often in the last years consists in the application of a fiber mesh embedded in two layers of cementitious matrix. This technique, called TRM (Textile Reinforced Mortar), represents an improvement with respect to the application of FRP (Fiber Reinforced Polymer), often being responsible for compatibility issues with masonry substrate. The adding of further materials (fibers and matrix) makes the analysis of masonry elements, difficult in itself, highly demanding as characterized by a huge number of variables.

This is particularly evident when a micro-model approach is chosen as it is necessary to model each different material with distinct properties. Such an approach may provide reliable and detailed results, but a high computational burden, convergence troubles, and mesh issues represent the downside. A valid alternative is a macro-modeling technique, where the constituents of the wall could be replaced by a homogenous orthotropic material. On the other hand, the definition of its fictitious properties needs calibration by a preliminary experimental campaign [1]. A suitable

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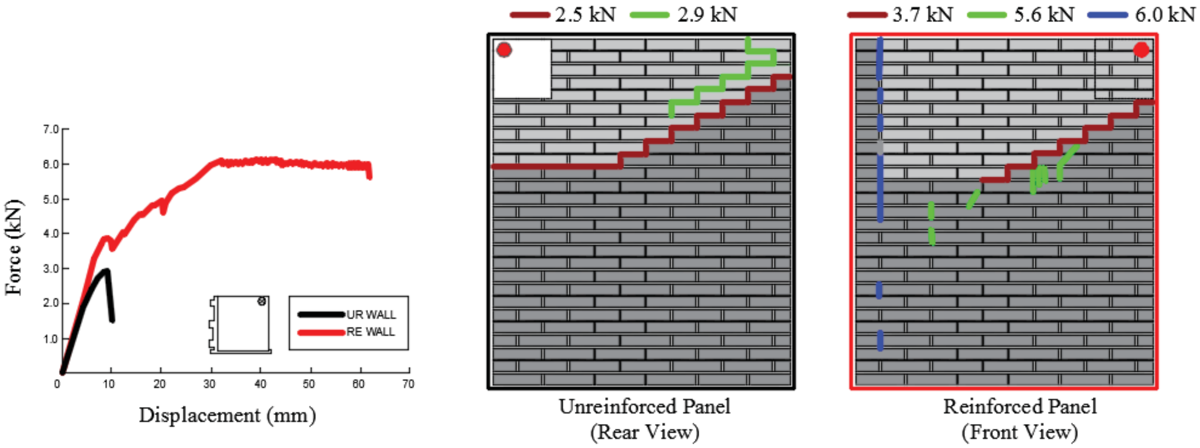
compromise, that reduces by far the number of variables involved, could be found by the use of homogenization procedures to a composite material as masonry. This approach consists, first of all, in the application of a Boundary Value Problem on an RVE (Representative Volume Element) of the wall in order to define averaged material properties. The results is an orthotropic material with a softening behavior in post elastic phase both under tension and compression. In order to preserve the distinct behavior in the two directions, the implementation to a structural level of the homogenized properties is pursued by using a discrete approach. In this framework, the rigid spring method "RBSM" has been applied for several cases [2], ensuring reliable results. The approach consists in modeling the structure as an assembly of rigid cells linked by non-linear springs. However, there are a couple of aspects that need to be improved. First of all, the implementation of the springs joining the rigid cells might be not so immediate. Second, this method leads to an uncoupling of the in and out of plane actions.

In this paper, a fast and easy implementation of a discretized homogenization approach is presented. The structure is model as a repetition of elastic cells linked by non-linear interfaces. These latter are modeled with 8-noded bricks elements and the homogenized properties are addressed by taking advantage of the already implemented in Abaqus Concrete Damage Plasticity constitutive model. CDP, originally conceived for modeling concrete, has been widely applied to masonry cases [3]. Such an approach makes the procedure much more competitive addressing successfully the drawbacks of the existing discretized approaches.

The TRM is modeled, directly on the homogenized model, with elasto-plastic trusses (simulating the fiber mesh) embedded in the 3D solid elements of the cementitious matrix, realistically simulated in two layers, as done in [4].

In order to show and validate the effectiveness of the proposed method, both experimental and numerical references are provided. The first one is deeply exposed in [5] for the reader interested. Briefly, two configurations of brick walls (reinforced and TRM reinforced) were tested out-of-plane in order to simulate the behavior of an infill wall during seismic events. In Figure 1 the experimental outcomes are synthesized in terms of load-displacement curve and damage pattern.



Unreinforced Panel
(Rear View)

Reinforced Panel
(Front View)

FIGURE 1: Experimental load-displacement curve and crack pattern of the UR and RE panels.

Furthermore, a detailed 3D heterogeneous micro-modeling of both configuration has been carried out, providing a useful comparison for the result of the homogenized models.

DISCRETE HOMOGENIZATION MODEL

The homogenized properties that are implemented in the discrete model have been obtained by means of consolidate procedures, already reported in [6]. One of the main advantages of the proposed method is the easy set-up of the model. In fact, the elastic properties, coming from the local analysis of RVE, are transferred directly to the elastic cells, ensuring major numerical stability of the analysis. The differential homogenized non-linear properties are associated with the interfaces according to the direction, providing a differential behavior. The use of CDP for defining the softening behavior in the post-elastic phase results straightforward and user-friendly. Moreover, this method does not require a refined discretization as a micro-model approach, providing as well, highly satisfactory results. The interfaces are discretized by 4 elements along the depth and the length, with one element in the thickness.

Elastic cells are divided by 2 elements in the depth, and 13 elements in the plane, reaching a total number of 2280 elements (against 140000 elements of micro-model).

For this specific case, the damage pattern resulted to be strongly related to the texture of the wall. In fact, the high mechanical properties of the bricks and the asymmetrical boundary conditions lead to a stepped crack inside the joints (Fig. 1). In order to reproduce this behavior, wedge-shaped elements are introduced instead of using a parallelepiped discretization. Obviously, in this case, the non-linear mechanical properties are concentrated in the diagonal and horizontal interfaces (Fig. 2).

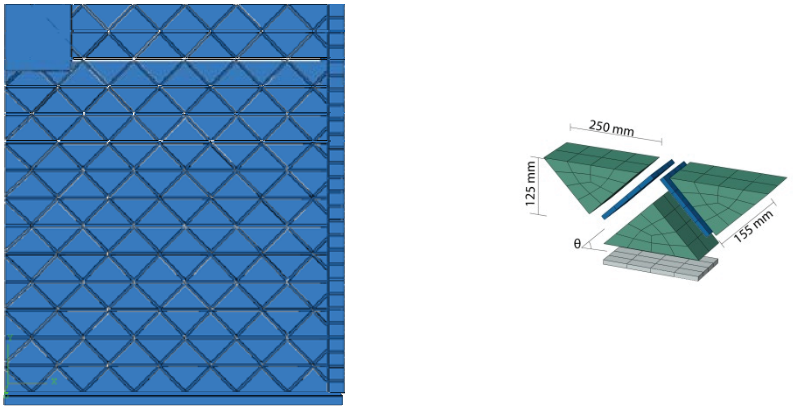


FIGURE 2: Geometric configuration and discretization of the homogenized UR panel.

RESULTS

The results are exposed in this section in terms of damage pattern and load-displacement curves. In Figure 3 the experimental damage pattern of the unreinforced panel is compared with the outcomes of the homogenized model. It is evident from the picture that the crack pattern is reproduced with very high accuracy, being able to approximate the direction of the experimental stepped crack.

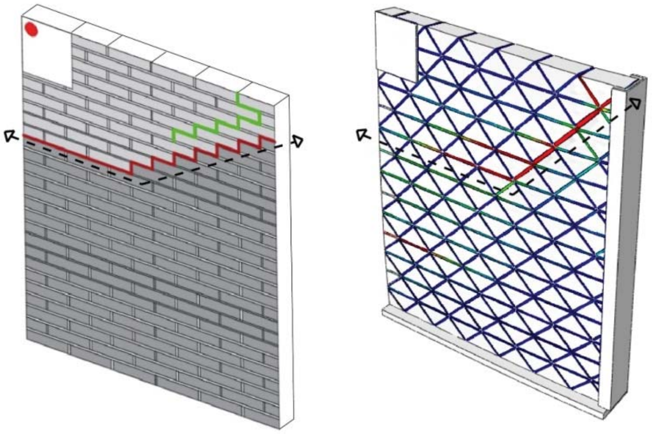


FIGURE 3: Damage pattern from the experimental tests (Left) and from the homogenized model (Right) at 10 mm.

Also in terms of global behavior, the response of both homogenized models are very promising. In Figure 4 it is provided a comparison among the proposed method with the experimental and numerical references. Concerning the unreinforced configuration, it is noticeable how the homogenized model is able to reproduce the load-carrying capacity (3 kN) and the global displacement (10 mm).

Even the homogenized reinforced scenario provides satisfactory results. The response follows the micro-model ones until a load of 6.2 kN. Then, after a slight softening, the homogenized curve approaches the plateau recorded during the lab-test. It is important to clarify that the extension of the experimental plateau is likely related to a sliding phenomenon. So, its reproducibility might be quite hard. Moreover, the decision to use a less refined mesh for the homogenized models may limit its capacity in ductility.

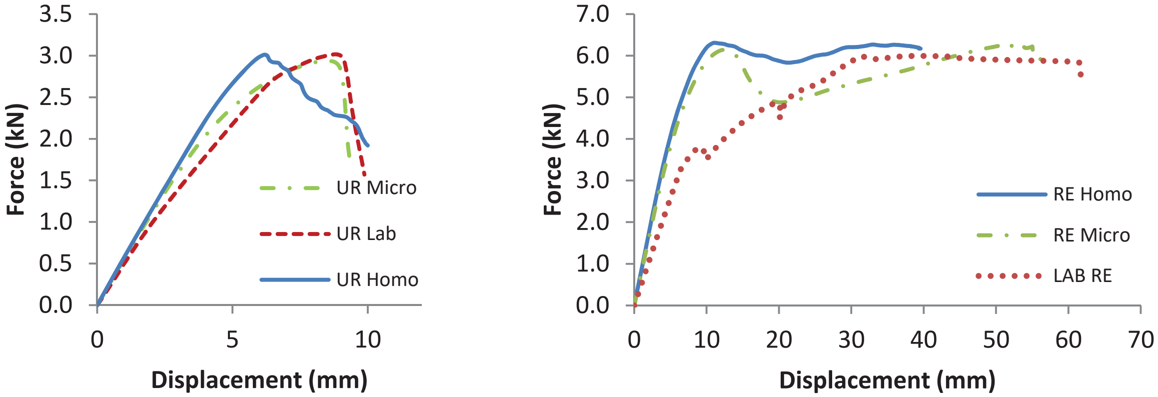


FIGURE 4: Load-displacement curves obtained experimentally, with the micro-modeling approach, and by the homogenized model. UR panel (Left) and RE panel (Right)

CONCLUSIONS

It may be concluded that the results showed the high effectiveness of the proposed method in reproducing the experimental outcomes and even detailed micro-modeling. The performance is even more appreciable considering the reduced computational burden required in the homogenized analyses, that results almost ten times lower than the corresponding heterogeneous approaches.

These promising results might open the way to future more complex applications, as vaults and domes, even reinforced.

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