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OUT OF PLANE BEHAVIOR OF THERMAL INSULATED MASONRY WALLS AS PART OF BUILDING RETROFITTING

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Abstract

Unreinforced masonry panels are located at the facades of multi-story framed buildings, considered as non-structural elements, are not included in the structural design. Such structures are subjected to strong earthquake motions, leading to potentially damaging conditions for the masonry in the form of in-plane damage or/and its out-of-plane dislocation and partial collapse. This study focuses on the out of plane response of unreinforced masonry panels built with clay bricks units horizontally perforated representing a typical masonry infill subassembly. The examined masonry panels constructed and tested at the Laboratory of Strength of Materials and Structures (Aristotle University of Thessaloniki) are subjected to cyclic out of plane bending as built or attached with different thermal insulating facades. The response of these tests is presented in terms of horizontal load applied versus the corresponding horizontal displacement in an effort to record the influence of the thermal façade on masonry's response. Moreover, numerical models were developed in order to replicate the observed at the laboratory behavior. These models include non linear constitutive material laws together with non linear interfaces to represent the debonding of the thermal insulating facades. The measured response is presented and discussed together with the corresponding effort to numerically simulate the observed performance.

Keywords: ETICS, Thermal insulation, Out of plane behavior of masonry wallets, numerical investigation

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1. INTRODUCTION

The common practice to form the envelope of multistorey buildings with load bearing structures with R/C or steel frames is the unreinforced masonry infills. The behavior of such infills has been a point of interest for researchers in the past years. Infills are considered to be nonstructural members. However, under strong earthquake motions, they interact with the surrounding frame and develop stress fields due to in plane and out of plane loads that can lead to non linear mechanisms and even collapses. Numerous publications deal with the in-plane interaction of masonry infills and surrounding RC frames [1-5]. This study focuses on the out of plane response of masonry panels. Different retrofitting schemes of the out of plane masonry walls have been investigated [6-8]. Manos et al. conducted experiments in masonry wallets with external thermal insulation composite systems (ETICS) under in plane [9] and out of plane [10, 11] loads, together with numerical simulations. Herein, numerical models are developed with dimensions representing actual masonry panels, using the previously validated numerical methodology [10]. This investigation aims to evaluate the effect of ETICS on the behavior of the masonry infill, that is the substrate of such energy retrofitting solutions. The need to investigate such components derives from the necessity to limit the energy consumption of existing buildings. Particularly, the Energy Performance of Buildings Directive (European Directive 844/2018), aims to reduce energy consumption and to transform the existing building stock into nearly zero energy buildings by 2050 [12, 13].

2. METHODOLOGY

Ongoing extensive research at the Laboratory of Strength of Materials and Structures (Aristotle University of Thessaloniki) deals with behavior of infilled frames without or with ETICS. Figure 1 shows the actual construction detail of the examined infill walls. The first steps of this investigation include material testing both of the materials used for the construction of the infills and the ETICS as well. Following, triplets (3 clay units and 2 mortar joints) under shear and normal loads were tested in order to measure the tangential behavior of the clay unit – mortar interface. Additionally, triplets were constructed and tested under out of plane (OOP) flexure aiming to measure the tensile behavior of the clay unit – mortar interface. Moreover, the bond strength between masonry and ETICS was quantified through pull out tests. All these experimental results are used to define the non-linear properties of the numerical models discussed in section 4, as depicted in a typical cross-section of a model with ETICS. Particularly, the masonry substrate is simulated through simplified micro-modelling, that is solid elements representing the clay units and non linear interfaces between the clay units, in which the non linear behavior of both the mortar joints and the interface between clay unit and mortar is assigned. Masonry walls are formed with dimensions 3.03 x 2.02 x 0.15 m3 (length x height x thickness), as depicted in figure 2. Each model is placed between two steel beams. The bottom steel beam is fixed while the top steel beam is only restrained in the out of plane displacement. Between steel beams and masonry nonlinear interfaces are assigned. At the top steel beam, a vertical load equal to 2.4KN is applied. Following, the out of plane monotonic load is applied at the mid height of the wall, in the direction that the ETICS develop tensile stresses. The aim is to predict the out-of-plane flexural capacity and the modes of failure of masonry facades with thermo-insulating attachments.

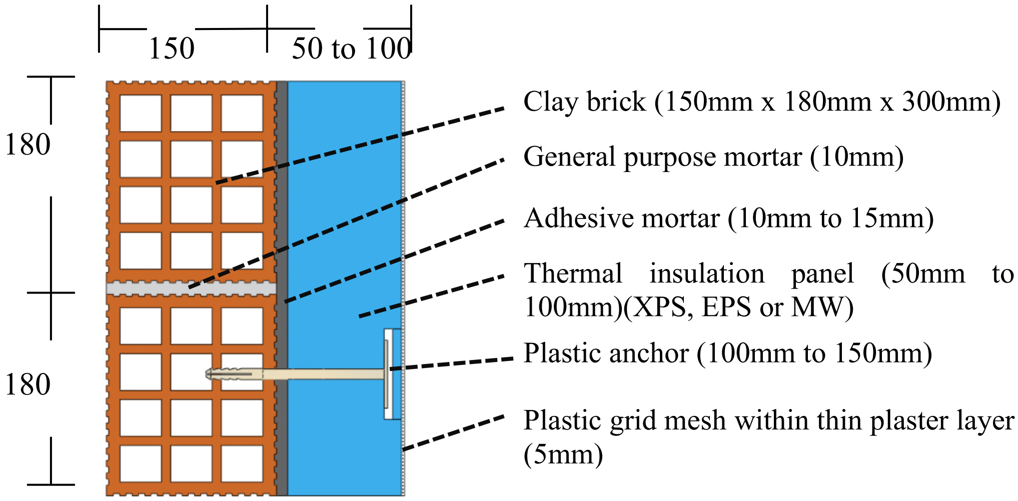

Figure 1: Typical cross-section of a thermal insulated infill wall

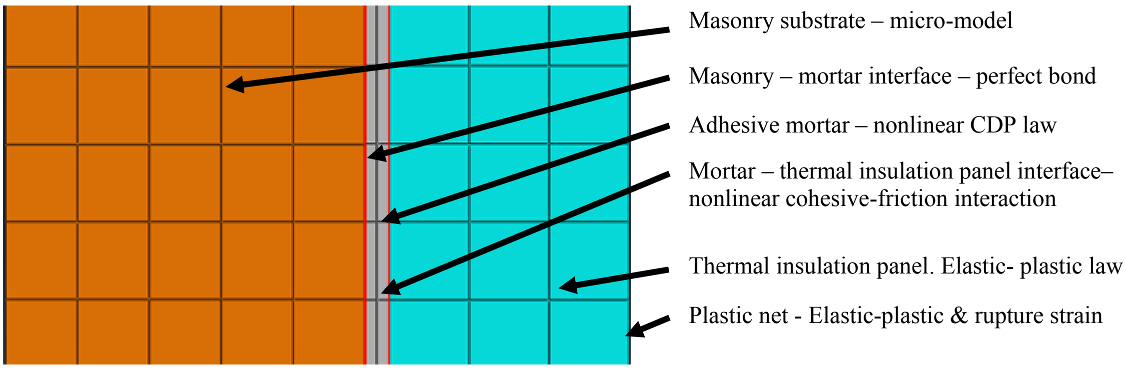

Figure 2: Cross-section of a masonry wall and a thermal insulation of the employed numerical model.

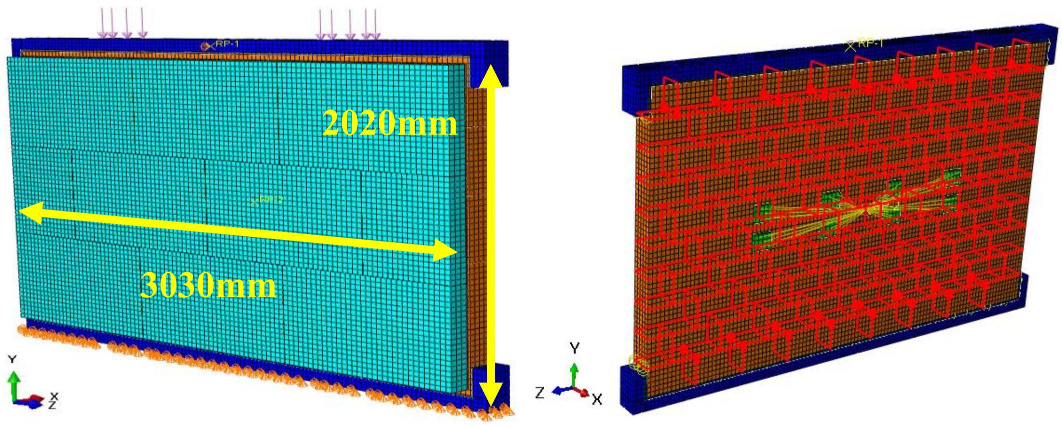

Figure 3: Used numerical simulation of masonry and thermo-insulation (left) and the interfaces of the masonry wal (right)

3. MATERIAL TESTING

All specimens were built by builders following the relevant prototype work conditions. They employed, typical in Greece, hollow clay brick units with 12 horizontal holes, that had nominal dimensions: length = 330 mm, height = 180 mm and thickness = 150 mm. Information on the masonry mechanical characteristics found according to European Standards is reported in [9] together with the basic mechanical properties of all the employed thermo-insulating materials. Table 1 lists only the relevant information on the compressive and flexural strength of the masonry. The values listed in columns (1) and (3) of Table 1 were found from laboratory tests performed by the authors. The measured fxk1 value equal to 0.168 MPa, which was obtained by the triplet testing under out of plane flexure (figure 4), is larger than the corresponding characteristic value provided by Euro-code 6 for mortar type M2 equal to 0.1 MPa. The mean measured shear strength of the clay – mortar interface was derived by triplet testing as depicted in figure 4 (right) equal to 0.23MPa, while the friction coefficient was found 1.0.

An overview of the bond strength properties between the used adhesive mortar and either the masonry substrate or the thermo-insulating panels is also presented by Manos et al. [9] and is not repeated here. During the current experimental study, a series of tests were conducted to define the basic mechanical properties of the used adhesive mortar and the interactive behaviour between either the adhesive mortar and the façade or the adhesive mortar and the masonry substrate. The measured bond strength is listed at table 2. Three different external thermal insulation are examined here, all with thickness 100mm, expanded polystyrene (EPS), extruded polystyrene (XPS) and mineral wool (MW). Due to space limitations their mechanical properties are not discussed here, but the corresponding laboratory measurements are published by Manos et al. [9, 10].

Table 1 Basic mechanical properties of the used brick and mortar

Brick mean compressive strength	Brick normalized compressive strength	Mortar compressive strength	Mortar flexural tensile strength
2.39MPa	2.97MPa	2.15MPa	1.16MPa

Figure 4: Used numerical simulation of masonry and thermo-insulation (left) and the interfaces of the masonry wal (right)

Table 2 Bond strength of adhesive mortar.

Bond between the Adhesive Mortar and the Thermal Insulating Panel (Normal to the Facade) (MPa)			
MW	**EPS**	**XPS**	**Masonry substrate**
Mean = 0.068 SDV = 0.023	Mean = 0.105 SDV = 0.012	Mean = 0.178 SDV = 0.068	Mean = 0.578 SDV = 0.258

4. NUMERICAL PREDICTIONS

In what follows the numerical results of the masonry wallet with or without any thermo-insulating attachment in terms of OOP load versus OOP displacement at mid-height. The numerical non-linear analysis was of a continuous monotonic "pushover" type subjecting the thermo-insulating façade to flexural tension. Figure 4 depicts the flexural response in terms of applied OOP load at mid-height versus the corresponding OOP displacement of the bare unreinforced wall, together with predicted mode of failure, that is the damage of the bed joint at the mid height of the wall. The maximum predicted applied load equals to 7.30KN.

Figure 6 depicts the numerical prediction of all simulated models. Particularly, the 3 model with ETICS are compared with the bare model in terms of terms of OOP load versus OOP displacement at mid-height. The maximum predicted load is 43.82KN, 37.85KN and 17.55KN for the models with XPS, EPS and MW insulation respectively. Figure 7 shows the predicted mode of failure of these models. Apart from the cracking of a number of bed joints, represented by the damage of the corresponding interfaces, the response of the model with XPS ETICS exhibited bedonding of the XPS panel at the upper boundary of the wall. The EPS model exhibited the same debonding as mode of failure together with multiple damage of horizontal interfaces, while the MW model predicted the damage of the MW panels placed at the upper part of the masonry substrate.

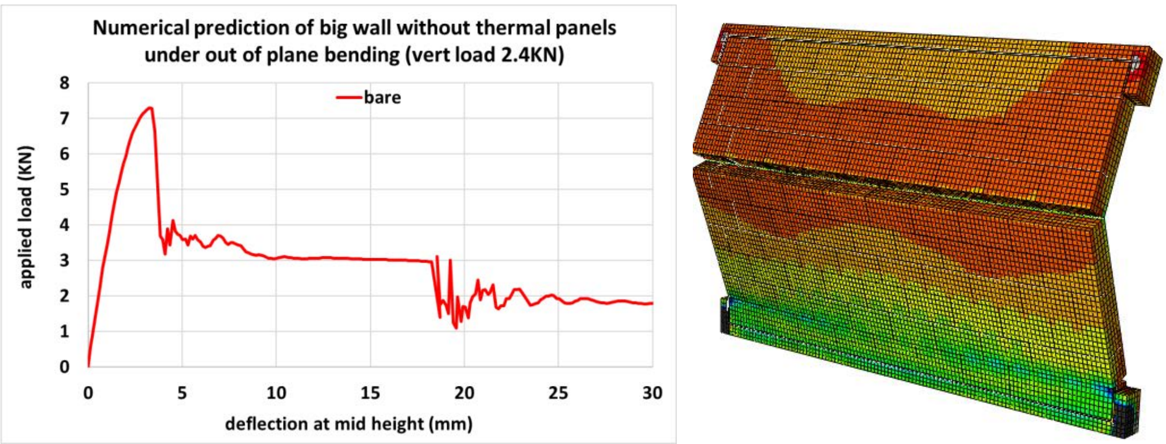

Figure 5: Response of numerical model of bare wall in terms of out of plane load versus the deflection at the mid height (left) and the predicted mode of failure (right)

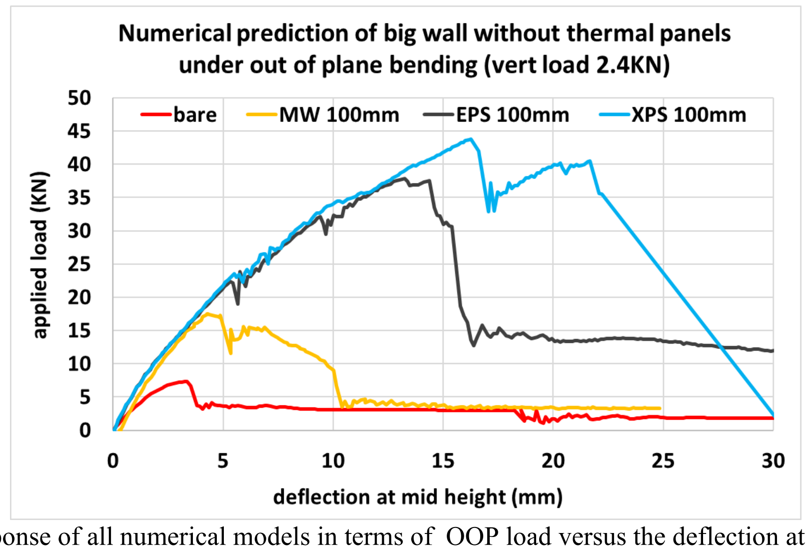

Figure 5: Response of all numerical models in terms of OOP load versus the deflection at the mid height

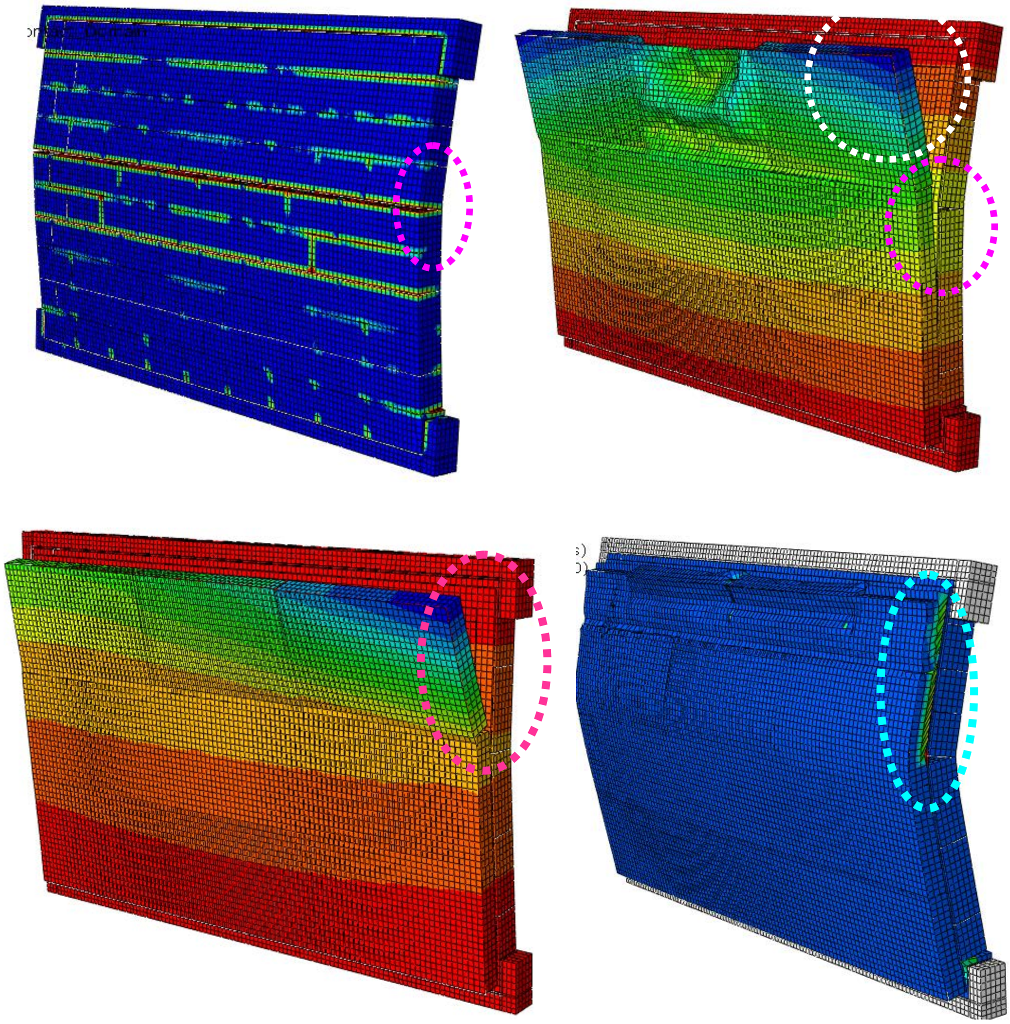

Figure 7: Predicted mode of failure of insulated models. a) cracking of a number of bed joints, represented by the damage of the corresponding interfaces, b) debonding of XPS panels c) debonding of EPS panels d) damage of MW panels

CONCLUSIONS

The used numerical simulations involving the specific thermo-insulating facades (MW, EPS, XPS 100mm thick), included a number of non-linear mechanisms. These mechanisms were quantified on the basis of extensive tests of all the relevant materials themselves as well as their behaviour at the interacting contact surfaces. In this way the numerical simulation results should be considered as “blind test” results without undergoing any particular adjustment.

The thermo-insulating panels when attached on brick masonry walls in the way described in this study result in a noticeable increase of their OOP flexural capacity when the thermo-insulating panels are subjected to flexural-tension. This increase is quite substantial when these panels are made of either expanded polystyrene (EPS) or extruded polystyrene (XPS).

Attaching these thermo insulating panels increases the flexural displacement performance of such brick walls which otherwise is of brittle nature. Thus it can be stated that attaching thermo-insulating panels on brick masonry walls improves their out-of-plane flexural performance.

It should be underlined that the boundary conditions which connect a brick masonry wall to the surrounding structure of a building is expected to exersice significant influence on the out-of-plane flexural performance of such brick masonry facades with or without thermo-insulating attachments. Therefore, this is a more complex problem than the one studied here which needs further investigation.

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