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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE OUT OF PLANE BEHAVIOR OF THERMAL INSULATED MASONRY WALLETS

George C. Manos[1], Lazaros Melidis[2], Kostas Katakalos[3], Anthimos Anastasiadis[4]

[1,2,3,] Lab. Strength of Materials and Structures, Aristotle University
gcmanos@civil.auth.gr, lazmelidis@gmail.com, kkatakal@civil.auth.gr

[4] Dr. Civil Engineer, Research Associate, Thessaloniki, Greece,
anastasiadis@asacon.eu

Abstract

Multi-story buildings are composed of multi-bay steel or R/C frames having unreinforced masonry panels considered as non-structural elements 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 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

Unreinforced masonry panels are used in multi-story buildings made of steel or reinforced concrete (R/C) to form the exterior facades or the interior partitions. Thermo-insulating panels are also attached on the exterior facades of these masonry panels in order to improve the energy efficiency of these building as well as to reduce noise and moisture penetration. This type of masonry façades is widely applied in many countries ([1, 2]). These masonry infills are considered as non-structural elements and they are not included in the structural design. However, they interact with the surrounding structural members, when such structures are subjected to strong earthquake motions. This is because masonry infills are forced to follow the displacement response of the supporting surrounding structural members (slabs, columns and beams) leading to potentially damaging conditions due to simultaneous in plane and out of plane loads. One of the most serious consequence of either of these forcing scenarios, when the seismic forces are considered as acting either separately (in-plane or out-of-plane) or combined, is the dislocation and partial collapse of such unreinforced masonry panels ([3, 4]). Figure 1a depicts a typical damage pattern observed in numerous multi-story buildings in Durres, Albania due to the recent strong earthquake sequence (26th November, 2019). Similar damage patterns have been observed in many past strong earthquake sequences in Greece (Athens 1999) and Italy (L' Aquila 2009).

Figure 1. Typical damage pattern observed in masonry infills. a) Albania, Durres 2019. b) Italy, L' Aquila 2009. c) Greece, Athens 1999.

EuroCode 6 ([5]), while accepting that vertical unreinforced masonry panels are subjected to both in-plane and out-of-plane seismic forces, includes design provisions based on the assumption of un-coupled in-plane and out-of-plane limit states. This simplification has been adopted in the large majority of relevant past research either for masonry walls or for infill masonry panels, similar to the ones studied here. The current research follows this simplification in the effort to study the influence of thermo-insulating attachments on the seismic performance of masonry panels [6, 7]. Only the out of plane behaviour for a thermo-insulated masonry panel is studied here. This is done by subjecting in the laboratory masonry wallets to simple loading conditions in order to generate stress fields within such specimens simulating similar stress fields in a masonry panel out-of-plane direction. The influence of a thermo-insulating attachment for the in-plane behaviour of masonry panels has been investigated and discussed before [3,4 8]. Results are presented from tests employing unreinforced masonry wallets, having relatively simple boundary conditions, which are subjected to out of plane bending. The mechanical properties of all the employed thermo-insulating materials are defined through testing. Following, numerical models were developed utilizing all the geometrical and mechanical properties in order to replicate the experimentally measured out of plane behaviour. All these results are presented and discussed focusing on the influence of the external thermal insulation system (ETICS) in the overall out of plane response.

2 SPECIMEN CONSTRUCTION AND MATERIAL PROPERTIES

The specimens are masonry sub-assemblies which are constructed and tested at the Laboratory of Strength of Materials and Structures (Aristotle University of Thessaloniki, Greece). The thermo-insulating materials are produced by “FIBRAN Anastasiadis Dimitrios S.A.” and are applied on the specimens to be tested in the same way that are applied in prototype construction. A cross section of a masonry wallet attached with ETICS is depicted in figure 2. All specimens were built with the same 12-hole clay brick unit of nominal dimensions length=320mm, height=180mm and thickness=150mm. This brick unit is commonly used in prototype construction for this type of un-reinforced masonry panels in multi-story buildings in Greece. Similarly, a relative weak general-purpose mortar was used for all specimens. The thermo-insulating layer was added to one side of all specimens two months following their construction following the relevant construction practice. Three different thermo-insulating materials, with code names XPS, EPS and Petro, were investigated, having a panel thickness of 100mm. Specimens of all materials used for building these specimens were taken during construction and tested for determining the relevant mechanical characteristics. The mechanical properties of masonry materials are listed in table 1. Due to space limitations, the mechanical properties of ETICS materials are not reported here. However, their mechanical properties and the bond strength between ETICS and masonry substrate together with the in-plane behavior of thermal insulated masonry wallets are extensively discussed before [8].

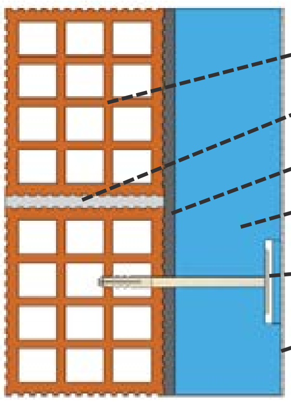

Figure 2 Typical cross-section of a thermal insulated infill wall.

Brick unit	
mean compressive strength perpendicular to bed joints (f_b)	2.97 MPa
Mortar	
compressive strength (f_m)	2.15 MPa
flexural strength (f_{mt})	1.16 MPa

Table 1 mechanical properties of masonry materials used

The behavior of 4 wallets subjected to out of plane bending is discussed here. The first one is bare without any thermal insulation. The other three specimens are thermal insulated with MW, EPS and XPS panels with thickness 100mm respectively. The dimensions of these wallets are depicted in figures 3a and 3b. The out-of-plane load was applied at a horizontal cross-section located at the mid-height of wallet as depicted in figure 3. The applied out-of-plane load and the corresponding out-of-plane displacement at the mid-height central point of the wallet was recording during the test with a data acquisition system.

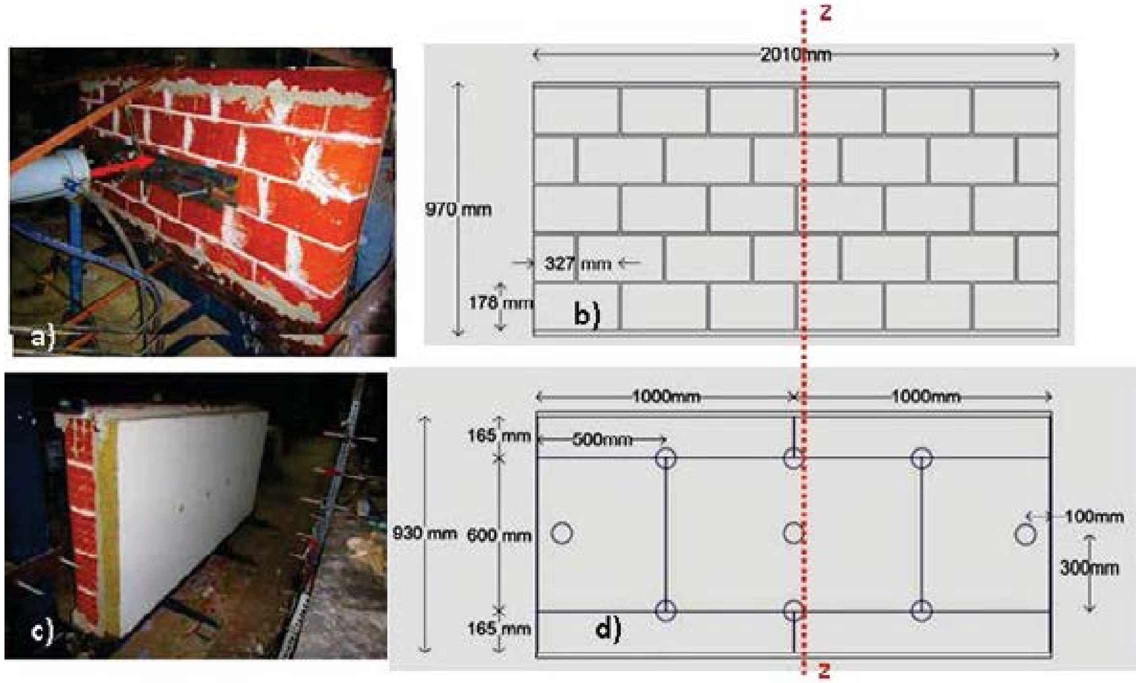

Figure 3. Out-of-plane flexure of a masonry wallets. a) and b) View from the brick façade. c) and d) View from the thermo-insulating (mineral wool) façade. The circles indicate the location of the anchors.

3 EXPERIMENTALLY OBSERVED BEHAVIOR

The observed out of plane performance of the tested specimens with or without thermal insulations is presented and discussed in terms of the out of plane load applied at mid-height versus the out of plane deflection together with the observed damage. Firstly, the observed performance of the bare masonry wallet without any insulation, which represents the control specimen. A linear behavior is observed till the first cracking at the minimum load (8.81KN) for an out of plane deflection about 2mm. At this point the flexural failure of the bed joint develops and it is followed by a sudden decrease of bearing capacity (figure 4).

Following, the response of the tested specimens with external thermal insulation panels are presented. The masonry specimen attached with MW panels with thickness of 100mm exhibited a maximum load 14.77KN for an out of plane deflection 5mm. The masonry wallets insulated with EPS and XPS with thickness 100mm reached a maximum load 35.62KN and 38.91KN respectively for out of plane deflection 5mm and 3mm respectively. The mode of failure of the thermal insulated panels included bed joint flexural cracking followed by a partial debonding of the thermal façade's panels.

Figure 4. Damage pattern of bare wallet

4 NUMERICAL MODELING

Three-dimensional finite element numerical models were formed, adopting a macro modeling approach with a homogenized material obeying the Concrete Damaged Plasticity (CDP) constitutive law for the masonry, that can satisfactorily represent the behaviour of brittle materials, like concrete or masonry, with different stress – strain laws for compression and tension. The material law resembling the masonry part was calibrated to match the response of the corresponding wallet specimen. The attachment of the thermal insulation panels to the masonry is done with a layer of adhesive mortar which is numerically simulated with two layers of interfaces; the first interface is joining the mortar joint with the numerical simulation of the masonry and it is assigned with a perfect bond whereas the second interface is joining the mortar joint to the numerical simulation of the thermo-insulating panel and it is assigned with a cohesive-friction interface. The thermo-insulating panels were numerically simulated by 3-D finite elements. The ETICS properties and interface properties were defined from results obtained from material testing [8]. In this way, the measured flexural response was numerically simulated, utilizing the capabilities of commercial software [9]. The numerical predictions include one monotonic pushover analysis for deflection where the thermal panel are on the tensile face. All the numerical prediction for the bare and the insulated models are depicted in figure 5. The corresponding damage patters are depicted in figure 6. In this figure, the plastic strains of the model are depicted resembling the horizontal cracking of the bare wallet of the mid bed joint (6a) and the detachment of the thermal panel following the bed joint failure (6a), as that was the predicted mode of failure for all insulated wallet models.

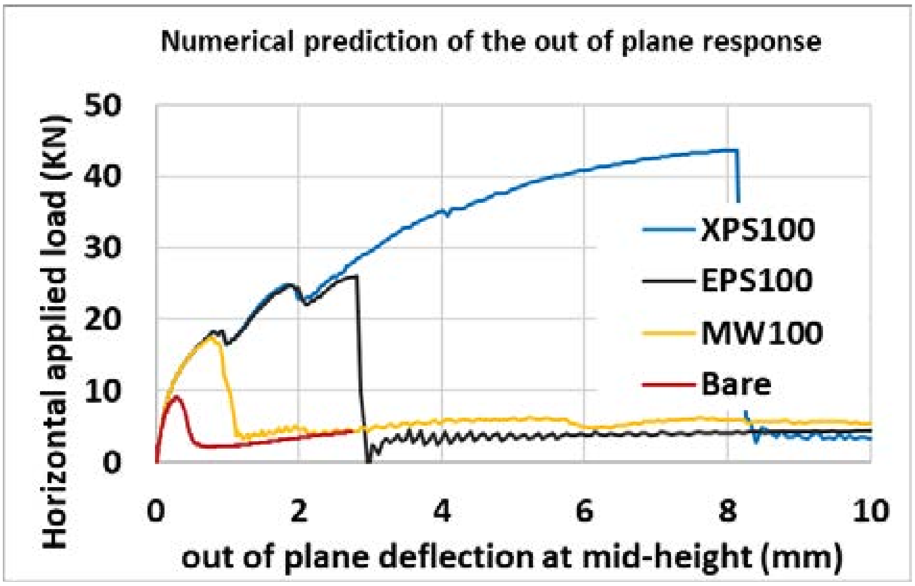

Figure 5. Numerical predictions of the tested specimens in terms of applied load versus the out of plane deflection at mid-height

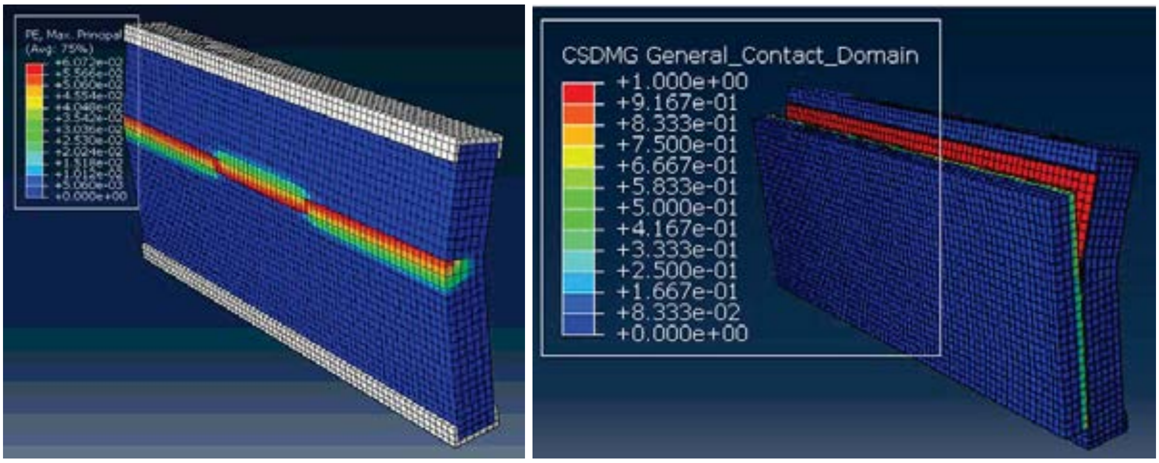

Figure 6. Plastic strains of the bare wallet model (a). The failure of the interface between adhesive mortar and insulation panel appeared for all insulated panels (b).

5 DISCUSSION

The behavior of 4 wallets, one bare and three attached with different insulating panels with thickness 100mm is discussed here. For these wallets both experimental results and numerical predictions are given. The table below (table 2) includes the absolute maximum load for each specimen and the corresponding deflections. For all specimens the mode of failure was the same and was characterized by the bed joints cracking at the mid-height section. Both the tested specimens and the numerical models exhibited partial detachment of the external thermal insulation following the bed joints crack.

	Experimental measurements		Numerical predictions	
Specimen detail	Absolute maximum load (KN)	Deflection at maximum load	Absolute maximum load (KN)	Deflection at maximum load
Bare	8.81	2mm	8.96	0.4mm
MW 100mm	14.77	5mm	17.55	0.8mm
EPS 100mm	35.62	5mm	26.09	2.8mm
XPS 100mm	38.91	3mm	43.59	8.1mm

Table 2. Summary results of all tested and numerically simulated wallets. Absolute maximum load is given together with the corresponding displacement

6 CONCLUSIONS

The behavior of thermal insulated wallets under out of plane bending is discussed here, mainly focusing on the response and the contribution of the ETICS employed in the overall wallet's response. Apart from the experimental observations, numerical models were developed using all the available information about the mechanical properties of the materials used and the geometrical details in an effort to numerically reproduce the behavior observed at the laboratory. The main conclusions are listed below:

- The observed mode of failure of all specimens was the cracking along the bed joint at mid-height joint. However, the existence of ETICS contributed in an increase of maximum load measured. The thermal insulated wallets exhibited larger bearing capacity. This increase differs depending on the panels used. The measured increment of load increase is 68%, 304% and 342% for MW, EPS and XPS insulating panels respectively.
- The developed numerical models discussed here can satisfactorily capture the observed mode of failure. All models exhibited plastic strains in a horizontal cross section resembling the failure of the tested specimens. Following the detachment of the thermal panels occurred, as it was observed during the experimental sequence. Additionally, the models discussed here can satisfactorily capture the maximum load increase and the force – deflection curves up to a point.

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