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In-plane and out-of plane response of currently constructed masonry infills

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ABSTRACT

In most of the Reinforced Concrete buildings in Greece, as well as in other earthquake prone countries, the current infill construction, for the exterior walls of buildings, consists in a cavity masonry wall, made of two thin walls. The two walls are not transversely connected. The seismic vulnerability of those enclosures (to in-plane and out-of-plane actions) is high, as many seismic events have shown.

In the last decades, emphasis was given to the study of Innovative Infill Systems with improved seismic behaviour. The in-plane and out-of-plane behaviour of the (vulnerable) currently constructed masonry infills has not been systematically studied, experimentally and analytically. Within the present work, two full scale RC infilled frames were tested. One was subjected to in-plane cyclic displacements; the second specimen was subjected to repeated out-of-plane displacements, until severely damaged, and subsequently subjected to cyclic in-plane loading. Hysteresis loops for the entire loading history, the observed damage at several drift values and the overall behaviour of the infill are presented and discussed upon. The obtained results are compared to the results recorded during testing of innovative infill systems. It is shown that the performance of the currently constructed infill system is inferior in terms of both load and deformation capacity.

1. Introduction

Enclosures and partition walls in RC structures, currently made of clay bricks in most European countries, are traditionally considered as non-structural elements and, thus, they are not taken into account in the seismic design of buildings.

Nevertheless, when structures are subjected to earthquakes, infill walls contribute to their overall seismic response. This contribution has been proven by numerous seismic events, as well as by experimental work and numerical calculations. This effect depends on several parameters, such as the distribution of the infills (in-plane and in-height), the relative frame-infill stiffness, the infill-RC column interaction, etc. On the other hand, a very important issue of both public safety and economy is related to the limitation of damages in infill walls: failure of infill walls may cause injuries or even casualties, whereas extensive damages of infills (caused by earthquake not necessarily as strong as the design one) may be significant from the economic point of view (repair or reconstruction of infills, repair of damages to facilities, plasters, painting, etc) [1]. This fact is recognized by current Codes for Earthquake Resistant Design either explicitly or implicitly [2]. Indeed, in EC8 [2], qualitative guidance is included for the protection of infills against premature cracking and failure.

In Greece, as well as in other earthquake prone countries (e.g. Portugal, Italy, Turkey), the following, very vulnerable, construction type was adopted for enclosures in the ‘70s, and is still used for the construction of infill walls: cavity brick masonry walls are constructed. The typical thickness of each leaf (made, typically, of horizontally perforated clay bricks) is close to 100 mm. The space between the two (unconnected) leaves is used to accommodate insulation or sliding doors and windows. In an effort to improve the behaviour of those vulnerable infills, a typical solution adopted in Greece and widely applied up to now is the construction of RC tie-beams at mid-height of perimeter infill walls. Although the seismic behaviour of those infills was repeatedly proven to be poor (Fig. 1), they are still in use. On the other hand (see Section 2), even though the behaviour of Infilled RC frames was experimentally investigated in numerous studies, the available research data on the seismic behaviour of the Current Infill System (CIS) is rather scarce.

This paper presents the results of two full-scale tests on RC frames filled following the currently applied infill system (CIS). This research was motivated by the EU funded project INSYSME (www.insysme.eu, [3]). In the framework of that project, two innovative infill walls systems, for use in new construction, were developed at the Laboratory of Reinforced Concrete, NTUA [4,5]. In order to document the

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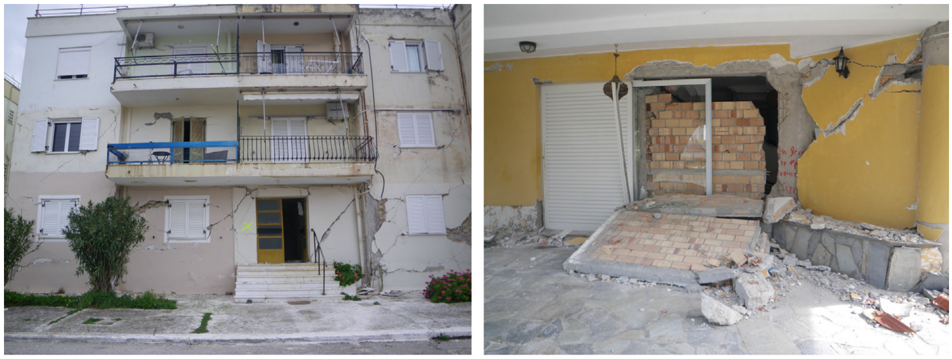

(a) (b)

Fig. 1. (a) In-plane and (b) out-of-plane failure of infill walls during earthquakes.

preponderance of the developed infill systems, their comparison with the behaviour of the currently applied system was investigated through the experimental campaign presented herein.

2. Literature survey

The international literature is rich in results of tests of small or large scale RC or steel infilled frames. Tests simulate various types of infills, constructed with a vast variety of masonry units, either in material (clay bricks, concrete blocks, etc.) or in geometry and pattern of perforations. Furthermore, various ratios of frame to infill stiffness were examined, along with various Codes applied for the design of the frame (sub-standard or conform to current Codes), in order to investigate the effect of infills to the surrounding frame elements.

It is to be noted that in a number of experimental campaigns, infilled frames were subjected to monotonically increasing load or displacements up to failure (see i.a., [6–8], or-more recently-[9–11]). Data on the behaviour of infilled frames subjected to cyclic in-plane loads or displacements are available from tests performed during the last decades. To this purpose, scaled specimens were tested (e.g. [12–16] -scale 1:2, [17–21] -scale 1:3, [22]-scale 1:5, [18]-scale 1:9). In the recent years, emphasis was given to the development and the evaluation of innovative infill systems, able to sustain low damage [3,23–27], on masonry made of large width clay bricks [4,5,28,29], or on repair and strengthening of existing infill walls, using Cement Based Composites [22] or FRPs [19–21,30,31]. Various loading histories were applied: in a limited number of tests, load was applied until the maximum load capacity was reached; afterwards, displacement controlled cycles were applied [32]. Most of the tests were displacement controlled, with the number of cycles applied per drift value varying from one [15,16,20,21,30,33], to two [22], or three cycles [14,25,26,34]. The available literature related to the out-of-plane behaviour of masonry infills is not as rich as for their in-plane behaviour. In a number of investigations the out-of-plane behaviour of bare masonry walls is investigated [30,34–38], or thick masonry infilled frames are tested [39].

Last but not least, several full-scale tests (either cyclic or repeated) were performed on infilled frames in- or out-of-their-plane, within the Project INSYSME [3]. In the framework of this project, aiming at the development of innovative infill systems, NTUA has developed two infill systems, in cooperation with the Greek brick manufacturing industry XALKIS S.A. Data on the performance of those two systems (both granted with a patent by the Greek Patent Office) can be found elsewhere [4,5,40].

Although thin masonry walls (simulating masonry infills) were tested by several investigators [10,23,26,34,37,41–43], the currently constructed infills are not simulated and experimentally investigated. Recently, in [41] the infill walls used in Portugal have been experimentally and analytically studied. The specimen tested in [41], typical in Portugal, presents similarities with the one in use in Greece. However, the two leaves of the cavity wall are of unequal thickness, whereas the infills are not provided with RC tie-beams. Nonetheless, the results of this recent work are valuable as far as the in-plane behaviour of the system is concerned. The experimental work presented herein aims, therefore, to contribute to the study of the enclosure system still in use in several earthquake prone countries, taking into account the specific features of the system in Greece.

3. Experimental programme

It is reminded that the current infill construction for perimeter walls (CIS) consists in a cavity masonry wall. The exterior leaves (typically, approximately 90 mm thick), transversely unconnected, leave a space between them, where the insulating material is accommodated, along with sliding doors and windows. No special connectors or other devices are provided to connect the enclosures to the surrounding RC elements. In Greece, with the purpose of improving the behaviour of this type of enclosures, a RC tie-beam is typically constructed at mid-height of perimeter infill walls. The tie-beams are not fixed to the RC columns. Furthermore, RC tie-beams are constructed independently to each exterior leaf and, hence, they do not provide any transverse connection to them. During seismic, in-plane, loading the diagonal cracks are expected to occur in the intersection of the two diagonals of the infill wall. The expected beneficial effect of the RC tie-beam is to provide extra resistance to the diagonal cracking of the infill wall (thanks to the expectedly higher tensile strength of the concrete), as well as to reduce the opening of the shear cracks (thanks to the longitudinal reinforcement of the tie-beam).

This system was reproduced in the full-scale specimens tested within the present work (Fig. 2). More specifically, a reinforced concrete frame was designed according to EC8-Part1 [2] (Fig. 3). It should be noted that, although the CIS is relevant for a significant portion of the existing building stock, combined with substandard RC frames, the decision was made to investigate the behaviour of CIS within frames constructed according to EC8-Part1 [2]. The main reason is that the CIS is still in use in new constructions and the second reason is that its comparison with newly developed systems for enclosures was sought. A cavity infill wall was constructed within the frame (Fig. 2a). Each leaf (90 mm thick) was made of horizontally perforated clay bricks (Fig. 2b). The bricks are 210 mm long, 90 mm wide and 120 mm high, the average weight per unit is equal to 1.80 kg, and the voids ratio is equal to 35%. The strength parallel to the holes is equal to 10.00 MPa, while the strength perpendicular to the holes is equal to 3.50 MPa. The diagonal compressive strength of walls constructed with the same bricks is equal to 0.35 MPa for plain walls, while it is equal to 0.47 MPa for walls reinforced with a tie-beam at their mid-height. A general purpose cement-lime mortar, classified as M1-M2 [44] was used