16TH EUROPEAN CONFERENCE ON
EARTHQUAKE ENGINEERING THESSALONIKI
18 - 21 JUNE 2018

OUT-OF-PLANE CYCLIC PERFORMANCE OF FULL-SCALE INFILL MASONRY WALLS SUBJECTED TO OUT-OF-PLANE LOADINGS USING AIRBAGS

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ABSTRACT

The infill masonry (IM) walls are widely used for partition purposes and to provide also thermic and acoustic insulation to the reinforced concrete (RC) structures. Usually, the IM walls are considered non-structural elements and no special attention is given to them during the design process of new buildings and safety assessment of existing ones. Only the gravity load contribution is considered. However, recent earthquakes exposed that the infill panels influenced the seismic response of the RC buildings and some of the extensive damages or collapses observed were due to the infills presence. The infills out-of-plane (OOP) collapse vulnerability when subjected to transversal loadings resulted in several number of collapses/extensive damages that in general increased significantly the risk to the population and the rehabilitation' costs of the buildings. The present manuscript will start to present a literature review of experimental studies on IM walls OOP tests considering and not previous in-plane damage. The main results and conclusions from the experimental works will be discussed along the manuscript. After that, it will be presented an experimental campaign of full-scale IM walls OOP quasi-static tests that were carried out at the Laboratory of Earthquake and Structural Engineering (LESE) to assess the influence of the gravity load in the panel response. The results will be presented and discussed in terms of damage observed, cracking pattern, force-displacement curves, maximum strength, stiffness and strength degradation, and accumulative energy dissipation.

Keywords: Infill Masonry Walls; Out-of-plane behaviour; Experimental testing; gravity load

1. INTRODUCTION

The infill masonry (IM) walls are widely used for partition purposes and to provide also thermic and acoustic insulation to the reinforced concrete (RC) structures. Usually the IM walls are considered non-structural elements and no special attention is given to them during the design process of new buildings and safety assessment of existing ones (Furtado et al. 2016; Furtado et al. 2015). However, its poor performance was observed in recent earthquakes (de la Llera et al. 2017; De Luca et al. 2014; Gautam et al. 2016; Hermanns et al. 2014; Romão et al. 2013; Vicente et al. 2012; Yatağan 2011) and their out-of-plane (OOP) vulnerability when subjected to transversal loadings resulted in innumerous of collapses/extensive damages that in general increased significantly the risk to the population and the rehabilitation' costs of the buildings. The risk associated to this type of failure can be greatly increased due to constructive details aspects commonly adopted in the Southern countries of the Europe, such for example no connection between the panel and the surrounding RC elements, no connection between the leafs (in the case of double-leaf IM walls) and insufficient width support condition of the

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panel.
Over the literature, tests were carried out to study and characterize the OOP behaviour of IM wall that fill steel or RC frames considering and not the interaction with the in-plane (IP) loading demand (Angel et al. 1994; Beconcini 1997; Calvi and Bolognini 2001; da Porto et al. 2015; Dawe and Seah 1989; Flanagan and Bennett 1999; Furtado et al. 2016; Griffith and Vaculik 2007; Griffith et al. 2007; Hak et al. 2014; Moghaddam et al. 1988; Mosoarca et al. 2016; Pereira et al. 2012; Preti et al. 2015; Silva et al. 2016; Varela-Rivera et al. 2012). Some other shake table tests of simple IM panels or scaled infilled RC structures can be found in the literature (Corte et al. 2008; Fardis et al. 1999; Klingner et al. 1996; Komaraneni et al. 2011; Liauw and Kwan 1992; Stavridis et al. 2012; Tondelli et al. 2016; Zarnic et al. 2001).
A brief literature review of IM walls OOP tests will be presented, containing information regarding the specimens' details, test protocols and main findings gathered from each author. Thereafter, it will be presented an experimental campaign of IM walls OOP tests with the aim of assess the influence of the application of axial load (here designated gravity load) in top of the frame 'columns in the wall OOP performance. For this, three full-scale specimens were built and tested under different loading conditions. Details regarding the test setup, loading protocol will be provided .The experimental results will be presented and discussed in terms of observed damages, cracking pattern, force-displacement curves, maximum strength, stiffness and strength degradation, and accumulative energy dissipation.

2. LITERATURE REVIEW OF IM WALLS OUT-OF-PLANE TESTS

Moghaddam *et al.* (1988) tested four steel infilled frames with brick walls under a shake table excited biaxially (IP and OOP direction). Two small walls and two larger walls were tested to assess the effect of the infills presence and in particular of the use of reinforced horizontal bed joints. The authors concluded that the infills' presence reduced the frame displacements even after the infills' cracking. It was observed that the reinforcement reduced the vulnerability of the panel by the improvement of the arching mechanism phenomena.
Dawe and Seah (1989) tested 9 full-scale concrete masonry infilled steel frame subjected to a uniform OOP pressure applied through airbags. The main goal of the study was to investigate the influence of the panels' thickness, openings, mortar interface between panel and frame and the efficiency of horizontal connections with the frame by the use of reinforcement bars. It was observed that the infills OOP strength prior to the first significant crack is provided by pure flexural action and that at the post-cracking phase the OOP strength is provided by arching mechanism. The authors concluded that the IM walls ultimate loads increased with larger panel thicknesses, however a decrease was observed for smaller panel aspect ratio. It was not observed any influence of the openings in the IM panels OOP strength. Finally, the authors remarked that the horizontal reinforcement provides higher OOP ductility capacity.
Angel et al. (1994) carried out an experimental campaign composed by combined IP and OOP tests of IM walls made by clay brick or concrete blocks. The strategy adopted was to first submit the specimens to different IP drift demands which resulted in different damage levels and then submit the panels to an OOP monotonic distributed loading applied by airbags. From these tests, the authors concluded that the panels' OOP strength depended highly of the slenderness ratio, masonry compressive strength but not from the tensile strength. The authors observed that cyclic loadings within the elastic region did not affected the panel stiffness. The IP shear demand combined with gravity load increased slightly the panel initial OOP stiffness but the OOP strength was not affected. However, the damage due to the previous IP test reduced the OOP strength for slender panels. Retrofit techniques were tested increased of the panels OOP strength and deformation capacity.
Beconcini (1997) tested several infill panels that were built between the ceiling and the floor of the laboratory. A horizontal beam at the infill panel mid-height was used to apply a linear OOP distributed load. All tests ended with the panel collapse, condition that corresponded to the attainment of the specimen peak load. The author observed that with the absence of vertical joints, the cracking load was around one half of the cracking load of panels provided of them, while their presence did not affect the peak load, since the panel due to its boundary conditions always arched only in the vertical direction. The authors observed that for panels with same thickness, the brick units' dimensions did

not affect the ultimate load, however it was influenced by brick units' cores direction.
Flanagan and Bennett (1999) studied the response of damaged IM walls subjected to OOP distributed loads through airbags. The authors concluded that the infills achieved higher OOP stability under both inertial (uniform) loads and the imposed displacements which was mainly due to the arching mechanism or the development of IP membrane forces. It was observed that very tall and thin panels (high h/t ratio) were more vulnerable due to the loss of stability under inertial loads. From the IP-OOP interaction the authors concluded that it was not significant for moderate loading demands and that through the loading sequence it was observed higher loss of stiffness than loss of strength. Prior OOP loadings may eliminated the diagonal cracking associated to an IP limit state. Prior IP loading appeared to result in higher deflections under uniform lateral loads. Some strength reduction may occurred, but arching mechanism still developed, which resulted in substantial deformation capacity. A combined IP cracking and uniform lateral load test resulted on the reduction of the OOP strength capacity.
Calvi and Bolognini (2001) performed four OOP tests with and without previous IP damage, with and without reinforcement. The main aim was to assess the potential for OOP expulsion of traditional and slightly IM walls at different level of damages induced by IP action. From the tests, it was observed that the panel' state of damage play an important role on the OOP response of the panel.
Griffith *et al.* (Griffith and Vaculik 2007; Griffith et al. 2007) tested eight full scale confined and non-confined IM walls, and pre-compressed with different stress values from 0 to 0.1MPa, to OOP distributed loadings applied through airbag system. From the study, the authors concluded that the post peak strength was enhanced by the vertical pre-compression of the specimens; and that the ability of the wall to OOP deflect at the center height until up to the wall thickness. The authors observed that parameters such as strength and stiffness were significantly affected by the application of the cycle loading.
Varela-Rivera et al. (2012) carried out an experimental campaign of confined IM walls subjected to combined OOP pressure distributed loads and axial loads with the aim of evaluate the influence the last variable on the response of the wall. The authors concluded that as the axial load increases, the OOP maximum strength also increases (however limited by crushing of the masonry). Pereira et al. (2012) tested eight 1/1.5 scaled IM walls subjected to combined IP-OOP cyclic loading in order to assess the efficiency of different retrofit solutions and the effect of previous IP damage. It was observed that the previous IP damage modified the panel failure mode due the variation of the panel support conditions. It was also observed that the bed joints reinforcement improved the OOP stiffness and strength of the panels.
Hak et al. (2014) tested five RC frames infilled with strong clay vertical hollow bricks under OOP cyclic loadings after being subjected to different IP damages levels. From this study, the authors concluded that the development of the strength mechanism was based in two-directional arching action. It was also observed that the typical OOP failure mechanism was characterized by the opening of a predominant horizontal crack at the panel mid-height and the formation of a stepwise crack pattern, which developed from the central crack to the infill panel corners. The OOP response of a previously undamaged masonry stripe tested under vertical single-bending conditions was also evaluated. da Porto et al. (2015) tested six full-scale specimens subjected to OOP loadings with previous IP damage with the goal of characterize mechanically both original and retrofitted walls and validate the efficiency of consider the bed joint reinforcement.
Preti et al. (2015) tested two engineered IM walls subjected to combined IP and OOP loadings with main goal of develop a design approach to reduce the infill panel seismic vulnerability and reduce the interaction with the surrounding frame when subjected to lateral loadings. Furtado et al. (2016) carried out an experimental campaign of three full scale IM walls with the main purpose of characterize their OOP behaviour with and without previous IP damage. The authors concluded that the previous IP damage reduced almost 60% of the maximum strength and a fragile failure mechanism was observed.
In real seismic scenarios the IM walls are subjected to combined bidirectional loadings which result in a different behaviour of those observed when the panel is only subjected to OOP loadings. As observed in recent experimental works, previous IP damage reduce significantly the strength capacity and deformation of the panels. It is observed that when subjected to IP seismic loads the infill panel tends to detach from the surrounding RC frame. This detachment of the panel increases their vulnerability to OOP loadings, since it is mobilized the entire panel, which could result on the integral

collapse exhibiting a typical rigid body behaviour.
Mosoarca et al. (2016) tested the efficiency of different strengthening solutions on three full-scale specimens subjected to OOP loadings. The authors applied the OOP loadings through an actuator linked to a steel profile that was anchored to the centre of the IM wall and thus complete cyclic loadings were achieved.
Silva et al. (2016) studied new IM walls constructive systems, which combine simplicity with low cost assumptions, and carried out OOP testes in previously damaged walls. The authors observed that the strengthening solutions increased the maximum lateral strength and stiffness, however the post-peak behaviour changed and the failure mode become more fragile. Akhoundi et al. (2016) studied the effect of the workmanship and the opening in the OOP response of reduced scale IM walls. From the study, it was observed that the workmanship has a significant effect in the panels OOP strength and stiffness. The opening reduced the initial stiffness of the panel proportionally of the opening area, however no reduction was observed in the panel OOP strength.
Some other experimental tests were carried out through shaking table tests of simple IM panels or infilled RC scaled structures (Corte et al. 2008; Fardis et al. 1999; Klingner et al. 1996; Komaraneni et al. 2011; Liauw and Kwan 1992; Stavridis et al. 2012; Tondelli et al. 2016; Zarnic et al. 2001). Table 1 summarize the experimental tests available in the literature regarding the IM walls OOP behaviour. From the analysis of the experimental studies presented here, the following conclusions can be drawn:

- The maximum OOP strength capacity depends greatly of the panel slenderness;
- The ultimate OOP strength increased with the increasing of the panel thickness, but decreased with the aspect ratio;
- Cracking patterns depends of the panel aspect ratio;
- The IM walls follows a linear elastic behaviour up to the formation of the first crack. After that, the behaviour observed was nonlinear. This nonlinearity was related to the presence of new cracks and the propagation of existing ones up to the formation of the final cracking pattern;
- Workmanship can affect, significantly, the panel OOP behaviour by disturbing their boundary conditions;
- The maximum OOP deformation was observed in panels made with solid bricks;
- Previous damage due to IP previous loading demands reduced the OOP initial stiffness, strength and potentiate fragile ruptures which can lead to fragile OOP expulsions. This is due to the loss of the boarder constrains that were modified, since the detachment of the panel from the surrounding frame occurred and a rigid body behaviour occurs when subjected to OOP loadings;
- The masonry compression strength revealed to be more important to the arching mechanism development than the tensile strength.

Table 1 – Literature review on experimental tests in IM walls subjected to OOP loadings.

Authors	Type of test	Scale	Type of load	Frame Type	Infill type	Number Of tests	Wall dimensions				
							t (mm)	L (mm)	H (mm)	H/L	H/T
Moghaddam et al. (1988)	ST	<1	IP/OOP	S	SB	4	63 101	1025 1860	755 1400	0.74 0.75	12.0 18.4
Dawe and Seah (1989)	M	1	OOP	S	CH	9	90 140 190	3600	2800	0.77	31.1 20.0 14.7
Liauw and Kwan (1992)	ST	1/3	IP/OOP	RC	CH	2	N/A	N/A	N/A	N/A	N/A
Angel et al. (1994)	M	1	IP/OOP	RC	CH CB	8	48 90 148 96 180	2440	1625	0.66	33.8 18.1 11.0 16.9 9.0

Klingner et al. (1996)	ST	1/2	IP/OOP	RC	SB	8 (58)	N/A	N/A	N/A	N/A	N/A
Beconcini (1997)	C	1	OOP	A	CH	33	80 120	1000	2800 3500	2.8 3.5	35 23.3 43.8 29.2
Fardis et al. (1999)	ST	1	IP/OOP	RC	CH	2	N/A	N/A	N/A	N/A	N/A
Flanagan and Bennett (1999)	C	1	IP/OOP	S	CH	9	100 200 330	2240	2240	1	22.4 11.2 6.79
Calvi and Bolognini (2001)	M	1	IP/OOP	RC	CH	10	135	4200	2750	0.65	20.4
Zarnic et al. (2001)	ST	1/4	IP/OOP	RC	SB	2	N/A	N/A	N/A	N/A	N/A
Griffith and Vaculik (2007); Griffith et al. (2007)	C	1	OOP	A	SB	8	110	4000 2500	2500	0.63 1	22.7
Corte et al. (2008)	C	1	OOP	RC	SB	2	N/A	N/A	N/A	N/A	N/A
Komaraneni et al. (2011)	ST	1/2	IP/OOP	RC	SB	3	N/A	N/A	N/A	N/A	N/A
Stavridis et al. (2012)	ST	1	IP/OOP	RC	SB	1	N/A	N/A	N/A	N/A	N/A
Varela-Rivera et al. (2012)	C	1	OOP	RC	SB	3	150	3700	2700	0.73	18
Pereira et al. (2012)	C	1/1.5	IP/OOP	RC	CH	8	150	3500	1700	0.49	11.3
Hak et al. (2014)	C	1	OOP	RC	CH	5	235	4220	2950	1.43	12.6
da Porto et al. (2015)	M	1	IP/OOP	RC	CH	7	120	4150	2650	1.57	22.1
Preti et al. (2015)	C	1	IP/OOP	S	CH	2	190	2930	2460	1.19	12.9
Furtado et al. (2016)	C	1	IP/OOP	RC	CH	3	150	4200	2300	1.83	15.3
Mosoarca et al. (2016)	C	1	OOP	S	CH	3	250	2650	3500	0.76	14
Tondelli et al. (2016)	ST	1/2	IP/OOP	RC	CH	1	N/A	N/A	N/A	N/A	N/A
Silva et al. (2016)	C	1/1.5	IP/OOP	RC	CH	3	100	2415	1635	0.68	16.4
Akhoundi et al. (2016)	C	1/1.5	IP/OOP	RC	CH	3	100	2415	1635	0.68	16.4

3. EXPERIMENTAL ASSESSMENT OF THE GRAVITY LOAD INFLUENCE IN THE OOP CAPACITY OF IM WALLS

3.1 Introduction

The experimental work presented throughout this section was carried out with the aim of obtain preliminary results regarding the possible effect of the gravity load. For this, axial load will be applied in the top of the RC frame columns simultaneously with the OOP loading pressure applied with airbags at the IM wall (Furtado et al. 2017).
Throughout this section it will be presented detailed information regarding the test setup, specimens' description and test instrumentation, loading protocol, material and mechanical characterization. Finally, at the end of the section the results from the OOP tests will be presented and discussed in

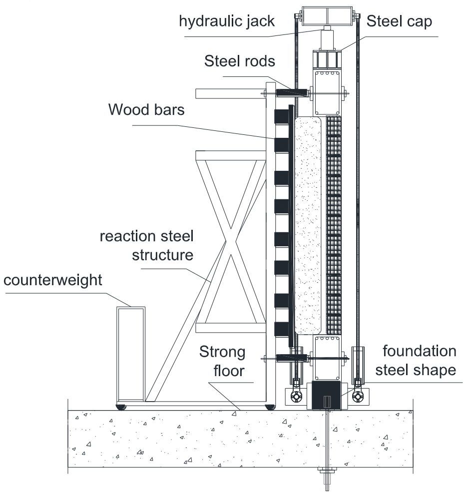
terms of damages observed along the tests, cracking pattern, force-displacement curves, maximum strength, stiffness and strength degradation, and accumulative energy dissipation.

3.2 Test Setup

The OOP test consisted on the application of a uniform distributed pressure, throughout the entire panel under tested, through nylon airbags. With this procedure, it is pretended to mobilize all the infill panel considering all the distributed inertia forces that results from a seismic excitation. The uniform load applied through all the infill panel is reacted against a self-equilibrated steel structure that is composed by five vertical and four horizontal alignments that are rigidly connected to the RC frame with steel re-bars in twelve previous drilled holes. Between the self-equilibrated steel structure and the RC frame it was included twelve load cells that allow the monitoring of the loads transmitted throughout the experimental test. In front of the self-equilibrated steel structure it was placed a wooden platform to withstand the airbags pressure and transfer it to the structure and consequently to the tested panel. This self-equilibrated system uses the RC frame bending stiffness and strength to react against the OOP forces developed from the application of the pressure on the panel. This OOP test setup can be adaptable to specimens with different geometries, types of masonry units and existence of openings. As disadvantage, is the impossibility of perform complete cyclic tests. With this test setup only, charge-discharge loadings can be carried out. In the case of tests combined with gravity load, this load is applied in the top of each column through hydraulic jacks inserted between a steel cap placed on the top of the columns and an upper HEB 200 steel shape, which, in turn, was connected to the foundation steel shape resorting to a pair of high-strength rods per column. Hinged connections were adopted between these rods and the top and foundation steel shapes. In Figure 1 it can be observed the general view of the test setup.

a)

b)



c)

Figure 1. Test setup: a) Front view; b) Lateral view; and c) schematic layout.

3.3 Specimen's details, material and mechanical properties

Three IM walls were built with the full-scale dimensions 4.20x2.30meters respectively length and height. The infill panels were built within a RC frame with columns and beams cross-sections of 0.30x0.30meters and 0.50x0.30meters respectively. The IM walls were built with hollow clay horizontal bricks, as frequently adopted in the Southern Europe (Furtado et al. 2016). The mortar used to construct the specimens was an industrial pre-dosed M5 class ("Ciarga" type). No plaster was adopted. All the panels were built totally supported in the bottom RC beam. The contact between both specimens and the surrounding columns and the bottom beam is provided by approximately 1cm layer of mortar (full bedded joints). No gaps were introduced between the panel and the frame and no reinforcement was used. Regarding the contact between the top beam, half-brick and mortar are used to fill the gap that resulted from the IM wall construction. Specimen Inf_01 is single leaf panel, totally supported in the bottom beam subjected to monotonic OOP load combined with 270kN applied in the top of the frame columns. Specimen Inf_02 is also a single leaf panel, totally supported in the bottom RC beam that was subjected to cyclic OOP test without gravity load. Finally, the specimen Inf_04 is similar to specimen Inf_01, but with difference regarding the OOP, that was applied cyclically. In Table 2 is summarized the testing campaign and the mechanical and material properties of each specimen under study.

Table 2 - Summary of the specimens' information: type of test, gravity load, mechanical and material properties.

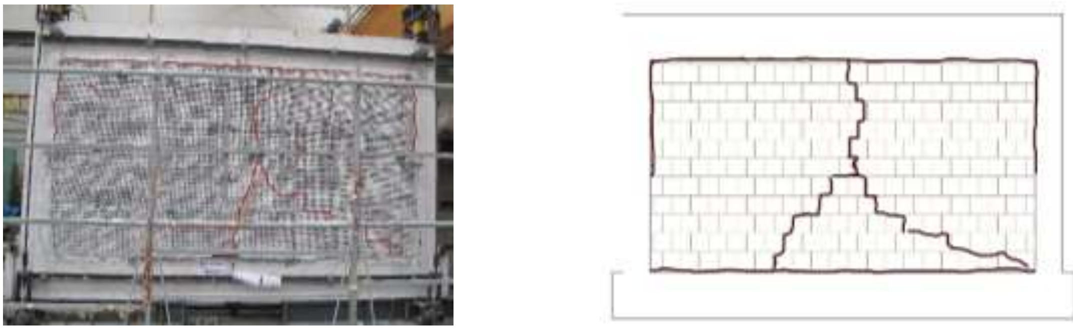
Specimen	Type of test	Gravity load (kN)	Infill panel support conditions	Masonry compressive strength (MPa)	Mortar compressive strength (MPa)	Mortar flexural Strength (MPa)
Inf_01	Monotonic	270	Full Support	0.53	16.55	5.65
Inf_02	Cyclic	-	Full Support	0.53	5.66	2.11
Inf_04	Cyclic	270	Full Support	1.10	8.76	5.16

3.4 Loading condition and instrumentation

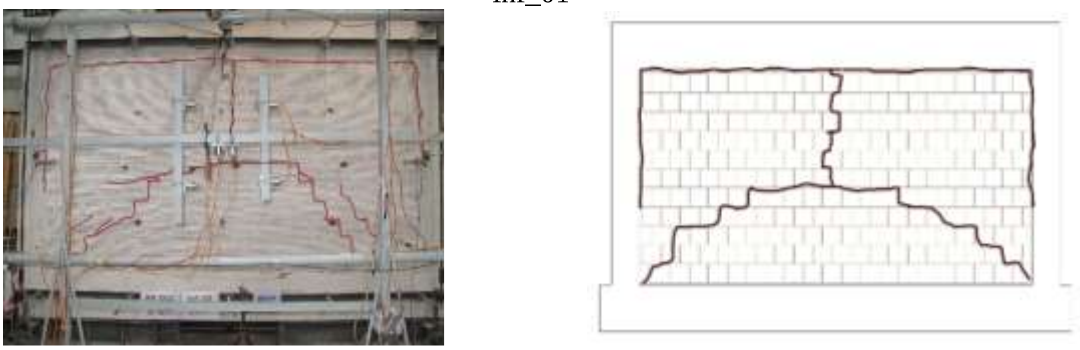
As can be observed in Table 2, specimens Inf_01 and Inf_04 were subjected to combined gravity load and OOP load. The gravity load was not applied in specimen Inf_02, which will be the reference specimen. Monotonic OOP loading was applied in specimen Inf_01 and the remaining ones to cyclic load. The pressure level inside the airbags was set by two pressure valves which were controlled according to the target and measured OOP displacement at the central point of the infill panel. The displacement monitoring were continuously acquired during the tests using a data acquisition and control system developed with the National Instruments LabVIEW software platform (NI 2012). Half-cyclic OOP displacements were imposed with steadily increasing displacement levels, targeting the following nominal peak displacements: 2.5; 5; 7.5; 10; 15; 20; 25; 30; 35; 40; 45; 50; 50; 55; 60; 65 and 70 (mm). Two half-cycles were repeated for each lateral deformation demand level at the control node. The central geometric point of the IM wall was selected as the control point because it was expected that occur the largest deformation of the panel.
To capture the specimens OOP displacements and rotations between the panel and the RC frame it was used twenty-one displacement transducers, thirteen of them LVDT - Linear variable differential transformer (and the remaining eight DWT - Draw-Wire Displacement Transducer. The LVDTs were divided along three vertical and three horizontal alignments distributed along the quarters of each dimension of the panel. The rotation of the panel was measured through a pair of DWT placed at the middle border of each side of the panel. As previously stated before, twelve load cells were used to monitoring the forces of each steel re-bar that link the RC frame and the reaction structure during the tests. The gravity load applied on the top of each column was kept constant and was continuously monitored by two load cells that were inserted between the jacks and the top of each columns.

3.5 Test results

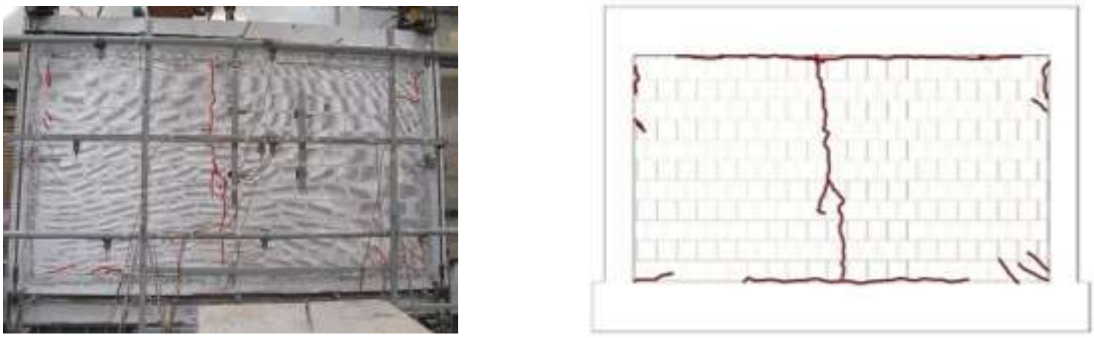
Different damages were observed during the OOP tests on the panels with and without gravity load. The reference specimen Inf_02 damage observed within the test was characterized by a trilinear cracking, with slight cracking between the top of the wall and the top beam. The deformation of the panel was concentrated in the centre, typically of a wall with three borders constrained. On the other hand, the Inf_01 and Inf_04 damages observed were characterized by a vertical cracking at the middle of the panel. It was also observed the detachment of the panel from the top and bottom beams. The damages observed and cracking pattern of each specimen is illustrated in Figure 2.



Inf_01



Inf_02



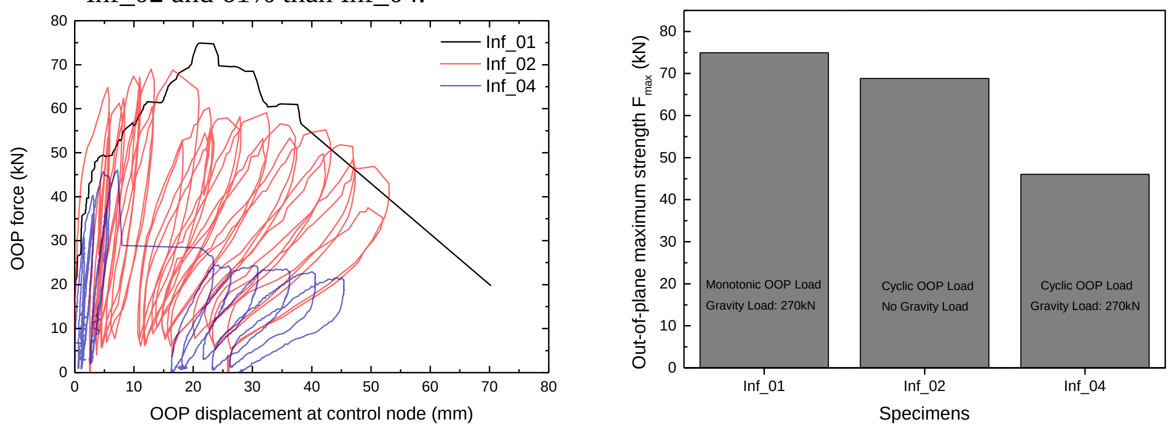
Inf_04

Figure 2. Test results: Damages observed and cracking pattern.

From the force-displacement curves (Figure 3a), the following observations can be drawn:

- Specimen Inf_01 reached a maximum OOP strength of 74kN for an OOP displacement of 21mm. An ultimate OOP strength of 21kN was obtained for an OOP displacement of 72mm. Specimen Inf_02 achieved a maximum OOP strength of 67kN for an OOP displacement of 17mm. An ultimate strength of 48kN was reached for an OOP displacement of 54mm. Finally, the rupture of the panel Inf_04 occurred for the OOP displacement of 7.23mm which corresponded to a maximum strength of 46kN. An ultimate load of 28.3kN was reached for an OOP displacement of 44.6mm;

- After the appearance of the first crack that corresponded to the exhaustion of the OOP capacity of the wall Inf_04 the OOP force reduced from 46kN until 28.3kN. This effect can be attributed to the gravity load application, since the rupture of the top and bottom joint between the panel occurred similarly of Specimen Inf_02;
- It is observed higher OOP strength degradation on specimen Inf_01;
- The panel Inf_01 achieved the highest maximum strength (Figure 3b), about 10% higher than Inf_02 and 61% than Inf_04.



a) b)

Figure 3. Test results: a) Force-displacement; b) Maximum strength.

The stiffness degradation (Figure 4a) was evaluated by comparing the peak-to-peak secant stiffness values resulted from the first cycle of each imposed peak displacement for all the tests. From the results, the following observations can be drawn:

- As expected due the nature of this type of elements, it is clear the trend of the stiffness degradation with the increase of the OOP displacements and corresponding loose of the internal integrity;
- The panel with less stiffness degradation for the same OOP displacement were the panel Inf_01, on the other hand the panel Inf_04 obtained larger stiffness degradation (about 45%). Since the panel Inf_04 failure occurred for small OOP values, and consequently reduced significantly their OOP stiffness;
- Regarding the effect of the axial load on the top of the columns, no conclusions can be drawn, since the specimen Inf_01 was the one the lower stiffness degradation for the same OOP displacement, which was not observed for the specimen Inf_04. This difference can be explained by the fact that the specimen Inf_01 was subjected to a monotonic OOP loading instead of the specimen Inf_04 that was subjected to cyclic OOP loadings.

For each infill panel, the energy dissipated in each individual loading half-cycle and the cumulative energy dissipation throughout the whole test history were calculated (illustrated in Figure 4b). The cumulative dissipation energy was evaluated for all the tests (except for test Inf_01), considering the area of each loading cycle. From the results it can be observed that the specimens Inf_02 and Inf_04 reached an accumulative energy dissipation of 6kNm and 1.8kNm respectively. The application of the gravity load reduced the energy dissipation capacity of the panel Inf_04 about 4 times.

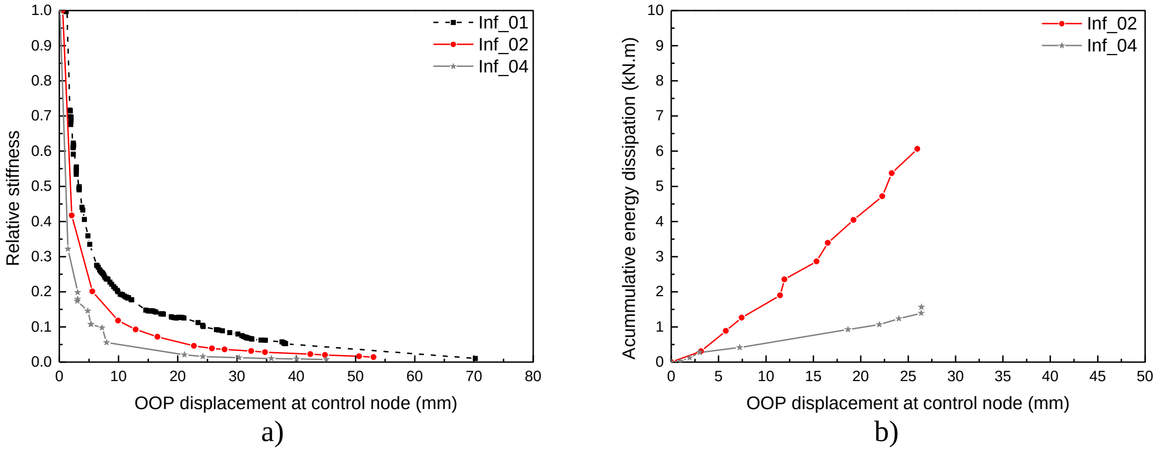


Figure 4. Test results: a) strength degradation; b) accumulative energy dissipation.

4. CONCLUSIONS

Recent earthquake events demonstrated that the IM walls OOP collapse is a potential risk for the population and that the lack of sufficient knowledge regarding the effect in the panel OOP performance requires several efforts characterize experimental and numerically this phenomenon. This manuscript presented an experimental work focused the influence of the gravity load in the panel OOP capacity.

A summarized literature review on IM walls OOP experiments was presented, from which it was observed that: i) High slenderness panels reached lower maximum OOP strength; ii) cracking pattern depends of the panel aspect ratio; iii) workmanship can introduce large variabilities in the panel OOP strength capacity; iv) the ultimate strength capacity of the panel increases with the increase of the panel thickness; v) previous damage due to previous IP loading demands reduce the OOP initial stiffness, strength capacity and potentiate fragile ruptures which can lead to fragile OOP expulsions; iii) The masonry compression strength revealed to be more important to the formation of the arching mechanism than the tensile strength.

An experimental activity composed by three full-scale IM panels that were subjected to quasi-static monotonic and cyclic OOP loadings with the aim of obtain results regarding the possible effect of the gravity load was presented. From the results, it was observed that the application of the gravity load on the top of the columns modified the panels' cracking pattern. It was also observed a pronounced strength degradation after reached the maximum strength. Further number of tests have to be made in the future to confirm the preliminary results regarding the influence of the gravity load that were achieved within the present manuscript.

5. ACKNOWLEDGMENTS

The authors would like to acknowledge the technicians of the Laboratory of Earthquake and Structural Engineering (LESE), Mr. Valdemar Luis, Mr. Guilherme Nogueira and Mr. Nuno Pinto for their support in the experimental activity reported in this paper, and Preceram for the provision of all the bricks used in the experimental tests. This work was financially supported by: Project POCI-01-0145-FEDER-007457 - CONSTRUCT - Institute of R&D In Structures and Construction funded by FEDER funds through COMPETE2020 - Programa Operacional Competitividade e Internacionalização and by national funds through FCT - Fundação para a Ciência e a Tecnologia. This work was object of specific financial support of FCT through the P0CI-01-0145-FEDER-016898 – "ASPASSI Safety Evaluation and Retrofitting of Infill masonry enclosure Walls for Seismic demands".

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7. APPENDIX

Type of test: ST- Shake-Table; C- Static Cyclic test; M – Static Monotonic test; PD- Pseudo-dynamic test
Type of load: OOP – Out-of-plane; IP – In-plane; IP/OOP – Combined In-plane and out-of-plane
Frame Type: S- Steel frame; RC – Reinforced Concrete frame; A - Absent
Infill Type: SB – Clay solid brick; CB - Clay hollow brick; CH – Concrete hollow brick
N/A: Not applicable