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In-plane response of masonry infill walls: experimental study using digital image correlation

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Abstract

The behaviour of the infill masonry (IM) walls in the reinforced concrete (RC) buildings has been subject of numerous numerical and experimental studies with the main purpose of characterizing their influence in buildings' response under seismic loadings. Although being considered non-structural elements, during an earthquake this type of elements tends to interact with the reinforced concrete surrounding frames, which can result in different types of in-plane damage, namely diagonal cracking, corner crushing, shear-friction failure which significantly reduce the out-of-plane performance of such type of elements. In order to study the in-plane behaviour of IM walls and its interaction with the surrounding frames, a full scale experimental test involving a double leaf infill panel was carried out in the Laboratory of Earthquake and Structural Engineering – LESE. In addition, a Digital Image Correlation (DIC) technique was used and to monitor the experimental test response aiming at validating the potential of DIC as a non-contact, full-field, optical tool to measure displacement fields of both in-plane (2D) and out-of-plane (3D) structural motions. DIC consists on recording images at different stages of a test, with dissimilar perspectives, by dividing them in small sections, or subsets, and tracking their displacements along the different captured images. This research paper presents the in-plane experimental test and the results of the DIC technique application.

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Keywords: Infill masonry walls, in-plane experimental test, double-leaf panel, digital image correlation

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1. Introduction

The behaviour of the infill masonry walls (IM) walls in the reinforced concrete (RC) buildings has been studied in numerous numerical and experimental research works mainly for characterizing the effect of their presence in the structural response of buildings subjected to earthquake loading. Albeit considered non-structural elements, this type of elements tends to interact with the reinforced concrete surrounding frames during a seismic event, which may lead to different types of in-plane damage, namely diagonal cracking, corner crushing, shear-friction failure. In addition, in-plane damage is likely to reduce significantly the out-of-plane performance of IM walls as shown in Fig. 1 [1-3].

a) b) c)

Fig. 1: IM walls in-plane damages reported in recent earthquakes a) Detachment of the surrounding RC frame b) Diagonal cracking and corner crushing and c) diagonal cracking.

It is widely recognized that existing experimental tests reported in the state-of-art are very scarce, especially in what concerns full scale infilled RC frames. Thus, the increase of experimental testing should be a priority in order to achieve deeper knowledge of the IM walls behaviour when subjected to cyclic loadings.

Aiming at studying the in-plane cyclic behaviour of double leaf infill panels and its interaction with the surrounding frame, a full scale experimental test was carried out in the Laboratory of Earthquake and Structural Engineering – LESE. This type of the IM wall is very common in the Portuguese building stock and can be found in most of the buildings' façades.

For this experimental study, the displacement and deformation fields were also measured by using the Digital Image Correlation (DIC) technique during the test. DIC is a non-contact and full-field optical technic to measure displacement fields in both in-plane (2D) and/or out-of-plane (3D) response. It consists in recording images in different stages of a test, with dissimilar perspectives (if stereoscopy is required), dividing them in small sections, or subsets, and tracking their displacements throughout different captured images. Although the technique is commonly used with small test specimens, it can also be employed for structures of any size, its accuracy being essentially dependent on the recorded images resolution. The technique can be most relevant in civil engineering applications, likely to require large surfaces' monitoring, because it allows replacing discrete arrays of displacement sensors, decreasing experimental setup complexity, detecting full displacement and strain fields in any direction and producing 3D surfaces' reconstruction in every monitoring step.

The present research paper aims at presenting the in-plane experimental test and the DIC technique results obtained thereof.

2. Introduction

2.1. General overview and test specimen' description

Within the scope of the present experimental campaign, one in-plane test of a full-scale infilled RC frame was performed. The general dimensions of the specimens were selected as 4.80x3.30m^2, with RC columns and beams cross sections of 0.30x0.30m^2 and 0.30x0.50m^2 respectively, which is representative of the Portuguese building stock [4]. Fig. 2: Infilled RC frame specimen dimensions a) general dimensions, b) columns and c) beams dimensions and reinforcement detailing.

shows the infilled RC frame geometry and the corresponding column and beam section dimensions and reinforcement detailing. This specimen includes a double-leaf panel (including a 150x200x300mm brick panel and another 110x200x300mm brick panel) representing some of the existing Portuguese building's façades, as illustrated in Fig. 3.

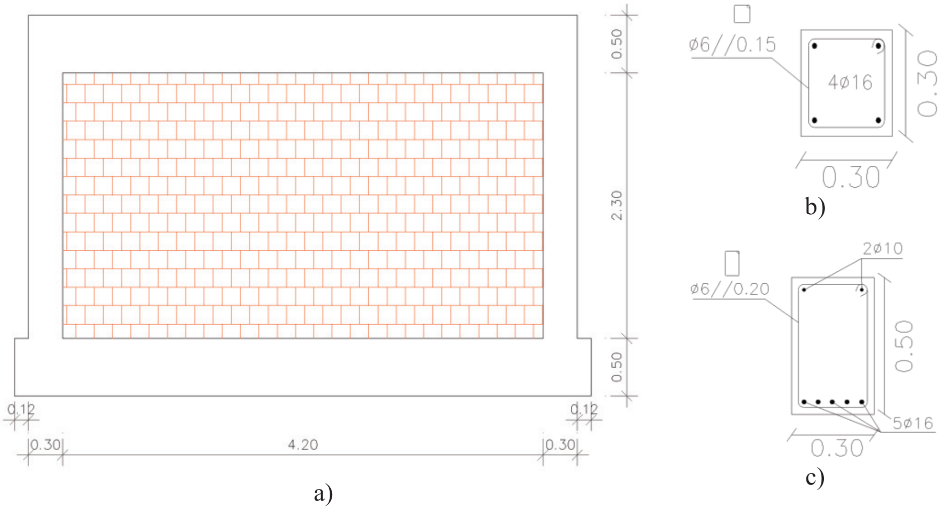


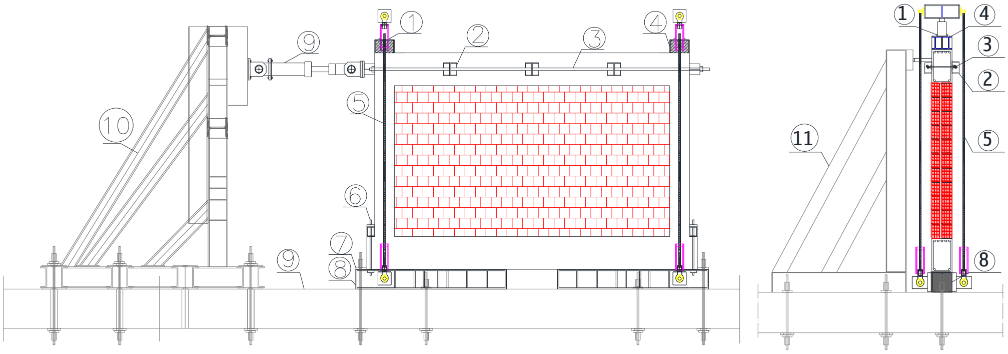
Fig. 2: Infilled RC frame specimen dimensions a) general dimensions, b) columns and c) beams dimensions and reinforcement detailing.

a) b) c)

Fig. 3: Infilled RC frame specimen: a) 150mm thick panel construction, b) 110mm thick panel construction and c) experimental test apparatus.

2.2. Test setup description

The in-plane test consists on the application of a horizontal force in top of the RC frame using a servo-controlled hydraulic actuator (+/-500kN capacity with +/-150mm stroke) attached to a steel reaction structure. The horizontal force transmission to the RC frame is made by two pre-stressed rods (in the front and rear specimen sides) tying up two steel shapes in the left and right extremities of the top beam, in order to apply in-plane loading cycle reversals. The column axial load was applied using one hydraulic jack per column, attached to top and bottom steel devices by means of high-strength rods with hinged extremities. The in-plane test of the infilled frame was made under the so-applied column axial load of 300kN that was kept constant with the prescribed value measured by load cells attached to the jacks. The test setup was provided also with an additional guiding structure to prevent out-of-plane displacements of the infilled RC frame, while allowing it to slide along guiding steel shapes. Fig. 4 shows the layout of the in-plane experimental test setup, with the illustration of each element and corresponding description.



a) b)

Fig. 4 – Layout of the in-plane experimental test setup, a) front and b) lateral view: 1 – hydraulic jack (for axial load application), 2 – plates for horizontal force distribution, 3 – horizontal high-strength rods (ø30mm), 4 - head steel shape, 5 – vertical high-strength rods (ø30mm), 6 - steel rod (ø20mm) connecting the RC frame to the foundation steel shape, 7 - high-strength rods (ø30mm) fixing the foundation steel shape to the reaction slab, 8 - foundation steel shape, 9 – strong floor, 10 – in-plane reaction frame 11 – out-of-plane reaction and guiding structure

2.3. Instrumentation

The instrumentation of the experimental tests was composed by a total of 21 displacement transducers, both Linear Variable Displacement Transducers (LVDTs) and Draw Wire Transducers (DWT), as illustrated in Fig. 5. The instrumentation was divided in 3 different groups according to the corresponding measurement objective: *i)* out-of-plane displacements of the infilled RC frame (3 LVDTs); *ii)* diagonal displacements in the infill panel and in the RC frame (8 DWTs) in both specimen sides and *iii)* in-plane displacements of the infilled RC frame (10 LVDTs). Additionally, the Digital Image Correlation (DIC) technique was also used as described in the next sub-section.

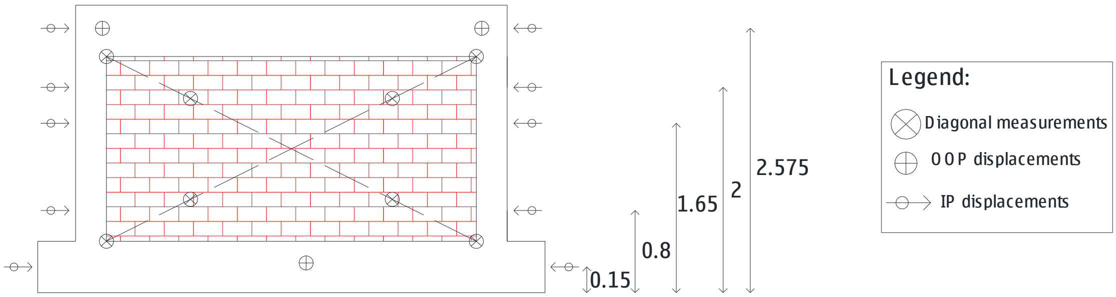


Fig. 5: Layout of the in-plane experimental test instrumentation.

2.4. Digital Image Correlation (DIC) monitoring technique

The DIC setup included the VIC-3D™ system from Correlated Solutions equipped with a 4.1MPixel CMOSIS camera and a Schneider-Kreuznach 16mm focal distance lens. For an in-plane experiment, only one camera is required therefore considering the wall behavior as a 2D analysis. For this test, image calibration was only necessary in order to reduce lenses distortion effects and to compute a scale measurement (from pixels to mm). The full equipment setup is presented in **Error! Reference source not found.**

The data was then compared with the LVDTs measurements for specific points and steps of the test. Since the speckle pattern was only applied in the masonry infill, and since the LVDTs for comparison were positioned in the RC frame the data was not expected to perfectly agree, especially for large displacement values. This can be seen in

Fig. 9 in the section denoted by infill separation, which may be explained by the tensile behavior between the RC frame and the adjacent masonry wall.

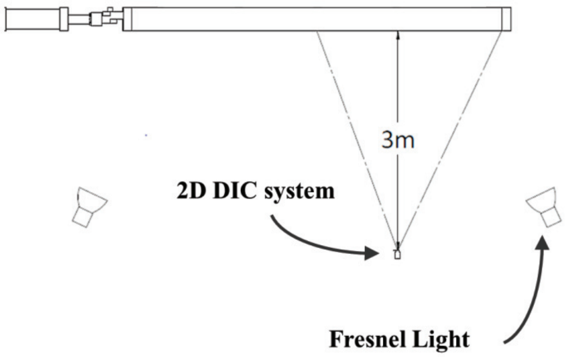


Fig. 6: Digital Image correlation setup.

DIC data was also used to produce full-field displacement and strain maps that can be used for the reconstruction of the wall measurement and evaluation of the principal strains and their directions. This information was published by Tiago Ramos et al. [5] in the course of this project.

2.5. Loading condition

As previously stated, the aim of the present experimental campaign is to better understand the in-plane behaviour of IM walls, particularly concerning double-leaf IM walls. To this end, cyclic in-plane displacements were imposed at the top of the IM wall with steadily increasing displacement levels. Aiming at subjecting the IM wall to 0.5% maximum in-plane drift, the following nominal peak displacement levels (mm) were considered: 2.5, 3.5, 9, 12 and 15, with 3 cycle repetitions for each displacement level.

3. Experimental test results

The results of the in-plane test were evaluated in terms of force-displacement hysteretic curves as illustrated in Fig. 6a. From the result analysis, the following main observations can be drawn:

- Results are different (non-symmetric) between the positive and negative loading sense, which was due to longitudinal extension and slacks of the horizontal pre-stressed rod during the experimental test. For this reason the positive loading will be adopted as reference;
- A continuous increase was observed in the in-plane strength until 0.25% drift, after which the strength stabilized until 0.5% drift, though with clear stiffness degradation during the test;
- The maximum strength was characterized by the onset of diagonal cracking in the weaker panel (110 mm thick) and detachment of the surrounding RC frame. At the 0.3% drift it was possible to observe panels' detachment relative to the top beam and also corner crushing in the stronger panel (Fig. 8).

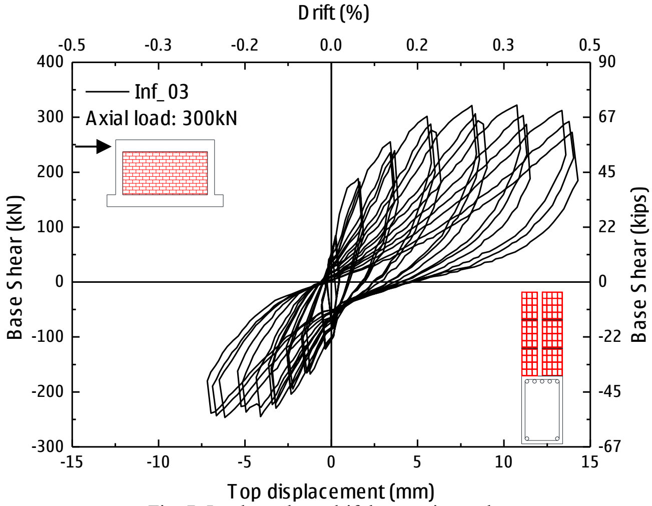


Fig. 7: In-plane shear-drift hysteretic results

a) b)

Fig. 8: In-plane final cracking pattern: a) Stronger panel (t=150mm) and b) weaker panel (t=110mm).

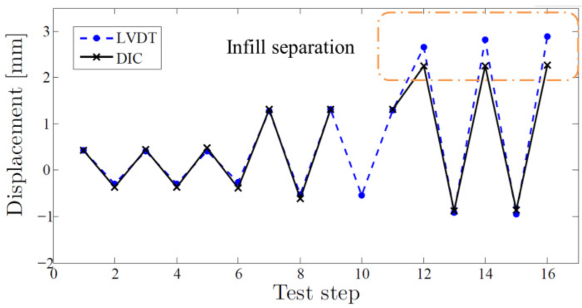


Fig. 9: Comparison between an LVDT (sensor 14) and DIC measurements.

4. Conclusions

This paper reports an experimental campaign carried out at the Laboratory of Earthquake Engineering at the Faculty of Engineering of University of Porto in order to study the in-plane behaviour of a full scale double leaf infill masonry wall. The experimental test setup was presented, including all the instrumentation and loading conditions. It was observed a continuous increase of the in-plane strength until 0.25% of drift, after which the strength got stable. There was no strength degradation until 0.5% drift, but clear stiffness degradation was found during the test. The maximum strength was characterized by diagonal crack starting in the weak panel and detachment relative to surrounding RC frame, particularly after 0.3% drift when the top beam in both panels became clearly detached and also corner crushing was found in the strong panel.

Digital image correlation has proven to be a versatile technique for displacement measurements that can be applied for structural health monitoring purposes. Its ability to return full-field displacement maps can even reduce equipment cost and complexity, being its accuracy essentially a function of the recorded images resolution.

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