CHALLENGES AND RECENT OUTPUTS ON THE EXPERIMENTAL CHARACTERIZATION OF INFILL MASONRY WALLS OUT-OF-PLANE BEHAVIOUR

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ABSTRACT

It is widely consensual that further and deeper research is required on the out-of-plane seismic response of infill masonry walls to reduce the vulnerability of such elements and to develop effective retrofit strategies for preventing panel collapse, increasing human life protection and reducing economic losses. This type of study is also important to support the development of accurate numerical models able to represent the expected response of infill walls subjected to out-of-plane loadings, combined or not with in-plane loadings. In this context, experimental testing is an excellent tool to characterize the infill masonry walls walls cyclic behaviour subjected to static or dynamic loads. For this, at the Laboratory for Earthquake and Structural Engineering (LESE) of the University of Porto, an experimental campaign of quasi-static out-of-plane of full-scale infill masonry walls was carried out. An innovative testing set-up was developed in order to perform these tests using airbags which was lately upgraded with pneumatic actuators. The main details regarding each approach will be provided and discussed.

Keywords: Masonry infill walls, out-of-plane, experimental testing, airbags, pneumatic actuators.

INTRODUCTION

Several authors [1-4] reported that the out-of-plane (OOP) performance and capacity of infill masonry (IM) walls can be strongly influenced by the following issues: connection between the panel and surrounding reinforced concrete (RC) frames; connection between the internal and external leaves (in the case of two-leaf IM walls); insufficient support width due to constructive procedures adopted for thermal bridges’ prevention and, last but not the least, the existence of previous in-plane damages. Moreover, IM walls OOP collapse can also introduce plan and/or height vertical stiffness irregularity which can induce formation of mechanisms such soft-storey or torsion, likely to originate building collapse.

Due to the need of further knowledge regarding the seismic behaviour of IM walls, the experimental cyclic or dynamic tests proved to be useful tools that allow the characterization of their expected behaviour and the evaluation of IM walls capacity considering different geometries, masonry units, openings, previous damage levels, and borderer constrains and support conditions, among others. Nevertheless, this type of tests presents high level difficulties due to the setups’ complexities and because it is necessary sufficient capacity and
lab facilities to test full-scale specimens. Some experimental studies were performed recently on this topic, but still the available number of full-scale tests is much reduced [4-6].

One of the major goals of the IM walls OOP tests is to reproduce correctly the seismic actions effects. Due to the distributed IM wall mass, the tests setups used at laboratory conditions were conceived in order to mobilize the entire panel. Different approaches have been proposed throughout the literature, namely shaking-table tests where the seismic behaviour of the IM wall is characterized. With this particular test, bi-directional earthquakes can be induced to the infill panel and thus it is possible to evaluate the combined effect on the wall capacity. Quasi-static tests were carried out by different authors by applying distributed or local forces that mobilize the OOP response of IM walls.

The use of local loads (two or four application points) applied by hydraulic actuators is commonly adopted to overcome the difficulties inherent to the complexity of test setups that guarantee the entire mobilization of the panel. However, some authors indicated that one disadvantage of this approach is that it can introduce or modify the expected IM wall failure mode when subjected to a real earthquake. Different methodologies can be adopted to apply uniform OOP loadings, starting from water bags [7] or airbags [8]. Griffith et al. [1] tested unreinforced masonry walls by applying OOP pressure loadings through the entire specimen. Double-leaf airbags were used, one in each façade of the specimen to perform complete cyclic, instead of the load-unload inherent to the adoption only for the one-layer airbag. One of the disadvantages associated to the use of the double-leaf airbags is the impossibility of following damages’ evolution throughout the test; the synchronization between the two airbag layers is also a difficulty. The main goal of this research work is to present two test setups developed to perform quasi-static cyclic OOP tests of full-scale IM walls.

**QUASI-STATIC CYCLIC OUT-OF-PLANE TEST OF FULL-SCALE INFILL MASONRY WALL USING AIRBAGS**

The OOP test of IM walls using airbags consisted on the application of a uniformly distributed surface load through a system composed of seven nylon airbags, reacting against a self-equilibrated steel structure, as shown in Figure. 1. The application of a uniform OOP loading aims (as observed) to globally mobilize the out-of-plane response of the IM wall, as discussed in the previous section [9, 10]. This reaction structure is composed of five vertical and four horizontal alignments of rigidly connected steel bars, in front of which a vertical wooden platform is placed to resist the airbag pressure and transfer it to the steel reacting grid elements. Thus, 12 steel threaded rods, crossing the RC elements in previously drilled holes, were used to equilibrate the reaction force resulting from the pressure applied by the airbags in the infill panel. The steel rods were strategically placed to evaluate the load distribution throughout the entire infilled RC frame resorting to load cells attached to each rod, which allowed continuous measurement of the forces transmitted to the reaction structure to which the rods were directly screwed [11]. On the other extremity of each tensioned rod, appropriate nuts and steel plates were used to anchor the rod and apply its reaction force to the concrete surface by uniformly distributed normal stresses, thus avoiding load concentration on the RC elements crossed by the rods.
The control system is composed by two main components: (i) airbag control; and (ii) axial load control. The airbag control is composed by two electronic proportional directional control valves (0-10bar), two air compressors (100lt, 10bar), two manual filters pressure regulators (0-16bar) and two transducers (pressure and displacement). Each air compressor is connected to one pressure regulator (limit defined as 2bar) and one electronic valve, respectively, in order to guarantee two air entrances on the airbags set (one in each extremity).

The panel loading was achieved by the airbags inflation control, while monitoring their interior pressure and the imposed OOP displacements in the infill panel. The schematic layout of the airbag loading system is presented in Figure 2. The airbag control program implemented is based on target displacement control, where a given displacement transducer is defined as the reference one, for which a target displacement history is defined previously. The comparison between the target and the measured displacement and the interaction with the electronic pressure valves drive the control requirements of air inflation or deflation.

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Fig. 1 - Layout of the OOP test set-up using airbags. (a) front view and (b) lateral view. 0 - strong floor, 1 - foundation steel shape, 2 - high-strength rods (ø30mm) fixing the foundation steel shape to the reaction slab, 3 - steel rod (ø20mm) connecting the RC frame to the foundation steel shape, 4 - vertical high-strength rods (ø30mm) to apply axial load, 5 - steel cap, 6 - steel rods (ø20mm) connecting the RC frame to the reaction structure, 7 - distributing load plate, 8 - self-equilibrated reaction steel structure, 9 - counterweight, 10 - wood bars, 11 - hydraulic jack (for axial load application), 12 - vertical wooden platform, 13 - airbags, 14 - infill panel, 15 - RC column, 16 - steel plate for rod force distribution.

Fig. 2 - Control system diagram of quasi-static OOP tests of IM walls using airbags.
QUASI-STATIC CYCLIC OUT-OF-PLANE TEST OF FULL-SCALE INFILL MASONRY WALL USING PNEUMATIC ATUATORS

An upgrade of the test setup presented before was developed, which concept was based on the previous one with airbags, but consisting on the application of a distributed OOP loading through 28 pneumatic actuators that mobilize the entire infill panel surface resorting to wood plates with dimensions 0.5x0.5m² placed between the actuators and the panel. The pneumatic actuators are linked to four horizontal HEB140 steel shapes reacting against 5 vertical alignments HEB200. The horizontal alignments are coupled with hinged devices that allow lateral sliding. This reaction structure is self-equilibrated since the reaction of the OOP loading applied in the panel is provided by the top and bottom beams of the RC frame. The steel structure is connected to the RC frame along ten points (5 in the bottom and 5 in the top beam) which are coupled with ten load cells that allow monitoring the OOP tests loading transfers. Figure 3 show the schematic layout of the new testing system with different views to understand the global behaviour.

The control system is similarly to those described in the previous sub-section, and is composed by two main components: (i) pneumatic actuators control; and (ii) axial load control. The pneumatic actuator control is composed by one electronic proportional directional control valves (0-10bar), one air compressors (100lt, 10bar), one manual filter pressure regulator (0-16bar) and two transducers (for pressure and displacement). The air compressor is connected to the pressure regulator (limit defined as 2bar) and the electronic valve. The panel loading was achieved by the pneumatic actuators air entrance control, by monitoring their interior pressure and their imposed OOP displacements.

![Diagram](image)

Fig. 3 - Schematic layout of OOP test setup using pneumatic actuators. (a) back view; (b) and (c) side views.
One of the advantages of this test setup is the fact that it is adaptable to walls with different geometric dimensions, with and without openings. The validation tests demonstrated the capacity of the platform to carry out the tests with success. With this type of actuators the test velocity increased due to the fact that the time duration to fill the actuators are quite less than the airbags. Finally, another advantage is the possibility to place the instrumentation behind the panel (opposite direction of the OOP loading) as can be observed in Figure 4, which allow to monitor with improved quality and information the cracking propagation monitoring throughout the test.

![Fig. 1 - Global view of an experimental test using pneumatic actuators. (a) lateral view; (b) back view.](a)

![Fig. 1 - Global view of an experimental test using pneumatic actuators. (a) lateral view; (b) back view.](b)

CONCLUSIONS

This research work aims to present the experimental campaign carried out at the Faculty of Engineering of the University of Porto to study the IM walls OOP behaviour through quasi-static full-scale tests. Within this work was developed a test setup that consisted in the application of a uniform distributed load through nylon airbags. The innovation consisted in the use of a self-equilibrate steel reaction structure that is linked to the RC frame along twelve points to support the airbag load reaction. With this test setup 6 specimens were tested with different particularities such as type of loading (monotonic or cyclic), previous in-plane damage, axial load in the top of columns and reduction of the panel width support. Recently, the test setup was updated and the airbags were substituted by pneumatic actuators with a new self-equilibrated steel structure that is more suitable to modify the loading configuration according to the panel geometry and with openings.

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