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EXPERIMENTAL INVESTIGATION OF SEISMIC BEHAVIOUR OF EXISTING MASONRY INFILLS

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Abstract

The seismic vulnerability of masonry infills has been observed persistently during post seismic surveys, and their seismic behaviour has been investigated for decades due to its complexity involving different aspects that need to be addressed and the diversity of existing masonry infill typologies. Despite the copious experimental studies conducted, only a few of them had the opportunity to analyse different aspects of the same masonry typology due to the reduced number of specimens usually involved in a testing campaign. The out-of-plane response of masonry infills, and the reduction of the out-of-plane resistance of the infill panels due to the damage caused by in-plane deformations, are usually the most critical aspects regarding life safety. Furthermore, the out-of-plane experimental tests on masonry infills have almost always been conducted through pseudo-static tests with different loading techniques (4 point loading, central loading, constant pressure with airbags or other systems), meanwhile a complete experimental campaign on existing masonry infills through dynamic tests on a shaking table has not taken place yet.

Within this framework, an experimental campaign focusing on non-ductile infill specimens made of horizontally hollowed weak clay units representing one of the most common infill systems present in Italy, is currently ongoing at the Eucentre Foundation of Pavia. In the present paper, the results from the first phase of the ongoing study will be discussed. In the scope of this research program, in-plane cyclic tests and out-of-plane dynamic tests are conducted on full-scale infill panels built inside single storey single bay composite steel/reinforced concrete frames, along with tests of characterization of the masonry materials. The first phase of tests included five specimens, four of them built with all edges bonded to the frame and one specimen with free vertical edges. The four specimens with the same boundary conditions were used to characterize the pure in-plane behaviour, the pure out-of-plane behaviour, and the out-of-plane behaviour with previous in-plane damage. The specimen with the vertical edges free was subjected to pure out-of-plane excitation to explore the one-way bending/arching behaviour of infills.

Keywords: Masonry infills, Existing infills, Shaking table tests, In-plane, Out-of-plane, Seismic behaviour

1. Introduction

The poor performance and severe damage repeatedly observed in masonry infilled frame structures during earthquakes have posed significant threat to life safety and led to major economic losses [1, 2, 3]. In the last decades, extensive research has been carried out to explore and improve the seismic behaviour of masonry infills, which is inherently complex due to many interrelated aspects required to be considered. The seismic behaviour of infills has been studied in the literature mainly in terms of their in-plane response [4, 5, 6], out-of-plane response [7, 8, 9], and the interaction between in-plane and out-of-plane behaviour [10, 11, 12, 13], considering the influence of the infill typology and masonry properties, aspect ratio, boundary conditions, frame properties, local interaction between the panel and the frame, and the global response of the structure. Despite the attention that masonry infills have received over the last few decades, guidelines provided for masonry infills in current seismic codes are rather general [14, 15]. Infills are usually assessed as non-structural elements and their safety is verified

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without giving special consideration to infill typology or structural configuration. Thus, expanding the current experimental database is crucial for more accurate seismic assessment of masonry infills.

The study reported in this paper was contrived to fully characterize the seismic behaviour of an infill typology which was commonly used between the 1960s-1980s in Mediterranean countries as enclosures and partitions in reinforced concrete frame structures which are typically not designed for seismic actions. The typology consists of horizontally perforated hollow clay masonry units of 8- 12 cm thickness, often in two layers of walls with a cavity in between. Such a type is recognized as “weak” infills due to its high percentage of perforation and slenderness introduced from the small thickness. In the present study, five single leaf infill panels have been constructed within steel/concrete composite single storey single bay frames; four specimens fully bonded to the frame in all edges and one specimen with two vertical gaps around 25 mm between the panel and the columns. The infills were 13 cm thick, including a 10 mm thick layer of plaster on one side. Out of the four specimens fully adhered to the frame, one was tested purely in-plane and another purely out-of-plane. The remaining two were first subjected to different levels of in-plane drifts and subsequently to out-of-plane excitation to study the influence of the level of previous in-plane damage on the out-of-plane capacity. The specimen with free vertical edges was tested in the out-of-plane direction, to investigate the out-of-plane arching mechanism in a single vertical bending wall. The in-plane tests were displacement-controlled pseudo-static cyclic tests at increasing target drifts and the out-of-plane tests were shake table dynamic tests with incremental peak floor accelerations applied until collapse. The results of the in-plane tests are reported in terms of force-displacement curves, drift capacity, damage propagation and performance levels. For out-of-plane tests, the recorded accelerations and displacements, the damage evolution and failure mechanisms observed during the tests, and the effect of boundary conditions and previous in-plane damage, are elaborated.

2. Experimental Programme

2.1 Description of specimens

The first phase of the experimental campaign consisted of tests on 5 infill specimens, herein after referred to as T1, T2, T3, T4 and T5. The structural frames in which the masonry infills were built were fabricated with steel C-sections filled with reinforced concrete, such that the infill boundaries are in contact with the reinforced concrete surface as shown in Fig. 1(a). The frame was designed to represent a single story single bay of an existing frame structure, and to remain undamaged during the tests, which enabled reuse of the frames in the subsequent phases of the experiment. The infills were built with horizontally perforated 12 cm thick 25 x 25 cm units (Fig. 1(b)), laid in running bond with 10 mm thick mortar joints. The head joints were poorly filled as seen in Fig. 1(c) to reflect the common Italian construction practices during 1960-1980. The infill panels were 3.5 m long and 2.75 m high with an aspect ratio of 1.27. Representing one leaf of a double wythe wall, the panel was plastered on one side with a thickness of 10 mm, and the resulting total thickness of the panel was 13 cm. The bond between the panel and the frame was achieved by applying a mortar joint. Four specimens (T1-T4) were fully adhered to the frame continuously along the boundaries. The specimen with the vertical gaps (T5) was bonded to the frame along the top and bottom horizontal edges to the frame beams. The vertical gaps were approximately 25 mm each and continuous along the entire height of the panel.

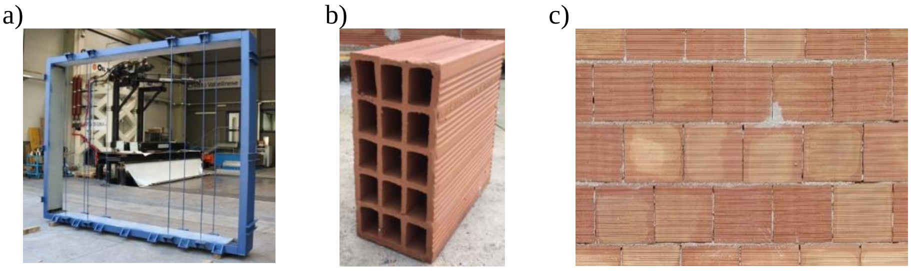

Figure 1. a) Steel concrete composite bare frame; b) Horizontally perforated units; c) poorly done head joints

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2.2 Mechanical characterisation of units, mortar, and masonry

A comprehensive series of tests was carried out to determine the mechanical properties of units, mortar and the masonry. According to current standard provisions the resistance in compression of the units [16], the flexural and compressive resistance of the mortar [17], and the mechanical behaviour of the masonry in terms of vertical and horizontal resistance with and without plaster [18], diagonal compression test to determine the tensile resistance [19], pure shear tests [20] and flexural tests [21] have been conducted.

2.3 Test setup and instrumentation

The test setup and instrumentation were designed uniquely for the in-plane and out-of-plane tests. The in-plane tests were realized by applying pseudo static drift cycles in displacement control through a servo-hydraulic actuator supported by a strong steel frame. To restrain the out-of-plane movement of the frame at the top, four inclined steel braces (two in each side) have been used, connected to the top two corners of the frame and supported on the floor. The specimen was rigidly fixed to the floor through a steel beam foundation. The shake table has been used as a strong floor for the in-plane tests, which was kept stationary during the static tests with an active control. Such a disposition was necessary in order to conduct the entire test sequence on a specimen in one location, thus avoiding damage to the specimen due to transportation.

The out-of-plane excitations were applied to the specimen through the shake table, during which the actuator used for the in-plane tests was disconnected and the out-of-plane restraints remained attached. The schematic diagram and a picture of the full test setup is shown in Fig. 2(a) and (b).

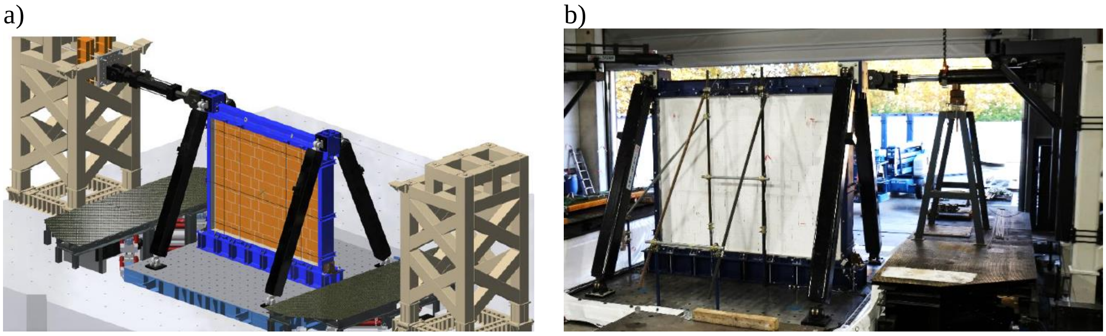

Figure 2. a) Schematic diagram of the test setup; b) actual configuration

The response of the entire specimen, i.e., the structural frame and the infill panel, was measured during the in-plane and out-of-plane tests. For the pseudo static cyclic in-plane tests, linear transducers were installed as shown in Fig. 3 to measure the applied displacements and the consequent drift. During dynamic tests, the out-of-plane accelerations were recorded through accelerometers placed along the length at mid height and along the height at centre as shown in Fig. 4(a). The out-of-plane displacements were monitored through an optical acquisition system with markers (Fig. 4(b)) and high-resolution infrared cameras.

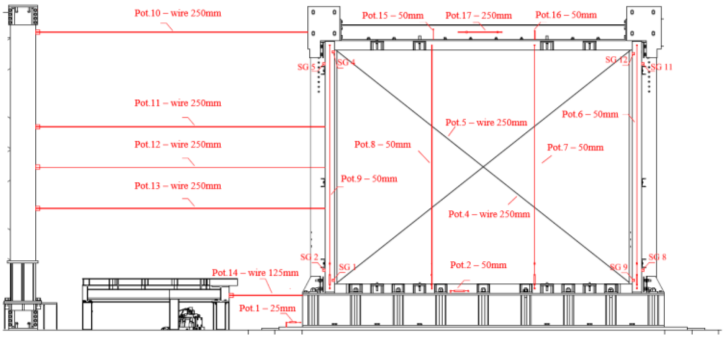

Figure 3. Instrumentation installed for the in-plane tests

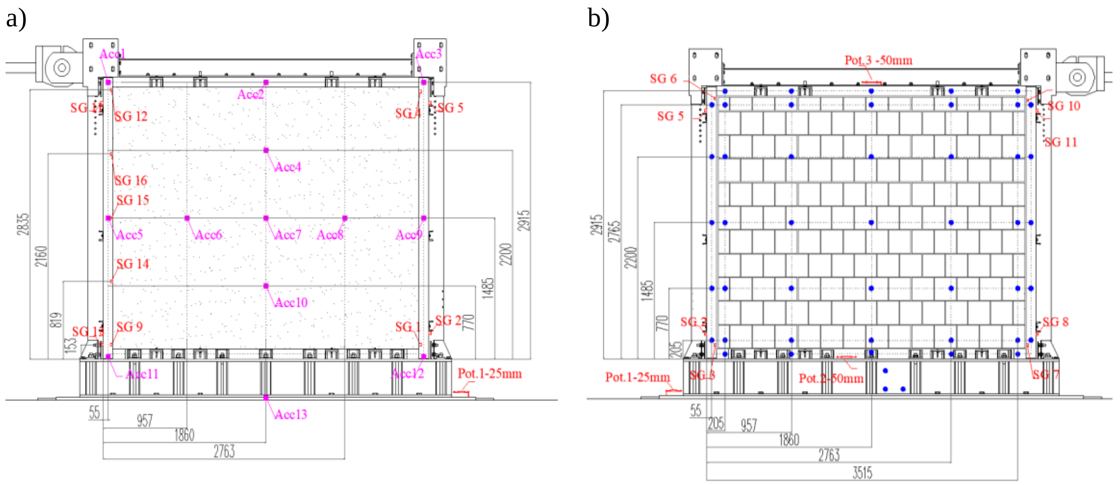

Figure 4 The layout of a) accelerograms; b) optical markers for the out-of-plane tests

2.4 Loading Protocol

The in-plane static cycles were applied with increasing target drift levels, and the cycles were repeated three times for each drift level. It should be noted that before the tests on the infilled specimens, all the bare frames were subjected to a maximum drift of 1.5%, which was the expected maximum drift for the infilled specimen. By subjecting the bare frames to the same drift level prior to tests on infills, it was aimed to bring all the bare frames to the same level of damage and thereby stiffness, ensuing a similar performance among them during the subsequent tests on infills. As will be elaborated later on with force-displacement curves obtained, it is important to emphasize that all the bare frames remained within the elastic region during the tests.

Then, the infills been constructed within the frame and the in-plane tests were performed on specimens T1, T2 and T3. Specimen T1 was loaded till its ultimate conditions were reached, incrementally increasing the target nominal drift up to 1.0%. The specimens T2 and T3 were stopped at nominal drift levels of 0.3% and 0.65% respectively, to be followed by out-of-plane tests to study the influence of the different levels of in-plane damage on the out-of-plane response.

Out-of-plane dynamic tests were performed on specimens T2, T3, T4 and T5 till the ultimate conditions were reached. The dynamic excitations were applied through the shake table in the out-of-plane direction only. The signals have been applied in the form of a target spectrum adapted from the Required Response Spectrum (RRS) method given in [22], with an incrementally increasing peak floor acceleration (PFA). The frequency range of the plateau of the target spectrum obtained with the RRS method was modified according to the methods proposed in [23], considering floor response spectra (FRS) from a series of nonlinear dynamic analyses performed on infilled frames with different heights (more details of the nonlinear dynamic analysis can be found in [24]). A summary of the loading protocols for in-plane and out-of-plane tests is presented in Table 1 and 2, respectively.

Table 1 – Summary of the in-plane tests

Nominal drift (%)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.65**	**0.75**	**1.0**
T1	x	x	x	x	x	-	x	x
T2	x	x	x	-	-	-	-	-
T3	x	x	x	x	x	x	-	-

Table 2 – Summary of the out-of-plane tests

Nominal drift (%)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.75	0.80	1.00	1.25	1.50	1.80	2.00	2.25	2.50
T2	x	x	x	x	x	-	-	x	-	x	x	x	x	x	x	x
T3	x	x	x	x	x	-	-	x	-	x	x	x*	-	-	-	-
T4	x	x	x	-	x	-	-	x	-	x	x	x	x	-	-	-
T5	x	x	x	x	x	x	x	-	x	x	-	-	-	-	-	-

*Test repeated 3 times

3. Results

The experimental results will be presented in terms of the damage propagation in the infills in all tests, force-displacement response of in-plane tests, and the recorded displacements and accelerations in the out-of-plane tests.

3.1 In-plane response

The specimen T1 has been subjected to increasing in-plane cyclic drifts until ultimate conditions were reached. According to the level of damage experienced by the infill panel with increasing drift, damage limit states have been defined as operational, damage, life safety and ultimate. The horizontal boundaries were the first to crack at the starting nominal drift of 0.1%, although rather sporadically, followed by the fist main diagonal crack and continuation of the cracks along the boundaries at 0.2% nominal drift. At 0.3% it was deemed that the operational limit state has been reached, with two more diagonal cracks appearing along with a horizontal cracking zone above the 2nd course, accompanied by slight spalling of the plaster around some cracks. The damage state observed on each side of the specimen, i.e., bare and plastered, at 0.3% nominal drift is illustrated in Fig. 5(a) and (b). When the nominal drift was increased to 0.4%, large pieces of plaster was spalling around the horizontal crack and new diagonal cracks appeared as depicted in Fig. 5(c) and (d), the damage limit state was pertinent in this stage. Cracking of unit face shells, spreading and widening of the diagonal and horizontal cracks, and more spalling of plaster were observed at a nominal drift of 0.5%, which exacerbated at 0.75% with new cracks along bed joints, and pieces of units entirely detaching from the infill in the cracked zone. Therefore, life safety limit state was assumed at 0.75% nominal drift, and the damage state is illustrated in Fig. 5(e) and (f). The ultimate limit state was reached at 1.0% nominal drift, the infill having lost its robustness by losing most of the plaster and units around the main cracks. The level of damage was similar in specimens T2 and T3 for each level of nominal drift, the only difference was that the horizontal cracking zone was around the mid height of the wall, which is more conforming in a panel fully adhered to the frame. In specimen T1, it is likely that a local weakness shifted the damage to the lower courses.

The force-displacement cycles of specimen T1 are reported along with the backbone curves in Fig. 6(a). It should be noted that the backbone curve for the infill panel is derived by subtracting the response of the bare frame from the full response of the frame and the infill. As it was mentioned previously, the response of the bare frame remained elastic at all drift levels considered. A comparison of the backbone curves of the infill panels (only) for specimens T1, T2 and T3 is presented in Fig. 6(b).

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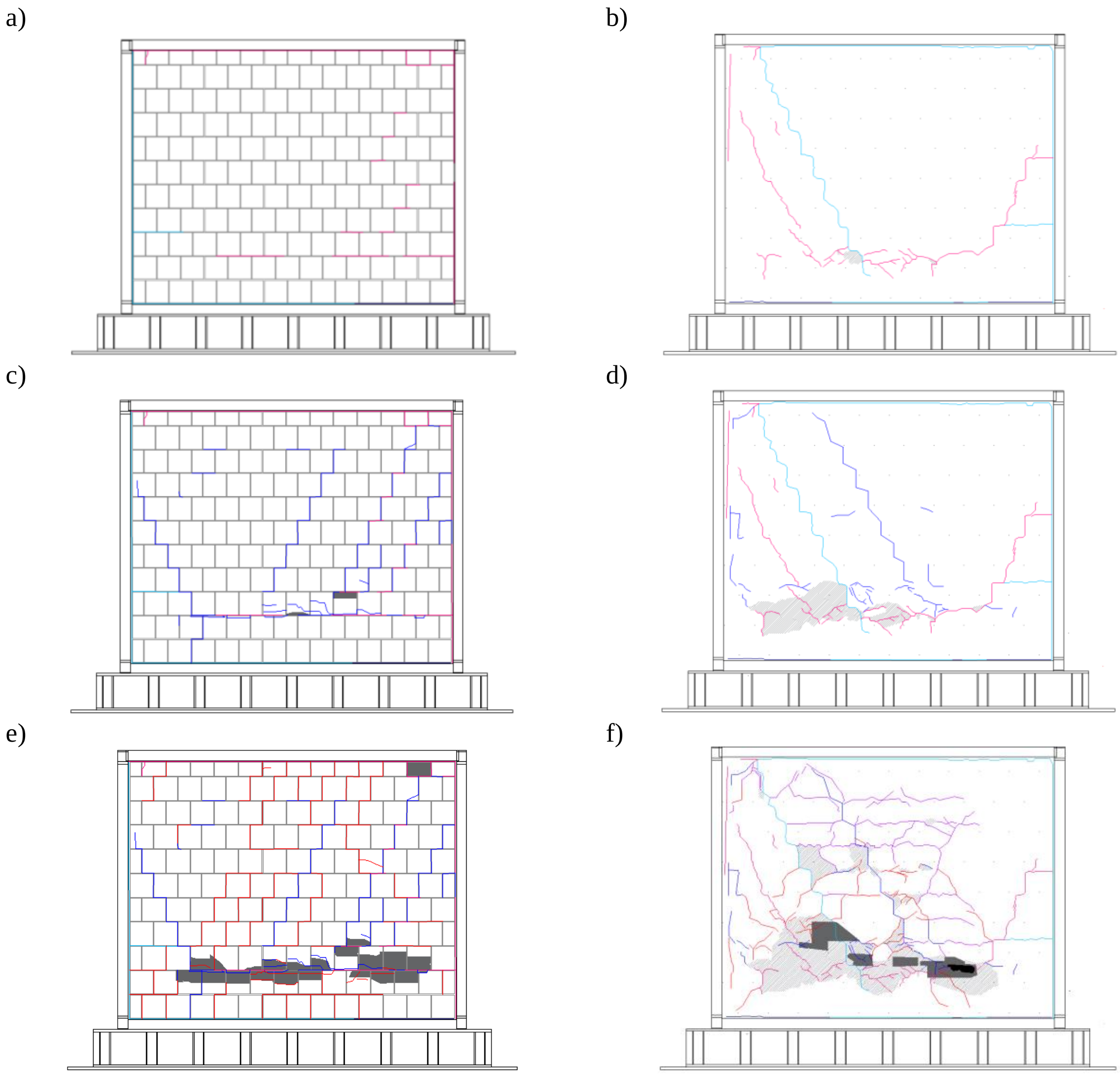

Figure 5. The damage state of the infill (a) bare face at 0.3% (b) plastered face at 0.3% (c) bare face at 0.4% (d) plaster face at 0.4% (e) bare face at 0.75% (f) plaster face at 0.75% drifts. (grey shade represent damage in the plaster, black shade stands for damage in the clay unit)

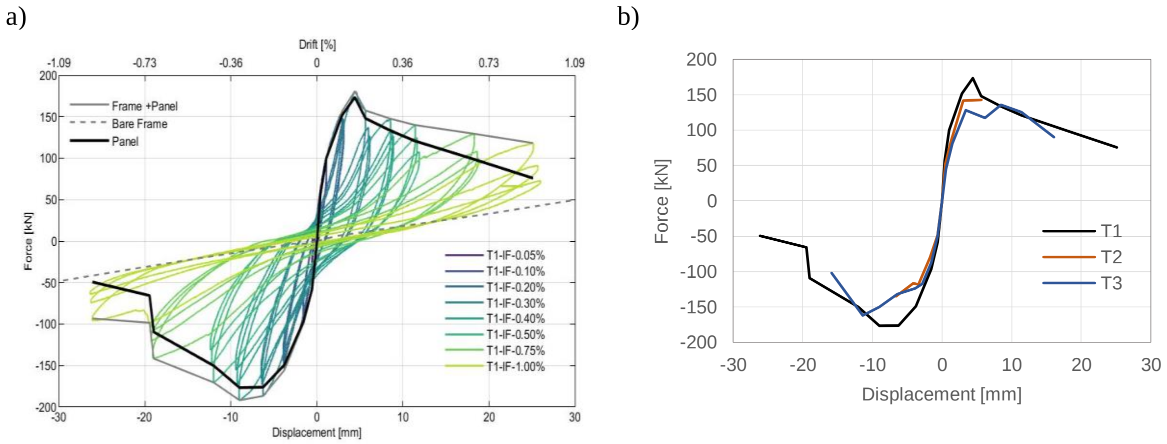

Figure 6. (a) The force-displacement cycles of specimen T1 (b) Force-displacement backbone curves derived for infill panels

3.2 Out-of-plane response

Specimens T2, T3, T4 and T5 have been subjected to out-of-plane acceleration signals with increasing amplitude till ultimate capacity was reached. Specimens T2 and T3, having previous in-plane damage (at drift levels 0.3% and 0.65%) suffered the most damage and then reached collapse at nominal PFA 2.5g and 1.5g (recorded PFA of 2.75g and 1.69g), respectively. The level of in-plane damage greatly influenced the out-of-plane capacity of the infills, with the maximum acceleration recorded at the centre of the panel reducing by 42% for the specimen T3 with respect to specimen T2. The existing damage caused by in-plane cycles propagated during the out-of-plane shaking, with widening of existing cracks, spalling and expulsion of plaster and units in the damage zone at mid height and at the top boundary. As example, the damage state succeeding the in-plane cycles and before the dynamic tests of T3, compared with the damage state attained before out-of-plane collapse is presented in Fig. 7.

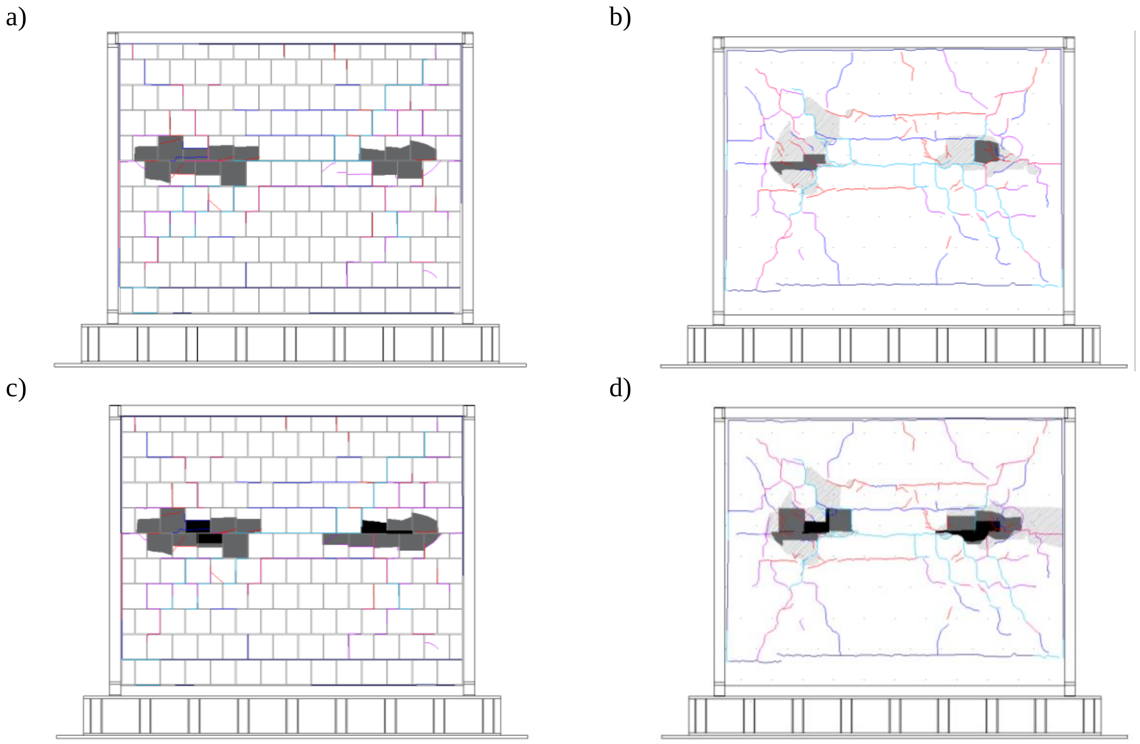

Figure 7. Damage state attained in specimen T3 after in-plane drift of 0.65% (a) bare face (b) plaster face and before collapse as seen on (c) bare face (d) plaster face

Without having any previous in-plane damage, specimen T4 was more robust and stronger, and did not exhibit any significant damage till 1.8g nominal PFA or reach collapse. The specimen presumably exhibited a double bending/arching mechanism, which is also perceived in the acceleration and displacement along the length at mid-height and along the height at centre profiles at maximum response with increasing PFAs (Fig. 8 and 9).

The behaviour of specimen T5 differed from the other specimens due to having free vertical edges. The specimen was subjected to only out-of-plane excitation without any previous in-plane damage, and the maximum acceleration on the panel was reached at the centre at a nominal PFA of 0.6g (recorded PFA 0.7g) without collapse. The behaviour of the panel during the tests resembled a single vertical bending/arching behaviour, also inferred from the damage pattern consisting of horizontal cracks along the top and bottom edges and along the bed joints above 6th and 7th courses (close to mid height), spanning the whole length of the wall. Towards the latter ground motions with higher intensities, the damage to the top boundary intensified, resulting in a gap between the top edge and the frame, however the arching mechanism could still be observed when the infill boundary came into contact with the beam surface. The described behaviour could also be exemplified by the acceleration and displacement profiles measured along the height at mid length (Fig. 10(a) and (b)). The shape of the acceleration profile is a noteworthy result, indicating that the applied horizontal load on the panel is not uniform but more triangular. The triangular shape of acceleration profiles was observed in all specimens, in both directions (along length and height) for double bending specimens (T2, T3 and T4), and along the height in specimen T5.

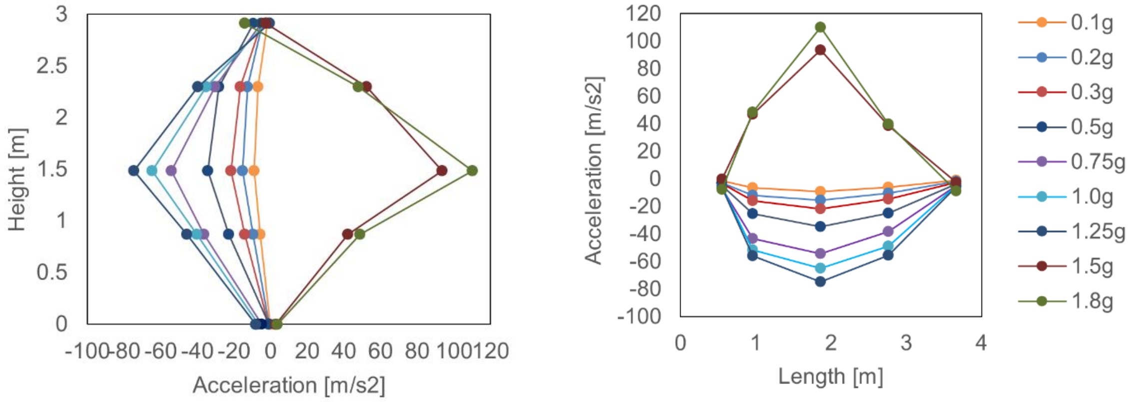
a) b)

Figure 8. Acceleration profiles recorded on infill T4 (a) along height at centre (b) along length at mid-height

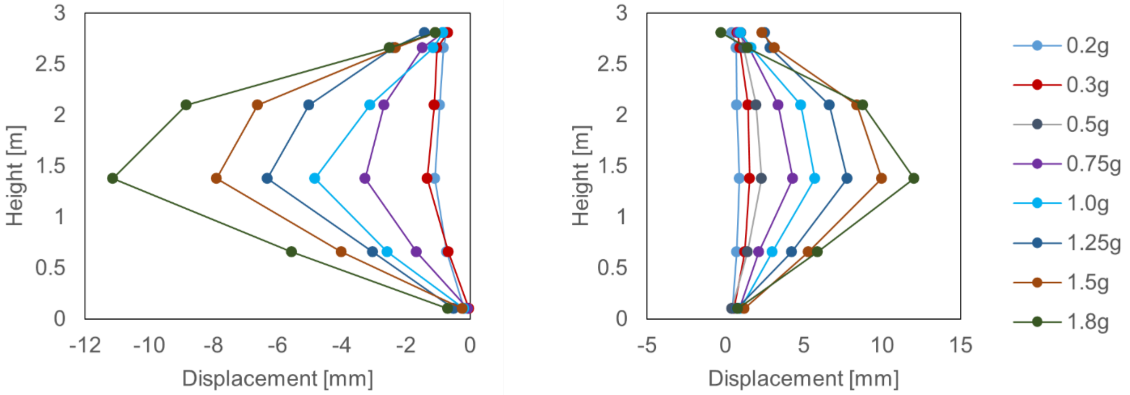
a) b)

Figure 9. Displacement profiles recorded on infill T4 along height at centre (a) negative direction (b) positive direction

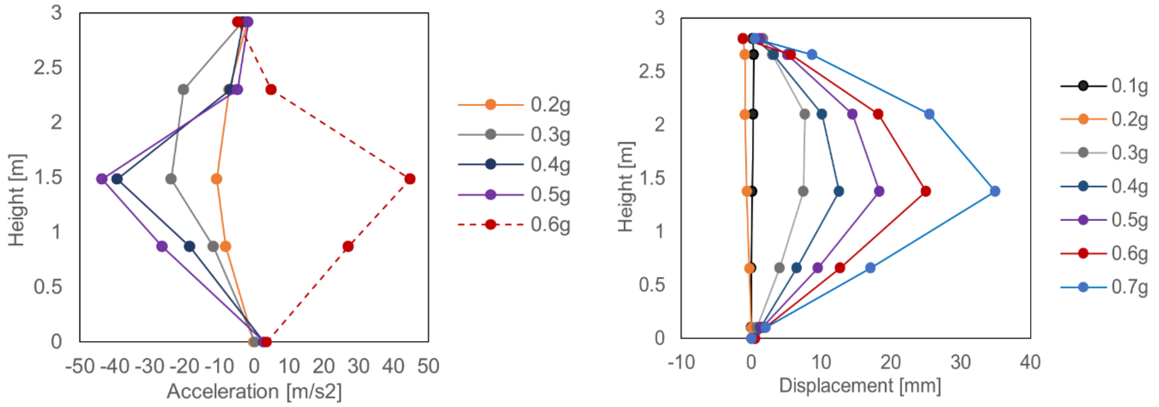
a) b)

Figure 10 (a) T5 acceleration profile along the height (dashed line extrapolated profile from previous based on measured max acceleration at centre (b) Displacement profiles along height at maximum response in the positive direction

4. Discussion

The influence of the level of in-plane damage and the boundary conditions on the out-of-plane capacity of infills has been substantiated through the experimental results. Such effects could be further analysed through comparisons of the maximum accelerations recorded during the dynamic tests. In Fig. 11(a), the maximum recorded accelerations at the centre of the panel when the panel response was maximum (except for a few instances, the maximum response was always observed at the panel centre) with respect to the recorded PFA of the ground motion are presented, and the corresponding amplifications, i.e., the ratio of the maximum acceleration to the recorded PFA, are delineated in Fig. 11(b). The maximum accelerations in T4 are increasing almost linearly with the PFA, which can also be seen from the amplification, which fluctuates around a mean value of 5.85 not exceeding a variation of 5% from the mean. It should be kept in mind that the capacity has not been reached for T4, and at this stage no evident damage has been observed. On the other hand, specimens T2 and T3 reached collapse, and the drastic reduction of the capacity in the specimen with higher in-plane damage (T3) is prominent in terms of accelerations, reaching collapse much earlier at a lower PFA than the specimen with the lower damage (T2). Even though the amplification is also generally higher in the specimen T2 than T3, the variation is ambiguous with sudden drops and increases, while the variation is lower for specimen T3. It is also evident that the behaviour of specimen T5 with vertical bending is highly contrastive when compared to the fully supported specimens. Similarly, the maximum displacement at the centre of the panel is examined in Figure 12, and the results are consonant with the observations made hitherto. The reduction in stiffness is clearly observed decreasing from the undamaged specimen to the most damaged specimen, and the highest displacements are exhibited by the specimen with free vertical edges. Furthermore, from the damage patterns examined in the infills in the previous section, it could be inferred that the specimens fully connected to the surrounding frame exhibited a double bending/arching mechanism, and the specimen only connected to the top and bottom beams displayed single vertical bending/arching mechanism, when subjected to out-of-plane motions.

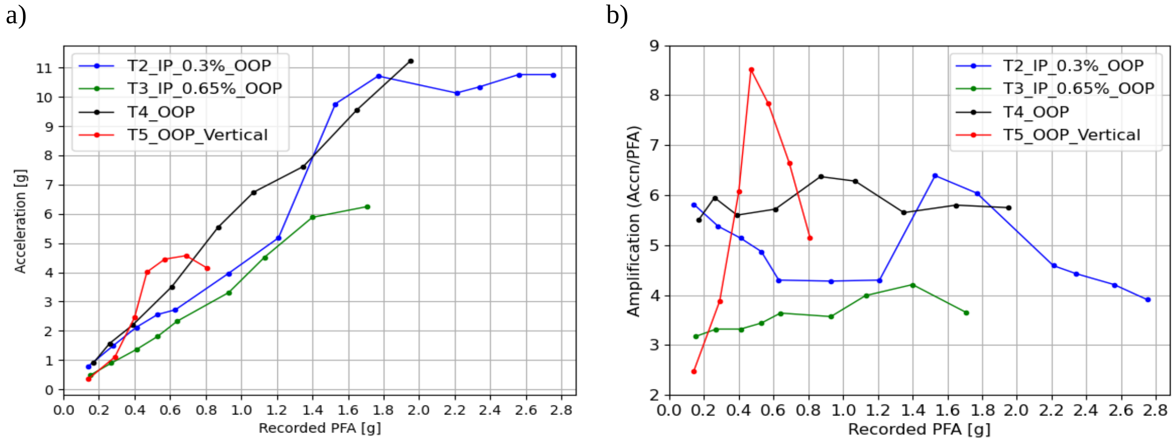

Figure 11. (a) Max acceleration at the centre vs recorded PFA (b) corresponding amplification at the centre with respect to recorded PFA

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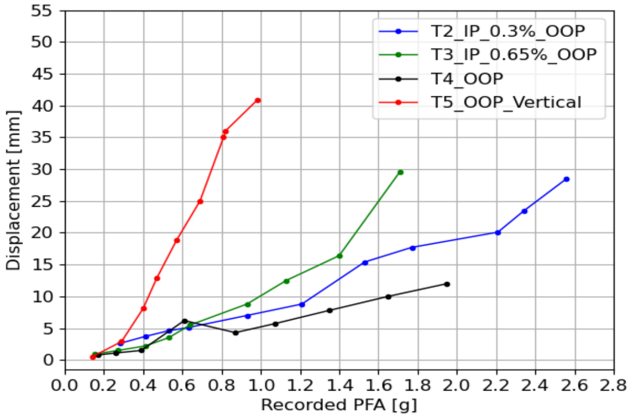

Figure 12. Max displacement at the centre vs recorded PFA

5. Conclusions

The seismic behaviour of an existing weak masonry infill typology has been investigated through an extensive experimental campaign, and the results from the first phase of the program have been presented and discussed. The first phase involved tests on five full scale masonry infill specimens surrounded by steel/concrete composite frames designed to simulate the behaviour of a r.c. existing structure. The in-plane behaviour, out-of-plane behaviour and the in-plane/out-of-plane interaction of infills fully adhered to the frame have been explored, and the out-of-plane behaviour of a vertically spanning specimen has been examined. The main observations from the test series are summarized as follows.

1. An undamaged infill possesses a considerable out-of-plane capacity, which drastically reduced with the presence of previous damage due to in-plane loading.

2. The boundary conditions of the panel significantly influence the out-of-plane response. The vertical spanning infill had a significantly lower stiffness compared to the fully supported infill exhibiting high displacements and had a lower out-of-plane capacity.

3. The distribution of accelerations is not uniform over the panel but closer to being triangular. In double bending specimens the triangular distribution was two-way, and in the single bending specimen the distribution was observed along the vertical.

In the following phases of the experimental campaign, the seismic response of specimens with a thin gap at the top will be explored, as well as the influence of presence of openings on the seismic behaviour of infills.

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References

[1] Braga, F., Manfredi, V., Masi, A., Salvatori, A., Vona, M. (2010) Performance of non-structural elements in RC buildings during the L'Aquila, 2009 earthquake, *Bulletin of Earthquake Engineering*, **9**(1), pp. 307–24.

[2] Hermanns, L., Fraile, A., Alarcón, E., Álvarez, R. (2012) Performance of masonry buildings during the 2011 Lorca earthquake, *Proceedings of 15th World Conference on Earthquake Engineering*, Lisbon, Portugal.

[3] Rossi, A., Morandi, P., Magenes, G., (2021) A novel approach for the evaluation of the economical losses to seismic actions on RC buildings with masonry infills, *Soil Dynamics and Earthquake Engineering*, **145**, pp. 106722, doi 10.1016/j.soildyn.2021.106722.

[4] Dawe, J. L., and Seah, C.K. (1989) Behaviour of masonry infilled steel frames, *Canadian Journal of Civil Engineering*. **16**(6), pp. 865-876. https://doi.org/10.1139/l89-129.

[5] Mehrabi, A. B., Benson Shing, P., Schuller, M. P., & Noland, J. L. (1996) Experimental Evaluation of Masonry-Infilled RC Frames, *Journal of Structural Engineering*, **122**(3), pp. 228–237.

[6] Morandi, P., Hak, S., Magenes, G., (2018) Performance-based interpretation of in-plane cyclic tests on RC frames with strong masonry infills, *Engineering Structures*. **156**(1), pp. 503–521. https://doi.org/10.1016/j.engstruct.2017.11.058.

[7] Abrams, D. P., Angel, R., Uzarski, J. (1996) Out-of-Plane Strength of Unreinforced Masonry Infill Panels, *Earthquake Spectra*, **12**(4), pp. 825–844.

[8] Furtado, A., Rodrigues, H., Arede, A., Varum, H. (2016) Experimental evaluation of out-of-plane capacity of masonry infill walls, *Engineering Structures*, **111**, pp. 48-63.

[9] Milanesi, R. R., Morandi, P., Hak, S., Magenes, G. (2021) Experiment-based out-of-plane resistance of strong masonry infills for codified applications, *Engineering Structures*, **242**, p. 112525.

[10] Angel, R., Abrams, D. P., Shapiro, D., Uzarski, J., Webster, M. (1994) *Behavior of reinforced concrete frames with masonry infills*, University of Illinois Engineering Experiment Station, College of Engineering, University of Illinois at Urbana-Champaign.

[11] da Porto, F., Guidi, G., Dalla Benetta, M., Verlato, N. (2013) Combined in-plane/out-of-plane experimental behaviour of reinforced and strengthened infill masonry walls, *Proc. 12th Canadian Masonry Symposium*, Vancouver, Canada

[12] Ricci, P., Di Domenico, M., Verderame, G. M. (2018) Experimental assessment of the in-plane/out-of-plane interaction in unreinforced masonry infill walls, *Engineering Structures*, **173**(1), pp. 960-978, doi 10.1016/j.engstruct.2018.07.033.

[13] Morandi, P., Hak, S., Milanesi, R. R., Magenes, G. (2022) In‐plane/out‐of‐plane interaction of strong masonry infills: From cyclic tests to out‐of‐plane verifications, *Earthquake Engineering Structural Dynamics*, **51**(3), pp. 648‐672.

[14] CEN (2004) *Eurocode 8 - Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings*, EN 1998-1, European Committee for Standardisation, Brussels, Belgium.

[15] NTC (2018) Istruzioni per L'applicazione Delle "*Nuove norme Tecniche per le Costruzioni" di Cui al Decreto Ministeriale 17 Gennaio 2018*, Ministero delle Infrastrutture e dei Trasporti, Circolare 20 Febbraio 2018, Italy. (In Italian)

[16] EN 772-1 (2015) *Methods of test for masonry units - Part 1: Determination of compressive strength*, Brussels, Belgium: CEN.

[17] EN 1015-11 (2019) *Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar*, Brussels, Belgium: CEN.

[18] EN 1052-1 (2001) *Methods of test for masonry - Part 1: Determination of compressive strength*, Brussels, Belgium: CEN.

[19] ASTM E519-02 (2017) *Test Method for Diagonal Tension (Shear) in Masonry Assemblages*, ASTM International.

[20] EN 1052-3 (2001) *Methods of test for masonry – Part3: Determination of initial shear strength*, Brussels, Belgium: CEN

[21] EN 1052-2 (2016) *Methods of test for masonry - Part 2: Determination of flexural strength*, Brussels, Belgium: CEN.

[22] AC 156 (2010) *Acceptance criteria for seismic certification by shake-table testing of nonstructural components*, International Code Council. (n.d.).

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[23] Milanesi, R. R., Morandi, P., Dacarro, F., Albanesi, L., Magenes, G. (2017) In-plane cyclic and out-of-plane dynamic testing procedures for infilled RC frames, *Proc. 7th International Conference on Advances in Experimental Structural Engineering*, Pavia, Italy.

[24] Hak, S., Morandi, P., Magenes, G., Sullivan. T.J. (2012) Damage control for clay masonry infills in the design of RC frame structures, *Journal of Earthquake Engineering*, **16**(1), pp. 1-35.