INFILL MASONRY WALL CONTRIBUTION TO STRUTURAL ROBUSTNESS OF RC FRAMES WHEN SUBJECTED TO AN EXTREME EVENT – column loss scenario:

AN EXPERIMENTAL STUDY

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ABSTRACT

In spite of the continuous evolution of engineering, structural collapse is still a reality, usually triggered by a relatively small damage that causes subsequent failures of the adjoining structural elements, leading to total or partial collapse of the structure. In the last 50 years, with Ronan Point Building partial collapse (1968) and later with the total collapse of the World Trade Center (2001), both considered disproportional to the original damage, the interest in conceiving robust structures increased. Previous studies revealed the influence of non-structural masonry walls in the behavior of framed structures, showing that, in the occurrence of an extreme event, like a column failure, infill masonry walls can help maintaining structural integrity and reduce the probability of progressive collapse. Therefore, it was concluded that masonry walls can improve structural robustness by creating alternative load paths through compressive struts in the infill wall after a column loss. In the present work, experimental tests are carried out on a real-scale reinforced concrete one story one bay frame in order to evaluate the impact of the introduction of a thermal masonry wall with joint reinforcement on its behavior. The results obtained from tests carried out with two other types of masonry are also analyzed: traditional masonry wall and thermal masonry wall without joint reinforcement. The results show that the introduction of a masonry wall in a reinforced concrete frame increases its initial stiffness by 160%. In the case of a traditional masonry wall, there is no increase in the resistant capacity of the structural system, while if a thermal masonry wall is considered there is an increase of 20%. The addition of wall joint reinforcement increases the ductility of the masonry wall and consequently of the structural system.

Keywords: structural robustness, reinforced concrete frame, masonry wall, traditional brick, thermal and structural brick, joint reinforcement.

1 Introduction

Structural robustness is an essential concept in civil engineering that has been highly investigated in the last five decades, motivated by severe events that resulted in a large number of human losses, such as the collapse of the Ronan Point Building in 1968, Bad Reichenhall arena in 2006 and World Trade Center in 2001, among others. In these cases, the consequences were considered disproportional to the original damage, raising questions about structural safety to progressive collapse and leading to a higher concern in conceiving robust structures.

Most of collapses are related with unexpected loads, design mistakes, poor construction, deterioration or weak maintenance, making it hard to predict those incidents through current design codes [3].

In the last few decades growing interest in the effects of infill walls on the behavior of frames has been recorded. It is known that the infill panels, usually considered as non-structural elements, have a significant effect on the global seismic response of framed structures. In particular, if infill walls are regularly distributed both in plant and height, they can increase stiffness and resistance of the structure [1].

More recently, the contribution of infill walls to RC framed structures' behavior under vertical action has been widely investigated by many authors [2, 6, 7], revealing that current design practices that neglect infill walls contribution lead to inaccuracy in structural stiffness, capacity and ductility.

An extreme event such as a local impact, an explosion or an earthquake, can cause severe damage in one or more columns, leading to partial or total collapse of a structure. Therefore, downward displacement resultant from a damaged column can distort a bare RC frame resulting in bending that exceeds its capacity, leading to failure. In the case of an infilled frame, the infill wall can interact with the surrounding frame, restraining its deformation, increasing its stiffness and resistance and redistributing loads to nearby elements, avoiding collapse by providing an alternative secure load path [2].

Helmy et al. [6] conducted a numerical study carried out for a typical ten-story reinforced concrete framed structure considering different column removal case scenarios, having concluded that the bare frame without infill walls would partially collapse, once beams would behave differently from what they were designed for.

Later, numerous authors [2, 7], conducted experimental tests comparing the performance of bare and infilled RC frames under the loss of a column, concluding that the masonry walls can provide an alternative path to the loads originally supported by the beams. In many cases, the contribution of the masonry walls was proved to be determinant in preventing the collapse of the damaged structure and therefore its contribution should be incorporated in the structural model [2].

In the current study, the role of infilled walls is investigated. In particular, the effect of a thermal brick masonry wall on a single story-single bay RC frame is evaluated in terms of stiffness, strength capacity, ductility and failure mechanism. An experimental program was designed to test the hypothesis that masonry walls can be used to reduce the vulnerability of RC frames to progressive collapse by increasing structural robustness.

2 Experimental program

2.1 Introduction

The research presented here is part of the project "ROBUST BRICK - Use of masonry in improving structural robustness of buildings" [5], which the main objective is to investigate the effect of masonry walls on the structural behavior of RC framed buildings subject to the collapse of vertical elements due to the occurrence of extreme and unpredictable events. In this chapter the experimental methodology developed within the scope of the project and therefore also adopted within the scope of the present work is presented.

The objectives of the "ROBUST BRICK" project [5] were also the study of several parameters related to the composition of masonry walls and their influence on the structural behavior of RC framed structures, among others: type of masonry wall, single or double masonry panels; types of bricks, traditional bricks, or thermal bricks; the effect of vertical reinforcement; continuous and discontinuous joint effects; and the effect of joint reinforcement.

Due to the extension of the objectives proposed by the project, the research presented in this paper is limited to the study of the influence of the thermal brick in comparison with the traditional one, and the study of the effect of the addition of joint reinforcement.

2.2 Specimen description

Experimental tests were conducted in the 1:1 scaled RC frame, designed accordingly to EC2 [4]. Geometric dimensions are shown in **Fig. 1**. The RC frame was overdesigned so that it could be tested with and without infill masonry wall.

The RC frame was produced with a length of 5000 mm and a height of 2550 mm. One of the masonry walls consisted of a double panel with continuous joints and the brick units adopted had 300×200×150 mm on the outer side and 300×200×110 mm on the inner side, with average compressive strength of 2.5 Mpa [5]. The other infill masonry wall consisted of a single panel with discontinuous joints and the brick units adopted had dimensions of 300x190x240 mm, with average compressive strength of 7,3 Mpa [5]. The compressive strength of the concrete was evaluated at 28 days of age obtaining an average compressive strength of 38,8 Mpa [5]. The tensile strength of steel reinforcing bars (rebars) was obtained from uniaxial tensile tests. The average values for the yield stress of the steel bars with 10, 16, and 20 mm diameter were 540, 533, and 618 MPa, respectively and the corresponding values of the average tensile strength for these bars were 570, 640, and 720 Mpa [5].

2.3 Test setup, instrumentation and loading procedure

The RC frame was connected to a reaction wall (B1 and B2) and a reaction slab (B2-C2). Column C2 was also pre-tensioned by four threaded bars, as shown in **Fig. 1**. Column removal is equivalent to a gravitational force applied in the same location. In the present work, due to limitation of space under the RC frame, vertical upward force was applied to the bottom face of the B2-C1 node, using a hydraulic jack in displacement control mode, at a rate of approximately 0.01 mm/min, monitored with a load cell and an LVDT (Linear Variable Differential Transducer), as also shown in **Fig. 1**. In order to measure reinforcement strain, 40 strain gauges were applied on critical predefined cross sections in both beams and columns.

2.4 Test protocol

As already mentioned, the "Robust Brick" project provided for the testing of four RC frames, each one being assigned the study of a typology of masonry wall distinct from the rest. **Table 1** summarizes the testing program foreseen in this project.

The consideration of different types of brick units, as well as the existence or not of a reinforcing layer and the consideration of different types of joints (continuous or discontinuous, with and without joint reinforcement) allow the creation of different scenarios and to compare the influence of the different solutions adopted on the behavior of a RC frame, as well as to concluded whether some oh them may have more advantages than others.

It should be noted that in the course of the "Robust Brick" project, it was not possible to carry out the tests planned for the frame P4, which were carried out under the scope of this work.

Table 1 - *Test program from "Robust Brick" project.*

Prototype	Test	Test description	Masonry wall
P1	P1_EI	*Bare frame test in elastic phase until 30 mm of vertical displacement*	*Double panel traditional brick masonry wall with discontinuous joints (300x200x15mm + 300x200x110mm and 40 mm air space)*
	P1_M	*Infilled frame test until masonry wall failure*	
	P1_BF	*Bare frame test until collapse*	
P2	P2_EI	*Bare frame test in elastic phase until 30 mm of vertical displacement*	*Double panel traditional brick masonry wall with discontinuous joints (300x200x15mm + 300x200x110mm and 40 mm air space) with reinforced mortar layers*
	P2_M	*Infilled frame test until masonry wall failure*	
	P2_BF	*Bare frame test until collapse*	
P3	P3_EI	*Bare frame test in elastic phase until 30 mm of vertical displacement*	*Thermal brick masonry wall (300x190x240mm) with discontinuous joints spaced by 80 mm*
	P3_M	*Infilled frame test until masonry wall failure*	
	P3_BF	*Bare frame test until collapse*	
P4	P4_EI	*Bare frame test in elastic phase until 30 mm of vertical displacement*	*Thermal brick masonry wall (300x190x240mm) with discontinuous joints reinforced with Murfor Compact I truss and spaced by 80 mm*
	P4_M	*Infilled frame test until masonry wall failure*	
	P4_BF	*Bare frame test until collapse*	

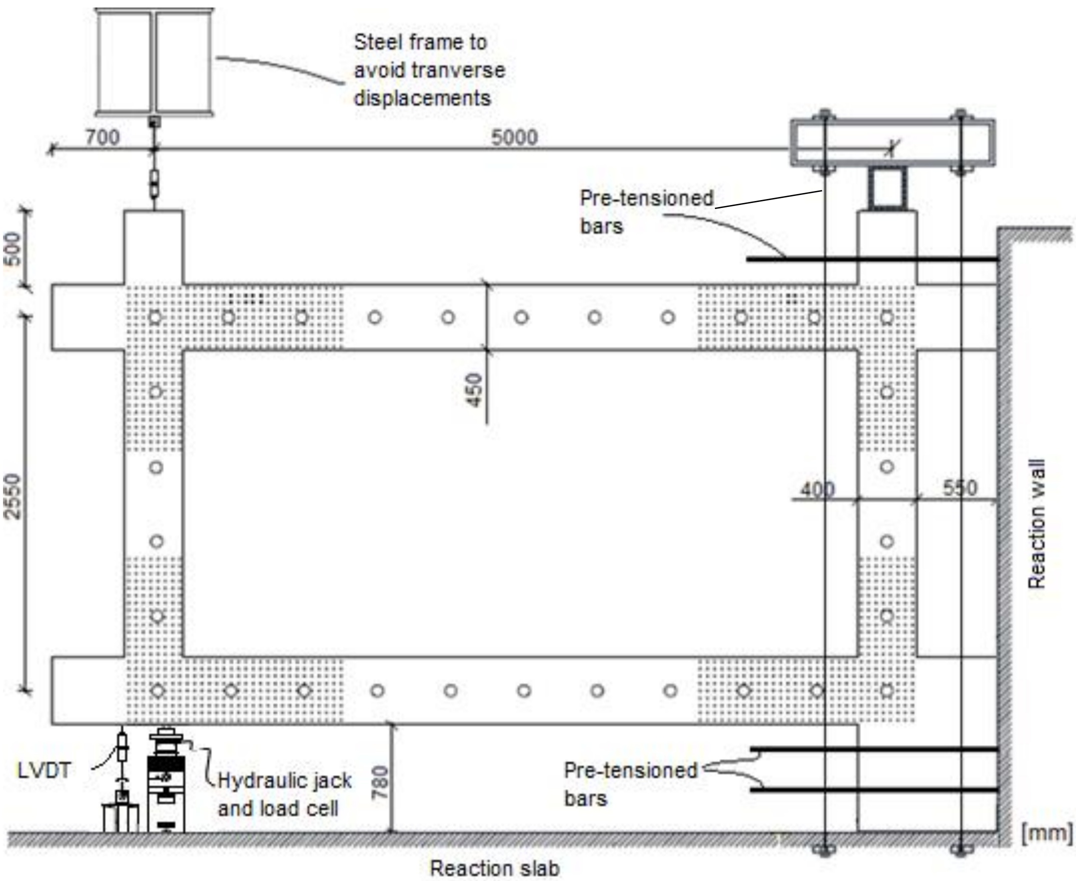


Fig. 1 – *RC frame geomety and intrumentation (dimensions in mm).*

3 Experimental results and discussion

3.1 The bare frame

Fig. 2 shows the load-displacement diagrams obtained using the load cell and LVDT "L1" during the tests performed in the bare frame P4. In the first test, P4_El, the maximum displacement imposed was only 30 mm, the main goal being, as it was mentioned, to analyze the behavior of the bare frame in elastic range, before yielding.

The analysis of P4_El test in **Fig. 2** reveals a reduction of the initial stiffness for a load of 50 kN and for a displacement imposed of about 10 mm, corresponding to the appearance of the first cracks in the section F of the lower beam closer to the reaction wall. The bare frame was unloaded after a 30 mm imposed displacement and no extensions beyond yielding of the rebars were recorded. In the second test of the bare frame, P4_BF, the non-linear behavior, the formation of the failure mechanism and the ductility of the RC frame were analyzed. It should be noted, however, that, between the two tests, the test in which a thermal masonry wall with joint reinforcement is considered was performed, the results of which are presented and discussed below. **Fig. 2** shows, however, that during this test the damages produced in the RC frame will have been marginal, since the stiffness of the load-displacement diagram corresponding to the test of the RC frame under elastic range (P4_El) after the appearance of the first cracks is similar to stiffness of the equivalent diagram during the initial loading phase of the P4_BF test, where the bare frame was test up to failure. **Fig. 2** also shows that in the P4_BF test, the crack propagation phase occurs up to 90 mm of vertical displacement corresponding to a load of 250 kN. Thereafter a significant loss in stiffness is observed due to the yielding of the reinforcement rebars in the more stressed sections, and to the development of the collapse mechanism. This phase extends until a displacement imposed of about 125mm and an applied load of 280 kN. Subsequently, the ductility of the bare frame was exploited and a maximum displacement of 240 mm was imposed, limited by the available space between the top of the frame column and the bottom of the beam of the lateral steel frame. During this phase, it was possible to reach a maximum load of 290 kN, taking advantage of the hardening of the steel, and simultaneously the location of the plastic deformations was observed in the sections where plastic hinges were formed.

Fig. 3 shows a photograph of the bare frame at the final instants of the test, right before unloading. In **Figs. 4 (a)** to **(d)** it is possible to observe the failure mechanism and the location of cracks in the most deformed sections, which occured in the extreme sections of the beams.

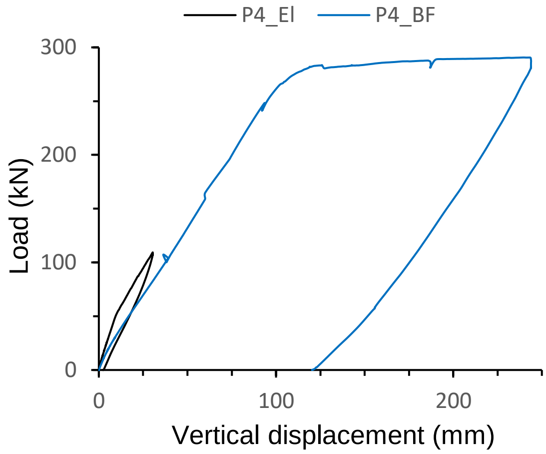


***Fig. 2** - Load vs. vertical displacement curves.*

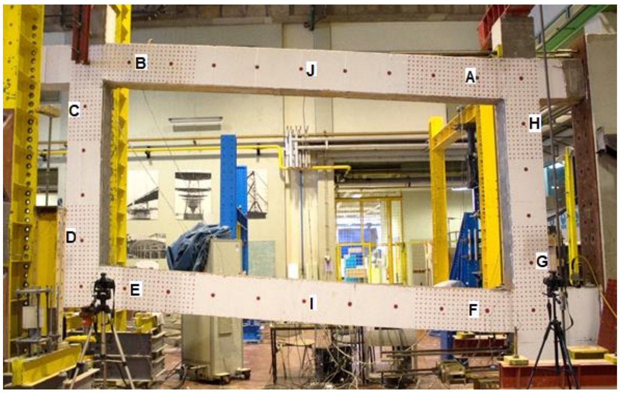


***Fig. 3** - Bare frame experimental test at maximum displacement.*

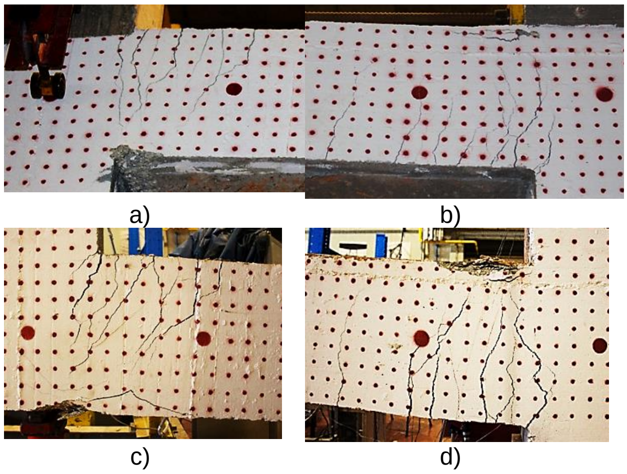


***Fig. 4** - Visible cracks in a) upper left corner, b) upper right corner, c) bottom left corner and d) bottom right corner of the bare RC frame.*

3.2 The effect of an infill traditional brick masonry wall (frame P1)

In **Fig. 5** the load-displacement diagrams obtained during the P1 frame tests are presented under the following conditions: (i) bare frame, in elastic range, up to a vertical displacement of 30 mm (P1_El); (ii) with the frame infilled with a traditional double masonry wall, loaded until the failure of the masonry wall (P1_M); (iii) bare frame up until its failure (P1_BF). The comparison between the curves presented in **Fig. 2** and **Fig. 5**, related to the tests under conditions (i) and (iii), allows us to conclude that the overall behavior of the bare frames P1 and P4, i.e. without a masonry wall, is very similar, the former developing, like the latter, a collapse mechanism consisting of the formation of plastic hinges in the sections closest to the compressed beam-column nodes. The maximum load recorded during the test P1_BF was 290 kN, achieving a maximum displacement of 235 mm, again limited by the space available between the RC frame and the steel frame.

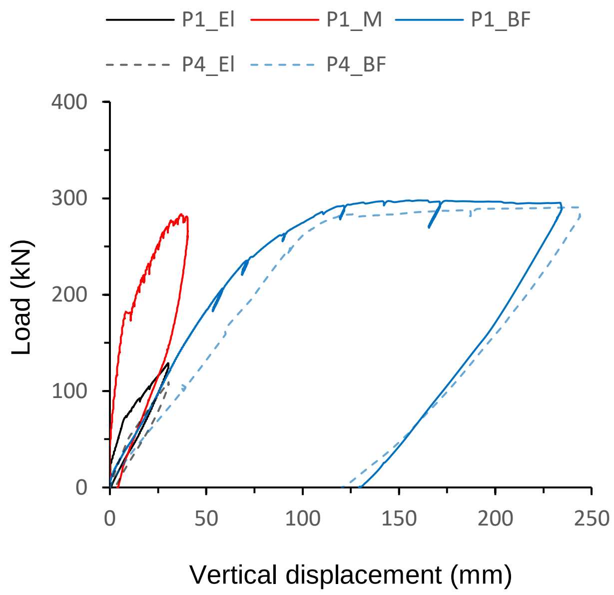


Fig. 5 *- Load vs. vertical displacement curves.*

Analyzing now the curve P1_M in **Fig. 5** and comparing it with the others, it is observed that the initial stiffness of the structural system (frame/wall) is significantly higher (about 160%) compared to that of the bare frame, even before the occurence of the first crack. In fact, for a displacement of 10 mm, a load of 180 kN was registered in the P1_M test, 2,6 times higher compared to the test of the bare frame. However, this increase in stiffness is shown to be slightly lower than the ones recorded in the experimental tests performed under similar conditions by Brodsky and Yankelevsky (2017), of 208%.

The same curve P1_M also shows that for a test load of 180 kN, there is an instantaneous increase in displacement (from 6 mm to 12 mm), without increasing the test load in this process. This corresponds to the formation of the first cracks in the masonry wall and the beginning of the formation of the compressive strut. It is observed that from this moment the stiffness of the structural system decreases, remaining, however, higher than that of the bare frame in the cracking propagation phase in the P1_BF test. For an imposed displacement of 6 mm, the stiffness of the structural system in P1_M test begins to decrease rapidly due to the degradation of the resistant capacity of the masonry wall, leading to the crushing of the the latter for a vertical displacement of 40 mm and reaching a maximum load of 280 kN.

Fig. 6 shows three photographs recorded at the end of the P1_M test, making it possible to observe the compression diagonal strut that developed in the masonry wall and the occurrence of the crushing of the latter in the upper right corner next to the reaction wall (see **Fig. 7 (b)**).

The distortion of the frame leads to compression of the masonry wall resulting in a diagonal compression strut joining opposite corners of the frame allowing forces to be transmitted along the masonry wall and the detachment of the wall-frame interface in the non-compressed corners. When the capacity of the masonry is exceeded, a diagonal crack is formed that runs through the whole height of the wall, with the load being transmitted by the intact part of the masonry wall.

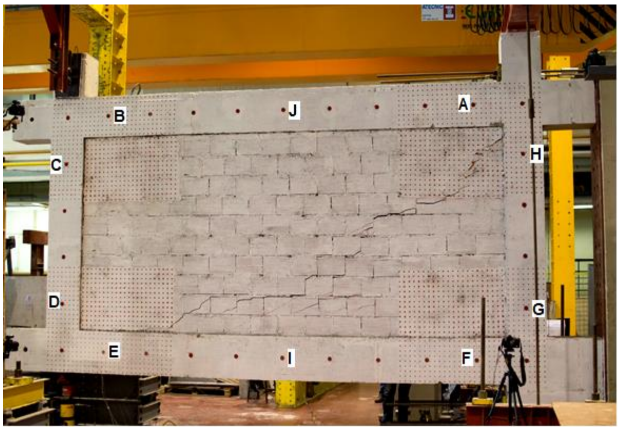
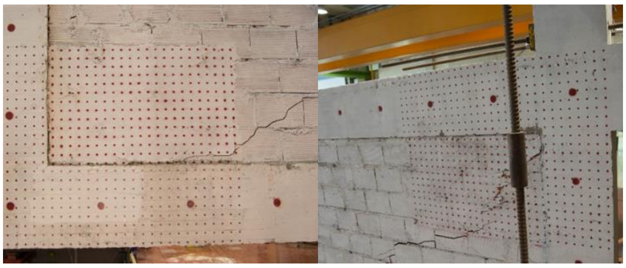


Fig. 6 *- Infilled frame test with traditional brick masonry wall at maximum displacement.*



a) b)

Fig. 7 *- Crack pattern of the masonry wall in a) bottom left corner and in b) upper right corner.*

3.3 The effect of a thermal brick masonry wall (frame P3)

Fig. 8 shows the load-displacement diagrams related to the frame P3 tested under similar conditions to those of the frame P1. It should be noted that in this case, between the two tests performed in the bare frame (P3_El and P3_BF), the frame was filled and tested with a thermal masonry wall with discontinuous joint. The analysis of the curves related to the tests of the bare frame allow us to conclude once more about the similarity between the overall behavior of the prototypes P3 and P1, and therefore of the prototype P4. Therefore, it can be conclude that the differences in the behavior exhibited by the frames during the tests of the frames infilled with the masonry walls can be explained based on their typologies.

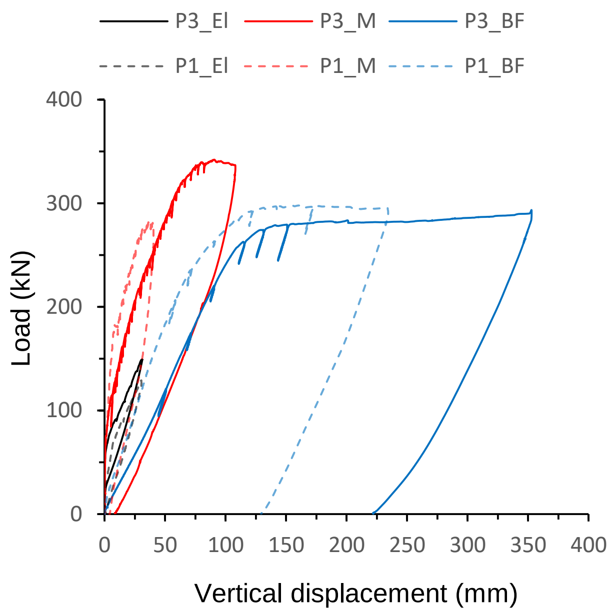


Fig. 8 *- Load vs. vertical displacement curves.*

The analysis of the curve P3_M in **Fig. 8** allows to conclude that the frame P3, filled with a masonry wall of thermal brick, once again exhibits a stiffness higher than that of the bare frame, similar to that of the prototype filled with a traditional masonry wall (P1_M). In the test P3_M, however, a gradual degradation of stiffness up to rupture from 75 kN instead of the sudden one, observed in the test P1_M to a load of 100 kN above, occurs when the first slots in the masonry.

This loss in stiffness of the structural system in P3_M test is, as it was mentioned, mainly gradual up to displacements of 60 mm, therefrom increasing significantly up to 80 mm of displacement, at which point the maximum load of 340 kN is reached. **Fig. 9** also shows that, during this phase, the stiffness of the structural system P3_M tends to approximate the stiffness of the P3_BF, a tendency never seen during the P1_M test.

It is also observed that, by comparing the tests P1_M and P3_M, and even taking into account that their reinforcement was oversized so that they did not experience significant damages during the tests with masonry walls, the effect of the thermal masonry with discontinuous joint (P3_M) allows to increase the resistance of the structural system by 20%, a situation not observed for the effect of traditional masonry (P1_M).

Fig. 8 also shows that, after reaching the maximum test load, the degradation of the strength of the structural system in P3_M test is relatively fast and that the thermal masonry wall has reduced ductility, in spite of being higher than that of the P1_M test. The test was finished and the set unloaded when the vertical displacement imposed was 110 mm, at which point the masonry blocks were generally broken. The reason for the end of the test was not to impose significant damage on the prototype that would make the next test impossible.

The comparison of the results obtained in the tests P1_M and P3_M also reveals that the failure of the traditional masonry wall (P1_M) occurs for a vertical displacement of 40 mm, much lower when compared to the displacement recorded when the thermal masonry failed (P3_M) of 110 mm.

The differences in the overall behavior exhibited by the two structural systems P1_M and P3_M can be explained based on the behavior and mechanical properties of the masonry that constitute them. From the point of view of the stiffness degradation, more initial and gradual in the P3_M case, the difference in the behavior can be explained based on the arrangement of the masonry units. In fact, thermal brick masonry, unlike traditional masonry, has vertical dry joints and the bricks are horizontally connected through male-female connections. This type of dry vertical joint causes the stresses to develop mainly along the horizontal joints, causing their premature cracking and the consequent loss of earlier stiffness of the structural system.

From the point of view of resistance, it was found in Chapter 2 that the compressive strength of the thermal brick and the corresponding triplet test pieces are about four times and two times higher (section 2.3), respectively, to the homologous resistances of elements and traditional masonry specimens, which explains the most significant contribution of thermal masonry to the overall strength of the structural system. However, and as noted, this thermal masonry wall is rather more deformable. The weaker and more deformable bonding between the thermal bricks allows their rearrangement as the force and vertical displacement are applied to the structure. The increase in displacement at the load application point leads to an increase in the deformations of the RC frame and the dry type joint allows the rearrangement of the bricks to accommodate the deformations caused by the distortion of the frame. This causes that the failure of the thermal masonry wall occurs not only for higher loads but also for higher displacements compared to the case of traditional masonry wall.

Fig. 9 shows three photographs recorded at the end of the P3_M test. Contrary to what was observed in the P1_M test, where the formation of a single compression strut was observed within the masonry wall between the compressed corners of the frame (see **Fig. 6**), the development of multiple small compression structures, spaced approximately

300 mm apart corresponding to the width of the bricks, was observed. It should also be noted that, in this case, cracking rarely crosses the bricks, preferentially concentrating along the joints (horizontal and vertical), which allows to take advantage of the strength of the thermal bricks.

Fig. 9 also reveals that the break mechanism of the thermal brick masonry wall is completely different from that of the traditional masonry wall. In the latter case, the rupture occurred, as described in the literature, by crushing the material next to the upper compressed corner. In the first case, although crushing was more evident in the lower compressed corner (see **Fig. 10 (a)**), there was a generalized failure of the first row of bricks placed on top of the lower beam.

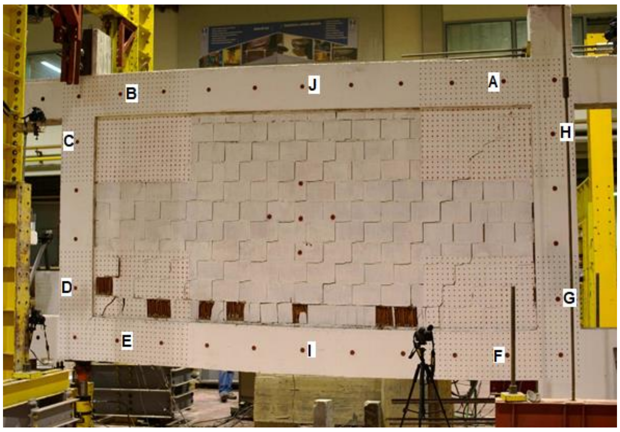
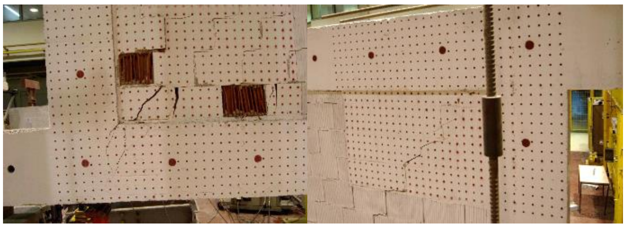


Fig. 9 - *Infilled frame test with thermal brick masonry wall at maximum displacement.*



a) b)

Fig. 10 - *Crack pattern of the masonry wall in a) bottom left corner and in b) upper right corner.*

3.4 The effect of a thermal brick masonry wall with joint reinforcement (frame P4)

Fig. 11 shows the load-displacement diagrams obtained during the tests performed in P4 prototype. The behavior of bare frame has already been discussed in section 3.1. Therefore we shall pass directly to the analysis of the behavior under the effect of a thermal masonry wall with a discontinuous joint reinforced with Murfor Compact I truss. In **Fig. 11** is also plotted the curve related to the test P3_M to allow a better comparison between the effect of the two different masonry wall, and to conlude about the effect of joint reinforcement in the overall behavior of the RC frame.

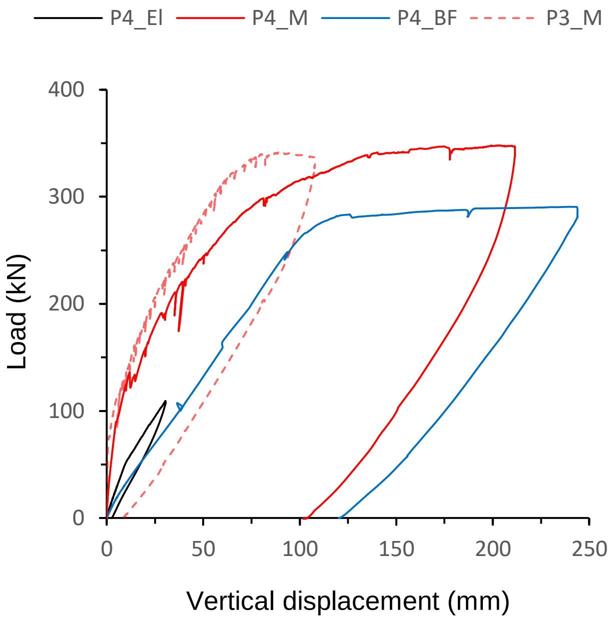


Fig. 11 - *Load vs. vertical displacement curves.*

As in the case of P3_M, the initial stiffness loss is also precocious in P4_M test when compared to the P1_M test, due to the appearance of the first cracks in the masonry wall for a displacement of about 5 mm and an applied load of about 90 kN. For a load of 130 kN and a displacement of 10 mm, a significant decrease in the stiffness of the structural system occurs due to the appearance of a crack along a horizontal joint of the masonry wall, as shown in **Fig. 12**. Thereafter, and for successive increases in displacement, a continuous degradation of stiffness is observed, associated with the formation of multiple diagonal cracks spaced approximately 600 mm, the equivalent of the width of two bricks. However, in this case, and in contrast to the remainder (P1_M and P3_M), the structural system never showed negative stiffness throughout the test. In the difficulty of establishing a stopping criterion of the test, it was decided to finish it when the stiffness of the system was apparently null and the masonry wall presented severe damages. The maximum load of 350 kN was recorded for a displacement of 150 mm and it remained approximately constant until the end of the test when the displacement imposed was 215 mm. A resistance increase of about 20% was also observed compared with the P4_BF test.

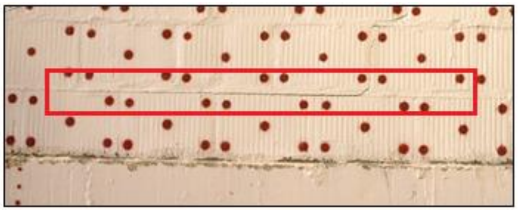


Fig. 12 - *Crack formation along horizontal joint.*

In general, the behavior of the P3_M and P4_M tests is very similar up to 110 mm. The difference in overall behavior between the two is mainly significant for displacements above this level. While in the P3_M test there is a loss of the resistant capacity due to the fragile failure of the bricks of the first row in contact with the lower beam (see **Fig. 9**), in the P4_M test, there is a gradual increase, although small, of the resistant capacity up to 350 kN for vertical displacement increments. The maximum capacity registered in P4_M test is very close to the one registered in P3_M test, indicating that the type of brick used in the construction of the masonry wal is a determining factor for the resistance of the structural system. The joint reinforcement on P4 frame has an effect mainly on the its ductility.

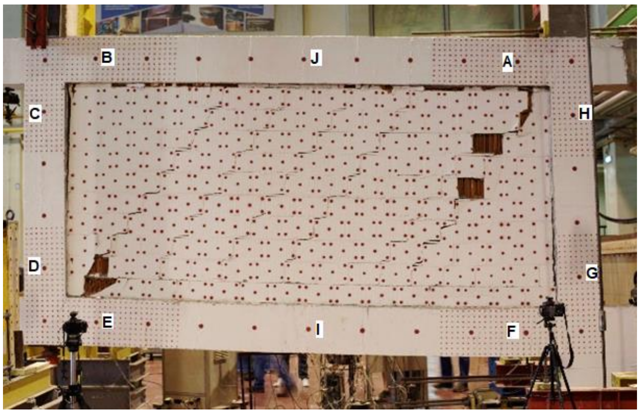
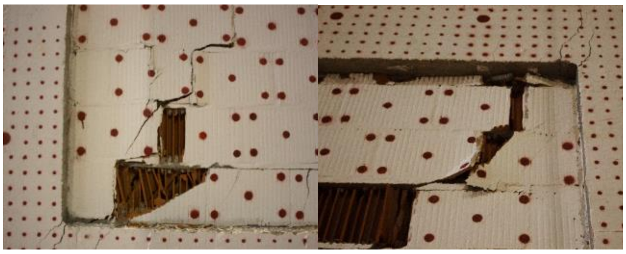


Fig. 13 - *Infilled frame test with thermal brick masonry wall with joint reinforcement at maximum displacement.*



a) b)

Fig. 14 - *Crack pattern of the masonry wall in a)bottom left corner and in b) upper right corner.*

Figs. 13 and **14** shows several photographs recorded at the end of the P4_M test. There are 4 parallel main compressive diagonal struts with a width equivalent to two bricks. The exception is the diagonal strut closest to the reaction wall whose width appears to be twice the others. In the same figure it is also possible to observe the level of damage of the masonry wall, with the evident crushing of the bricks next to the compressed corners of the frame, as well as in the last row of bricks in contact with the upper beam. However, as it can be seen from the load-displacement diagram showed in **Fig. 11**, the structural system maintained a constant load capacity, even when the applied displacement was increased up to 215 mm, thus exhibiting what is considered a ductile behavior. It is assumed that the joint reinforcement is responsible for this behavior in a way that it allows to absorb the tensile stresses that develop in the direction approximately perpendicular to the formation of the compression struts. **Fig. 15** helps to support this hypothesis, and it was found that at the end of the P4_M test, the joint reinforcement exposed on the bricks that had been crushed was heavily tensioned. It should also be noted that the P4_M test was completed without the maximum ductility of the system having been explored since, as already mentioned, it was necessary to perform one more test (P4_BF).

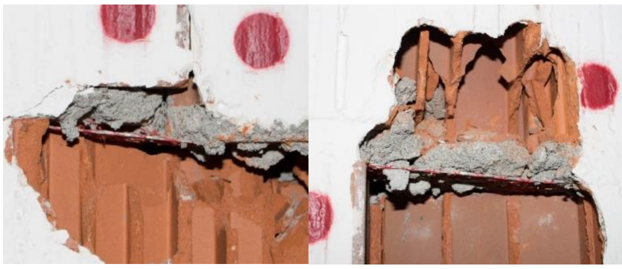


Fig. 15 – *Murfor Compact I reinforced truss being solicited in tension.*

3.5 Final considerations

From the presented results obtained from the three tested RC frames infilled with three different types of masonry wall the following conclusions can be drawn:

- The consideration of infill masonry walls in RC frames introduces, in a general way, an increase in structural initial stiffness;
- The increase in initial stiffness observed with the introduction of a traditional brick masonry wall is similar to the one registered with the introduction of a thermal brick masonry wall and equal to 160%;
- The introduction of a masonry wall in a RC frame allows the formation of an alternative load path when subjected to a vertical load applied in the alignment of one of the columns, reducing stresses in the structural elements closest to the removed column;
- The introduction of a traditional brick masonry wall in the behavior of a RC frame constitutes, among the analyzed configurations, the one whose behavior most closely resembles that of an equivalent diagonal strut, the applied load being transferred to the rest of the structure through the bottom beam B2 and by the compression strut formed in the masonry wall, instead of the column B1 and the upper beam B1;
- When a thermal brick infill wall is considered, the behavior of the structural system is different from the previous one, since the load is transmitted to the remaining structure through multiple diagonal compression struts connecting beams B1 and B2; consequently, the upper beam is more solicited in this case compared to the former one;
- Thermal brick masonry walls have higher compressive strength than traditional masonry walls and, consequently, the RC frame infilled

with a thermal masonry wall has an increase in resistant capacity of 20%, in addition to the increase in stiffness, when compared to the bare frame, whereas, if filled with a traditional masonry wall, on an increase in stiffness is observed. However, it should be noted that the way in which the tests were programmed limits the conclusions about the effect of the masonry walls on the strength capacity of the structural system, as the reinforcement were oversized so that the infilled frame tests could de done without yielding. On the other hand, if the frame were less reinforced, the conclusions about the effect of the walls on the resistance would be more direct and conclusive;

- The collapse of the thermal masonry wall occurs for higher vertical displacement values, almost triple the ones registered in the collapse of a traditional masonry wall;
- Since the introduction of a thermal brick masonry wall into the RC frame behavior, unlike traditional masonry, leads to an increase in the resistant capacity of the structural system, the latter being achieved for greater displacements, it is a more advantageous solution;
- The addition of a Murfor Compact I horizontal reinforced truss to a brick wall doesn't influence the initial behavior of the structural system, since the behavior is similar to that of the test in which a masonry wall of the same brick was introduced without any reinforcement, in particular in terms of initial stiffness and resistant capacity of the structural system;
- However, the introduction of the joint reinforcement in the thermal brick masonry wall introduces changes in the overall behavior of the structural system, in particular, it confers ductility to the masonry wall and consequently to the structural system, increasing the ductility level extent and prolonging the favorable influence that the masonry wall introduces in its behavior, since the resistant capacity is maintained for greater displacements;
- The reinforced truss, when in tension, helps maintaining the integrity of the masonry wall for successive increments of vertical displacement, preventing the occurrence of an abrupt decrease in the resistant capacity of the structural system, typically associated with the fragile behavior of the masonry walls;
- From the seismic action point of view, the ductility of structures is admittedly important, even more than the resistant capacity itself, since it consists of an imposed displacement. However, in the case of vertical actions, the ductility is also important, since it allows the system to maintain its resistant capacity for greater displacements, allowing, with increasing deformation, the creation alternative load mechanisms to be developed in other parts of the structure. Therefore, the introduction of joint reinforcement constitutes an advantageous solution since it leads to a better performance of the non-structural masonry walls and it improves their role in creating an alternative load path after a sudden column loss.

These results reveal the importance of non-structural masonry walls in the behavior of RC frames, namely their contribution to increasing the robustness of these structural systems. Indeed, the contribution of these elements to the response of the structure when subjected to an extreme event, such as the sudden loss of a column, should not be neglected, since, although they are not structural elements and therefore they're not taken into account in the structural design, the masonry walls allow the creation of alternative load paths. In this way, the transmission of the loads to the rest of the structure is ensured and the collapse of the structural elements can be avoided since the stresses are less significant in the elements adjacent to the removed column.

4 Conclusions and further developments

4.1 Conclusions

The present experimental study aimed at evaluate the influence of different masonry walls in structural behavior of a single story-single bay RC frame under column removal and conclude whether infill walls can work as reserve of strength to mitigate the consequences of an extreme event.

The results obtained from the tests allowed to conclude that the introduction of a masonry wall changes the behavior of the RC frame, in particular, it was verified that the introduction of a masonry wall, whether of thermal brick or of traditional brick, introduced a 160% increase in the initial stiffness of the structural system.

However, while in the case where a traditional brick masonry wall was introduced, the formation of a single diagonal strut was observed connecting the compressed corners of the masonry wall, in the case in which the introduced wall was made of thermal brick (with or without joint reinforcement) the formation of multiple cracks, parallel to each other, connecting the beams, were observed indicating that masonry walls constituted by different brick units have different behavior and failure modes and have a different effect on the behavior of RC frames.

In fact, the results of the tests with different types of masonry evaluated reveal that their contribution to the overall behavior of the structure is different. The masonry wall made of traditional brick, of low compressive strength, did not introduce improvements in the resistance of the structural system. On the other hand, the introduction of a thermal brick masonry wall, with higher compressive strength, increased the resistant capacity of the structural system by 20%, which was reached for higher displacements. However, the results are inconclusive with respect to the effect of the masonry wall in the overall resistant capacity of the structural systems, since rebars were overdesigned.

Finally, the addition of the Murfor Compact I reinforced truss to the thermal masonry wall provided ductility to the behavior of the masonry wall, with the failure being achieved for significantly greater displacements.

4.2 Further developments

The results obtained in this paper contribute to develop the knowledge about the contribution of infill masonry walls to the robustness of RC frames when subjected to an unforeseen extreme action. However, this topic needs further studies in order to better understand the effect of these non-structural elements on the behavior of structures. In this sense, some topics to be developed in the future are proposed to give continuity to the present work:

- Study of other types of masonry walls commonly used in the construction consituted by other materials, such as concrete block masonry walls, in order to obtain a vast knowledge about the effect of different masonry walls on the behavior of RC frames;
- Study of other types of reinforcement of masonry walls, such as the addition of reinforcement applied on masonry wall faces (vertical reinforcement), in order to understand how the introduction of different types of reinforcement can benefit the behavior of masonry walls;
- Execution of experimental works whose tests with and without masonry wall take place in different RC frames, i.e. not in the same frame, in order to obtain the full behavior of the infilled frames up until failure;
- Parametric study of the relation of resistance of the compressive strut/resistance of the RC frame versus resistance of the whole structural system, since the tests of the present dissertation are inconclusive from the point of view of the resistant capacity;
- Execution of experimental works with lower reinforcement than the one used in the present work, since the failure of the masonry walls always preceeded the colapse of the RC frame and therefore it wasn't possible to conduct the experimental tests until structural failure.

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