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A REVIEW ON CONSTRUCTION DETAILS THAT INFLUENCE THE STABILITY OF BRICK FAÇADES

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ABSTRACT

This paper presents the results of an investigation on the stability of brick façades over horizontal actions through the analysis of commonly used constructive solutions, emphasizing its importance in order to achieve it. Therefore, current practices were contrasted with the requirements of standards as well as with the reference bibliography usually employed in Spain, particularly those concerning the seismic action.

Keywords: stability, brick façades, construction details, seismic action.

INTRODUCTION

INTEMAC's investigation carried out in recent years, in the scope of building inspection and monitoring campaigns, revealed the uncertainty about the adequateness of common solutions adopted to solve singular points of brick façades, in order to guarantee its stability.

Despite the fact that this problem has been known for years due to the warning signs that many façades present frequently, significant events, such as Lorca's earthquake (May 11, 2011), enabled to check the extension and the importance of its consequences.

FAÇADE STABILITY. CONSTRUCTION DETAILS.

Since the early 20th Century, the use of masonry walls has changed significantly. The previous bearing walls were, in many cases, replaced by thick self-supporting façade enclosures whose thickness has been reducing until the present day, by a minimum of ½ feet (11,5 cm) in many cases, which were designed with the only aim of covering the building. This reduction of the thickness limits its behaviour and execution. The lack of adequate constructive solutions to solve the particular details is the origin of countless pathology, as exposed in this article.

Until the enforcement of the CTE [5], there wasn't a specific Spanish legislation for the façade stability design and the Eurocode 6 [6] and NTE recommendations [7] were applied. The CTE introduced important changes in what relates to the façades, defining the actions that must be considered in its calculation, especially those developed in its "Documentos Básicos de Fábricas, DB-SE-F, y Salubridad, DB-HS". The walls are the only elements of façade enclosure that are actually regulated in Spain. However, many contradictions are found among these documents, which evidences that the adequate solutions found to assure the stability are, in general, unfavourable regarding sealing and acoustic and thermal isolation and vice versa.

In the present investigation, different supporting configurations of façade enclosure in the horizontal structure were identified, which respond mainly to the execution demands and constructive limitations existent in each different era. In Fig. 1, a summary of the most common types used in Spain throughout the years in shown.

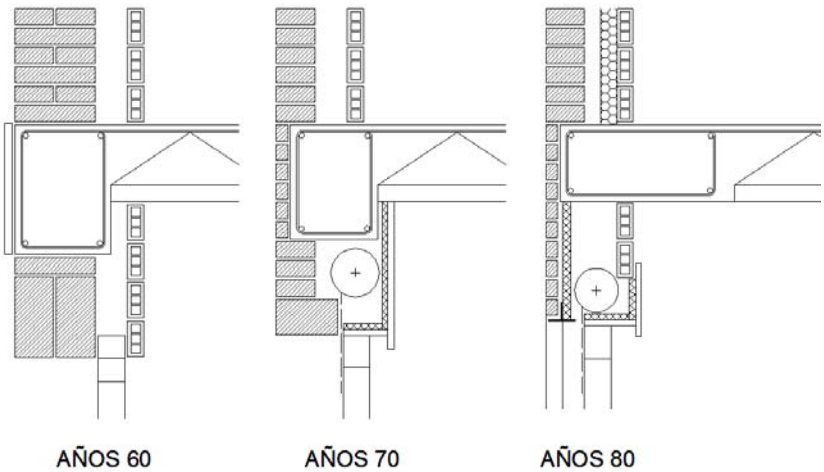

Fig. 1 Evolution in recent decades of the brick façade enclosure walls [8]

From this figure, it is visible that the historic evolution of the façade enclosures motivated that the outer panel would start to be semi cantilevered, with a partial support over the horizontal structure, in the aim to look for isolation of the slab and to avoid thermal bridges. The immediate consequence of this was the decrease of stability of the outer panel, which has become one of the most frequent causes of damage in façade enclosures.

The behaviour of present day brick façades is also limited by the evolution experimented by the buildings themselves. The frame structures have been losing rigidity and increasing their span length, which converts into higher deformability of the horizontal structures, affecting directly the constructive elements that are supported by them, especially the wall partitions as façade enclosure and interior walls.

As exposed in detail in posterior chapters, and against the design theories that sustain that the façades are a mere covering with the only goal of isolation, it can be affirmed that in Spain, the brick façade enclosures are a part of the structure. Considering that the execution of walls is made establishing a connection with the structure and that their rigidity is much higher than the structure itself, there is no doubt that they limit the structural behaviour of the building in a determinant manner.

It's not a new approach, given that it has been studied by many authors. In this sense, building inspection works carried out in the city of Lorca after the earthquake held in May 2011 have allowed for the verification of this hypothesis. The contribution of the walls in the overall building stability, facing the seismic action, meant that many buildings with major structural deficiencies resist the earthquake. However, these partitions were severely damaged, as seen in the images shown in this article, and caused all the casualties produced.

Taking into account the lessons learned in Lorca's earthquake, three important construction details in the execution of brick wall façades are analysed in this article, particularly its exterior partition. Furthermore, in accordance to the experience acquired in this field, typical solutions were collected according to the common Spanish construction techniques, in order to establish a comparison of them with the information contained in the existing codes in Spain and to critically reflect on the suitability of each detail presented. All the images included are examples of Lorca's earthquake damages.

a) About the slab support of façade enclosures

The execution of the façade enclosures starts by placing the first row of bricks of the exterior partition over a mortar base laid previously on the floor slab. It is common to place these first brick pieces with some cantilever to facilitate veneer exterior edges of the slabs and so hide the structure.

Traditionally this configuration was admitted as valid given that the support is not less than 2/3 of the thickness of the partition, in a condition that, although not strictly stable, appear to be supported by practice. Thus, if the exterior panel is formed by header bond metric brick, the effective support in the slab is reduced to about 8 cm. That circumstance, questionable in itself, worsens considering the following aspects:

- The order of magnitude of the tolerance allowed by the standards during construction of the structure, in particular slabs, is unaffordable for the façade enclosures. The CTE considers deviations of up to 20 mm (25 mm according to PIET-70) between the edges of two consecutive slabs in the vertical plane and 50 mm in the total structure. If we also take into account that, after removal of the formwork of the floor, the support surface of the enclosure cannot be completely horizontal neither vertical the front of the slab, the execution of the outer brick panel is complex (Fig. 2 and 3 below).

Fig. 2 Half thickness support of the enclosure façade outer panel

Fig. 3 Progressive loss of support as a function of height

Undoubtedly, the stability of a masonry wall depends very determinately of adequate support from its base.

- To improve waterproofing and drainage conditions, standards recommend using a waterproof sheet to collect and evacuate outside water leaked in through the wall and condensation that may exist in the air chamber, extending foil in the blade support brick exterior with horizontal structure. This leads to friction reduction between building enclosure and framework, compromising the stability of the façade, especially if the sheet has slope as it is recommended by standards (Fig.4 and 5).

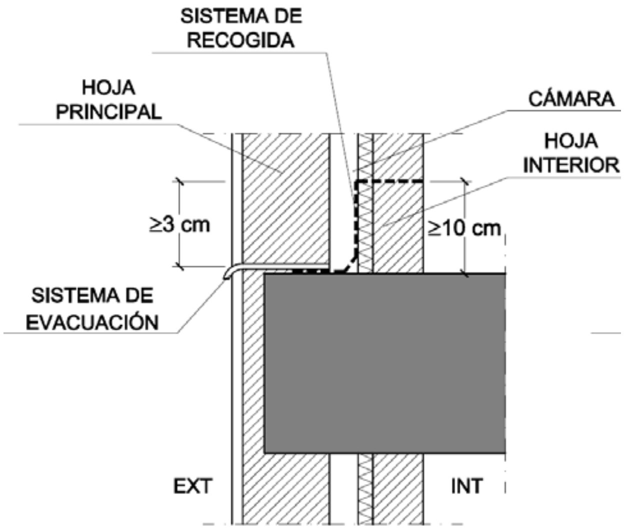

Fig. 4 Support on floor structure as indicated in CTE

Fig. 5 Support on waterproof membrane

In order to improve the conditions of the aforesaid support, often resort to placing auxiliary metal profiles fixed in the frame. These profiles should allow supporting enclosure walls placed directly on them. However, the adhesion between the metal profile and the grout is at least questionable. Furthermore, deviations between plants also influence the placement of these profiles, which are not in the front of the floor flatness sufficient for proper anchorage, causing gaps between profile and floor structure.

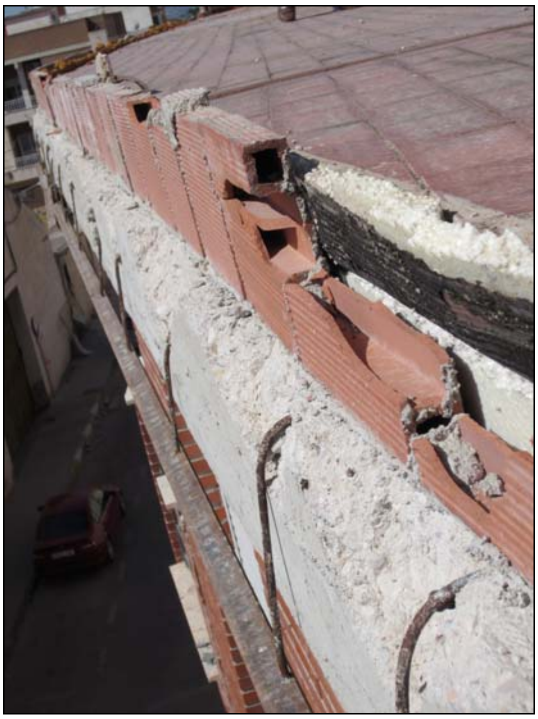

Fig. 6 Support on metal profile

Fig. 7 Drop façade by an inadequate support

b) In relation to the top support of the enclosure in framework

All Spanish references consulted indicated the need to build the outer sheet of the enclosure to a height of 2 cm below the top floor slab, even in some standard (NTE-FFL) expressly indicated the non acceptance of the enclosure if this requirement was not met.

This joint is filled with cement mortar, once the slabs have developed some of the expected deformation. Theoretically, the elasticity of the mortar should permit frames long-term deformation in order to prevent the transmission of loads to the enclosure walls. Is recommended to start the construction of the enclosures by higher plants, allowing the enclosures also settle and reach their final position before caulking. As noted in the PIET-70, the joint is filled in 24 hours after the execution of the enclosure walls.

However, it is common that layout lack and / or errors related to the bed joint thickness of the brick masonry, result in much higher or lower gaps than indicated. With gaps of less than 2 cm, it is hard to run a cement mortar filling. In the second case, it is common to fill the joint with rubble masonry and mortar solution that ultimately prevents the formation of the patched joint (Fig. 8).

Fig. 8 Caulking without seal, left, and caulking with rubble, right

If there is an outer coating, the CTE-DB-HS1 proposes two types of solutions: create a joint of decoupling that will be filled once drying shrinkage has finished on the main sheet with a material whose elasticity allows the predicted deformation of the floor and provides a drip edge to protect the seal leaks, or place a mesh inside the outer coating (Fig. 9).

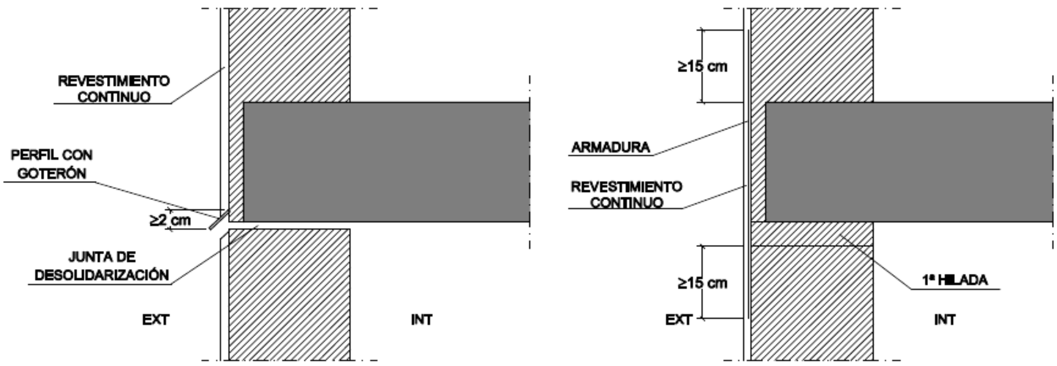

Fig. 9 Two types of solutions for outer coating proposed by the CTE-DB-HS1

At this point, we could make a reflection which is especially important in case of seismic action. Many authors have studied how enclosure increases the stiffness of the structure, which so significantly changes its behaviour and response actions that request. In Lorca we confirmed that this circumstance was decisive. The connection of the panels to the structure, Fig. 10, has caused that horizontal actions due to the earthquake were resisted by the collaboration of non-structural masonries in many buildings with structural deficiencies. Furthermore, it has been the main cause of the damage observed in numerous enclosures and interior partitions.

Fig. 10 Examples of enclosures executed without gaps

The transmission of gravity loads collected by floors through enclosures, produced by the rigidity of the masonries and their connection to the framework, has been studied by many authors. This accumulation of charges on the ground floors could justify the observed buckling panels brought to lateral earthquake in Lorca (Fig. 11).

Fig. 11 Ground floor buckling panels

Other factors to consider are the retraction effect of the concrete framework and the moisture expansion of the brick outer sheet along its lifespan, factors which are not covered by Spanish standards. According to Ms Lucía Sánchez Marta, Industrial engineering final project developed by INTEMAC [9], masonry façades are "structural" elements which should not been forgotten. This study proved that this phenomenon even cause that many pillars are tension members, at least in higher plants.

c) Pillars meeting

Existing standards refer to thermal and waterproofing requirements for enclosures, main aspects that limit the constructive solutions recommended for the meeting of the pillars. In summary, we can retain the following indications that CTE provides for enclosures:

1. The façade's outer panel must be anchored on all four sides ... *"so as to ensure its stability and the transmission of horizontal forces to which it is subjected."*
2. Each enclosure must be stiffened with perpendicular walls.
3. The enclosure must provide sealing, waterproofing and insulation.
4. The enclosure must be independent from the structure so that each element is not affected by the other's movement.

As we have exposed in this article, it is particularly difficult to ensure compliance with items 1 and 4 at the same time.

Fig. 12 Damage at pillar meeting

The most common solution is one in which the enclosure's head is placed against the pillar. Brick walls execution begins at the tops, ensuring that their head is, as said, placed against the pillar. Prior to the enclosure execution, it is usual to place a plastic panel around the pillar, which allows separating the movements between pillar and façade and, at the same time, prevents the adhesion of the pieces that cover the pillar in order to give continuity to the facade. The pillar coating is executed with brick bits cut *in situ*, which inevitably weakens the masonry, causing cracking due to differential movements between the two elements, originated by both thermo hygrometric causes and the pillar's own structural movements. In order to avoid that kind of problems, the bed joints are sometimes reinforced.

In this context, the CTE-DB-HS1, establishes two possible actions for when the main panel is interrupted by pillars (Fig. 13).

- In case of continuous outer coating, reinforcement must be placed along the pillar so that it exceeds 15 cm on both sides.

- If thinner parts than the main panel are placed, reinforcement must be applied to achieve their stability.

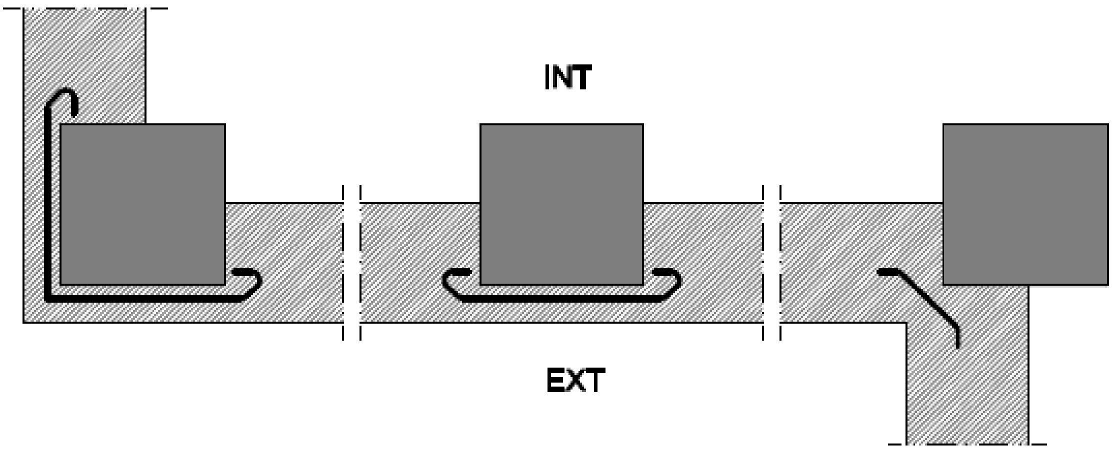

Fig. 13 Pillars meeting with façade as CTE indicates

Following standards guidelines, the expansion joints of the façade should match the general joints of the building and it is desirable that intermediate joints coincide with pillars meetings.

If vertical joints are insufficient, movement's restrictions caused by the pillar meeting to the wall would cause cracks in veneer pieces, particularly in those colloquially called "guns", obtained from cutting bricks (Fig. 14).

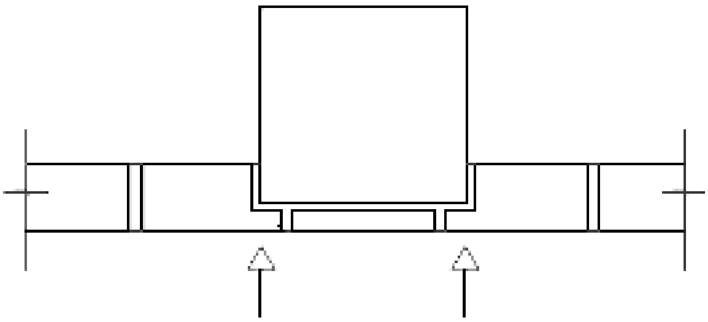

Fig. 14 Susceptible cracking points

These points favor the entry of water from outside, not only through the aforementioned cracks, but from the plating capillary filtration itself. To avoid these problems, one alternative is to place the whole outer panel in front of the pillars, making it independent by one separating element such as a compressible insulation panel of low density or even a polyethylene panel. Although this solution would be is complete with the placement of connecting keys between pillar and masonry, Fig. 15, this would represent a significant loss in the panel's stability. In most cases, anchoring elements consist of low rigidity metal strips. These elements are criticized in part of the literature available.

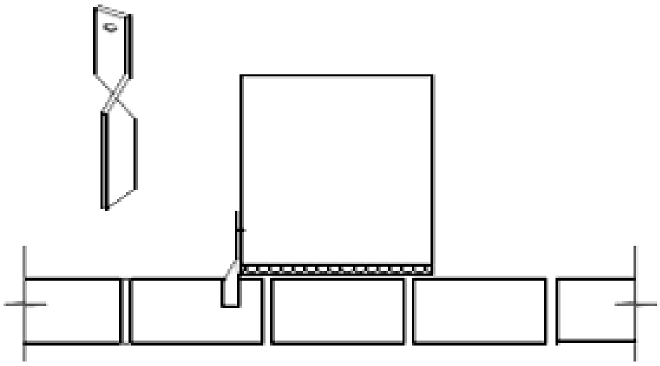

Fig. 15 Metal strips anchoring elements

This reflection can be extended to other parts of the façade in which there is also a decrease in masonry thickness: pipes, conduits as shunts, downspouts or chimneys, drums of blinds, etc.

e) Carpentry inclusion in the enclosure

Timber inclusion (primarily windows) in enclosures means a discontinuity in the panel front thus weakening structural behaviour and weakening its sealing and isolation.

By introducing the window opening, specific points appear in the façade that are likely to favour moisture entry into housing perimeter. Standards indicate that to avoid this water inlet, the sill must be placed over an impermeable panel, compromising the adhesion of mentioned batter.

For carpentries support, standards cover the same construction detail observed in Lorca in most of the buildings checked. Carpentry is located on the inner side of the wall to prevent moisture penetration and the existence of thermal bridges. However, the wall lined on the inside (drywall or thick brick wall), rarely has enough bearing capacity to collect loads transmitted through the windows, especially those related to wind or earthquake.

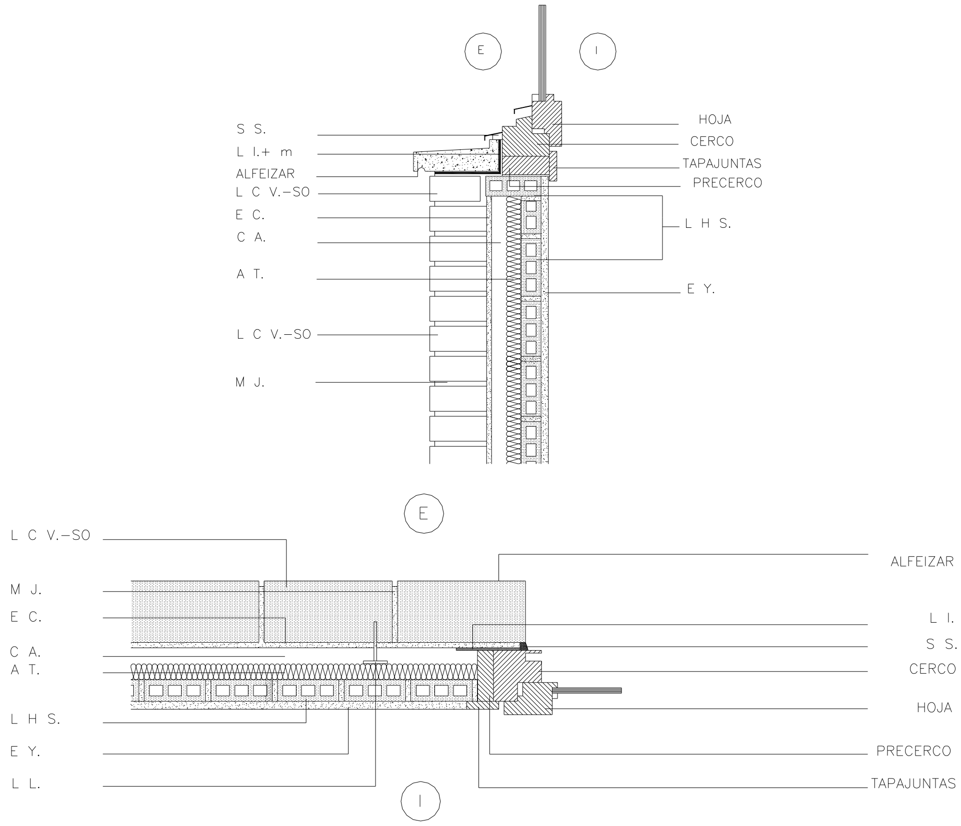

Fig. 16 Theoretical carpentry location in the enclosure wall [9]

However, we can affirm that carpentries behaviour in Lorca has been surprisingly good and not quite coincident with the reasoning set out above. Through inspections, we observed only carpentry disjointed from their original position. There have been even cases where brick from outer leaf has fallen, and the inner, supposedly weaker, has stood holding the windows (Fig. 17).

Fig. 17 Carpentry behavior after Lorca's earthquake

CORRECTIVE MEASURES

Possible repair solutions measures open up a great debate. More developed seismic standards from countries such as New Zealand and Japan indicate the obligation to eliminate the link between masonry and structure. In our opinion, restoring or even enhancing the connection masonry-floor slab, despite the benefit obtained by the increasing of the panel stability, introduces undesirable effects on the overall behaviour of the structure. The stiffening causes not only smaller displacements but also increases the efforts to be resisted.

Some documents refer the possibility of building a "confined wall" with reinforced concrete intermediate elements in vertical and horizontal direction so as to limit masonry deformation caused by actions in its plane. These elements are concreted once the wall is placed.

One optimal solution could consist on building enclosures which would resist by themselves to external actions (such as earthquake, wind, etc., as defined by the standards), and transmit them to the structure by connections that, in turn, enable an independent structural behaviour between both elements. Appropriate measures should be also taken to prevent brittle fracture and partial collapse or displacement of its plane.

One of the solutions employed to solve all the points discussed, including the "unavoidable" slabs coating, is to make both elements independent providing an auxiliary intermediate structure between them that would hold the masonry. Currently on the market there are several patented profile systems available for this purpose (brackets type), according to the terminology defined in UNE-EN 845-1:2001, although its introduction in Spain is not significant.

CONCLUSIONS

The analysis performed leads us to question the brick façade systems, as traditionally solved in Spain. The common construction solutions do not offer sufficient assurance to guarantee even the basic structural requirements determined by standards.

As obvious examples, we have shown some of the multiple damages observed in Lorca town after the earthquake in May 2011. Construction techniques existing in Lorca are similar to those of any medium-sized Spanish city. All issues studied in this paper, (masonry supports, façade whose stiffness determines the behaviour of the structure, etc.) have been observed in most of the damaged buildings, and many of them were built in recent years.

In our opinion it is necessary to review and update Spanish standards, regarding the masonry enclosures construction. The current problem is the result of normative gaps, which is paradoxical given the importance of the façade in economic terms within the overall budget of any building.

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