THE INFLUENCE OF HYGROTHERMAL CLAY EXPANSION ON HOLLOW BRICK MASONRY PATHOLOGY

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ABSTRACT

In Portugal, hollow clay brick masonry is a very traditional solution for building walls. However, in some recent construction, we have registered some pathologies related with the clay expansion due to hygrothermal actions, particularly in building envelope walls.

Beside the numerous cracking problems registered in the cases we have analyzed, we have also detected many instability problems in the building envelope walls, which even resulted in the collapse of a significant area of a building façade.

In spite of not being a recent problem, only in the last years it has assumed some expression in our country, fact that can be related with some recent solutions for the building envelope walls, where the outside layer of the masonry, unlike the traditional solutions, is not totally confined with the structure elements, usually in concrete.

In this paper we will present three cases where this phenomenon has been detected, according with the following structure: description of the observed pathologies, prospecting and measuring actions, possible causes of the analyzed problems and rehabilitation proposals.

The buildings have distinct purposes, namely a hotel, a theater and a cottage complex.

Key words: masonry, clay brick, moisture, expansion, pathology, cracking.

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INTRODUCTION

In Portugal, hollow clay brick masonry is a very traditional solution for building walls. Usually they are just used as filling elements of the concrete structures, and are coated with hydraulic mortars.

In 1991, with the introduction of the RCCTE – "Regulation of the Building's Thermal Performance", concerns with the buildings' insulation have become common in Portugal, changing the building practice considerably, not only by the consequent resort to insulation materials, but also because the aspects related to the buildings' thermal inertia, as well as to the treatment of thermal bridges, have come to influence the conception of building elements in a considerable way.

The increasing lightening of the buildings, particularly of the façades, has led to the use of thinner elements. Together with this factor, the masonry cloths' lesser confinement, resultant from the treatment of thermal bridges, have come to enhance some aspects related to the clay's behavior against the hygrothermal actions which, till then, had not proved to have such influence on wall design.

CHARACTERISING PORTUGUESE BRICKS

The hollow clay brick represents the greatest part of brick production in Portugal. With a percentage of holes that can go up to 70%, its mechanical resistance to compression strains ranges from 2 MPa to 7 MPa (APICER, CTCV, DEC-FCTUC, 2000).

The most common formats for these elements are those shown in Figure 1. Unlike other European countries, the production of specific units for the execution of singular points, such as wall corners, lintels, etc., is not common.

EXPANSION OF BRICK MASONRIES

The Influence of Temperature

In Portugal, the thermal amplitudes to which the exterior walls are subject, can reach approximate values of 60 ºC. It is then possible to calculate the thermal expansion of a wall, without movement restrictions, which is about 0,3 mm/m.

The heating to which the envelope walls are subject also plays an important role in the thermal shock phenomenon, that occurs, for instance, when in a Summer day, during which the heating of the exterior walls is quite significant (particularly to the South/West orientations), precipitation occurs, causing the sudden cooling of its outer surface. This sudden cooling results in strong contractions on the walls' outer surfaces, while in its interior the conditions are fairly stable.

The Influence of Moisture

Moisture induced changes of clay brick are responsible for variations in its dimensions, especially in the irreversible expansions. The material wetness can be attributed to the rainwater absorption (which usually runs across the outer coatings of the walls or infiltrates through cracks) or to the adsorption water vapor found in the air (hygroscopic expansion).

This expansion of clay brick with moisture can reach levels higher than 1 mm/m (CTCV, 2000). This phenomenon changes, in a considerable way, according to the type of manufacture, including the composition of the clays and the temperatures and boiling time of the bricks. In Portugal there is no record of complete studies of characterization of brick expansion with moisture, but we know that this process can take several years to develop (Logeais, 1973).

To avoid problems related to this phenomenon, some normative documents such as the prEN 772-19 (APICER, CTCV, DEC-FCTUC, 2000) determine the limit values for the brick expansion, to be observed in accelerated tests, carried out during the materials' quality control.

Masonry Deformation

The movements of masonries caused by the hygrothermal actions can be responsible for the wall's degradation, namely its cracking. The configuration of this type of pathologies can be divided into two main groups, depending on the masonries' confinement:

- In those cases in which the restrictions to the walls' free movement are small, the deformations can reach values which are incompatible with its resistance, especially in singular points, like wall corners, openings, etc. (see Figure 4, Figure 9 and Figure 12).
- In those cases in which the walls are confined by very stiff elements, the restrictions imposed on the masonries' movement can cause its deformation, if they are too slender (see Figure 2).

THERMAL CONCERNS AND WALL DESIGN IN PORTUGAL

The Problem of Thermal Inertia

From the point of view of the maximization of the buildings' thermal inertia, which is most important in mild climates in which there are no habits of continuous heating, some technical documents advise that in cavity walls, the elements of highest mass should be applied through the inside of the insulation layers.

Although the principle is correct, its interpretation has not always been the most adequate, since in certain cases, the thicknesses of the walls' outer cloths were excessively reduced, being common practice in Portugal the use of hollow brick masonry with 0,11 m thick for its execution.

<u>Thermal Bridges Correction</u>

With the rising of envelope walls' thermal resistance, in the current zone, the existence of thermal bridges has acquired greater importance, since it can cause condensations.

As precaution, several recommendations for the adequate correction of this problem have came up, having in common the general principle of attempting to perform its treatment from the outside. A solution which has been initially proposed, inclusively by the RCCTE (1990), consisted in the appliance of not very thick brick "linings" from the outside of the structural elements, i.e., columns, beams and top slabs (see Figure 6, Figure 10 and Figure 13). This solution has been adopted to the image of the building practice of other European countries.

Once again the interpretation of these principles has not always been the correct one, because in certain cases other building aspects have not been properly considered, as from the point of view of the mechanical behavior of the masonry units.

Taking the practice of other European countries still as an example, one has to say that, contrary to what happens in Portugal, the use of special units for the execution of singular points in walls, such as corners, lintels, etc. is common. Furthermore, brick production control is usually more strict, which allows to minimize the problem of its expansion with moisture, as well as a better characterization of the units and, in particular, of its mechanical behavior.

CASE STUDIES

<u>Methodology</u>

Next we would like to give three examples of buildings in which the pathologies related with masonry cracking caused by hygrothermal expansion have taken on a quite significant proportion. The buildings in question show different purposes (a hotel, a theatre, and a cottage complex).

The methodology followed during the study of the buildings was the following (see Figure 3):

- *Description of the pathology* – visual analysis.
- *Prospecting and measurements* **-** physical analysis.
- *Diagnosis defining the causes* **-** based on the collected information.
- *Retrofit solutions.*

For each of the analyzed cases, the main problems observed are described, as well as the most relevant aspects of its configuration.

Hotel

The hotel that has been studied (about 15 years old) showed an evident cracking on its vertical envelope, on the following areas:

- On the wall corners, where cracks showed a more or less vertical development and next to the base of some roof contours, having that cracking a slightly horizontal development (see Figure 4);
- On the balconies' railings, more or less in the middle of its thickness, especially on the lower part of the railings (see Figure 4);

In one of the façades there was even an area of the wall's outer cloth that has collapsed (see Figure 5).

The composition of the building elements in question is shown in Figure 6 and Figure 7, which clearly denote its brittleness. The most relevant aspects of this composition are the following:

- The façades consisted hollow brick cavity walls, being the space between cloths totally filled with thermal insulation.
- The masonry outer cloths, 0,20 or 0,15 m thick, as well as the insulation layer, completely covered the vertical elements of the resistant structure (columns), of reinforced concrete.
- On the floor levels, the thermal bridges correction was sorted out with the resort to hollow brick, 0,07 m thick, having been placed as sheathing before the concrete covering, in order to form an outer "lining" of the top of the slabs.

Prospectings carried out have shown that the composition of the walls, in those areas, did not exactly correspond to the project specifications. For instance, the bricks that composed the "lining" of the top slabs not always were complete, and the coating mortar reached high thicknesses (see

- Figure 8).
- The balconies' railings and the roofs contours consisted of a reinforced concrete wall, about 0,10 m thick, and of a hollow brick outer "lining", 0,07 m thick, placed as sheathing before the concrete covering.

Theatre

In the case of the theatre that we had the opportunity to study (about 3 years old), the situation was even more expressive, with the cracks reaching a more significant intensity and opening (see Figure 9). Besides the cracks next to wall corners, several others have been detected next to openings and in the masonry cloths' holding areas.

In Figure 10 and Figure 11 we can see the building's vertical envelope composition, of which we would like to point out:

- The façades consisted of a reinforced concrete inner wall, 0,20 m thick, covered on the outside by a hollow clay brick veneer wall, being the space between them partially filled with thermal insulation.
- Movement joints of brick veneer wall have not been considered.
- On the top of the slabs, the holding of the veneer walls was partially achieved by short corbels, of reinforced concrete, coated on the outside with hollow clay brick, 0,07 m thick. These elements were applied only during the execution of the masonries, that is, after the execution of the concrete structure.
- In the lintels, the holding of the masonry outer cloths was also achieved by small horizontal elements of reinforced concrete.

Cottage Complex

Regarding the cottage complex (still in construction), the situation was similar to that of the above described buildings. Figure 12 and Figure 13 illustrate the studied problems.

Rehabilitation Proposals

For each of the analyzed cases, rehabilitation solutions were complex and extremely expensive. The announced treatment principles were the following:

- Appliance of an exterior insulation finishing system (EIFS), after the demolition of the walls' outer cloths.
- Execution of reinforced concrete locking elements (small beams and pillars) conveniently spaced, with posterior appliance of a reinforced outer coating, composed of special mortars with polymers.

CONCLUSION

In the conception of a building element there are multiple requirements to fulfill. However, in no situation the optimization of a certain aspect shall put at risk more important ones, as, for example, the security of use.

As far as the masonry walls are concerned, and in particular those which compose the vertical envelope of the buildings, the hygrothermal movements must be adequately considered, especially in cloths with poor resistance, some slenderness or freedom of movements.

Some of the aspects to take into account in the conception of these elements are:

- When in the treatment of thermal bridges, despite being advisable to perform it from the outside, it should never put at risk the stability of the walls.
- The masonries' base course should have an adequate stability.
- The existence of very stiff elements (like, for instance, reinforced concrete elements), adequately spaced, and which guarantee the confinement of the

masonries, prevents the deformations and strains from reaching values that are incompatible with the units' resistance.

- To foresee the existence of cracking joints adequately spaced.
- In the control of brick production, maximum values for expansion with moisture must be determined.

REFERENCES

APICER, CTCV, DEC-FCTUC (2000). Manual de Alvenaria de Tijolo. Portugal.

Bonshor, R. B.; Bonshor, L. L.; (1996). Cracking in Buildings. London, UK.

CSTB - Centre Scientifique et Technique du Bâtiment (1985). Parois et Murs en Maçonnerie de Petits Éléments. Document Technique Unifié n.º 20.1. CSTB, France.

Freitas, V. Peixoto de; Abrantes, Vítor; Pinto, P. da Silva (1999). Relatório LFC/IC – 062/99, Porto, Portugal.

Freitas, V. Peixoto de; Pinto, P. da Silva (1999). Relatório LFC/IC – 065/99, Porto, Portugal.

Freitas, V. Peixoto de; Pinto, Manuel; Pinto, P. da Silva (2000). Relatório LFC/IC – 079/00, Porto, Portugal.

Logeais, Louis (1973). Pathologie des Ouvrages en Maçonnerie. Annales de l'Institut Technique du Bâtiment et des Travaux Publics, France.

RCCTE – Regulamento das Características de Comportamento Térmico de Edifícios (1990). Decreto-Lei n.º 40/90, Portugal.

Silva, J. A. R. Mendes da; (1998). Fissuração das Alvenarias – Estudo do Comportamento das Alvenarias sob Acções Térmicas. Doctorate Thesis in Civil Engineering. Coimbra, Portugal.

ILLUSTRATIONS

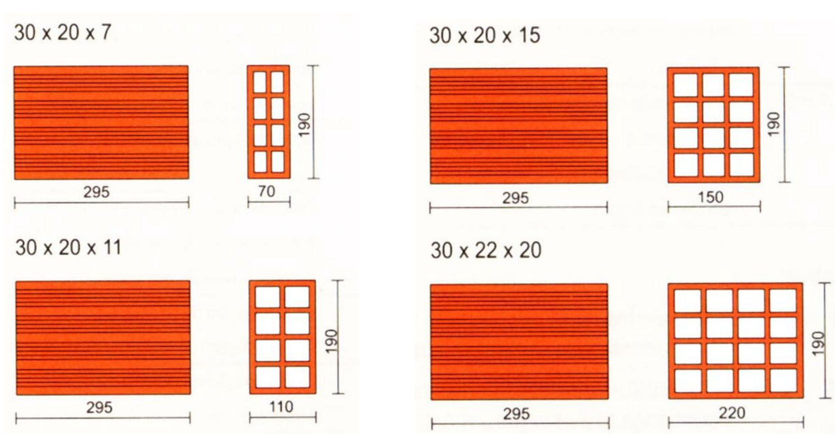

Figure 1. Hollow clay brick formats in Portugal (APICER, CTCV, DEC-FCTUC, 2000).

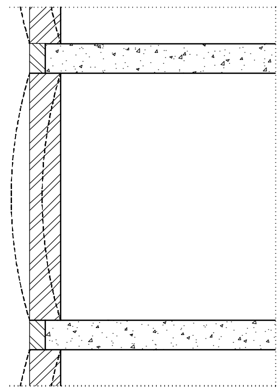

Figure 2. Wall deformation due to the expansion of its components.

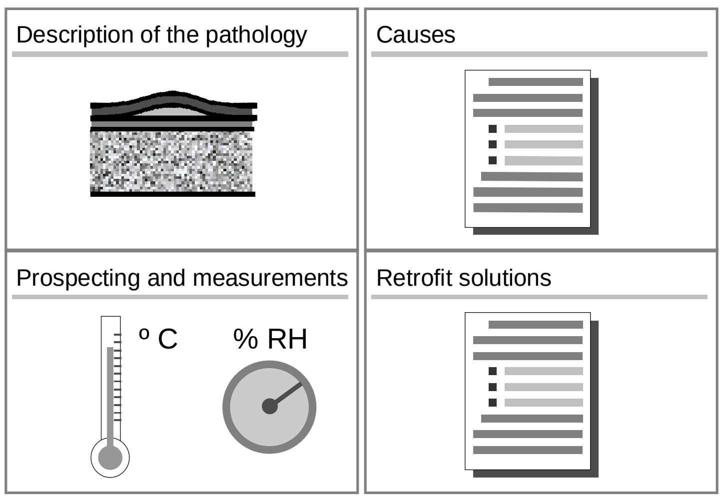

Figure 3. Methodology for studying building pathology.

Figure 4. Hotel’s cracking problems.

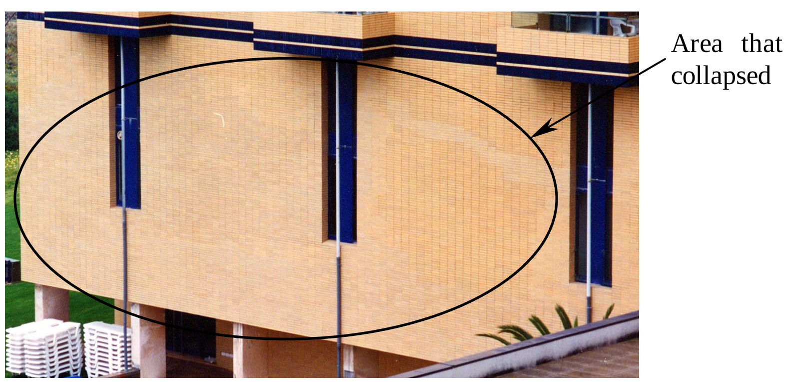

Figure 5. Wall of the hotel that fell down.

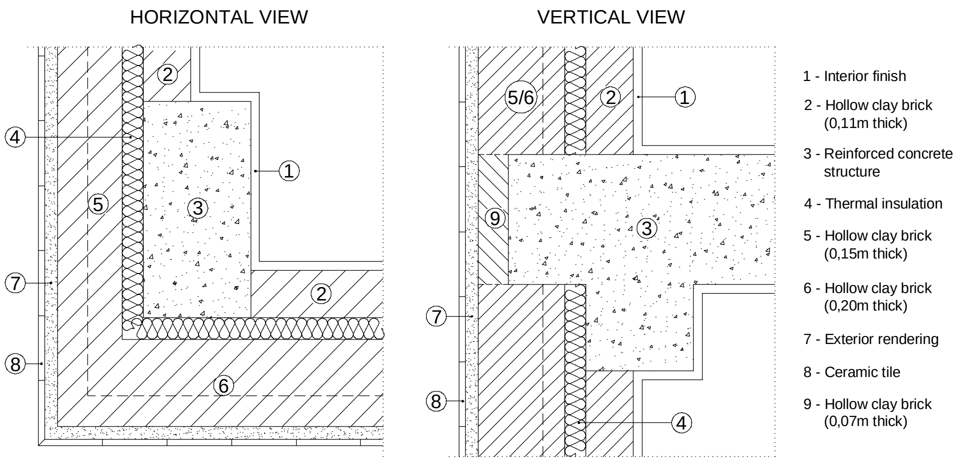

Figure 6. Composition of the hotel's exterior walls.

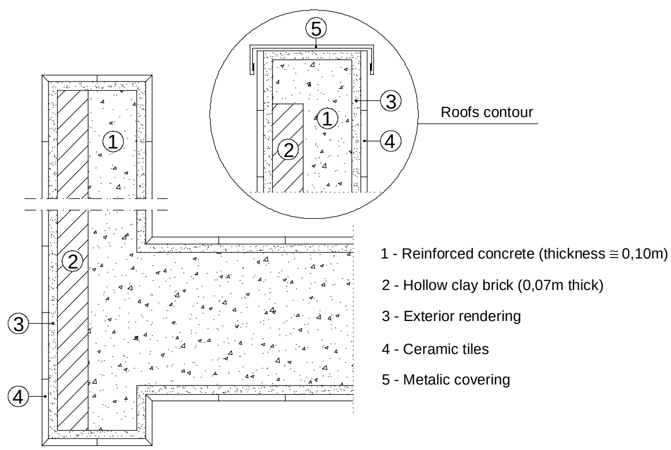

Figure 7. Composition of the hotel's balconies and roofs contour.

Figure 8. Prospecting carried out at the hotel to confirm the composition of exterior walls.

Figure 9. Theater’s cracking problems.

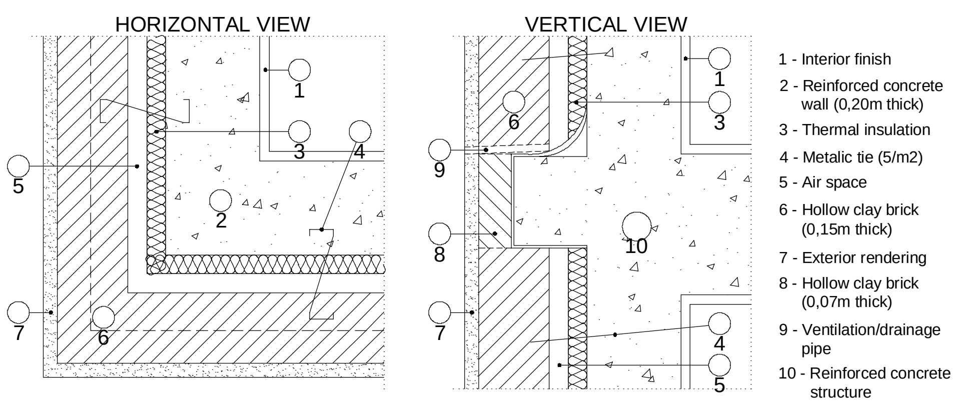

Figure 10. Composition of the theater’s exterior walls.

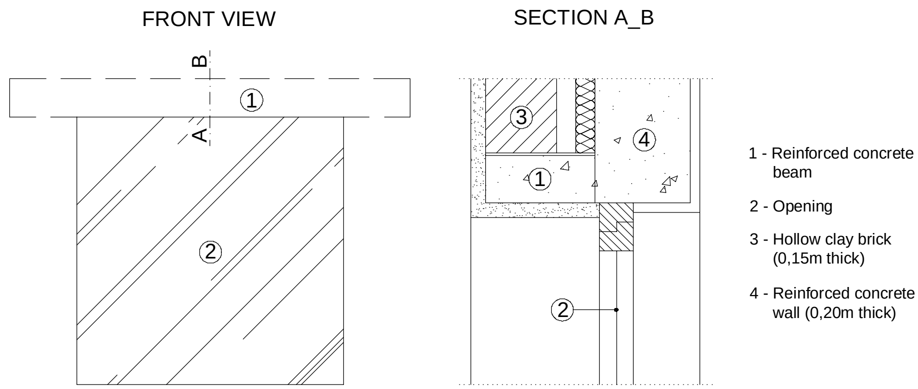

Figure 11. Theater's exterior walls near openings.

Figure 12. Cracking problems in the cottage complex.

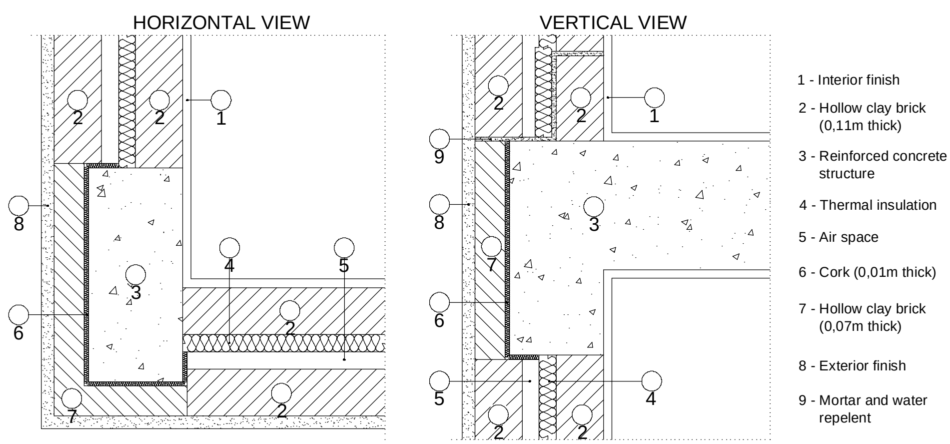

Figure 13. Composition of the exterior walls of the cottage complex.