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PATHOLOGY AND REHABILITATION OF EXTERNAL ANGLES IN UNRESTRAINED MASONRY WALLS

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Abstract

External masonry walls, in Portugal, have changed a great deal in the last decade, in consequence of new goals and challenges related with thermal performance and condensation control. One of the most contradictory measures on this matter is the external thermal bridge correction at external angles using traditional perforated bricks. This technique has lead to the improvement of thermal behaviour, but also to some constructive risks, which lead to consequent pathologies and defects. This paper deals with rehabilitation techniques, particularly with the reinforcement and reconstruction of the external angles of walls, after cracking. This paper describes these reinforcement and reconstruction procedures at work sites, discussing the numerical and analysis of the cracking phenomena at external angles of unrestrained façade walls.

Key Words

Pathology, rehabilitation, cracking, external corner angles.

1 Introduction

In Portugal, the design of masonry is frequently disregarded, since it is not used in a structural manner, under evaluating its function and importance in some cases. However, external masonry walls have suffered significant changes in the last decades, in consequence to the evolution of materials and their functional and economical constraints, leading to lighter and slender wall solutions more vulnerable to natural movement effects and climatic agents.

In the last decade, many external masonry walls were built without attending to basic stability principals; disrespecting minimal basal support conditions over floor slabs and beams, absence of vertical and horizontal confinement, lack of cavity wall tying and creation of movement joints at wall corners.

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Such phenomenon is related to the inadequate response to our national thermal code, (RCCTE [1]) on the attempt to minimize thermal bridge effects that unexpectedly raised serious problems: loss of water tightness of external masonry walls and severe cracking at external wall angles, etc.
The main purpose of this paper is to discuss and analyse, on the basis of a numerical approach stress fields and cracking of unconfined external angles. Further on, it also illustrates and discusses, the reinforcement and reconstruction techniques that strengthen with the use of reinforced masonry, external unconfined cavity walls at angles, usually carried out for building repair in the last past years.

2 Unrestrained masonry angle joints

2.1 Masonry angle joints

The attempt to improve thermal behaviour of buildings, using recommendations from our national thermal code have encouraged some new advantages: reduction of superficial condensation risks that lead to less defects of internal wall coverings and renderings; however, some disadvantages have been brought up: poor mechanical behaviour and stability problems of non-loadbearing external masonry walls, particularly with double leaf cavity walls. The insufficient theoretical and practical knowledge of new technological solutions in the project design and execution phase have originated frequent and systematic defects in recently built buildings.
Among the most frequent errors and faults of good execution practice, of external enclosure masonry walls, the most recurrent problems are:

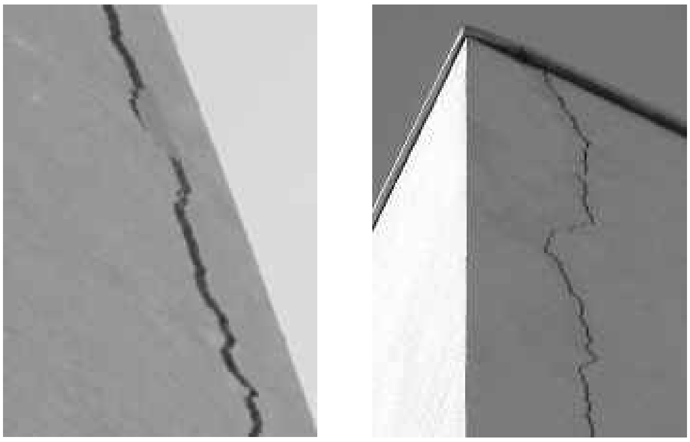
- Poor basal support conditions of the outer leaf of external cavity walls;
- Lack of wall ties or deficient connection of both leafs of cavity walls;
- Absence of connection of external cavity walls to the main concrete structure of building;
- Insufficient horizontal or vertical fastening and confinement;
- Use of low strength bricks and slender wall leafs for masonry enclosure wall solutions.

The poor solutions that are normally executed in respect to external angles are, in a certain level, consequence of the lack of detailing in the design phase. When building designers seek to improve thermal behaviour of buildings, acting through masonry enclosure walls, (bondage of brick slips, partial breath support of wall leafs, the use cavity walls) special attention should be given to masonry in order to minimise future pathologies.
At unrestrained external wall angles the restraint of volume changes - expansion and contraction movements originated from thermal and moisture changes - induce significant strain and stress concentration at fragile points of masonry. These movements, along with low tensile strength of masonry, result in cracking of one of the walls at the corner angle and it’s rendering.
Such movements, that occur after wall construction do not only depend on the temperature range to which the wall will be subjected, but also to initial temperature and moisture content of the wall and its units (clay bricks).
Due to wetting and drying cycles of brickwork through time, reversible expansion and shrinkage takes place. But the irreversible expansion of clay bricks, takes place over years and not even the shrinkage of mortar joints can ease or equilibrate, this well known phenomena. Many authors have estimated irreversible expansion of brick masonry, but this parameter is still quite unknown to the Portuguese brick industry, which estimates this value to be round 0.7 to 1.2 mm/m.

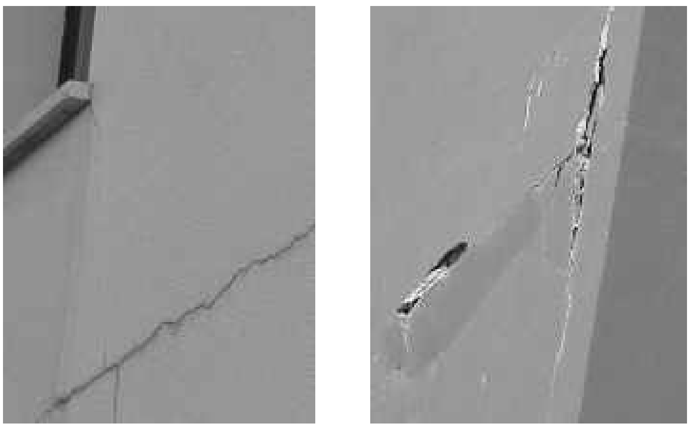
Pathologies and defects

The major problems that occur at corner angles are: the loss of water tightness, vertical cracking along corners and horizontal cracks at floor level. Figure 1, illustrates and comments these problems.

Water tightness problems due to poor bricklaying techniques, allowing the occurrence of potential humidity problems and water infiltrations.



Vertical cracking along corners due to expansion of orthogonal walls at external angle.
Cracking is induced by flexural and shear stress of one wall in relation to the other orthogonal wall.



Horizontal cracking at floor level - interface between masonry walls and structural concrete floor slabs.
Cracking induced by shear stresses originated by the incompatibility of different movements of masonry and concrete.

Figure 1 Main pathologies and defects at external corner angles

3 Numerical approach

3.1 Finite element analysis

The numerical approach, using the finite element method, is a valuable tool to evaluate local ad peak stresses in masonry. It also allows to establish and to better understand the relationship between cracking that occurs at critical areas of masonry walls and stress and strain values originated in those areas.

The finite element approach used in assessing this problem, was treated as a linear elastic analysis problem, considering a plane stress state using 2D continuum isoparametric elements of eight nodes, as shown in Figure 2. The model simulates an external angle where two orthogonal masonry walls with 3 meters of length each, join together as a corner.

The considered masonry material properties used for modelling are mean values for our common clay brick, usually referred for this type of analysis. In Table 1 are shown material characteristics used.

Table 1 Elastic properties of materials.

E – Young´s modulus	2500MPa
α – Coefficient of thermal expansion	$6X10^{-6}$m/mºC

Once we created the macro-elements, the FEA model was successively meshed (see Figure 2), until satisfactory and refined stress values results were obtained.

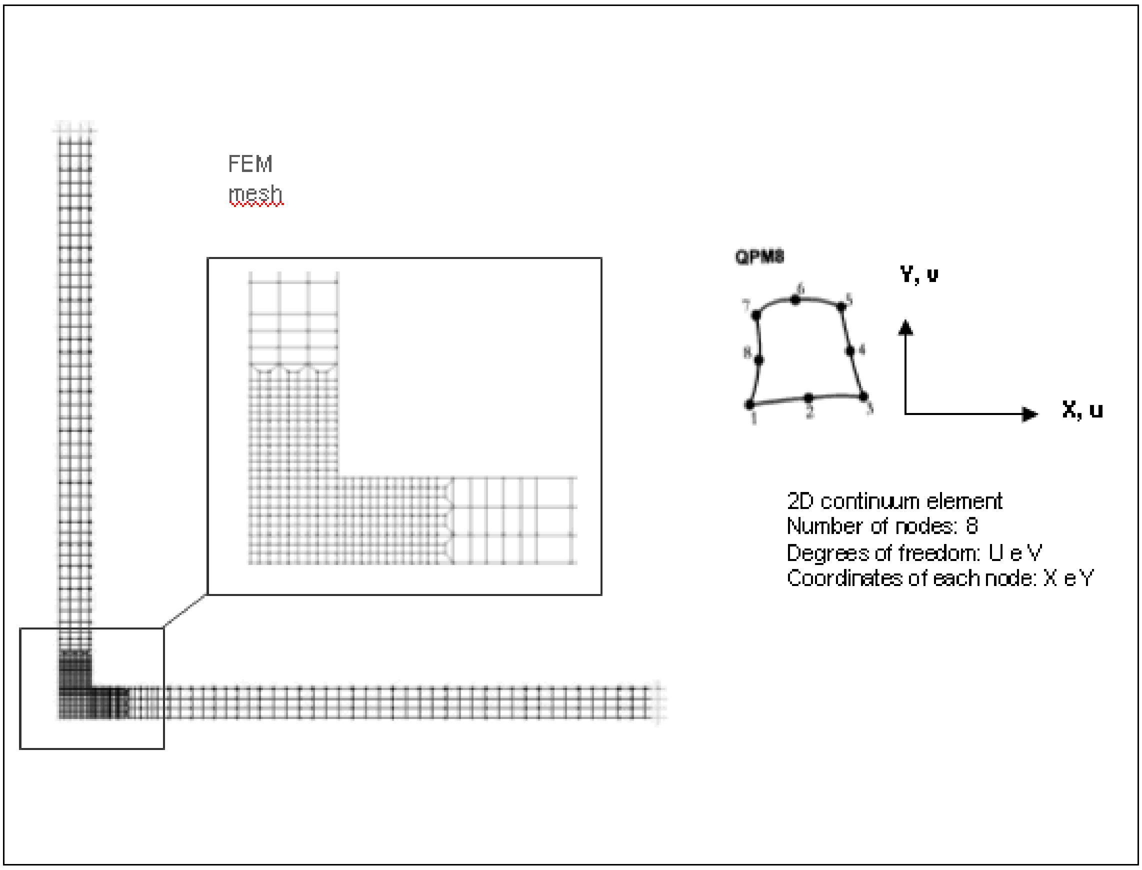


Figure 2 Finite element analysis elements and mesh

3.2 Stress plots analysis

All result diagrams, as the example shown in Figure 3, are based on an imposed temperature load equivalent to a 3mm displacement at the external angle of the model. This displacement used is a mean value of 1mm/meter expansion ratio that normally is reached in more severe cases.

The finite element analysis produced internal stress results (σ_x, σ_y, σ_{min}, $\sigma_{máx}$, τ_{xy}, τ_{min}, τ_{max}) and strains (ε_x and ε_y).

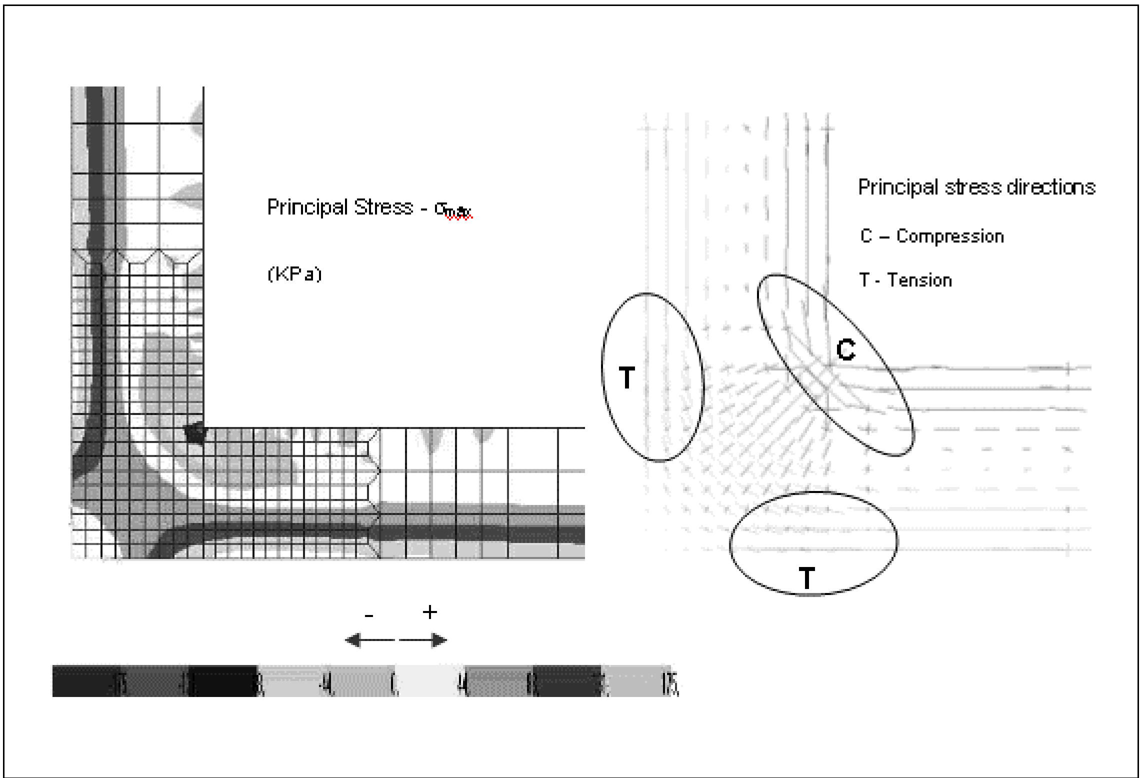


Figure 3 Computed stress output

Through this FEA analysis, some comments on results obtained, must be made:

- Stress analysis shows that the main tensile stresses occur near the masonry external edge, due to bending of the walls, that are rigidly connected;
- Maximum stress values attained are around 0.3MPa (in compression and in tension) and the principal stress directions (see Figure 3), evidence these areas of high stresses. As we know, clay material cannot support very high tensile and shear stresses and as a result of this, we can explain the appearance of cracking at external angles;
- The wall face (external wall) where the first crack appears depends on secondary effects, such as local shear stresses, bricklaying defects, different solar exposure conditions of the walls, etc, that can additionally induce important stresses to those imposed by flexural movements at external wall angles;
- The value of main stresses originated by expansion and contraction movements of both (or only one) walls rigidly bonded at the façade angles, are developed in a short distance from the external angle;
- The numerical approach is able to support, with acceptable accuracy, the defects observed and their behaviour after rehabilitation actions.

4 Reconstruction of external angle joints

4.1 Project solutions and restrictions

Cracking at external angles of extensive unconfined masonry walls, necessarily happens because of natural expansion and contraction movements of materials, associated to moisture and temperature changes [2] and in lower scale causes, to chemical reactions in materials, such as soluble salts in clay bricks and sulphate attack on mortars. These movements are conditioned by various factors relative to the materials used in the type of renderings and coverings and to climatic exposure of walls, aggravated frequently by the irreversible expansion of clay bricks [3] or in other cases, by the excessive shrinkage of cement blocks.

The traditional solution to minimize these problems consists in creating movement joints or concrete confinement pillars, or the use of steel reinforcement bars. Other complementary measures to reduce potential undesired movements are: use of light coloured paint coats, the use of thermal insulation and the use of moisture protection actions.

The next study cases to be presented, in which the creation of movement joints, were not previously considered because of the serious difficulties in guarantying water tightness of the wall and also the lack of a wall bracing scheme necessary to resolve the overall instability of the outer leafs of double leaf cavity walls lead consequently to cracking. Faced with this scenario, we assumed that the rehabilitation of external angles was the best solution and in some worse conditions, should be previously demolished and reconstructed.

The principle of the reinforcement technique used is not only based on increasing local resistance, but also on improving ductile behaviour of the external wall. Thus introducing into mortar bed joints steel reinforcement bars, it is our intention that shear and flexural stress, roused by the relative movement of one wall to the other, is distributed in a significant extent of the confining orthogonal walls, mobilizing flexural additional strength of the reinforcing steel bars introduced. It is also intended that within the wall plane, there won’t rise any stress peaks or stress concentrations in sensible areas (between the more solicited and current areas of masonry). The mismatching of the anchoring extent of steel bars in mortar bed joints and their vertical spacing helps minimizing stress and strain peaks.

The conception and design of this kind of reinforcement solutions, as well as the models defined to study these techniques cannot be independent from the execution constraints raised at the worksite: the roughness of the cutting of masonry, introduction of reinforcement and the adhesion conditions of fixing mortar are factors of relevant importance.

The possibility of demolition of the external corner angle - in some reconstruction cases - or the cutting in a “tooth wise” shape of masonry - in regard to other rehabilitation cases - is relative and depends importantly on the bricklaying mode.

4.2 Demolition and reconstruction of external angle joints

In some external angles the instability situation is of great concern: the poor basal support conditions and the lack of use of wall ties of unconfined cavity walls at angles (corner joints) lead to severe cracking, significant water infiltrations and deterioration of masonry.

In these cases, partial demolition of the other leaf and brick slips in areas of greater damage were necessary. The masonry external angles were reconstructed with horizontally hollowed clay bricks put vertically and reinforced with 4 ϕ 12mm bars and concrete infill. Horizontal welded wired reinforcement in mortar bed joints was also used and associated to the vertical reinforcement of angles mentioned above. Figure 4, illustrates the reconstruction lay out in these cases.

The demolition and reconstruction of external angles was executed according to the following stages:

- Cautious demolition of the outer leaf and brick slips. A “zig-zag” cut by course of bricks was opened, to allow an adequate enchainment and connection of existing masonry to the new reinforced masonry to be layed;
- Since their does not exist in abundance, in our national construction industry, vertical perforated clay bricks compatible with the bricks mainly used and needed in this specific case, corner angle bricks were created by cutting out 15cm width horizontally hollowed clay bricks (0.15x0.20x0.30) into 0.15x0.20x0.20 shaped bricks;
- Setting mortar for bed joints for the first layer of bricks and corner brick, then placed mortar infill for (placed in a vertical position) casting 4 ϕ 12mm bars at the corner holes;
- Careful placing of galvanised wire welded horizontal reinforcement (type Murfor RND/Z of 5mm; 50mm width) in all horizontal bed joints of new masonry. This horizontal reinforcement was anchored into the old masonry, of about 35cm and 70cm on one side and on the other respectively, alternating in bricklaying courses.
- Repetition of the stages above, carefully positioning the corner brick with it´s larger dimension alternatively, to one side and then to the other, to achieve a good level of final enchainment. Wall ties were also used.

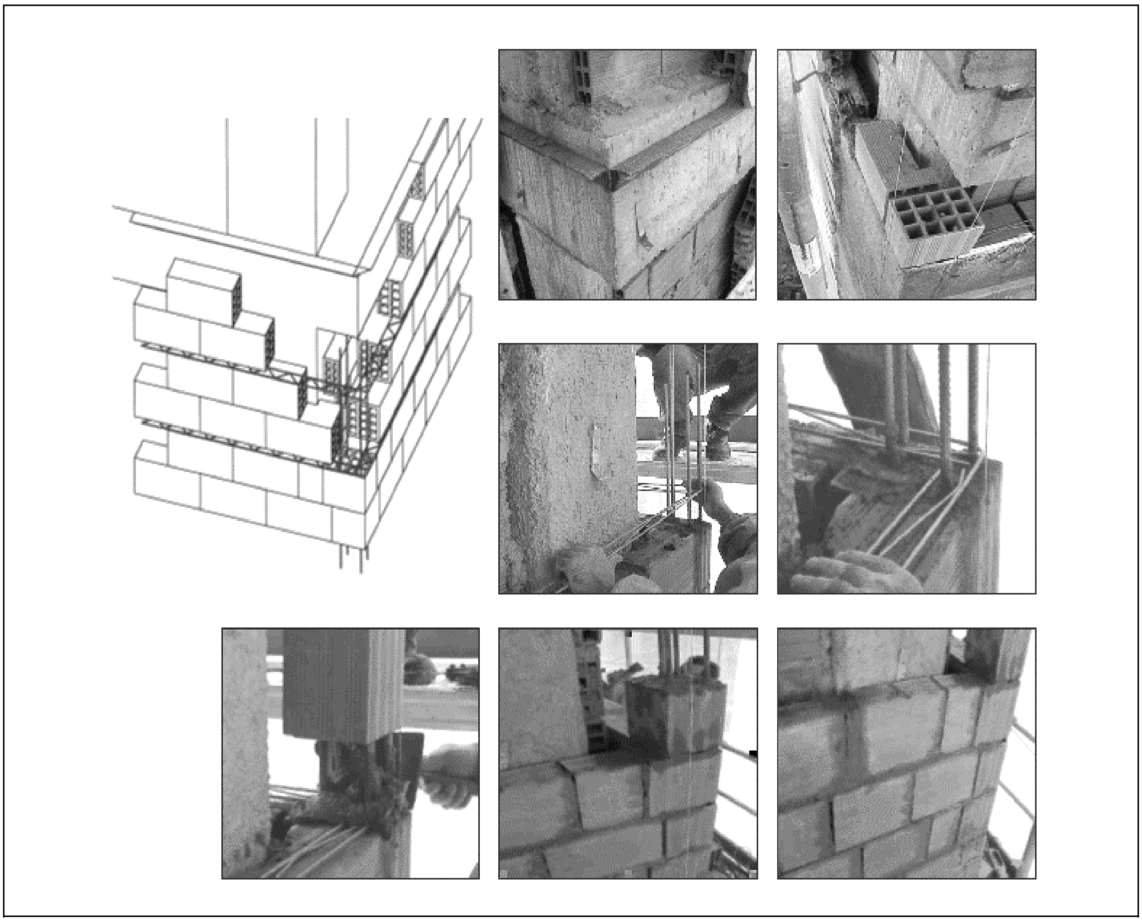


Figure 4 Demolition and reconstruction of external corner angles

4.3 Rehabilitation technique of external angle joints

The external angles of the building were produced with 7cm horizontally hollowed clay bricks used as outer brick slips for thermal bridge correction. This original solution was maintained in the rehabilitation technique of external angles, opening horizontal joints across the corner angles in both directions. Wire welded reinforcement was applied, spaced and extended to reduce to compatible values of stress for clay masonry and fixed with pre-dosed mortar with low potential shrinkage. The external angle rehabilitation lay out is shown in Figure 5. This rehabilitation technique was carried out in accordance with the following stages:

- Opening of the horizontal joints across the external angles (cut with a cross-cut saw), with adequate width and depth to apply the wire welded reinforcement spaced of 30 cm between cuts, with different and alternated extensions of cuts, see Figure 5;
- Careful placing of galvanised wire welded horizontal reinforcement (type Murfor RND/Z of 5mm and 50mm width) into the masonry cuts. This reinforcement is continuous so that it allows bending at the corner angle;
- Applying and enclosing of reinforcement with pre-dosed micro mortar (type Sika Monotop 612), applied in accordance to specific manufacturer instructions, also including final rendering;
- Repairing damaged brick slips and fragile renderings;
- In two corner angles, thermal bridge correction was only executed on one of the orthogonal faces of the concrete pillar, evidencing stability problems. Beyond the reinforcement scheme used in all other cases, there was also used stainless steel clamps spaced between horizontal reinforcement.

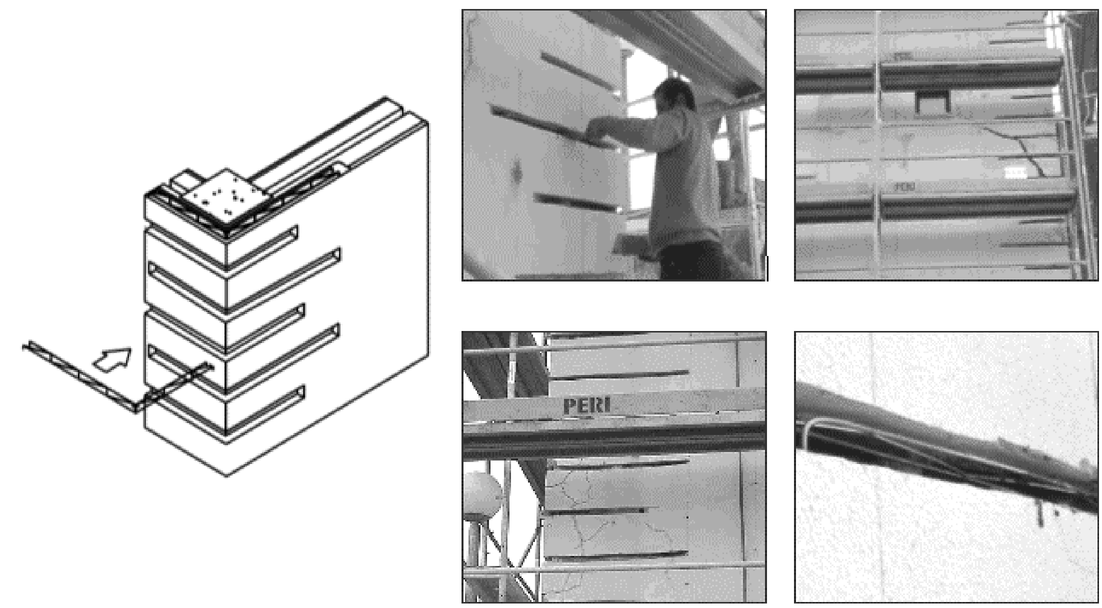


Figure 5 Rehabilitation techniques of external corner angles

5 Conclusions

There main conclusions are, now, presented under different points of view: “masonry angle cracking”, “reconstruction and reinforcing techniques” of unrestrained masonry at external angles and, at last, “numerical approach analysis”.

Masonry angle cracking:

- It is quite notorious that, in Portugal, masonry design and its execution are insufficiently supported on a sound technological knowledge, particularly in what concerns external angle detailing and execution, used to enhance thermal performance;
- Non-loadbearing masonry design must be promoted, particularly in what concerns adequate detailing of singular points;
- It is fundamental to control expansion due to moisture and temperature changes to prevent masonry defects.

Reconstruction and reinforcing of unrestrained masonry external angles:

- The described techniques (for reconstruction and rehabilitation of masonry angles in walls) seem to be positively responding;
- The further coming masonry strains and stresses have been well resisted by the introduction of vertical and horizontal reinforcement, proving the efficiency of these rebuilding techniques;
- The use of semi-reinforced masonry and connection elements (such as wall ties, anchors and crack controlling meshes to oppose to movements due to moisture content variation, temperature effects and long term effects, such as creep and irreversible expansion) have contributed for cracking control of external and unrestrained masonry walls at external angles and other masonry singular points;
- It is quite important to survey the buildings where these (or other) rehabilitation techniques have been used, to obtain the desired knowledge on their behaviour and durability over time.

Numerical approach:

- The wire welded shaped reinforcement, used in the rehabilitation techniques seem to be adequate in retaining compression stresses in the interior area of the wall corner angle and tensile stresses in the outer zone of the wall angle;
- The evaluation and estimation of stresses and movements are essential to prevent and to control masonry defects;
- 2D finite element analysis has proved to be an adequate and sufficient tool to study singular situations and reduced areas in non-loadbearing masonry walls;
- The numerical approach shows that the main reason for cracking of external masonry angles is the local over-stress due to deflection, corresponding to high tensile external stresses in the wall;
- There are no reasons to think that the length of the reinforcement bars should be longer than what it is imposed for a correct fixing.

References

Portugal, Leis, Decretos, 1990, Regulamento das Características de Comportamento Térmico dos Edifícios. Dec-Lei nº 40/90 de 6 de Fevereiro de 1990. Portugal.

Vicente, R., 2002, Pathology of Masonry Enclosure Walls. Mechanical behaviour of enclosure walls with external thermal bridge correction, (in Portuguese), MsC Thesis in Civil Engineering University of Coimbra, Portugal.

Silva, J. Mendes et al., 1995, Dimensional variation and water absorption of clay bricks. An experimental approach. Proceedings of International Symposium on Moisture Problems in Building Walls, CIB-W40, pp.127-136
Porto, Portugal.
Silva, J. Mendes, Carvalhal, M.J.A.T, Vicente R., 2003, Global Rehabilitation of Recent Masonry Façade, Affected by Severe Cracking. Case Study, (in Portuguese), 3º ENCORE, LNEC, pp. 1329-1328
Lisboa, Portugal.
Bonshor, R. B, Bonshor, L.L., 1996, Cracking in Buildings. BRE
Garston, United Kingdom.
Building Research Establishment (BRE), 1979, Digests 227-229, Estimation of thermal and moisture movements and stresses: Part 1-3
Garston, United Kingdom.
Silva, J. Mendes, Abrantes, V., Vicente, R., 2001, Precocious degradation of enclose external masonry walls with thermal bridge correction, Case Studies. (in Portuguese), Proceedings of the National Congress on Construction, IST
Lisboa, Portugal.