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A STUDY OF SOME DAMAGED ENCLOSURE WALLS

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ABSTRACT

Over the last 30 years the brick walls built in Spain have mainly been enclosure walls to framed structures which have usually been built in concrete.
However, the fact remains that due to a "loose" interpretation of the MV-201 Code "Resisting brick walls" of 1972, and its subsequent adaptation in code NBE FL-90, it has been taken over all these years that because these enclosure walls were not loaded, it was not necessary to calculate the same as there were no standards demanding the same.Over these 28 years hundreds of buildings have been built with brick enclosure walls and throughout this time subtle but fundamental changes in building have been made which reveal the true resisting characteristics of Spanish enclosure walls.
The 5 subtle but fundamental changes which have led to the current situation are as follows (Fig. 1):
1 The outer leaf of the enclosure walls has passed from one brick (24 cm) thickness to that of half brick thickness (11.5cm).
2 The outer leaf is no longer supported in all its breadth but overhangs 4cm of its 11.5cm breadth.
3 The framed structure of 4 to 5m span has been changed to one of 6 to 8m span.
4 The edge beams of the structure have been replaced by flat beams.
5 The recommendation to tie the walls to the foundations to obtain better stability.

The effect of these larger spans, particularly in more slender brickwork, as is the case of public buildings, has sometimes led to the spalling of brickwork and on occasions to the collapse of complete panels of brickwork onto the street.
Every now and again Spanish society hears with some alarm of incidents which were completely predictable and avoidable and which may well entail irreparable damage.

Key words: *Brick Masonry Cracks, Enclosure Walls, Structural & Masonry Movements.*

An analysis shall now be made of the causes which have led to the fall or cracking of brickwork in five important buildings.

The pathological or damage process is usually the result of the combination of a number of causes. However, there is usually a main cause which stands out from the others and without which the damage incurred would not have required emergency measures to be taken.

In order to systematize the disorder of these specific buildings and to clarify their investigation, we have proceeded to analyse each case under the following headings: a) Symptoms; b) Analysis: c) Diagnosis: d) Discussion, e) Treatment; f) Prevention; g) Preventative treatment (1), though here and for reasons of space we shall limit the results to the summary of points c) and d).

1. ENCLOSURE WALL DAMAGED BY EXCESSIVE FLOOR SLAB DEFLECTION

Residential housing estate, with 6 storey buildings set above ground floor portal and commercial outlets, and underground car park.

The building reveals generalised cracking, though not excessively thick or visible, which was first noted 9 years after construction.

A. Diagnosis

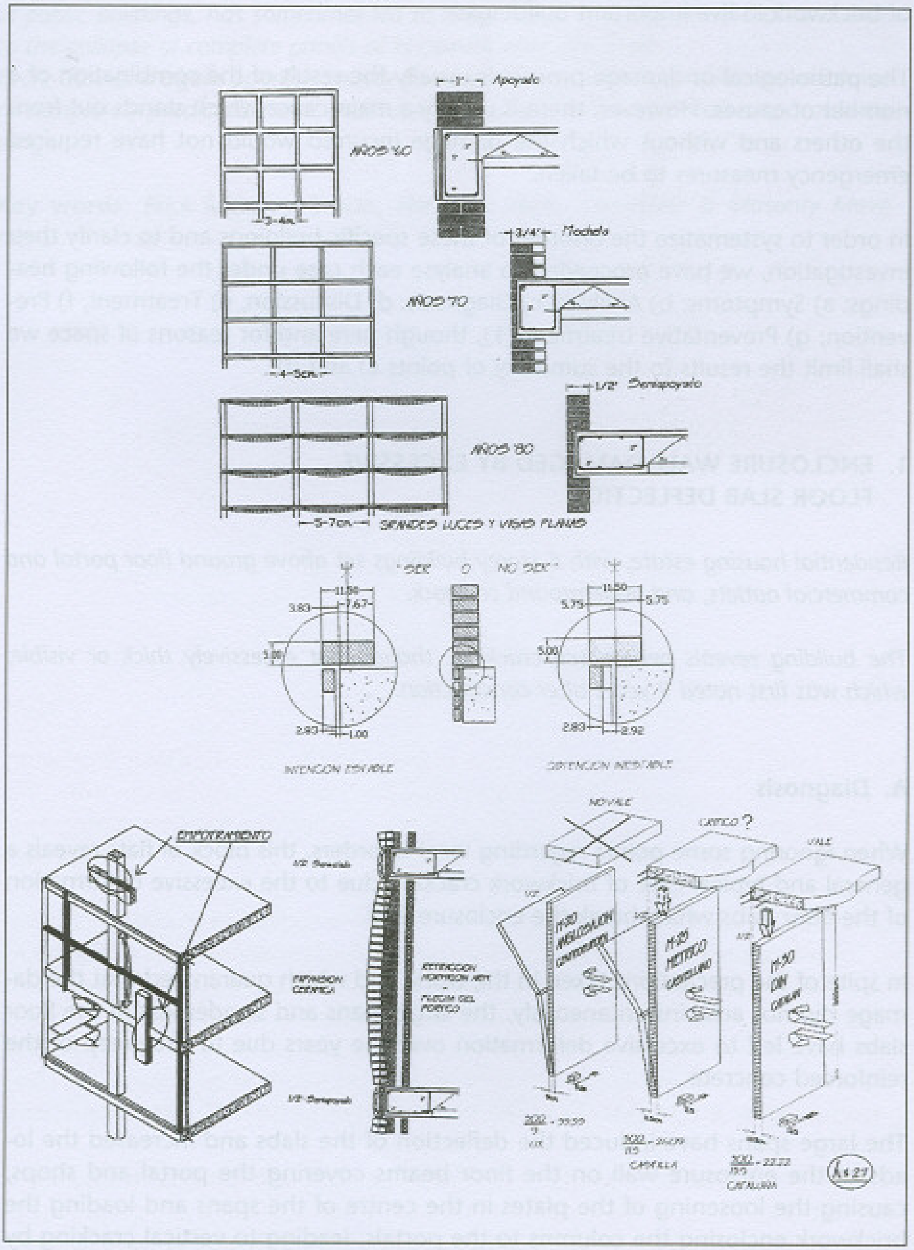
When ignoring some points regarding local disorders, this block of flats reveals a general and typical case of brickwork cracking due to the excessive deformation of the floor slabs which break the enclosure wall.

In spite of the precautions taken in the work, and which guaranteed that the damage did not arise instantaneously, the large spans and slenderness of the floor slabs have led to excessive deformation over the years due to the creep of the reinforced concrete.

The large spans have induced the deflection of the slabs and increased the loads of the enclosure wall on the floor beams covering the portal and shops, causing the loosening of the plates in the centre of the spans and loading the brickwork enclosing the columns to the portals, leading to vertical cracking by shear stress.

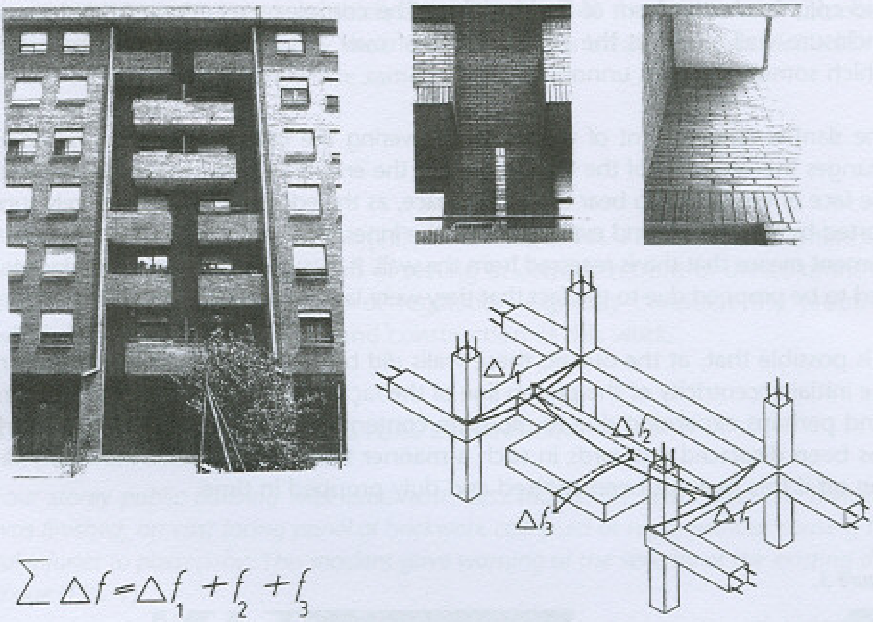
The design of the building, and particularly that of the balconies, has led to an accumulation of successive deflection, between the overhang of the balcony and the recessed header façade beams, which has further aggravated the creep and led to horizontal cracking following the bed joint and 45º cracks which have broken the orthogonal masonry.

Figure 1. Subtle but fundamental changes in enclosure walls.



The brick breastwork has been pushed out by the longer facing brickwork, leading to almost complete lack of bed support and causing 45º cracking in the said brickwork. The expansion stresses of the longer panels of brickwork have accumulated in the corners, causing the vertical cracking of the brickwork at the corner supports.

Figure 2.



$$\sum \Delta f = \Delta f_1 + f_2 + f_3$$

B. Discussion

The structure functions suitably in spite of excessive deformation and is capable of supporting the masonry without breakage. The reinforcement of the structural perimeter and the reestablishment of acceptable deflection is neither simple nor economically viable.

The structure complies with the stipulations established in the EH-80 code and the excessive deflection produced was not initially predictable (see Annexe VII). The building also complies with FFL-78 stipulations (see Annexe III) and the distance between vertical expansion joints is in accordance with that indicated in the 1972 MV-201 Code.

2. ENCLOSURE WALLS DAMAGED BY INSUFFICIENT SUPPORT IN FLOOR SLABS

5 storey housing block over shops and portals. Basements and garages. The building has general cracking in the area of the portals, it being necessary to prop two facing walls with threaten imminent collapse. This intervention was required only a few years after the building was completed (Figs. 3).

A. Diagnosis

The structure does not reveal appreciable deformation though there is clear spalling of brickwork at the propped areas.

The 6" brick wall to the propped façades overhangs sufficiently to cover the slabs and columns in the form of flush walling. The complex execution of this type of enclosure wall, requires the cantilevering of over 1/3 of the width of the brick, which sometimes goes unnoticed.

The slanted arrangement of the rowlock covering the beam on the ground floor, changes the verticality of the load transfer of the enclosure wall and leads this down the face of the façade to bear on empty space, as the edge of the brick is barely supported by the beams, and even less so in the inner section when the slanting arrangement means that this is recessed from the wall. It may well be said that the façades had to be propped due to the fact that they were lacking an real support at the time.

It is possible that, at the outset, these walls did bear on their supports, however, the initial eccentricity of the plumb line of the façade with respect to the supports (and perhaps expansion due to moisture content) has meant that the brickwork has been displaced outwards in such a manner that it would have inevitably fallen off if this had not been spotted and duly propped in time.

Figure 3.

In the other façades, the fabric partially bears on the slab beams and partially on the brick cladding of meagre thickness set in front of the beams and columns, thereby leading to cracking by shear stress as well as breaking the brick cladding to the columns and lintels of the same.

B. Discussion

The wall clearly complies with both EH-90 as well as FFL-78 Codes, and where no mention is made of the problems of setting brickwork in front of the columns or edge beams. No Spanish code or regulation explicitly considers the problem which has arisen in the design and construction of this work.

3. FRONT DAMAGED BY MOISTURE EXPANSION

Four storey public building with basement. Less than three years after the building was finished, an east facing panel of brickwork collapsed at night without causing fatal injuries to passers-by. This incident gave warning of the severity of the existing damage (Fig. 4).

A. Diagnosis

The high moisture expansion which appeared in recent testing has been gradually produced throughout the life of the building and has led to the outer displacement or swelling of the wall from its supports in response to this natural expansion.

In a vertical direction the building has 17 metres of continuous brickwork with thin mortar joints which can barely absorb the increased thickness of a fabric which, in turn, has restricted vertical movement between each floor slab. This vertical expansion has lead to the bowing of the brickwork which has vertically split the fabric in those areas of greater restriction such as the jambs of the openings.

The horizontal movement has been permitted as a result of numerous vertical expansion joints spaced every 9m, and this has prevented further damage except at the corners which were pushed by the longer panels of brickwork and which led to the displacement of the fallen unit from its original support, which was correctly carried out.

B. Discussion

After the initial shock reaction, various opposing opinions were voiced regarding the cause of the damage. The majority of these opinions could only justify the specific localised damage, but not the general damage, regardless of the structure, orientation and floor level where these appeared. Each aspect was duly discarded by means of investigation until it was only left to verify the expansion once more.

Moisture expansion test were carried out on site during construction and showed an average of 0.34 mm/m, which was in accordance with the Spanish code UNE 67-036-86. When these tests were carried out after the falling of the wall, this time pursuant to that stipulated in the current standard UNE 67-036-94, the test results revealed values of 1.4 mm/m which are sufficient to displace the rectangular panel by 2.1 cm every 15m, thereby unbalancing the same by setting its centre of gravity off vertical from the supporting heel.

In spite of the fact that more measures were taken in this work then were required by regulation and that the building complied with all standard requirements, the wall collapsed due to factors of supposedly correct construction, that is to say, the use of suitable mortar for the brickwork and the pointing of all the joints to prevent the passage of moisture due to the climatic setting of the building.

The same brick with the same expansion laid without mortar filled vertical joints, would not have pushed out the section of walling, though it would also have fai-

Figure 4.

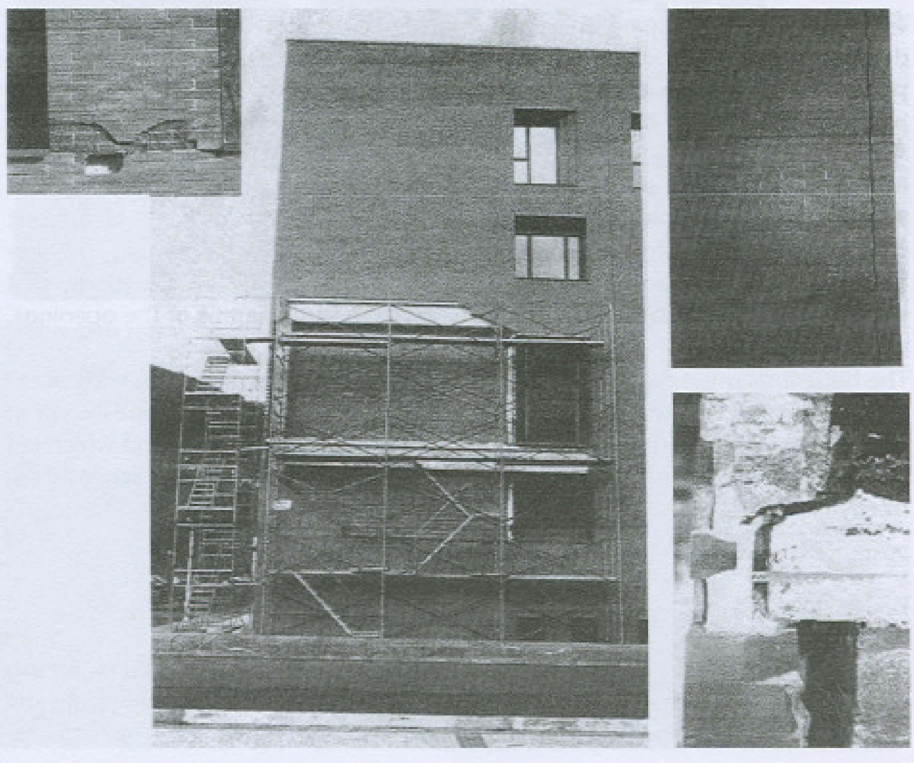
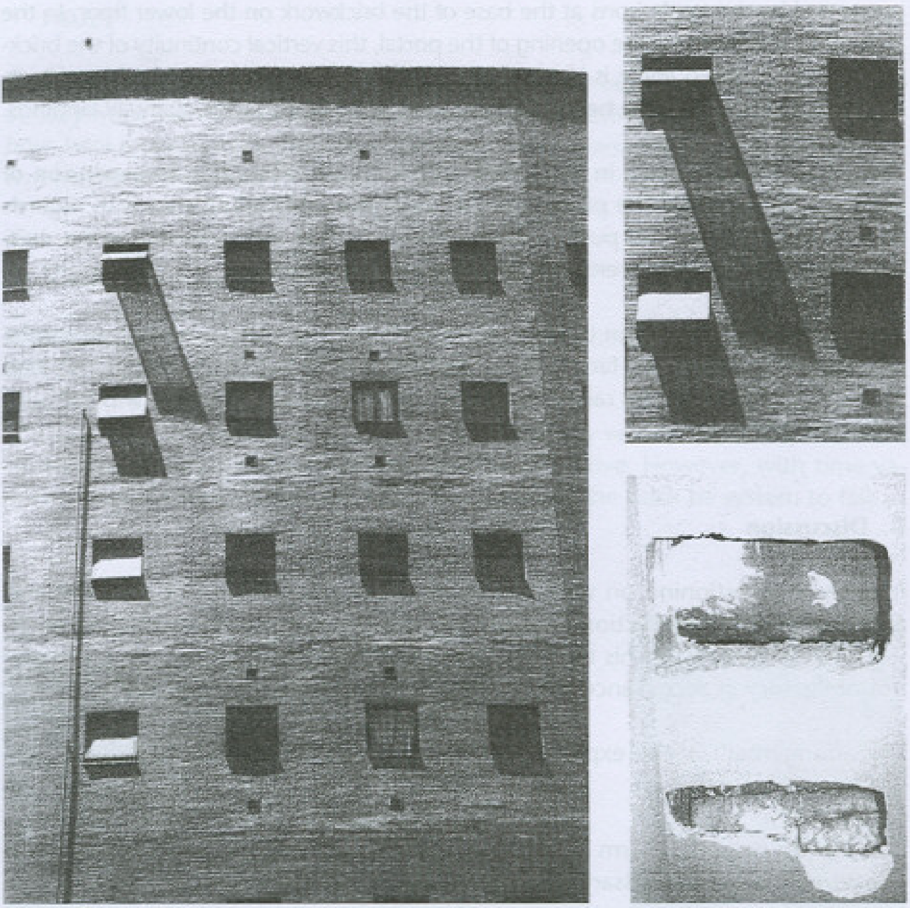


Figure 5.



led to prevent the vertical cracking in the brickwork, as this is abutted with the slabs as recommended in the code FFL-78.

4 CRACKING OF ENCLOSURE WALL DUE TO INSUFFICIENT SUPPORT

Storey apartment block with basement and curved walls. Around three years after the work was finished vertical cracking suddenly appeared in one of the curved sections of the stairwell.

A. Diagnosis

The polygonal layout of the structural edge beams differs noticeably from the continuous curve followed by the 6″ thick brick facing wall.

At certain points the brickwork runs completely free of the slab beams and is only supported by the angle irons at the base of the brickwork on the lower floor. In the area of the stairwell and the opening of the portal, this vertical continuity of the brickwork above the said angle is lost and the brickwork also fails to be suitably supported on the structural edge beams which run at mid-height of the stairway landings.

The continuing increases in the length of brickwork panels due to expansion of the brick has revealed the precarious nature of the said curved area with regards to their support, and has pushed the brickwork further outwards due to the existing curvature and has eventually destabilised the brickwork.

The structural shrinkage on the face of the slabs has marked the movement of the facing panels due to the fact that no horizontal movement joints were installed and as the brickwork was raised very soon after the structure which was still subject to shrinkage.

B. Discussion

In reply to questioning on why the design angle plates were not placed it was alleged that the construction control envisaged for this particular building made it unnecessary to place this technical supplement and that, furthermore, this was not obligatory in accordance with the FFL-78.

The arrangement of the expansion joints was in accordance with building standards.

The slightly polygonal form of the structure was raised very quickly which makes one think that the necessary slab backing was made in each case when it was known what its precise cantilever would be, in accordance with the raised brickwork.

The polygonal structure was produced involuntarily by employing straight boards with a limiting infill of fresh concrete in the making of the slabs.

The savings implied by the elimination of metal angle plates must certainly have been imperative at the time in order to offset the cost of the other parts of the work, and they must have been seen to be superfluous as there is not a long building tradition regarding the use of the same.

The speed of construction required to comply with a specific opening date led to lack of attention regarding execution in order to avoid the loss of time involved in any rebuilding. The sub-contracting system of piecework means that it is almost impossible to assure the correct execution of the work in these cases as the gang of bricklayers prefer not to raise a problem when a deficiency is seen as they charge per m^2 of work and any interruption of the work leads to a loss of time and money.

5. COLLAPSE OF AN ENCLOSURE WALL DUE TO CONSTRUCTION DESIGN FAULT

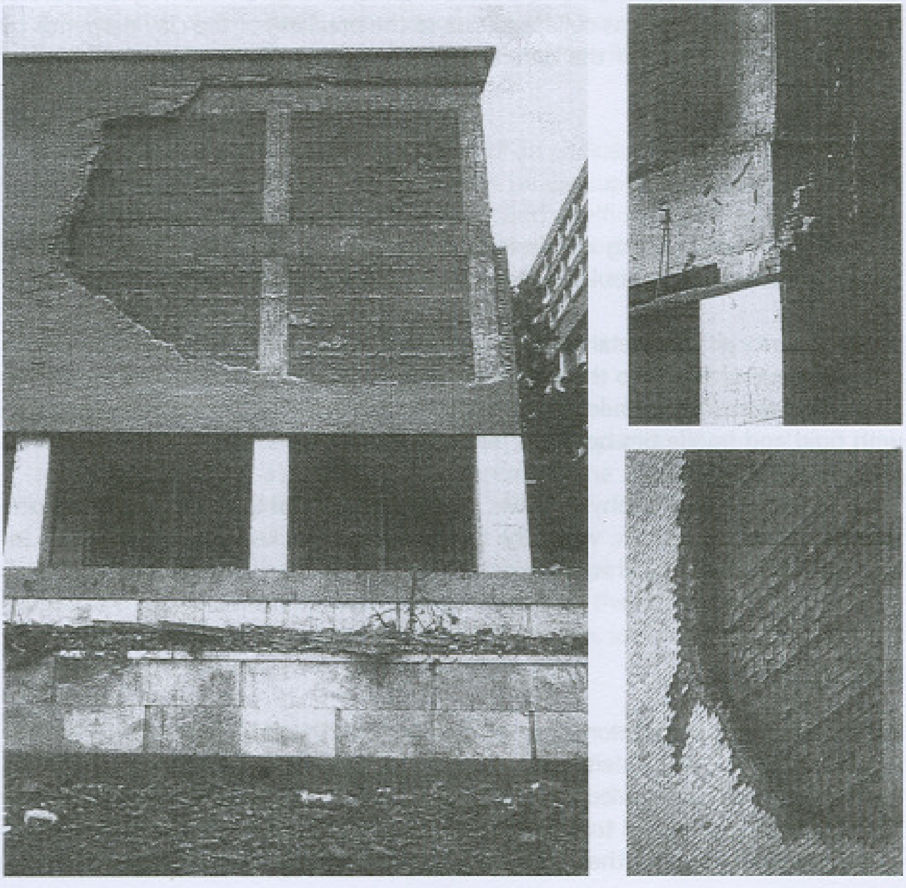
Three storey public building with portalled ground floor built over 35 years ago. One Sunday when the air was still a panel/section of west-facing brickwork collapsed without fatal consequences. The collapse has led to the questioning of the building system employed (Fig. 6)

A. Diagnosis

After many years without incident this construction suddenly became inoperative and caused the fragile collapse of the wall.

The wall has clay brick perpends or ties which initially worked perfectly, and hence the many years that the building has been operative, However, with time various circumstances have arisen which have caused the brick tie system to fail.

Figure 6.



The western facing brickwork has been more vulnerable to temperature change caused by exposure to sun.

The facing clay brickwork has become excessively hot or cold depending on the prevailing weather and has not been able to bear the temperature changes in each brick. As this brickwork is laid with perpends or header bricks between the two leaves, each one of these has been subject to constant temperature changes between the interior and exterior of the building.

The metal support has probably been yielding over the years due the combined effect of the creep in the concrete together with the taughtening of the curved steel bars which have progressively been loaded as the horizontal layer of brick started to split. This led to the gradual tensing and stretching of the bars with the ensuing lowering of the hanging lintel.

This combination of effects has reached a critical moment as the lintel hanger system has not had sufficient inertia and the lintel has turned in such a manner as to threaten the collapse of the outer layer of brickwork.

On reaching this point in an unexpected manner and given the fragile nature of the wall, the brickwork has collapsed due to the breaking of the clay perpends by shear stress as a result of the differential settlement between the two leaves of brickwork.

B. Discussion

This relatively old building is built in a form no longer in use today. However, at the time it was built it would have been difficult to forecast the collapse of wall.

The deficiency of the metal support and the unsuitability of the welded bar ties in particular, leads one to the obvious conclusion that no forethought was given to the fact that these would have to support the load, as the wall was arranged with rigid and fragile ties between the leaves, set every 5 courses.

Time has demonstrated physical laws and the ductility of the steel has caused the support to yield and turn, while the brickwork has cracked and collapsed on losing equilibrium due to this turning.

7. CONCLUSION

1. The fact that the obligatory standards of the MV-201 and its subsequent adaptation in the NBE FL-90, denominated "Resisting brick walls", do not contain a section dedicated to the calculation of brick enclosure walls to reinforced concrete or steel structures, has led to the opinion over the last three decades that it is "not necessary to calculate" these enclosure walls and this has generally been the case.

2. The NTE FFL-78 "Brick Facing Walls" confirmed the technical functionality of exposed brick enclosure walls, and considered it necessary to "caulk" with 2 cm of mortar the joints below slabs in order to guarantee the "vertical bowing effect" of the brickwork against wind action, for pressure (but not suction) purposes.

   This stopping of the joints to stabilize the wall inevitably implies the transfer of loads from the structure to the enclosure wall, so that the wall collaborates in preventing the deformation of the structure or, on the other hand, and as is frequently the case, yield and cracks. Due to the fact that the loads transferred in this manner have to be eccentric (if the brickwork overhangs from the edge of the slab) and the stresses incurred tend to bow the brickwork so that it lose its verticality.

3. The gradual evolution of concrete and steel structures, with greater structural spans and more slender slabs, employing more ductile steel, has increased the deformability of these structures.

4. The evolution over the last 30 years in the widths of brickwork from 1′ down to 6″, with the corresponding semi-overhang of the unit over the edge of the slab together with typical errors incurred in the construction process of reinforced concrete structures, has on many occasions led to precarious supports for the half thickness wall.

5. Even without considering the calculation of an enclosure wall, it is clear that for a half brick thick wall of 11.45 cm (when totally supported on the floor slab) of a free inter floor height of 3m, its buckling coefficient will reach the maximum authorised limit of 27. As such, any wall panel of greater height is unstable against any action be it wind or loads induced by the structure.

6. The lack of consideration of the building standards regarding the degree of moisture expansion of clay bricks, together with the commercial pressures of a very competitive market with a host of "similar" products, has meant that this aspect has been ignored in both the design and spacing of vertical and horizontal joints as well as in the quality control of the manufacturer who is not obliged to take this into consideration.

7. As brick is a fragile material two very different type of damage may be incurred, the cracking and subsequent resettlement of the brickwork in its new position or the rapid and sudden failure of the section, leading it to break without a prior warning in the form of cracks.

IN CONCLUSION, it is clear that there are more than sufficient reasons to justify the hazards of many Spanish half brick enclosure walls which overhang from the edge of the floor slab. This is particularly true in those enclosure walls with over 3m free height (hospitals, offices, public buildings, etc.) where the situation is clearly precarious and where any of the normal actions on the building (wind, structural deflection, brick expansion, etc.) may lead to the sudden collapse of the brick wall without warning.

IT IS SUBSEQUENTLY NECESSARY TO SUPERVISE LIMIT ENCLOSURE WALLS

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