



DESIGN OF LARGE SIZE NON-LOADBEARING MASONRY WALLS: CASE STUDIES IN PORTUGAL. TECHNICAL AND ECONOMICAL BENEFITS

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Abstract

Masonry walls exhibit cracking frequently. This is mostly a consequence of the lack of detailing in the design project and the absence of a clear responsible for the performance and safety of this building element. The incorporation of a low percentage of bed joint reinforcement allows creating a composite material with tensile strength. This reinforced material leads to conceive new technological solutions but also a crack-free architecture. Here, the recurrent damage in Portuguese masonry walls is detailed and new solutions for medium and large size masonry walls are addressed. For a given case study, an economical analysis is carried out, comparing the original solution and the alternative solution adopting bed joint reinforcement.

Key Words

Bed joint reinforcement, cracking, non-loadbearing walls, case studies

1 Introduction

Masonry works, including rendering, amount to 13-17 % of the total building cost, Bezelga (1984). Nevertheless, it is common that walls exhibit inadequate performance and defects. Figure 1 illustrates the fact that masonry walls are responsible for 25% of the damage in buildings. From the damage in enclosure walls, around 50% are due to cracking and water leakage, both for France and Spain, Bureau Securitas (1984) and ASEMAS (1997). The performance of (non-structural) masonry walls is usually linked to the structural system and the foundations selected for the building. In particular, it is normal that damage results from inadequate behaviour of the beams, slabs and foundations, due to shrinkage, creep, thermal movements, excessive deformation and soil settlements.

The financial risk of masonry walls is demonstrated by the Spanish experience, ASEMAS (1997), where 20% of the damage claims are accepted by common agreement and the legal actions are judged favourable to the petitioner in 70% of the cases. The designer (the architect in Spain) is considered the sole responsible in 12%

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of the cases and co-responsible together with the other agents in the remaining 88% cases.

The building industry is traditionally against changes and innovation but the situation described must be addressed taking into account technological developments, namely using bed joint reinforcement.

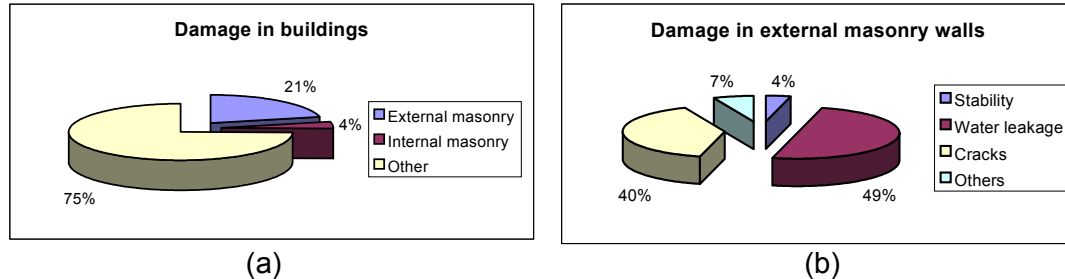


Figure 1 Survey of the damage indexes in masonry walls, Bureau Securitas (1984).

2 Building defects in Portuguese masonry

The defects observed in Portuguese masonry walls are mostly related to the following aspects: (a) floors and reinforced concrete structures excessively slender, leading to significant loading and severe cracking; (b) inadequate tying between (infill) masonry and structure, meaning that no ties are used but also no movement joints are made; (c) very low strength masonry walls; (d) cavity walls inadequately built; (e) singular points, e.g. around openings, without proper detailing; (f) solutions to resolve thermal bridges that result in additional damage; (g) inadequate rendering selection and too fast application; (h) architectural solutions for the façades that do not take into account the quality of the workmanship, the requirements for durability and the raining water.

Figure 2 illustrates some damage-prone situations observed in different buildings, collected from Silva (2002) and Sousa (2002).

3 Applications in long walls

Building long-span masonry walls requires special attention, taking into account the competitiveness of the solution (cost and execution period), safety and the performance under service conditions (cracking). Next, some recent case studies are illustrated.

3.1 Materials

Reinforced masonry is a composite material made of units, mortar and reinforcement. Reinforcement must be placed according to the building technology of walls, meaning that horizontal joints act as continuous planes for placement of reinforcement. This leads to a macroscopically homogeneous material with horizontal tensile strength.

Masonry units in Portugal are, commonly, of clay brick, with variable thickness, height of 0.20 m and length of 0.30 m, or concrete block, with variable thickness, height of 0.20 m and length of 0.40 or 0.50 m. The quality of the masonry products is, in general medium or low, in spite of the recent modernization of industry and the requirements for certification, Sousa (2002). Therefore, the selection of products cannot be based simply on the cost.

Mortar in Portugal is commonly prepared on site from cement and sand, exhibiting poor workmanship, adhesion, water retention ability and elasticity modulus. The joints have thickness around 1 or 1.5 cm. Recently, the usage of ready-mixed and pre-mixed mortars have increased, which is clearly beneficial for masonry.

Bed joint reinforcement must be in agreement with EN845-3, CEN (2001).



Figure 2 Examples of damage-prone situations: (a) simultaneous construction of the structure and the walls; (b) large cantilever spans and flexible structures; (c) curved walls and insufficient bond between the units; (d) inadequate correction of thermal bridges; (e) inadequate brick and bond; (f) lack of movement joints; (g) non-acceptable solutions around openings; (h) masonry joints with unacceptable thickness; (i) unacceptable opening of chases.

3.2 Definition of actions

Non-structural masonry walls are subjected to in-plane actions solely due to their self-weight. Masonry walls exhibit very high stiffness in their own plan and, as a consequence, typical cracking occurs, see Figure 3a. Damage is usually associated with the deformation of the top slab, which is partly supported by the masonry wall, and the deformation of the bottom slab, which leads to tensile stresses in the masonry walls. Figure 3b illustrates a possible solution to avoid damage, by: (a) separating the wall and the top slab, using a deformable interposition layer (e.g. expanded polystyrene); (b) separating the wall and the bottom slab using a damp proof course or similar (e.g. a PVC membrane); (c) placing distributed bed joint reinforcement, for crack control, and additional bed joint reinforcement in the wall base, to provide the necessary strength to the self-weight of the wall. The latter should be designed according to the beam theory or to the deep-beam theory, as a function of the height to span ratio.

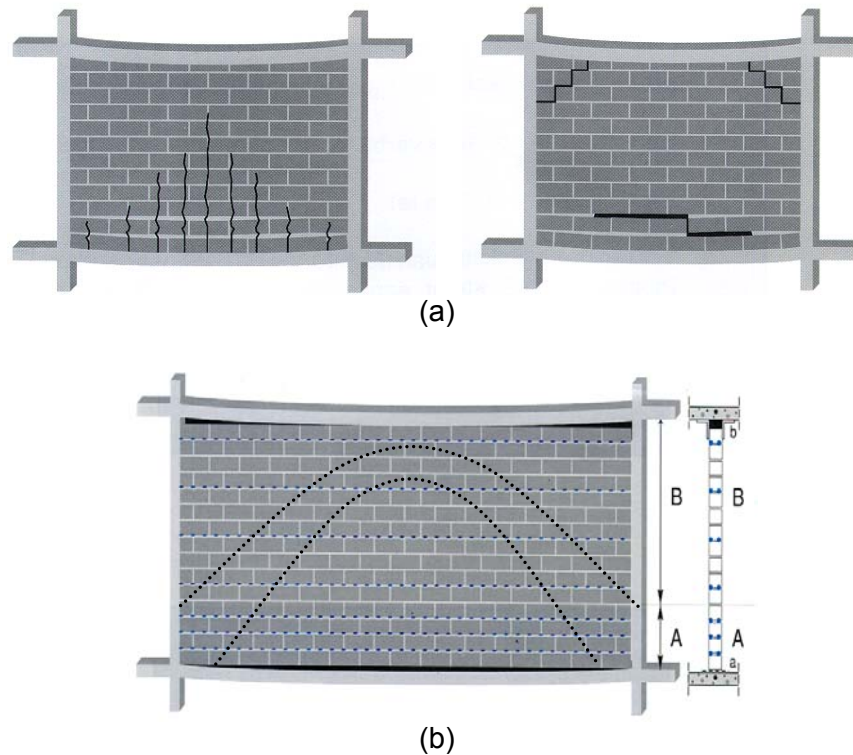


Figure 3 Behavior of non-structural masonry walls: (a) damage due to excessive slab or beam deflection; (b) possible solution to avoid damage and arching effect.

With respect to the out-of-plan actions, both internal / external wind pressure and seismic effects must be considered. In the Portuguese case, typical values of horizontal actions for internal walls are in the range of 0.20 to 0.45 kN/m².

Finally, for indirect actions or crack control, the minimum value from Eurocode 6 requires a steel cross section larger than 0.03 % of the wall cross section and vertical spacing between bed joint reinforcement lower than 600 mm.

3.3 Case studies for the stadiums in the Euro 2004

Figure 4 presents the examples of masonry with bed joint reinforcement in three new stadiums in Portugal, built for the European Championship 2004. These high performance walls are cost competitive in comparison with the traditional solution using vertical and horizontal embedded reinforced concrete elements. Bed joint reinforcement is introduced in the masonry simultaneously with the wall construction, meaning that almost no changes are made in the traditional technology for building masonry walls.

Next, the solutions adopted for the new stadium of “Sporting Clube de Portugal” are addressed. The following materials have been used:

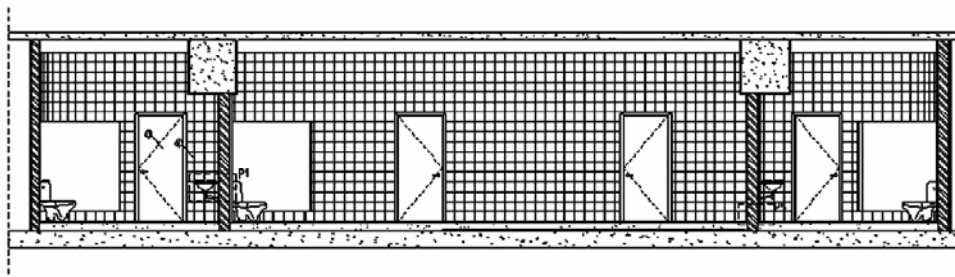
- Concrete blocks $0.50 \times 0.20 \times 0.20$ m³ from Group 2b (EC6), with a normalized compressive strength of 7.3 N/mm².
- Joints with a thickness of 1.5 cm and mortar 1:4 (cement:sand, by weight) using cement 42.5 (Mortar class M6);
- Galvanized Murfor® bed joint reinforcement, with two rebars of 5 mm and width of 0.15 m (RND/Z.5-150);
- Embedded columns using concrete class C16/20 and steel class S500.



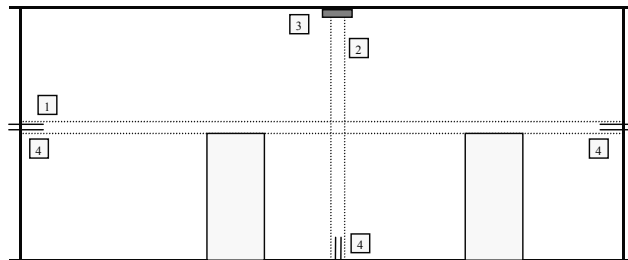
Figure 4 Global views and details of the Euro 2004 stadiums with bed joint reinforcement Murfor®: (a) Sporting; (b) Benfica; (c) Braga.

One situation with repetitive pattern that is worth to discuss are the walls of the toilet rooms, which have a span of 10.40 m and a height of 4.40 m, with door openings for access. The original solution included apparent vertical and horizontal reinforced concrete elements embedded in the wall. The reinforced concrete elements would be connected to the structural neighboring elements by steel dowels and angles, see Figure 5. Figure 6a illustrates the adopted alternative solution using bed joint reinforcement, which features the following advantages: homogeneous material with tensile strength; no requirement for special U block in the horizontal element and for special two-large cells block for vertical element (if the r.c. elements are not to be apparent in the faces of the wall), and no requirement for any reinforced concrete embedded elements. Therefore, the alternative solution is faster to build and is more rational. Figure 6b provides the model adopted for analysis with respect to out-of-plane loading.

In general, long non-loadbearing masonry walls could be found in several locations of the stadium. Wall lengths larger than 30 m and slab spans up to 16 m could be encountered. The typical solution in these cases was based in reinforced concrete elements properly connected to the surrounding frame and placed inside pockets of the masonry units. The usage of bed joint reinforcement allowed increasing significantly the spacing between the embedded vertical elements. Typical maximum spans were given for panels with different reinforcement ratios. From these spans, the works were prepared, taking into account the free span of each panel and optimizing the solution with respect to the free span (i.e. span between transversal walls or columns of the surrounding structure).



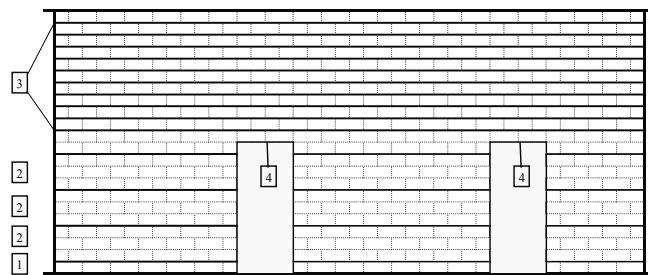
(a)



Legend: 1 - Horizontal r.c. element with $4\phi 10$ and stirrups $\phi 6@0.15$; 2 - Vertical r.c. element with $4\phi 10$ and stirrups $\phi 6@0.15$; 3 - Steel angle $L75\times 75\times 8$; 4 - Dowels $4\phi 10$ inserted in the surrounding concrete

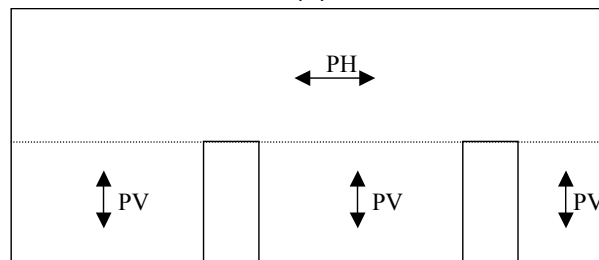
(b)

Figure 5 Access walls for the toilet rooms: (a) architecture and (b) original solution.



Legend: 1 - One truss RND/Z.5-150 at the wall base; 2 - One truss RND/Z.5-150 each three courses (each 0.60 m); 3 - Ten trusses RND/Z.5-150, 4 - Two hooks LHK/S 170

(a)



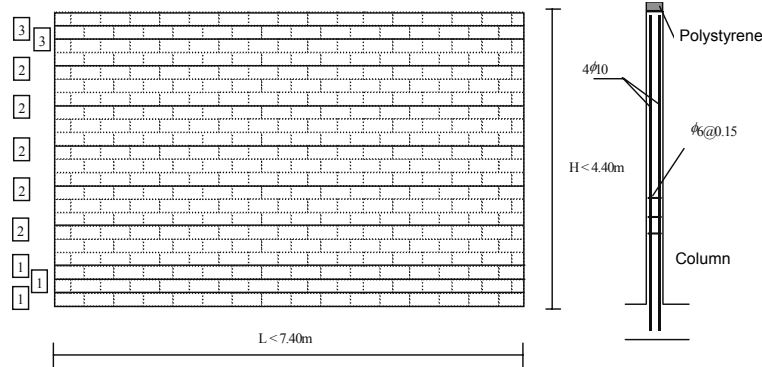
(b)

Figure 6 Access walls for the toilet rooms: (a) adopted alternative solution and (b) model for structural analysis and design (arrows indicate the spanning direction).

The following typical solutions have been adopted (maximum height of the walls $h < 4.40$ m), see also Figure 7:

- Spacing of r.c. vertical elements up to 7.4 m, without support at the top. Bed joint reinforcement (in general): RND/Z.5-150, each 3 courses (0.60 m). Base reinforcement: 3 consecutive courses. Steel in r.c. element ($4\phi 16+\phi 6@0.15$);

- Spacing of r.c. vertical elements up to 7.4 m, with support at the top. Bed joint reinforcement (in general): RND/Z.5-150, each 3 courses (0.60 m). Base reinforcement: 2 consecutive courses. Steel in r.c. element ($4\phi 10 + \phi 6 @ 0.12$);
- Spacing of r.c. vertical elements up to 9.0 m, without support at the top. Bed joint reinforcement (in general): RND/Z.5-150, each 2 courses (0.40 m). Base reinforcement: 4 consecutive courses. Top reinforcement: 2 consecutive courses. Steel in r.c. element ($4\phi 10 + \phi 6 @ 0.12$);



Legend: 1 - Three trusses RND/Z.5-150 at the wall base; 2 - One truss RND/Z.5-150 each three courses (each 0.60 m); 3 – Two trusses RND/Z.5-150 at the wall top

Figure 7 Typical example of the walls built in the new stadium of Sporting.

4 Cost analysis

The alternative solution proposed for a large shopping mall in Portugal, Odivelas Parque, is similar to the solutions detailed in Section 3.3. The walls are made of concrete blocks with $0.50 \times 0.20 \times 0.20 \text{ m}^3$, with typical spans of 12.0 m and a typical height of 5.80 m. The experience of damage in these constructions resulted in the original prescription of heavily reinforced walls, see Figure 8. The original solution included r.c. columns at a maximum distance of 3.0 m and r.c. beams every 5 courses (or 1.20 m). In addition, dowel bars were supposed to be placed at the base, every 0.40 m.

The original solution includes a beam of $0.20 \times 0.20 \text{ m}^2$, with $A_{sl} = 4\phi 10$ and $A_{st} = \phi 6 @ 0.20$ every 1.20 m. For each square meter of wall, the weight of steel $M_{sl} = 4 \times 0.785 \text{ cm}^2 \times 1 \text{ m} \times 7700 \text{ kg} / 1.20 \text{ m} = 2.01 \text{ kg}$ and $M_{st} = 5 \times 0.283 \text{ cm}^2 \times 0.65 \text{ m} \times 7700 \text{ kg} / 1.20 \text{ m} = 0.59 \text{ kg}$, in a total of 2.61 kg of steel / m^2 of wall. Also, per square meter of wall, the concrete volume is $V_c = 0.14 \text{ m} \times 0.17 \text{ m} \times 1 \text{ m} / 1.20 \text{ m} = 0.0198 \text{ m}^3$ of concrete / m^2 of wall. In such a way, the additional cost of the original beam per m^2 of wall, with respect to a standard masonry wall, can be estimated as $2.61 \text{ kg} \times 0.78\text{€} + 0.0198 \text{ m}^3 \times 99.0\text{€} = 4.0 \text{€} / \text{m}^2$ of wall.

The original solution includes also a column, every 3.00 m. Similarly, the additional cost is equal to 1.6 € / m^2 of wall. The cost of the dowel bars and the special units (U shape and two open cells) will be assumed equal to 2.0 € / m^2 of wall.

The proposed solution results in an additional cost, with respect to a unreinforced wall, equal to 2.8 € / m^2 of wall. In the values above, the increase of productivity is not included. From the experience gained in situ, the productivity gain is in the order of 1 to 2 (original vs. proposed alternative solution). For Portugal, this means a productivity of 0.45 h / m^2 of main worker (10.5 € / h) and 0.27 h / m^2 of auxiliary worker (8.0 € / h). These values result in an additional saving of $-6.9 \text{€} / \text{m}^2$ of wall. For the 20.000 m^2 of walls, the proposed solution leads to savings of $[(4.0 + 1.6 + 2.0) - (2.8 - 6.9)] \text{ euros} / \text{m}^2 \times 20.000 \text{ m}^2 = 234.000 \text{ euros}$, being the largest item associated with the productivity gain.

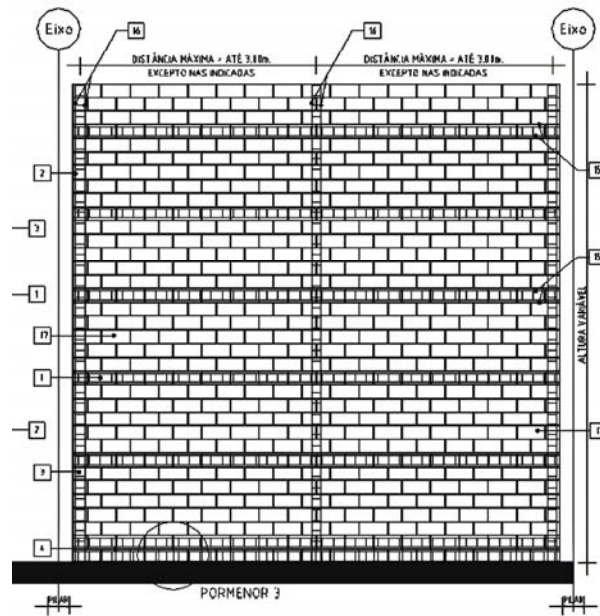


Figure 8 Aspect of the original solution for non-load bearing masonry walls in a shopping mall.

5 Conclusions

Cracking of non-loadbearing walls is a major defect of the building industry. Bed joint reinforcement is a possible solution for this problem. The usage of bed joint reinforcement can also allow building large size non-loadbearing walls, with better performance and lower cost. Here, innovative case studies are presented and discussed.

In addition, it is also stressed that according to the new European seismic regulations, the non-structural masonry infills should be taken into account in the seismic analysis. The adverse effects of irregularity must be considered and collapse must be avoided. Therefore, bed joint reinforcement or other similar solutions should be adopted in areas of high seismicity.

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