Analyse of EC6 and its recent changes - application to reinforced masonry structures

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October 2019

Abstract

In the present paper it will be highlight the advantages of applying an unreinforced and reinforced masonry structure in order to contribute to the growth of this sector in the national context, while trying to counter the ideology that structural masonry is a less efficient construction technique when compared to other construction techniques.

Thus, this paper intends to enhance the conception and design processes of a masonry structure, along with expose the behaviour of masonry walls, when subjected to different types of loading.

It will be given more emphasis to reinforced masonry, since it has a greater stress redistribution ability, therefore becoming a more reasonable solution and consequently more propitious to be apply within the framework of Portugal.

The design rules for reinforced masonry elements will be presented according to a provisional Eurocode 6 version which is expected to be released in 2019 and will replace the current version of EN1996-1-1 (2008). The main reasons for these changes will also be explained.

This paper concludes with the study of a practical case in order to implement the design rules in a reinforced masonry structure and carry out the respective security checks on the structural walls, according to the provisional version of EN1996-1-1.

Key-words: Reinforced masonry; Eurocode 6; Unreinforced masonry; Structural behaviour; Structural masonry conception

1 Introduction

Masonry develops a key role as constructive technique since the first civilizations, as a result of its advantages such as low cost, ease production and application. However, with technological advances and the emergence of new forms of construction, masonry construction in seismic zones has been replaced by reinforced concrete and steel structures due to their better seismic behaviour. The apparition of reinforced masonry structures came to counter this decadence, and is, in fact, an efficient solution to be applied in a seismic region.

The motivation for this work is, therefore, to understand the conception and design of a reinforced masonry (RM) in order to apply these concepts in a study case.

It is expected to come out a new version of Eurocode 6 in 2019, which will give new guidelines and provide better design principles to be implemented in unreinforced (URM), reinforced and confined masonry. Consequently, this work will also provide further explication to those alterations in masonry design.

As such, one realizes the importance that armed masonry may have at the national level. This dissertation was motivated by the need to import this form of structural design to Portugal, seeking to study the behaviour and safety verification of a reinforced masonry structure through the implementation of a study case.

2 Structural behavior of reinforced walls

2.1 Tension load

The tension strength of an URM is generally very low, and it's controlled by the bond between the masonry units and mortar. Eurocode 6 doesn't have design guidelines for walls subjected to only tension loads because it's very rare for that to happen. It only take into consideration tension when a flexure mechanism occurs. [1]

The incorporation of reinforce in a masonry wall increases the ultimate strength, because after the occurrence of the first crack, it will contribute to redistribute tension along the wall until the reinforcement breaks. [1]

2.2 Compressive load

An URM wall typically doesn't have problems when subjected to compression forces related to the weight of the building. Normally, this force could be considered as favorable when a shear load is taking into account.

In an URM wall, the collapse usually occurs by rupture of masonry units, due to the interaction of the unit and mortar since it is a more deformable material than the brick, such as shown in the Figure 1. Consequently, when subjected to compressive forces the unit will try to follow the mortar and, when the tension strength is reach, a vertical crack occurs. [1]

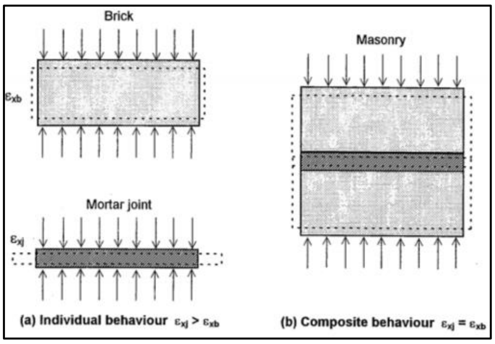

Figure 1 – Individual and composite behaviour of the brick and mortar joint in compression [1]

The expected new version of Eurocode 6 doesn't have an increase of compressive strength due to the incorporation of reinforced in masonry. However, since the inclusion of reinforced bars in the bed joint can delay the deformation of the mortar, this can provide an increase of compressive strength of the wall. [2] Nevertheless, numerous authors have suggested different formulations to take in to account the increment of strength due to the reinforcement. [3]

2.3 Shear load

The main reason why the URM structures are, nowadays, scarcely used is because of their

poor performance when subjected to a seismic load due to the brittle behaviour of masonry. [4]
The collapse of a URM can occur because of a shear or bending mechanism. The first one is characterised by the appearance of a diagonal crack in the interface of the bricks and mortar, risen by a state of biaxial tension-compression stress. Whereas, a bending mechanism can be originated by the occurrence of excessive compressions in one edge, resulting in a local crushing of the units of masonry. This incident its usually mentioned as “toe crushing” and is also related to high levels of compressive loads. On the other hand, in the other extremity a local accumulation of tension stresses can occur, that easily overcome the tension strength of the bed joint. For low levels of compression load can also occur a sliding failure case by the split of the entire bed joint. [4]
In the Figure 2 it’s possible to understand the contribution of axial load for the incremented of shear strength as well as a failure controller.

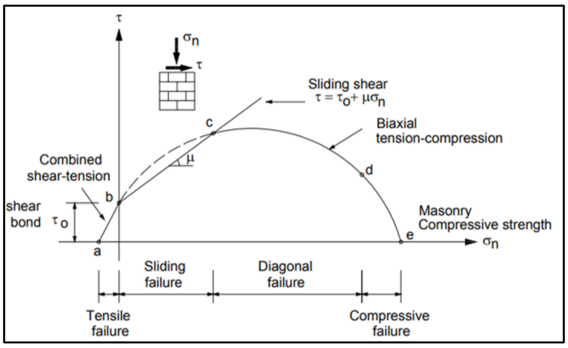

Figure 2 – Behaviour of URM under a combined shear and normal stresses [4]

The appearance of the first crack in a URM wall leads to an enormous decline of masonry strength. A RM wall behaves equally to an URM wall until the first crack happens, after this, the reinforced presented in the bed joint, while in tension, will redistribute the stress along the entire wall. [4]

The consideration of the increment of strength due to the bed joint reinforcement can only be assumed if the truss mechanism is guaranteed. In this regard, the reinforced in the bed joint must be corrected associated with de vertical reinforcement. [4]
Following analyses in recent seismic events, it was perceptible that in shear walls, out-of-plane displacements in their edges could occur. Caused by the alternance of tension-compression and the buckling of vertical reinforcement due to the cyclic behaviour. [5]
The Eurocode 6 has design principles regarding masonry walls subjected to shear load, considering the strength given by the masonry and bed joint reinforcement. The contribution of vertical reinforced, known as “dowel effect” is given in Annex J, yet, in the current version this annex can’t be applied in Portugal. [2]

2.4 Flexural load

When a building is subjected to an earthquake, the majority of the load is directed to the shear walls. Yet a small part of the load can be transmitted to the wall arranged in the other direction resulting in out-of-plane movement. The wind pressure also originates this type of movement. [4]
As shown in Figure 3, usually the bending performance is analysed in the vertical and horizontal directions since these are the principal directions of a wall. However, since usually the wall is fixed in three or four sides, it results in a combination of both bending. [4]

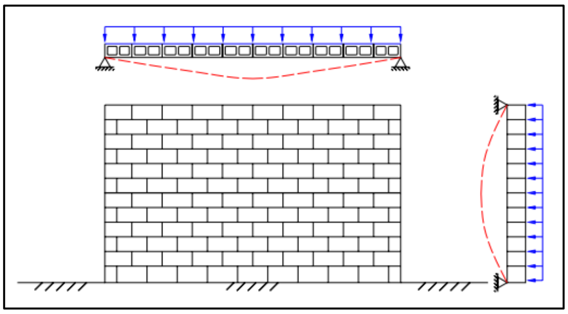

Figure 3 – Flexure in the two principal directions [4]

In RM walls, the vertical reinforcement will maintain the wall consistence after the appearance of the first crack and will continue to receive stresses until vertical reinforcement reaches the ultimate deformation. [4]

Research studies have shown that an area of vertical reinforcement of 0.2% of the total area of the wall, leads to the increase of the ultimate load and ductility. Studies also have revealed that for high percentage of reinforcement the increase will not be very appropriate since, although it increases the ultimate load, it will also reduce the deformation's capacity. [6]

In RM the cavities to introduce vertical reinforce are normally filled with grout. Investigations have shown that for the same percentage of reinforcement, whether the cavities are partially or totally grouted, the results for the ductility's capacity or the ultimate load will be similar. [6]

3 Design of reinforced masonry, according to provisional EN1996-1-1

In the next subchapters the alterations that occurred in a provisional version of Eurocode 6 will be enhanced. For the best understanding of the flowing subchapters, masonry can be divided in the following two sets: [2]

- Set 1 – Group 1 units;
- Set 2 – Group 1 lightweight aggregate units, group 2, 3 and 4 units and units not fitting into Table 1.

3.1 Axial verification

Recent studies have shown that the introduction of bed joint reinforcement increases the compressive strength. [3] [20]

However, both versions of Eurocode 6 don't give any equation to consider the effect of bed joint reinforce to contradict the strain of the mortar, but there are other standards that provide expressions to account this effect. [8]

3.2 In-plane and out-of-plane verification

According to the provisional new version of EN1996-1-1, the design of a single reinforced rectangular cross-section, or when compressive reinforcement in neglected, the design value of the moment resistance, M_{Rd}, can be taken as express in Eq. (1). [2]

$$M_{Rd} = A_s\, f_{yd}\, z \tag{1}$$

Where A_s represents the cross-sectional area of the reinforcement in tension, f_{yd} is the design strength of reinforcing steel and the lever arm, z, is given by Eq. (2). [2]

$$z = d\left(1 - 0.5\frac{A_s\, f_{yd}}{b\, d\, \eta_f\, f_d}\right) \leq 0.9\, d \tag{2}$$

In Eq. (2),d, is the effective depth of the section, b is the width of the section, f_d is the design compressive strength of masonry and η_f is factor that defines the equivalent rectangular stress block. [2]

The main alterations for the current versions are: [2] [9]

- Acknowledge the rectangular distribution of tension as 0.8x, eliminating the parameter λ;

- Changing the limitation of the maximum value of the lever arm to 0.9d and introducing η_f to separate the different groups.

These alterations came to give some consistency to Eurocode 6. The maximum resistance moment was also reduced and can be calculated through the expression given in Eq. (**3**). [2] [9]

$$M_{Rd} \leq 0.37\ \eta_f\ f_d\ b\ d^2 \qquad (3)$$

This reduction takes in to account the yield strength of the reinforcement for A500 ribbed steel ($\varepsilon_{yd} = 2.18$‰) and the limit values given in Eurocode 6, which limit the compression strain to 3.5‰ e 2.0‰ depending of the group unit. [9]

3.3 Walls subjected to second order effects

When a slenderness ratio is greater than 12, the second order effects should be considered by adding a design moment, M_{ad}. Then the resistance moment can be given by the Eq. (4). [2]

$$M_{Ed} = M_{1Ed} + M_{ad} = M_{1Ed} + N_{Ed}\ e_2 \qquad (4)$$

Where M_{1Ed} is the first order design value of the moment applied and N_{Ed} is the design value of the vertical load. [10]

The current version of EC6, calculates the second order eccentricity based on a nominal curvature, taking in consideration what was already done with reinforced concrete. [10]

In the provisional version, the second order eccentricity is calculated by following a section analysis for reinforced masonry section but has in consideration the limit strains of masonry, ε_{mu}, and the limit stain for steel, ε_{yd}, as shown in Eq. (5). [10]

$$\left(\frac{1}{r}\right) = \frac{|\varepsilon_{mu} + \varepsilon_{yd}|}{d} \qquad (5)$$

By implementing the limit strain for each set, the values of the second order eccentricity of the vertical load, e_2, are the ones presented in Eq (6) and Eq (7). [10]

$$e_2 = \frac{h_{ef}^2}{1800\ d} \qquad (6)$$

And

$$e_2 = \frac{h_{ef}^2}{2400\ d} \qquad (7)$$

Where h_{ef}, represents the effective height of the wall.

3.4 Shear verification

In the provisional version shear resistance is given by Eq.(8) .

$$V_{Ed} \leq V_{Rd1} + V_{Rd2} \qquad (8)$$

Where V_{Rd1} is given by Eq. (9).

$$V_{Rd1} = f_{vd}\ t\ d \qquad (9)$$

Compared to the current standard, the Eq. (9) considers the effective depth of the wall in spite of the full length l and fixes the inclination of the crack yield at 45º. [11]

The design value of the contribution of the reinforcement, V_{Rd2}, is given by the Eq. (10).

$$V_{Rd2} = 0.6\ A_{sw}\ f_{yd}\ d/s \qquad (10)$$

Where A_{sw} represents the cross-sectional area of horizontal shear reinforced in a bed joint, s is the spacing of shear reinforcement and d is the effective depth of the wall, that can't be considerer greater than the clear height of the wall. [11]

It was introduced a 0.6 constant since the horizontal reinforced is not fully yielding. The introduction of the relation A_{sw}/s makes the calculation independent of the interpretation of the engineer although it considers the total area of reinforcement. [11]

4 Study case

4.1 Conception and modeling

An implementation of structural masonry was executed, based on the architecture plants represented in the Figure 4.

This building was supposed to be constructed with reinforced concrete elements, so the transition to masonry elements creates some implications. Namely, some alterations regarding the dimensions of the rooms and the utility disabling of the roof because of the vertical continuity of the walls. Having a roof isn't a constraint to structural masonry but it has to be correctly projected.

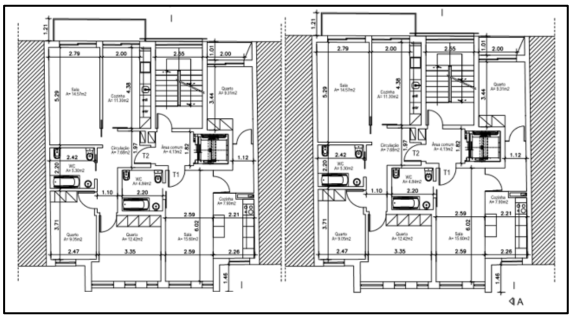

Figure 4 – Plants of the building in studying

Since the plants have different arrangements, it was decided to overlap the both plants with the intention to apply walls in a place that was already supposed to have a wall in order to maintain most of the initial architecture. In Figure 5, it's possible to see the reinforced walls predicted for this building

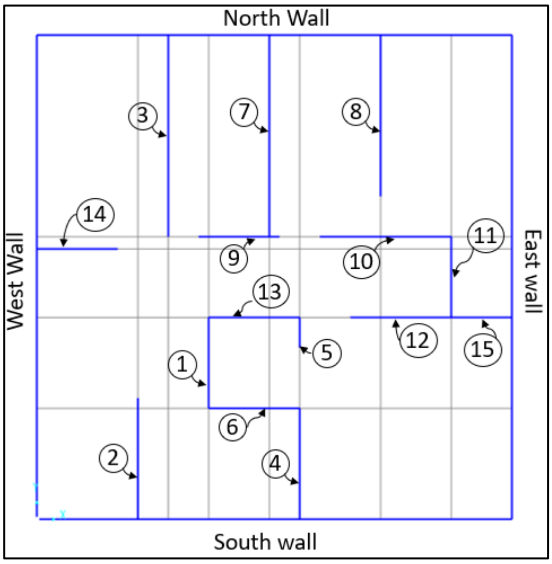

Figure 5 – Nomenclature of the study walls

It will be made the safety verification to a representative wall, shown in Figure 6 in other to a greater understanding.

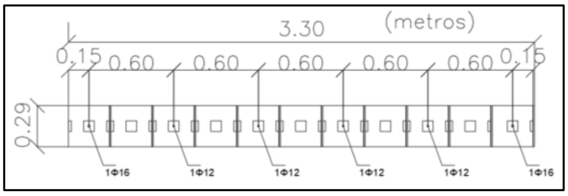

Figure 6 – Representative Wall.

4.2 Ultimate Limit States

In the following subchapters the security check will be presented in detail for just the example element, represented in Figure 6. The results of the remaining walls are presented in the main dissertation. It was also used the software VEMA to verify the in-plane and out-of-plane safety, since this software gives interaction curves to different sets of walls. [12]

4.2.1 Safety verification to axial load

Since the Eurocode 6, doesn't have in consideration the bed joint reinforced, the safety verification is calculated by considering the wall as unreinforced masonry. The wall doesn't have 2nd order effects.

4.2.2 Safety verification to in-plane bending and axial load

Since there is no defined loading for this wall, it was decided to construct the interaction curve between the resistance moment and the normal resisting effort, in order to obtain the range of stress values that the wall can withstand. The VEMA program provides interaction curves for reinforced masonry walls, although only accounting for the contribution of the edge reinforcement to the calculation of the resilient moment. Therefore, two interaction diagrams will be constructed: one where the contribution of all the reinforcement presented in the wall is counted (represented as REAL) and another where only the contribution of the reinforcement presented in the edges is counted (represent as VEMA), thus making a comparison with the verification given by the VEMA program.

To obtain the interaction curve it is necessary to perform numerous iterations of the neutral line, which would make the process slow. As a result, only a few more prominent neutral line positions were accounted for, therefore creating an approximate envelope of the interaction curve. In Figure 7 the deformation lines calculated to develop the approximate envelopes can be visualized.

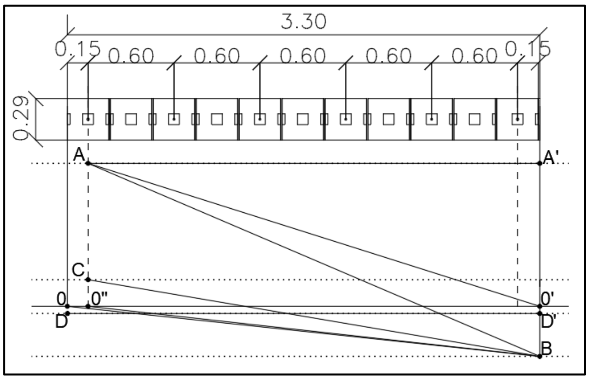

Figure 7- Strain lines analysed (in-plane)

Figure 8 shows the points corresponding to the strain lines analysed in the interaction curve.

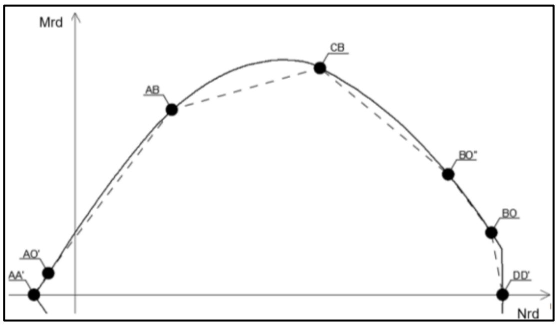

Figure 8 - Interaction curve (N_{Rd}- M_{Rd}) and respective points concerning strain lines reviewed

After calculating all the deformation lines, the Figure 9 was obtained. It represents both interaction curves for the wall in study.

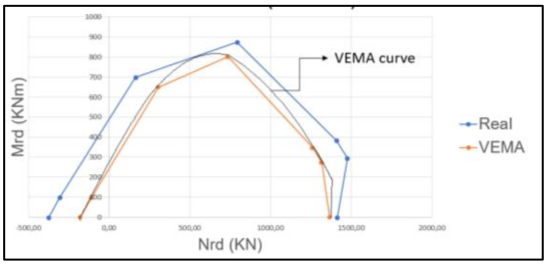

Figure 9 – In plane Interaction curves

4.2.3 Safety verification to shear

Checking was performed as explained in subchapter 3.4. The calculation model is shown in Figure 10, where, as recommended in a provisional Eurocode 6, it was assumed a shear resistance plane acting at a 45º across the effective wall depth and an effective length for the calculation of simple masonry strength equivalent to 0.8 in wall length, since the vertical reinforcement used on the wall is equally spaced.

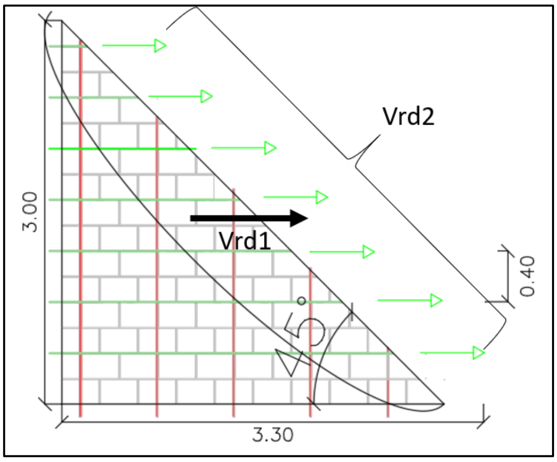

Figure 10 – Shear model

4.2.4 Safety verification to out-of-plane bending and axial load

The analyses regarding the safety verification to out-of-plane bending and axial load were the same performed for the in-plane bending verification. Therefore, the same strain lines introduced in the subchapter concerning the verification in-plane were considered in this case, which can be seen in Figure 11.

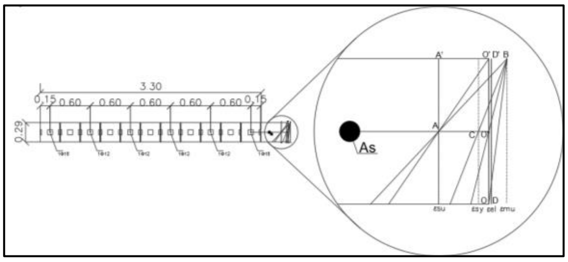

Figure 11 - Strain lines analysed (out-of-plane)

In out-of-plane bending, the vertical reinforcement is placed in exactly the same position, which simplifies the model since only one reinforcement force resulting from all the bars has to be considered. In this case, VEMA already provides the actual values of resistive forces, considering all reinforcements.

After calculating all the deformation lines, the Figure 12 was obtained, which represents both interaction curves for the wall in study.

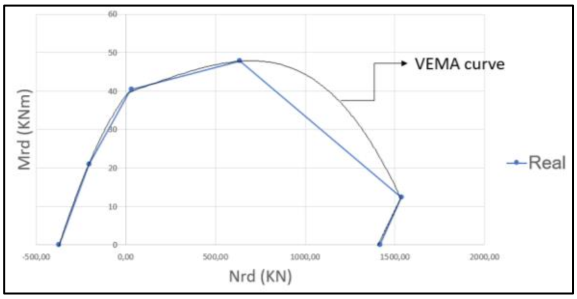

Figure 12 – Out-of-plane interaction curve

5 Conclusions

Knowledge of the application of a masonry structure is still quite primitive compared to other countries, such as Italy, which, despite having a higher seismicity than the national context, continues to make technological advances in order to not abandon the element. It has allowed this type of construction to remain competitive compared to other construction methods.

Eurocode 6 is, in itself, a breakthrough for the application of simple and reinforced masonry. However, it remains limited by Eurocode 8 which prevails over the masonry standard. As such, until a new version of EC8 comes out, seismic limitations prevailed.

With this paper, it was sought to apply a reinforced masonry structure to a reinforced concrete building, demonstrating the accomplishment of the ELU safety checks for all wall elements through the provisional version of EN1996-1-1 and a presentation of a program that aided the calculation. With the data taken from the seismic analysis, it was found that all walls met the respective requirements. Thus, the objective of the paper to apply a reinforced masonry structure and emphasizing that its application in Portugal is at all possible, has been accomplished

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