Openings in walls of buildings built with non-load bearing masonry and their consequences on the stability of the structure

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Abstract. *Since the 1960's, in the Recife Metropolitan Region of Brazil, it was noticed an increase in building construction in "non-load bearing masonry". This sort of masonry consists of hollow ceramic bricks, or concrete blocks, seated with horizontal holes, 0.09 m thick for use mainly in residential building constructions up to four floors. One of the main characteristics of the constructive process is that the walls should not be demolished or opened, except for what has already been established on the project, or it will cause a serious risk of compromising the stability of the construction. This paper aims to do a structural analysis on the impacts caused by large openings on non-load bearing masonry, through computational models based on the Finite Element Method. It concludes that through the application of the studied model it is possible to analyze structural problems caused by the openings, allowing to make known how the buildings structure will behave. It is also possible to predict the extension of the impact on the whole structure due to modification, besides allowing to know to what extent the building could withstand, to the tension state due to the removal of part of the masonry, without collapsing.*

Keywords: *Non-load bearing masonry, Finite Element Method, Walls Opening*

1. INTRODUCTION

Masonry is a constructive system used since antiquity for the most varied purposes. By using blocks of various materials, such as clay, stone and others, constructions that defied time were built, going through centuries or even millennia and reaching our days as real monuments. (RAMALHO, 2003)

This constructive system has been used in Brazil since the 16th century, with the arrival of the Portuguese colonizers. Though, it was as a more economical constructive option that in the early 1960s the first multi-story buildings in Brazil were built using reinforced structural masonry, usually for 4-storey buildings. Meanwhile, the "Central Parque Lapa" a condominium built in São Paulo in 1972, was built with 4 blocks of 12 floors with structural masonry of concrete blocks.

At Recife's Metropolitan Region (RMR), in Pernambuco, there was noticed a growth of masonry buildings constructed in the 1960s, after the creation of Banco Nacional de Habitação (BNH), a national bank created to give financial support to investments on housing. At the time, the system known locally as "edifício caixão", consisted of blocks of buildings constructed with non-load bearing masonry, for residential building constructions up to 4 floors were widely disseminated, motivated by the fact that this is the maximum number of floors that buildings built in Brazil can have without a mandatory use of elevators.

According to Porto (2012) the construction techniques called by non-load bearing masonry, also known as masonry "Resistant" are composed of hollow ceramic blocks seated with holes in the horizontal or concrete blocks, where the floors are intercalated with pre-molded or massive slabs, and molded ladder on site using reinforced concrete. Due to the financial crisis that devastated the country in the 1980s, there was noticed a decay in expenses in the various economic sectors, and that included construction. Some businesspersons decided to build "prédios-caixões" in non-load bearing masonry without using Reinforced Concrete (RC) band and in an effort to further reduce costs, some even removed lintels and sills from the projects of those sort of buildings.

This construction system was executed empirically, in total disagreement with the current international rules and was popularly known as "structural masonry". Of course calling them like that was a mistake, but that's how it was spread informally. Several buildings made this way in the Metropolitan Region of Recife collapsed or presented serious pathologies over time. One of the factors that directly contributed to the arising of these problems was the absence of technical norms related to structural masonry in the country and the incipient presence of qualified technical information about this constructive system (OLIVEIRA; SILVA; SOBRINHO, 2008).

After several buildings in the RMR collapsed and many others were interdicted such as the Monza building in the neighborhood of Piedade, in Jaboatão dos Guararapes City (Fig. 1), the construction of buildings with this technology has been forbidden. At the same time in Brazil, the study of the structural system of non-load bearing walls has increased, creating the technical standards 15812-1 and 2 (2010), NBR 15961-1 and 2 (2011) and NBR 15575-2 (2013) which are very recent Brazilian Norms. These new technical standards gave the necessary subsidies to the construction of buildings in proper structural masonry following a safe and stable form.

In the process of maintaining structural and non-load bearing masonry quality and safety residents play a very important role, because in this constructive system one is not to remove walls or open spans, unless it is indicated in the project, on penalty of compromising the stability of the whole building. However, sometimes the dweller out of complete ignorance of the danger decides to remove walls partially or completely, without even imagining the consequences of that act, a fact that could promote the ruin of the building.

The present article brings to discussion this sort of intervention for opening gaps in diverse sizes, which were not planned in the project for the non-load bearing masonry walls, located on the ground floor of a "prédio-caixão". It was considered the cases in which the RC bands were used and the cases in which they were not used. For this analysis, the analytical and computational models were used by the Finite Element Method (FEM) and the arc effect theory was used.

Figure 1. Edifício Monza, at street Felício de Barros de Medeiros, in Piedade, Jaboatão dos Guararapes. Source: (Jornal Diário de Pernambuco)

2. MASONRY AND STRUCTURE

2.1 Structural masonry and non-load bearing masonry

The main difference between structural masonry and non-load bearing masonry is that the structural masonry uses structural blocks according to technical standards, which supports the loads calculated previously, aiming to improve the construction's durability. When the structural masonry is reinforced it provides a greater ductility, which means the probability of an occurrence of abrupt collapses will decrease.

"it is known that buildings made by non-load bearing masonry also associated with concrete beams and pillars, when the masonry becomes cooperative with the reticulated reinforced concrete and should help the (theoretical) increase of global stiffness". (PORTO, 2012). There is several places in Brazil where this construction format is registered.

Combine this reality with the fact that the dwellers acting on their own modify their flat, to adapt them to their needs, reducing or eliminating walls or creating new rooms. They may also modify its façade opening windows or creating a small slab outside the unit on the ground floor (known in Brazil as "puxadinho"), usually using only empirical knowledge without the support and supervision of an engineer that would be responsible for the structural project for the intervention or even responsible for the execution itself. Allied to this fortuity there is also the culture to rarely provide preventive housing maintenance, which is needed to minimize the impact related to natural deterioration of materials according to time and pathological issues.

All this data shows the disposition of these buildings to the abrupt collapse, without previous notice, which began occurring in Pernambuco in the end of the 1980s, some partial and others total, however in this period buildings in reinforced concrete have been ruined. Consequently, the Ministério Público Federal, (Federal Public Prosecutor Service) and the Ministério Público Estadual (State Public Prosecutor Service) filed a lawsuit in Federal Court in 2005, preventing five cities of the RMR from granting a license for the construction of non-load bearing masonry buildings until they suit into the guidelines of the Brazilian Association of Technical Standards (ABNT).

Thus, according to Oliveira and Sobrinho (2008) we currently have in Recife around 6,000 buildings such as “prédio caixão” that means, built in non-load bearing masonry corresponding to 72,000 dwelling units that houses close to 250,000 people. In some of them dwellers have created openings not provided in the original structural project but the building remains stable, so it is considered that the arc effect is one of the factors responsible for this result.

2.2 Characterizing non-load bearing and structural masonry

According to Ramalho (2003), the structural masonry is a constructive system that must have certain characteristics, as mentioned in Table 1.

Table 1. Characteristics of Structural Masonry and Non-load bearing Masonry

Characteristics	**Structural Masonry**	**Non-load bearing Masonry**
Modulation	It consists in adjusting the architectural project to the standardization of the blocks offered in the market. In practice, the dimensions of the walls are multiple of the length of the block, both horizontally and vertically. The drawing should represent the first and second rows of each wall, in addition to the path of the pipes respecting the modulation.	Modulation was not made as a consequence, the brick was cut to fit the length of the walls respecting the dimensions provided on the architectural project.
Electrical, telephone and hydro sanitary projects	They must be foreseen in the architectural and structural projects, the pipes must pass inside the holes of the blocks by the impossibility of making rips in the walls.	There were no holes in the blocks. As a solution, tears were made in the walls to allow the passage of conduits and pipes.
Specifications	The project must contain the specifications of all the materials that will be used.	Usually the average compressive strength was adopted in addition to a global safety factor equal 5.
Family	The blocks must all be from the same family.	Did not exist.
Workers	The need for a qualified workforce capable of making use of the appropriate tools for its execution.	It used the same masonry sealing procedures.

Source: RAMALHO (2003) e OLIVEIRA (2017)

The buildings built in non-load bearing masonry have not always followed the rules, in some cases they were built without any beams between the floors, and without lintels and sills in the openings.

2.3 Structural conception and acting efforts

The structural project consists in determining on blueprint, which walls will receive vertical loads, as well as horizontal actions. Several factors can contribute to this choice, the two main ones being the use of the building and the symmetry of the structure. Once the

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structure is chosen, it will consider the actuating actions, both vertical, produced by the action of gravity, usually called loads, the proper weight of the structure, the floor's overhead and ceiling covering, as well as the furniture and people, as horizontal, the action of the wind and the out of plumb.

The wind action must be transferred to the walls and foundation, but it cannot be considered if the building has less than 5 (five) floors and plant with stiff walls in both directions according to the NBR 6123 (ABNT, 2013).

The concept of structural safety is based on theories that take into account the following premise: the same body, under the same bonding conditions, receiving the same solicitation over time will produce the same structural responses (stresses, strains, deformations, displacements).

For safety criteria on current standard regulation, masonry should be dimensioned by the Ultimate Limit States (ULS), as well as analysed for durability, appearance, user comfort, and structure functionality by the Service Limit States (SLS).

2.3.1 Resistance to compression of masonry

One of the main factors in the compressive strength of wall panels is the block strength. These factors can be analyzed according to NBR 15.961-2 (ABNT, 2011).

The block influence on masonry was measured by the efficiency factor in NBR 10837 (ABNT, 2000) at Table 2. The efficiency factor of a wall is determined by the ratio of its compressive strength to that of the block. By regulation, this value is on average 0.50 for the ceramic block. This factor can also be considered by the ratio of the compressive strength of the prism and that of the block. Then the factor can be given by the two expressions Eq. (1):

$$\eta = \frac{f_p}{f_b} \; or \; \eta = \frac{f_{par}}{f_b} \tag{1}$$

Where, η is the efficiency factor; f_p is the compressive strength of the prism; f_{par} is the Compressive strength of the wall; f_b is the compressive strength of the block;

Table 2. Efficiency factor values

Efficiency factor (η)	**Block**	**Minimum value**	**Average Value**	**Maximum value**
$\frac{f_{par}}{f_b}$	Concrete	0,4	---	0,6
	Cerâmic	0,2	---	0,5
$\frac{f_p}{f_b}$	Concreto	0,5	**0,7**	0,9
	Cerâmico	0,3	**0,5**	0,6

Source: RAMALHO (2003)

2.3.2 Effective Thickness (t_{ef})

The effective thickness is the wall thickness without the coating NBR 10837 (ABNT, 2000) mentions a minimum thickness of 0.14 m for reinforced and unreinforced walls. NBR 15.961-1 (ABNT, 2011) states that in structural masonry buildings with more than 2 (two) floors the minimum wall thickness is 0.14 m.

2.3.3 Effective Height (h_{ef})

The effective height of masonry walls and pillars, according to Standard NBR 15.961-1 (ABNT, 2011) follow the specifications below:

h_{ef} = h, when the base and at the top are locked;

h_{ef} = 2h, when the top is free;

2.3.4 Slenderness (λ)

Slenderness is defined by the ratio of effective height to effective thickness, Eq. (2)

$$.\lambda = \frac{h_{ef}}{t_{ef}} \tag{2}$$

Where, λ must be less than or equal to 24 for unreinforced walls and less than or equal to 30 for reinforced masonry.

2.3.5 Simple compression, simple bending, shear strength and composite bending

In structural masonry, the elements submitted to simple compression are the walls and the pillars, be they reinforced or not. In the axial compressive strength, the tension acting on compressed elements will be the acting force divided by the area, according to Figure 2. The Brazilian standard considers the cross section as the gross area, disregarding the voids, at Eq. (3).

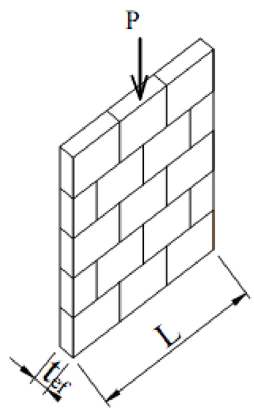

Figure 2. Axial Compression. (ALVES, 2006)

$$\sigma_{alv,c} = \frac{P}{t_{ef}.l} \tag{3}$$

Where, $\sigma_{alv,c}$ is the acting compression stress; P is the total load acting on the wall; t_{ef} is the effective wall thickness; l is the length of the wall.

According to NBR 15.961-2 (ABNT, 2011) in structural masonry walls, the resistant effort of the calculation is obtained by the following equation at Eq. (4) and Eq. (5):

$$Nrd = fd\,.\,A\,.\,R \tag{4}$$

$$Nrd = \gamma_f N_k \leq \begin{Bmatrix} 1.0 & \text{paredes} \\ 0.9 & \text{pilares} \end{Bmatrix} x \frac{0.7 f_{pk}}{\gamma_m} x \left[1 - \left[\frac{h_e}{40 t_e} \right]^3 \right] xA,\ \gamma_f = 1.4 \text{ e } \gamma_m = 2.0 \tag{5}$$

Where, N_{rd} is the resistant axial force of calculation; f_d is the compressive strength of the calculation of masonry; A is the gross area of the resistant section; and

$R = 1 - \left(\frac{\lambda}{40}\right)^3$, Is the reducing coefficient due to the slenderness of the wall.

According to Ramalho (2003), beams and lintels are linear structural elements intended to support and transmit vertical actions through a predominant bending behavior. Typically, the term lintel is used when the structural member is placed over spans of door and window openings.

Masonry elements requested by horizontal shear stress, knowing that the maximum shear forces generally occur close to the support, the shear stress (Fig. 3) is calculated by the following formula Eq. (6):

$$f_{cis} = \frac{V}{b.t_{ef}} \tag{6}$$

Where, V is horizontal shear stress, without increasing; b is the effective width of the cross section; t_{ef} is the effective thickness.

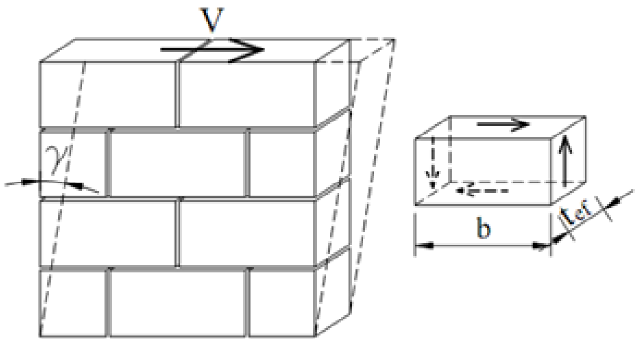

Figure 3. Shearing. (ALVES, 2006)

The composite bending occurs when there is an interaction between axial loading and bending moments (Fig. 4), and is a common requirement in structural masonry walls such as in non-load bearing masonry walls that make a building. It occurs because the walls that are part of bracing lateral system support the gravitational actions, coming from the own weight overloads of use, besides actions coming from the wind, the counter-attraction of the soil or the water and the out of plumb Which is very common in these types of building.

It is necessary to analyze when tensile tensions appear in the transversal sections, because the tensile strength of the masonry is very reduced, therefore, it is necessary to include a reinforcement bar that can absorb the resultant of the traction.

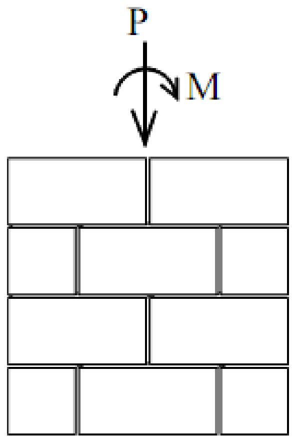

Figure 4. Composite bending. (ALVES, 2006)

3. ARC EFFECT

According to Parsekian (2013) there was an idea of the actions in the operation of the concrete structures, which we will adopt a bi-supported beam that supports a masonry wall as shown in Figure 5. The usual scheme is to consider the action of the wall on the beam as a linearly distributed vertical force with uniform rate.

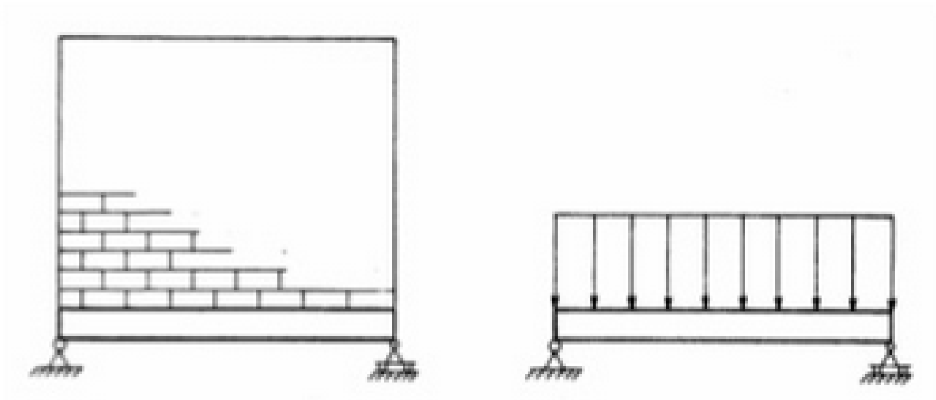

Figure 5. Wall on beam - usual action. (PARSEKIAN, 2013)

Wood (1952) described the behavior of a wall working together with a beam as being that of a tied arch, where the beam acts as a tieback forming the arc on the wall. So, taking into account the arc effect on the behavior of the wall-beam assembly, the loading of the beam can be expressed by vertical and horizontal forces near the supports, according to Figure 6.

The vertical load is transferred from the wall to the corners near the supports of the beam, and in the central part of the beam there is a tendency of separation with the masonry. In the case of a very flexible beam, there may be a complete separation of the wall, so there is a transfer to the beam only of part of the wall below the separation curve, working mainly as a

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tieback, in this case transferring the all of the vertical load to the supports. This phenomenon will not occur if the beam is extremely rigid.

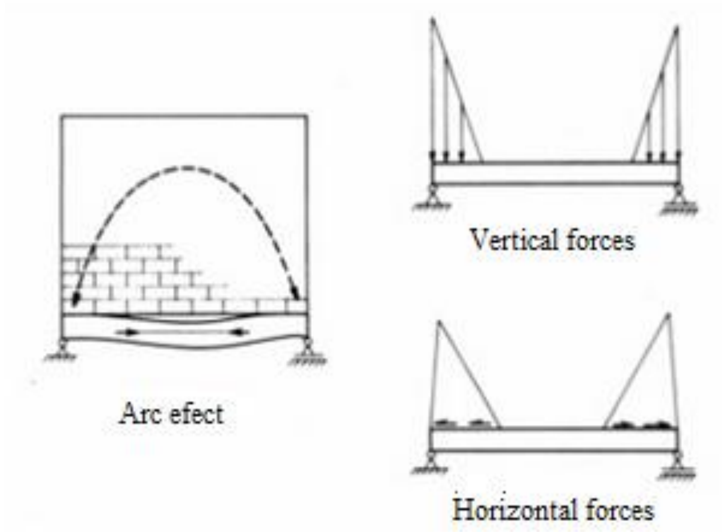

Figure 6. Wall on beam - alternative action. (PARSEKIAN, 2013)

Several authors have stated that triangular diagrams can represent the distributions of shear and vertical stresses, as below at Figure 7.

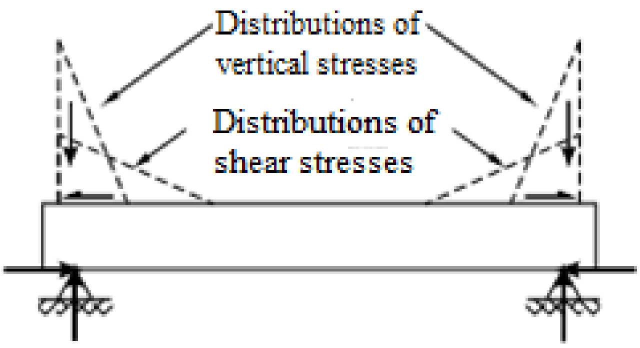

Figure 7. Vertical and shear tensions in the beam. (BARBOSA, 2000)

The shape of the horizontal stress diagram is represented by a compressed region and another tensile as shown in Figure 8. When the neutral line is located inside the beam, the situation of a beam working with flexion, with the upper reinforcement compressed and the inferior tensile, this is, compression through all height of the wall. If the neutral line is located at the bottom of the wall, the beam is under fully tensile, working as a tieback, as well as the base of the wall.

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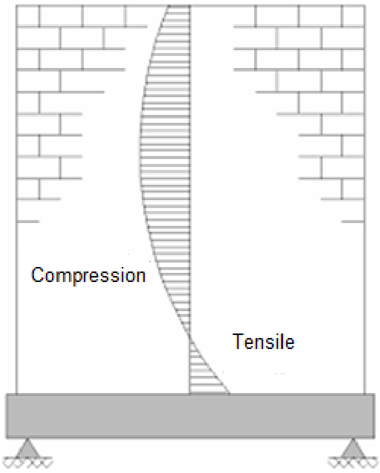

Figure 8. Diagram of horizontal tensions. (PARSEKIAN, 2013)

The level of the neutral line is influenced by the load and by the ratio H/l (height (H) by the span (l)), these authors indicate, for the case of a wall with H/l ratio < 0.5, before the beam starts cracking the neutral line is located inside the beam. In the case of walls with H/l ≥ 0.75, is noted that since the beginning of the loading, the upper and lower reinforcement are requested by tensile tension, according to Figure 9. (PAES, 2008)

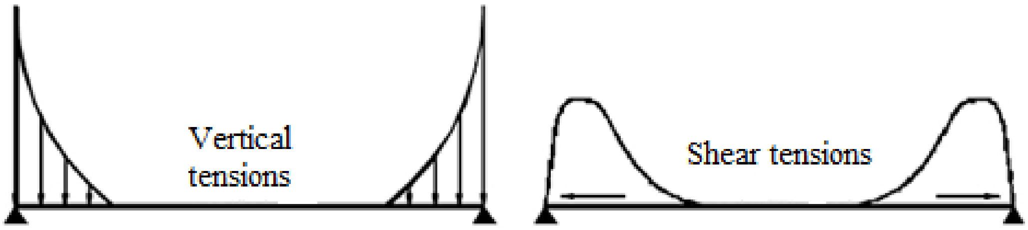

Figure 9. Concentration of the base of the wall. (PAES, 2008)

The arc effect is important at the interaction of the masonry wall with its supporting structure. Because its behaviour impacts the transfer of the vertical load from the wall to its supporting element, a part of the load located in the centre of the beam is directed towards the region where the supports are. In this case, the load forces of the beam, especially the bending moments, tend to be decreased in the middle of the beam's span, but in the other hand it has a higher concentration of stresses at the ends of the walls, at the supports.

The arc is formed from a ratio H/l ≥ 0.7, for a ratio between the height of the wall (H) and the span of the beam (l) greater than 0.7. In these cases, the weight of the wall portion above 0.70L would be considered only as an increase in load, not influencing the formation of the arc, as shown in Figure 10. (BARBOSA, 2000)

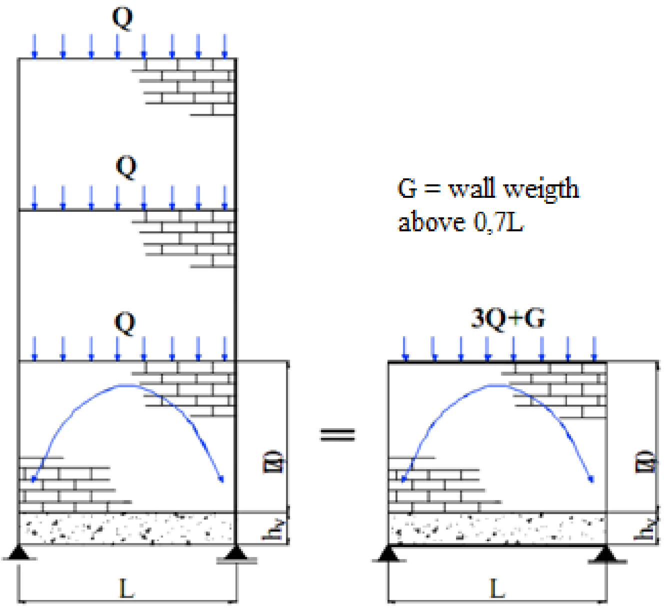

Figure 10. Wall-beam system with equivalent load. (BARBOSA, 2000)

Considering that most structural masonry constructions have ceiling height around 2.80m, spans with less than 4.0 m will present the approach described above. We also have to consider that in addition to the height of the wall and span of the beam, the stress distribution will be influenced by other factors such as beam inertia, wall thickness, and wall modulus elasticity ratio of the beam.

Pereira (2016) makes an analogy of the arc effect of the masonry wall with the wall pillar effect Figure 11 “represents a wall pillar, with a horizontal dimension covering and passing the gap between the two piles, suggesting the existence of connecting rods, or the arc effect, with an angle greater than 60º with the horizontal" (PEREIRA, 2016). Also represents a structural masonry wall, with a uniformly distributed load, supported on two piles, identical situation to the previous figure, changing only from wall pillar to brick wall, where we visualize the effect of the arc, because we can consider such a wall sufficiently rigid in relation to the beam.

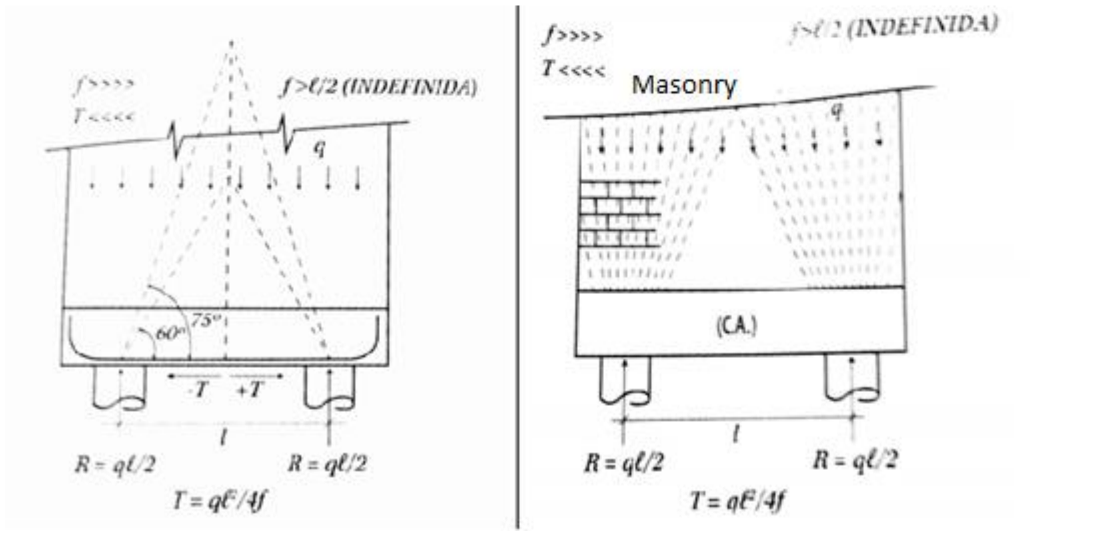

Figure 11 - Wall pillar in block with 2 piles and Structural masonry on 2 piles (PEREIRA, 2016)

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4. CHARACTERISTICS OF STRUCTURAL PROJECT

The object of study is a wall on the ground floor of a "caixão" building. The building is composed by four floors, and the floor plan is shown in a copy of a very common lay out found in blue prints that configure almost a pattern for buildings of this type in the Recife's Metropolitan Region (RMR), Pernambuco, as Figure 12.

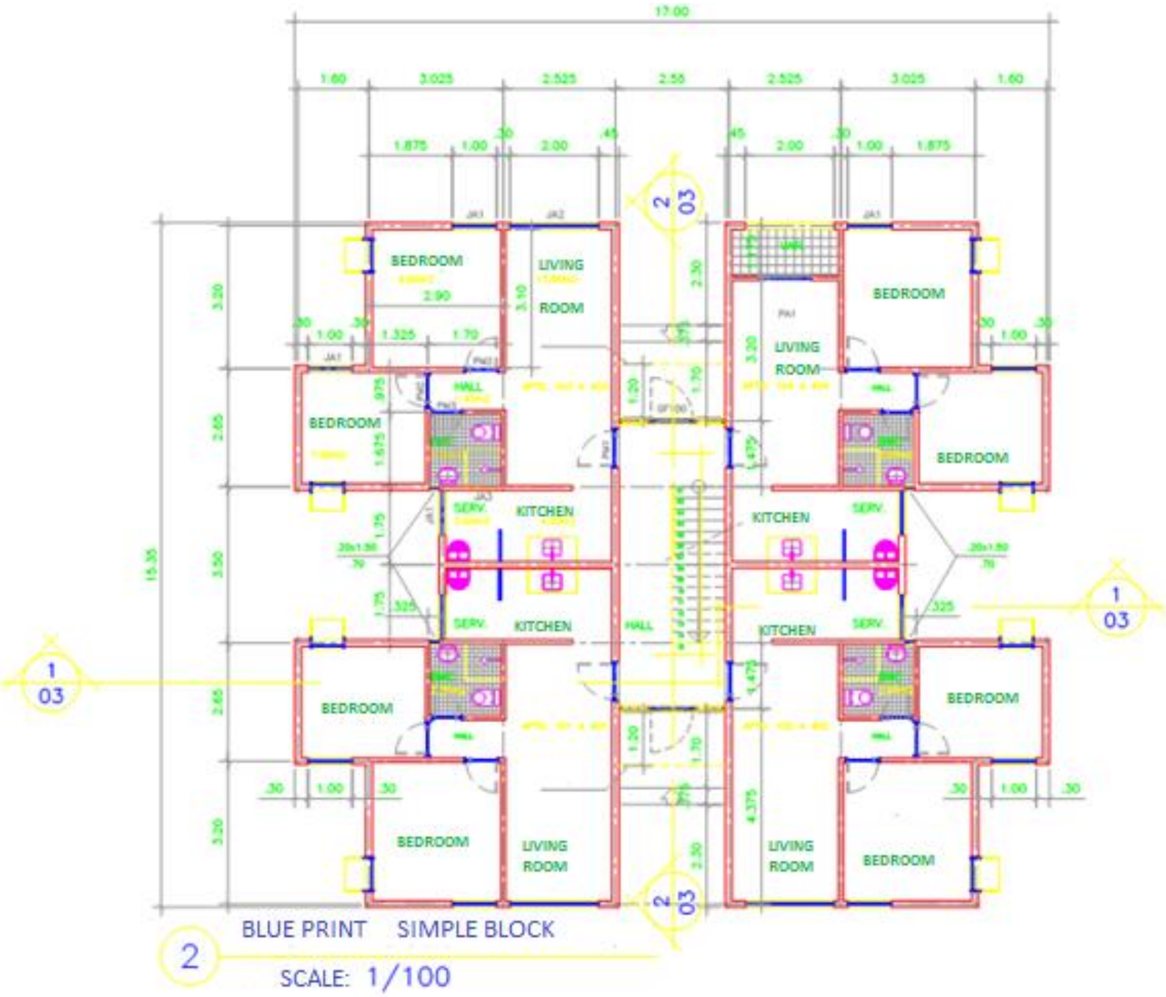

Figure 12. Ground floor of building.

Nowadays, the buildings with four pavements in masonry should follow the current regulations of structural masonry; therefore, we consider the whole theoretical foundation supported by these rules. But, it is known that in RMR there are more than 6,000 buildings built in non-load bearing masonry. Even if some of its structural factors are different from current standards, we will analyze this type of building.

If the plant is considered to be of a structural masonry building, the first step is to proceed with modulation of the structural project. In other words, to adapt the longitudinal length of the walls to the type of block chosen, therefore some dimensions of walls will be increased for improvements. The procedure is necessary because, according to NBR 15961-2 (ABNT, 2011), the concrete block used in the structural masonry must be an entire piece; it must not

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be cut, in order to maintain its full properties. That way walls should be adapted to the block dimensions.

On non-load bearing masonry building constructions, it was common practice to cut the brick, in order to adapt the walls to the dimensions of the project. Masonry was also to accommodate conduits and pipes and this procedure causes a decrease in walls resistance.

According to the NBR 15.961-1 (ABNT, 2011) and 15.812-1 (ABNT, 2010), the values for elastic properties of masonry in concrete blocks and in ceramic blocks can be adopted according to the Table 3:

Table 3. Properties of masonry deformation

Material	**Property**	**Value**	**Maximum value**
Concrete block	Modulus of longitudinal deformation	800 f_p	16 GPa
	Poisson Coefficient	0.2	---
Ceramic block	Modulus of longitudinal deformation	600 f_p	12 GPa
	Poisson Coefficient	0.15	---

Source: NBR 15.961-1 ABNT (2011) e NBR 15.812-1 (2010)

The value adopted of the Modulus of Elasticity of masonry "non-load bearing" has been obtained in experimental procedure of the Pitanga's thesis (2016).

For this project was chosen:

- 8-holes ceramic block (0.09 m x 0.19 m x 0.19 m)
- Deck beam (T beam) with dimensions 0.40 m x 0.12 m, as shown in Figure 13.

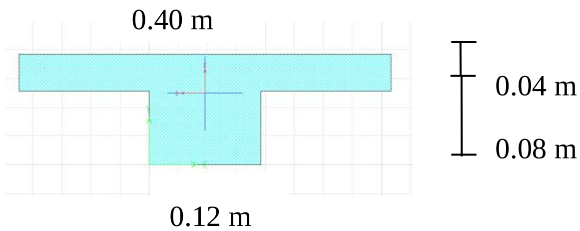

Figure 13. T Beam.

- Specific weight of concrete: 25 KN/m^3;

Modulus of Elasticity of concrete $E = 0.85 \times 5{,}600 \times \sqrt{f_{ck\ cinta}}$

- Modulus of Elasticity of concrete E_{con} = 21,287,367.15
- Poisson Coefficient (Concrete) μ = 0,20.
- Specific weight of masonry ceramic block 11 KN/m^3;
- Compressive strength of masonry: 2.5 MPa (2,500 kN/m^2);
- Modulus of Elasticity of masonry E_{alv} = 1.049 MPa (PITANGA, 2016)
- Poisson Coefficient (Masonry) μ = 0.15.
- Slab overload: 2.5 KN/m^2.

It is important to notice that the thickness of non-load bearing masonry is 0.09 m and that is not compatible with the minimum slenderness of the technical resolutions NBR 15.961-1 (2011), where the maximum slenderness limit for non-reinforced masonry is a 0.14 m thickness. In this case, for a building with a height between the slabs of 2.80 m, the slenderness calculus would result in a minimum thickness for the block of 0.12 m. Then, for this case it would consider the minimum thickness of 0.14 m for residence in structural masonry with more than 2 pavements.

With the software used to make the structural analysis of the building, it calculated the structure own weight, through the specific weight of the adopted materials, plus overhead in the slab. That value took into account the floor, ceiling and the additional load of people and furniture.

For the analysis, a wall of 3.20 m was chosen in the *yz* axis where x = 12.10 m, which in the initial project divides the living room from a bedroom. In the same room openings of 0.80 m; 1.20 m; 1.60 m; 2.00 m; 2.40 m and 2.80 m were made in the middle of this wall with a height of 2.60 m, which was not foreseen in the project.

The wind action was not calculated because the building had four pavements.

5. FINITE ELEMENTS METHOD (FEM)

Usually, working with these models requires the use of effective numerical methods, among which we can mention the Finite Element Method (FEM). The FEM procedure initially consists of dividing the domain of the analyzed structure into sub domains or non-overlapping elements, of finite dimensions, called finite elements, which are interconnected by nodal points, as shown in Figure 14.

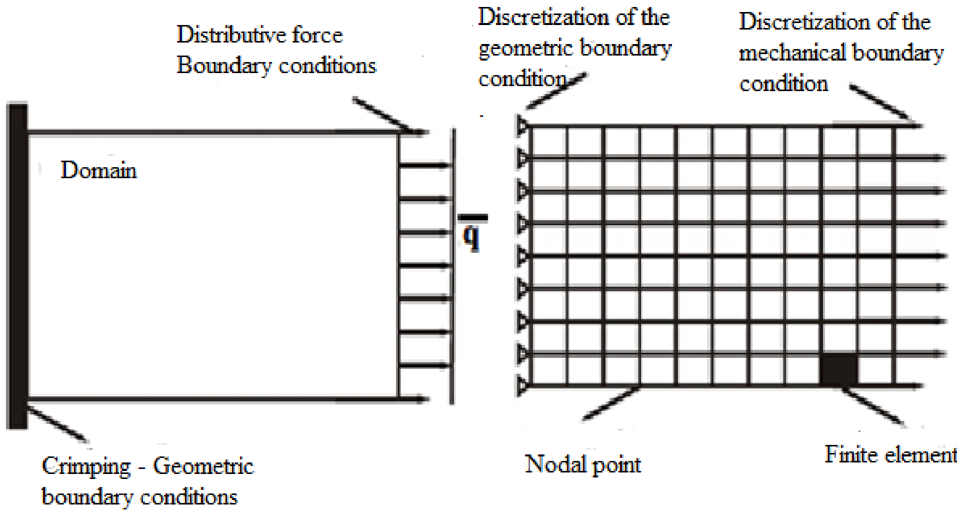

Figure 14. Discretization of a traction plate. (SORIANO, 2009)

The Finite Element Method (FEM) consists not only of transforming the continuous solid into an association of discrete elements and writes the equations of compatibility and equilibrium between them. But, to admit continuous functions that they represent (SORIANO, 2009). For example, the field of displacements in the domain of an element and, from there, to obtain the state of corresponding specific deformations that, together with the constitutive relations of the material, allows defining the state of tensions in the whole element. This state of tensions is transformed into internal efforts that have to be in balance with external actions. This method is very wide, and there are currently many finite element types available for modeling structures, as presented, among others, in Bathe (1996), Crisfield (1986), Zienkiewicz and Taylor (1989), Azevedo (2003) and Soriano (2009).

The most common techniques are the direct method, the energetic formulation and the weighted residual method (Galerkin method). For this work software that makes the structural analysis of the building through the method of Finite Elements was adopted, being the building discretized in quadratic elements of 0.20 m. The wall was initially analysed separately, by the analytical and numeric method, and comparing of the results. After that modelling of the whole structure of the building was made, the results of this analysis were compared to the same wall.

Calculating the load distributed on the slab, own weight plus overload, obtained 4.1 kN/m^2. The wall analyzed receives load of two slabs, it was considered the overhead in the cover equal to the others floors, and for that type of slab the calculation is equal to that of a bi-supported beam. The load distributed at the base of the wall in the analytical calculations was 59.60 KN/m^2, and the result provided by the software, summing all the reactions at the points (200.99 KN / m2) and dividing by the length (3.20 m), totaled 62.80 kN/m^2. It was verified that the values are close, in the case of the results obtained, it must be taken into account that the software shows the closest values of reality.

There was a solid influence of the arc effect on the wall above the aperture, both when we analyze the wall inside the building structure and when we analyze it in separate. However, the analyzed interior wall of the structure of the building presents other tensions that do not appear in the isolated wall, this fact occurs due to the interaction of walls, "It is clear that there will only be spread of the load through a corner if at that point the interaction forces can be developed" (RAMALHO, 2003).

To analyze the arc effect using Finite Element software, six models with openings in the middle of the interior wall of the ground floor were used. The wall supports the load of the slab of two environments. In other words, a wall quite loaded, as it shows on Figure 15.

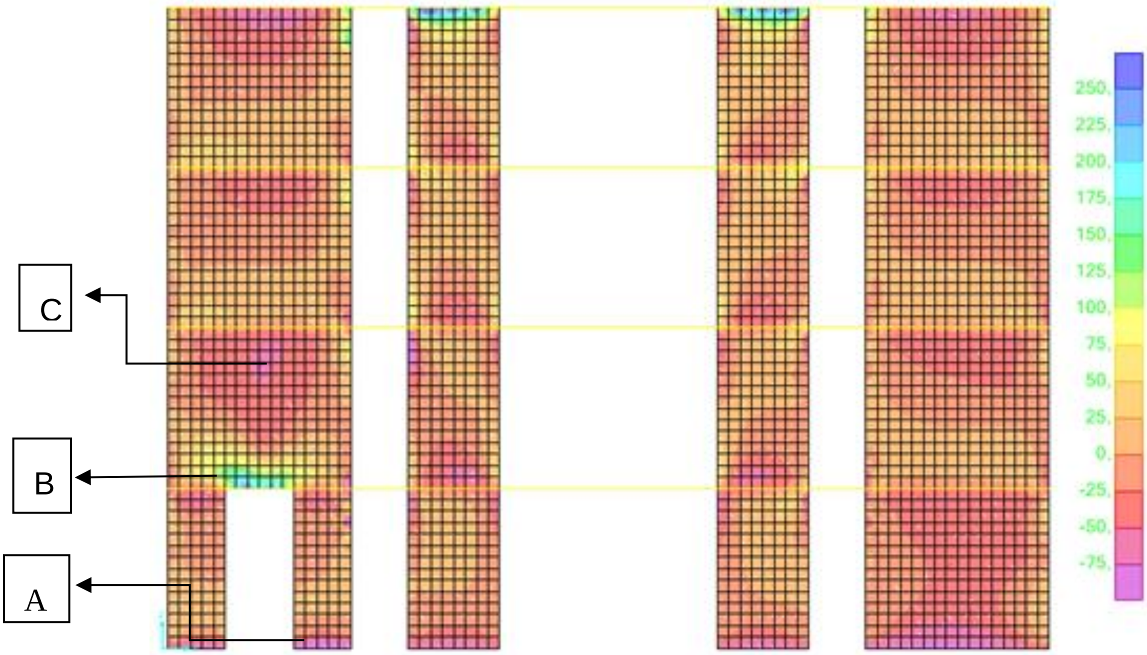

Figure 15. Diagram of tensions in the wall of non-load bearing masonry with opening of 1.20 m x 2.60m. (LIRA, 2017)

The figure 15 shows the pier A are the compressive stress increase; B tensile stress on the top of the opening; and C is area compressive stress at arc effect. The maximum stress at the base of the wall will be displayed, in the original model and in the six cases analyzed. With the formation of the arc effect, after creating the aperture, tensile stresses will appear just above the aperture, as well as compressive stresses on the wall above the aperture in demonstrative frames, which will also be explained.

The table 4 presents the results of the non-load bearing masonry building with and without RC band, while table 5 presents the RC band results.

Table 4. Values of maximum stresses on the wall where the aperture is located.

APERTURE DIMENSIONS	A - Maximum compressive stress at base (kN/m^2)		B - Maximum tensile stress on the aperture (kN/m^2)		C - Maximum compression stress at arc effect (kN/m^2)	
	Without RC band	With RC band	Without RC band	With RC band	Without RC band	With RC band
Not gap	-105,91	-103,85				
0.80 m x 2.60 m	-135,87	-124,92	**1.055,84**	**72,96**	-52,46	-65,67
1.20 m x 2.60 m	-144,38	-136,87	**928,84**	**165,51**	-81,46	-87,21
1.60 m x 2.60 m	-161,08	-148,95	**1.112,95**	**248,93**	-107,20	-105,00
2.00 m x 2.60 m	-184,16	-162,20	**1.005,62**	**305,38**	-125,53	-115,79
2.40 m x 2.60 m	-208,45	-172,97	**1.224,10**	**336,90**	-120,06	-114,49
2.80 m x 2.60 m	-238,84	-182,34	**1.079,05**	**359,72**	-117,60	-97,87

Table 5. RC band values above the aperture

APERTURE DIMENSIONS	Bending moment in the mid span of the RC band (kN.m)	Maximum bending moment (kN.m)	Shear force at the beam supports (kN)
0.80 m x 2.60 m	1,12	1,26	-8,31
1.20 m x 2.60 m	3,97	4,11	-11,34
1.60 m x 2.60 m	3,91	4,22	-13,20
2.00 m x 2.60 m	3,53	3,96	-12,19
2.40 m x 2.60 m	3,01	3,91	-15,47
2.80 m x 2.60 m	2,52	4,39	-17,05

However, in the building with resistant masonry without RC band, as the gap increases, a large increase in tensile stress occurs at the base of the wall above the opening. As in this case, the wall over the aperture is not supported by a RC band to distribute the loads, and bearing in mind that the tensile strength of the masonry is low, the blocks in that region can crack, and consequently, in a cascade effect, the wall can collapse, leading to edification to collapse (figure 16).

The tension diagram in non-load bearing masonry building with and without belt beams, when the wall opening is 2.80m x 2.60m, are shown in Figures 16 and Figure 17.

By isolating the wall where the opening was made, maintaining the physical characteristics of the materials and loading of the building wall, it is noticed that the bending moment is reduced at the center of the beam. As well as an increase of the shear effort near the supports (Figure 18), confirming the impact of the arc effect on the wall supported by concrete RC band, even in relation to the graphs found in the bibliographical studies.

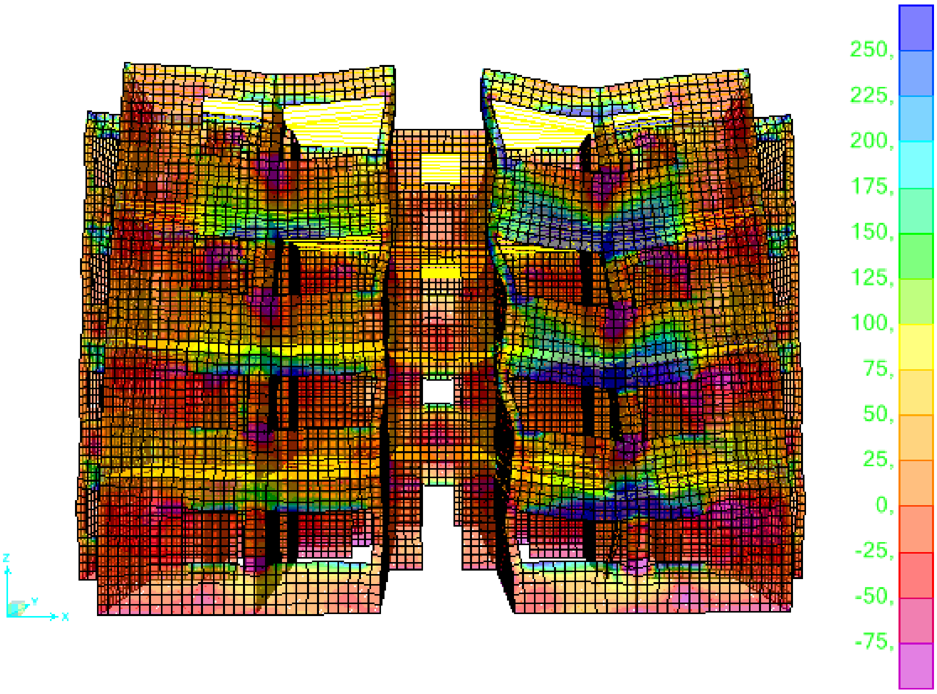

Figure 16. Tensile Diagram in non-load bearing building WITHOUT the RC band, when the wall opening is 2.80 m x 2.60 m. (LIRA, 2017)

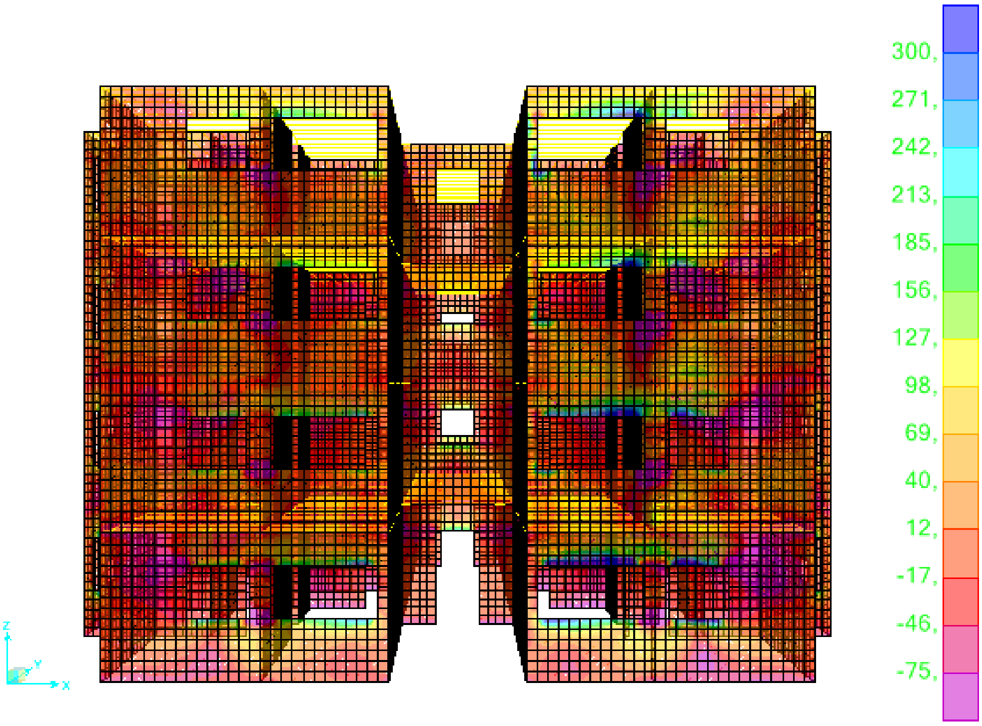

Figure 17. Tensile Diagram in non-load bearing Building WITH the RC band, when the wall opening is 2.80 m x 2.60 m (LIRA, 2017)

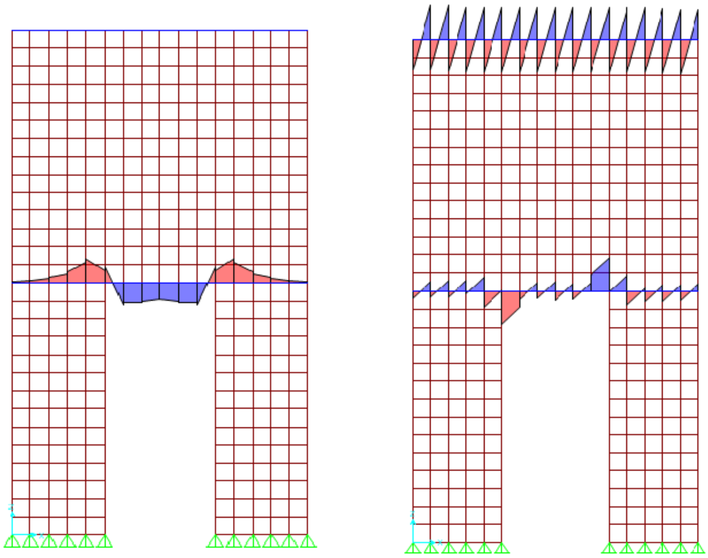

Figure 18 A – Bending moment diagram in beam on the insulated wall **Figure 18 B– Shear stress diagram in beam on the insulated wall. (LIRA, 2017).**

Some non-load bearing masonry buildings without the RC band built in the RMR, replaced the use of band on the walls by using a lower reinforcement of 2 rebar ϕ = 10 mm (3/8 ") with stirrups within the slab. In the modeling, simulating this reality, was considered a 0.10 x 0.14 m beam, with a bottom reinforcement of 2 bars ϕ = 10 mm, resulting in 95% similar values to buildings in non-load bearing masonry with RC band.

6. CONCLUSIONS

Against the above, it is concluded that:

- The buildings in non-load bearing masonry, do not meet some safety requirements of the structural masonry standards
- The “caixão” building, in non-load bearing masonry uniformises tensions and displacements, when constructed with RC band.
- The structural analysis of the wall, which has the arc effect, above the aperture, confirms the stress distribution diagram found in the literature.
- The arc effect causes a reduction in the bending moment in the middle of the span of the wall support beam just above the opening and an increase of the shear stress close to the arc supports.
- In the non-load bearing masonry walls, in general, the arc effect is not taken into account. So, some loads caused by this effect are not evaluated. Therefore, in the case of the support beam, in relation to the bending moment increases the margin of safety, but it is not taken into account that the beam works as a tieback when the arc effect occurs.

Most masonry projects do not consider the arc effect, however this effect interferes directly in structure behavior. It is concluded that even making openings in a wall of the building, a modification occurs on load’s directions, as a consequence of the arc effect. Stability can be ensured if the RC band is able to withstand the horizontal stress equal to the projection of the inclined load that follows towards the arc, and the remaining piece of the walls will be used as support and are able to withstand vertical component of that effort.

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