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NUMERICAL ANALYSIS OF STRUCTURAL MASONRY PANEL USING MACROMODELING AND SIMPLIFIED MICROMODELING

Emily Rocha dos Santos[1], Geraldo José Belmonte dos Santos[2]

[1]*Programa de Pós-Graduação em Engenharia Civil e Ambiental, Universidade Estadual de Feira de Santana, Bahia, Brasil. E-mail: milyrocha1@hotmail.com*
[2]*Programa de Pós-Graduação em Engenharia Civil e Ambiental, Universidade Estadual de Feira de Santana, Bahia, Brasil. E-mail: belmonte@uefs.br*

Abstract. The structural masonry is among the oldest construction techniques, but over time it was replaced by concrete and steel constructions. Recently, the number of buildings executed in structural masonry is increasing, mainly due to the social interest housing programs, leading at the same time the increase of the cases of structural pathologies, highlighting the need of additional studies and research in this area. Unlike frame structures, where the walls are used only as enclosure elements, in structural masonry the panels are load-bearing structures and can be represented by some of their 5 possible distinct elements (block, mortar, grout, interface and reinforcement) or by panels of a single homogenized material. The representation of the panel by distinct elements generates difficulties but is essential for local analysis of stresses and load distributions in the panels what permit to evaluate the structural performance of this constructive technique and emergence of the building pathologies (damage and crack pattern). In this work, the modeling and analysis of a structural masonry panel was carried out using the Ansys software based in the Finite Element Method (FEM), applying the simplified micromodeling and macromodeling techniques. The panel was analyzed in a two-dimensional way, being detailed the expressions for stress and strain that govern the problem, as well as the properties of the equivalent material considering the orthotropy applied in the macromodeling technique (homogenization). The panel analyzed was detailed as a structural masonry wall, formed by solid blocks of concrete and having a concrete beam as a supporting element. For analysis, a linear load was applied to the panel, being evaluated in this work, in a comparative way, the panel, containing opening and the panel without opening. The panel modeling was performed using the PLANE42 element in state of plane stress, what is bi-linear Lagrange element (4 nodes) and two degrees of freedom per node. Through the results obtained in this work, it was possible to evaluate that the wall and beam set works in a similar way to the arch, with compressive stresses on the wall and tensile stresses on the beam being predominant, with a concentration of stresses also being observed for the area of the panel close to the support. It was also possible to verify that the presence of the opening in the panel causes a high concentration of tensions at the top and at the bottom, justifying the use of the joint reinforcement at lintel bearing. When comparing the stress results obtained between the micromodeling and macromodeling technique, it was observed that the homogenization technique has convergent results on the global behavior.

Keywords: structural masonry, micromodeling, macromodeling, finite element.

1 Introduction

Masonry is a building element that has been used as load-bearing structures for thousands of years. We know that, until the early twentieth century, the masonry building was empirically calculated, and there were no current technical standards for the design and construction of structural masonry [1]. In the 20th century the first studies of masonry as a structural element began to be developed and mathematical models for design were created and improved, thus enabling the reduction in costs and material consumption [2].

According to Ladini [3], the first studies on structural masonry took place between the 1950s and 1960s and aimed to reduce the height of the elements used in the structures. In the late 1970s, research began to improve the mathematical methods used to design of masonry structures. In Brazil, the Brazilian Association of Technical Standards published, in 1989, the NBR 10837 “Hollow concrete blocks – Bases for design of structural masonry – Procedure”, and in 2010, the NBR 15812 "Structural masonry - Clay blocks". Subsequently, the NBR 10837 was replaced in 2011 by NBR 15961 "Structural masonry - Concrete blocks", which brought as a main change the design through the limit state method, what adopts more realistic criteria and with greater control over safety [3]. In 2020, the standards NBR 15812 and NBR 15961 were updated and replaced by NBR 16868-1 "Structural masonry: Part 1 – Design", NBR 16868-2 "Structural masonry: Part 2 – Execution and site control" and NBR 16868-3 "Structural masonry: Part 3 – Test methods".

According to Niero Junior [4], structural masonry can be defined as a set of main components such as: block, mortar, grout, reinforcement and interfaces. The block is defined by NBR 16868-1 [5] as the masonry basic unit, representing the main component for design, because through it occurs the efforts transmission in the structure. Mortar is a construction material with adherence and hardening properties, obtained by mixing binders (Portland cement), fine aggregate, additive and water. As a component of structural masonry, mortar is a workable paste used to bond masonry block units, whose purpose, according to NBR 13281 [6], is to ensure the uniform distribution of stresses between the elements. The grout is defined by NBR 16868-1 [5] as a component used to fill the empty spaces of the block, whose purpose is to solidarize the reinforcement to the masonry and increase its resistant capacity. The reinforcement of structural masonry is the same applied to reinforced concrete structures, however, in masonry structures the steel bars are surrounded by grout, thus ensuring a mutual work between the components.

The growing number of buildings using structural masonry, mainly due to the social interest housing programs, associated to the increase of the structural pathologies (damages and cracks), highlights the need of constant studies and research in this area. The analysis of stresses and load distributions on masonry panels is fundamental to the evaluation of the performance of this construction technique, providing information about the behavior of load distribution along the panels and the possible crack pattern [7]. For that, the method more used for analysis is the Finite Element Methods (FEM), what aims to determine the state of stress and strain of an element by replacing the weak form equilibrium of a continuous system by a discrete system via local interpolation of the primary variable (e.g., displacement) within subregion called elements [8] and the behavior of the whole is equivalent to the sum of the behavior of the parts [9]. Using the FEM, it is possible to model a masonry panel through the following approaches: Simplified Micromodeling, Detailed Micromodeling and Macromodeling [10].

The detailed micromodeling represents the masonry with the properties of each constituent, considering the interaction between block, mortar and interfaces (grout and reinforcement, if they exist), where each element is discretized with its respective mechanical behavior, leading to more complex and closer to reality modeling [10]. Depending on the level of accuracy required one can use the simplified micromodeling, in which the elastic properties of the laying mortar are not taken into consideration being the joints potential rupture planes. Macromodeling is the most practical method, because no distinction is made between the individual components. For this approach the masonry is treated as a single solid with homogeneous elastic properties [10].

According to Barreto [7] numerical modeling is fundamental, because if properly validated, it allows the simulation and analysis of the structure's behavior as a virtual experiment of the reality with the desired degree of accuracy. In this context, the objective of this work was to evaluate the structural masonry panel through the finite element method using simplified micromodeling and macromodeling techniques, analyzing the stress and strain profile acting along the panel.

2 Methodology

The modeling performed for the development of this work was done using ANSYS software. It was adopted the modeling in plane stress state using quadrilateral finite elements for the discretization of the masonry panels. The plane element adopted has four nodes with two degrees of freedom at each node (translations in the x and y directions), this being the Plane 42 element (ANSYS 6.0, Element Library) used for two-dimensional modeling of solid structures.

In this paper, the validation of the adopted model was initially performed using the experimental data from Juste [11], where blocks, mortars, prisms and structural masonry small walls were tested. For validation and calibration, a masonry panel was modeled with the material properties obtained in the experimental work of Juste [11]. Initially, the detailed micromodeling model was used, representing the units (blocks) and mortar with their respective elastic properties. The interface was considered bonded. In the second step, the homogenizated model was used to represent the masonry panel, representing the units (blocks) and mortar as a single element with equivalent properties. A comparison was then performed between the stress and strain results in the panel for the applied micromodeling and homogenization techniques with the experimental results of Juste [11].

After the model validation, three structural masonry panels supported on a concrete beam were analyzed, and the stress and strain distribution for panels with and without openings was evaluated.

3 Model Validation

To validate the applied model, the experimental results of Juste [11] were used, where blocks, mortars, prisms and small walls were characterized. The small walls were molded to characterize and determine the strength and modulus of elasticity of structural masonry panels, and tests were performed on 24 walls with dimensions of 80cm x 80cm, varying the properties of the block, mortar, type of laying and direction of load application. Three specimens were modeled for each parameter considered. The model of the wall is shown in Figure 1.

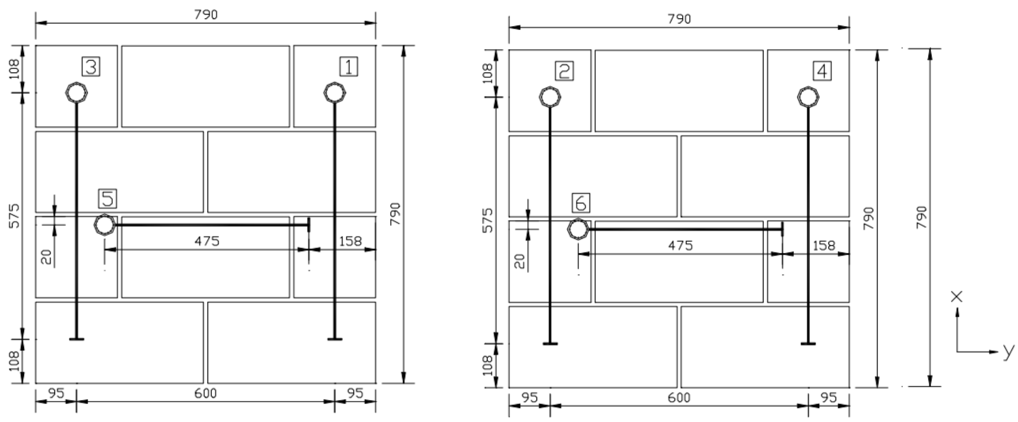

Figure 1. Experimental configuration of the small wall model with strain gauges in the two faces and dimensions in cm. Fonte: Juste [11].

Four strain gauges (1, 2, 3, 4) were allocated to measure the vertical displacements of a region including blocks and mortar and two strain gauges (5, 6) to measure the horizontal displacements at the centers of the walls (see Figure 1). The materials used to compose the walls were characterized through laboratory tests. To validate the model of this work, were used the experimental results obtained for the small wall tested with blocks of 4.5 MPa and mortar with total settlement, with vertical loading applied on the panel in a way perpendicular to the blocks laying plane. The blocks used were 14x19x39 cm. The Figure 2 presents the stress and strain results obtained experimentally for the type of wall adopted in this work.

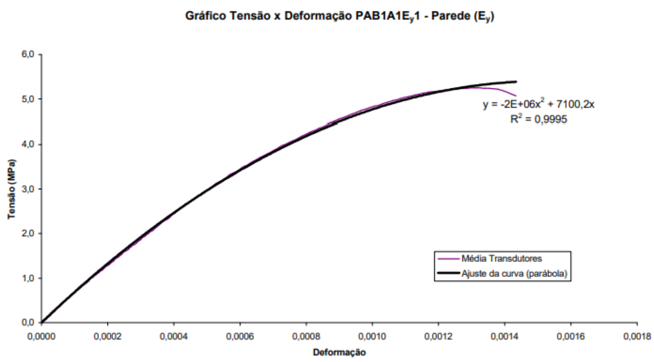

Figure 2. Stress-strain graph - PAB1A1Ey [11]

The Figure 3 presents the stress and strain results obtained experimentally for characterization of the mortar and block used to make the PAB1A1Ey1 wall.

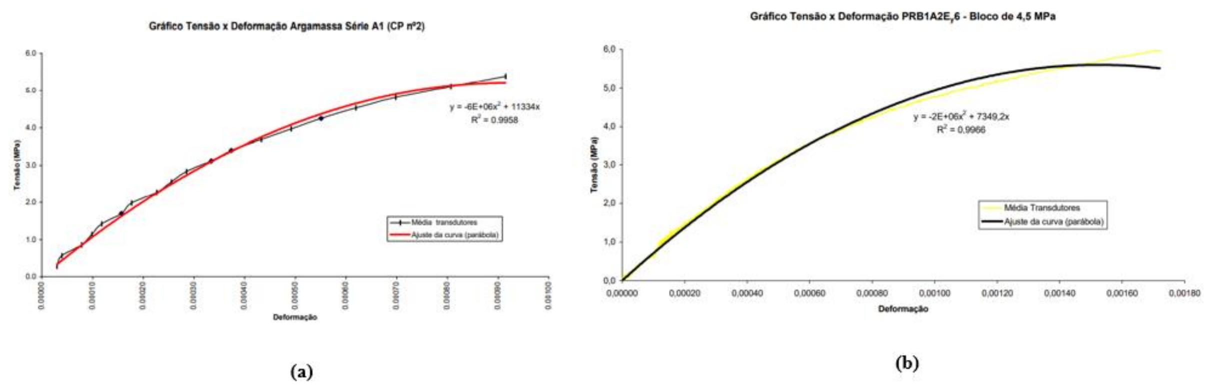

Figure 3. Stress x Strain graph - (a) Mortar; (b) Block; [11]

3.1 Detailed Micromodeling

Using the experimental results of Juste [11], the wall was initially modeled using the Plane 42 element in the Ansys software through the detailed micromodeling technique. In this approach, the blocks and the mortar were represented separately, and the elastic properties of each material were considered.

The modeled wall was subjected to a load applied at the top. In the first step the wall materials were considered to have linear elastic behavior, whose properties are shown in Table 1. The interface between the units and the mortar was modeled using a bonded contact element.

Table 1. Elastic Properties of Materials

Material	Modulus of elasticity (Mpa)	Poisson
Mortar	9796	0,2
Block	6228	0,1

In the second stage of modeling, a wall model was built considering that the materials used had a plastic behavior, and the stresses and strains for the mortar and the block were represented according to the experimental results shown in Figure 3. The results obtained in each step of the modeling are shown in Figure 4.

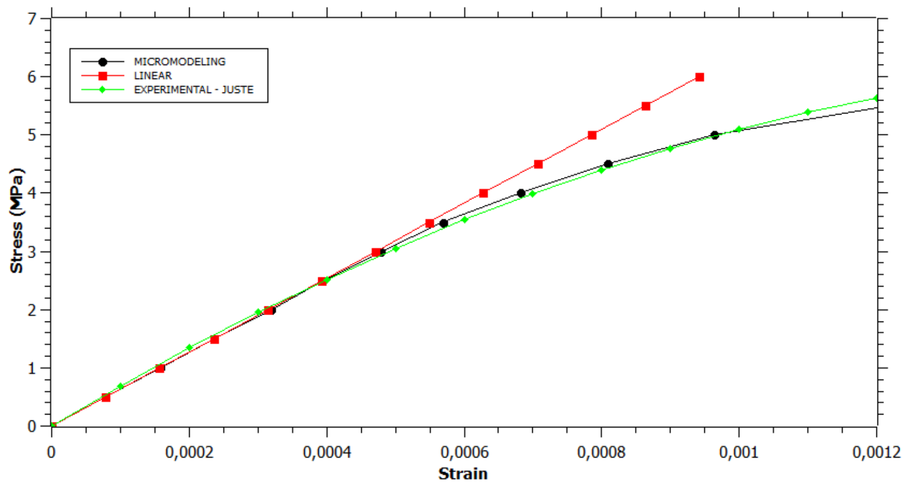

Figura 4. Comparation of the results experimental e numerical micromodeling.

Through the results of stress and deformation obtained for each model, it can be concluded that the detailed micromodeling technique presents results closer of the experimental results of Juste [11] when using the plastic model than the elastic model. This is justifiable, because at this stage the modeling was performed considering the actual behavior of the material, with the stress and strain distribution obtained experimentally.

3.2 Homogenization

In the modeling using the homogenization technique, the whole panel is modeled as a single equivalent material, not being considered the elastic properties of the block and the mortar separately. A material with an equivalent modulus of elasticity obtained experimentally for the small wall tested by Juste [11] was modeled. Table 2 presents the modulus of elasticity and Poisson coefficient considered for the panel.

Table 2. Elastic Properties of Materials

Material	Modulus of elasticity (Mpa)	Poisson
Wall	6496	0,2

For that modeling it was considered that the material presented plastic behavior, being considered in the model the stress and strain distribution for the small wall indicated in Figure 2. The Figure 5 presents the results obtained for the stress and strain of the wall considering the homogenization model in comparison with the micromodeling method and the experimental results of Juste [11].

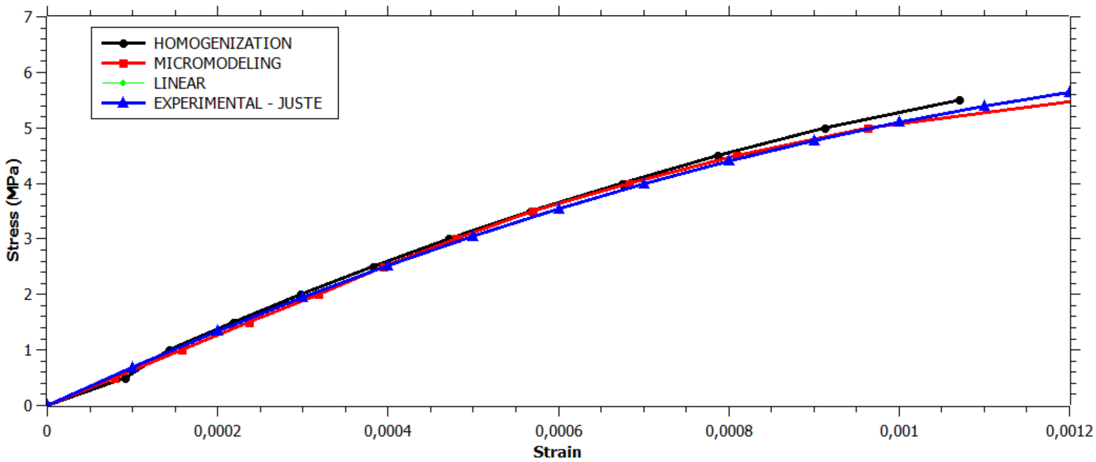

Figure 5. Micromodeling vs. Homogenization

Through the results obtained, it was possible to conclude that the Homogenization model for the masonry panel presents a behavior close to the micromodeling model and both are consistent with the real behavior of the structure, and can therefore be used to represent a masonry panel.

4 Masonry Panel

To analyze the distribution of stress and strain in structural masonry panels, masonry panels were modeled with and without openings, with the latter supported on a concrete beam. The modeling was done in a two-dimensional way, for the plane stress state, considering the homogenization technique for the materials. The stress and strain properties shown in Figure 2 for the equivalent panel material were considered. The concrete beam was considered to have a modulus of elasticity of 21 MPa. For the panel a loading corresponding to the allowable stress of the wall was considered, according to NBR 16868-1 [2], and a loading of 1 MPa was applied at the top of the panel.

Initially, a masonry panel with dimensions of 3.40 m long and 2.20 m high was modeled, supported on a concrete beam. The blocks had a dimension of 14x19x39 cm and the concrete beam had a cross section of

14x40cm. The modeled panel is represented in Figure 6(a). Subsequently, a masonry panel with a 1.0x1.0 m opening was modeled. The blocks had a dimension of 14x19x39 cm and the concrete beam had a cross section of 14x40cm. The modeled panel is shown in Figure 6(b).

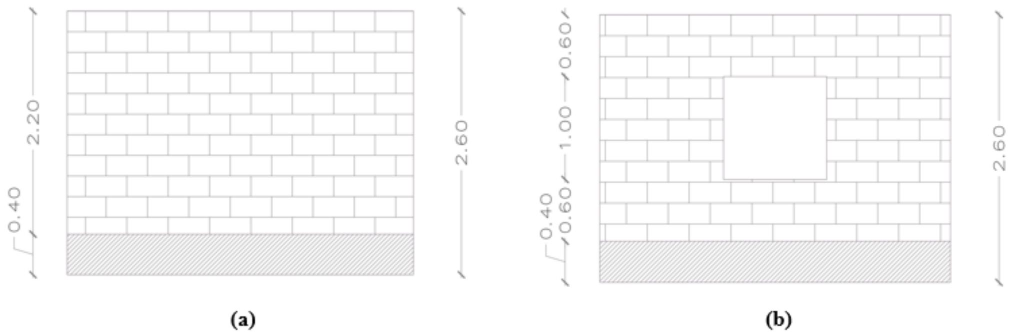

Figure 6. (a) Panel without opening; (b) Panel with opening

The Figure 7 presents the normal stress and displacement results obtained for the panel without opening, with an indication of the tensile and compressive stress concentration points.

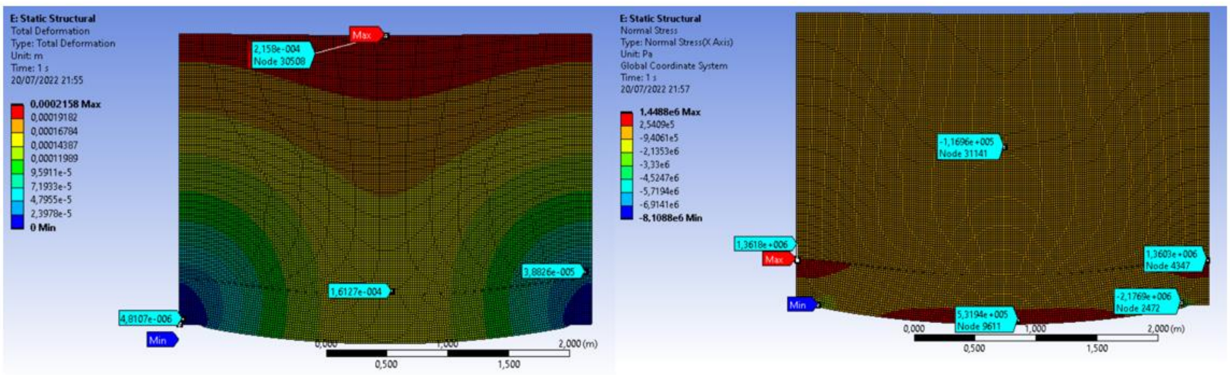

Figure 7. Normal Stresses and Displacement - Panel without Opening

Through the results obtained it was possible to conclude that the greatest deflection of the panel occurs in the center of the wall, at the top near the place of load application. It was observed, by the normal stress diagram, that the panel is subjected predominantly to compression stresses, being identified tensile stresses in the beam near the supports and on the underside of the beam.

The Figure 8 presents the normal stress and displacement results obtained for the panel with opening, with an indication of the tensile and compressive stress concentration points.

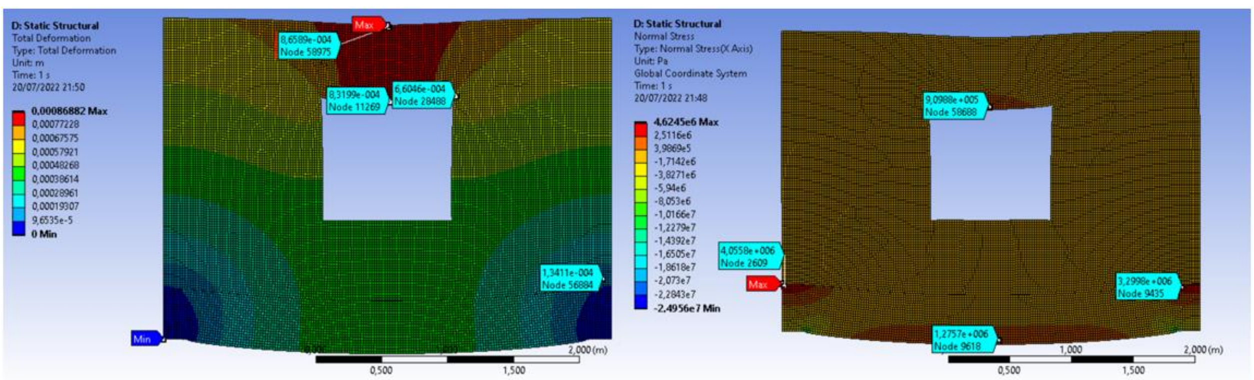

Figure 8. Normal Stresses and Displacement - Panel with Opening

A predominance of compressive stresses was observed, with tensile stresses identified in the panel at the opening span and on the underside beam and near of the supports. The maximum concentration of compressive stress was evident in the corners of the opening, the greatest deflection of the panel occurs in the center of the wall, at the top, and a greater displacement is evident in the panel with opening than in the panel without opening.

5 Conclusions

Through the results obtained in the validation of this work, it was possible to conclude that the modeling of the masonry panel using the Finite Element Method through the techniques of detailed micromodeling and macromodeling (homogenization), presents results consistent with the actual behavior of the structure, and the homogenization technique presents results close to the micromodeling technique, justifying its possibility of application in the analysis of masonry panels. Through the results obtained with the modeling of the wall without opening, it was possible to conclude that the behavior of the panel resembles a tied arch, with the wall almost entirely compressed and the support beam with tensioned parts. It was possible to observe that the stress concentration occurs near the supports. The analysis of the stress distribution profile for the panel with opening allows us to assess that the presence of the opening does not modify the arch effect also evidenced in the panel without opening. It was possible to determine that the presence of the opening causes the emergence of tensile stresses at the top of the beam and a concentration of compressive stresses at the corners. The presence of the opening also reduces the stiffness of the element, being evidenced a greater displacement of the center of the concrete beam.

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