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# Safety analysis of modern heritage masonry buildings: Box-buildings in Recife, Brazil

Jenner Carvalho [a], Javier Ortega [b], Paulo B. Lourenço [b,*], Luís F. Ramos [b], Humberto Roman [a]

[a] Department of Civil Engineering, Federal University of Santa Catarina, Florianópolis, Brazil
[b] ISISE, Department of Civil Engineering, University of Minho, Guimarães, Portugal

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ABSTRACT

Box-buildings are structural masonry buildings named as such because of their shape. There are around 5000 of them in Recife, Brazil. This paper presents a safety analysis of one box-building that suffered collapse on December 2007. The research aims at quantifying the safety of this type of existing buildings and at better understanding their structural behavior to try to identify the reasons for the collapse. A finite element model was prepared and a set of nonlinear numerical analyses were performed. The results of the analyses show good agreement between the observed damage in the real building and the damage achieved numerically at the current condition (LF = 1). The model thus seems to represent satisfactorily the real behavior of the building but the safety factor obtained seems too conservative and does not justify the collapse observed in reality. Since results show that the building should not have failed under normal working conditions, a collapse assessment about why the building fell is therefore provided and a sensitivity analysis was performed in order to understand the importance of the material parameters and their influence on the structural response of the building.

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## 1. Introduction

It is estimated that there are between 4000 and 6000 buildings constructed with the common characteristics of the so-called box-buildings in the Recife Metropolitan Region (RMR), Brazil. They are inhabited by more than 250,000 people, comprising approximately 10% of the population of the region. Up to 90% of these buildings seem to present some risk of collapse, with different severity, and a total of 230 of these buildings are classified as having high risk of collapse and have already been evacuated [9]. Twelve box-buildings have collapsed over the past 20 years, causing a dozen casualties. Due to the large number of buildings and people involved, this situation has become one of the major urban problems in Recife. The problem affects generally low income families, which are mostly the inhabitants of these buildings. The inhabitants face problems such as the evacuation of buildings and relocation, and the fear to continue to live in an area where other buildings have collapsed.

There was a big rural exodus towards the cities during the 1970s, particularly in Brazil, and box-buildings arose at that time because of housing shortage, bringing great masses of workers which accumulated on the peripheries of the urban centers. These buildings are the result of speculative activities, with low cost and high speed construction with unskilled labor. The building development was made by non-experts interested only in the fast return of the investment, with no consideration of specific technical norms or standards, thus, critically reducing their safety coefficient. The main problems seem to be a poor choice of materials and the adoption of technically inadequate building solutions, followed by a fast progressive degradation process, with premature ageing and many damage manifestations.

Many research projects have been carried out in Brazil concerning this problem [16,25]. However, the characterization of the materials is particularly difficult, given the low quality of the materials and the many factors which seem to be affecting them. The unsuitability of the masonry used in the buildings for a structural purpose was confirmed, proven to be insufficient to bear the stresses to which it is subjected to. Still, the anomalies encountered are not only a result of inadequate materials and defects in construction works but also are affected by the lack of maintenance and different environmental causes, such as moisture or chemical attacks. The reasons for the collapse are still unclear and no sound methodology to assess the safety and strengthen these buildings is available. Therefore, the main objective of the present work is to contribute to find an adequate solution to this problem.

* Corresponding author at: ISISE, Department of Civil Engineering, University of Minho, Campus de Azurém, Guimarães 4800-058, Portugal. Tel.: +351 253 510 200.
*E-mail address:* pbl@civil.uminho.pt (P.B. Lourenço).

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It is common to see social housing in poor condition, in different countries. Efforts in rehabilitation and conservation need to also address this modern heritage which involves social housing and modern buildings, which are a part of the current urban landscape. Conservation engineering is a multidisciplinary approach that needs a full understanding of the materials and the structure, and aims at acquiring enough data to produce optimal interventions. Here, one box-building that suffered collapse is adopted as a case study of an experimental and numerical research in order to quantify the safety of this type of buildings and better understand their structural behavior. For this purpose, an extensive testing program was carried out by de Carvalho [8], including non-destructive and minor destructive testing on the building, as well as laboratory testing.

The possibility of using sophisticated numerical models for the analysis of structures and for structural safety assessment has been highly enhanced in the recent years but performing a structural analysis of an existing construction remains a complex task, given the uncertainties about the material properties, the morphology of structural elements, the connection between structural elements, and the construction phases, among other aspects, see Lourenço [21] and Lourenço et al. [24]. For a deeper comprehension of the specific purposes and challenges in the modelling of the mechanical behavior of an extremely heterogeneous material such as masonry, the reader is referred to Lourenço [19] and Roca et al. [32]. In this study, the structural assessment was carried out using the finite element method as the analysis tool. Moreover, given masonry inherent uncertainties, a sensitivity analysis was also carried out to understand the importance of each material parameter and its influence on the global structural response of the building.

## 2. Description of the studied building and testing

The research is focused on one of the box-buildings of the residential complex *Sevilha*, in *Jaboatão dos Guarapes*, within the RMR. The residential complex is composed by four blocks of very similar characteristics. Block B partially collapsed on December 2007 and it was later demolished. Fig. 1 shows the building after the collapse. Failure of the foundation masonry walls was observed. This collapse triggered the experimental and numerical research carried out by de Carvalho [8]. The visual inspection and testing program described next was performed on the block C of the complex.

### 2.1. Characterization

The general features of the studied building correspond to the common features and characteristics of the box-buildings regarding appearance, structural system and materials. In the absence of documentation of the original project, an exhaustive visual inspection was performed comprising the roof and, especially, the foundations. In some cases, renderings were removed and openings were executed in order to observe and inspect the structural building elements.

The building is four-stories high and has a water reservoir on the top made in reinforced concrete, with a total height of 17 m. The strong squared shape of the building is only disrupted by the staircase, which is situated in the central part of the building and is set back further than the rest of the façade. The staircase also holds the entrance to the building and supports the water reservoir. The structure consists of unreinforced masonry walls, which supports the beam and block floor slabs and transfer the load to the foundation walls, executed also in masonry. The external walls are rendered with mortar and painted.

The architectural plans of the building are shown in Fig. 2. The internal structural masonry walls act also as partition walls and define the layout of the building, which is quite regular and almost symmetric with respect to the two orthogonal axes. The plan has an H shape configuration with the staircase dividing it in two parts. There are four apartments per floor of small dimensions, around 55 $m^2$. The inter-story height is 2.60 m and the ground floor is elevated with respect to the outside ground level, meaning that it is necessary to climb four steps in order to access the building. The roof is covered with fiber cement sheeting and it is not accessible.

Fig. 3 shows a construction detail from the foundations to the ground floor. The foundations are made using continuous reinforced concrete footings, with a width of 500 mm and a height of 150 mm, and unreinforced masonry walls. The masonry walls are built with hollow clay blocks with dimensions about $90 \times 190 \times 190\ mm^3$ with 8 holes positioned horizontally. They lay on their largest dimension, 190 mm, and the average thickness of the mortar bed joints is 30 mm, but it is very variable. The external mortar rendering has a variable thickness between 40 and 50 mm. No internal rendering is present and altogether, the masonry walls are around 230 mm thick. The depth of the ground water table is 0.75 m and, therefore, a significant part of the foundations is in direct contact with water. As there is no waterproofing, the first layers of the masonry are permanently saturated. Moreover, there is no sewage collector in the building and the water is contaminated, which may result in accelerated degradation of the mechanical properties of the blocks [10].

Regarding the structure above ground, the structural unreinforced masonry walls are constructed with the same masonry units used in the foundations but lying on their smallest dimension, 90 mm. The thickness of the mortar bed joints varies between 20 and 30 mm, the external mortar rendering can reach up to 60 mm thickness, while the internal mortar rendering varies between 20 and 25 mm. Therefore, the overall thickness of the walls varies between 120 and 150 mm. The beam and block floor system is used for the floor slabs, consisting of prestressed concrete joists and hollow concrete tiles with an overall thickness of 200 mm. The spacing between joists is 450 mm. There are reinforced concrete tie-beams at every floor level.

### 2.2. Testing and obtained data

The investigation campaign performed on the building to assess the existing damage and to better understand its structural

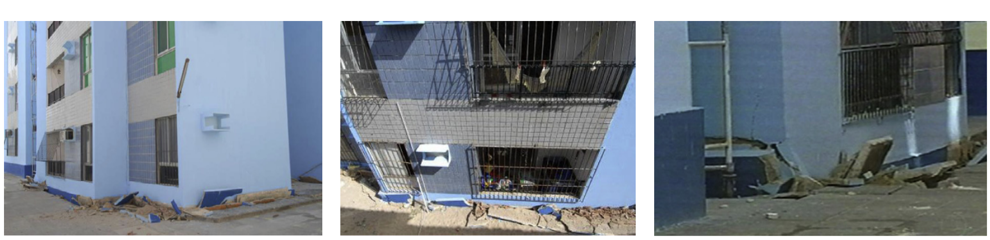

**Fig. 1.** Views of the building after the collapse.

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