Construction and Building Materials 182 (2018) 20–34

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Structural performance of unreinforced masonry elements made with concrete and horizontally perforated ceramic blocks – Laboratory tests

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HIGHLIGHTS

- Experimental campaign and a critical analysis of structural performance of unreinforced masonry elements.
- Large characterization of materials and components used in masonry buildings.
- Prisms and wallets.
- Masonry buildings constructed in Pernambuco and their relationship with several failures.

ARTICLE INFO

Article history:
Received 3 January 2018
Received in revised form 8 June 2018
Accepted 11 June 2018

Keywords:
Masonry buildings
Accidents with masonry buildings
Experimental tests

ABSTRACT

This paper discusses masonry buildings constructed in Pernambuco and their relationship to several failures that have occurred, some of which included the death of inhabitants. Topics such as the main features of this building technique and its peculiarities that played an important role in its structural behaviour are discussed in detail. Additionally, the paper presents a large characterization of materials and components used constituting the most important current research on this topic in Brazil. Its content analyses in depth, experimentally, the behaviour of single bricks, prisms and wallets that allow the identification and quantification of the influence of several mortar rendering layers on the load capacity of elements tested. A critical analysis concerning the factors that contribute to the performance observed is presented from which it was possible to realize a significant variability of results. A summary with the main results of all experimental tests is presented.

1. Introduction

There have been numerous studies performed on the behaviour of masonry prisms under axial compression [1–3]. The effects of variables such as the height-to-thickness ratio of the prism, mortar type and grout strength, unit geometry, and various capping compounds have been the point of focus of many researchers [4,5].

The occurrence of several accidents in the Metropolitan Region of Recife (MRR) with masonry buildings constructed with non-structural blocks supporting loads beyond its own weight has drawn the attention of the regional and national technical community for the need to establish criteria of research, study and rehabilitation, within acceptable levels of reliability. Masonry buildings constructed with such technique is often referred as resistant masonry buildings.

Approximate numbers indicate that there are around 6000 residential building constructions in the region made with this type of masonry buildings where close to 250,000 people live. Several pathological manifestations and collapses involving human deaths have also been reported.

The established framework, which constitutes a serious social problem that afflicts many developing countries, demands the carrying out of consistent scientific research that allows a deeper understanding of the problem and allows for the creation of technical retrofitting interventions to avoid new accidents.

This constructive practice had an important impetus from the beginning of the 60's, and its success was due to the lower cost compared to the construction with conventional reinforced concrete structure and higher speed of construction on-site [6].

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https://doi.org/10.1016/j.conbuildmat.2018.06.092
0950-0618/

On the other hand, the search for cost minimization, the lack of quality control of the components and the construction procedures, together with the lack of specific design codes has caused a series of pathologies and accidents over the last years.

Even taking into account that this is not the only factor to be considered, it is important to be in mind that since masonry structures are primarily stressed in compression, the compressive behaviour of masonry is of crucial importance for design and safety assessment purposes [7–9].

With regard to retrofitting strategies, there is scarce information in the literature on the subject. The research developed at the School of Engineering of São Carlos (EESC-University of São Paulo, Brazil), which investigated the contribution of the coating in the strength of masonry prisms built with non-structural blocks [10], is one of the most important researches presented in Brazil.

In local practice, what has been observed is the use of retrofitting solutions based on empirical knowledge that need more in-depth reflection on its effectiveness and applicability [11]. In this context, the work presents results of research developed within the framework of the FINEP/HABITARE Project entitled Development of Models for Retrofitting Masonry Buildings Constructed with Non-Structural Bricks. The Project was conducted by the Catholic University of Pernambuco – UNICAP, as executing agency, by the Technological Institute of Pernambuco – ITEP, as proponent, by the Secretariat of Science, Technology and Environment – SECTMA, as an intervening agency and the University of Pernambuco – UPE, and Federal University of Santa Catarina – UFSC, as co-executors.

The main objective of this work is report and discusses an extensive experimental campaign developed to understand the role of mortar coating on the compressive behaviour of unreinforced masonry elements, made with non-structural blocks. The experimental results allow evaluating the efficiency of several rehabilitation techniques.

The importance of research is justified because there are, in many developing countries, a large number of residential constructions made with the types of blocks studied that have collapsed, with human victims, in the last decade.

Based on the research, it can be stated that the results obtained offers several interesting aspects that may be applied both in the rehabilitation (strengthening or repair) of masonry structures and in the construction of new structures with special performance requirements.

2. Experimental program

In order to evaluate the behaviour of resistant masonry elements used for structural purposes, blocks, prisms, wallets, walls and foundation elements were experimentally tested. The prisms were made and tested in the Materials Laboratory of the Catholic University while the walls, walls and foundation elements were made and tested in the ITEP. The details of the elements and tests performed are presented below.

2.1. Units: Concrete and ceramic blocks

Ceramic and concrete blocks used in the research were of the same type as those usually employed in real resistant masonry buildings in the region. The dimensional characteristics of these blocks were obtained through tests of 60 ceramic blocks and 30 concrete blocks. Table 1 summarizes the results obtained for both types of blocks studied.

Table 1
Main characteristics of the blocks tested.

(a) Ceramic blocks – NBR 15270-1 [12]	
Length (mm)	190
Width (mm)	90
Height (mm)	190
Thickness of horizontal and vertical septa (mm)	7.0
Compression strength (MPa)	**2.15**
(b) Concrete blocks – NBR 6136 [13]	
Length (mm)	390
Width (mm)	90
Height (mm)	190
Thickness of horizontal and vertical septa (mm)	21.5
Thickness of the internal transverse septa (mm)	22.5
Thickness of external transverse septa (mm)	25.0
Compression strength (MPa)	**2.30**

The bold values are average compression strength (MPa) of ceramic and concrete blocks tested.

2.2. Fine aggregate and mortars

The sand used in the preparation of the mortars for laying and coating the tested models is usually found in the MRR, and all the lot used in the development of the research was acquired from the same supplier. Table 2 summarizes the results of sand characterization.

The mortars used both in the laying of the blocks and in the coating, were defined from cement, lime and sand mixtures in proportions of 1:2:9, 1:1:6 and 1:0.5:4.5 by volume.

Table 3 presents the values of the compressive strength of the mortars, obtained through tests of 15 specimens in accordance with the Brazilian standards NBR 7215 [20] and NBR 7222 [21]. The amount of cement used in the mortars was 220 kg/m^3 and 150 kg/m^3 for the mixture proportions of 1:1:6 and 1:2:9, respectively.

In the case of concrete blocks, the laying grout cords were applied both to the longitudinal and to the transverse septa of the blocks, a situation that is usually referred to as total settlement.

2.3. Steel mesh and connectors

Two types of steel mesh were used as reinforcement of mortar coating in the prisms tested: one using galvanized steel and another with ribbed welded steel. The galvanized steel mesh is formed of wires with a diameter of 2.7 mm and a spacing of 5 cm in the horizontal direction and 10 cm in the vertical, making a steel area of 1.06 cm^2/m and 0.53 cm^2/m, respectively. The ribbed welded steel mesh had wires with a diameter of 4.2 mm and a spacing of 10 cm in the horizontal and vertical directions, making a steel section of 1.38 cm^2/m in both directions. Steel connectors were 5.0 mm in diameter.

2.4. Prisms

Approximately 500 prisms made with three vertically placed blocks were tested – 300 made with ceramic blocks and 200 with concrete blocks. The prisms were all capped at the top and bottom

Table 2
Characteristics of the natural sand used.

Maximum characteristic size (mm) – NBR 7211 [14]	4.80
Fineness module – NBR NM 248 [15]	3.20
Unit mass (g/cm^3) – NBR NM 45 [16]	1.42
Specific mass (g/cm^3) – NBR 9776 [17]	2.60
Swelling – NBR 6467 [18]	1.25
Critical humidity (%) – NBR 6467 [18]	3.00
Powdery material content (%)– NBR 7219 [19]	1.26