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Review

Physical characterization and compression tests of one leaf stone masonry walls

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ABSTRACT

Most of the ordinary buildings of Porto, Portugal, build up to early 20th century are made of one-leaf granite walls with large stone blocks. The influence of stones' shape, internal voids and mortar on the mechanical characteristics has been studied. Aiming at assessing the behavior of these structures, a number of wall panels retrieved from a building were tested in laboratory. Compression tests were performed to evaluate the wall response, both in original state and after injection with lime mortar. The results show a relatively low stiffness, which increased about three times after injection.

Contents

1. Introduction

The rehabilitation of old masonry buildings is a topic of great interest, given the growing need and will to protect and restore the safety and functionality of this large heritage spread all over the world. In Portugal, the cities' historical centres are mainly dominated by this type of constructions, which are made of masonry walls supporting timber beams and trusses. In the Northern part of Portugal, the masonry consists often on stone blocks, usually with irregular shapes, placed on more or less regular layers in one or multiple leaves. Stone masonry is a heterogeneous composite structural material, mostly made of stones and mortar with complex links and interactions, for which the definition of realistic behavior laws remains a big challenge. Research works carried out in Italy on buildings damaged by earthquakes have characterized and classified masonry according to the geometrical and mechan-

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ical analysis of the walls' elevation and cross-section [1,2]. In Portugal, some work has been done on the survey of stone masonry constructions in different regions [3] and a first attempt to create a database was done through the study of stone walls from buildings of the town of Tentúgal [4].

In order to evaluate mechanical properties of masonry, several authors tried to reproduce different typologies in laboratory by designing physical models that respect the *in situ* characteristics of walls [5–11]. However, it is not easy to build wall samples in laboratory to represent historical stone masonry. Binda and Saisi [2] and Binda et al. [12] has developed and improved methodologies for the evaluation of the structural and material properties of masonry based on Non-Destructive Techniques (NDTs) and Medium Destructive Techniques (MDTs) *in situ* tests. However, some of these tests give access only to the quality of the masonry and not to its mechanical properties and, even when quantitative values are assessed, only small portions of the masonry are involved in these tests. Other experimental studies were carried out *in situ* on masonry panels hit by earthquakes in order to evaluate the mechanical properties of different typologies of walls [13–16]. Due to the variety of applied techniques and the type of tested masonry, these experimental studies showed a large scatter of results. For the same type of wall and test the differences are much smaller [14]. However, this type of tests is not viable in most cases. In Portugal, a wall extracted from a building in Azores damaged after the 1998 earthquake was transported to the Laboratory of Earthquake and Structural Engineering (LESE) of the Faculty of Engineering of University of Porto (FEUP) and tested under constant vertical force and horizontal cyclic displacement applied to the top [17]. Cases like that are hardly referenced in the bibliography.

On the other hand, different authors suggest that grouting and/or repointing is an effective way to improve the behavior of historical stone masonry walls [8,12,15]. Nevertheless, the grout must be compatible with the materials of the original construction [12].

In Porto, the ordinary buildings built up to the beginning of the 20th century are made of one-leaf stone masonry walls with large granite blocks. In this context, for which a significant lack of structural information still persists, the present work aims at contributing for the understanding of the phenomena involved in the behavior of such particular type of structures. Recently, a building located at the centre of Porto, Portugal, with this type of walls was used as case study, allowing for surveying the *in situ* geometrical characteristics of its masonry walls. After that, one of the walls of this building that was meant to be demolished was cut into six panels which were transported to the LESE in order to evaluate its mechanical properties through experimental testing. This paper presents the results of the compression tests performed in three of the panels for assessing the walls' vertical response, first in its original state and afterwards with the internal voids of the joints injected with lime mortar. This last procedure was adopted in only one of the three panels in order to evaluate changes in the mechanical properties when the internal voids (detected by observing the cross-sections after cutting the panels) were filled. The experimental results were also compared to those obtained *in situ* with the double flat-jack procedure [18].

2. Description of the building

The building used as case study is located in the centre of Porto, Portugal, and it was constructed in 1916. The building shows quite large areas, with a rectangular configuration, $11.5 \times 30.0\ m^2$, an underground floor (floor -1) plus two floors above (floor 0 and floor 1) and a sloped roof. Porto traditional constructions are typically characterized by granite masonry walls, wooden floor beams and roof trusses covered with ceramic tiles. The walls of the main facades are covered with mortar and (or) ceramics, except for the windows' and doors' frames, the top and the floor span lines and some other decorative elements.

At the time of this study, the building was under rehabilitation. The foreseen intervention included the demolition of the internal structural wall in floor -1, the opening of new doors in some of the remaining walls and the removal of the cover mortar, see Fig. 1.

3. Characterization of the stone masonry walls

3.1. Geometrical characterization

The characterization of stone masonry walls involves a thorough investigation of geometry (elevation and cross-section) and constitutive elements [2]. The texture of the building walls (elevation and cross-section) was studied, as well as the percentage and general characteristics of the wall constituents (stone, mortar and voids). The procedure included the walls' photographic record, using a ruler as scaling factor, and the evaluation of each material quantity through image analysis, resorting to computational tools.

This methodology was applied to three walls identified by C, D and E in Fig. 2, the first two located in floor -1 and the last one on floor 1. According to the new architecture and the rehabilitation project, the walls D and E were cut to open doors and the wall C was meant to be demolished. Thus, the latter was sectioned into several panels transported to the LESE to be tested (addressed in subsequent paragraphs). Three different areas, numbered from 1 to 3, were studied in the three walls. The wall E was used to analyze the elevation and cross section layout in terms of stones, mortar and voids. The photos of the elevations of walls C and D were not used for the geometrical survey because considerable portions of mortar were covering part of the stones around the joints, thus prevented the proper evaluation of the stones contours. Figs. 3 and 4 show the elevation and cross-section of the walls' panels after image analysis.

The survey showed that, in general terms, this masonry consists of medium to large size stones (50–90 cm diagonally measured) arranged on regular alignments, showing a significant number of small stones around (wedges), with mortar joints and, occasionally, some pieces of brick. The larger granite stones have prismatic shapes and exhibit reasonably good physical conditions with just slight superficial material disaggregation. The mortar joints show variable thickness (0.5–2 cm), cream color and quite brittle behavior.

The cross section of all the surveyed walls consists of a single leaf of granite stones with variable height and 30 cm thick for wall E, 40 cm thick for wall C and 50 cm thick for wall D. Large voids were observed in the cross sections, in particular in their internal zones, which were imperceptible by the elevation analysis. In fact, the mortar was originally placed along the border lines, after positioning the stones, without filling the inside, where the absence of mortar is actually quite visible, cre-

Fig. 1. Rehabilitation works in the studied building.