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Mechanical characterization of rubble stone masonry walls using non and minor destructive tests

I. Lombillo [a,*], C. Thomas [b], L. Villegas [a], J.P. Fernández-Álvarez [c], J. Norambuena-Contreras [d]

[a] Dept. of Structural and Mechanical Engineering, University of Cantabria, Civil Engineering School, 39005 Santander, Spain
[b] Dept. of Science and Engineering of Materials, University of Cantabria, Civil Engineering School, 39005 Santander, Spain
[c] Hydrogeophysics and NDT Modelling Unit, University of Oviedo, 33005 Oviedo, Spain
[d] GITECO Research Group, University of Cantabria, Civil Engineering School, 39005 Santander, Spain

HIGHLIGHTS

- The paper presents an experimental study by using N&MDT applied in a rubble stone masonry construction of the 16th century.
- The stress levels obtained by using simple flat-jack and hole-drilling tests were equivalent.
- The estimation of compressive strength using double flat-jack test has led to a reasonable value for the case analyzed.
- The composition of the transverse section of the load-bearing walls has been identified through impact-echo methodology.
- The N&MDT used in this study can be used for providing valuable information of rubble stone masonry walls.

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ABSTRACT

As is well known, the diagnostic analysis of ancient buildings supposes important challenges from the point of view of its evaluation under field conditions. In this context, Non and Minor Destructive Techniques (N&MDTs) can be used for the mechanical characterization of ancient buildings. However, there are not many examples of application of the techniques in rubble stone masonry. Therefore, this paper presents a preliminary experimental study by using N&MDTs applied in a particular construction: the Riva–Herrera palace located in Santander, Northern Spain. In this way, different non and minor destructive techniques as flat jack, hole-drilling and sonic tests have been used in order to evaluate the mechanical and morphological characteristics of different rubble stone masonry walls, under field conditions. The results of this study show that the N&MDTs used in this study can be potentially used for providing valuable information about the mechanical and morphological characteristics of rubble stone masonry walls. In addition, this knowledge of great important in the intervention process has been obtained with a minimal effect on the structural component analyzed.

1. Introduction

The diagnosis of ancient buildings supposes important challenges from the point of view of its evolution under field conditions. This is because of the complexity of their geometry, the variability of the properties of traditional materials, the different construction techniques that are commonly used, lack of knowledge about existing damage, and how certain actions affect the constructions throughout their life. Due to this, the architectural heritage buildings are subjected to a number of difficulties in diagnosis and restoration under field conditions. Therefore, these difficulties limit the application of the standards and guidelines which currently apply in building construction. As a result, understanding, analysis and repair of historic buildings remain among the most important challenges of modern technicians [1]. Moreover, within the intervention process, previous knowledge is fundamental in order to choose the most appropriate materials and techniques applicable to Cultural Heritage preservation and prevention of damage [2,3]. Thereby, the rehabilitation process should be based on an accurate preliminary investigation [4]. However, it is important to mention that no individual test can provide all required information, so it is necessary to use different complementary techniques or methods in order to compare results [5,6].

In this context, Non and Minor Destructive Techniques (N&MDTs) can be used for the mechanical evaluation of ancient buildings [7]. Thus, among these techniques, the flat jack and hole-drilling tests are the most renowned. However, sonic

* Corresponding author. Tel.: +34 942 201 743.
E-mail address: ignacio.lombillo@unican.es (I. Lombillo).

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techniques, several direct transmission and impact-echo tests, based on transient pulse propagation through a solid elastic isotropic medium and used for determining the homogeneity of materials, also can be considered [8,9]. Flat jack technique was tuned by the Italian researcher Paolo Rossi (ISMES-Istituto Sperimentale Modelli e Strutture) in the early 1980s [10]. The first application in situ of the flat jack technique in heritage buildings was on the brickwork walls of the Palazzo della Ragione in Milan [11]. On the other hand, the first use of this technique on rubble stone masonry was in the early 1990s [12]. These tests were used to gauge the suitability of the technique on irregular stone masonries. In addition, the first reference about the estimation of stress using hole-drilling technique corresponds to Barla and Rossi [13]. This reference deals with obtaining the existing stress level in a concrete tunnel. However, the Spanish Researcher Sánchez-Beitia developed and optimized a methodology applicable in masonry structures. The purpose of this technique is to quantify, in situ, the stresses to which the stone or brick masonry are submitted during their service life. There are studies related to the application of the hole-drilling technique in sandstone masonries both in laboratory [14,15] and on site [16–18]. However, there are not examples of application of the technique in rubble stone masonry.

For these reasons, this paper has been prepared with the objective of developing a preliminary experimental study applied in a particular case of intervention: the Riva–Herrera palace located in Santander, Northern Spain. For that, different Non and Minor Destructive Techniques (N&MDTs) as flat jack, hole-drilling and sonic tests have been used in order to evaluated the mechanical and morphological characteristics of different rubble stone masonry walls, under field conditions. In addition, in order to obtain useful information about the chemical, physical and mechanical characterization of the main masonry materials (stones and mortar) in Riva–Herrera palace, different experimental tests on tests samples also have been developed. In this regard, the stones and lime-based mortars were chemically characterized by elemental microanalysis using energy dispersive X-ray spectroscopy (EDAX), the chemical properties were characterized by X-ray florescence (XRF) and the mineralogical composition was obtained by X-ray diffraction (XRD). Moreover, stones were physically characterized by apparent and relative densities, porosity and water absorption. The compressive strength of stones samples was also estimated.

2. Materials and methods

This section describes the materials and processes used to obtain useful information about the physical, chemical and mechanical characterization of the stones and mortar in the rubble stone masonry. In this way, the procedures used for the morphological and mechanical characterization of masonry walls by using such non and minor destructive techniques as simple and double flat jack test, hole-drilling test and sonic tests are described below.

2.1. Description of the Riva–Herrera palace

The Riva–Herrera palace evaluated in this study is shown in Fig. 1. Thus, Fig. 1a represents a view of the east area of the complex, while Fig. 1b shows an aerial view of the palace in its actual state. Archaeological studies carried out in the building have shown that there are no medieval elements in the Riva–Herrera building complex. Hence, although the exact date of construction of the tower and the attached palace has not documented, it is probably the first Renaissance building in Santander [7]. The building has its origin in the 16th century East tower, dating back to 1555. The three-story East tower has a structure based on rubble stone masonry walls, with clear predominance of limestone. Some pieces of marlstone can also be detected, dispersed in the limestone masonry walls. The windows and the door are made in sandstone, as are the corners of the tower and some elements with ornamental character. All mortars are lime-based mortars. Thus, next terraced housing was built onto the tower's original walls (west and north), see Fig. 1. This housing consists of a two-story rectangular building, with a double-arched door on the ground floor. Just as in the tower, load-bearing walls are of rubble stone masonry, with clear predominance of limestone versus marlstone. The double-arched main door, most windows and other architectural elements with ornamental purpose are made in sandstone.

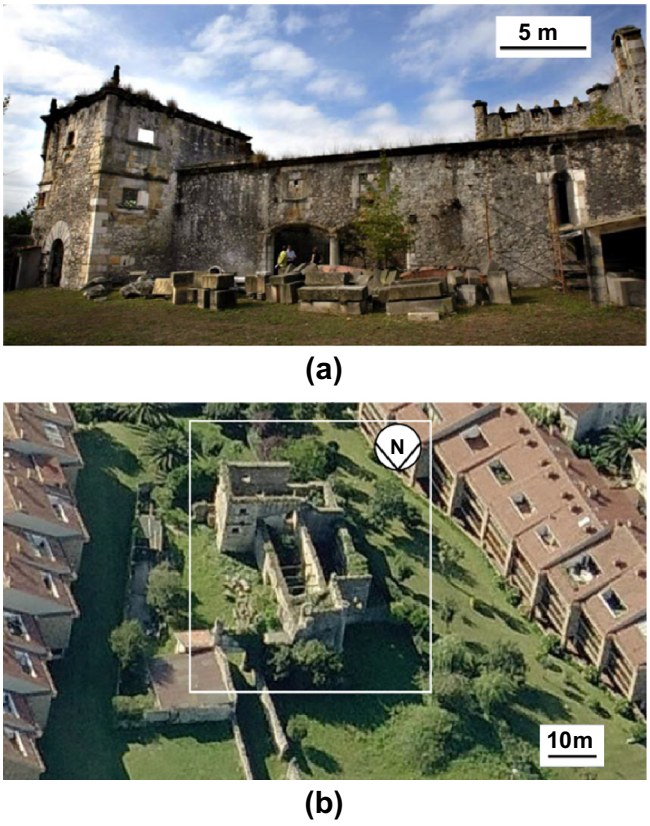

Fig. 1. The Riva–Herrera palace: (a) Current view of the east area of the complex, and (b) aerial view.

The complex building was completed in the 17th century with the construction of a chapel, covered with a vault, and the majority of the enclosure. A great stony gate was also added, which was subsequently renovated to provide access to the parade ground. Afterwards, the whole building was subjected to other interventions (modifications on walls and demolition of roofs). In the 20th century the palace conditions became worse and worse. As a result, the building ended up in a state of neglect. In 2006 Santander City Council decided to renovate the palace, work that is still going on nowadays.

2.2. Characterization of materials

The stones and lime-based mortars were chemically characterized by elemental microanalysis using energy dispersive X-ray spectroscopy (EDAX), the chemical properties were characterized by X-ray florescence (XRF) and the mineralogical composition was obtained by X-ray diffraction (XRD). The location of the sampling of materials is shown in Fig. 2a. In this way, for EDAX characterization, a JEOL JSM – 5800 LV scanning electron microscope with an energy dispersive X-ray microanalysis unit incorporated, has been used. In addition, for the XRF characterization, an ARL ADVANT'XP X-ray fluorescence spectrometer equipped with proportional flow and scintillation detectors have been used. At last, for XRD characterization, a PHILIPS PW 1820 X-ray diffractometer has been used.

Moreover, stones were physically characterized according to [19] and consistently with the procedures applied in [20]. Moreover, compressive strength on stones samples has been estimated according to [21]. The equipment used for this test was a hydraulic press of 15-ton.

2.3. Flat jack testing

Simple and double flat jack tests were carried out on rubble stone masonry walls of the Riva–Herrera palace. The locations of the flat jack tests on the ground floor of the building complex are shown in Fig. 2a. This masonry wall is predominantly made of lime-based mortar and limestone with some dispersed pieces of marlstone (Fig. 3). The simple flat jack test was focused on determining the vertical compressive stress in the palace's north wall's outer leaf, perpendicular to the plane defined by the flat jack, at ground floor level. In addition, on the same site, a double flat jack test was