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NON-DESTRUCTIVE TESTING FOR THE ASSESSMENT OF STONE DECAY IN RELIGIOUS HERITAGE CHURCHES OF SAN ROQUE (SEVILLE) AND NUESTRA SEÑORA DE LA ANTIGUA (TORREALHAQUIME, CADIZ)

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Abstract

The study of ultrasonic transmission through constructive elements allows to detect areas where different defects and alterations are present, such as fissures, internal voids, lacks of cement on the stone (decohesion), detachment of layers, etc. The velocity of the sonic wave is directly related with the compactness and the density of materials, so when this wave passes through the air existing in these internal discontinuities, the transmission time through the element increases. The structural situation of two churches (San Roque, Seville and the Parish Church, Torre Alhaquime) has been studied and determined by means of ultrasonic testing of the columns that support the main naves. On both buildings, some fissures and cracks had been observed. On San Roque the discontinuities appear on the bases and on Torre Alhaquime the fissures appear on the capitals. We have applied the method of direct transmission to define the extension of this deterioration and to detect non visible problems.

Keywords: ultrasonic, transmission, diagnostic, built heritage, non-destructive testing

1. Introduction

Different methods and techniques used in engineering are very efficient in the diagnosis and analysis of the state of cultural heritage buildings [1]. Nondestructive testing (NDT) by ultrasound has been widely employed to evaluate several characteristics of building materials, like concrete or mortars [2-6], and in the field of cultural heritage proposed for detecting fissures and cracks [1], for determining the physico-mechanical behaviour of materials [7, 8], for

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evaluating the weathering degree of the rocks [1, 9] and for the assessment of the conservation state of different materials, plasters [10], frescoes [11] or bronze sculptures [12].

It is also very useful to compare the response of constructive elements or laboratory samples before and after conservation, especially consolidation, treatments [13-15]. Its use in singular elements, like columns and sculptures, is wide [1, 16] as well than in archaeological sites and megalithic artefacts [17, 18]. Some authors establish a classification of marble damage based on the values of velocity [19].

The values of ultrasonic pulse velocity has been combined with other non destructive or microdestructive tests in order to develop correlations to predict values of compressive strength [20], a property that requires a high number of normalized samples for its measure. In combination with different tests and measurements, it allows to define the structural situation of complete buildings [21].

In the present work we use this technique to assess the conservation state of structural elements of two churches from the south of Spain, in order to detect the presence of internal cracks.

2. Experimental

Longitudinal ultrasonic waves in the direct transmission method were measured with a portable equipment (Steimkamp BP 5), with two transducers - emitter and receiver - and a frequency of 50kHz. The accuracy of measurements is assumed to be ± 10%. During the measurement the coupled pressure was steadily increased until the transmission time displayed on the equipment was constant and therefore independent from the pressure applied.

This study focused on the deterioration evaluation of the columns of two important churches:

- San Roque (built around1760), in Seville. It is a baroque church with three naves, separated by two rows with three columns.
- Nuestra Señora de la Antigua parish church (from 1775), in Torre Alhaquime (Cádiz). It is a simple church with three naves, separated by two rows with two columns, neoclassic in the interior with a baroque façade.

On both cases, the presence of fissures and cracks on some of the columns made the conservators to decide exploring the rest in order to detect non visible (internal) deterioration of the stone pieces that form the columns. The schemes of the plans of both churches appear in Figure 1.

San Roque has six columns made of a red micritic brechoide limestone, with the configuration shown in Figure 2a. The problems are located on the bases and on the lower part of the shaft on column 1 (Figure 2b). Measurements on the two square pieces that formed the base, on both directions and on three points of each face were carried out. When irregular values of propagation time were obtained, we took measurements each 10 cm all along the face.

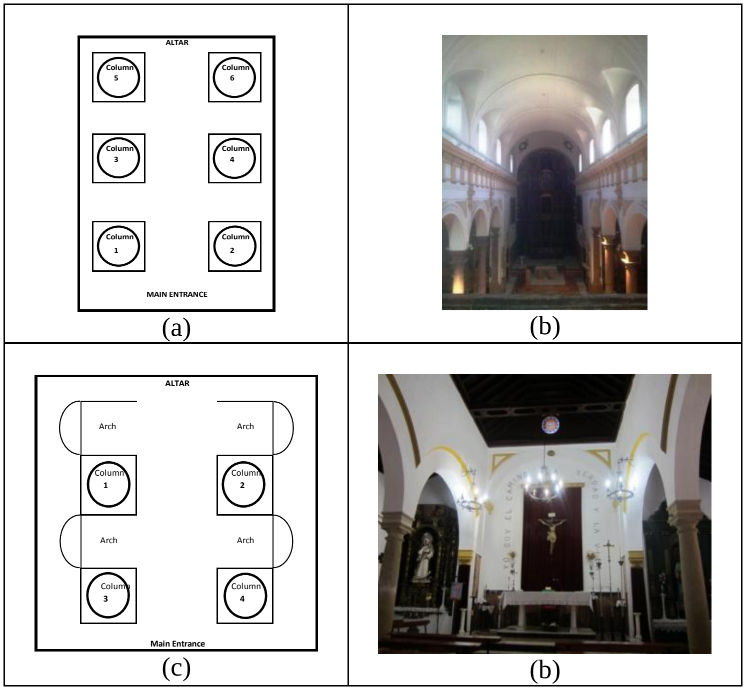


Figure 1. Schematic plan and general view of altar and columns of: (a, b) San Roque church [parroquiasanroquesevilla.es]; (c, d) Torre Alhaquime church.

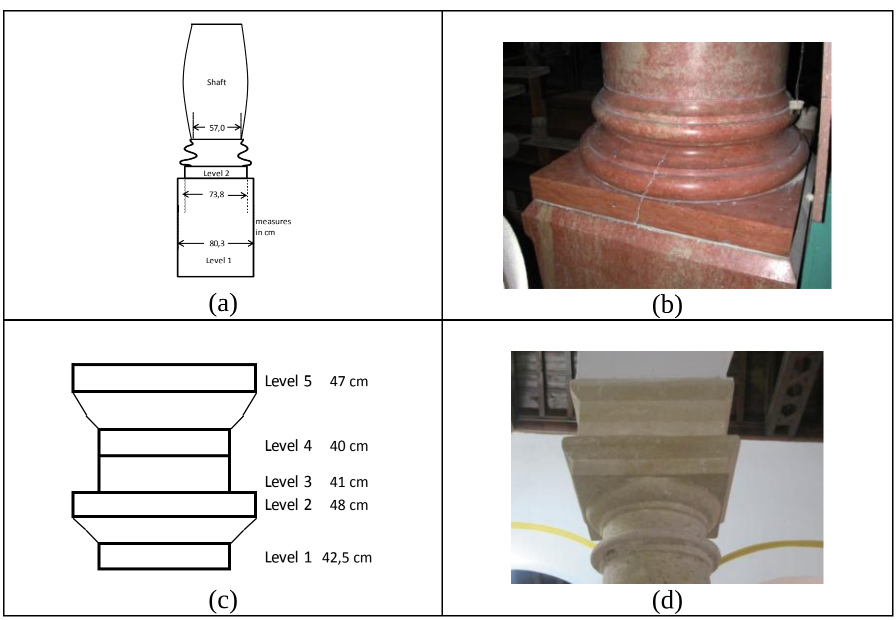


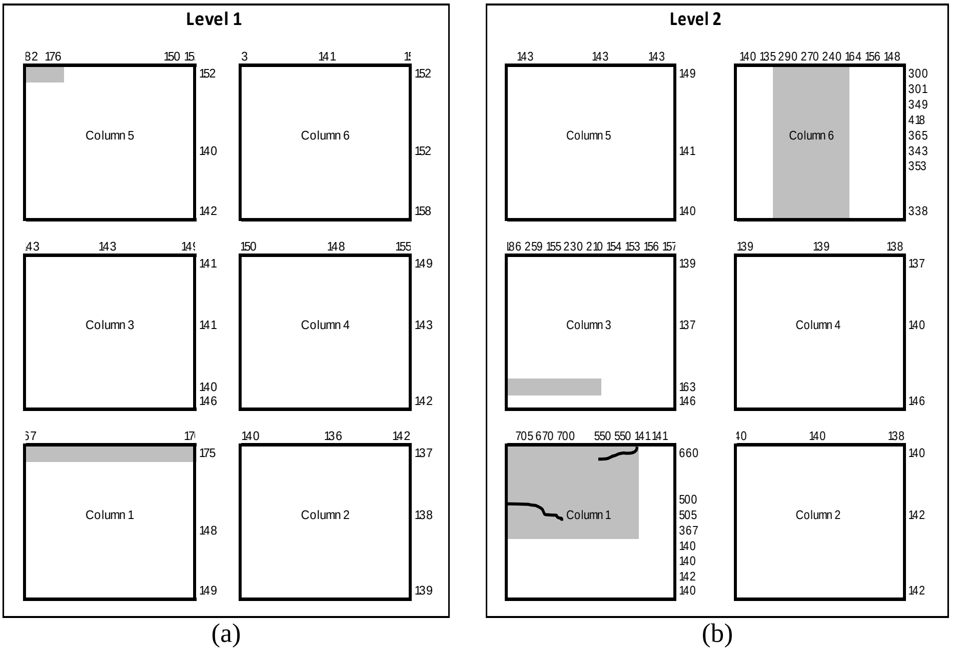
Figure 2. (a) Schematic representation of the columns of San Roque with (b) a detail of the base of column nº 1; (c) the schematic representation of the capitals of Torre Alhaquime church with the average measures for the four capitals, and (d) a detail of the capital 2.

The average velocity obtained on the six columns ranges between 5200-5300 m/s, showing the high compactness of the stone.

Torre Alhaquime has four columns made of a calcarenitic stone, as well as the capitals, where the cracks appear. The configuration of the capitals is represented on Figure 2c-d, each part being made of a separate stone block. We made measurements at five levels on each capital, on three points of each face and on both directions.

3. Results from San Roque church

On Figures 3 and 4 are presented the results of transmission times on both levels of the bases. The normal values, 150 µs on level 1 and 140 µs on level 2, correspond to the average velocity of ca 5250 m/s. When high values are obtained, zones with deterioration, marked on grey, can be defined. This deterioration does not consist on decohesion or loss of compacity, and it is only evident on column 1, which presents two fissures on level 2 (Figure 2b). On the other columns, the defects probably are internal and only detectable by this technique.

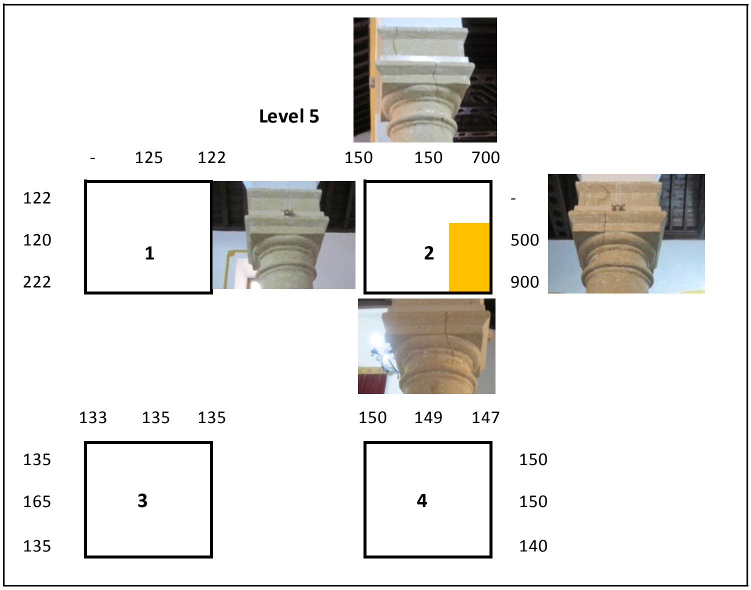


(a) (b)

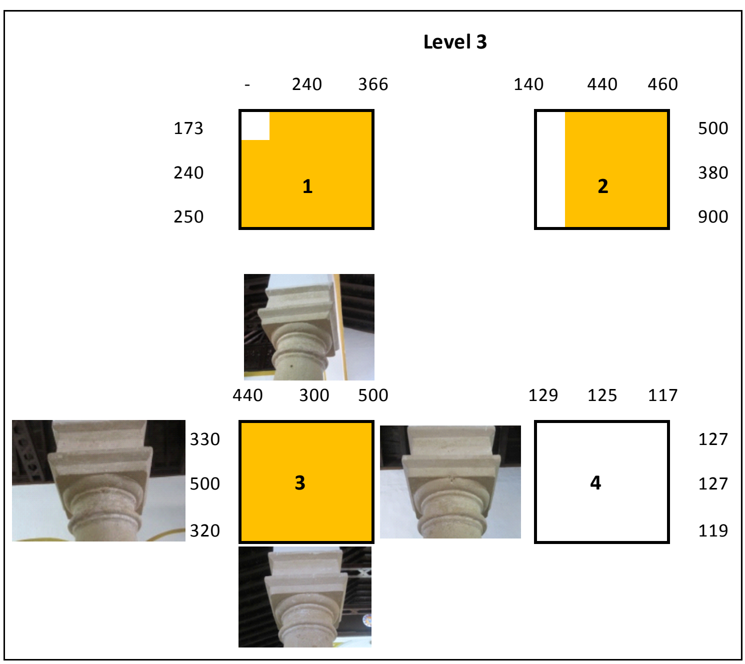
Figure 3. Transmission time (µs) on San Roque columns at: (a) level 1 and (b) level 2.

4. Results of Torre Alhaquime church

In this calcarenitic stone the average velocity ranged between 3300-3500 m/s, and the transmission times were around 140 µs for levels 2 and 5 and 120 μs for levels 1, 3 and 4. When different (higher) values were obtained a more detailed inspection was carried out.



(a)



(b)

Figure 4. Transmission time (μs) on Torre Alhaquime capitals at: (a) level 5 and (b) level 3.

As an example, on Figure 4a are shown the results of level 5 with the pictures of column 2. It is clearly seen that the cracks cause a high time of ultrasonic transmission; the same situation occurs in the lower levels of this column (Figure 4b for level 3).

Column 4 has a similar situation with the column number 2, while 1 and 3 did not show macroscopic external deterioration. In spite of this, the values of transmission time on columns 1 and 3 for level 3 are very high on every measure points, which could be related to an internal failure (Figure 4b).

5. Conclusions

The measure of ultrasound transmission is a useful tool to evaluate the state of conservation of building elements, and accurate enough to detect internal discontinuities or to determine the position and extension of cracks and fissures. The non-destructive character of ultrasonic velocity measurements and its ability to quantify physical-mechanical conditions of building materials, allows a complete sampling on the elements under inspection.

It is possible to carry out rapidly a complete survey and get the information on real time, provided that the undamaged areas give the reference values of transmission time that could be used, by comparing, to detect anomalies.

On both churches under study, with the use of this technique it has been possible to detect the existence of non visible defects on the stone elements that form part of the columns that have to be investigated more extensively in order to secure the building.

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