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USO DEL MÉTODO DE IMPACTO ECO EN RESTAURACIÓN EN LA HABANA VIEJA

USE OF IMPACT ECHO METHOD IN RESTORATION IN OLD HAVANA

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El método de impacto para las ondas mecánicas es una técnica de ensayos no destructivos (END) desarrollado para la determinación del estado del hormigón en puentes y carreteras. En este trabajo se hace una extensión del mismo al diagnóstico de edificaciones en restauración. El método presenta un grupo de cualidades que hacen atractiva su extensión en la determinación precisa de defectos (hendiduras, embutidos, agujeros, espesor de la estructuras y la laminación), para lo que no se necesita una gran infraestructura instrumental. Se presenta un estudio preliminar de la aplicación de método de impacto eco en la detección de fallas en un edificio de La Habana Vieja. Particularmente se estudia la evaluación de columnas del Hotel Santa Isabel, construido en el siglo XVIII con las columnas de piedras calcáreas y repello de estuco a base de cemento.

The impact method for mechanical waves is a nondestructive testing technique (NDT) developed for the determination of the state of the concrete in bridges and highways. In this work it is carried out its extension to the diagnosis of buildings in the restoration process. The method shows a group of features that makes it attractive: the precise determination of defects (fissures, inlays, holes, thickness of structures and lamination) and it doesn't need great instrumental assembly for its application. It is presented a preliminary study of the application of the impact echo method in the flaw detection in one building of Old Havana. Particularly the evaluation of columns is studied for the case of Santa Isabel Hotel, constructed in the eighteenth century with ashlars' columns of calcareous rocks covered with stucco based on cement.

PACS: Mechanical testing, 81.70.Bt, Nondestructive testing 81.70.–q, elastic constant 62.20.Dc

INTRODUCTION

In Cuban colonial times buildings were made from different materials as wood, bricks, and a mixture of different calcareous rocks from the sea. The politics of conservation of old structures needs the development of non destructive methods for evaluating the health of buildings and monuments made by the Spanish government in Cuba.

The impact echo method (IEM), based on the propagation of elastic waves and resonance phenomena, is well known for concrete structures [1]. Like the ultrasound method, from the point of view of the use of mechanical waves, the IEM has the advantage that it can evaluate the structure from only one side. In the case of ultrasound, the transmission method is more used due to scattering phenomena in the coarse grain of the concrete. The fundamental idea of the IEM is to produce resonance frequencies of the material under test, so longer wavelengths are employed. This means a better resolution relative to the scattering [2].

Nevertheless, the IEM has been used in concrete and similar building materials [1-5], in which there is great experience. For the case of restoration with older materials, the use of IEM and the study of its performance in practical applications is less common. This is the case of Old Havana. In this paper the IEM is applied to health structure evaluation of the columns of ashlar of calcareous rocks covered with stucco based on cement in Santa Isabel Hotel, located at the eastern side of the Plaza de Armas, in Old Havana. Figure 1 shows a photo of this building; a mansion which was constructed for the Countess of San Juan de Jaruco but that was later bought by the Count of Santovenia, whose initials can be seen in the decorative iron balcony rails. It was converted into a hotel in 1867 [6]. Recently it was restored, and is now run by the Office of the City Historian of Havana through its company called Habaguanex.

IMPACT ECHO METHOD

In Figure 2, a block diagram of the impact echo method is shown. An impact transducer hits one side of the element (in this case a column). The short time of the hit implies that it can be assumed as a delta function which contains all the spectral frequencies. The structure acts as a filter absorbing the fundamental and overtone frequencies for resonance. A pick up transducer is employed in order to detect the resonance sig-

nals, which are evaluated with the use of Fast Fourier Transform (FFT). In this case, the signal is recorded by a Tektronics oscilloscope and sent to a PC for FFT evaluation implemented with *Matlab 7.0*. A spectral pattern will be used as a clue for evaluating homogeneities in the structure. This is possible because we can compare the result with a theoretical spectral pattern obtained from FEM in a healthy column. The pick up transducer was developed using piezoceramics PZT (Figure 3).

Figure 1: The Santa Isabel Hotel, located in the Plaza de Armas, Old Havana.

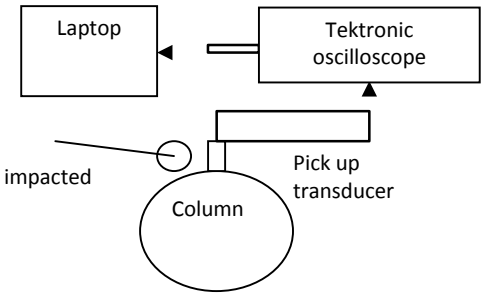

Figure 2: Block diagram of the Impact Echo Method setup.

SANTA ISABEL HOTEL. EVALUATION

Figure 3: Photographs of the Pick up transducer and impactors.

SIMULATION RESULTS

Figure 4 shows the spectral pattern obtained with FEM. The peaks correspond to modals from a circumferential slide of the column with an average diameter of 45 *cm* [7, 8].

It is assume a plain strain condition with a longitudinal velocity of 3000 *m/s*, according to an ultrasonic evaluation of the material using the transmission method with 54 *kHz* transducers. A Poisson ratio of 0.2 and a density of 2500 kg/m^3 were assumed. In Figure 5 the firsts four eigenvectors are shown.

Figure 6 a) and b) shows two photos of columns situated in the first level of the Santa Isabel Hotel. Four columns situated in the middle of each side of the inner balcony were evaluated in the test. Figure 6 c) and d) show one of these columns with visible cracks and the experimental application of the impact echo method respectively.

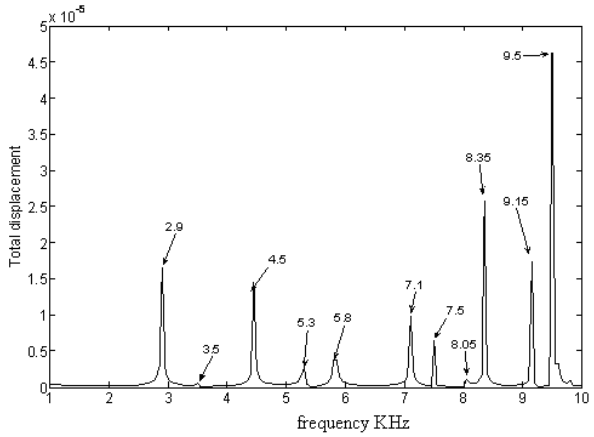

Figure 4: Harmonic analysis of a circumferential slide of the column. A plain strain condition is assumed.

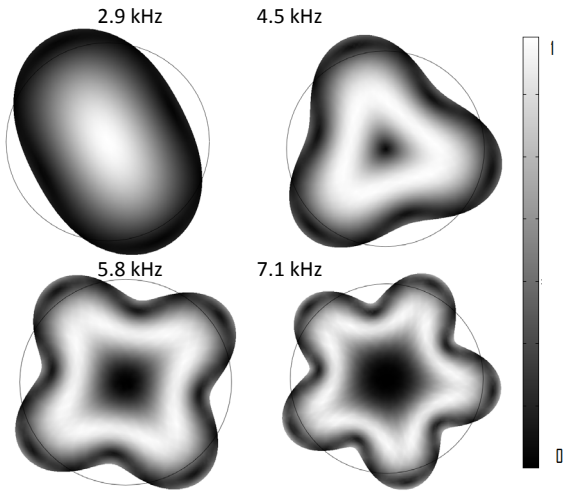

Figure 5: Deformation in relative color scale that corresponds to the firsts four modal frequencies. Only the strongest modes are shown.

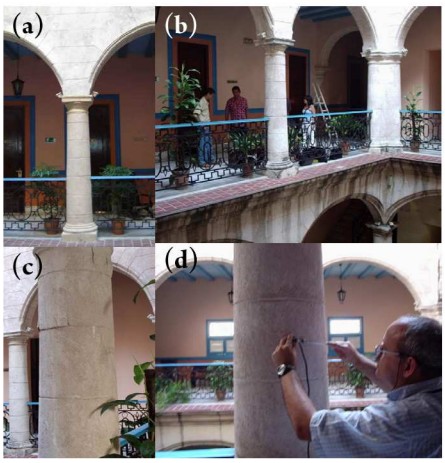

Figure 6: a) and b) details of the columns in the interior balcony in the Santa Isabel Hotel, c) Cracks in one column, d) An example of the application of the impact echo method in a column.

RESULTS

Figure 7 shows two spectral patterns A and B, obtained from two columns with a visual good condition. They serve as reference for comparing with others patterns that could present external cracks. In order to confirm this, it is necessary to compare with theory for the case of homogeneous material. The next expressions obtained with FEM for the first four peaks are useful for this task [9].

$$\begin{aligned} f_1 &= 0.92\frac{V_L}{2D} \\ f_2 &= 1.5 f_1 \\ f_3 &= 2.0 f_1 \\ f_4 &= 1.5 f_1 \end{aligned} \qquad (1)$$

Here V_L is de longitudinal velocity of 4000 *m/s* and a diameter $D = 0.45$ *m* is assumed for theoretical calculations.

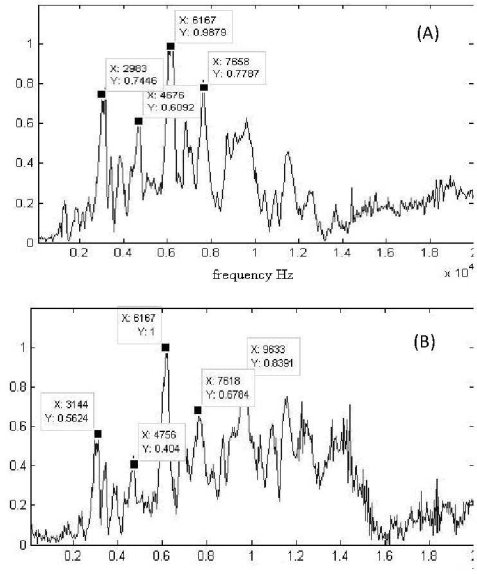

Figure 7: Spectral patterns A and B from two columns without cracks. *X* is the frequency value and *Y*, the relative amplitude.

With this expression, the following table is obtained according to the frequency peaks of Figure 7 and expressions (1).

Table I
Theoretical and experimental relations between peak frequencies, f_1 was taken as a reference frequency.

Model	Theoretical relations	Frequency (A)* Hz (relation)	Frequency (B)* Hz (relation)
1	1.5	2983 (1.00)	3144 (1.00)
2	1.5	4676 (1.57)	4756 (1.50)
3	2.0	6167 (2.07)	6167 (1.96)
4	2.4	7658 (2.57)	7618 (2.42)

(A) and (B) from Fig. 8. In parenthesis the experimental relations relative to its first mode. Theoretical relation according to equation (1).

Comparing the theoretical relations with the experimental ones, there is a good agreement between them. This means that the column was in good condition as it was suspected, according to visual inspection. If there were a defect, then a spectral peak would appears with a relative weight strong enough to hide the normal peaks. Then, it is possible to use the two spectral patterns A and B, as references for columns without cracks.

As a detail, if we take the experimental measurement of $f_1 = 2983$ *Hz*, the velocity will give the following value:

$$C_p = \frac{2Df_1}{0.92} = 2918\ m/s \qquad (2)$$

This value agrees with the ultrasonic one value obtained at 54 *kHz*.

In Figure 8 we show a spectral pattern of the columns with visual cracks (Figure 6). In this case there is a different spectral pattern compared with the previous cases. A peak frequency of 1169 *Hz* appears.

This low frequency could be interpreted as laminations of the stucco vibrating in a flexural mode. Then, it was possible to evaluate the interior of this column, "in good condition", and only the stucco has to be repaired.

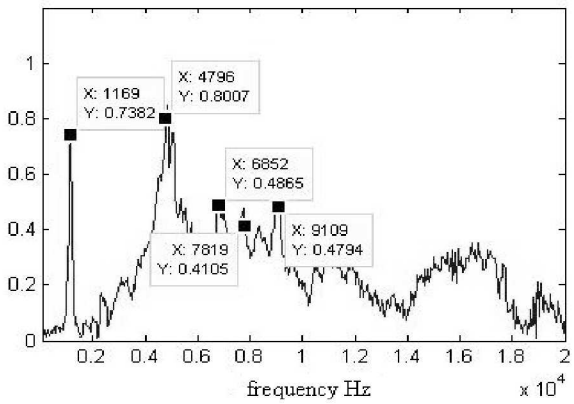

Figure 8: Spectral pattern in the column with visual cracks. *X* is frequency value and *Y* relative amplitude.

CONCLUSIONS

The use of impact echo method is presented in the restoration of ashlar - calcareous rocks columns in Old Havana. The performance of the method is good enough for this purpose. It is recommended to increase the use of IEM in other restoration materials like wood.

ACKNOWLEDGEMENTS

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