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Optical Evaluation of Vibrations in a Concrete Column by the LPD Method

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Abstract: In this work we present the results of the optical evaluation of vibrations of a conventional concrete column with a metal frame. In a previous work [1] we reported the optical evaluation of a pure concrete column, without a metal framework. In this evaluation we expected to obtain a noticeably different result, but that was not the case, then the obtained results are surprisingly similar. From the LPD evaluations, the first 12 vibration resonances were found, which fit very well with the basic applied theory (the cantilever theory). Using known average values, we estimate the corresponding column effective length, obtaining an average value of 2.5 m. As in the former case of the concrete column, we find a discrepancy with respect to the length value, measurable from the ground (1.75 m), which can be explained again by the fact that the column and its base were built on inconsistent terrain.

Key words: Structural vibrations, resonance, sound excitation, laser photo deflection.

1. Introduction

In a previous work we publish the results of evaluating the vibrations of a pure concrete column [1] by means of a non-conventional opto-acustic procedure: The LPD (Laser Photo Deflection) Method. In this case, we report the optical evaluations of the vibrations of a typical concrete column with a metal frame.

As stated in previous publications [2, 3], the main objective of evaluations in this type is to gain experience in the vibrations of simple structures individually, then in order to be able to interpret the complex results that eventually occur in the evaluation of a building.

Another objective of this work is to verify the effectiveness of the LPD Method in the evaluation of structural vibrations, reaffirming the fact of constituting a nondestructive procedure of great sensitivity and precision, whose versatility allows for easy field measurements.

2. Method and Materials

First of all, I must indicate that the instruments used in this work are not a compact equipment, but rather an experimental arrangement composed of different components, of which the photo deflection sensor is the most important of them, which is why I want to explicitly highlight its function.

2.1 The Photo Deflection Detector

The Photo Deflection Sensor is a well-known device used in particular in photo deflection spectroscopy (PDS) [4]. Fig. 1 shows the basic detail of the sensor, which is to transform the spatial variation of an incident ray into an analog voltage signal. Therefore, if the incident laser signal oscillates sequentially around an equilibrium point, the voltage response will have the same variation.

2.2 The Photo Deflection System

The complete experimental setup is shown in Fig. 2. There is a concrete column fixed outside our building about 5 m from the Laboratory. A laser beam is

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launched towards a small mirror placed on the column, receiving the reflected beam again in the laboratory, finally reaching the photo deflection sensor.

In this experimental setup, any movement of the column up to the range of a few nanometers will be detected by the optical system, particularly its vibrations.

2.3 Theoretical Foundation

To explain the vibrations of the column we use the well-known cantilever theory [5], which gives us the eigen vibration frequencies (f_n) of the column "Eq. (1)," depending on the parameters: E, the rigidity modulus of the material, I, the moment of inertia, L, the length of the column, ρ, the density and A, the cross section.

$$f_n = \frac{\alpha_n{}^2}{2\pi}\sqrt{\frac{EI}{\rho AL^4}} \qquad (1)$$

where, α_n = 1.875, 4.693, 7.855, 10.996…

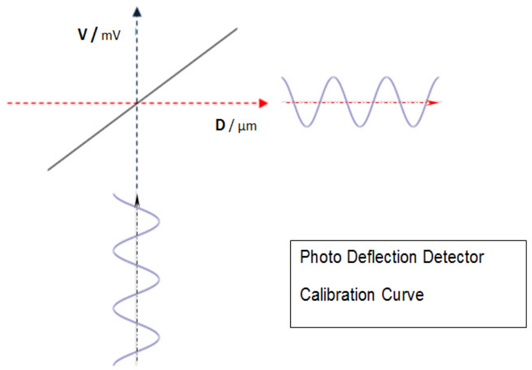

Fig. 1 Calibration curve of a typical photo deflection sensor, schematic.

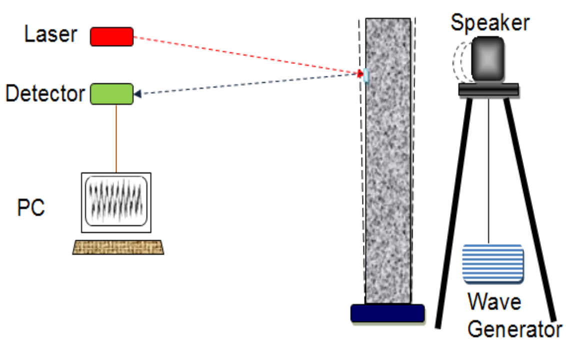

Fig. 2 Experimental arrangement of the complete LPD system used to evaluate the acoustic forced vibrations of a concrete column.

3. Results and Discussions

The experimental procedure used was the following; As the diagram in "Fig. 2", indicates, the column is subjected to the sound action of a speaker selectively fed by a sine wave generator, observing the vibration response of the column on the PC screen. As soon as a resonance is found, the response signal will grow noticeably, displaying ordinarily a notorious train of sine waves at the same reference frequency. At this point, the response is recorded for later (FFT) Fast Fourier Analysis. The occurrence of a resonance is eventually confirmed by a selective spectral scanning using a lock in amplifier.

3.1 Founded Resonances

In what follows we will summarize the first 12 resonances obtained and their corresponding spectral location (Hz).

3.2 Discussion

The resonances obtained experimentally by the LPD method are summarized in Table 1.

All these data were obtained with the same experimental arrangement, in particular with the reference mirror at the top of the column, so certain eigen vibrations will not be well detected, since their vibration zones are highly localized, which justifies in some cases the small signal response.

Both in this work and the one reported in Ref. [1], a ready-to-mix concrete mixture (Topex) is used, to which water is added, in the amount specified by the manufacturer, to obtain the required concrete mixture.

We do not have specific data on this material. The concrete values (density: ρ and rigidity modulus: E) used in our calculations were taken as an average value from Ref. [6]: ρ = 2,300 kg/m^3, E = 2.5×10^{10} Pa.

Since the results obtained in this case (concrete column with metal frame) are similar to those obtained in the previous work with the pure concrete column [1], we apply the same theory as a first approximation, deducing for each mode the corresponding effective length (L_{es}) of the column.

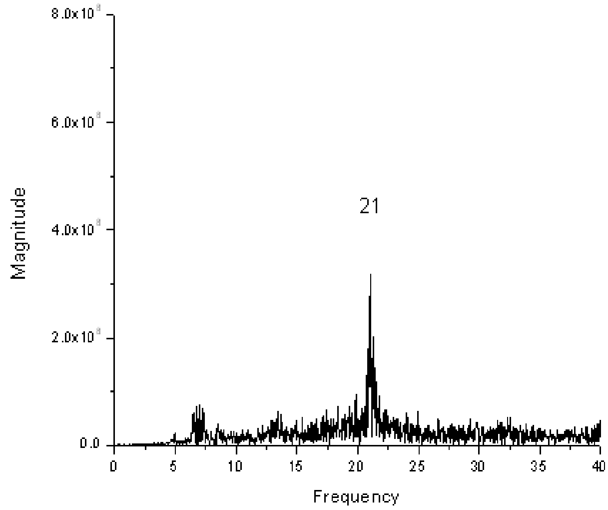

Fig. 3 Resonance 1: 21 Hz.

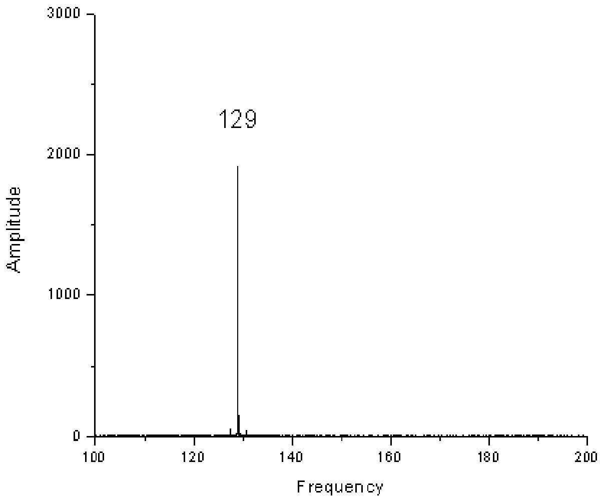

Fig. 4 Resonance 2: 129 Hz.

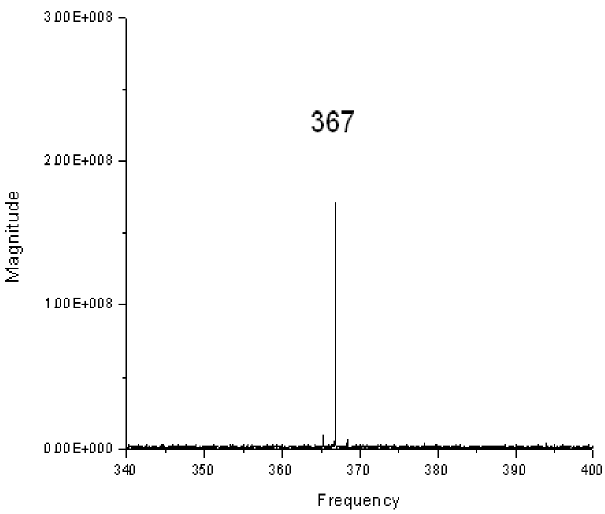

Fig. 5 Resonance 3: 367 Hz.

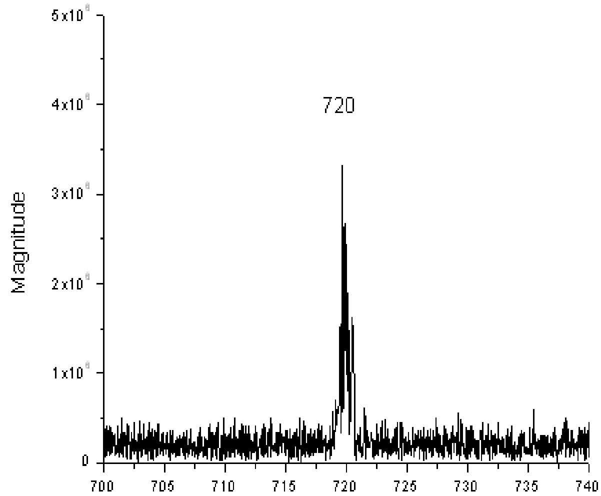

Fig. 6 Resonance 4: 720 Hz.

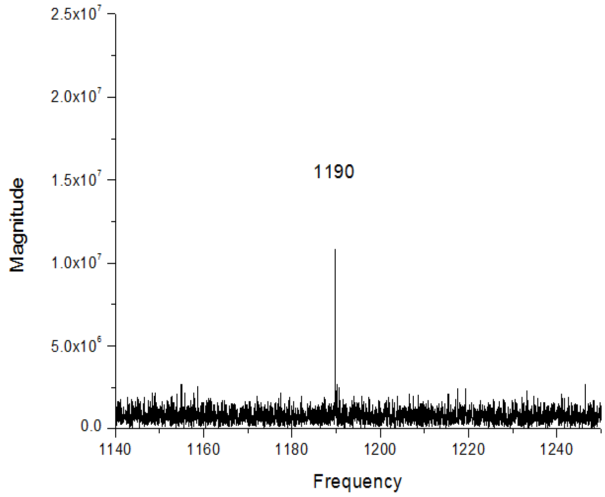

Fig. 7 Resonance 5: 1,190 Hz.

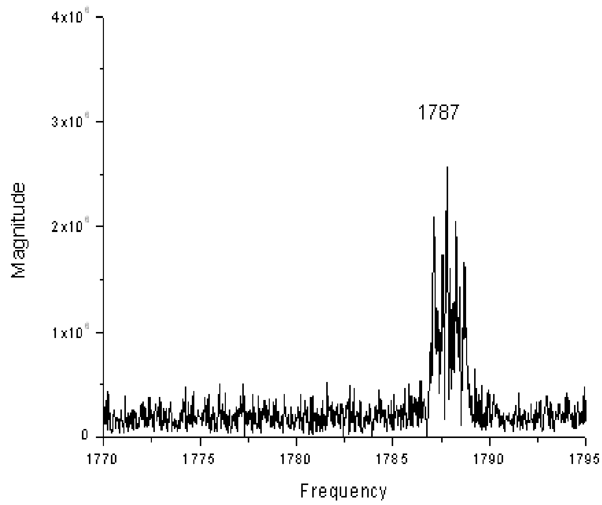

Fig. 8 Resonance 6: 1,787 Hz.

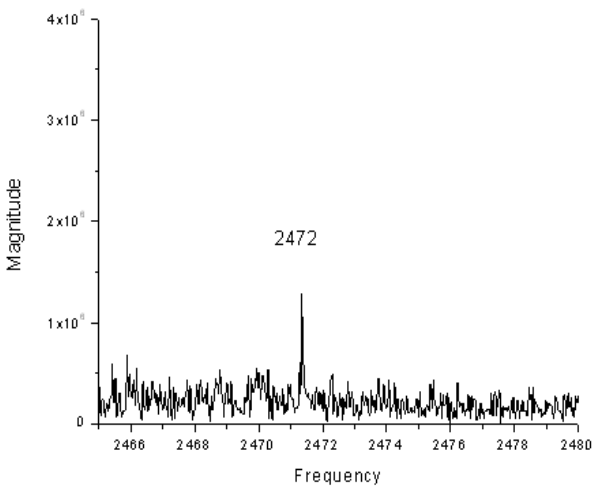

Fig. 9 Resonance 7: 2,472 Hz.

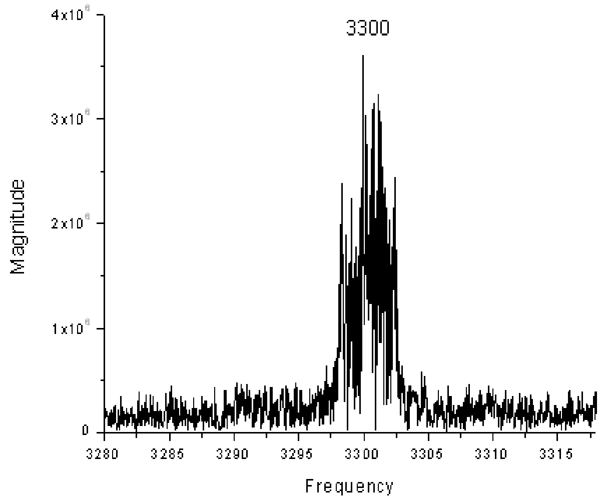

Fig. 10 Resonance 8: 3,300 Hz.

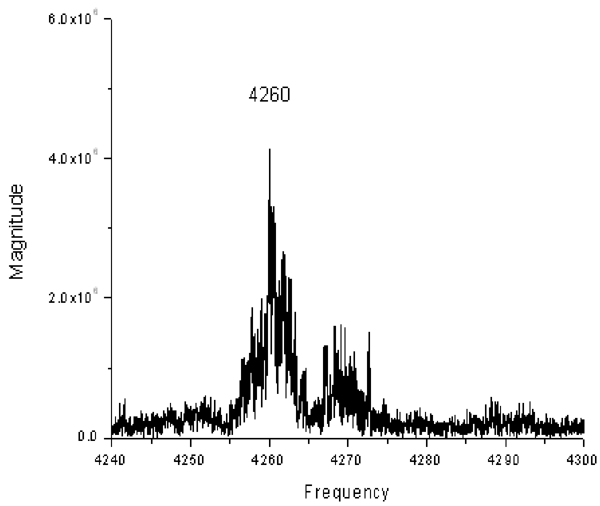

Fig. 11 Resonance 9: 4,260 Hz.

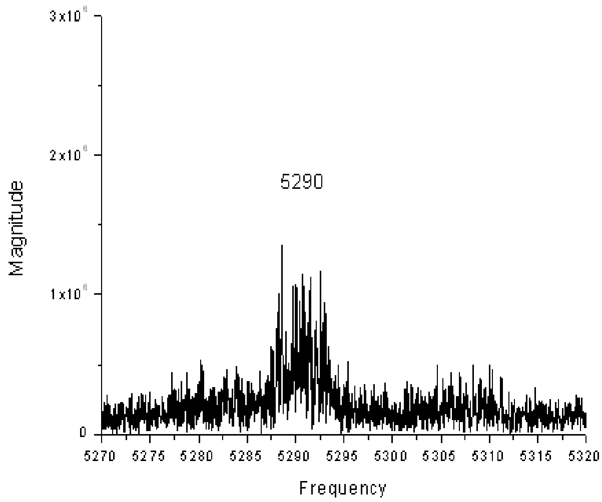

Fig. 12 Resonance 10: 5,290 Hz.

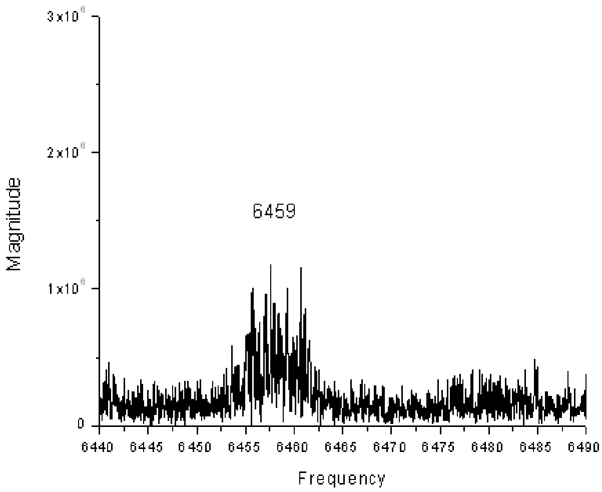

Fig. 13 Resonance 11: 6,459 Hz.

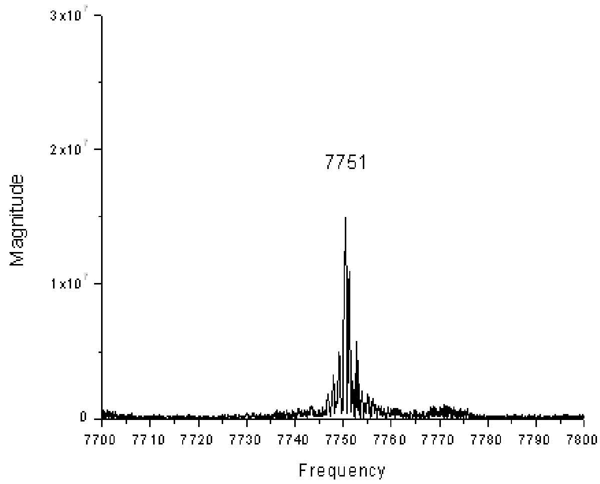

Fig. 14 Resonance 12: 7,751 Hz.

Table 1 Experimental results.

Vibration Mode	Detected Resonances (Hz)	Estimated Column Length L_{es} (m)	Theoretical approach (L = 2.5 m)
1	21	2.50	21
2	129	2.52	131
3	367	2.50	367
4	720	2.50	719
5	1,190	2.50	1,188
6	1,780	2.50	1,775
7	2,472	2.50	2,479
8	3,300	2.50	3,301
9	4,260	2.50	4,238
10	5,290	2.50	5,294
11	6,459	2.50	6,467
12	7,751	2.50	7,757

Table 1 shows the results, highlighting at the same time the good correlation between the experimental data and the theoretical approach.

However, as in the previous case [1] there is a large discrepancy, since the column has an effective length L = 1.75 m, measured from the ground.

Once again, we consider as a possible explanation the fact that the columns have been built on inconsistent terrain, therefore a greater length should be considered due to the depth of the embedment.

This aspect will have to be considered in a future evaluation, as well as verifying that a pure concrete column has the same eigen vibration frequencies as a concrete column with a metal frame, which results from these evaluations.

Another important point that must be highlighted in this section is the fact of the technical limitations of our available equipment and that at the same time condition us to work at the limit of its capacity, limiting ourselves, for example, to work with a minimum of response, both at low and high frequencies.

Finally, it should be mentioned that the measurements carried out were performed manually, for example by varying the sound frequency in steps of the order of 0.1 Hz, which means that a complete spectral scan can take several days, depending on the operator.

4. Conclusions

This work confirms the effectiveness of the LPD method to evaluate vibrations in general and in particular the eigen frequencies of structures, which constitutes an additional technique for the task of structural diagnosis.

We have noted that under common conditions a spectral measurement, for example in order to tune a resonance, requires relatively a lot of time (hours), as it is a manual task, so for the technique to be considered operational it is necessary to simplify and optimize its application, for example by automating, but also using equipment that guarantees proper operation in a wide spectral range.

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References

[1] Valera, A., Tafur, G., Esenarro, D., and Tafur, V. 2023. "Evaluation of Vibrations in Simple Structures Using the Laser Photo Deflection Method (LPD): Part 2." In *Proceedings of ICCEA 2022, pg. 461.* (Conference format)

[2] Lopez, R. 2011. "Analisis de vibraciones en estructuras simples mediante el Metodo de foto defección laser." Lic. thesis, Universidad Nacional de Ingenieria. (Thesis format)

[3] Melchor, M. 2016. "Evaluacion y medicion de las vibraciones de un edificio por medio de la tecnica Laser Photo Deflection." MSc. thesis, Universidad Nacional de Ingenieria. (Thesis format)

[4] Rose, A., and Gupta, R. 1984 "Combustion Diagnostics by Photo-Deflection Spectroscopy" In *Proc. Combust. Inst.* 20, 1339-45.

[5] Meirovitch, L. 2003. *Fundamentals of Vibration.* McGraw-Hill Publ.Comp.

[6] Engineering ToolBox. 2001. [online]. Accessed on May 1, 2022. Available at: https://www.engineeringtoolbox.com.