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# Optical Evaluation of Vibrations in a Roof by the LPD Method

Aníbal Valera, Guido Castillo and Kevin Mejía

*Facultad de Ciencias, Universidad Nacional de Ingeniería, Av. Tupac Amaru, Lima 15333, Perú*

**Abstract:** In this work, we present the results of the optical evaluation of resonance vibrations in a conventional roof. On this occasion, we took advantage of having an ordinary booth near the laboratory, making it easier for us to conduct this evaluation. The roof in question has a square geometry and is apparently made of concrete. Following our usual LPD (laser photo deflection) procedure, of exciting the vibrations of the structure through sound and detecting the response optically, we obtain by resonance the first 6 roof's Eigen oscillations, the same ones that are identified as Modes (1,1), (1,2), (2,2), (1,3), (2,3) and (3,3). The occurrence of these modes in this work is justified in a first approximation through the classical acoustic resonator theory.

**Key words:** Structural vibrations, resonance, sound excitation, LPD.

## 1. Introduction

This work is part of the series of evaluations carried out by our group [1, 2] using the LPD (laser photo deflection) method for determining the vibrations of simple structures. In this case, we report the evaluation of the vibrations of a roof.

In a previous publication [3] we had already reported the LPD evaluation of a roof, it is worth mentioning this work here because, in addition to being related to the current topic, it was the first work carried out by our group outside our laboratories. On that occasion, we received an invitation from a director of the CISMID Institute (Centro Peruano-Japonés de Investigaciones Sísmicas y Mitigación de Desastres) to carry out evaluations using our recently introduced LPD method, to a roof that they were already evaluating using conventional methods.

As can be seen from Fig. 1, the CISMID roof was a mixture of concrete and reed, about which we did not receive any additional information, since the invitation was explicit and exclusive to evaluate the vibrations of the sample using our LPD method.

As stated in the publication [3], we obtained 4 vibration resonances: 28.7 Hz, 41.1 Hz, 52 Hz, and 78.7 Hz. These experimental values were able to be fit to an empirical relationship:

$$f_{mn} = f_0 \left(m^2 + n^2\right)^{1/2} \tag{1}$$

where $f_0$ = 20.3 Hz and the corresponding digits were: (1,1) (2,1) (2,2) (3,3).

We did not insist further on the case, since it was an internal work of CISMID, but we bring it here up because, as we noted, it is strongly related to our present case.

## 2. Experimental

The experimental evaluations were carried out according to our ordinary procedure (LPD), which consists of sensing the alterations in the deviation of a ray reflected back from the structure, when it is subjected to a vibration, applying essentially 2 methods of external excitation to get the structure vibrations, the first one is simply through blows (hammer) and then a second option, which consists of subjecting the roof to selective sound

**Corresponding author:** Aníbal Valera, Dr.rer.nat., research fields: applied optics, solar energy, solar cells.

**Fig. 1 Layout and profile of the CISMID roof evaluated in 2007 [3].**

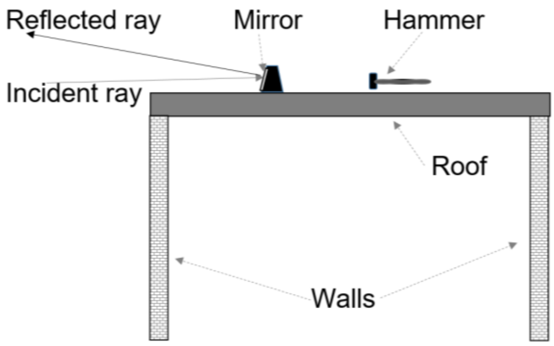


**Fig. 2 Experimental scheme of the configuration setup for the vibrational evaluation of the roof.**

waves. In any case, the same optical detection system (LPD) is maintained.

Fig. 2 schematically shows the experimental setup applied to the vibrational evaluation of the roof**,** highlighting the fact of having a mirror fixed to the roof that bounces the incident laser beam back to the Laboratory.

*2.1 Excitement by Blows*

The knocking procedure allows us to identify the approximate spectral position of the first vibration mode and eventually also the position of other vibration modes of the structure. It should be noted that depending on the position where the blows are applied, it will be possible to obtain the preponderance of some modes more than others. A typical example of the result of shock vibration is presented in Fig. 3, where we can observe the occurrence of oscillations induced by the blow that gradually become damped. From the data of the sequence shown, it is roughly observed that for elongation of 0.159 s, approximately 24 oscillations occur, so an average period of 151 Hz can be estimated for the excited proper oscillation.

An FFT (Fast Fourier Transform) evaluation of the result of a sequence of similar hits carried out in the period of 30 s will produce the spectrum presented in Fig. 4. From this spectral response, 3 prominences (maxima) can be identified around 150, 220, and 300 Hz. Additionally, minor prominences are also present in the spectrum but these are associated mainly with the vibration of the walls that support the roof, which will be discussed on another occasion.

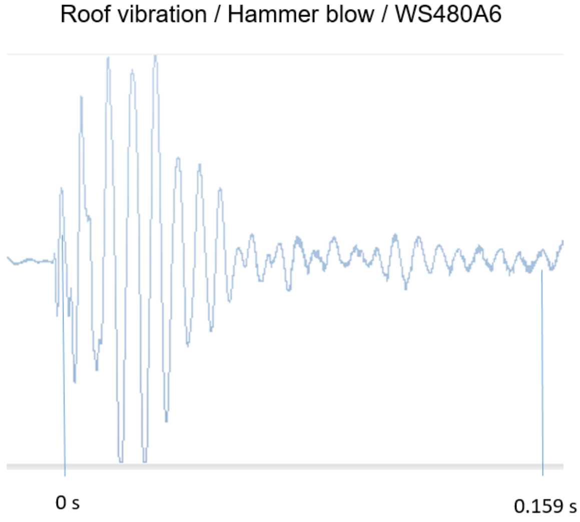


**Fig. 3 Roof vibration response to a hammer blow.**

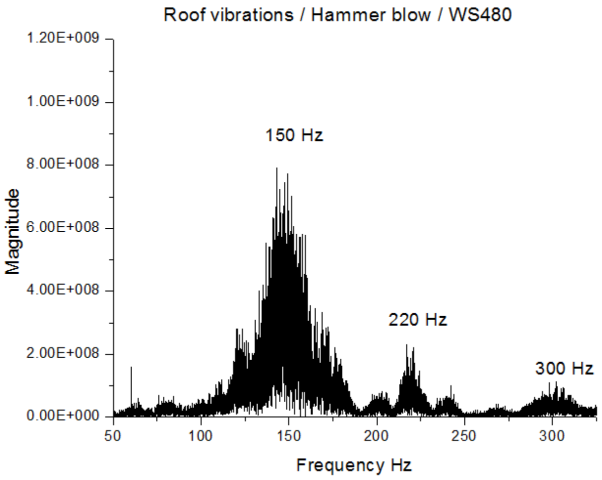


**Fig. 4 FFT spectral response of the Roof subjected to hammer blows.**

The obtained data will help us to find the precise resonance frequencies of the roof through the next step: Acoustic resonance.

*2.2 Excitement by Sound*

In the mode of forced excitation by sound, a speaker is placed near the structure that is fed with a wave generator, thus producing a continuous train of sinusoidal sound waves of specific frequencies set manually.

As is usual in this type of measurement, the structure will respond with an analogous vibration (same frequency), however with an extremely low amplitude, which in most cases borders on background noise.

However, as the sound frequency approaches a vibrational resonance of the structure, the amplitude increases significantly by much larger factors than the noise level.

Fig. 5 shows the wave train detected around 152 Hz, where its amplitude is maximized, corresponding to the first vibrational resonance of the roof.

Fig. 6 shows the result of the FFT spectral analysis of the wave train corresponding to Fig. 5, clearly indicating the occurrence of the resonance around 152 Hz.

**Table 1 Experimental results.**

| Resonance | Resonances (Hz) measured | Mode vibration estimated | Factor $f_0$ deduced |
|---|---|---|---|
| 1 | 152 | (1,1) | 107.5 |
| 2 | 240 | (1,2) | 107.3 |
| 3 | 305 | (2.2) | 107.8 |
| 4 | 341 | (1.3) | 107.8 |
| 5 | 388 | (2.3) | 107.6 |
| 6 | 456 | (3,3) | 107.5 |
| | | Average | **107.6** |

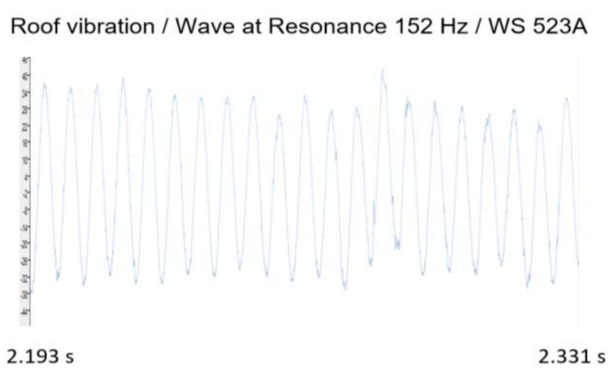


**Fig. 5 Wave response of the Roof subject to sound excitation around 152 Hz.**

Following the same procedure, 5 major resonances were also found, which are indicated in Table 1 and whose FFT spectra are presented below (Figs. 7-11).

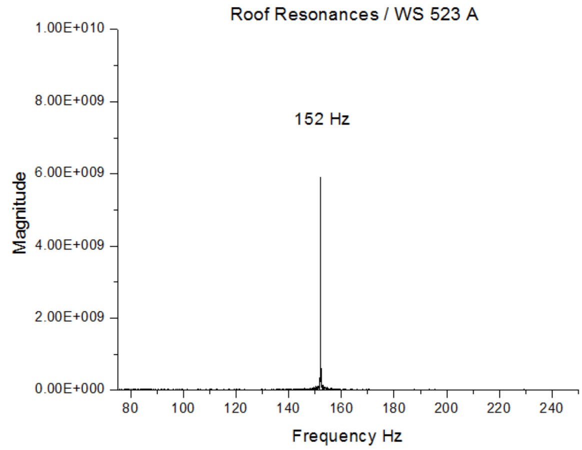


**Fig. 6 Spectral response of the Roof subject to sound excitation at 152 Hz.**

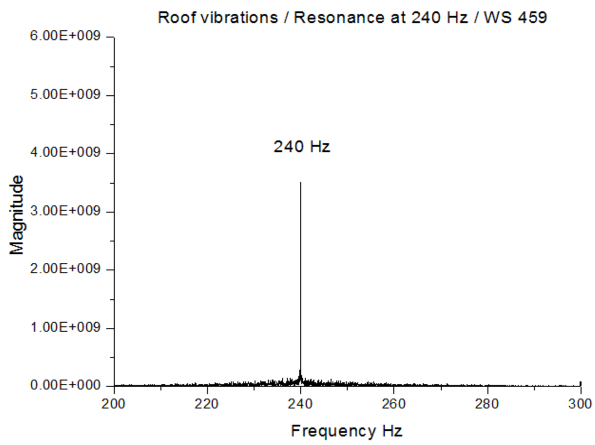


**Fig. 7 Spectral response of the Roof subject to sound excitation at 240 Hz.**

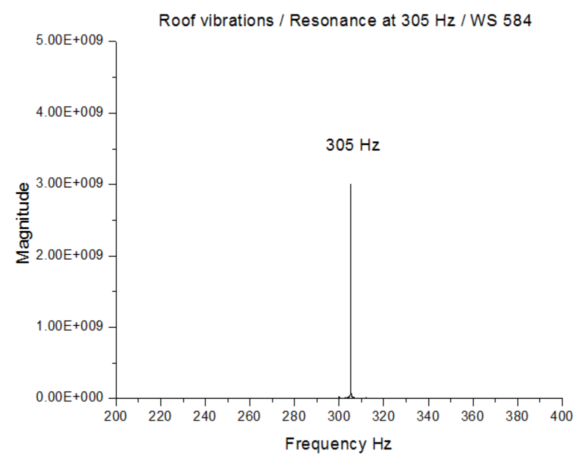


**Fig. 8 Spectral response of the Roof subject to sound excitation at 305 Hz.**

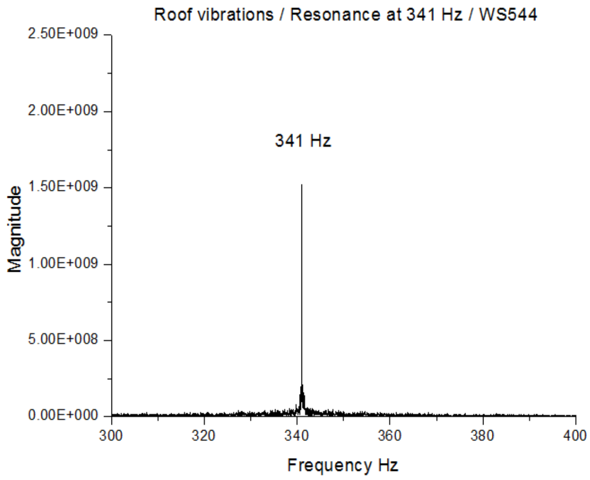


**Fig. 9 Spectral response of the Roof subject to sound excitation at 341 Hz.**

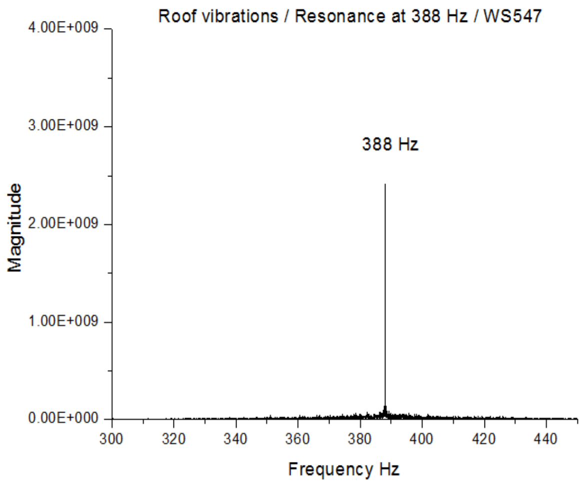


**Fig. 10 Spectral response of the Roof subject to sound excitation at 388 Hz.**

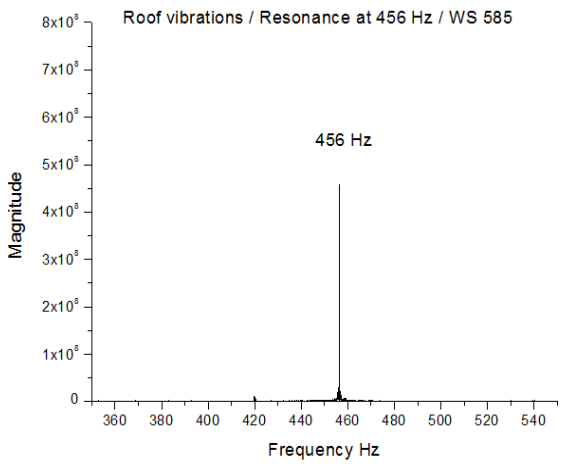


**Fig. 11 Spectral response of the Roof subject to sound excitation at 456 Hz.**

## 3. Results and Discussions

The first 6 vibrational roof resonances found in this work by the LPD method and detailed in Table 1, can be identified as the vibration modes of a flat plate according to the modes ($n$,$m$) and applying the already indicated relationship Eq. (1):

$$f_{mn} = f_0 \left(m^2 + n^2\right)^{1/2} \tag{1}$$

where $f_0$ = 107.6 Hz, as average and the corresponding digits were: (1,1) (1,2) (2,2) (1,3) (2,3) and (3,3) respectively.

The fitness of the experimental data to the empirical formula Eq. (1) is evident from the corresponding obtained $f_0$ values (Table 1). This result poses an additional challenge to us, which is how to theoretically justify this fact.

From a very elementary point of view, we can consider the roof as a classic sound cavity, in this case of square geometry, resulting in the well-known frequencies [4] of a cavity resonator, which in this case are identical to Eq. (1), and where the constant $f_0$ is given explicitly by Eq. (2):

$$f_0 = c/2a \tag{2}$$

where $a$ is the length of one side of the square roof (3 m) and $c$ is the speed of sound in the medium (roof), c= $\sqrt{E/\rho}$.

As we have mentioned previously, we have taken the opportunity to evaluate a roof built nearly 50 years ago for which we do not currently have specific data.

If we consider that the roof is built entirely of concrete ($E = 2 \times 10^{10}$ N/m$^2$, $\rho = 2.4 \times 10^3$ kg/m$^3$) then the value of the constant $f_0$ should be $f_0 = 481$ s$^{-1}$, which differs significantly from the value found experimentally ($f_0 = 107.6$ s$^{-1}$).

Faced with this result, we can only affirm the justification that, on the one hand, the theory of the acoustic resonator is very incipient for this case or that the configuration of the roof is not as supposed simply concrete, but includes other construction elements (bricks, iron rods) that should be taken into account in the deduction.

## 4. Conclusions

In this work, the LPD method has been successfully applied to determine the resonant vibrations of a roof. The exact correspondence of the roof's proper frequencies to a classic acoustic resonance function allows us to conclude that the obtained results are completely reliable.

Concerning the theoretical justification of our results, we have only been able to roughly outline a plausible justification that must be refined in the following works, having at hand specific data about the structure in question.

However, from the experimental point of view, we can affirm that there is no doubt that the results are completely correct since it is possible to order them all using a simple mathematical formula.

## References

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