EVALUATION OF THE USE OF MODAL ANALYSIS TO IDENTIFY THE NATURAL FREQUENCIES OF A LARGE BUILDING

Fabiano Eduardo Moraes Matos [1], Cláudio José Martins [2], Diego Goulart de Lucena[3] and Nathalia Alves Dornellas Fonseca [4]

[1] CEFET –MG / Banco do Brasil, FabianoEMMatos@hotmail.com

[2] CEFET –MG, cjmartins@civil.cefetmg.br

[3] CEFET –MG, diegoglucena@gmail.com

[4] CEFET –MG, nat_dornellas@hotmail.com

Abstract: The study proposes the evaluation of the use of the modal analysis for the survey of parameters of large buildings. To perform this experiment, 71 in situ vibration surveys were performed due to operational actions. The data were processed using FFT and SSI to obtain the spectra in the frequency domain and the verification of their natural frequencies. The experiment was carried out in two masonry towers with a height of more than 44m in order to validate the characterization form through modal analysis.

Keywords: natural frequencies, modes of vibration and modal parameters

INTRODUCTION

Some studies have used the modal analysis technique to evaluate the modal parameters of structures that presented significant dynamic loads such as bridges (LARDIES - 2011), slender chimneys (MINGUINI - 2014), and it is evident that the technique has great potential of application.

But some challenges had not yet been overcome, leaving still the question of the efficiency of its application in large structures essentially static. In this type of structure the main dynamic loads, usually winds with random, impulsive behavior and of unknown amplitude.

Focusing on this knowledge gap, a research methodology was proposed in two large buildings constructed in structural masonry in order to verify the feasibility of the capture of vibration signals in large structures for treatment and identification of modal parameters.

METODOLOGIA

For the execution of the experiments was chosen a residential condominium formed by 4 identical towers in structural masonry with 44 meters of height distributed by 17 floors, being 15 floors of type of more than 570 m² each and façade with area superior to 1619 m². The neighborhood consisting of houses in a region with winds in abundance makes the buildings subject to the actions of the winds and with it operational vibrations in the structure.

Structural analysis can increase its focus by observing the dynamic behavior of structures and considering the effects of external actions in relation to time, as Soriano (2014) also describes. Through this modal analysis, it is possible to identify the natural frequencies and their respective modes of vibration according to Rodrigues (2006).

Once the study object and its objective were defined, two surveys were planned to capture the vibration data in two identical towers, the first one to verify the quality of the data and the second the validation of the results obtained in the first survey.

Finally, with data processed and processed by the FDD Frequency Decomposition and SSI stochastic identification methods, the data were compared through linear regression for comparison of the modal parameters extracted and validation of the applied method.

EXPERIMENTO DE CAMPO

The initial concern of the study was with the quality of the data that would be obtained, since the structure under analysis has great dimensions characterizing itself as essentially static. Another aspect to consider is that the main loading to cause vibrations in the structure are the winds of random and impulsive behavior using the classifications used by Clough (2003)

On the other hand, a structure in structural masonry carries the transmission of the loads mainly by the prisms of concrete blocks and in a more distributed form than in buildings in reinforced concrete or metallic. Therefore, they require more elements and a greater quantity of materials to fulfill their structural function, guaranteeing a heterogeneous aspect and thus more susceptible to the recording of vibrations.

The survey of the structure became a great challenge in the research, because the scarce literature on the subject did not contribute in a significant way, being necessary to resort to the previous experiences with special works where the dynamic loads were predominant like in viaducts and bases of Aeolian generators.

Given this reality, two experiments were necessary to validate the proposed format for signal capture. The first one more conservative, with concern of obtaining records of the vibrations of good quality and that all the modes of vibration were registered. This first stage occurred in the building called tower 3 shown in the Fig.1.
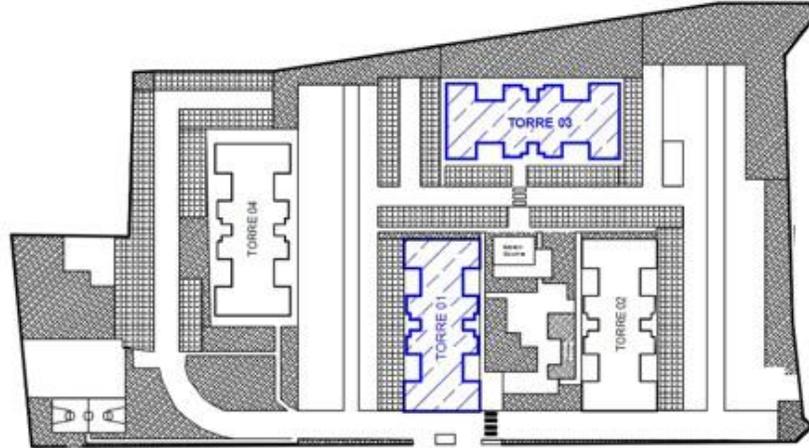

Figure 1 – Arrangement of towers in the development

In order to carry out the experiment, a distribution of 53 points was designed to read the vibrations in places determined in the slabs and distributed alternately in the floors as seen in the Fig. 2. The points were in greater number in the two lower floors to evaluate the vibrations related to the displacements of the structure near the ground.
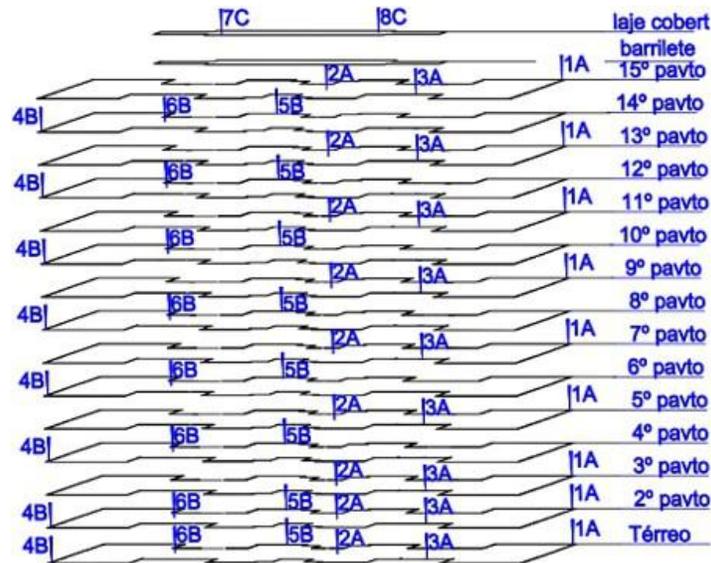

Figure 2 – Distribution of sites in tower 3

Two high-precision acquisition systems were used in the acquisition of the signals and the recording of the vibrations, composed of 3 accelerometers each as in the photo of the Fig. 3, being leveled and aligned with the axes of the building in each reading.

Figure 3 – Data acquisition equipment with 3 accelerometers for signal capture

Due to the fact that there was no knowledge of the amplitude of the wind loads in the region and much less of its behavior, the two-hour recording period of the vibrations for each given location was defined. This conservative definition occurred to ensure that all modes of vibration of the structure were recorded and thus the initial experiment totaled 106 hours of recordings.

Another important aspect in the configuration of the equipment was the adoption of the sampling rate of 100 Hz, thus guaranteeing a good coverage of the spectrum of vibrations present in the structure, avoiding aliasing errors.

Signals, as shown in Fig. 4, captured from random operational vibrations presented noise contaminations from the equipment itself and external sources. Furthermore, at this stage the direct reading of the vibrations in time does not indicate the modal parameters and a signal treatment is required.
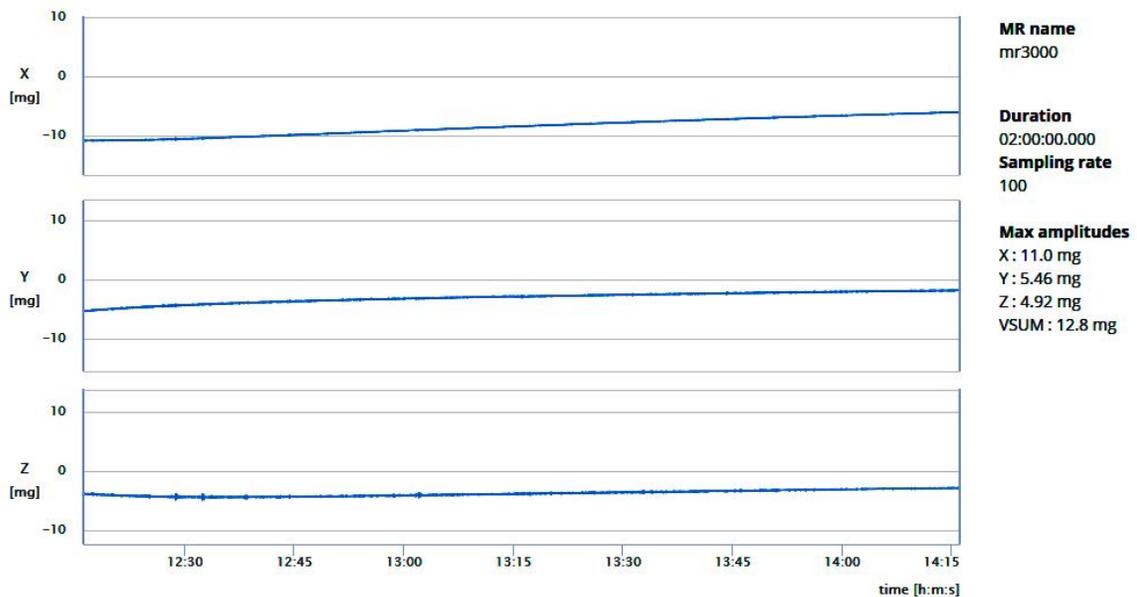

Figure 4 – Triaxial signal taken from a site of tower 3

Then, the measured signal processing was performed using the ARTeMIS Extractor software, using the FFT and SSI methods (fig. 05), obtaining the natural frequencies and the damping rates of each point.
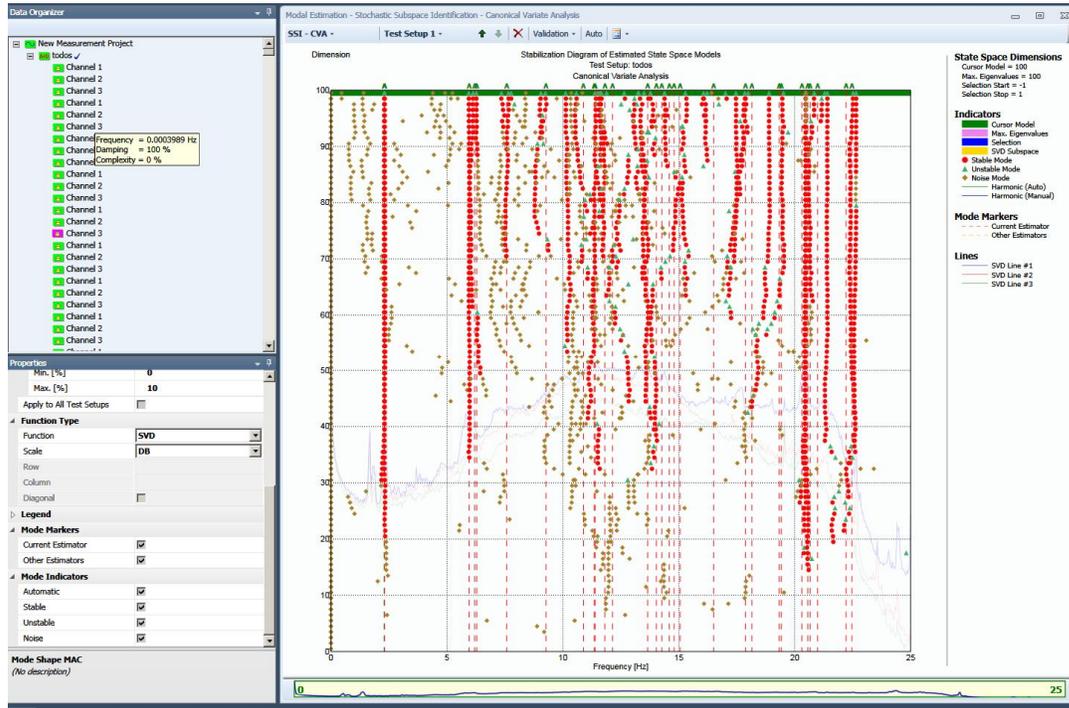
Figure 5 – Result obtained from SSI processing of data from tower 3

After analyzing the results obtained for tower 3, a new survey method was proposed to evaluate both the efficiency of the method and the need for points to be analyzed. For this reason a survey was proposed in 18 points, nevertheless concentrating the readings on the upper floors, thus proposing 3 surveys on the ground floor, fifth, ninth and thirteenth floors and finishing with 6 surveys on the fifteenth floor as shown in Fig. 6. It was the reading time for each point was also reset to 1 hour, thus totaling 18 hours spent in this second frame.
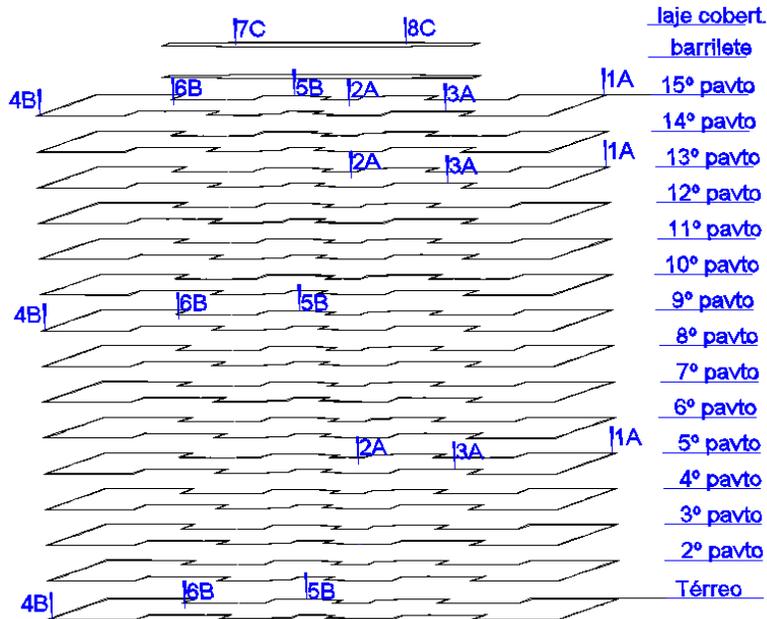

Figure 6 – Distribution of sites in tower 1

Using the same procedures for signal processing used in tower 3 (Fig. 7) for the two towers, the natural frequencies and damping were obtained for each mode of vibration found.
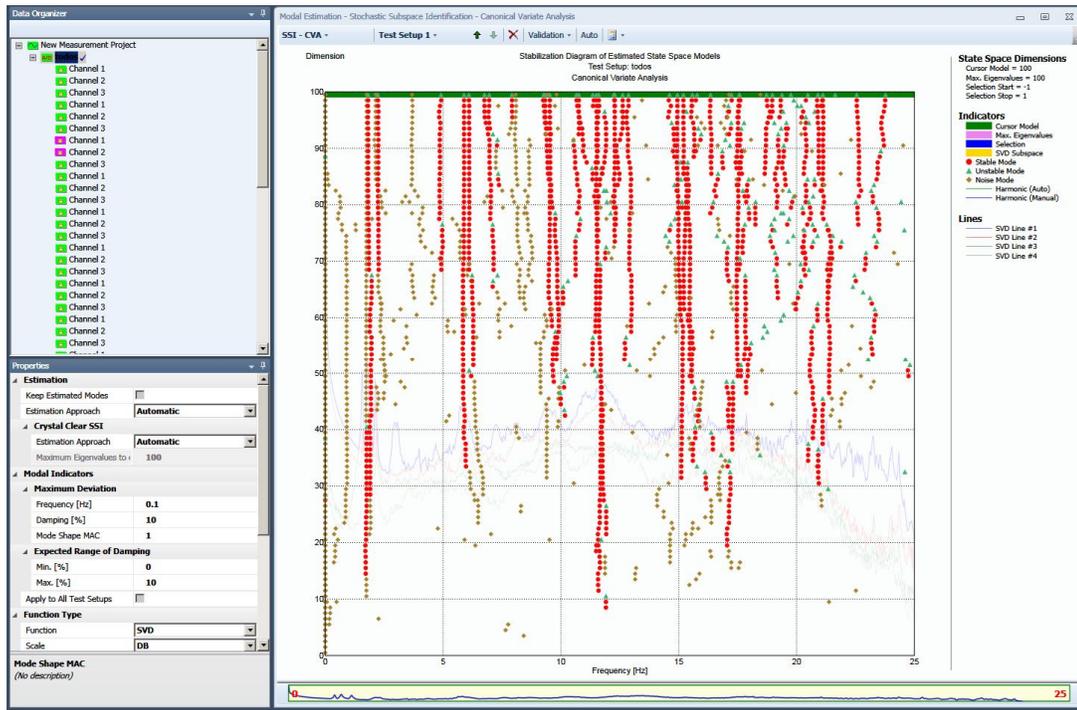
Fabiano E. M. Matos, Cláudio J. Martins, Diego G. Lucena, Nathalia A. D. Fonseca

Figure 7 – Result obtained from SSI processing of data from tower 1

DISCUSSIONS AND RESULTS

For the realization of signal treatments, several techniques can be applied as demonstrated by BRINCKER (2014). Among the most used procedures, two methods are: frequency domain decomposition (FDD) and subspace stochastic identification (SSI), which, due to their advantages, were selected for use in the treatment of the signals.

The first technique extracts modal parameters from the spectral density functions of the time series and stands out by the agility in its processing. As the amount of data was large totaling 106 hours of data captured, this technique was initially chosen and was performed for the two towers illustrated in the Fig. 8 and Fig.9.
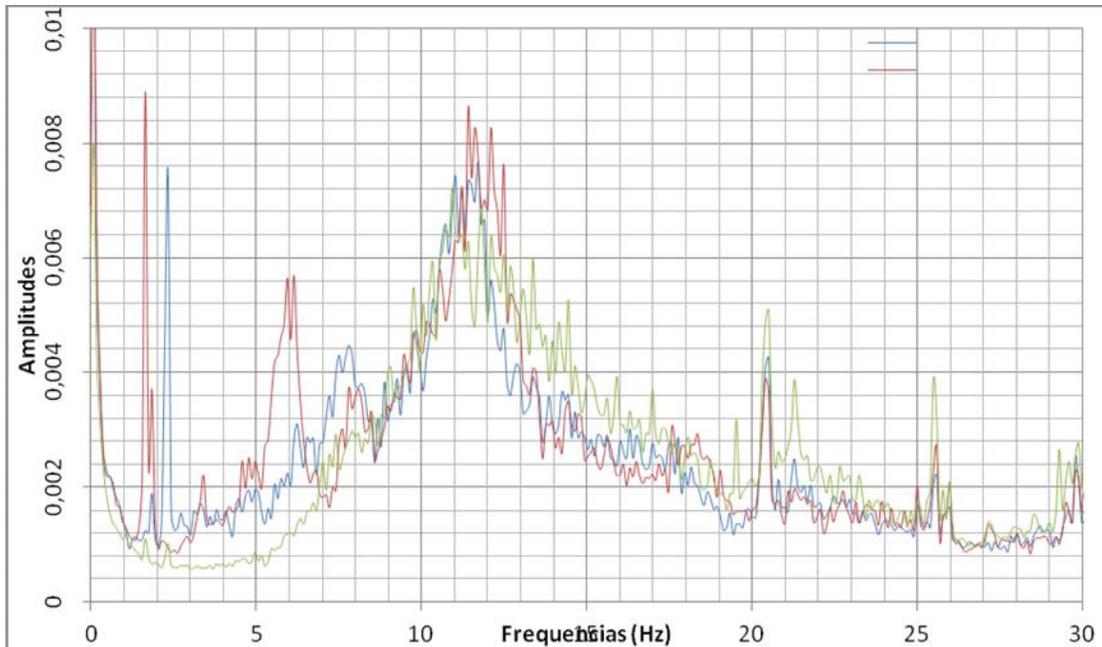

Figure 8 – Spectrum obtained by analysis using the FDD method for tower 3
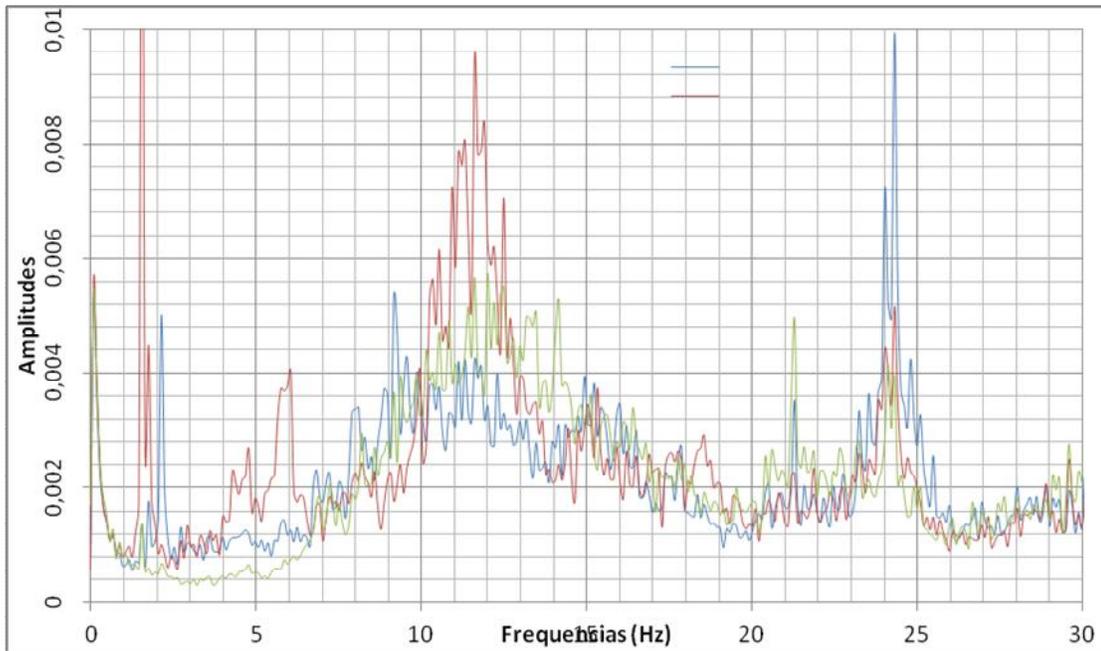
Figure 9 – Spectrum obtained by analysis using the FDD method for tower 1

After the analysis of the processes, the 25 initial modes of the towers 3 and 1 were identified and were listed in tab.1 and tab. 2.

Table 1 – Modes identified and respective frequencies and damping for tower 3

Vibration mode	Frequency (Hz)	Std. Frequency (Hz)	Damping (%)	Std. Damping (%)
1	2,297	0,018	1,566	1,16
2	2,321	0,021	1,361	1,383
3				
4	5,962	0,012	2,682	0,656
5	6,127	0,135	5,619	2,343
6	7,579	0,053	4,159	1,514
7				
8				
9	10,232	0,135	4,798	1,045
10	11,434	0,165	3,989	1,708
11	11,689	0,123	4,192	1,531
12				
13	13,703	0,231	3,577	0,683
14				
15				
16				
17	17,462	0,112	3,498	2,478
18	18,835	0,14	1,679	0,658
19	19,472	0,029	2,012	0,315
20	20,451	0,021	0,724	0,407
21	20,472	0,034	0,561	1,171
22	20,493	0,107	1,399	2,009
23	21,395	0,04	2,911	0,98
24	22,474	0,107	1,182	0,895
25	22,608	0,035	0,385	0,384

Table 2 – Modes identified and respective frequencies and damping for tower 1

Vibration mode	Frequency (Hz)	Std. Frequency (Hz)	Damping (%)	Std. Damping (%)
1	1,85	0,115	2,991	1,527
2	2,144	0,16	4,581	2,375
3	4,886	0,043	5,903	1,429
4	5,894	0,083	2,658	0,872
5	6,15	0,073	4,703	0,644
6	7,014	0,092	3,89	1,131
7	9,515	0,083	3,638	1,705
8	9,644	0,173	4,103	1,414
9	10,693	0,093	5,537	1,123
10	11,637	0,136	5,291	0,992
11	11,698	0,126	5,805	1,008
12	12,29	0,015	1,975	1,146
13	12,879	0,139	1,497	0,561
14	15,105	0,159	2,514	0,998
15	15,398	0,181	3,737	1,718
16	15,482	0,119	2,553	1,977
17	17,403	0,162	3,191	2,274
18	17,71	0,187	5,256	1,661
19	19,227	0,151	3,744	1,66
20				
21	20,676	0,235	2,951	1,183
22				
23	21,168	0,191	2,655	0,767
24	22,616	0,037	1,563	0,298
25				

The other technique selected was the subspace stochastic identification (SSI), which is based on the correlation functions of the time responses and has great utility for dissociation of frequencies very close to each other, but has a more robust processing which generates more time to obtain of its result. To ensure greater certainty of the results, SSI processing was performed for the two towers as shown in the Fig. 4 and Fig. 6.

The initial survey and its signal processing performed for tower 03 was important to verify the efficiency of the accelerometer sets in the collection of good quality signals for analysis, which was confirmed with data processing. However, it has been very time consuming both for the treatment of the signals and for its processing requiring a lot of time in this stage of the process.The second experiment in tower 01 aimed to verify if a smaller number of points and a reduced capture time for 1 hour could guarantee sufficient quality for a modal analysis of the structure.

The two experiments were a success both in the quality of the obtained signals, and in the verification that it does not take so many points to carry out a modal analysis of a large building.

Finaly, based on the surveys of towers 3 and 1 and the FFT and SSI processing, the frequencies of the vibration modes listed in Tables 1 and 2. The analysis of the results can verify a correlation of 99.82% between the experimental natural frequencies as shown in the Fig.10, thus indicating that the concern in the way of obtaining the modal parameters of a large structure has been overcome..
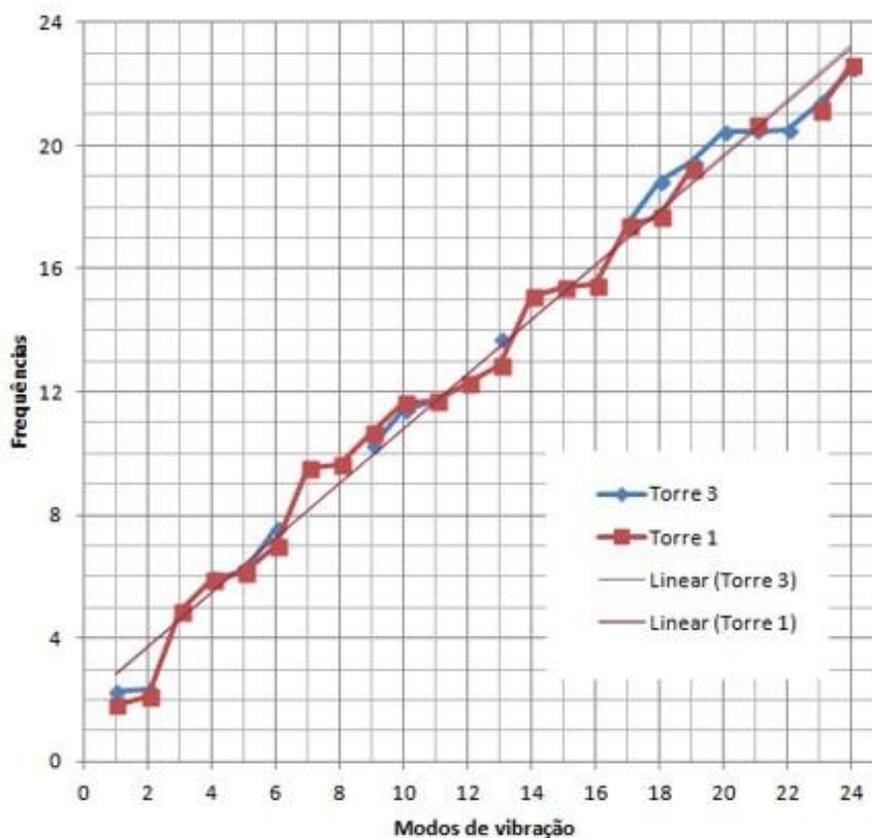
Figure 10 – Comparative experiment Tower 3 X Tower 1

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