Influence of the Intake Tower Dynamic Behaviour on Modal Identification of Cabril Dam

Paulo Mendes
Instituto Superior de Engenharia de Lisboa, Lisbon, Portugal

Sérgio Oliveira
Laboratório Nacional de Engenharia Civil, Lisbon, Portugal

ABSTRACT: This paper presents a study, which describes the influence of the dynamic behaviour of the intake tower on the experimental results obtained from operational modal analysis of Cabril dam. A 3D finite element model, for the intake tower of Cabril dam, was developed in order to study the dynamic behaviour of this neighbour structure of the dam. The main dynamic parameters computed and evaluated experimentally for this structure are summarized and discussed, to understand how they can interfere in the modal identification of Cabril dam.

1 INTRODUCTION

In 2002, two ambient vibration tests were carried out in Cabril dam, requested by the owner of the dam, EDP (Portugal Electricity Company), to evaluate the source of a resonance problem, for some reservoir water levels of exploitation during the operation of the power groups.

In this paper we present the results obtained in those tests, and we will discuss the influence of the dynamic behaviour of the intake tower in the results obtained with modal identification techniques, based on the development of a 3D finite element model for that neighbour structure of the dam.

2 DESCRIPTION OF CABRIL DAM

Cabril dam (Figure 1) owned by EDP, is located on the Zêzere River, in the centre of Portugal, and is the main structure of a multipurpose development designed for energy production. This dam is a double curvature arch dam with a maximum height of 130 m (the highest in Portugal) and a total length of 368 m between the abutments at the crest elevation.

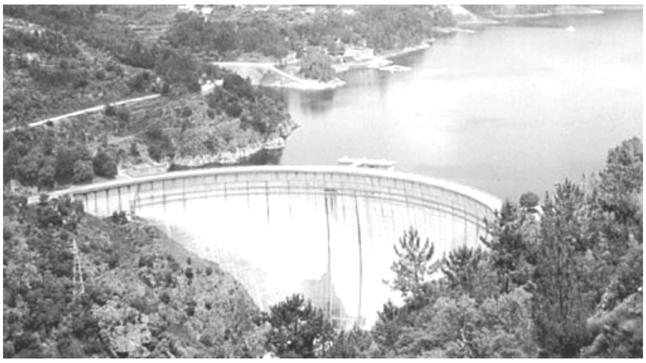


Figure 1 : View of Cabril dam.

3 AMBIENT VIBRATION TESTS

As was just referred above, two ambient vibration tests were carried out in Cabril dam. In the 1st test the power groups were operating in maximum power, and in the 2nd test the power groups were disconnected and the dam was excited only by environmental loads (Oliveira et al. 2004).

The ambient vibration tests were performed with 12 Kinemetrics ES-U force balance accelerometers, signal conditioning equipment developed at LNEC and data acquisition hardware and software from National instruments. For those tests, the equipment was configured for a maximum sensitivity of 2.5 Volt/mg; the saturation level of the acquisition system being around ±10 Volt. In the situation of maximum gain, the system makes it possible to measure accelerations until about ±4 mg (in fact, as will be demonstrated, maximum acceleration values of about 2 mg were measured in a situation where the power units were in operation), with a precision corresponding to 8 mg / 2^{16} (16 bits).

The ambient vibration data was acquired using a sampling frequency of 200 Hz, during more than 30 minutes in each test.

The accelerometers were installed in the sections shown in Figure 2, in the radial direction of the dam, 9 in the gallery at level 293 m (close to the crest) and 3 in the gallery immediately below, at level 274.5 m.

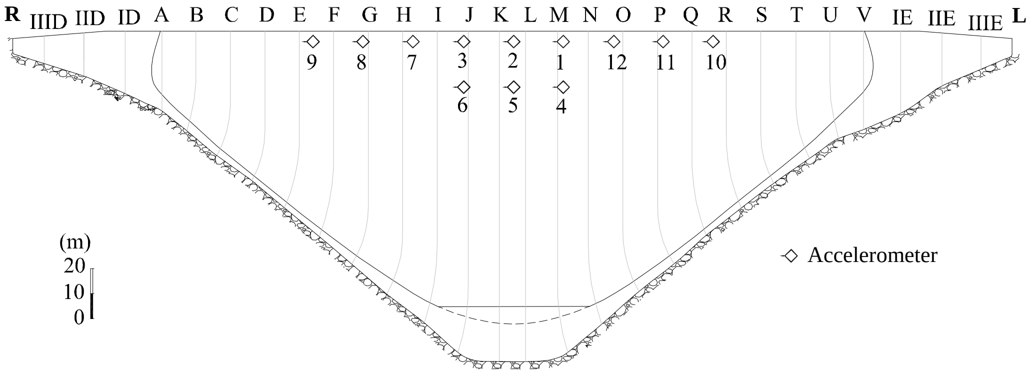


Figure 2 : Locations of the accelerometers in the ambient vibration tests.

Figure 3 and 4 shows two records obtained in the crest gallery at the central cantilever in the radial direction in those tests.

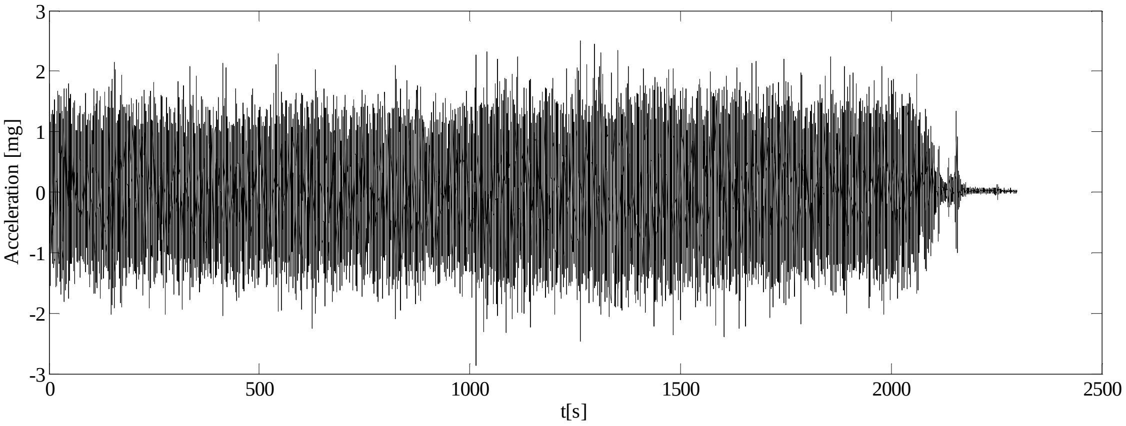


Figure 3 : Typical time history accelerations with the power groups operating (central cantilever).

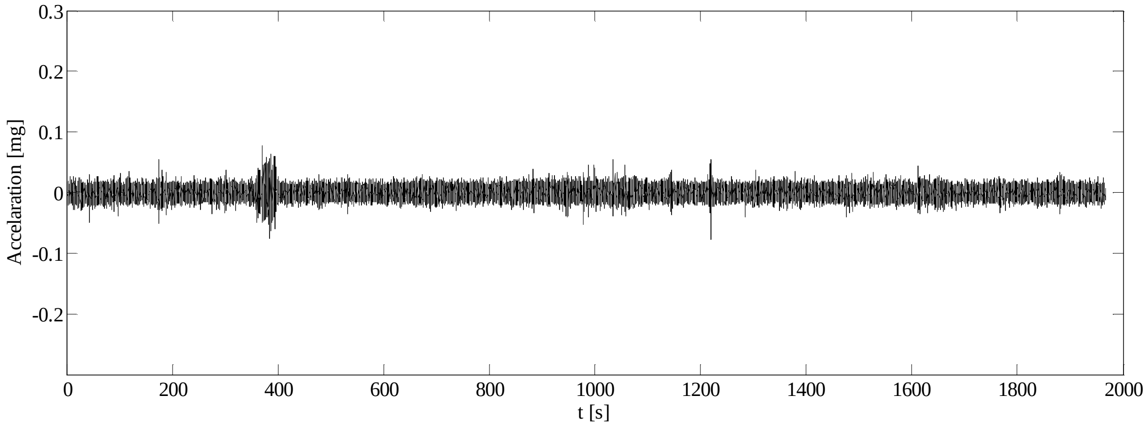


Figure 4 : Typical time history acceleration with only environmental vibration (central cantilever).

3.1 *Output only modal identification*

The output only modal identification of the experimental data measurements collected on the ambient vibration tests was performed using the Frequency Domain Decomposition (FDD) (Brincker et al. 2000). Figure 5 presents the singular values of the spectral density matrix, obtained in the test related with the operation of the power groups. The first 4 peaks related with structural modes were selected with the related frequency identified. It can be seen a peak between the 2nd and 3rd modes, with an exactly frequency of 3.57Hz, which corresponds with the frequency related with the operation of the power groups.

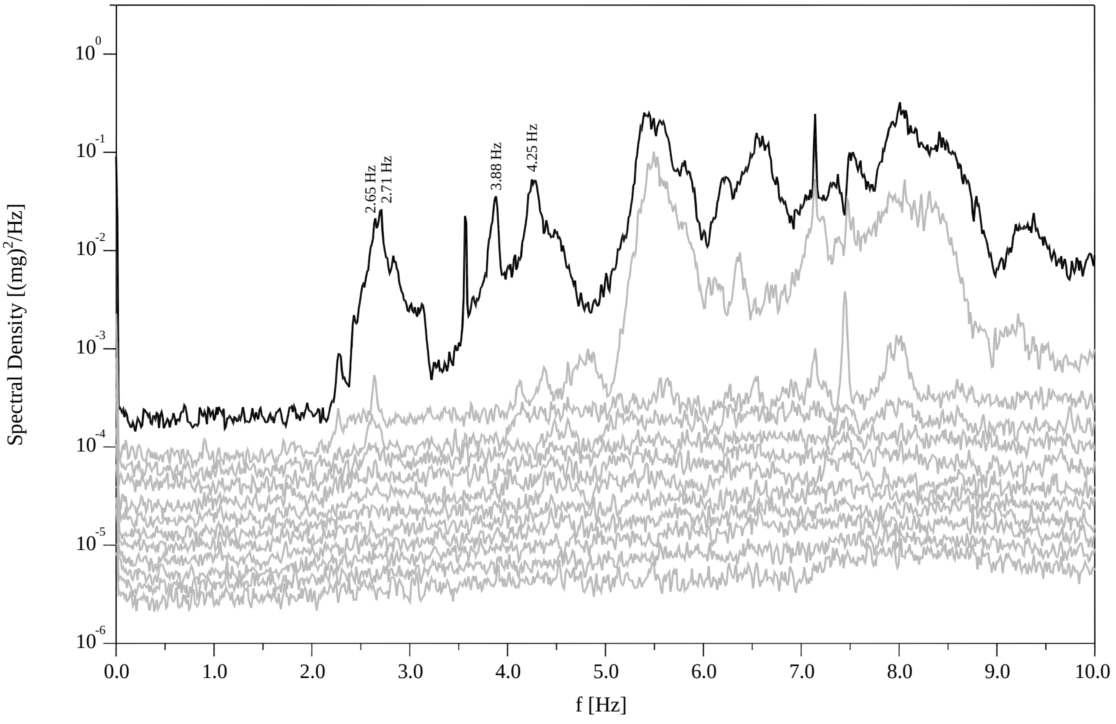


Figure 5 : Singular values of spectral density matrix for FDD method (power groups operating).

Figure 6 presents the singular values of the spectral density matrix, obtained in the test related with environmental vibrations only, without the operation of the power groups. In that figure, the 4 peaks related with structural modes were selected with the related frequency identified. In this test, the first two modes, with close frequency values, are clearly identified, essentially due to grow up of the 2nd singular value in that zone.

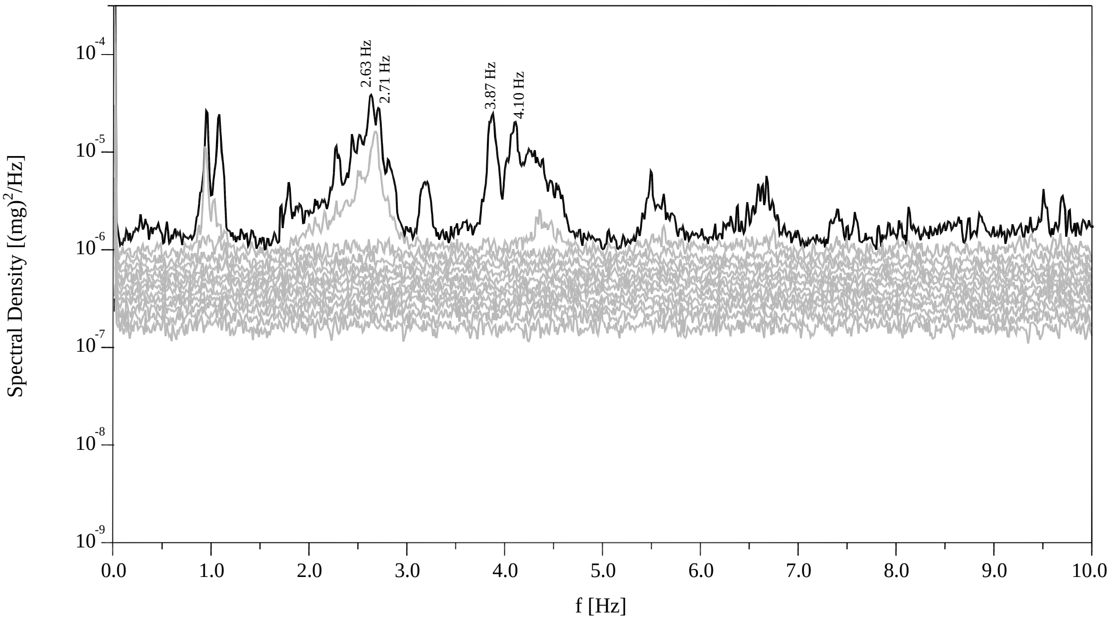


Figure 6 : Singular values of spectral density matrix for FDD method, (environmental vibrations only).

Analysing the previous spectra, we can also clearly identify two peaks around 1 Hz in the spectrum presented in Figure 6, but not in the spectrum presented in Figure 5. Two questions can be made: Why that peaks appear only in the spectrum correlated with environmental excitation? What is the source of vibration which can be correlated with those frequencies?

The answer to the second question is a neighbour structure of the dam, the intake tower. And the 1st question can be answered based on differences of level of the amplitudes of vibration in the two tests carried out.

In order to clarify this theory a 3D finite element model of the intake tower was developed and will be presented in the next section.

4 ANALYSIS OF THE DYNAMIC BEHAVIOUR OF THE INTAKE TOWER

Many dams have auxiliary structures, namely to help providing water to the power groups, these structures are known as intake towers. Cabril dam has one of these structures as can be seen in Figure 7, and in this section we will present a study of the dynamic behaviour of this structure using a 3D finite element model (Zienkiewicz, 2000). With these results, it will be possible to explain the above referred peaks, identified in the spectrum shown in Figure 6, around 1 Hz.

4.1 3D finite element model of the intake tower

This numerical model will be used to study the dynamic behaviour of this intake tower. The mesh is composed by 1098 isoparametric finite elements with 20 nodes, with a total of 9004 nodal points, which means a total of 27012 degrees of freedom. It is important to notice that it was necessary to simplify a little the shape of some structural elements, due to his complex shape, however these simplifications induced a decrease in the global stiffness of the model which are assured in the model using a higher Young’s modulus for concrete. Have this in consideration the intake tower material properties assumed were the following: Young’s modulus E = 50 GPa, Poisson’s ratio $\upsilon = 0.2$ and density $\rho = 2400$ kg/m³. In the numerical model the effect of water was also assumed in the numerical model considering the structure partial submerged (Newmark, 1971).

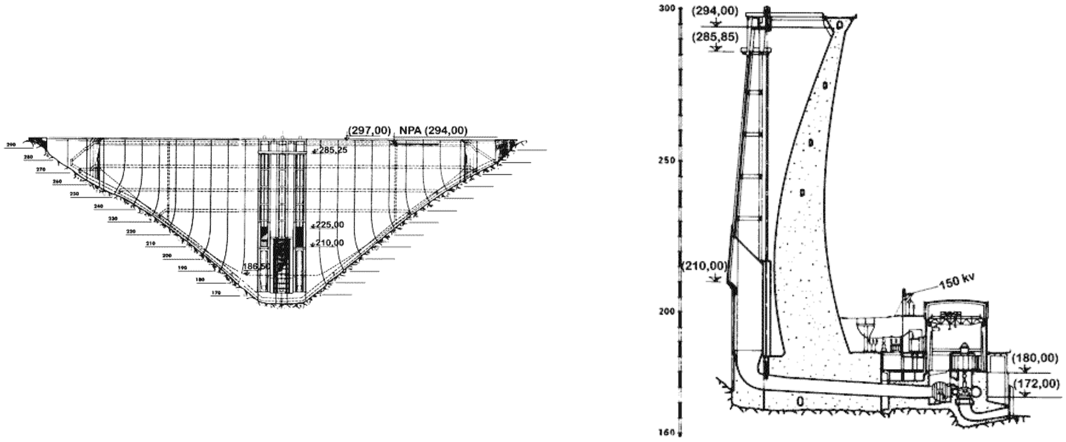
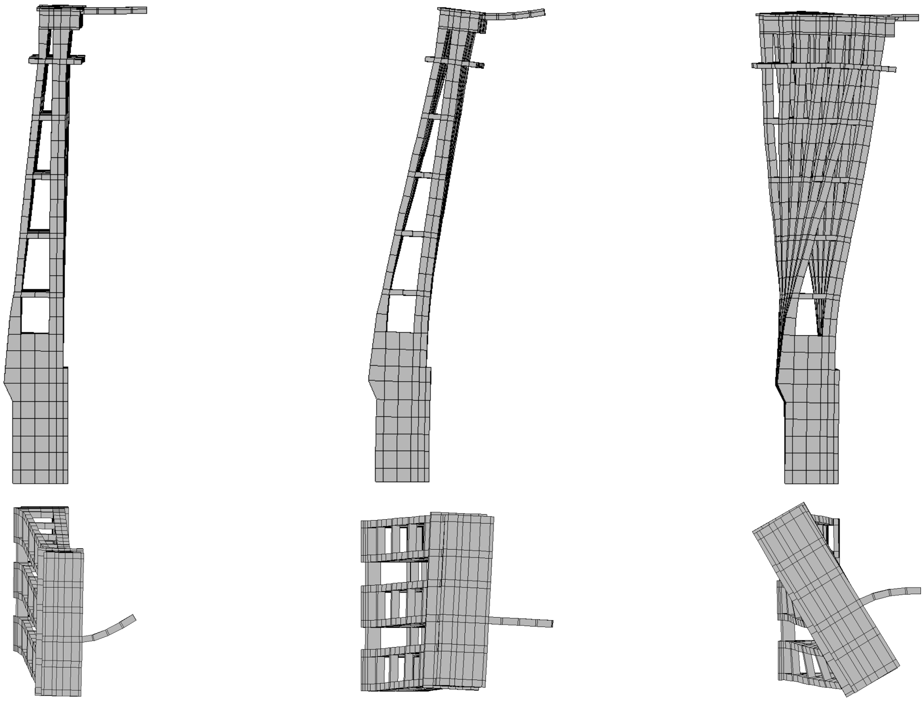


Figure 7 : Elevation and cross-section by the central cantilever and intake tower.

Figure 8 shows the first 3 mode shapes of the intake tower and the natural frequencies obtained. With these results, and reanalyzing again the spectrum of Figure 6 it is possible to assure that peaks are related with the influence of this structure in the experimental results obtained in the ambient vibration tests carried out in Cabril dam.



1st mode – $F_1 = 0.827$ Hz 2nd mode – $F_2 = 0.829$ Hz 3rd mode – $F_3 = 1.118$ Hz

Figure 8 : First three mode shapes computed for the intake tower.

Comparing numerical and experimental results, it’s possible to guarantee the existence of 3 natural frequencies around 1Hz. Analysing only the experimental results we can see on the 1st peak, the growing up of the 2nd singular value in that zone, but in this case we aren’t identifying the dynamic behaviour of the intake tower so we don’t have mode shapes of that structure to analyse this aspect. So in this case, only with the numerical results it was possible to prove the existence of two natural frequencies below 1 Hz.

5 CONCLUSIONS

In this paper we have showed the influence of auxiliary structures, as intake towers, on the analysis of the results from modal identification of data collected on dam's body. In this particular case it has been showed the importance of the magnitude of excitation to identify the influence of neighbour structures, on the monitored structures.

The use of both, experimental and numerical results it's fundamental to analyse and understand correctly the dynamic behaviour of civil engineering of structures.

6 ACKNOWLEDGMENTS

The authors wish to thank EDP for all the support provided in the preparation and execution of tests.

7 REFERENCES

Bendat, J. S.; and Piersol, A. G. 1983. Random data analysis and measurement procedures (3rd Edition). *John Wiley & Sons*.

Brincker, R.; Zhang, L.; and Anderson, P. 2000. Modal identification from ambient responses using frequency domain decomposition. *Proc. 18th International Modal Analysis Conference (IMAC-XVIII).*

Newmark, N.; Rosenblueth, E. 1971. Fundamentals of earthquake engineering. *Prentice-Hall, Inc, N. J*.

Oliveira, S.; Rodrigues, J.; Mendes, P.; Campos Costa, A. 2004 Damage characterization in concrete dams using output only modal analysis. *Proc. 22nd International Modal Analysis Conference (IMAC-XXII).*

Zienkiewicz, O. C.; Taylor, R. L. 2000. Finite Element Method (5th Edition) Volume 1 - The Basis. *Elsevier*.