Field observations on concrete box girder railway bridges

Luís Oliveira Santos, Jorge Rodrigues & Xu Min
LNEC - National Laboratory for Civil Engineering, Lisbon, Portugal

ABSTRACT: This paper presents the field observations performed during the static and dynamic tests of two concrete box girder railway bridges that are part of the railway line between Lisbon and Algarve, in the South of Portugal. After a brief description of the bridges, this paper presents the procedures used in the static and dynamic tests of both structures. The experimental results achieved are compared with the numerical values evaluated with a finite element model of each bridge.

1 INTRODUCTION

The Corona and Espinhaço de Cão Bridges, integrated in the railway line linking Lisbon and Algarve, were submitted to static and dynamic tests to evaluate its structural behavior under static loads and its dynamic characteristics (frequencies, mode shapes and damping ratios).

This paper presents the finite element models used to analyze both bridges and the experimental procedures adopted in the field observations, including the use of a hydrostatic levelling system to measure vertical displacements during the static tests and the output-only modal identification techniques used to analyze the data obtained in the dynamic tests. The experimental results are also compared with the values computed with the finite element models.

2 DESCRIPTION OF THE STRUCTURES

Corona Bridge has a total length of 208 m, divided in three intermediate spans with 48 m and two extreme spans with 32 m, as presented in Figure 1. Espinhaço de Cão Bridge has only four spans with a total length of 133 m (Figure 2).

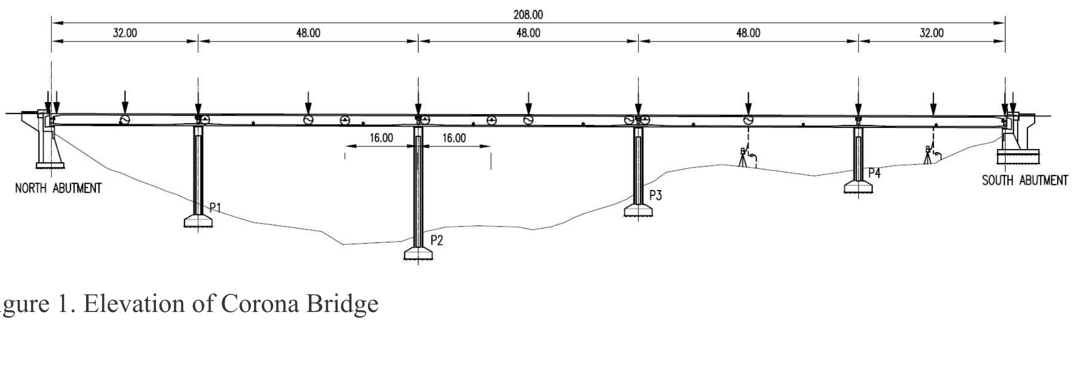

Figure 1. Elevation of Corona Bridge

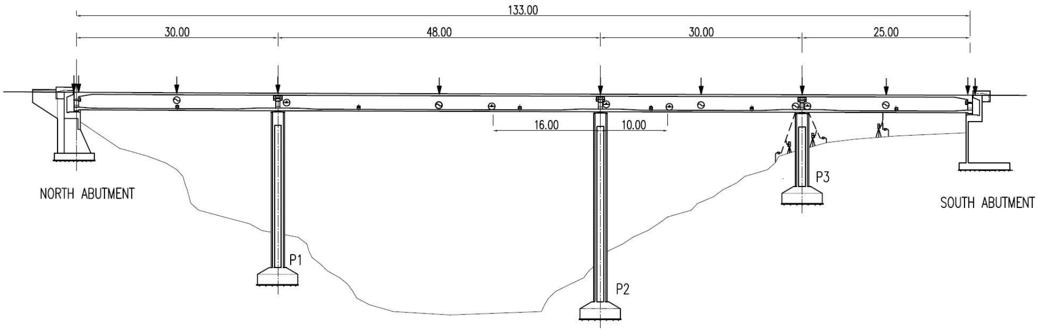

Figure 2. Elevation of Espinhaço de Cão Bridge

These bridges are similar structures although with a different number of spans. In fact, both bridges have a prestressed concrete box girder deck, 2.5 m height and 8.1 m width, rectangular piers with 3.50 m × 2.00 m and the same type of bearings, which are fixed for all horizontal displacements at the South abutments and allow longitudinal displacements at the other supports. Piers and abutments are in reinforced concrete with footing foundation.

General views of the bridges are presented in Figures 3 and 4.

Figure 3. General view of Corona Bridge

Figure 4. General view of Espinhaço de Cão Bridge

3 FINITE ELEMENT MODELLING

A three dimensional, linear, elastic numerical model of each bridge was developed in SAP2000 to evaluate its response to the static tests and its dynamic characteristics.

Shell and bar elements were used for modelling the deck (Figure 5). The piers were simulated by bar elements. Finally, the bearings at the top of the piers and abutments were modelled by link elements. The Corona Bridge model has 1952 shell elements and 561 bar elements and the Espinhaço de Cão Bridge model has 1300 shell elements and 374 bar elements

Before the load tests the preliminary FE model was used to estimate the deformation of the structure caused by static loads and the frequencies and shapes of the natural vibration modes. After the tests, the FE model was calibrated with the results from the static load tests, and then adjusted to the dynamic characteristics identified with the dynamic tests.

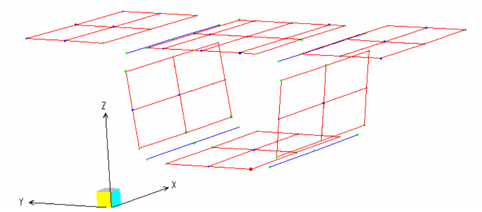

Figure 5. Finite element modelling of the deck

4 STATIC LOAD TESTS

4.1 *Testing procedure*

The static load tests were performed with a train composed by a locomotive and six ballast wagons with a total load of 3126 kN. These loads were placed in 12 positions, at Corona Bridge, and 8 positions at Espinhaço de Cão Bridge, in accordance to the load plan that maximizes the most important effects in the structures, however without inducing unwanted situations of early cracking in the concrete.

During the test, vertical displacements and rotations were measured at several sections. In order to measure the most reliable and redundant data, different types of sensors were installed.

Vertical displacements were measured at mid spans of major spans by an upgraded hydrostatic levelling system associated to pressure cells. Some of these sections were also instrumented with traditional mechanical deflectographs.

In both bridges, transverse and longitudinal rotations were measured by electric clinometers located at the top of piers P1, P2 and P3. Two other clinometers were placed close to pier P2 at the third span. At one of these sections a mechanical air-bubble clinometer was also used.

Three automated data-acquisition systems *DataTaker DT515* were used to read data from the hydrostatic levelling systems and from the electric clinometers, allowing an effective control of experimental data in real time.

Figure 6 presents some of the equipment used during these tests: a pressure cell from the hydrostatic levelling system, an electric clinometer and a data logger. Two deflectographs are presented in Figure 7.

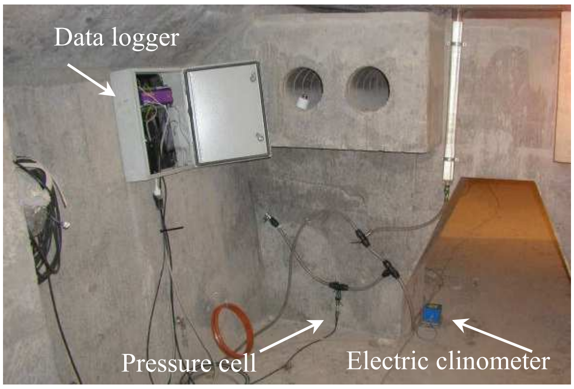

Figure 6. Equipment inside Corona Bridge


Figure 7. Deflectographs at Espinhaço de Cão Bridge

4.2 *Main results*

Extensive experimental data was obtained during the static test. From all these data, some illustrative results were chosen, including some influence lines and deck deformations.

Figure 8 presents the influence lines of the vertical displacement at the mid-span of the Corona Bridge major spans, achieved by placing only the locomotive in different positions along the deck. The same figure shows also the influence lines of the rotation at the top of piers P2 and P3. The deck deformations occurred when the locomotive and four ballast wagons fully occupied each of the major spans of Corona Bridge is presented in Figure 9.

Figure 10 presents for Espinhaço de Cão bridge the influence lines of the vertical displacement at the mid-span of the main span and the influence lines of the rotation at the top of piers P2 and P3. The deck deformation of Espinhaço de Cão Bridge when the load train was at the major span is presented in Figure 11.

These charts show a good agreement between experimental values and computed ones. It is also relevant the good agreement between values measured by different devices (hydraulic levelling system and deflectographs or electric and air-bubble clinometers).

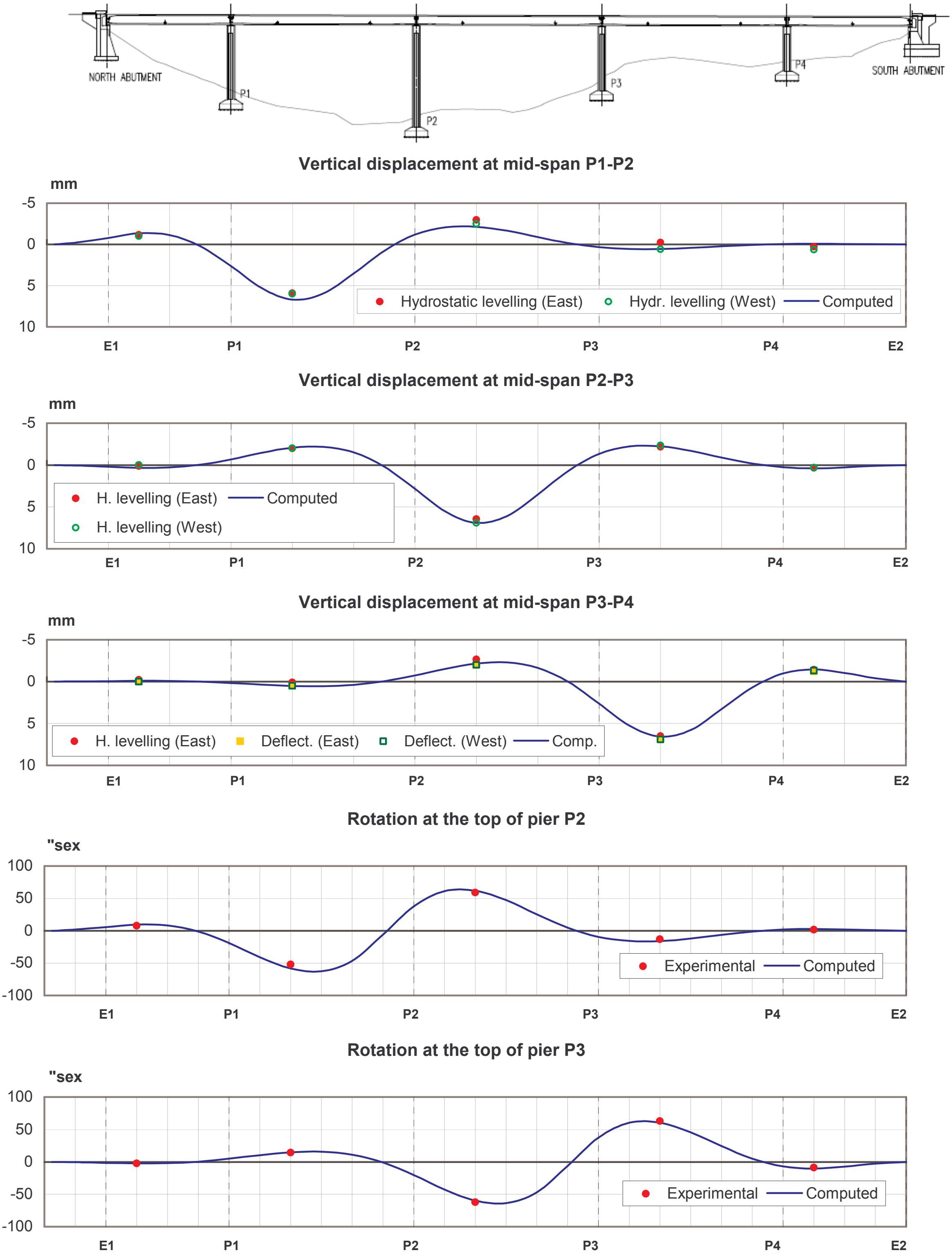

Figure 8. Corona Bridge: influence lines

In a general way, the experimental results obtained in the tests of the two bridges are similar. They confirm, however, that the Espinhaço de Cão Bridge has a largest stiffness as foreseen by the finite element models.

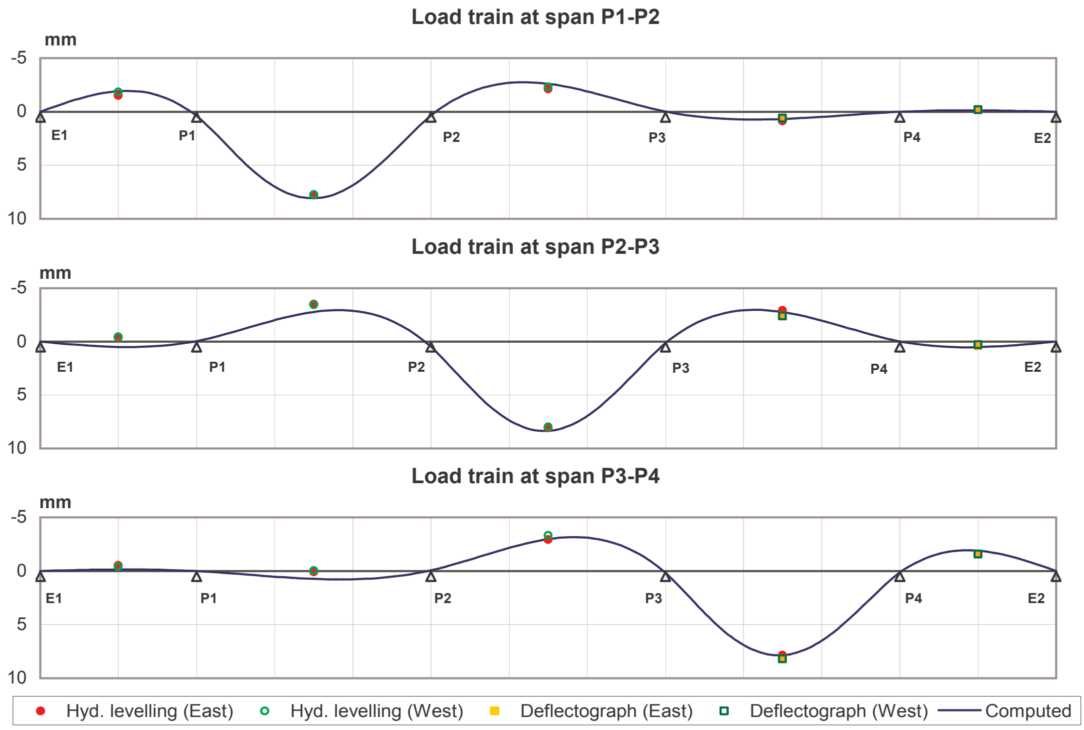

Figure 9. Corona Bridge: deck deformations with the load train at each major span

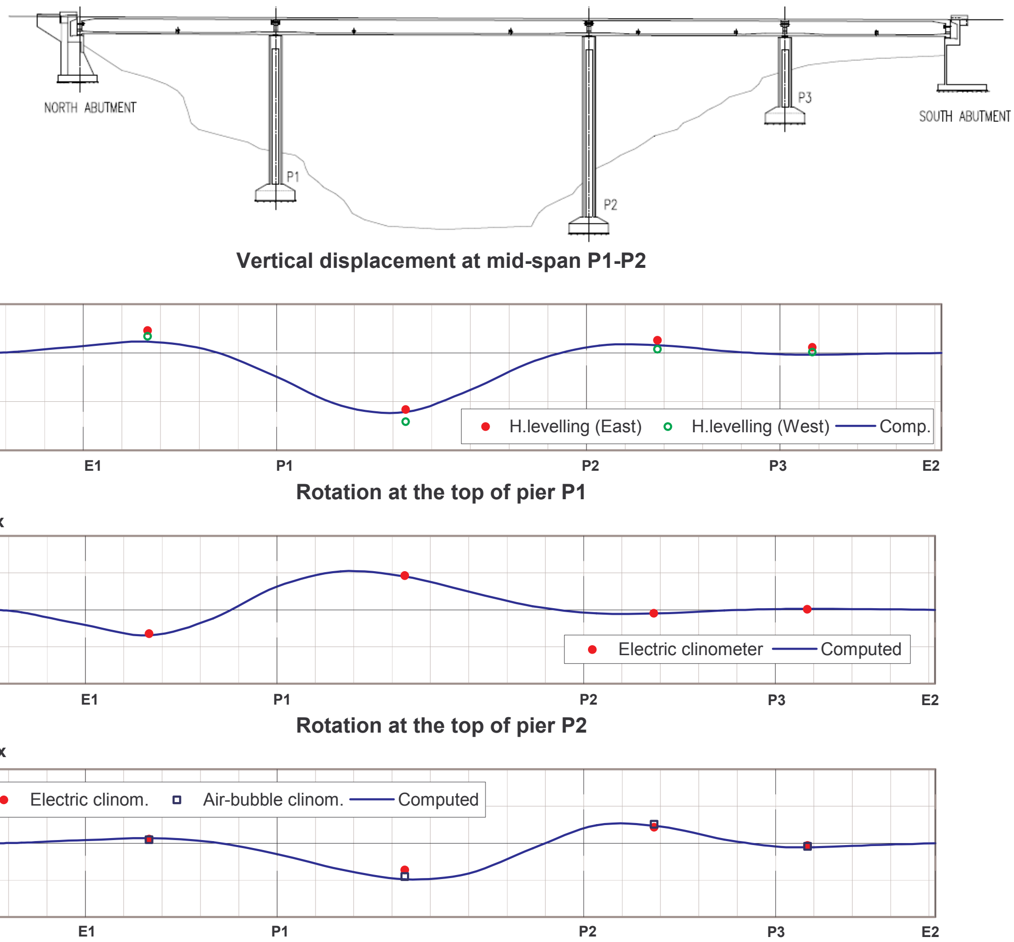

Figure 10. Espinhaço de Cão Bridge: influence lines

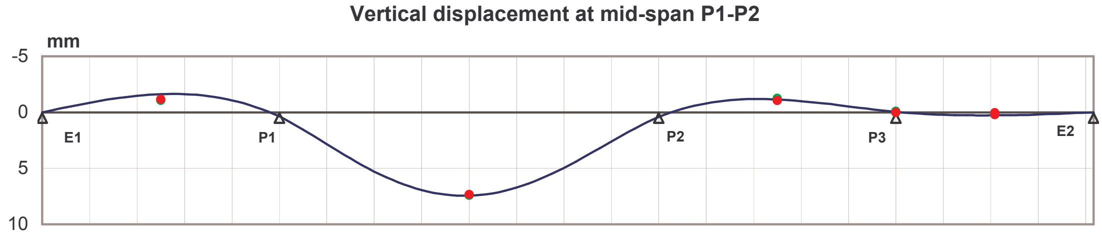

Figure 11. Espinhaço de Cão Bridge: deck deformations with the load train at the major span

5 DYNAMIC TESTS

5.1 *Testing procedure*

The dynamic tests consisted in the measurement of accelerations in the structures induced by the wind (ambient vibrations) and by trains crossing the bridges in a normal operation condition (including active tilting trains with speeds of 220 km/h). No restrictions were imposed to the railway traffic in order to perform the dynamic tests. An identification of the natural frequencies of the structures was performed from the measured accelerations as well as an analysis of the railway traffic induced vibrations.

The dynamic tests were performed with 15 Kinemetrics ES-U force balance accelerometers, signal conditioning equipment constructed at LNEC and data acquisition hardware and software from National Instruments.

Different equipment configurations (gain factors) were used for the two test situations: 1) ambient vibrations (mostly due to wind) and 2) railway traffic induced vibrations. In the ambient vibration tests the equipment was configured with a sensitivity of 2 Volt/mg and with 0.005 Volt/mg for the measurement of the railway traffic induced vibrations.

In Corona Bridge the dynamic tests were conducted in three set-ups and vertical and transverse accelerations were measured in 30 sections of the bridge deck, whose location is indicated in Figure 12. The ambient vibration data was acquired during about 22 minutes using a sampling frequency of 1000 Hz. The railway traffic induced vibration records were also acquired with a sampling frequency of 1000 Hz.

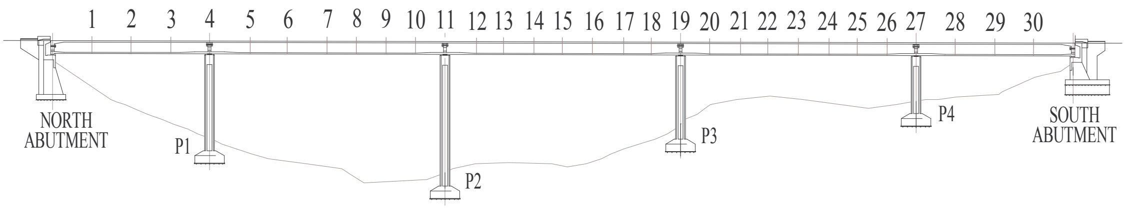

Figure 12. Corona Bridge: sections instrumented in the dynamic tests

In Espinhaço de Cão Bridge a similar testing procedure was adopted, however only two set-ups were performed with vertical and transverse accelerations being measured in 21 sections of the bridge deck, whose location is indicated in Figure 13.

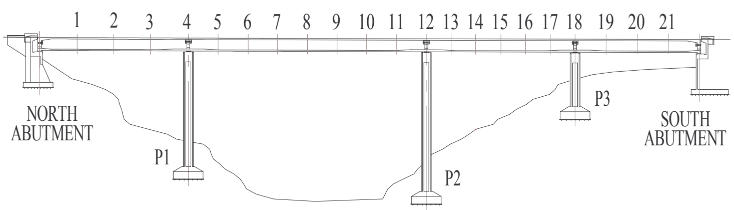

Figure 13. Espinhaço de Cão Bridge: sections instrumented in the dynamic tests

5.2 *Modal identification*

The ambient vibration data was considered to do an identification of the dynamic characteristics of the two bridges. For that purpose the acceleration records were initially pre-processed, with high-pass digital filtering at 0.2 Hz with a 1 pole Butterworth filter, low-pass digital filtering at 10 Hz with an 8 poles Butterworth filter and decimation to a sampling frequency of 25 Hz.

The modal identification procedures, adopted to analyze the ambient vibration data, consisted in a combination of the random decrement (RD) technique with a frequency domain method, the frequency domain decomposition (FDD) method, and also with a time domain method, the covariance driven stochastic subspace (SSI-COV) method. A more detailed description of these modal identification procedures can be found in Rodrigues & Brincker (2005).

The modal identification procedure was applied separately for the vertical records and for the transverse records.

Using the RD technique and considering a level crossing triggering condition, with a optimal value of the triggering level, the RD functions were evaluated for the accelerations measured in the different set-ups of the tests. Segments with a time length of 1024 values at 25 Hz (about 40 seconds) were considered for that evaluation.

The estimated RD functions were considered to apply the SSI-COV method and the FDD method.

To illustrate some of the results that were obtained for Corona Bridge, Figure 14 shows the stabilization diagram corresponding to the application of the SSI-COV method to the RD functions estimated with the data of the third set-up and Figure 15 shows the averaged singular values spectra corresponding to the application of the FDD method to the RD functions. The frequencies and mode shapes identified with the SSI-COV method are presented in Figure 16.

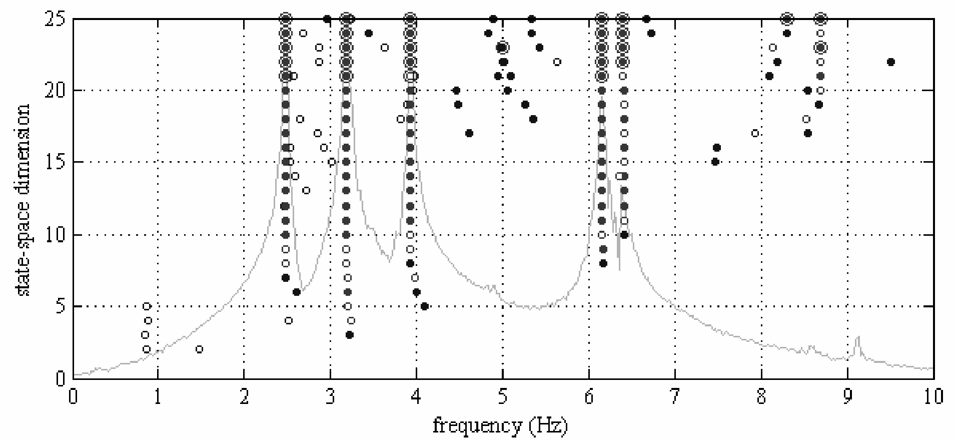

Figure 14. Corona Bridge: stabilization diagram for the vertical accelerations

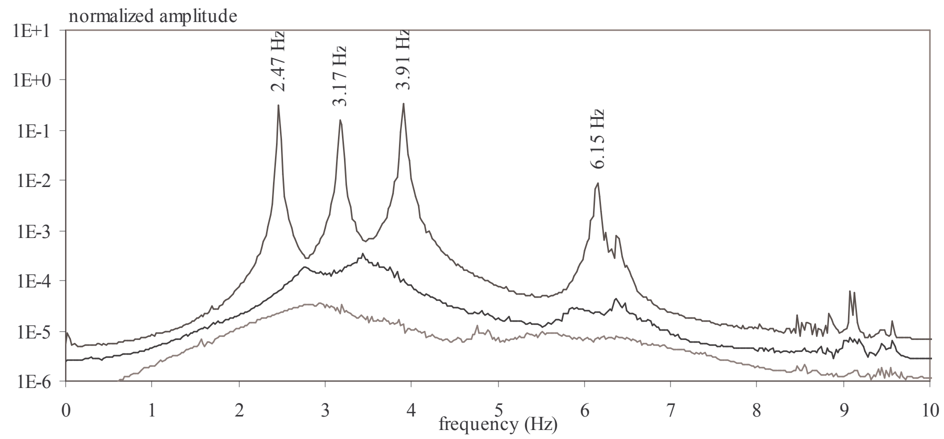

Figure 15. Corona Bridge: singular values spectra for the vertical accelerations

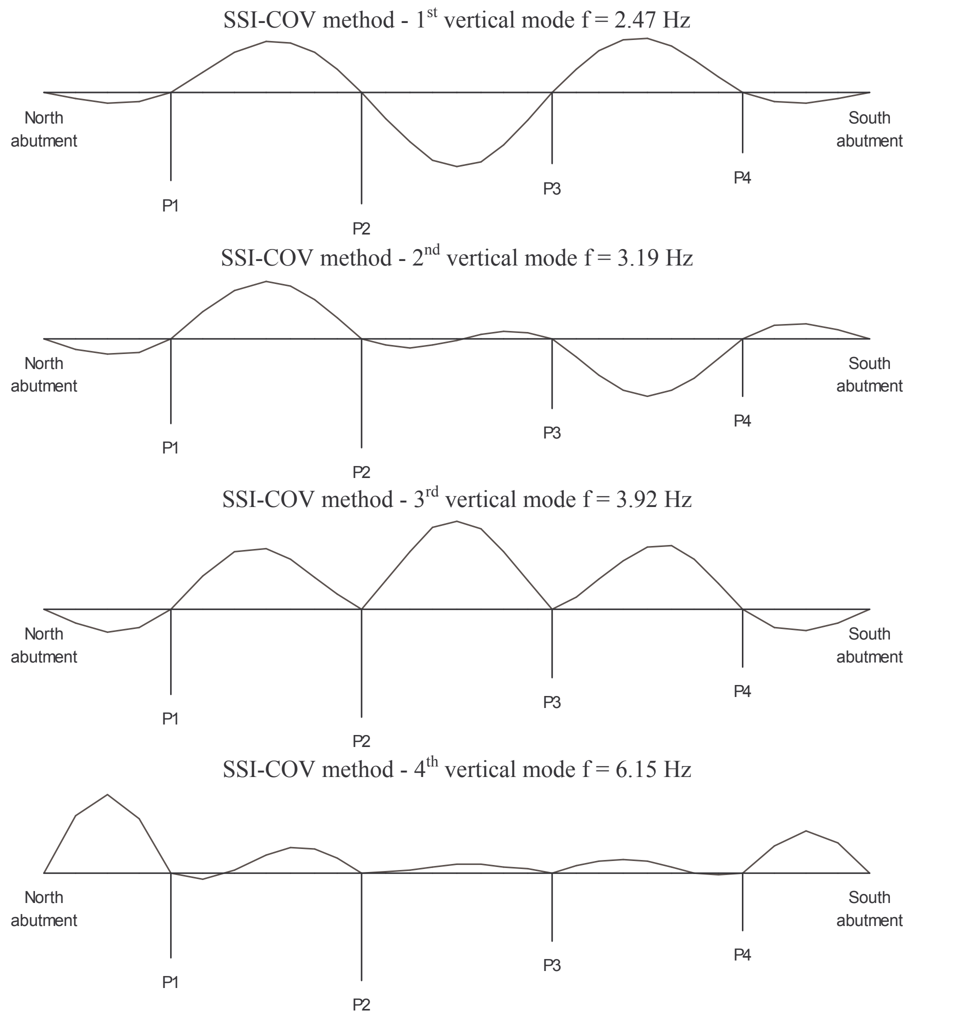

Figure 16. Corona Bridge: identified frequencies and mode shapes for the vertical modes

6 CONCLUSIONS

The experimental results obtained in the static and dynamic tests of the two railway bridges have a good correlation with the numerical values computed by FE model.

The hydraulic levelling system associated with pressure cells proved to be an accurate way of measuring vertical displacements in box-girder bridges.

The experimental data obtained about the structural behaviour of these bridges is an important contribution to the characterization of their actual condition at the beginning of their lifetime.

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REFERENCES

CSI, SAP2000. 2000 – *Integrated Finite Element Analysis and Design of Structures*.

Rodrigues J. 2004. *Stochastic Modal Identification – Analysis Methods and Applications in Civil Engineering Structures*, PhD Thesis, FEUP, Porto (in Portuguese).

Rodrigues, J., & Brincker, R. 2005. Application of the random decrement technique in operational modal analysis. *In 1st International operational modal analysis conference*, Copenhagen, Danemark.