Static and dynamic testing of the overpass bridge PS2

M. Xu, L. O. Santos and P. Silveira
Department of Structures, National Laboratory for Civil Engineering, Lisbon, Portugal

ABSTRACT: This paper presents the static and dynamic testing of a concrete arch overpass bridge. After a brief description of the structure, the procedures used in the static and dynamic tests are pointed out. The experimental results achieved are compared with the numerical values evaluated with a finite element model of the overpass bridge.

1 INTRODUCTION

The overpass bridge PS2, located at the A2 highway, between Lisbon and Algarve, Portugal, was submitted to static and dynamic tests in order to evaluate its structural behavior under static loads and its dynamic characteristics, as vibration frequencies, mode shapes and damping ratios.

This paper presents the finite element (FE) model used to analyze the structure and the experimental procedures adopted in the field observations, including 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 model.

2 DESCRIPTION OF THE STRUCTURE

The overpass bridge PS2 is a reinforced concrete bridge with a total length of 72 m (Figure 1). The deck is a ribbed slab with 0.55 m height and 9.40 m width, connected monolithically to the top of the arch and by seven concrete columns (Figure 2 and Figure 3).

Figure 1 : The overpass bridge PS2

The arch has a radius of 50.30 m with 53.40 m length. The arch cross section is a rectangle, 0.60 m height and a width that varies from 3.80 m, near piers P1 and P6, to 5.20 m at the arch crown. Piers cross section is also rectangular (2.50 × 0.25 m).

There are unidirectional bearings at the abutments.

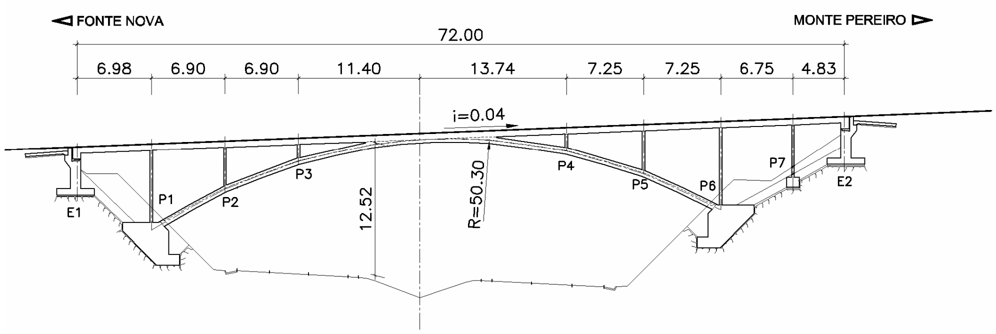

Figure 2 : Elevation view

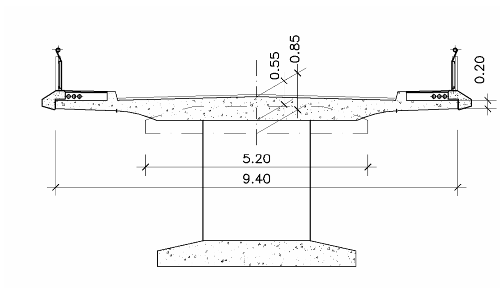

Figure 3 : The deck transverse section

3 ANALYTIC MODEL

A three dimensional, linear, elastic numerical model of the overpass bridge was developed in SAP2000 (CSI 2000) to evaluate its response to the static tests and its dynamic characteristics.

The FE model has 160 shell elements and 92 frame elements. The shell elements are used for the lateral cantilevers and the frame elements are used for the central rib and the columns. The connection between the lateral cantilevers and the central beam or the piers was modelled with body constraints. Four link elements were used for modelling the bearings at the abutments. Figure 4 present the FE model of PS2.

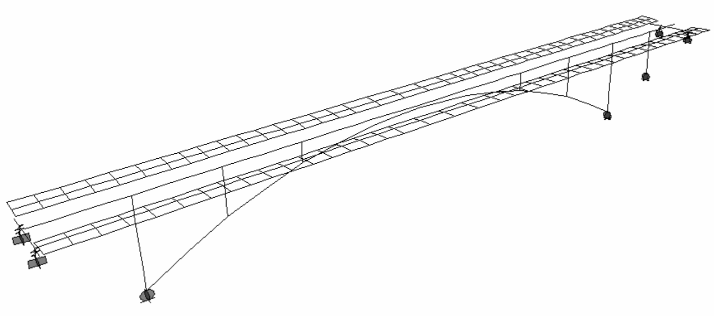

Figure 4 : The numeric model

This model was calibrated tacking into account the static load tests results and also the characteristics identified in the dynamic tests.

4 STATIC TEST

The static test was performed with two loaded trucks with a total weight of 570 kN (Figure 5). These loads were placed in 10 positions, in accordance to the load plan that maximizes the most important effects in the structure, however without inducing unwanted situations of early cracking.

During the test, vertical displacements of the arch under the columns and at the arch crown were measured with traditional mechanical apparatus as deflectographs.

The FE model was used for interpretation of the experimental results of the static test. The modulus of elasticity of the concrete was considered as 30 GPa for the columns and 34 GPa for the deck and the arch.

Figure 5 : Static load test

Figure 6 shows some load cases and the corresponded computed bridge's deformations, and in Table 1 the experimental values and analytical results are compared. It is obvious that a good agreement has been obtained.

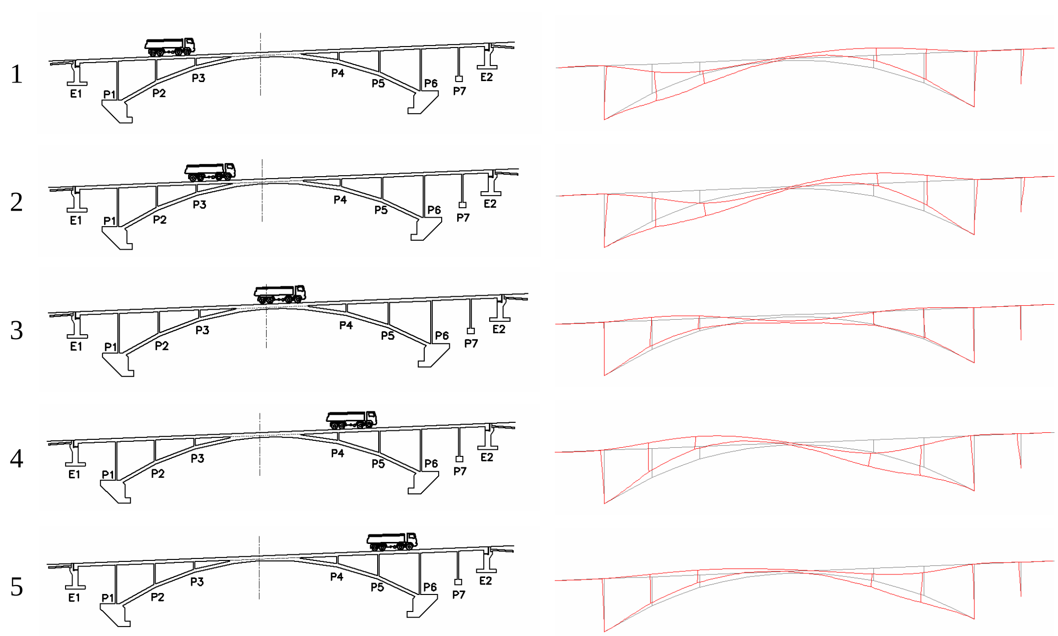

Figure 6 : Load positions and structural deformation

Table 1– Measured and computed arch vertical displacements (mm)

Load Case	P2 Measured	P2 Computed	P3 Measured	P3 Computed	Arch Crown Measured	Arch Crown Computed	P4 Measured	P4 Computed	P5 Measured	P5 Computed
1	5.3	5.5	6.4	6.4	-1.2	-1.5	-5.0	-5.2	-2.4	-2.8
2	4.7	4.4	9.8	9.2	0.0	0.2	-7.8	-7.5	-4.1	-4.4
3	-1.7	-2.2	-1.5	-1.8	4.2	4.3	0.0	0.7	-1.3	-1.1
4	-3.5	-4.0	-6.9	-7.2	-0.9	-1.2	9.9	9.8	5.1	5.7
5	-1.6	-1.8	-3.6	-3.5	-1.3	-1.5	4.7	4.4	4.6	4.8

Convention: + ↓, - ↑

5 DYNAMIC TESTS

5.1 Testing procedure

Dynamic tests were performed to obtain experimentally the dynamic characteristics of the structure, namely, vibration frequencies, mode shapes and damping ratios. During the tests, accelerations induced in the structure by the truck movement were measured using Kinemetrics Uniaxial Episensor (ES-U) accelerometers and other equipments for signal conditioning and data acquisition (Rodrigues 2004).

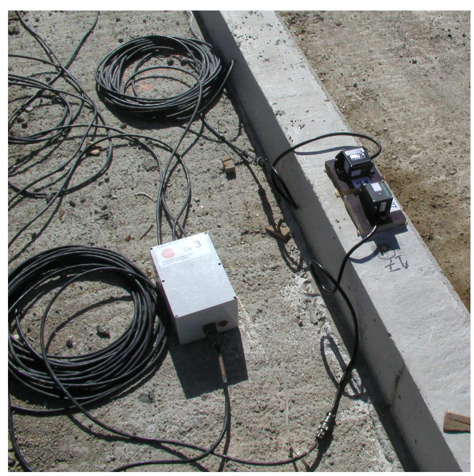

Figure 7 : Instrumentation during the dynamic tests

The dynamic tests of PS2 were carried out in four set-ups. During the tests, 15 accelerometers were used. Four of them were used as reference sensors, always in the same points, two for vertical acceleration and one for transverse and longitudinal acceleration each. In total, the accelerations were measured in 17 sections, 2 points for each one. The localization of the points is illustrated in Figure 8.

A sampling rate of 200 Hz was used for data acquisition. The records at each set-up had about 132 000 lines corresponding to a time length of about 11 minutes.

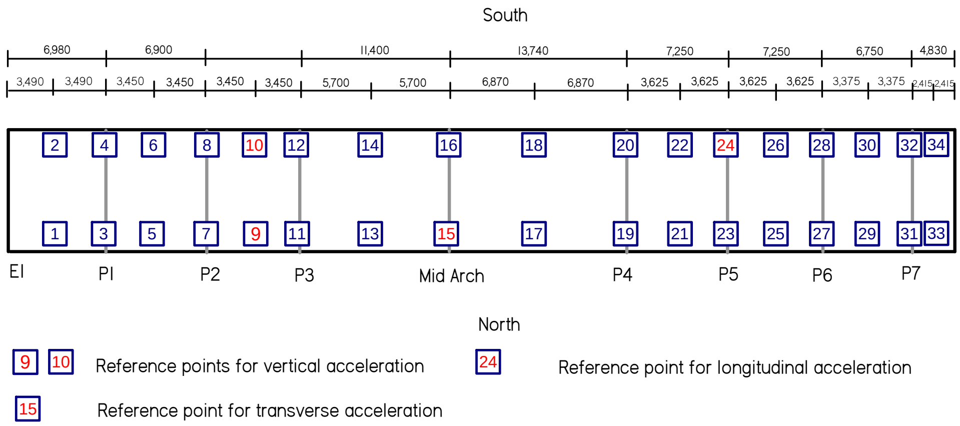

Figure 8 : Instrumented points in the dynamic tests

5.2 Modal identification

The software ARTeMIS – Output-only modal identification (SVS 2002) was employed for the modal identification of the bridge. This program allows to accurately estimate natural frequencies of vibration and the associated mode shapes and modal damping of a structure, from measured response only.

Before processing the signal for modal identification, the test signals were pre-processed with the following operations (Rodrigues 2004): trend removal; low-pass filtering at 20 Hz with a 4 poles Butterworth filter; and decimation of the signals from 200 Hz to 50 Hz. The advantage of decimating the signals was to reduce the size of the records, speeding up all the following computing processes without loosing information in the frequency range of interest.

In figures 9 to 11 the pre-processed records of the accelerations obtained at the reference points during 25 seconds are presented.

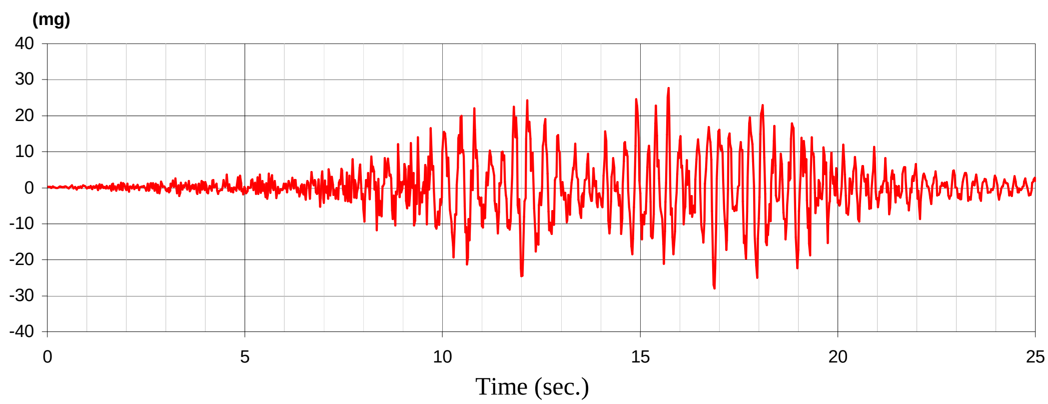

Figure 9 : Vertical acceleration in the reference point 9

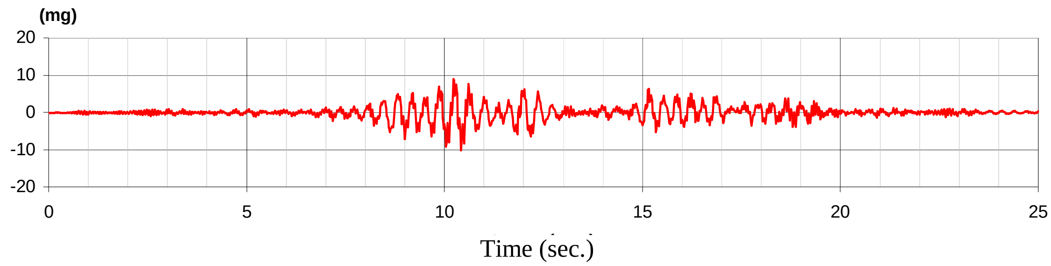

Figure 10 : Longitudinal acceleration in the reference point 24

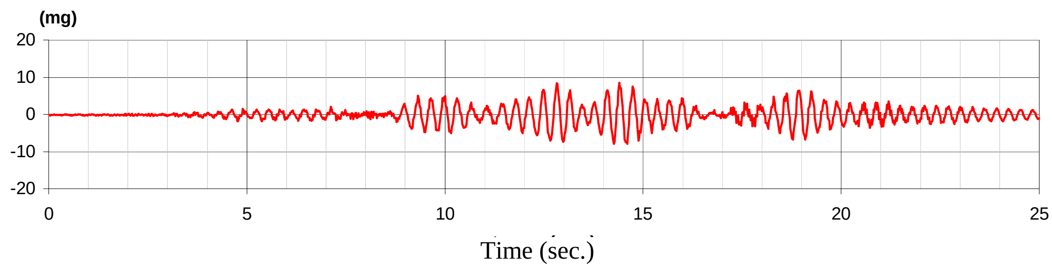

Figure 11 : Transverse acceleration in the reference point 15

Based on the test data, the spectral densities and correlation functions were estimated. The power spectral density (PSD) matrix was computed from independent samples with 2048 data points each one, with 66.67% overlap. For the sampling frequency of 50 Hz, the frequency resolution of the spectra is therefore 0.024 Hz.

The technique of Frequency Domain Decomposition (FDD) implemented in ARTeMIS was applied to estimate natural frequencies and mode shapes. In this technique the power spectral density (PSD) matrix is decomposed at each frequency line via singular value decomposition (SVD). The singular values (SV) plots, as functions of frequency, estimated from SVD can be used to determine modal frequencies and mode shapes. The peaks of singular values plots indicate the existence of structural modes. The singular vector corresponding to the local maximum singular value is the respective unscalled mode shape.

Figure 12 shows the spectra of the first 4 singular values of the PSD matrix. In this figure the natural frequencies identified by FDD are also presented.

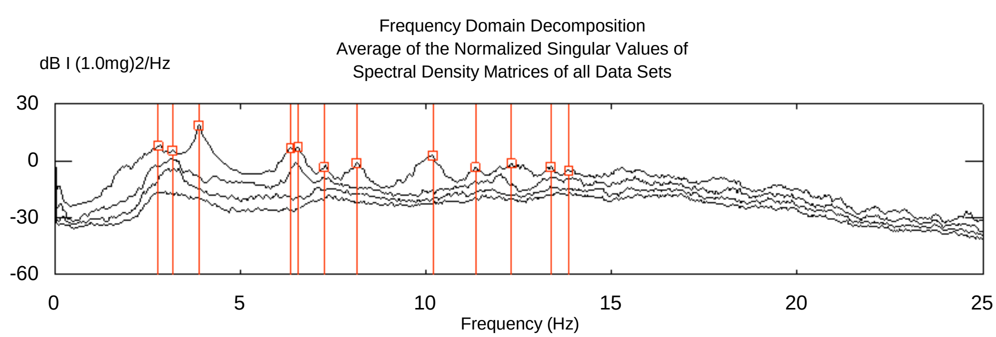

Figure 12 : Spectral of singular values of the PSD matrix and identified natural frequencies

A total of 12 vibration modes of PS2 were identified from the analysis of the dynamic tests data, using the FDD technique. Some of the peaks aren't very clear, however, analysing the coherence function and the mode shapes and comparing them with the modes computed by FE model, it was possible to identify the corresponding modes. The first 7 mode shapes are illustrated in Figure 13.

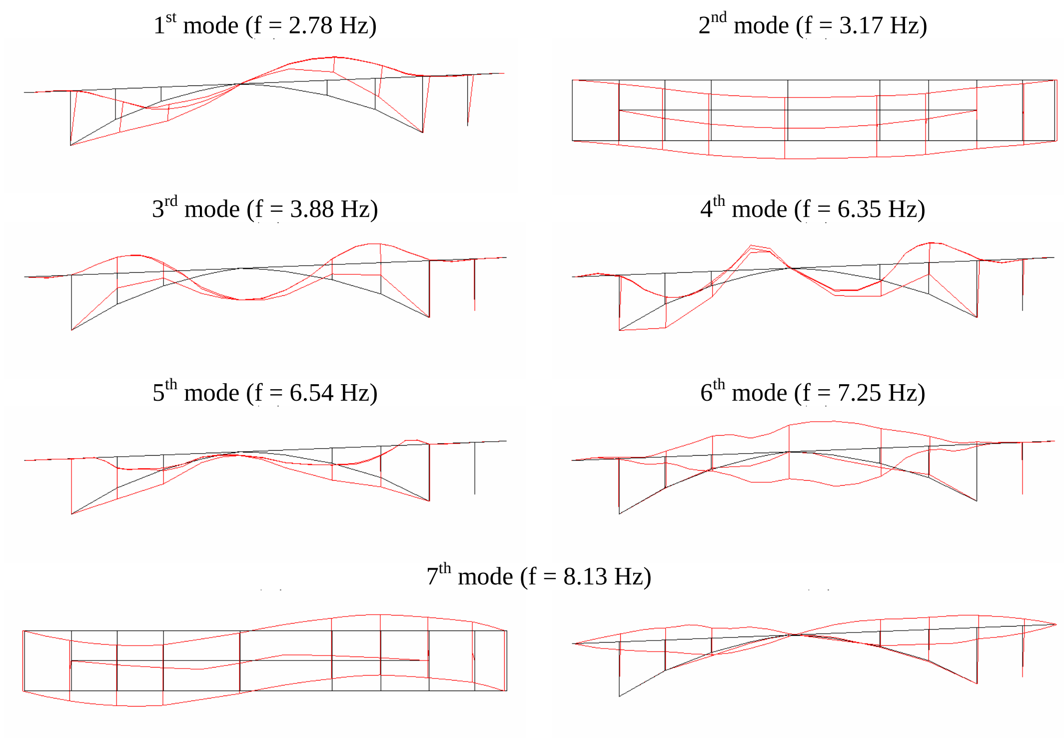

Figure 13 : Identified mode shapes

5.3 Analysis with the finite element model

The FE model calibrated by the static load tests results was also used to interpret the experimental results of the dynamic tests.

The FE model was more finely tuned according to the modal identification from the dynamic tests. The modulus of elasticity of the structural concrete was kept with the value previously referred, but the stiffness of the link elements, for modelling the supports at the abutments, was adjusted to fit the computed modal characteristics to the ones identified from the tests.

The natural frequencies computed by the updated FE model were compared to the frequencies identified from the tests, being these results presented in Table 2.

Table 2– Test identified and computed frequencies

Nº	Frequency (Hz)		Type of Mode
	Experimental	Computed	
1	2.78	2.83	Vertical
2	3.17	3.20	Transverse
3	3.88	3.58	Vertical
4	6.35	6.13	Vertical
5	6.54	6.75	Vertical
6	7.25	7.59	Torsional
7	8.13	8.11	Coupled (Transverse / torsional)
8	10.18	9.69	Vertical
9	11.33	11.70	Torsional
10	12.30	12.26	Vertical
11	13.35	14.32	Torsional
12	13.84	15.07	Torsional

6 CONCLUSIONS

The experimental results obtained in the static and dynamic tests of the arch overpass bridge have a good correlation with the numerical values computed by FE model.

Having a properly calibrated structural analysis model, is a major advantage to characterize the actual condition of the bridge at the beginning of its lifetime, and also allows to define a reference state to make later studies in order to detect a possible degradation of the structure.

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