Load testing of a large viaduct

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Summary

This paper presents the static and dynamic testing of the Loureiro Viaduct, located at the A10 highway, near Lisbon. Some innovative procedures were used during these tests, like an upgraded hydrostatic levelling system to measure vertical displacements or accelerometers to measure rotations. The dynamic tests allowed the identification of 25 modes of the natural vibration of the structure, using the technique of output-only modal identification. The experimental results are compared with the analytical values computed by the FE model developed.

Keywords: load testing, hydrostatic levelling system, monitoring, dynamic tests, modal identification, prestressed concrete bridge.

1. Introduction

The Loureiro Viaduct, located at the A10 highway, near Lisbon, was subjected to static and dynamic tests in July 2003, in order to perform an evaluation of the static behaviour of the bridge and to identify its dynamic characteristics (as vibration frequencies, mode shapes and damping ratios).

Loureiro Viaduct is a prestressed concrete structure, 1050 m long, with five major spans of 100 m, besides other 11 spans. The viaduct is curved in plan and the maximum height of the columns is 95 m [1]. The deck is a box-girder with 8.00 m width and a maximum height of 5.55 m. The piers of the major spans are rectangular with 8.00 × 6.00 m, from the foundations up to 30 m below the deck, but, from this height up, the piers are made by two concrete plates with 8.00 × 0.80 m, monolithic with the deck. Fig. 1 shows the elevation and plan views of the viaduct. General views are presented in Fig. 2.

This paper presents the finite element model used and the experimental procedures adopted. Both static and dynamic experimental results are compared with the analytical values computed by the finite element model.

2. Analytical model

A three dimensional, linear, elastic numerical model of the viaduct was developed in SAP2000 [2] to evaluate its response to static tests and its dynamic characteristics.

Shell elements were used for modelling the deck and the piers. Bearings at piers P8 to P15 and abutments were modelled by link elements.

Before the load tests the preliminary FE model was used to estimate the deformation of the structure on static loads and the 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.

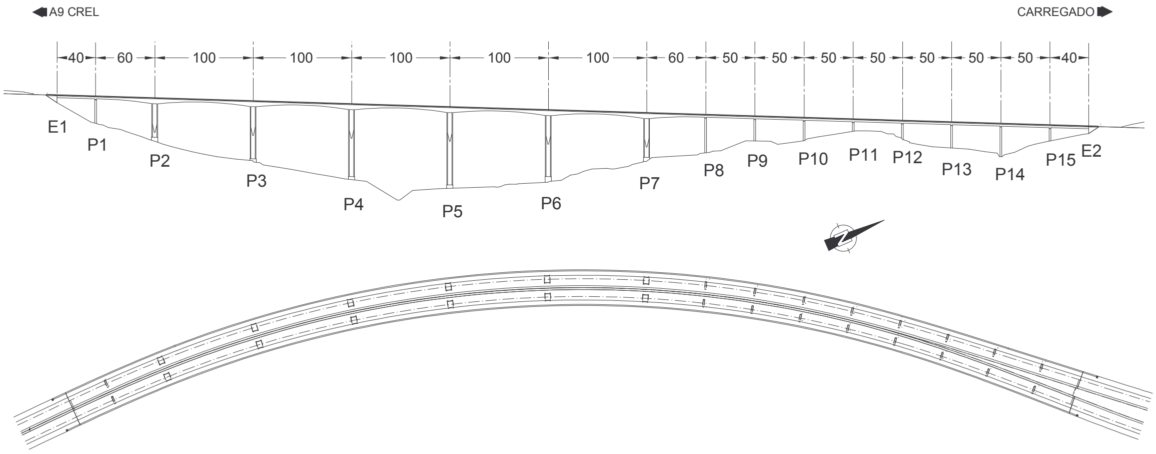


Fig. 1 Elevation and plan view of Loureiro Viaduct

Fig. 2 General views of Loureiro Viaduct

3. Static test

3.1 Testing procedure

The static test was performed with twelve loaded lorries with a total weight of 3527 kN (Fig. 3). These loads were placed in 27 positions, in accordance to the load plan that maximizes the most important effects in the structure, however without inducing unwanted situations of early cracking in the structure.

Fig. 3 Loaded lorries in use as a load test

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

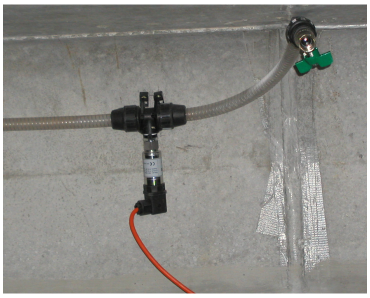


Fig. 4 Pressure cell used in hydrostatic levelling system

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 apparatus as deflectographs, which were also used at mid span and at the supports of the other spans.

Transversal and longitudinal rotations were measured by electric clinometers located at the top of piers P2, P4 and P6. Quite interesting was the use of force balance accelerometers during static test to measure rotations. As a matter of fact, during a static test, a uniaxial accelerometer measuring horizontal acceleration, measures that direction component of the gravity, which changes when that point rotates. These accelerometers were used at the top of piers P4 and P5 and at several sections of the deck, as presented in Fig. 5. To increase the redundancy of measured data, rotations at the top of pier P2 were also measured by mechanical air-bubble clinometers, in both longitudinal and transversal directions.

Strains were measured by inductance strain meters at the mid span P4-P5.

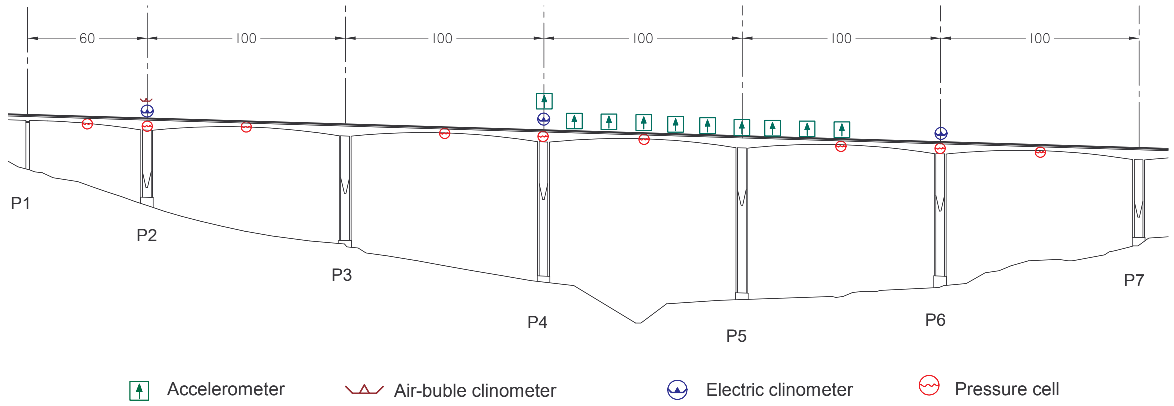


Fig. 5 Equipment used at major spans

Fig. 6 Logger

Three automated data-acquisition systems *DataTaker DT515* were used to read data from hydrostatic levelling systems and from electric clinometers. The reading of accelerometers and inductance strain meters was done by the acquisition system usually used in the dynamic tests. Both systems allowed an effective control of experimental data in real time.

3.2 Main results

Extensive experimental data was obtained during the static test. From all these data, some illustrative results are presented in Fig. 7. These charts show a good agreement between experimental values and computed structural deformations. It is also relevant the agreement between values measured by the hydraulic levelling system and by deflectographs.

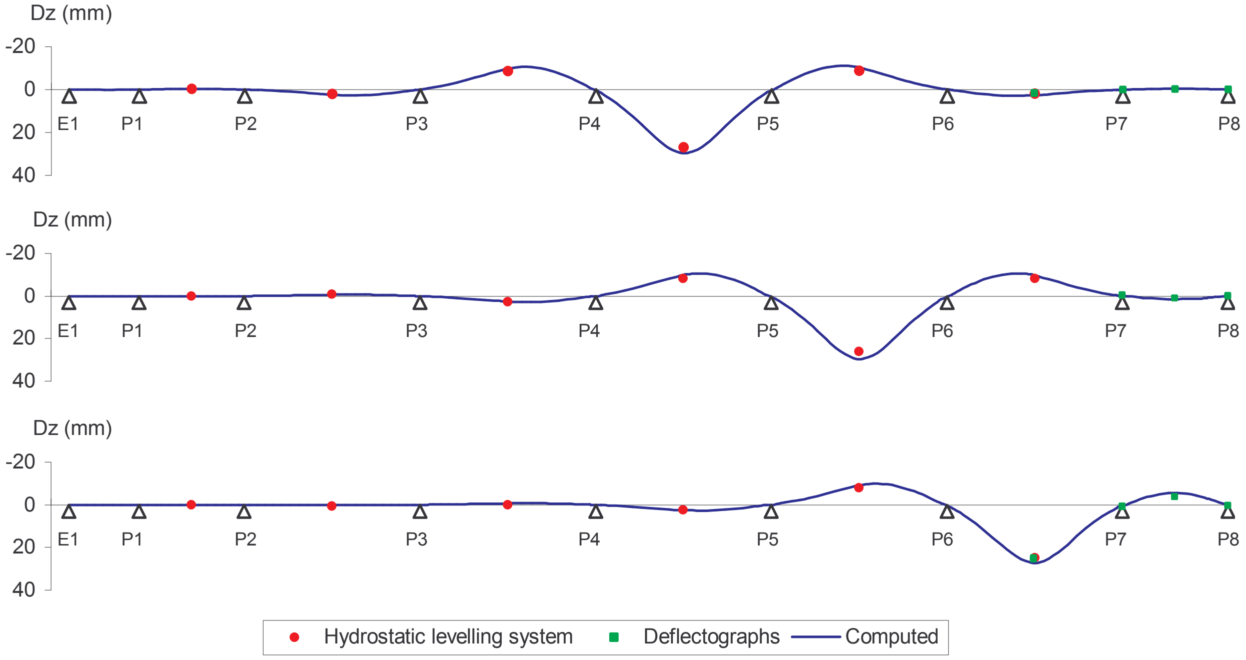


Fig. 7 Vertical displacements measured and computed

A good correlation was also achieved between rotations measured by electric clinometers, mechanical air-bubble clinometers, accelerometers and the values computed with numerical model.

4. Dynamic test

4.1 Testing procedure

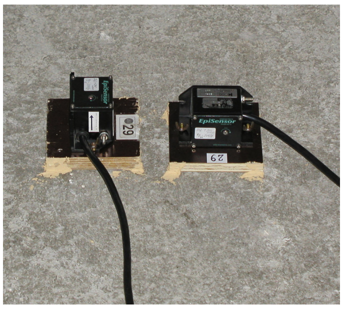


Fig. 8 Accelerometers

The dynamic test was performed to obtain experimentally the dynamic characteristics of the structure (vibration frequencies, mode shapes and damping ratios). During the test, accelerations induced by ambient excitations (mostly wind) were measured using 14 *Kinemetrics Uniaxial Episensor* (ES-U) accelerometers (Fig. 8), signal conditioning equipment developed at the Scientific Instrumentation Centre of LNEC and data acquisition equipment from National Instruments (DAQ board AI-16XE-50 and a SCXI-1000DC chassis with SCXI-1140 sampling and hold boards).

The ambient vibration test was carried out in nine set-ups. During these set-ups, vertical and transversal accelerations were measured at 29 sections of the viaduct, with 5 transducers fixed in 2 of the sections while the others were being moved from set-up to set-up. Several modes of the natural vibration of the structure were identified, using an output-only modal identification method to estimate the characteristics of each mode. The localization of the accelerometers is illustrated in Fig. 9. The fixed equipment is located in points 33, 34, 43 and 44, as indicated in Fig. 9.

In each set-up of the dynamic test, the ambient vibration data was acquired during a time length of about 30 minutes using a sampling rate of 1000 Hz. The records obtained in this way were latter pre-processed with low-pass filtering at 6.25 Hz using a 8 poles Butterworth filter and decimation to a sampling frequency of 15.625 Hz.

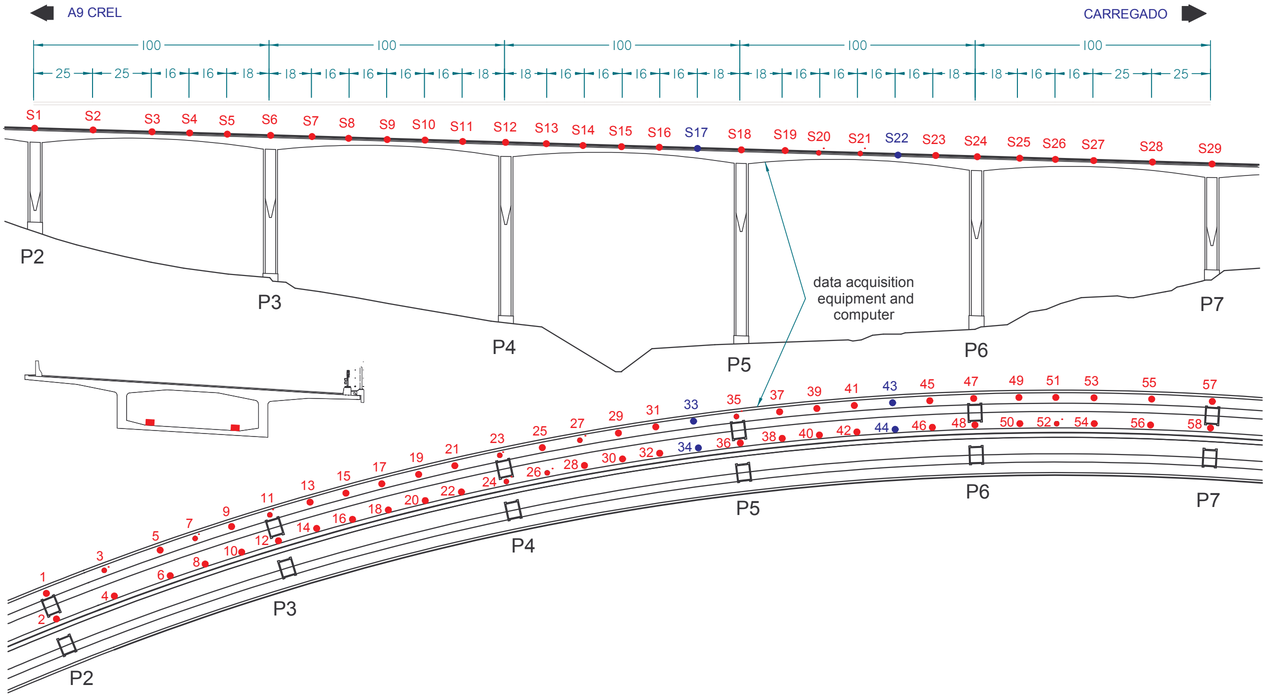


Fig. 9 Localization of accelerometers during dynamic test

Apart from the ambient vibration tests, dynamic tests with trucks crossing the viaduct at controlled speeds were also performed in order to evaluate the dynamic effects of that action.

4.2 Modal identification

The software ARTeMIS for output-only modal identification was employed for the modal identification of the viaduct [3]. This program allows to estimate the natural frequencies of vibration and associated mode shapes and modal damping ratios of a structure from the measured response only. It is fast and simple to use.

Based on the test data, the spectral densities and correlation functions were estimated. The power spectral density (PSD) matrix was computed from samples with 1024 data points each one, with 66.67% overlap. For the sampling frequency of 15.625 Hz, the frequency resolution of the spectra is therefore 0.015 Hz.

The technique of Frequency Domain Decomposition (FDD) implemented in ARTeMIS was applied to identify the natural frequencies and mode shapes of the structure. 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 the modal frequencies. 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. Fig. 10 shows the spectra of the first 9 singular values of the PSD matrix of the vertical accelerations. In this figure the natural frequencies identified by FDD are also indicated.

Using the FDD technique a total of 12 vertical vibration modes, 1 torsion mode and 12 transversal modes were identified from the analysis of the dynamic tests data,. The first 3 transversal and vertical mode shapes are presented in Fig. 11 and Fig. 12.

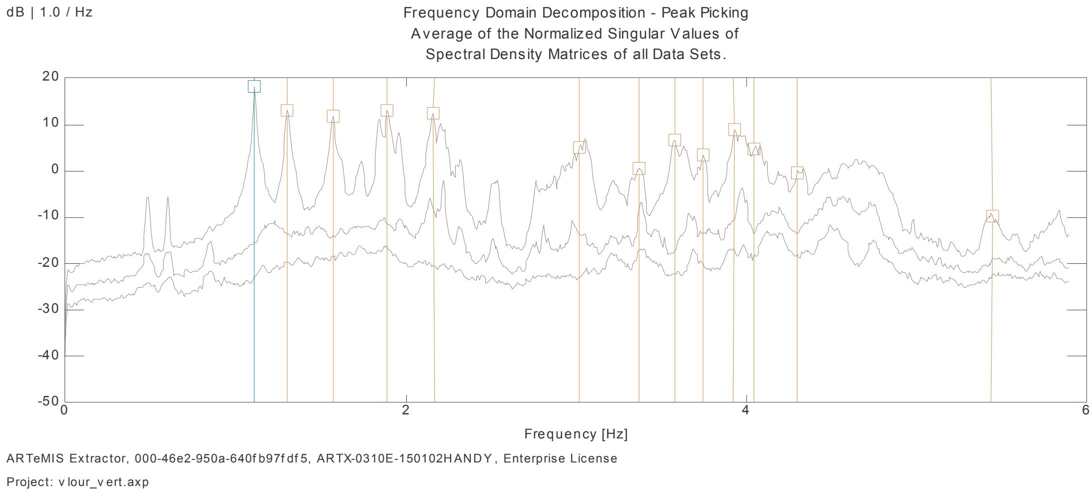
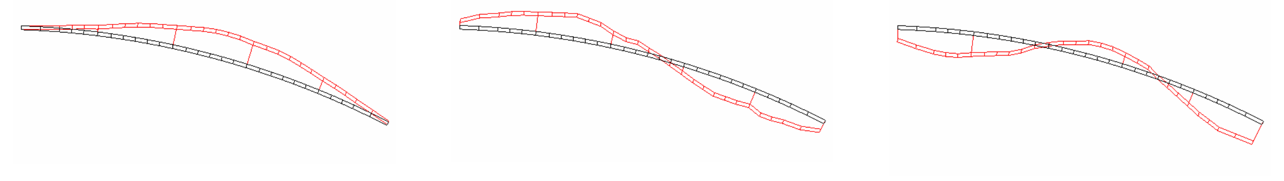
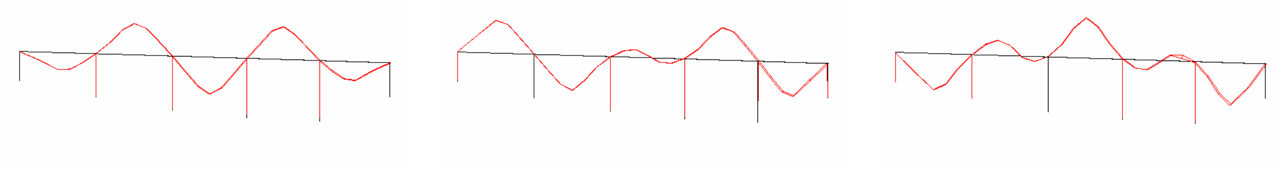


Fig. 10 FDD: Spectral of singular values of the PSD matrix and identified natural frequencies



f = 0.481 Hz f = 0.603 Hz f = 0.847 Hz

Fig. 11 Identified transversal mode shapes



f = 1.114 Hz f = 1.305 Hz f = 1.572 Hz

Fig. 12 Identified vertical mode shapes

4.3 Comparison with the finite element model

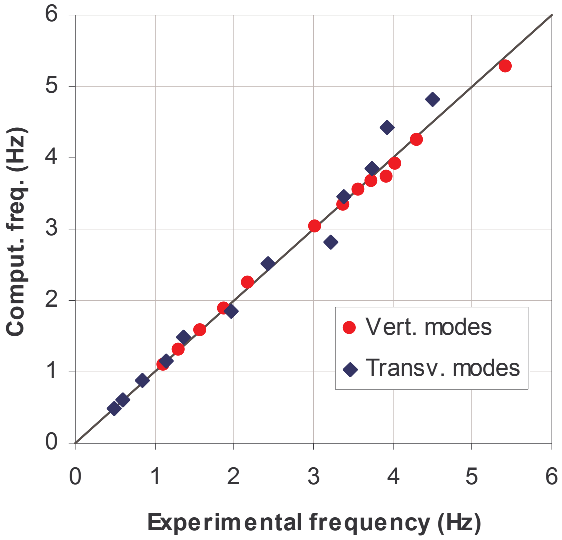


Fig. 13 FE model vs. experimental frequencies

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

The FE model was tuned according to the modal identification from the dynamic tests. 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 as presented in Fig. 13. A good agreement of the natural frequencies and mode shapes was achieved.

5. Conclusions

The experimental results obtained in the static and dynamic tests have a good correlation with the analytical 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 use of accelerometers to measure rotations during static tests was successfully achieved.

The experimentally data obtained about the structural behaviour of this viaduct is an important contribution to the characterization of its actual condition at the end of the construction and before its opening to the traffic. It is important to note that dynamic tests, similar to the ones that were presented here, can be performed during the lifetime of the structure, without the need to impose traffic restrictions.

Acknowledgements

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