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MODAL CHARACTERIZATION OF THE ODEMIRA BRIDGE

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Abstract. *This article presents the results of experimental measurements carried on Odemira bridge. These tests were conducted to determine the natural frequencies, the vibration modes and the modal damping of the bridge. Measurements were performed taken in to account ambient and forced vibrations. Vertical and horizontal accelerations were acquired, in the transverse and longitudinal direction of the bridge, in the first three spans of the Odemira bridge. In this article is also made the comparison of the experimental results with the results obtained from a finite element model.*

From the dynamic measurements it was possible to conclude that: The natural frequencies of the bridge are between 4.4 and 17.31 Hz; The three spans have identical behaviour, it could be identified for the first natural bending frequency around the value of 4.5 Hz and for the torsional mode the value around 7.2 Hz; The damping identified in the measurements for the first two spans was 2.8% and for the third span 1.8%; For the horizontal direction, was identified a frequency of 2.89 Hz; The finite element model of this bridge confirmed the first bending frequencies of the different spans.

Modal identification is often used for diagnostic and inspection the structural behaviour, including for example, the potential anomalies and the boundary conditions of the structure. It can be done at different stages of life cycle of the structures, namely in construction and rehabilitation.

1 INTRODUCTION

This paper presents the dynamic characteristics of the Odemira bridge based on identification of modal parameters made from the responses of the structure obtained in the experimental measurements of ambient and forced vibrations. These measurements were performed in order to determine the natural frequencies, the vibration modes, namely the bending and torsions, and the modal damping. Were acquired horizontal and vertical accelerations, according to the transverse and longitudinal direction, in the first three spans of the Odemira bridge adjacent to the left side of the Mira river.

The vibration modes of the finite elements model developed to analyse the behavior of the bridge are also presented here. The modal identification is often used for verifying the vibration serviceability limit state of the structures, for investigating the potential anomalies and the boundary conditions of the structure [1]. These tests can occur at different stages of the life cycle of the structure, construction and rehabilitation.

2 THE CASE STUDY: ODEMIRA BRIDGE

Odemira bridge is made of steel, built in 1941 over the Mira river. This bridge consists of four spans simply supported, defined by horizontal and vertical trusses supported by masonry and concrete columns. The first three spans of the Odemira bridge, adjacent to the left side of the Mira river, are equal and have a span of 30 m. The fourth span is longer, 42.15 m, Figure 1. The Figure 2 give up the plan and elevation of the Span 1. Is not represented the Span 4 because it was not possible acquire any information on this part of the bridge.

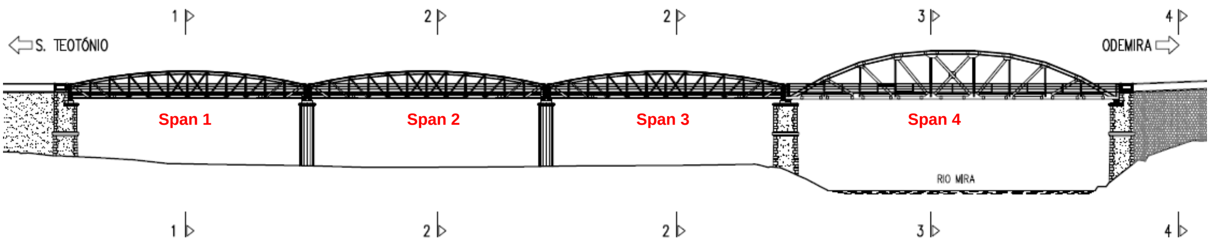
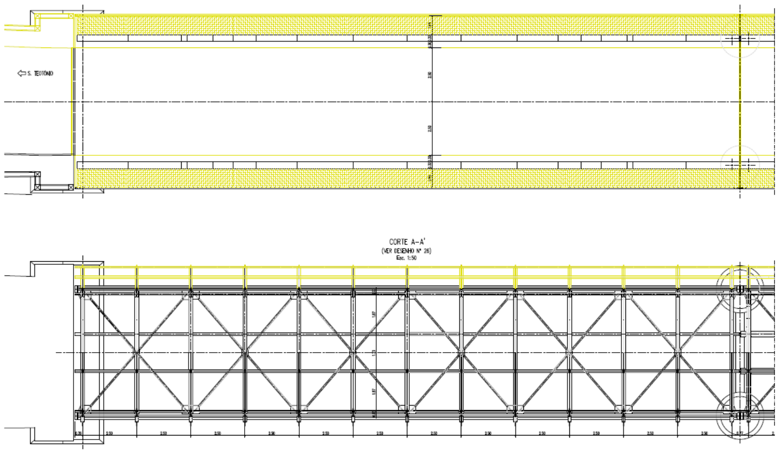


Figure 1: Representation of the Odemira bridge.



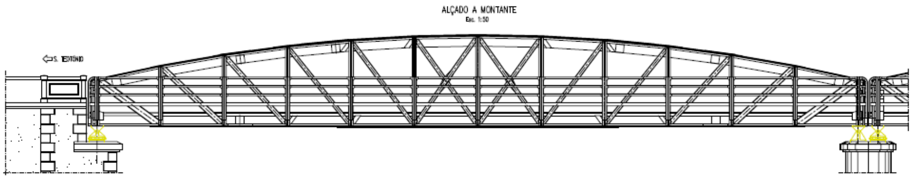


Figure 2: Plant and elevation of the span 1 of the Odemira Bridge.

3 FINITE ELEMENT MODEL

For the analysis of bridge behavior, a finite element model on ANSYS software was developed, with beam and shell elements. All steel structures - the vertical trusses and as well the horizontal bracing system of which span - were modelled with beams elements, while the concrete slabs, of the deck, were modelled with shell elements, see Figure 3. The steel adopted to this numerical simulation was S235, to agree with the values obtained from experimental tests done on this material. Additionally, the sections used in the numerical model correspond to the final configuration of the elements which, in some cases, have been reinforced or replaced in the rehabilitation works done in the bridge.

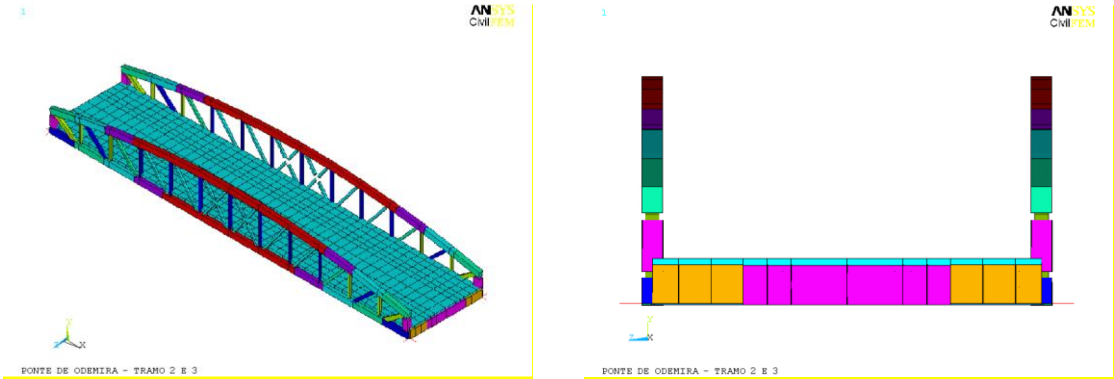
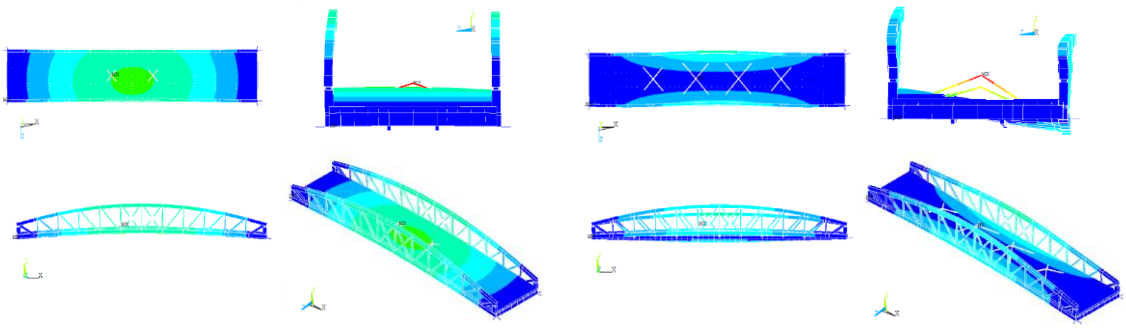


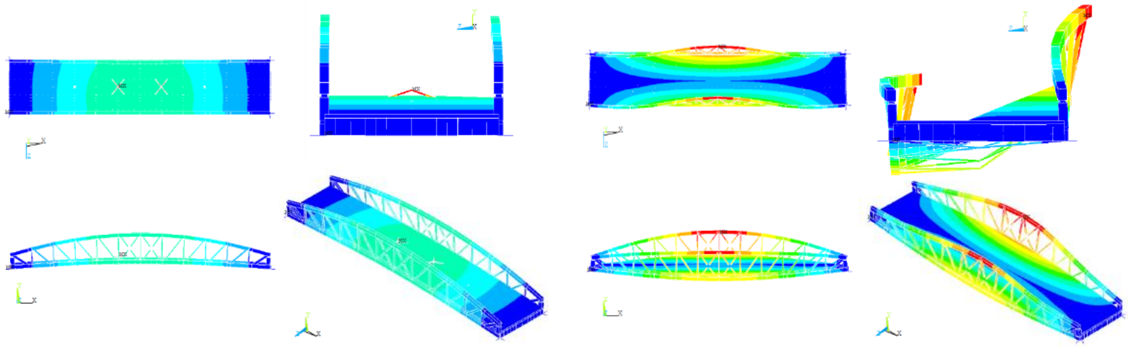
Figure 3: Numerical model developed to analysis which span of the bridge.

The next figures represent the configurations of the vibrations modes for the span 1 to 3, the first vertical bending mode and the first torsional mode. As mentioned above, as it was not possible to acquire signal in the span 4, due to rehabilitations works, in this paper is not presented any analysis to this part of the bridge.



1st of bending: 4.67 Hz   1st of torsion: 6.30 Hz

Figure 4: Numerical model – configuration of the vibrations modes of the span 1.



1st of bending: 4.53 Hz 1st of torsion: 6.52 Hz

Figure 5: Numerical model – configuration of the vibrations modes of the spans 2 and 3.

4 EXPERIMENTAL MEASUREMENTS

In each of the spans 1, 2 and 3, measurements were made, namely measurements of forced vibration due to a heavy vehicle braking and of ambient vibration. Seventy five tests points were used, in five setups, on each span of the bridge. The ambient vibration was the principal technique adopted. The induced vibration completed the modal survey of the structure enabling the determination of the modal properties of the structures in the longitudinal horizontal direction.

4.1 Measurement equipment

The data was acquired using the Pulse system – Type 3560/D with ten channels from the BRÜEL & KJAER®. This acquisition system consist for a computer with an interface LAN, software Pulse of eight channels and a signal conditioning system, for the amplification, digitalize and record the signal of channels. Were used, in these measurements, accelerometers type PCB 393B12 having a sensitivity of 10 V/g, and also accelerometers type B&K having a sensitivity of 0.32 V/g.

4.2 Methodologies adopted in the dynamic tests

4.2.1 Ambient vibration test

Ambient accelerations due to dynamic excitation by wind were measured on the deck, and on vertical trusses of each span. From these measurements it was possible to obtain natural frequencies, mode shapes and damping ratios for vertical, torsional and associated modes in each structure up to a maximum of 17 Hz. To achieve a good definition of the vibration modes, accelerations were acquired at six cross-sections of each span, and in each section four measuring points were used, see Figure 6 and 7. Two measuring points situated at the level of the deck permitted measure the acceleration in the vertical direction, and in one of them, the acceleration in the horizontal direction, perpendicular to the longitudinal axis of the bridge. The other two measurement points were located at the top of the arch of the trusses and in the same vertical lines of the previous ones, allowing measure accelerations in horizontal direction, transverse to the bridge. The methodology was repeated in each of the three spans and in each of the spans a section was always take as reference, Figure 7.

The Figure 6 represents the points and the direction of the measurements in each of the cross-sections used in the span 1, 2 and 3. The cross-sections instrumented are represented in the Figure 7.

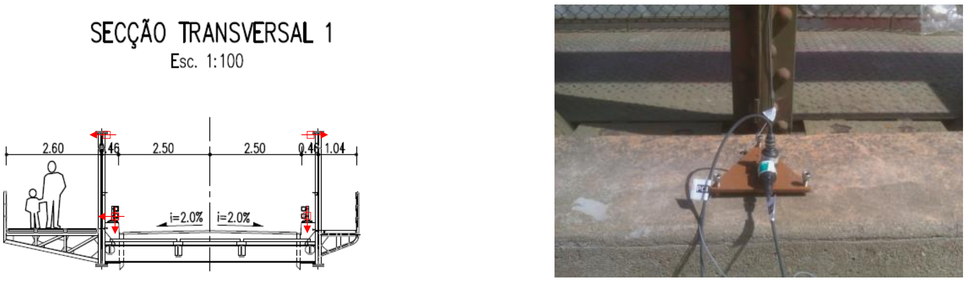


Figure 6: Schematic representation of the measurement points in the cross sections of spans 1, 2 and 3 and the position of the accelerometers in one of the instrumented point.

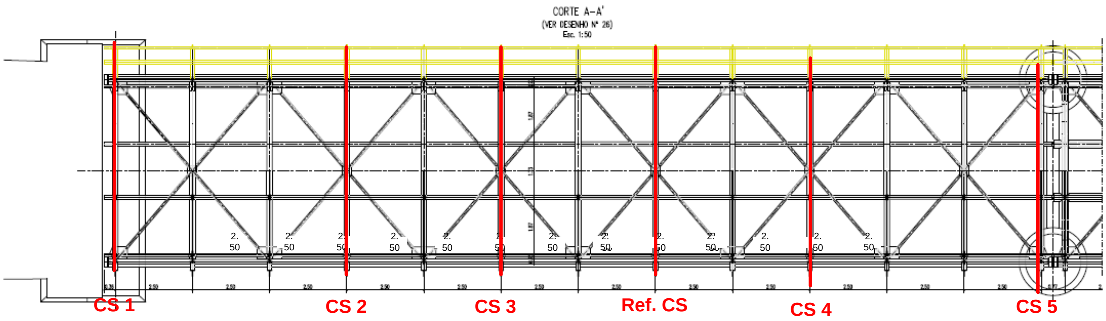
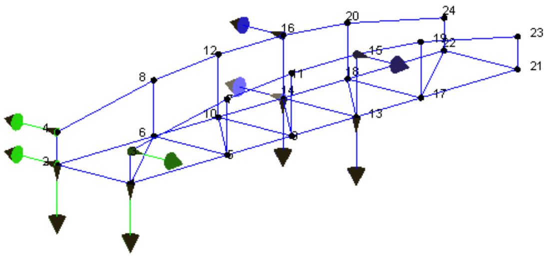
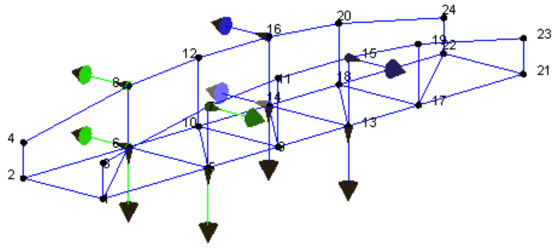


Figure 7: Schematic representation of the cross sections measured in spans 1, 2 and 3.

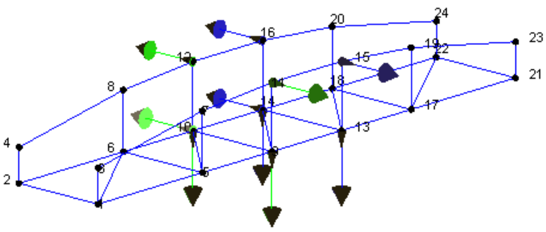
For each of the spans 1, 2 and 3 of the bridge, five setups of measurements were defined, the acquisition time in each of these setup was ten minutes. The Figure 8 shows the position and the direction measurements implemented in each of the setups 1, 2, 3, 4 and 5 in bridge Odemira.



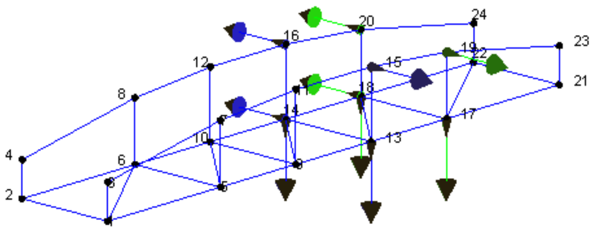
Setup 1



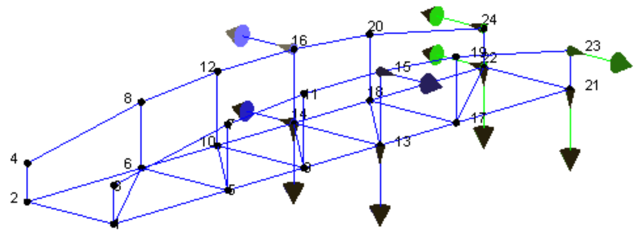
Setup 2



Setup 3



Setup 4



Setup 5

Figure 8: Schematic representation of the points and the direction of the measurements for each of the setups admitted for ambient vibrations.

4.2.2 Forced vibration test

The measurement of longitudinal acceleration, on each span, was obtained with the sudden braking of one truck. This operation was repeated four times in each of the spans 1, 2 and 3. Accelerations were acquired in two cross-sections of each span (span 1: section 3 and reference section; span 2 and 3: section 4 and reference section) at four measurement points of each section Figure 6 and 7. Two measuring points located at the level of the deck allow to measure acceleration in the vertical direction, and one of them, in the longitudinal horizontal direction of the bridge. The other two measurement points located at the top of the arch of the trusses and on the same vertical lines of the previous ones, allowed measured accelerations in the longitudinal direction of the bridge, Figure 9.

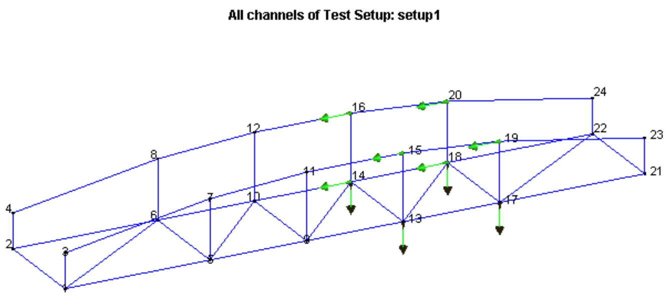


Figure 9: Schematic representation of the points and the direction of the measurements for the setup 1 admitted for forced vibrations.

4.3 Signal analysis

The program "ARTeMIS Extractor", version 3.2, was used to perform the modal identification of the structure [2]. The technique of the frequency domain decomposition (FDD) and the technique of stochastic subspace identification (SSI) were used in order to simulate the configuration modes, each of span of the structure were admit like a truss, [3].

5 RESULTS

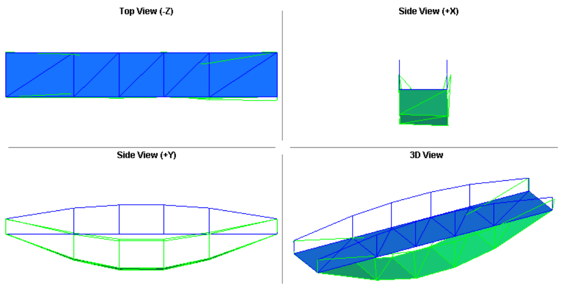
5.1 From the ambient vibrations

In the Tables 1 to 3 are presented the results of the measured signal in the span 1, 2 and 3. In the Figures 10 to 12 are represented the corresponding configurations of the vibrations modes.

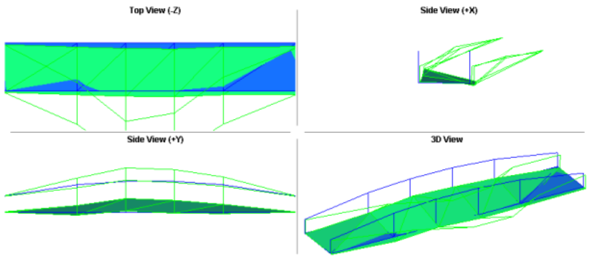
Span 1

Mode	Frequency [Hz]	Frequency - Standard Deviation [Hz]	Damping [%]	Damping - Standard Deviation [%]	Type of vibration
Mode 1	4.39	0.033	2.802	0.721	1st Bending
Mode 2	4.51	0.061	1.545	1.088	Bending + Torsional
Mode 3	4.94	0.104	3.219	1.427	Bending + Torsional
Mode 4	7.19	0.017	0.736	0.398	1st Torsional

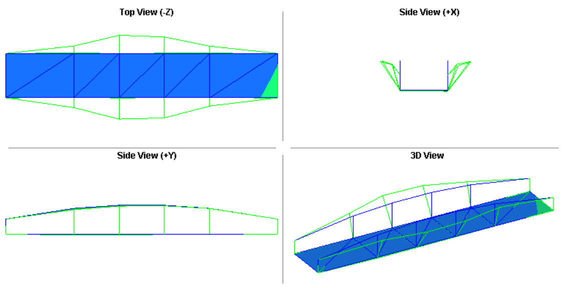
Table 1: Modes, natural frequencies and damping measured in the span 1.



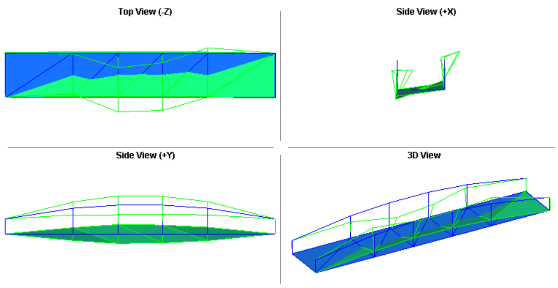
1st vibration mode: 4.39 Hz



2nd vibration mode: 4.51 Hz



3rd vibration mode: 4.94 Hz



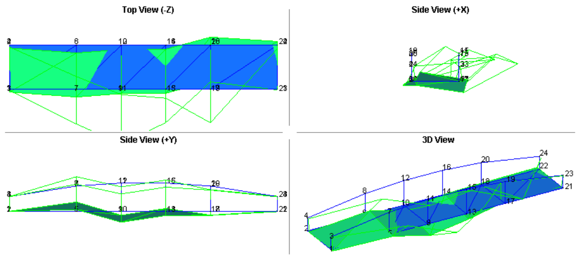
4th vibration mode: 7.19 Hz

Figure 10: Configurations of the vibrations modes on span 1.

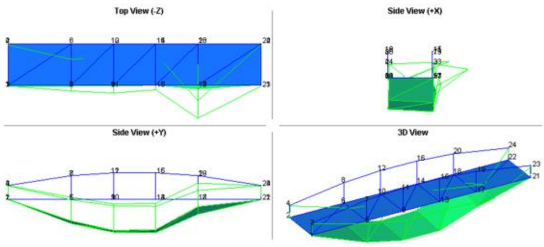
Span 2

Mode	Frequency [Hz]	Frequency - Standard Deviation [Hz]	Damping [%]	Damping - Standard Deviation [%]	Type of vibration
Mode 1	4.32	0.168	2.804	0.855	Bending + Torsional
Mode 2	4.47	0.011	0.619	0.202	1st Bending
Mode 3	4.58	0.079	1.515	1.114	Bending + Torsional
Mode 4	7.19	0.040	1.136	0.202	1st Torsional

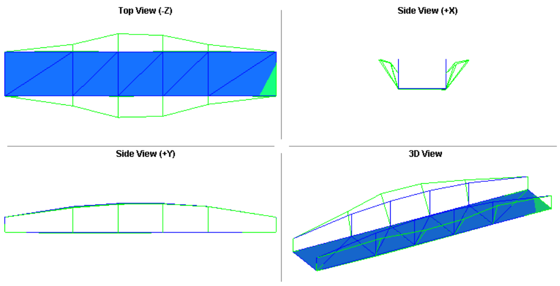
Table 2: Modes, natural frequencies and damping measured in the span 2.



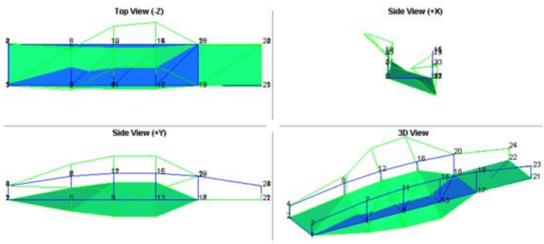
1st vibration mode: 4.32 Hz



2nd vibration mode: 4.47 Hz



3rd vibration mode: 4.58 Hz



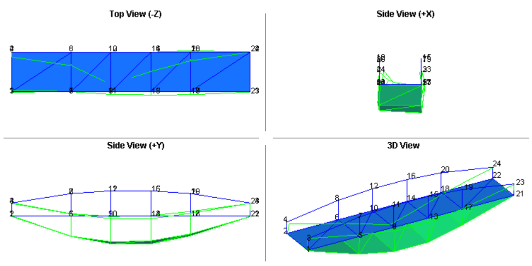
4th vibration mode: 7.19 Hz

Figure 11: Configurations of the vibrations modes on span 2.

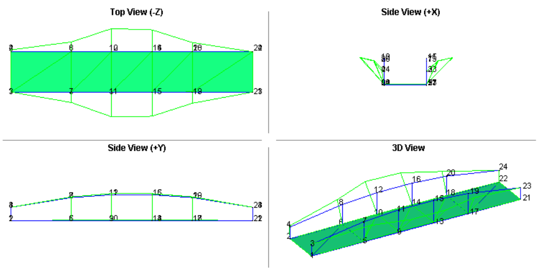
Span 3

Mode	Frequency [Hz]	Frequency - Standard Deviation [Hz]	Damping [%]	Damping - Standard Deviation [%]	Type of vibration
Mode 1	4.48	0.168	1.802	0.855	1st Bending
Mode 2	4.67	0.011	0.502	0.202	Bending + Torsional
Mode 3	7.32	0.079	0.752	1.114	1st Torsional
Mode 4	12.39	0.040	3.257	0.202	Bending + Torsional

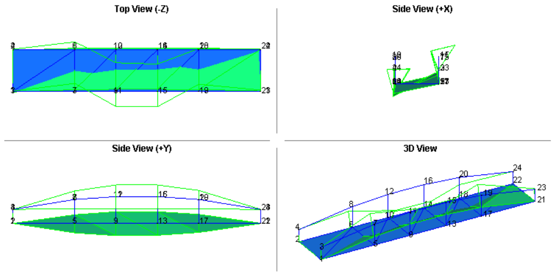
Table 3: Modes, natural frequencies and damping measured in the span 3.



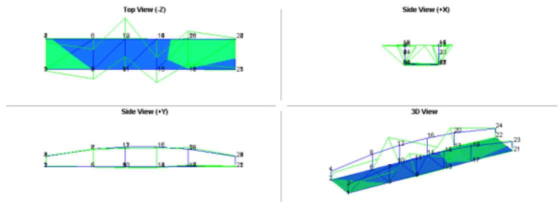
1st vibration mode: 4.48 Hz



2nd vibration mode: 4.67 Hz



3rd vibration mode: 7.32 Hz



4th vibration mode: 12.39 Hz

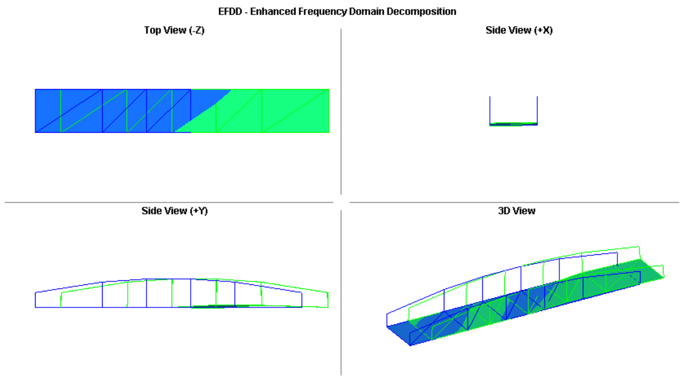
Figure 12: Configurations of the vibrations modes on span 3.

5.2 From the forced vibrations

In this section, is present the results obtained from the forced vibration in the longitudinal direction of the bridge. Signals were measured in all spans for the braking of a truck. In Table 4 are presented the modal results, only for the longitudinal translation vibration mode, the analysis of this vibration mode was made using the Enhanced Frequency Domain Decomposition method (EFDD) [3].

Mode	Frequency [Hz]	Frequency - Standard Deviation [Hz]	Damping [%]	Damping - Standard Deviation [%]	Type of vibration
Mode	2.89	0.15	2.56	2.2	Longitudinal

Table 4: Mode, natural frequency and damping measured in longitudinal direction.



Longitudinal translation vibration mode: 2.89 Hz

Figure 12: Configurations of the longitudinal translation vibration mode.

6 CONCLUSIONS

This paper presents the measurements of vibrations executed in three spans of the Odemira bridge, here defined as span 1, 2 and 3. These spans are adjacent to the left side of the River Mira. Ambient and forced vibrations allowed the extraction of the modal parameters of the monitored spans.

From these measurements it was possible to identified vibration modes of bending, torsional and associated modes. The natural frequencies identified are in the range of 4.4 to 17.31 Hz. The spans 1 to 3, have similar behaviours, having clearly identified a frequency corresponding to the first bending mode around 4.5 Hz and another corresponding the torsional mode about 7.2 Hz. Other frequencies were identified with bending and torsion associated. The damping associated to the first bending mode, for the span 1 and 2, is about 2.8%. For the third span a lower damping coefficient was measured, around 1.8%. The forced vibration permitted to determine the longitudinal translation vibration mode of the bridge, this value is about 2.89 Hz and the corresponding damping is around 1.8%.

The comparison of the results obtained in the dynamic tests with those obtained from the numerical model developed in ANSYS to analyze the behaviour of the bridge for the rehabilitation works, permit to say that there is a good correlation between the vibration modes measured and calculated, namely to the first bending mode and to the first torsional mode. The differences obtained with these two methodologies are small, approximately 6% for the first bending mode of the span 1, for spans 2 and 3 the values are identical. For the torsional mode the difference is about 12%. As the finite element model of the each span don't include all the infrastructure is not possible to compare the value obtained in the dynamic tests for the longitudinal translation mode.

REFERENCES

[1] Clough R. W., Penzien J., Dynamics of Structures, McGraw-Hill International Editions, 1993

[2] ARTeMIS2010 Extractor Pro, Structural Vibration Solutions, Software for Operational Modal Analysis.

[3] R. Brincker, P. Andersen, L. Zhang. (2000) Modal Identification from Ambient Responses using Frequency Domain Decomposition, Proceedings of the 18th International Modal Analysis Conference (IMAC), San Antonio, Texas, pp.625-630,2000.