Static and Dynamic Tests of "2 de Abril" Bridge

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Abstract

The "2 de Abril" bridge is located in the city of Celaya, Guanajuato Mexico. The bridge is very complex from the architectural and structural points of view. The bridge has a total length of 265 m. Static and dynamic tests were carried out in order to validate its behaviour under service loads at the end of the construction. Three different series of statics loads were carried out. Trucks were placed in different locations along the bridge and a series of topographical surveys were made: before, during and after each test. On the other hand, the bridge was instrumented with accelerometers, and the dynamic behaviour was measured under ambient noise and service loads. The results of the dynamic measurements were compared against the FEM calculations.

Keywords: Bridge, FEM, Dynamic tests, Static tests, Modal Analysis.

1. Introduction

This paper presents the works related to the static and dynamic tests of the *Boulevard Adolfo López Mateos* and avenue *2 de Abril* Vehicular Bridge in Celaya in the State of Guanajuato, Mexico.

The measurement of the behaviour of bridges through the development of static and dynamic load tests is an extremely useful tool to make a diagnosis about the state in which these structures are constructed. This is preponderant in the case of important bridges as is the case of continuous bridges or with a complex geometry. The first applications of these techniques were developed in the context of aeronautical engineering (particularly the dynamic tests). The use of these techniques in the case of bridges is relatively recent and has been possible thanks to the increase in computing power of computing equipment and the development of algorithms for identification of more sophisticated mechanical properties.

This paper is divided into six parts. In the first part the bridge is presented. In the second part the objectives of the proposed tests are described. The third part presents the statics load tests. The fourth part describes dynamic load tests. The fifth part concerns the mathematical modelling of the bridge. Finally, the last part shows the conclusions obtained from this study.

2. Bridge description

The bridge site is placed in an urban area and allows the railway crossing. The main bridge has a length of 265 meters, and a branch of 140 meters length. (See Figure No. 1). The deck is composite, formed 3 steel box girders, 80.0 cm height, and a reinforced concrete slab, 22.5 cm thick. The total width of the main bridge is 8.0 m. The deck branch is formed by 2 steel beam boxes. The reinforced concrete slab has a variable width from 5.5 to 6.0 m (See Figure No. 2). Under the main bridge crosses a tunnel that allows the circulation of vehicles in inverse direction than the bridge.

The substructure consists in box steel columns 5.0 cm thick, with different inclinations and lengths along the bridge (See Figure No. 3). The columns are anchored in their base to reinforced concrete footings that transmit the loads to concrete piles of 1.2 m diameter.

Figure 1: Plant and elevation of bridge

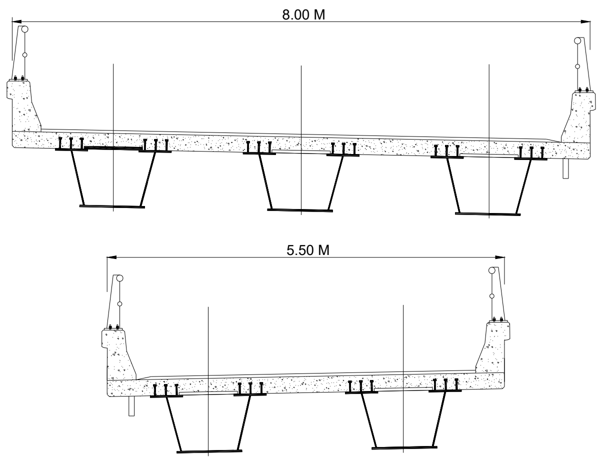


Figure 2: Cross Section for main bridge and secondary bridge.

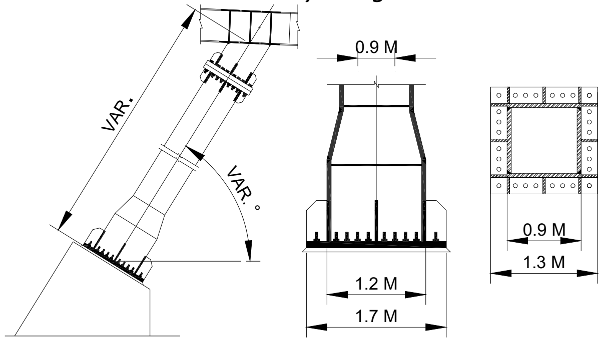


Figure 3: Cross Section box section steel of columns and typical column.

3. General purpose of the evaluation

Static and dynamic tests allow (previous instrumentation of the structure) to obtain important information about the "real" behaviour of the structure, in particular:

- Load-deformation relationships of different elements of the structure in the case of static tests.

- Vibratory properties of the structure (periods and modes of vibration) in the case of dynamic tests.

This information is relevant, since it allows a reduction in the uncertainties associated with the design, construction and real behaviour of the structure.

The proposed tests consider the measurement of static and dynamic response of the bridge under a known loads (trucks) on different points over the bridge.

4. Static tests

4.1 Description tests

To evaluate the response of the bridge under live loads, three different types of static loads were defined. For each load case the vertical deformations were measured in 38 different points along the bridge (Figure No 4, Images 1).

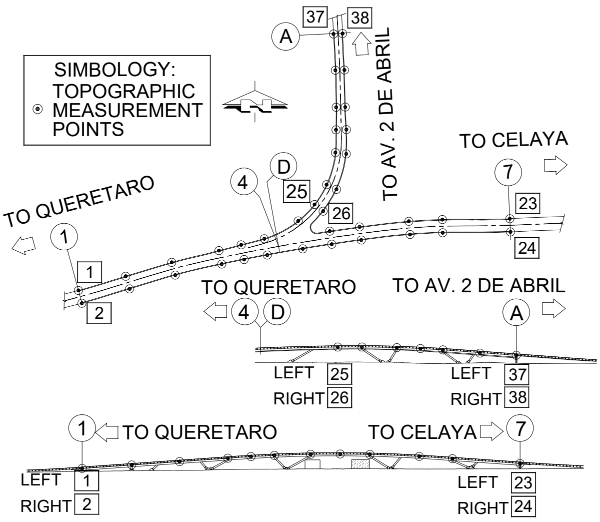


Figure 4: Location of deflection measurement points in plant and elevation

To avoid thermal effects, all the tests were performed during the night or very early in the morning.

(a)

(b)

Images 1: Measurement of control points for empty bridge and loaded bridge.

4.1.1 Static tests No 1

The purpose of the first test was to maximize the torsional effect on the left turn curve. It consisted on placing 2 loaded trucks (See Figure No. 5), on the central part of the curved branch of the bridge (left turn). Prior to the placement of the trucks, a topographical measurement of the "empty" bridge was made as a reference.

With the trucks positioned, it was measured its exact location and a new topographic survey of the bridge was made, the same was repeated for each load test. With the application of this load, the board of the left turn of the bridge had a maximum deformation of 1.0 cm. This deformation disappeared as soon as the load was removed.

4.1.2 Static tests No 2

The second load test was designed to maximize the deformations in the main span of the main bridge and the left turn of bridge. It consisted on placing five trucks in the array showed in the Figure No 6.

With the trucks positioned, their exact location was measured and a new topographic survey of the bridge was carried out. For this case, the maximum deformation of the bridge was 2.5 cm, in the central part of the span 4-5, which disappeared as soon as the load was removed.

4.1.3 Static tests No 3

The third load test was intended to maximize the displacements of the main bridge board. This test consisted in placing 5 trucks loaded on the central part of the span 4-5 of the main bridge (See Figure No. 7).

With the trucks positioned, it was measured its exact location and a new topographic survey of the bridge was carried out. As a result of the action of this load, the deck of the bridge had a maximum deformation of 3.1 cm at mid span. In the same way, as for the previous tests, the bridge returned to its initial position when the load was removed.

The trucks were presented in images 2a and 2b.

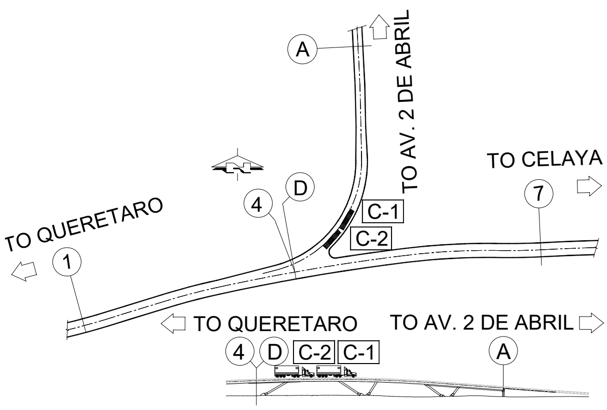


Figure 5: Location of Trucks C1 and C2 for static tests No. 1

Figure 6: Location of Trucks C1, C2, C3. C4 and C5 for static tests No. 2

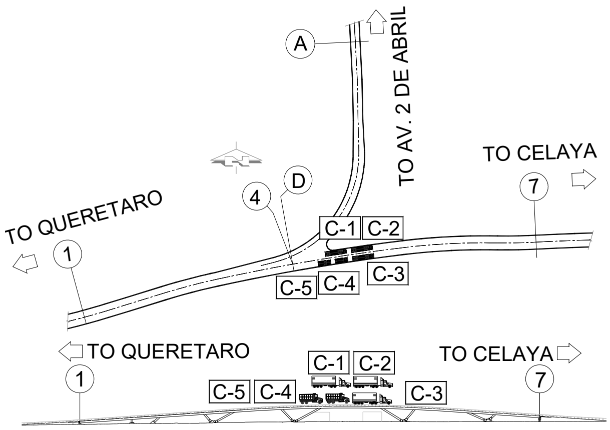


Figure 7: Locations of Trucks C1, C2, C3. C4 and C5 for static tests No. 3

4.2 Truck Weights

In order to know the loads applied in the various configurations for the various tests, the weighting of the trucks was performed immediately after the tests were carried out. See table No 1.

Table 1. Weight of truck used in tests

Truck [Number]	Identification [Hz]	Axis [Number]	Weight [Ton]
C1	NM-90-625	6	54.210
C2	393-EY-1	6	61.090
C3	SY-17-305	5	55.070
C4	KW-37-834	3	29.340
C5	HH-92-556	3	29.840

(a)

(b)

Images 2 Location of trucks in different tests

5. Dynamic tests

The bridge was submitted to a study of environmental vibration and vibration under live loads. The objective is to determine the natural frequencies of vibration through the analysis of the acceleration registers obtained on the structure. These dynamic properties will allow establishing the real conditions of the structure in comparison with the mathematical models (FEM) used for its design. It will also allow to observe the maximum acceleration levels recorded by the passage of heavy vehicles over the deck.

5.1 Methodology

Four different sensor arrangements were proposed along the structure. Each of these arrangements was made composed by 3 sensors (accelerometers). The purpose of each arrangement was to determine the main natural frequencies of the bridge and associated modes of vibration.

The arrangements included:

- Transverse direction measurement on supports
- Measurement in vertical direction on supports
- Transverse direction measurement at mid-span
- Measurement in vertical direction in extreme span.

Figures 8, 9, 10 and 11 show the accelerometer configuration for the 4 dynamic load tests. These four arrangements allowed us to identify the first 8 modes of vibration of the bridge.

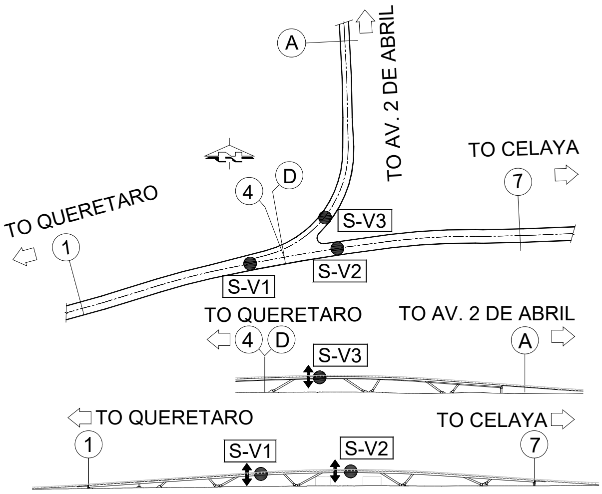


Figure 8: Location of accelerometers for dynamic test No 1 - Vertical sensors

Figure 9: Location of accelerometers for dynamic test No 2 - Transverse sensors

Figure 10: Location of accelerometers for dynamic test No 3 - Transverse sensors

Figure 11: Location of accelerometers for dynamic test No 4- Vertical sensors

5.2 Equipment used

A data acquisition system from Spectral Dynamics Company, model Siglab 20-42, was used. It has a capacity for 4 channels with 20 bits of analog-digital conversion. The accelerometers were connected by cable. See images 3 and 4.

Image 3: Installation of data acquisition system

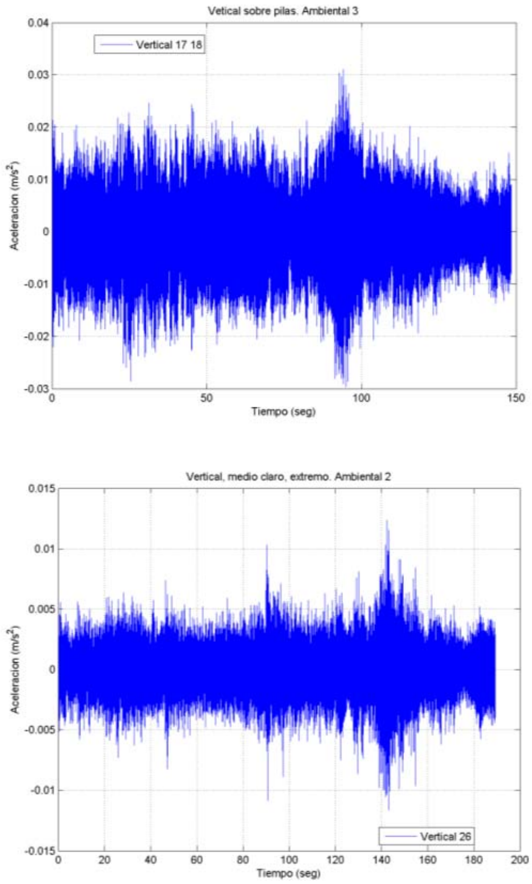
Image 4: Accelerometer installed on the deck.

5.3 Environmental vibration

Three series of 5-minute measurements were performed at each position of the sensors with a sampling rate of 512 Hz. The post-processing performed on each of the signals consisted of a filtering of the logs as well as a baseline correction. See Figure No 12.

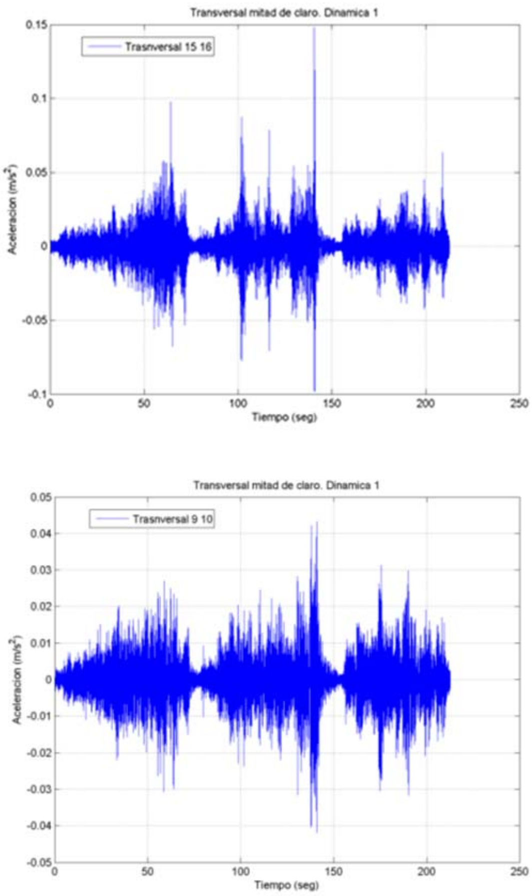
5.4 Dynamic Vibration

Four trucks were passed over the bridge at a controlled velocity of 25 to 30 km / hr. The weights ranged from 30 to 60 tons each (see Figure No. 13). The image No 5 shows the trucks on the bridge during the tests.

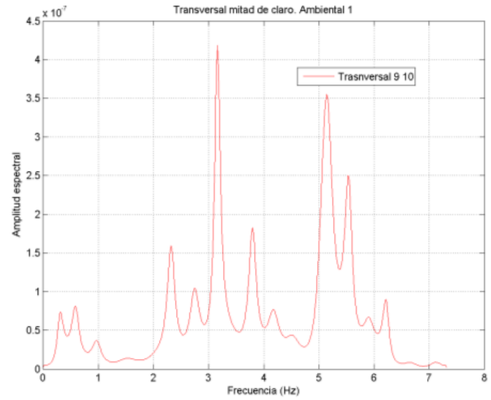


Figures 12: Vertical Acceleration Records for Environmental Vibration Test

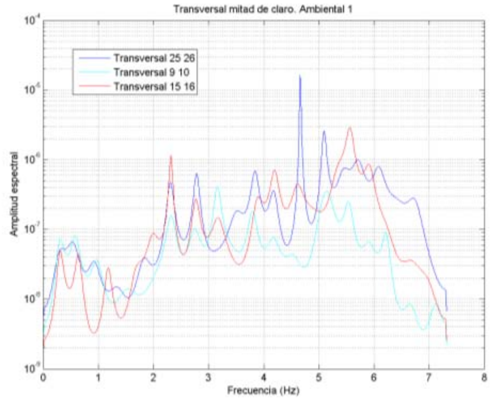
Images No.5: Vehicle circulating on the left branch during dynamic vibration test.



Figures 13: Horizontal acceleration records for the dynamic load test No.1



(a)



(b)

Figure 14: Power spectra for the records of the environmental vibration test 1

5.5 Natural Frequencies

To obtain the natural frequencies of the structure, the power spectra was calculated by means of the covariance method. The peaks of these spectra show the predominant frequencies of the bridge. Figures 14a and 14b.

The vibration frequencies identified from the power spectra of the acceleration registers for both "ambient vibration" and "dynamic vibration" tests were obtained. A very good correlation was observed in the results obtained by both types of tests.

It can be concluded that the frequencies identified in ambient and dynamic vibration are close to each other. However, in dynamic vibration it was not possible to determine the frequency number 6 (See Table No.2).

6. Numerical Modelling

6.1 Finite element method model

In order to validate the behavior of the bridge during dynamic load tests, a finite element model of the bridge was developed, considering bridge design hypotheses. With this model the fundamental frequencies and modes of vibration of the structure were calculated (Figure No. 15).

The detail of the results and the modal forms associated to each frequency of vibration allowed to identify some more modes are summarized on Table No.2.

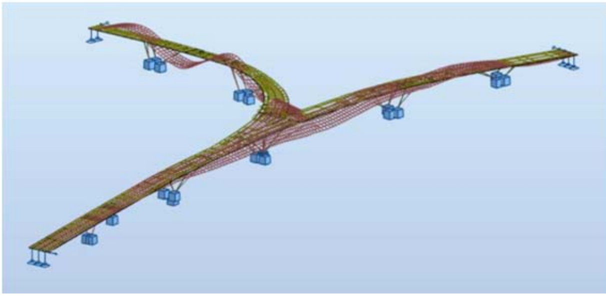


Figure No.15: Finite Element Analysis Model and First Vibration Mode of the Bridge

6.2 Comparison of results

Table 2 shows the comparison of the "real" vibration frequencies of the structure (estimated from the results of the load tests) with the "theoretical" ones, determined from a mathematical model of elaborated analysis with the design hypothesis of the structure. As can be seen, there is a very good correlation between "real" and "theoretical" values (less than 10% error).

Table 2. Comparison of natural frequencies (in Hertz), identified from the load tests

Frequency [Number]	Environmental Vibration [Hz]	Dynamic Values [Hz]	Values Analytical [Hz]
1	2.271	2.257	2.24
2	2.729	2.743	2.67
3	3.129	3.100	3.06
4	3.457	3.443	3.21
5	3.812	3.857	4.01
6	4.040	---	4.03
7	4.286	4.300	4.31
8	4.629	4.671	4.95

From the above it can be concluded that the "real" structure behaves according to the design hypotheses.

7. Conclusions

The results of the static and dynamic tests carried out, allow us to make the following conclusions concerning the bridge:

Static tests

- The loads used to carry out the tests correspond to the design trucks of the Mexican Department of Transports (SCT, T3-S2).
- The response of the structure to the different configurations of static loads was correct. The deformation values measured correspond theoretical ones.
- When releasing the structure of all loads it recovered its original configuration, so there were no parasitic deformations due to loading.

Dynamic tests

- A very good correlation between the “real” vibration frequencies and modal shapes (calculated from dynamic tests) and those evaluated by FEM calculations was found.
- The maximum accelerations recorded in ambient vibration are 0.051 m/s2, while in dynamic vibration they were 0.3 m/s2. This represents only 3% of the acceleration of gravity. These acceleration values are below the maximum acceptable values (limited to 2.54 m/s2 [1]).

The bridge was accepted and opened to traffic on November 2015.

8. References

[1] Walker, W. H., & Wright, R. N. (1972). “Vibration and Deflection of Steel Bridges”. AISC Engineering Journal, 20-31.