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STATIC AND DYNAMIC TESTS OF CUYUTLAN VIADUCT

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ABSTRACT

An extensive program of static and dynamic tests was performed on the new *Cuyutlan Railway Viaduct* before its opening to traffic. The viaduct is a prestressed concrete bridge of 8568 m length located on the Cuyutlan lagoon near of Manzanillo port on the Pacific coast of Mexico. The construction zone included some geotechnical challenges and is located in a high risk seismic zone. A series of tests were done to the bridge using of a fully loaded train of 5200 tons. The dynamic and static behaviour was measured in several points along the bridge considering service (normal circulation of full loaded trains) and accidental conditions (emergency braking of the train on the bridge). Measured accelerations and displacements in different directions were compared against those specified in design codes. The tests also included a detailed inspection of the full bridge *before* and *after* the test campaign in order to detect any damage over the structure originated by service loads. The bridge behaviour was satisfactory and it was open to traffic on 2011.

Keywords: Dynamic test, Railway bridge.

1 INTRODUCTION

The New Cuyutlan Viaduct is a structure of 8568 m long. The bridge is a part of the 12.1 Km railway contour of Cuyutlan lagoon, near the port of Manzanillo, on the Pacific Ocean coast in northern Mexico. The main user of the bridge is the railway company FERROMEX. The bridge site is very complex from a geotechnical point of view and is located in a high risk seismic zone. For that reason, FERROMEX decide to carry on an evaluation of the operational behaviour of the bridge before its opening to traffic. The evaluation included a fully inspection of the bridge before and after a pre-operation period (during this period several fully loaded trains passed over the bridge). A series of dynamic test were also performed during this period. Special a care was dedicated to the measurement of accelerations on the bridge deck in operation conditions. This paper presents the main results obtained from the evaluation period.

2 BRIDGE DESCRIPTION

The Cuyutlan viaduct is located near of the city of Manzanillo on the Pacific coast of Mexico. It contours the Cuyutlan lagoon to access the Manzanillo port (figure 1). The viaduct is part of the railway line which links the port of Manzanillo to central and northern Mexico. The trains running through this line transports merchandising only.

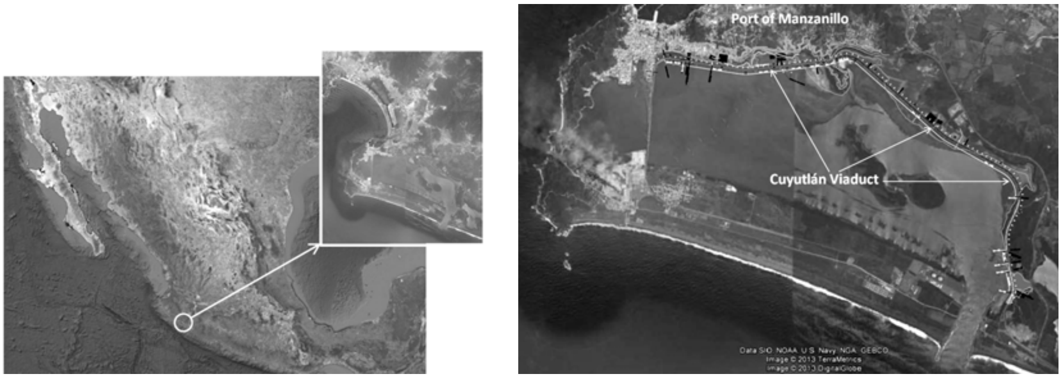

Figure 1 : Location of the bridge.

The Cuyutlan Viaduc is composed by 3 main bridges of 448.0, 252.0 and 7868.0 m length respectively. The deck has a "U" shape section formed by 2 main prestressed concrete beams of 2.7 m height and a concrete slab prestressed transversally (figure 2).

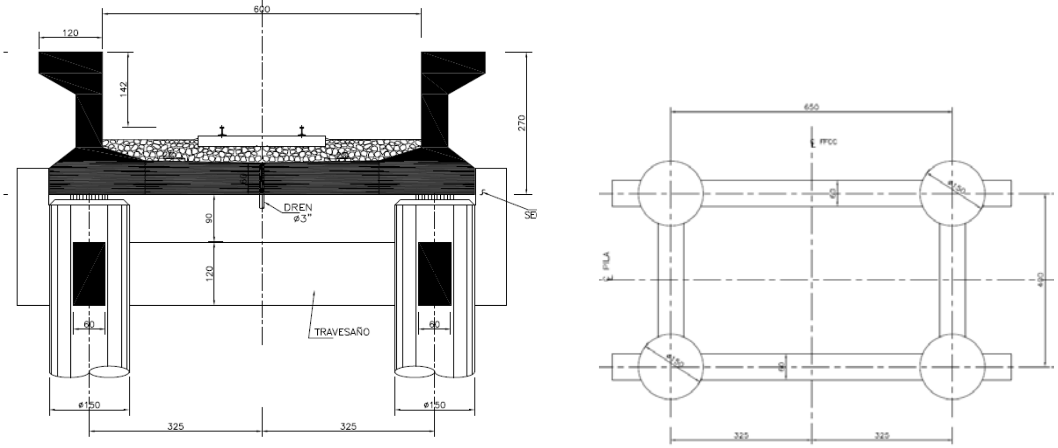

Figure 2 : Typical cross section

The bridge has 306 simply supported spans of 28 m length. The viaduct has 307 piers, each pier of the viaduct is formed by 4 reinforced concrete cast in place piles (figure 3 and 4).

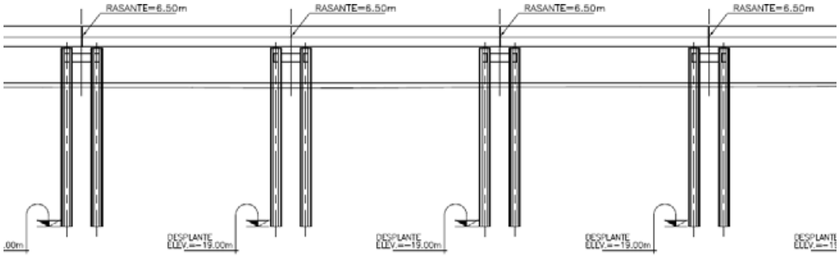

Figure 3 : Lateral view of a typical bridge spans

Figure 4 : General view of the deck and view of a typical pier

3 GENERAL POURPOSE OF THE EVALUATION

The owner of the bridge (Secretaría de Comunicaciones y Transportes, México) and its operator (FERROMEX) decided to carry out a series of dynamic and static tests on it to assess its behaviour before opening to traffic. The test and assessment program included the following topics:

- Complete inspection of the full bridge before operation,
- Topographical measurement of the full bridge before operation.
- Verification of the performance during the pre-operation period with fully loaded trains.
- Dynamic tests during the pre-operation period.
- Static tests during pre-operation period.
- Complete inspection of the full bridge after operation.
- Topographical measurement of the full bridge after operation.

4 INSPECION AND TOPOGRAPHICAL SURVEY

A detailed inspection of the entire bridge was carried out before and after the pre-operative period. These work included a detailed review of all structural elements of the bridge (figure 5). Any damage found (cracks and fissures) were marked and measured, and placed in a report. A comparison of the results of the inspection before and after pre-operative period was made. Furthermore, detailed topographic surveys were conducted across the bridge before and after the pre-operative period (figure 6), and were compared in order to detect possible settlement or deformation originated by service loads.

Figure 5 : Inspection work and detection of small cracks.

The damages found were the result of the construction of the bridge (small cracks), and not because from the passage of trains over the bridge. On the other hand, permanent deformation and settlements induced by service loads were negligible.

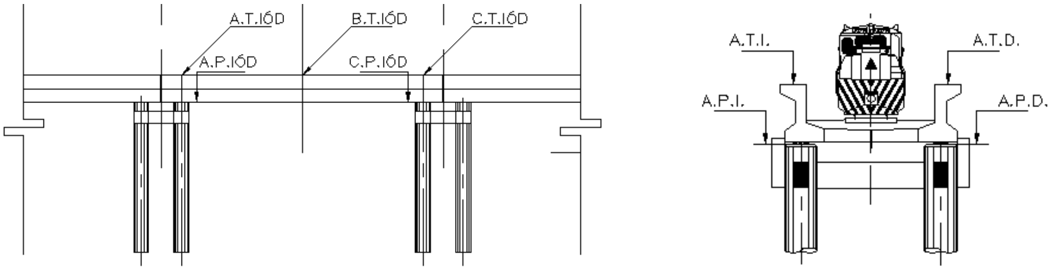

Figure 6 : Points of topographical measurement for each span of the bridge

5 STATIC TESTS

Twelve static tests were conducted in different parts of the viaduct. The tests procedure were the following:

- Topographical measurement of the test zone (loaded spans plus 1 additional span on each side) with the bridge "empty".
- Placement of the load, and topographical measurement of the "loaded" bridge (figure 7),
- Removal of the load, and topographical measurement for the "empty" bridge,

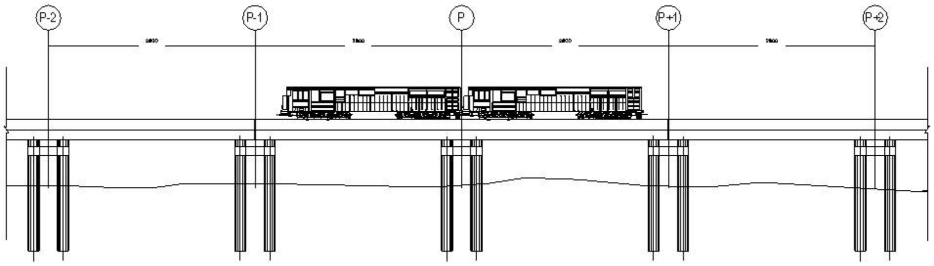

Figure 7 : Configuration of a typical static test

The load used for these tests was a tandem of two locomotives of 194 tons each.

Figure 8 : Static test

The main results of the static tests are summarized on table 2. In general, the results shown a good behaviour of the bridge, the measured deformations agree whit the expected ones. Furthermore, once discharged, the structure returned to its original state without any residual deformations.

Table 1: Vertical deformations of piles during static tests (m)

Static Test	**Pier (km)**	**Δz** Application of load	**Δz** Removal of the load
1	1+387	-0.013	0.012
2	2+168	-0.002	0.001
3	3+258	-0.006	0.006
4	3+426	-0.006	0.006
5	4+910	-0.005	0.007
6	6+002	-0.013	0.012
7	7+486	-0.002	0.001
8	7+878	-0.008	0.008
9	9+642	-0.005	0.004
10	10+034	-0.015	0.001
11	10+454	-0.01	0.01
12	11+070	-0.001	0.003

6 DYNAMIC TESTS

6.1 Description of tests

Due to the great length of the bridge, it was decided to perform 14 dynamic test series. These tests were distributed along the viaduct in function of different geotechnical and structural conditions along the bridge.

Four types of train running conditions were defined for the tests:

- **Train passage at standard speed**. During this test the train is running through the instrumented site at standard speed (40-50 Km / Hr) without braking.
- **Standard braking**. During this test, the train is running at standard speed, and standard braking is applied when the train passes over the instrumented zone.
- **Emergency braking**. During this test, the train is running at standard speed, and emergency braking is applied when the train passes over the instrumented zone.
- **Start the train** over the test site.

For these tests, a train consisting of two locomotives of 194 tons each plus 40 wagons. These wagons were loaded with iron mineral, providing a weight of 120 tons each, for a total of 5200 tons. The table 1 shows the summary of different tests performed.

Table 2 : Summary of the dynamic tests

Test	**Viaduct**	**Pier**	**Km**	**Acceleration measurement direction**				**Train running condition**	**Speed [Km/Hr]**
				ac1	**ac2**	**ac3**	**ac4**		
1	I	2	1+387	V	T	V	T	Standard speed	50
2	II	9	2+167	V	T	V	T	Standard speed	46
3	III	2	3+258	V	T	V	L	Normal Braking	50
4	III	8	3+426	V	T	V	L	Normal Braking	49
5	III	8	3+426	V	T	V	L	Starting of train	0
6	III	16	3+650	V	T	V	L	Emerg. Braking	49
7	III	61	4+910	V	T	V	T	Standard speed	49
8	III	99	5+974	V	T	V	T	Standard speed	49
9	III	153	7+486	V	T	V	T	Standard speed	48
10	III	153	7+486	V	T	V	T	Normal Braking	30
11	III	165	7+822	V	T	V	L	Normal Braking	46
12	III	230	9+642	V	T	V	L	Emerg. Braking	52
13	III	244	10+034	V	T	V	L	Standard speed	46
14	III	244	10+034	V	T	V	L	Emerg. Braking	51

V= Vertical, T=Transversal, L=Longitudinal

6.2 Instrumentation

The instrumentation was composed by 4 accelerometers PCB 319B12 (bandwidth 0.05-4000 Hz) and 10000mV/g sensitivity. Two accelerometers were placed over the piles, and two other were placed at the half of each span (figure 9). The orientation of each accelerometer was different depending type of test, and its summarized in Table 1.

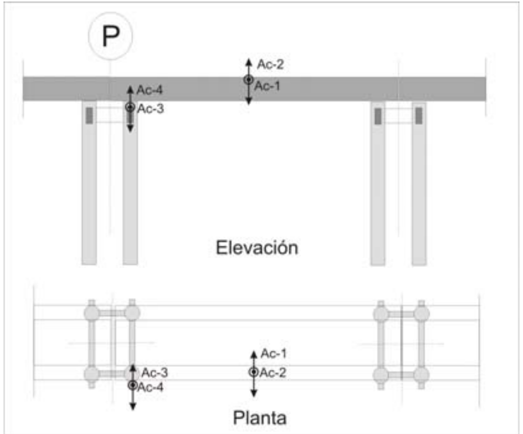

Figure 9 : General plan of the instrumentation

The sampling frequency during the tests was fixed at 512 Hz. The duration of the measurement was subject to the type of test and train speed. In all cases the test was started about 30 seconds before the passage of the train. In general, the duration of test varied from 100 to 200 seconds.

Figure 10 : Measurement equipment, and train passing over a test site

6.3 Results

Some of the typical results obtained during the dynamic tests campaign are shown on figures 11 and 12. Using the Power Spectral Density (PSD) functions, it was possible to estimate the vertical vibration period of the bridge span tested (Bendat and Piersol 2000). The values were bounded between 6 and 9 Hz (see figure 13).

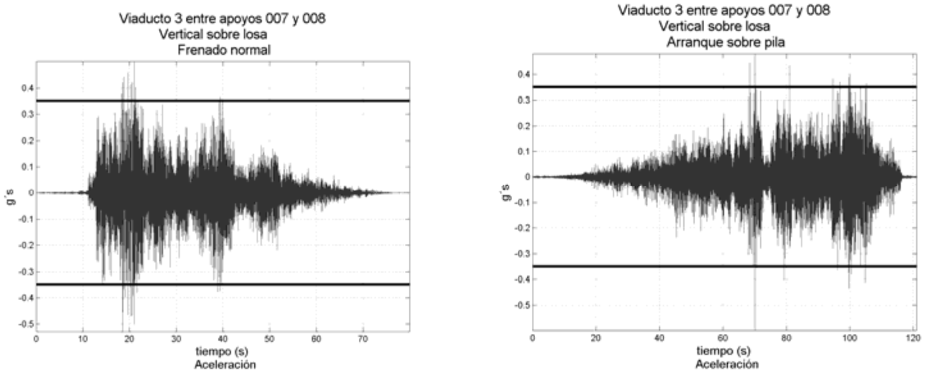

Figure 11 :Vertical accelerations at mid-span during : (a) Normal Braking over span 7-8; (b) Start of the train over span 7-8.

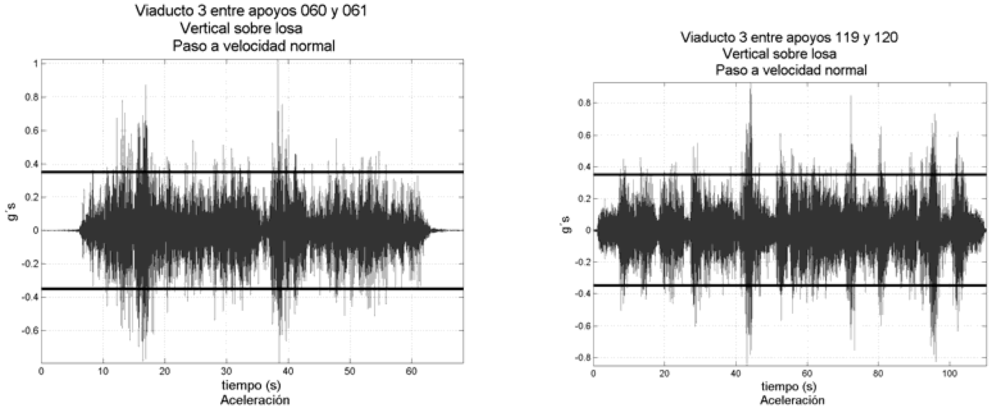

Figure 12 : Vertical accelerations at mid-span during standard speed test over the spans 60-61 and 119-120.

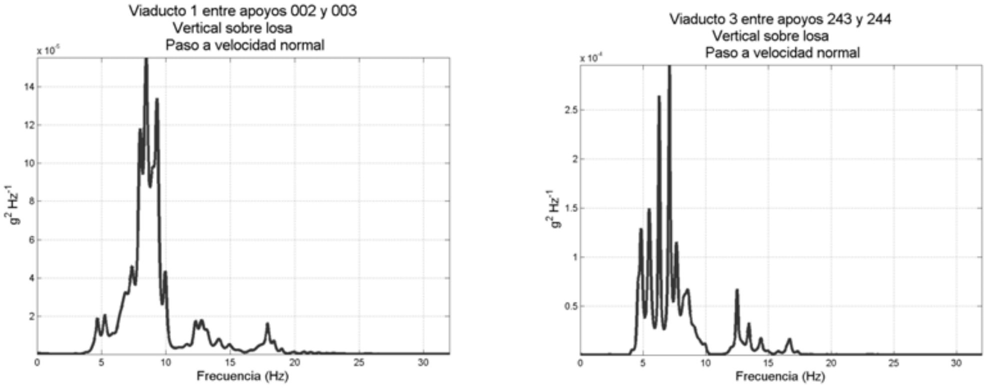

Figure 13 : PSD of vertical accelerations at mid span for standard speed test over spans 2-3 and 243-244

There are several international recommendations to limit vibration levels (acceleration) of railway bridges. In this work it was investigated three different international standards: Eurocode 1 2004, IAPF 2010, and UIC Code 776-2 2009. All studied codes have similar restrictions to the allowable vibration levels in railway bridges. The first review concerns the verification of the frequency of vibration of the structure as a function of the span. Figure 14 shows the verification of this criteria according to Eurocode 1 using the measured vertical vibration frequencies estimated for the bridge deck. If the structure under consideration is inside the limits indicated, there will be no resonance phenomena that endanger the movement of trains on it. This recommendation applies to bridges with "normal" typologies, as in the case of the Cuyutlan Viaduct.

On the other hand, when the risk of resonance is possible, or the type of bridge is considered atypical, vertical peak accelerations are limited to 0.35 g, for bridges on ballast.

On Figures 11 and 12 it is compared the maximum values of vertical accelerations at mid-span with the maximum allowed by the codes. As a result, in general, a majority lies within. There are small acceleration peaks that exceed these values, however the percentage of exceedance is low (less than 1.5 %), so it was not considered relevant.

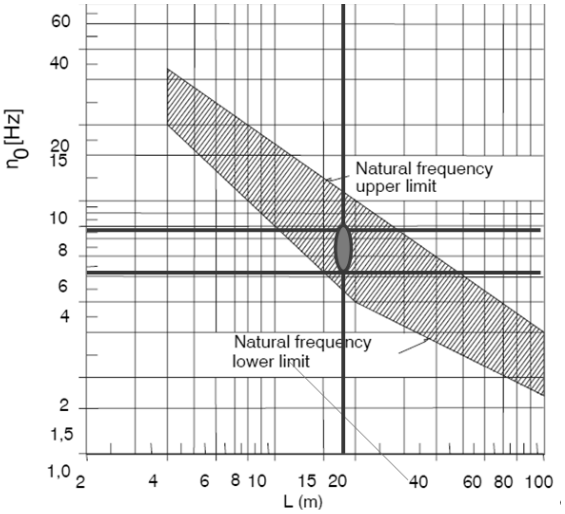

Figure 14 : Verification of vertical vibration criteria of railway bridges according to Eurocode 1

7 CONCLUSIONS

This paper presents the methodology used to assess the structural behaviour of the new railway viaduct of Cuyutlan, before its opening to traffic. The work carried out was: full inspection of the bridge, static and dynamic tests under real operation loads. All the test results show a satisfactory behaviour of the structure, as a result, the bridge was open to traffic on October 2011.

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