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Instrumentation and monitoring of segmental post-tensioned girders

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Abstract. As a result of the failure of prefabricated segmental girders during their construction, and in order to evaluate the structural safety of the superstructures of three bridges, different activities of instrumentation, monitoring and mathematical modelling were performed. This paper presents the first stage of a study describing the tasks of instrumentation and monitoring of stresses in an isolated precast post-tensioned beam during the process of application of the tension loading, and before being placed in its final position. The main goal of this task was to confirm the transmission and distribution of stresses at segmental joints. Also, ambient vibration tests were carried out in different phases of tensioning, as well as in the final position of the girder. Recorded stories of accelerations are presented and fundamental periods of vibrating of the isolated girder are derived. The results of the measurements will be used for the calibration of mathematical models and simulation of different scenarios of loads and thus assess the structural safety of the different sections of the superstructures of the three bridges in question.

1. Introduction

During the manufacture of post-tensioned prefabricated segmental concrete girders, 53m long, three of them failed in their shear key joints during the application of the post-tension load, while the rest do not show currently any kind of incipient form of instability. Most of the prefabricated beams have been already placed in the different spans of three bridges located along a new beltway in Mexico.

A technical opinion about the failure of the girders was requested. For this purpose a study was proposed to assess the behaviour of new beams and superstructures, to be built with the same type of construction system, under different types and levels of static and/or dynamic loading.

With this in mind, it was necessary to define an instrumentation scheme of the isolated girders during construction and of some spans of the superstructures. This paper only presents the instrumentation activities of some beams, representative of the superstructures, with the objective of measuring deformations, displacement and camber during their tensioning; parameters that could provide valuable information and help to determine probable causes of failure, as observed. Also, frequencies and periods of vibrating of some isolated girders were derived based on ambient vibration tests. These parameters were measured only during the tensioning.

Additionally, mathematical models were elaborated in order to reproduce the experimental data and collect reliable analytical information to predict the behaviour of the bridge under certain events of loading. A design review of the superstructure is not the aim of this paper.



2. The superstructures

Each span of the superstructures of the bridges studied is comprised of 5 posttensioned concrete beams of 2.4 m height, with 4 transversely symmetrical cables of pre-stress. Figures 1 and 2 show a typical cross section of the superstructure and the position of cables in a girder, respectively. Each girder is composed of five segments which are concreted in a special yard near the construction site; shear keys are provided for each segment which are assumed to be cast in the same order as they will be placed in their final position.

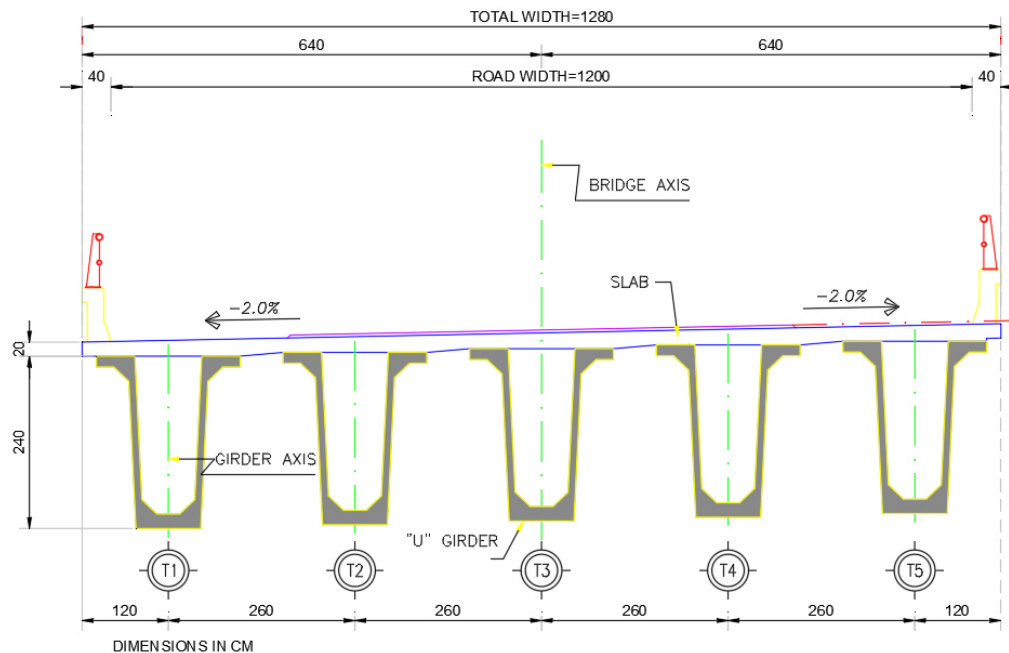


Figure 1. Typical cross section of the studied superstructures.

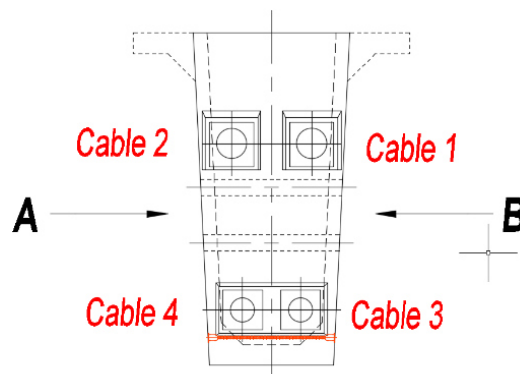


Figure 2. Position of cables/tendons for post-tensioning.

The sequence of tensioning was applied as follows: first, cable 1 is tensioned up to 50% of its design load; immediately after, cable 2 is tensioned up to 100% of its design load; cable 1 is then completed to its 100% design load. Then, tendon 3 is tensioned up to 50% of its load followed by the application of 100% of prestress to cable 4. The tensioning devices are returned to cable 3 in order to complete 100% of its design tension. The post-tension loads were: 384.7 t, 384.7 t, 305.8 t, and 308.5 t in cables 1 to 4, respectively.

Once the five segments are finished, they are transported separately and placed on appropriate temporary supports in a special area just by the approach of the bridge in construction. In this area, the

post-tension load is applied. Afterwards, girders are launched to their final position in each span of the bridge.

3. Instrumentation and monitoring

An instrumentation scheme was designed for monitoring strains and stresses during posttensioning of the girders. The scheme comprised electrical strain gauges, signal conditioning cards, communication devices and wiring as well as an industrial type automatic recording software [2].

Based on previous analyses and the identification of stresses in the beams, a total of 12 sensors were placed in each beam studied. Only the joints with the maximum compression stresses were instrumented placing a sensor (strain gauge) on each side at the bottom and top of the same joint, on both sides of the girder. In the vertical direction, sensors were placed at 0.30m and 2.0m from the bottom surface of the girder; the distance between sensors on both sides of a joint was 0.50m. The aim was to monitor the transfer and distribution of stresses between segments. Figure 3 shows the location and nomenclature of each of these sensors for a specific beam.

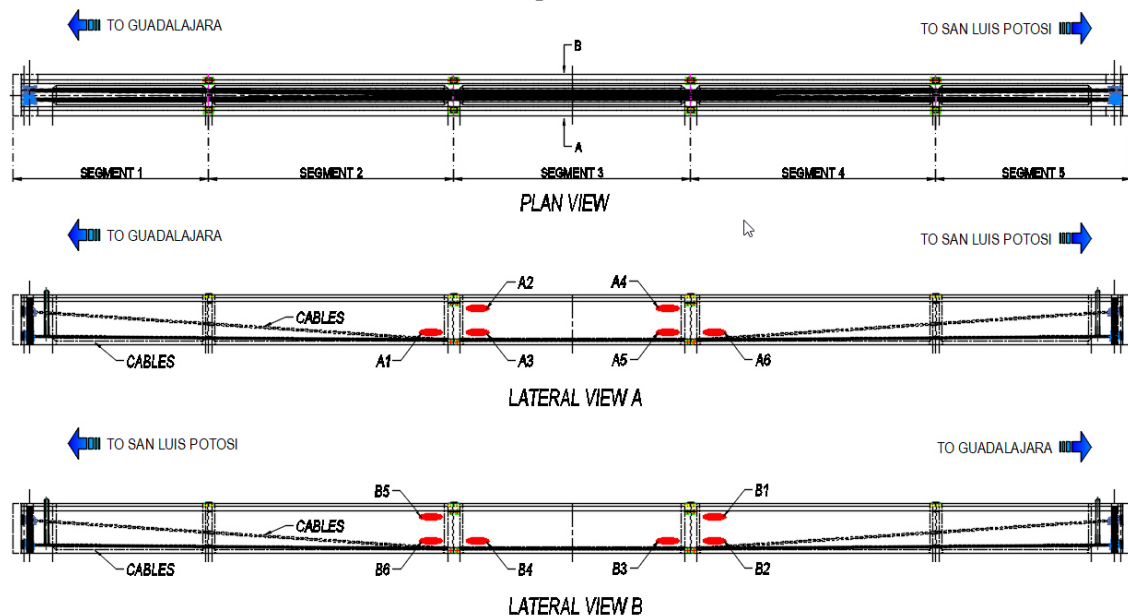


Figure 3. Instrumentation scheme for segments of beam TR7, Don Viejito bridge.

4. Results

4.1 Distribution of stresses

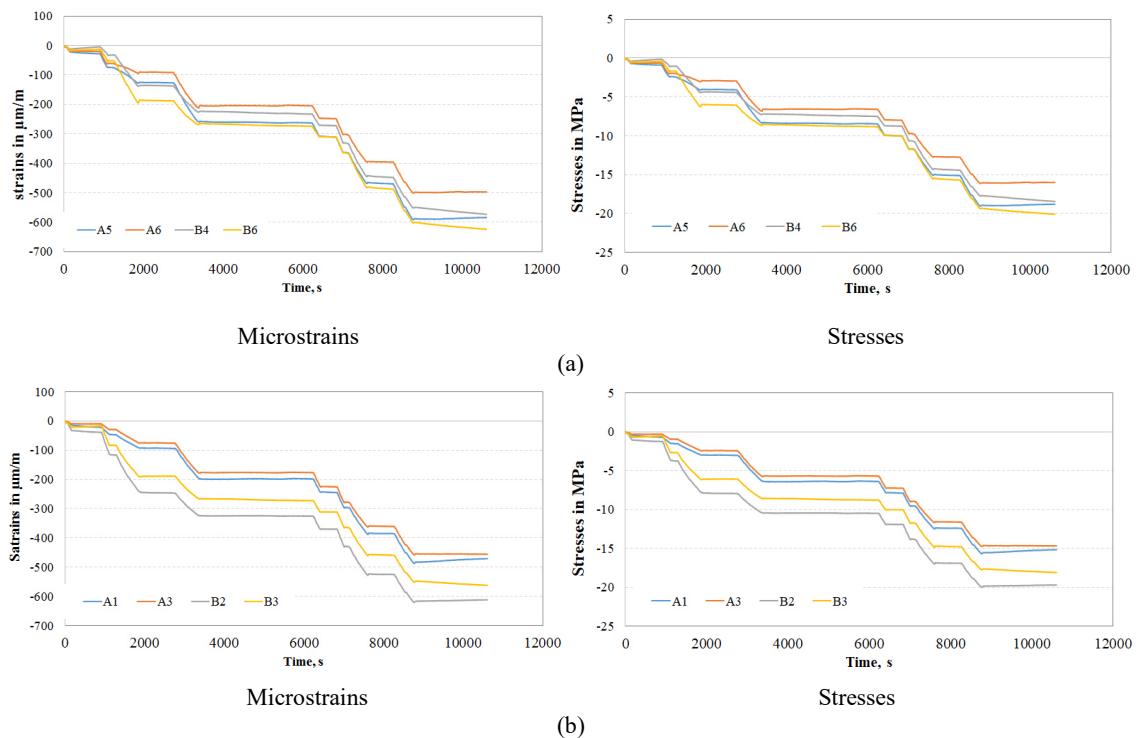
Below are shown some results associated to one of the instrumented girders (labelled as TR7), as a product of the tensioning of the cables. Table 1 shows a summary of the maximum values recorded. According to design calculations, no tension was to be expected during the application of the post-tension load. Also, it was expected an even distribution of stresses at each side of the matching joints.

As shown in the table, no tensions were registered in any sensor. Also, observing the magnitudes for the maximum values for pairs of sensors located on opposite sides of the joints: A1 - A3, A5 - A6, B2 - B3 and B4 - B6 it is shown that they are comparable. For example -18.43MPa and -20.1MPa for sensors B4 and B6, respectively. The difference may be attributed to the position of the sensors in the longitudinal direction. The same applies for the rest of pairs of sensors. Additionally, when comparing values of stresses at sensors on different joints but in the same longitudinal symmetric position, like joints B1-B5, B4-B3, A2-A4 and B2-B6, the results are better comparable confirming the assumption of an even distribution of stresses.

Table 1. Maximum strains and stresses recorded during tensioning of beam TR7.

Sensor	Initial condition		Final condition	
	$\mu\text{m/m}$	σ (MPa)	$\mu\text{m/m}$	σ (MPa)
A5	0	0	-592	-19.02
A6	0	0	-501	-16.1865
B4	0	0	-573	-18.4428
B6	0	0	-624	-20.1105
A1	0	0	-487	-15.696
A3	0	0	-458	-14.715
B2	0	0	-621	-20.0124
B3	0	0	-562	-18.1485
A2	0	0	-109	-3.5316
B1	0	0	-114	-3.7278
A4	0	0	-96	-3.1392
B5	0	0	-125	-4.0221

Figure 4 shows the stories of strains and stresses recorded during the tensioning of the 4 tendons in the sequence described above. Each graph shows, on the horizontal axis, the elapsed time during tensioning, and, on the vertical axis the recorded strain (left graph) in sensors, or equivalent stresses (right graph). Regarding these plots, the first two rows are associated to sensors at the bottom of the U girder, and the last row to sensors at the top of the girder. It is shown that shapes and magnitudes of stresses are similar; and all values increase as long as the load is increased.

**Figure 4.** Time histories of microstrains and stresses, girder TR7.

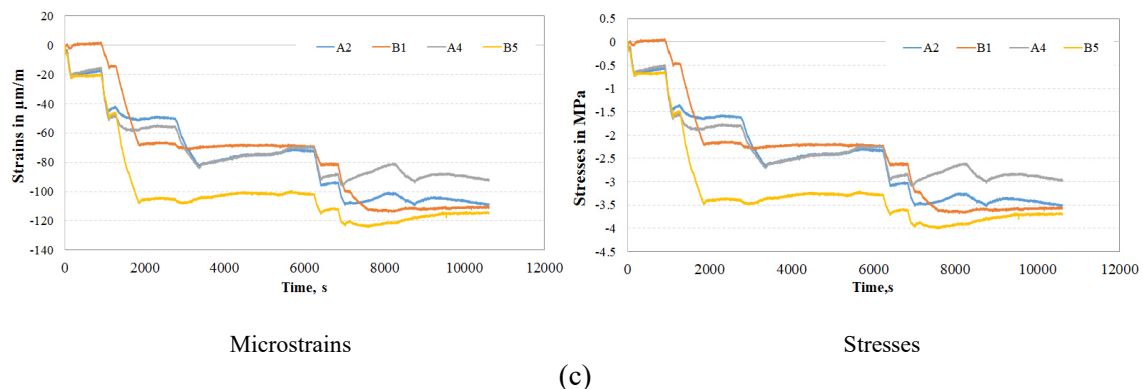


Figure 4. (Cont.) Time histories of microstrains and stresses, girder TR7.

Also, it is worth to note that the sensors at the top of the joints (A2-A4 and B1-B5) present the lowest values of the compression stresses, as expected.

4.2 Vibrational frequencies

In order to experimentally determine the dynamic properties of the post-tensioned girders before being placed in the superstructure of the bridge, during the six stages of tension of the four cables, ambient vibration tests were carried out with the purpose of obtaining frequency and natural vibration periods, as well as modal shapes. In particular, the results shown in this paper are focused on the measurements obtained from the fourth stage of tension of the cables up to the final tension of these elements (sixth stage). The ambient vibration tests comprised the recording of accelerations in three orthogonal directions: longitudinal (L), transverse (T) and vertical (V), at three different locations on the girders.

Figure 5 shows schematically the locations where accelerometers were placed during the tensioning of the cables of girder TR7. In order to clarify this matter, a photograph of an accelerometer already placed (position 2) on the top of the web of the “U” girder is included in this same figure. In this photograph the tendons at the bottom of the girder may be observed, as well.

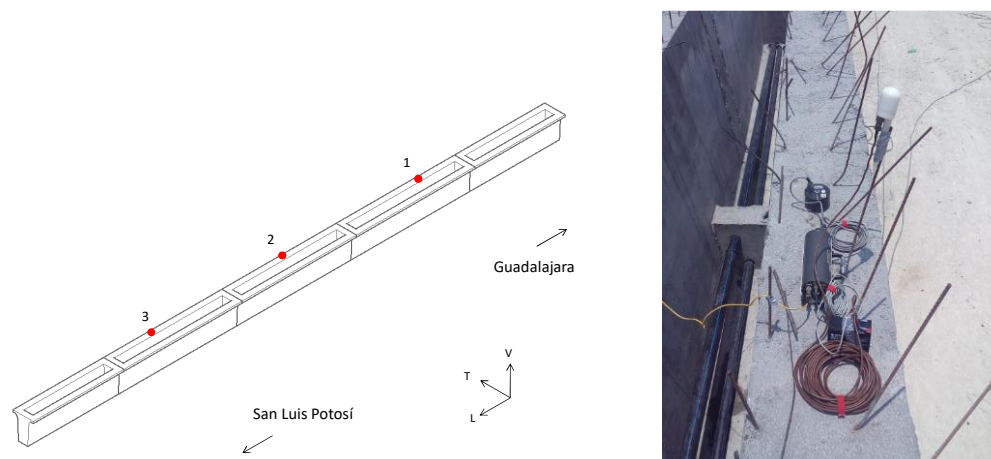


Figure 5. Schematic representation of location of sensors for ambient vibration of “U” girder TR7.

From the vibration program proposed for each of the post-tensioned beams, selected acceleration records were processed by means of a spectral analysis based on pairs of signals [1], from which the spectral density, coherence, phase angle and transfer functions were calculated.

Table 2 shows the identified periods of vibration for the different stages of post-tensioning mentioned. These values were derived from sets of functions like those shown in Figure 6, in accordance with a procedure based on the identification of frequencies associated to peaks on the spectral density function and correlation of values in the coherence function. Another check with the same frequency values is performed for the phase angle function, which quantifies the synchrony of both signals. In this way, the frequencies/periods associated to fundamental and higher modes of vibration of a structure may be identified.

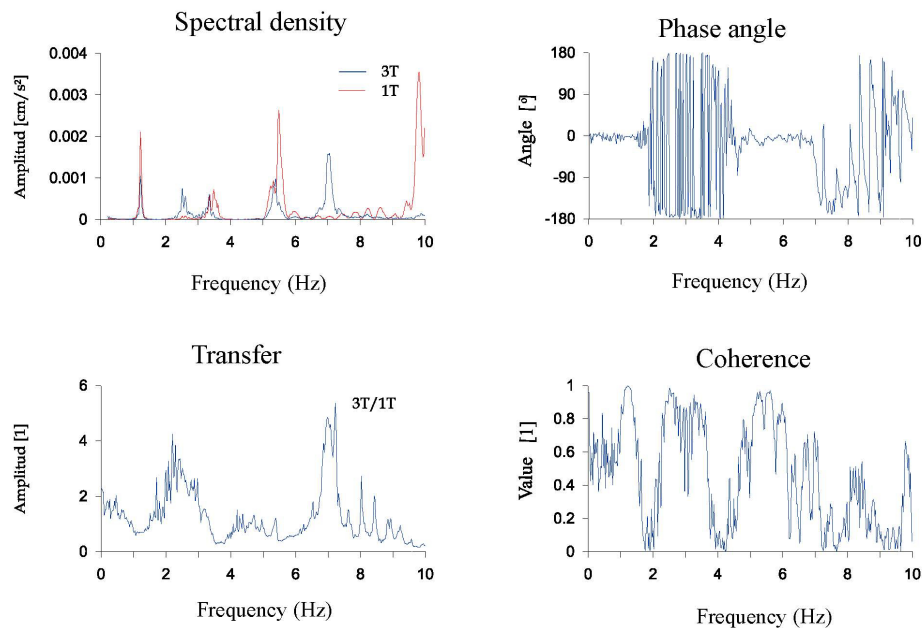


Figure 6. Spectral density, phase angle, transfer and coherence functions at locations 1 and 3; T component, 4th stage of tensioning of cables, girder TR7.

Table 2. Natural frequencies of vibration of girder TR7, after the 4th, 5th and 6th stages of posttensioning.

Mode	Component	Freq. [Hz]	Freq. [Hz]	Freq. [Hz]
		Stage 4	Stage 5	Stage 6
1	T	1.221	0.831	0.830
2	L-V	3.345	1.855	1.855
3	T	3.491	2.173	2.148
4	V	8.228	6.714	6.738

The identified frequencies presented in Table 2 show that the first modes of vibration, vertical and longitudinal, are coupled, a circumstance which can be attributed to the conditions of support at the ends of the girder, and to the sequence of loading. Another issue that is observed in the table is the effect of the post-tensioned load: up to certain magnitude of the applied load, the girder is supported on several points (joints) changing the supported length and in consequence the frequency. During the final stages of load, the girder is supported only at the ends. For the purposes of calibration of a mathematical model of the girder, attention should be focused in reproducing the first vertical mode and the first and second lateral modes of vibration.

5. Mathematical modelling

As mentioned, three-dimensional solid finite element models of several isolated girders were developed in order to be calibrated with experimental results. The calibration was performed using SAP2000 program [3] and the final post tension forces (stage 6). All models used the same mechanical nominal characteristics of materials and considered the same effect of pre-stress cables and ducts.

Figure 7 shows a 3D view of the mathematical model of a segment used to conform a typical girder.

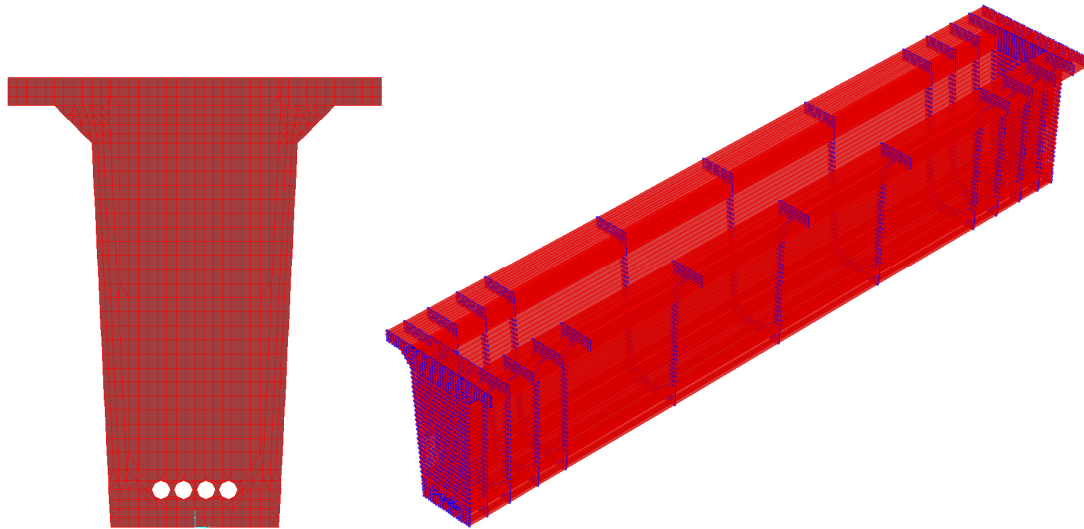


Figure 7. Mathematical model of a TR7 girder segment.

In the following table a comparison between the experimental and theoretical results are presented.

Table 3. Comparison of experimental and numerical vibrational periods for a type TR7 girder.

Direction Mode	Transversal (s)		Vertical (s)	
	1	2	1	2
Experimental	1.205	0.466	0.539	0.148
Mathematical model	1.133	0.522	0.568	0.147
Relative error	-6.0%	12.0%	5.4%	-1.0%

On the other hand, finite element results of axial stresses for the last post tension stages (3-6), showed only compression stresses in the whole cross section of the girders. Additionally, when comparing the maximum numerical stress at point B6, its magnitude was -22.57MPa and the one obtained experimentally was -20.1MPa, which is a fair approximation considering the difficulties involved in developing the model of the girder. The same situation was observed when comparing the maximum numerical and experimental camber: 78.3 vs 80mm, respectively.

6. Final comments

The results of the first stage of a study developed to instrument and monitor different joints of segmental girders for three bridges were presented. The objective was to assess the transfer and distribution of stresses at different construction joints of the girders. The results of this stage included the recording of strains during the application of the post-tensioning load on the girders before being

placed in their final position, as well as ambient vibration tests.

Regarding the results obtained with the strain gauges, a good behaviour was observed in spite of some minor misalignments and geometry flaws that were observed prior to the monitoring of the strains. A good transference and distribution of stresses was recorded. The results do not reveal any possible deficiency in the structural stability of the girders studied.

Although some coupled vibration modes were perceived, results of the ambient vibration study showed that these segmental girders have a global behaviour that does not differ significantly from the one assumed for a regular girder cast in a single element. It is expected that these behaviour will not have any effect on the global behaviour of the complete deck: girders and slab. Some changes in the frequency values were observed between different stages of tension.

Acknowledgements

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References

- [1] Bendat J S and Piersol A G 1989 *Random data: analysis and measurements procedures* (New York: Wiley Interscience)
- [2] Gómez-Rosas E, Gomez R, Arenas-Garcia L M, Mendoza-Garcia M A, Rosales-Gonzalez O N and Escobar-Sanchez J A 2012 *Instrumentation and monitoring of six road bridges by means of a measurement system developed at the Institute of Engineering of UNAM (in Spanish)* (VII Mexican Society of Instrumentation Congress, Culiacan, Sinaloa, Mexico)
- [3] CSI 2009 *SAP2000 Version 18.0.1, Integrated Finite Element Analysis and Design of Structures* (Computers and Structures Inc. Berkeley: California)