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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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SOME TECHNICAL ASPECTS OF THE CONSTRUCTION OF THE NEW HIGH SPEED RAILWAY IN MEXICO

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Abstract

The Institute of Engineering has participated as an advisor agency for the construction of the viaducts of the new and first high speed railway project in Mexico. In this paper we present different tasks that we have carried out for the Ministry of Communication and Transportation in order to validate some structural design and environmental assumptions. The activities comprised the review of the seismic spectra, instrumentation and load testing of large foundation piles, quality assurance for the construction of a box steel superstructure, ambient vibration of piers and the evaluation of noise vibration related problems. Each one of these tasks will be described as well as a general presentation of the project.

1 Introduction

The construction of the intercity railway Mexico-Toluca comprises the construction and operation of the required infrastructure for a regional rail corridor between the metropolitan area of Toluca (in the state of Mexico) and Mexico City. The main goal of this project is to alleviate the problem of mass transportation that takes place in the highway corridor connecting the town of Toluca to the city of Mexico. The proposed solution is a mass transit regional rail type that will provide a safe, fast, comfortable, and accessible in price and ecologically sustainable alternative to passenger transportation. The project will have a total length of 57.70 km, 6 railway stations and a rail maintenance workshop.

The project includes the construction of different type of railway viaducts with two constraints: minimize road and social impacts in urban areas during the construction of a new railway line of this nature, and using systems of elevated viaducts for crossing hill areas. This last constraint prompted the use of prefabricated concrete elements since serial production and quality control affect the duration of the construction process and the quality of the work itself. This allows to save construction time and produce clean, fast and safe works. The manufacture of these elements took place in mobile prefabrication plants close to the construction site, in order to avoid long transportation times that could generate nuisance to neighbors along the project.

Some of these viaducts are unique. Their specific design objectives were: (i) Increase the reliability of the rail system, assuming viaducts are critical elements. (ii) Improve the maintenance of these structures, passing from a concept of inspection and corrective maintenance to predictive maintenance, based on a continuous monitoring. (iii) Integrate the viaduct system in the procedures of a railway infrastructure management and companies responsible for its maintenance, in order to optimize and schedule this task. (iv) Better understanding of the phenomena of degradation of the infrastructure and the evolution of services or any pathologies and the real or expected useful life of these infrastructures; (v) Application of the best practices to the improvement of the criteria and current design tools, with special focus

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on improving the design of unique viaducts, their dynamic behavior, the increment of speed, and finally the use of the best available regulations.
As mentioned, the project will feature 6 stations including 2 terminals. For all of these structures areas with different purposes were designed: local service, lockers, hallways, ticket vending machines, access control (turnstiles), local control, surveillance and chief of station, vertical movements and equipment for mobilization of people with disabilities and senior citizens. Likewise, the area of platforms was designed with sufficient dimension to accommodate trains of 150 m in length during the first years of service, which may be increased according to the demand.

2 Monitoring of strains during a load test of a bridge pier foundation

For some parts of the railway project, standard load tests of deep foundations were required. These test comprised the application of a static axial incremental load, both in compression and tension [1]. In order to measure and evaluate the response of the load prototype, a monitoring scheme was proposed. Monitoring of deformations of the reinforcing steel and concrete was carried out with the help of strain sensors installed previously during the construction of the cast in place 1.50m diameter pile. Time histories of strains were recorded in three transversal sections along the length of the pile. In the following, the setup of a single test is presented including instrumentation tasks; results are discussed and recommendations for future work are provided.

2.1 Test setup

An auxiliary structure is built. It consists of an array of 5 cast in place piles: the pile at the center is the one under study, and the remaining 4 piles are called reaction piles. In addition, there are other structural elements necessary for the execution of these tests, such as steel beams of different depths which are accommodated in an array in the form of H with the aim of transferring the load to the pile test; also, a set of hydraulic jacks is used to apply the design load for each of the tests: compression or tension (Figure 1). Before the testing, all studies related to soil mechanics in the area of the pile were reviewed.

Figure 1 Structural arrays of girders and jacks for the compression and tension load tests

2.2 Instrumentation

Before carrying out the test, the pile under study was instrumented with two types of sensors: strain gauges of the extensometer type, model ST350, which were attached to the steel bars, and strain gauges, model EGP 530 which were embedded in the concrete. A total of 9 sensors were distributed in 3 cross sections along the length of the cast in place pile, as shown in Fig. 2. Each of this sections was instrumented with 2 ST350 sensors and 1 EGP350 sensor.

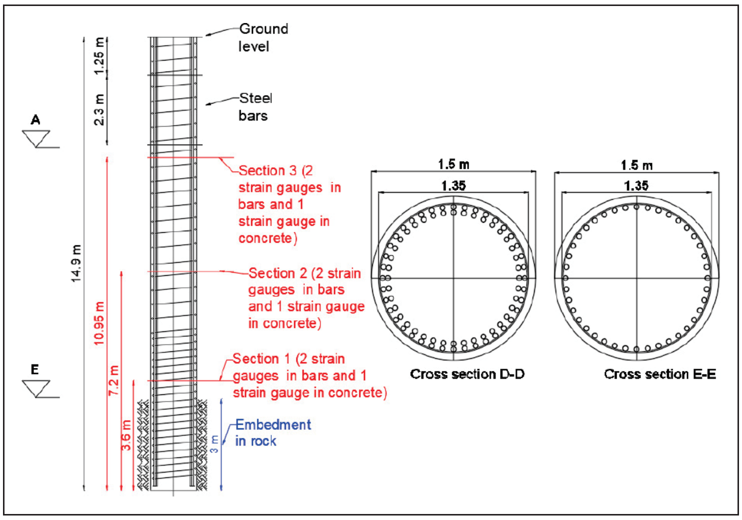

Figure 2 Location of strain gauges used for the load test, and cross sections S1 and S2

2.3 Test under compression load

This test lasted almost 21 hours. Figs. 3 and 4 show plots of stresses in the steel bars and concrete, respectively, obtained from the strains recorded in sensors placed in section S2 during the compression load test. Similar figures were obtained for sensors in sections S1 and S3. It is observed that compression stresses increase according to the increments of load, in some parts of the plots the results remain almost with the same magnitude (horizontal part) and after some lapse the stresses start decreasing (unloading stage). Before the unloading stage, several “jumps” in the plots are observed, which are associated to small adjustments in the loading equipment in order to keep the desired magnitude of load.

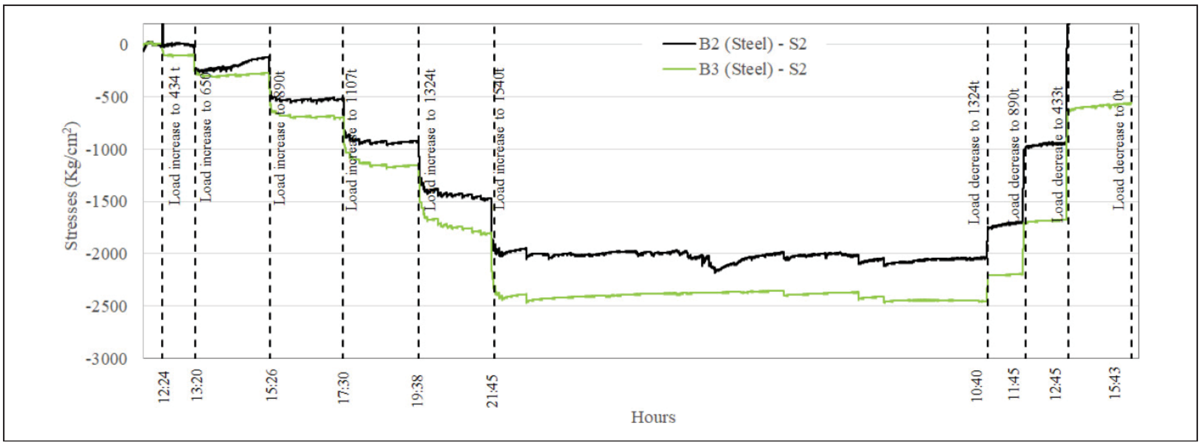

Figure 3 Time histories of stresses (kg/cm^2) in steel bars, sensors at section S2. Compression load

With regard to the stresses in the concrete, time histories are presented in the following figure. Notice the maximum value of the stresses (80 kg/cm^2) whereas that in accordance with the executive project of this pile was 350 kg/cm^2.

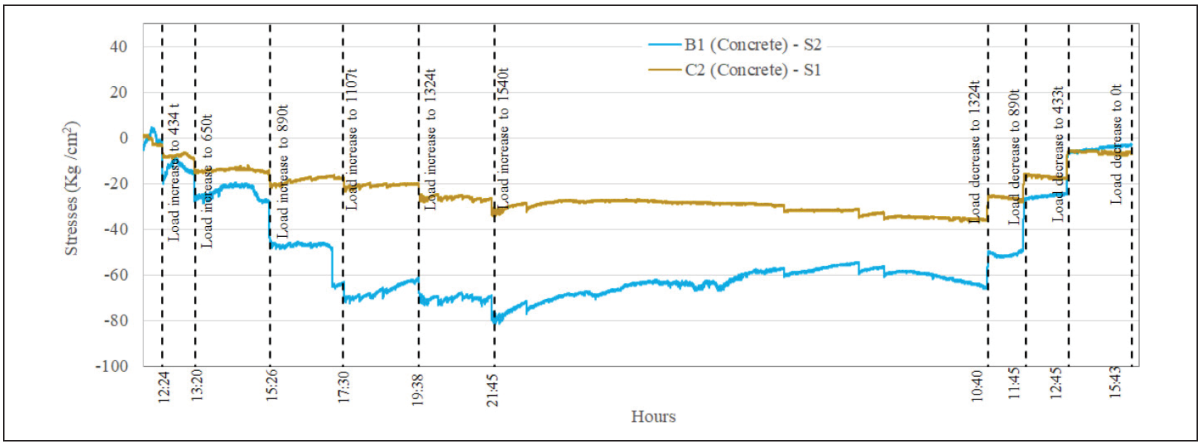

Figure 4 Time histories of stresses (kg/cm²) in concrete, sensors at sections S1 and S2. Compression load

2.4 Test under tension load

The configuration for the test was modified in order to apply the load upwards and "pull" the main pile up to its design capacity for this testing. This configuration was shown in Fig. 1. This lest lasted 18 hr. and 51 min. Time histories of stresses are shown in Figs. 5 and 6. Similar plots were presented for the compression test only that in those plots the values are negative. These plot were obtained from records located in sections S1 and S2. A better profile of the increments of tension stresses is observed when the tensile load is incremented.

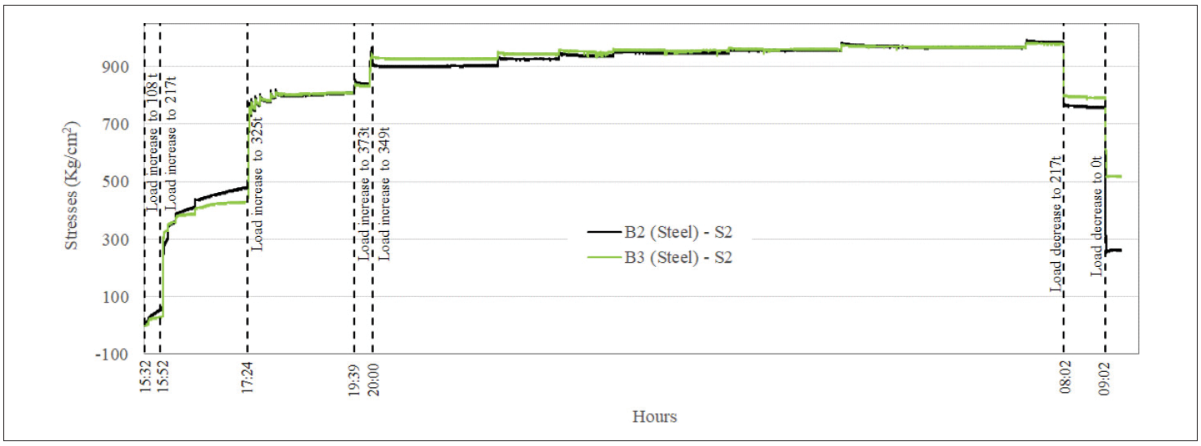

Figure 5 Time histories of stresses (kg/cm²) in steel bars, sensors at section S2. Tension load

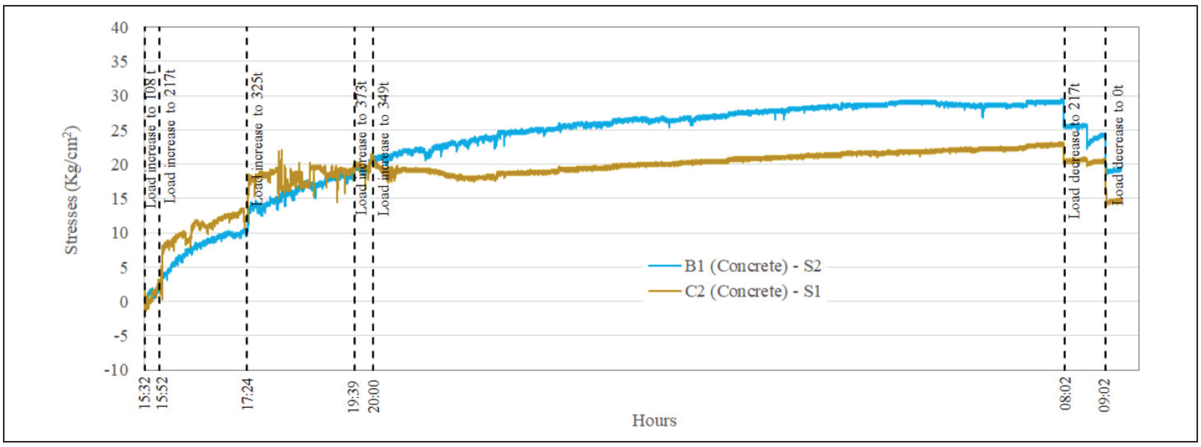

Figure 6 Time histories of stresses (kg/cm²) in concrete, sensors at section S2. Tension load

3 Experimental evaluation of the structural behavior of typical piers

According to the results of Pile Integrity Tests (PIT), up to date 27 pile foundations have been identified as “dubious”, based on possible flaws spotted in the concrete piles. Structural and geotechnical behavior of piers supported on these foundations is in doubt, so we are currently analyzing their behavior from the geotechnical and structural points of view. Figure 7 show some views of a typical pier/support including the superstructure.

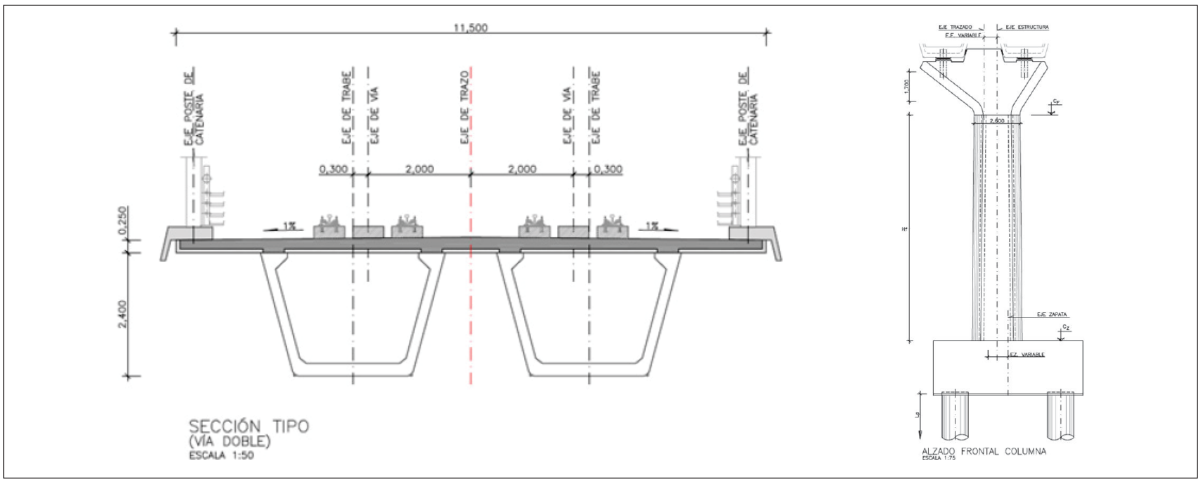

Figure 7 Typical cross sections of the superstructure and piers of a typical support

3.1 Ambient vibration tests

Ambient vibration tests were used to identify dynamic characteristics of structural systems (frequency and mode shapes). For this study, three high sensitivity tri-axial accelerometers were used with their respective digitizers. They were used for recording accelerations in the three components of accelerations: longitudinal (L), transverse (T) and vertical (V).
Three ambient vibration tests were performed for each pier. The first test used accelerometers at three locations on the footing, very close to the corners of this element. Two of these sensors were displaced in parallel and equidistant from the column of the pier, while the third was perpendicular to the other two. This, in order to identify any pitch or torsional mode in the footing. Depending of the goals of each test, this array was modified, for instance, for the second test, aimed to measure frequencies and mode shapes of the column, one sensor was placed on the ground (free field) and the remaining two sensors on the bent of the pier. Figure 8 shows two arrays of sensors for two different supports.

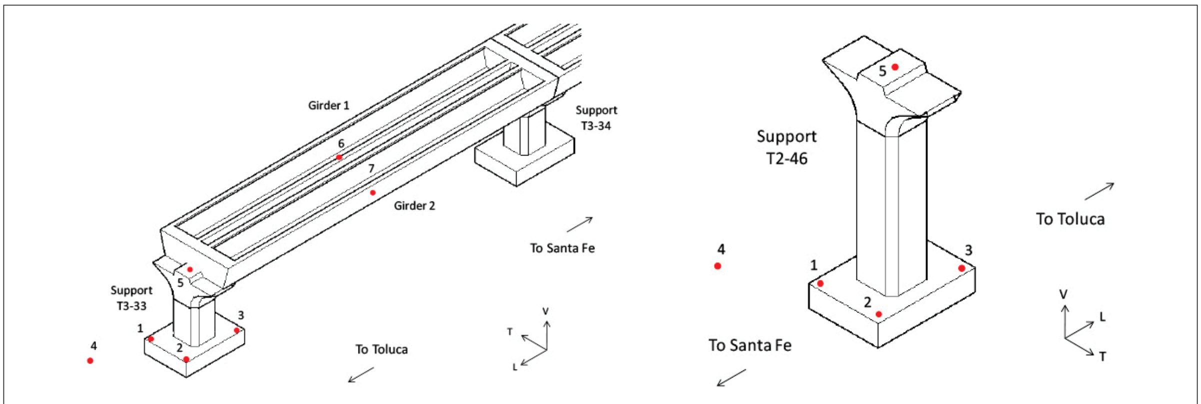

Figure 8 Schematic representation of the location of sensors

Acceleration records were recorded during the testing program of each support. These were processed using a spectral analysis by pair of signals [2]. In this way density frequency functions such as spectral density, coherence, phase angle and transference were derived. In the Figure 9 a set of these functions for the lateral component is presented.

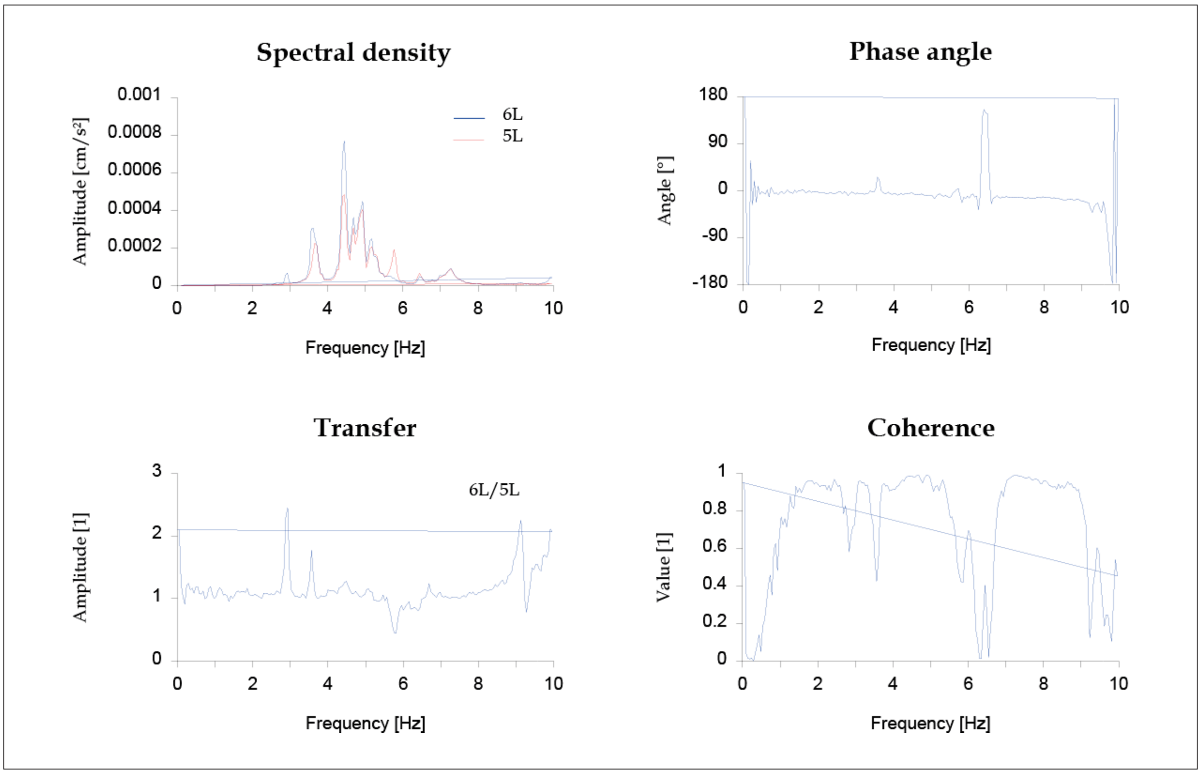

Figure 9 Example of frequency functions for component L, from records at locations 5 and 6

In addition, structural and geotechnical numerical models were prepared for the analysis of the supports. These models were based on structural design properties, as well as in field and laboratory information. The response of the models for different supports were compared and similarities were observed.

4 Studies of ambient noise in residential buildings

Environmental impacts of the construction of railways are measured in terms of comfort, noise and vibration, social, economic and visual effects. Noise emission was considered by neighbors one of the main concerns. The results of these activities will serve as a point of comparison to assess the level of comfort associated to the travelling train.

The methodology for evaluating the intensity of noise (DB) in the environment, produced by the transit of vehicles, people, machinery used in the construction of the project or work, etc., was based on the Official Mexican Regulation [3] which provides recommendations for maximum permissible limits of noise emission from fixed sources.

Measurements of ambient noise in two residential units were performed in working and leisure days, as well as during day and night, inside and outside of buildings in the residential units near the route of the railway. This work is still in progress, however, up to date results show that some values of noise are above the norm: inside the buildings noise levels are below the maximum limit of the norm, while outside noise measurements are above the norm in working hours and working days. This work included the comparison of average values for different scenarios vs standard values. Figure 10 shows a comparison of estimated, projected, screen efficiency, standards vs measurements of noise at two residential units. Estimated values were obtained with a software developed for this purpose.

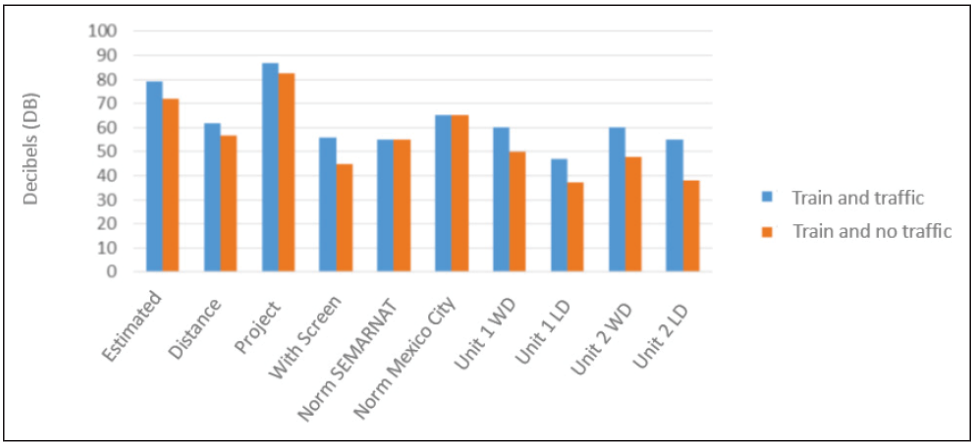

Figure 10 Comparison of noise levels

5 Quality assurance of the construction of a box steel superstructure

This is a special viaduct with mixed superstructure (Fig. 11). It consists of a double metal box girder and a reinforced concrete slab. The total length is 120 m and is divided in 3 spans of 36- 48 – 36 m. Both girders have a variable depth ranging from 2.2 m, in abutments and at the center of each span, to 3.2 m at the sections on the piers. Both girders are open section and they have a bottom flange of 2.3 m wide, two inclined webs 0.7 m length with a separation of 3.6 m at the top which is reduced to a minimum of 1.71 providing a bottom flange width 0.7 m. On the two metal box girders a concrete slab of variable depth was poured using 0.08 m thick pre-slabs as falsework. The cross section of the box girders is completed pouring a 0.30 m concrete slab on the bottom of the box girder in a distance of 1/5 of the span at each side of the piers. Piers are of reinforced concrete.

Figure 11 Viaduct 6 during the final stages of assembly

The following main activities were developed: a) Revision and approval of the documentation presented by the contractor for the quality control of the assembling, both in the shop as in the field, during installation of the box girders; b) Inspection and dimensional control of sub-assemblies and final assembly of the girders; c) Inspection and control of the anti-corrosion protection; d) Review and integration of documents and e) Review and integration of the quality Dossier.

6 Seismic spectra

Another task comprised the evaluation of the seismic environment, and determination of site and design spectra for some segments of the elevated viaducts. These tasks involved preliminary works such as the evaluation of information from seismological stations near the viaduct, ambient vibration studies, as well as geotechnical and geophysical exploration and interpretation of their results. Using selected records of earthquakes, obtained at the seismological stations, response spectra were obtained in order to define a spectral shape for different areas under study [4]. Geophysical studies involved the development of Electrical Resistivity Tomography and Seismic Refraction studies providing information about dynamic modules, geo-electric properties and wave propagation velocities. Stratigraphy and soil properties were verified with Geotechnical studies. Results included empiric transfer functions of soil deposits, site response linear equivalent analysis, response spectra at the surface and at different depths as well as a design spectra (see Figure 12).

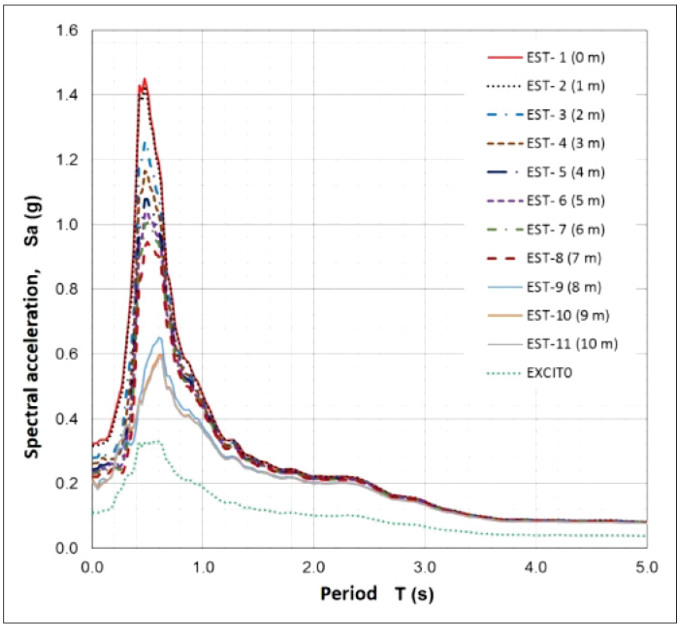

Figure 12 Response spectra for different depths for a specific soil deposit

7 Conclusion

Based on the results obtained during the compression and load tests of the piles, it is concluded that their structural behavior is adequate. Regarding the structural behavior of supports with foundation on “dubious” piles, analysis showed that their dynamic characteristics do not vary clearly for the different conditions of analysis considered, therefore their dynamic response would not be affected. It was concluded that flaws detected in the concrete of the piles do not affect the structural behavior of the studied supports. With respect to the results of noise emission, data above the allowable values of the norm were recorded during the day. In the specific case of the buildings, noise levels inside were below the maximum limit of the norm, while noise levels outside were above the standard during working hours and working days. Seismic response spectra at different depths, including the response spectrum at the base of the soil deposit were obtained. Results were used to review the structural design of the viaducts, allowing to assess the potential damage due to seismic load.

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