BRIDGE MONITORING WITH FIBER OPTICS TECHNOLOGY. AN EXAMPLE OF DYNAMIC TRAFFIC LOAD MONITORING IN MEXICAN BRIDGES

J.J. Orozco y Orozco[1], F. Sánchez Domínguez[2], L. Benatov Vega[3]

[1] Eurorva, S.A., México.
[2] Euroconsult, S.A., Madrid, Spain.
[3] Euroconsult, S.A., Madrid, Spain.

In this document we describe the monitoring performed on the Guadalajara-Colima (Mexico) road's bridges 'El Tapón' and 'El Nuevo' with fiber optics technology. First we detail the typology of the applied sensors and the data acquisition methodology. We will also present how to perform a static and dynamic monitoring, as well as the load tests performed for the "calibration" of the sensors, depending on real traffic loads.

The conclusion is that a simple data collection on the structure is not enough and that the recorded data can only be useful if we can automate their treatment and exploitation. It is also necessary to establish some rational criteria, based on the structural reliability theory, that allow us to define threshold values for each monitored parameter.

1 INTRODUCTION

The need for the preventive maintenance of service bridges by monitoring the real structural behavior of the infrastructure may be caused by various reasons. For example, the aging of the assets, the overall increase in traffic or budget adjustments or even by the increase in the users' safety demands.

The maintenance of a park or a set of bridges has been traditionally performed based on periodical and mandatory visual inspections where the subjective evaluation of aspect and physical-chemical criteria dominates.

The difficulty of integrating structural performance criteria in the infrastructure maintenance programs is due to the fact that they have not been taken into account before. However, now there is a low-cost monitoring technology that can determine bridge behavior based on completely objective criteria.

The advantage of performing bridge monitoring based on structural behavior-related criteria is that it makes it possible to respond to the urgent maintenance needs and to optimize possible interventions. In other words, this kind of bridge monitoring, based on the behavior under real traffic load gives access for the on site manager to a bridge behavior register; knowing the structural service performance provides information that

makes it easier to decide the priorities in the intervention in bridges where the accident or deterioration risk is greater.

2 MONITORING

Structural systems are designed and sized up to allow an economical use during the planned service time, fulfilling predefined requirements related to its aptitude to the service and structural safety.

Depending on the actions and influences to which the structures are subjected, we can encounter deterioration processes such as corrosion, fatigue or abrasion and they can even be damaged by extreme events that reduce their performance below the acceptable limits.

The case presented is that of two structures with a certain type of pathology that becomes apparent after the appearance of fatigue cracks and that have been continuously repaired during its useful life. These are structures that are already deteriorated due to the passing of time and the constant passing of great tonnage loads. As a structural safety measure, these structures have been monitored according to a first order criterion (strain measurement) in order to monitor their behavior during the construction of two new structures that will replace the damaged ones.

The two existing bridges are located between the Colima and Guadalajara (Mexico) road structures and have similar structural characteristics. Their board consists of a three-dimensional metallic structure (Figure 1) formed by nodes united to the superior concrete slab by 4 tubular profiles (RTP), while longitudinally and transversely they are united by reinforcing bars.

Figure 1. Details of the structure and the three-dimensional structure.

The first bridge is called "El Tapón" and it is composed of a single space of a 65 m span and the second bridge, "El Nuevo" has four spaces with spans at 18,36, 65,26, 63,82 and

12,56 metres. The pathologies observed during the periodical inspections are damaged RTP profiles, damaged transition joints, cracked soldered joints, displaced supports and concrete boards with section losses.

Due to these premises and that the client wanted to have a permanent monitoring system as early as possible in the detection of possible errors, we designed one based on optical fiber sensors.

In the bridges we distributed instrumentation sections throughout the axis of the board and in each auscultation section we implemented a node (Figure 2) by installing a 1,5m long optical strand to adjust the tubular profiles both in the superior and inferior profile, complementing each section with another optical strand installed supportively to the lower longitudinal bars.

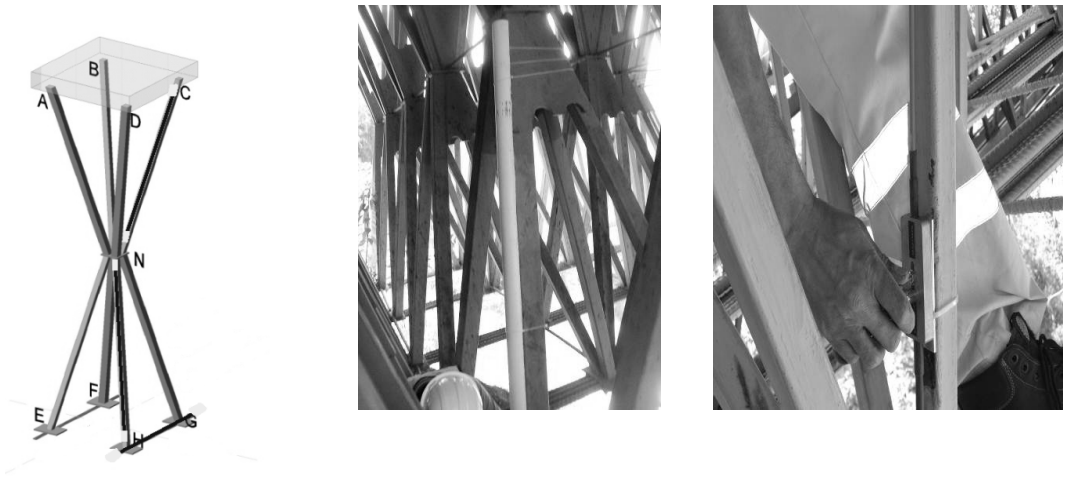

Figure 2. Details of the installation of optical strands.

The location choice for these sensors was based on structural criteria. They were installed in the maximum bending stress sections and the maximum shear stress sections, these stresses being considered the critical ones of the structure that can provoke the existing pathologies.

The instrumentation was complemented by the installation of various optical extensometers (Figure 3) on supports and joints.

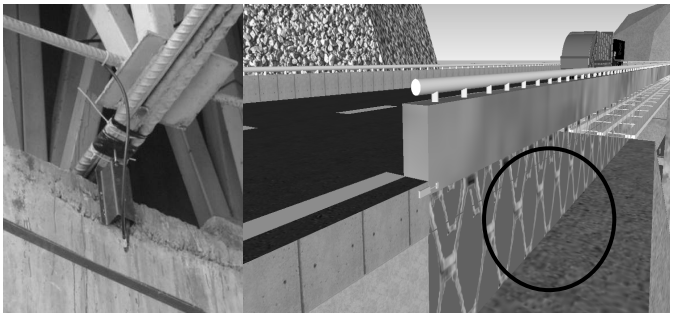

Figure 3. Details of the installation of an optical extensometer on supports and joints.

We used optical fiber sensors by OSMOS technology that are based on the principle of variation span intensity measurement (long-base optical strands and extensometers).

We chose such sensors due to their intrinsic characteristics that are described below.

1. The sensor maintains permanent contact with the selected most critical areas of the structure;
2. They allow a very wide measurement base that covers an important part of the structure;
3. They allow the monitoring of the phenomenon that can occur in the long term;
4. The same sensor allows the recording of dynamic phenomenon even in the case of high frequency;
5. It has the same reference for static and dynamic registers;
6. It offers great stability over time and the sensors are not affected by electromagnetic interferences;
7. The system is insensitive to parasitic effects when making the transmission through an optical fiber without amplification or signal processing;
8. Easy installation and maintenance.

3 OPTICAL SENSORS

As we mentioned before, the optical fiber sensors can control the evolution of a strain based on a measurement that can reach large amplitude. In this case we created sensors with specific length for the three dimensional structure since the length of the tubular profiles conditioned a special provision of the determined sensors.

In the ‘Tapón’ and ‘Nuevo’ Bridges two kinds of optical sensors were installed that are described below.

3.1 Optical strands

These sensors are used to measure the geometrical changes. They can be between 1 and 10 meters long and come with a great variety of configurations. Although they have a long base, they can measure strains with an accuracy of 1 micron.

3.2 Optical extensometer

The optical extensometer is a displacement transducer based on the variation of a very high precision span intensity. Its compact design makes it possible to measure a wide range of length and displacements up to 5 mm.

The sensor records the geometrical changes through a probe and internally converts them into optical signals. The sensor is able to record both dynamic and static measurements on the same measurement basis, for periods ranging from a few seconds to several years.

These sensors are also used for dynamic weighing on the traffic loads structure.

1 4 DATA ACQUISITION

By connecting the sensors to a standard optical fiber cable, the signal can be transmitted to long distances without the need for transformation or amplification. It can reach the monitoring stations installed in the bridges.

These stations comply with all network functions and are also responsible for acquiring the values of the measurements.

Each monitoring station has a data processing and analysis unit, as well as an acquisition data unit. The entire system is configured remotely through a web server or, in offline mode, through an editor. A database server establishes a modem link with all the measurement points and sets and stores all the raw and configuration data.

We installed an independent power system on the bridges through solar panels that guarantees the permanent monitoring of the structure and a satellite phone connection.

The system allows the data visualization in on-line mode and it is immediately and permanently accessible with a key. It also allows the process of both dynamic and static data in a fast and efficient way.

The web display of the monitoring allows a first instant review of the structure's state as it includes the instantaneous value of each sensor, the daily maximum and minimum and the historic maximum and minimum value.

The post-processing of the data will enable a more detailed study of the condition of the structure. With this, we can prepare the graphs and calculations needed for the study of the structure's static and dynamic behavior.

2 5 DYNAMIC AND STATIC MONITORING OF STRUCTURES.

Since it would mean cutting the bridge for load testing on static and dynamic conditions we decided to perform a simplified dynamic load test by making trucks drive in different directions and at different speeds, avoiding this way the difficulties and the road users' complaints.

Due to the lack of a structural evaluation, it is not possible to establish threshold values for the data we recorded in these tests that could serve as indicators for the structural safety of the bridges. Therefore, the idea is to repeat these tests periodically, verifying the recorded data through optical fiber sensors with the corresponding values of previous tests. If significant differences are detected, it is probable that in the time that passed between the two tests damage appeared in the structure. This damage has to be localized, evaluated and repaired so that the affected bridge can be used.

The truck we used (Figure 4) had to reach the set-point speed of each test before entering the bridge and maintain the speed consistency until leaving it.

The tests consisted of 6 phases with the truck circulating in two lanes and at the centre of the road.

Figure 4. Truck used during the load test and its passage through the structure.

Although greatly simplified, the implementation of this test made it possible to approach certain knowledge about the structure's behavior and to perform a 'calibration' of the monitoring system's sensors, that allows us to evaluate the dynamic behavior of the structure during the service time.

The following graphs (Figure 5) show the curves obtained by optical fiber sensors during the passage of the test truck's load and how the elastic behavior, amplitude, damping and vibration modes are analyzed in them. It should be noted that with the optical sensors we obtain signals that, without amplification, do not present noise and allow us to analyze the behavior with a lot of details. In addition to doing the optical transmission, we can make an absolute synchronization between all the optical sensors installed on the structures and see if the behavior is reproduced in each of them.

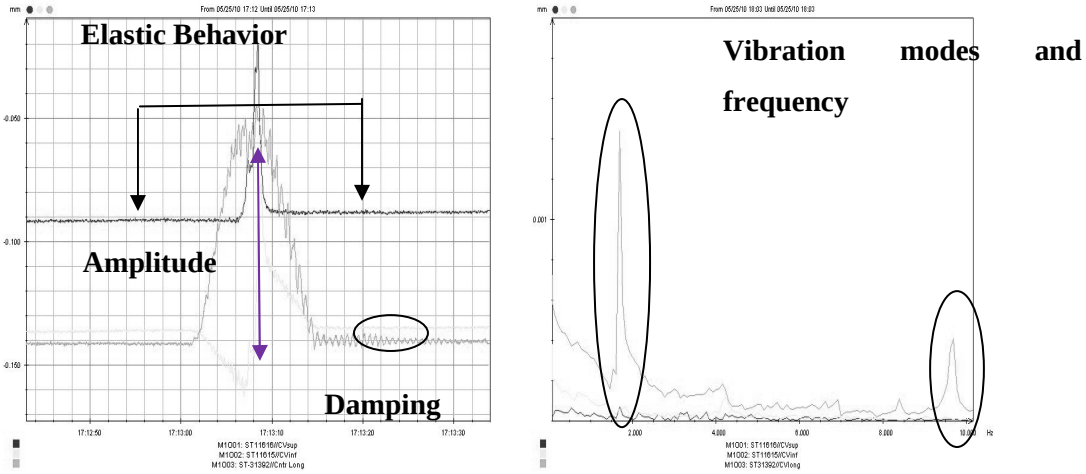

Figure 5. Graph of the structure's dynamic analysis.

3 6. STATIC AND DYNAMIC STRUCTURAL MONITORING OF STRUCTURES DURING SERVICE

Since we have optical strand sensors, we are currently monitoring the service performance of structures at a static and dynamic level, based on the same sensor.

6.1 Long-term static monitoring during the service

By recording the strains experienced by different elements of the structure, we monitor the bending and shear stress behaviors, as well as the evolution of the instrumented joints and supports.

The observation of static data records, obtained from the monitoring system, will detect if there is stress accumulation in the implemented elements that will help us in the prevention of further damage on the structure. If there is stress accumulation, this could be a symptom of a structural anomaly and result in future damages or pathologies. In the case of these bridges, we found stress accumulations in some elements, so we performed a specific data monitoring.

As mentioned, supports have been implemented by extensometers to check behavior and whether it is necessary to replace them if they do not do the work they had been designed for.

6.2 Dynamic monitoring of the traffic loads of bridges

For the structures under study and to obtain more complete information on their service performance, we also carry out the monitoring of their dynamic behavior under the traffic loads they experience every day.

Based on the strain data collected during the load test that was performed earlier, the actual loads are compared to the values obtained as reference.

In addition, a web camera was implemented in the monitoring system (Figure 6). This camera makes it possible to subjectively evaluate the loads in action and to relate them to the records retrieved. With this information, we can estimate the maximum generated amplitudes, the main frequencies, the vibration modes, the elastic behavior and damping.

The following figure shows the real example of the strains that occur in the various components implemented under the loads that are displayed on the presented web page.

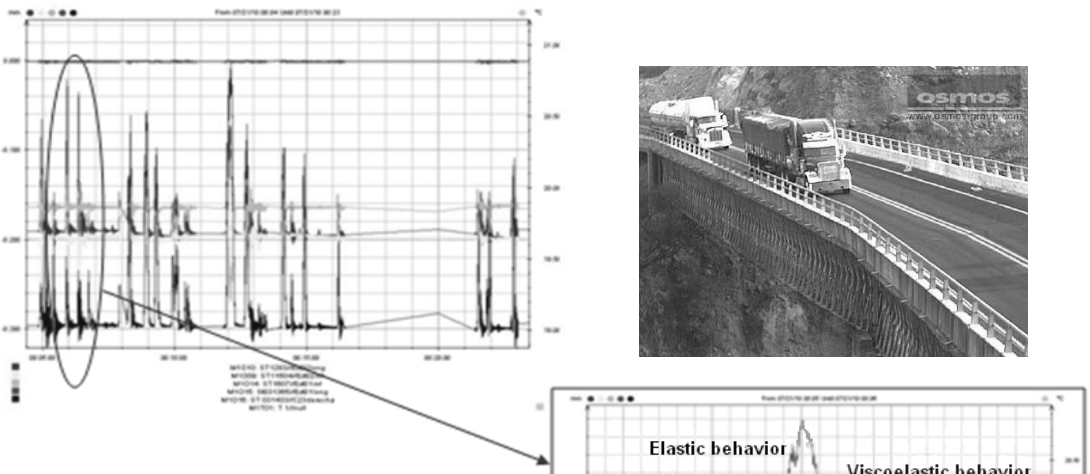

Figure 6. Data registry and the Web camera used to monitor loads.

4 7 CONCLUSIONS

It is now possible to have tracking systems and structural monitoring based on the analysis of structural behavior under service loads.

The instrumentation with optical strains is very fast and simple and provides accurate data on first-order effects (stresses and strains). This allows us to carry out the preventive monitoring of structures.

There are independent communication and power systems as well, which ensure permanent information availability. Structural engineering now has tools, such as monitoring with optical fiber, that was described in the sections about the ‘‘Tapón’’ and ‘‘Nuevo’’ bridges. This can, based on calculations and adjustments of the theoretical models, contribute to a better evaluation of the safety level of structures, now that cuts in investment budgets both for construction and maintenance are so determining.

We must add that mere data acquisition on a structure is not enough. These data can only be useful if we can automate their treatment and exploitation. It is necessary to establish some rational criteria, based on the structural reliability theory, that allow us to define threshold values for each monitored parameter we monitor through fiber optics sensors. If one of the measured values exceeds the corresponding threshold, the system will activate an alarm, automatically and in real time. This way the responsible for the work’s maintenance can immediately adopt the necessary risk mitigation measurements.

8 REFERENCES

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