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SMART STRUCTURES: FIBER-OPTIC DEFORMATION AND DISPLACEMENT MONITORING

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Abstract. *OSMOS developed two different types of fiber-optic deformation and displacement sensors, which are used for the monitoring of deformations, deflections and crack widths of various bridges in the world. One is next to Copenhagen, Denmark. There, the sensors measure permanently the static and dynamic behavior of the analyzed structure. They are part of the novel OSMOS monitoring system, which also integrates sensors for temperature, carbonation, chloride, moisture, pH, corrosion risk, and vibrations. All data are collected and processed by OSMOS. Additionally, the data are prepared for the on-line presentation via modem or World Wide Web.*

1 INTRODUCTION

As all structures – manmade or natural – are ageing, it is very important to know about their status, especially if they are used by the public, such as bridges or highways. The owners of the structures are aware of the importance to inspect and to maintain their structures and carry out controls, which can be classified in three categories: 1) Routine inspections, typically simple, visual inspections of the surface, which result in only minor cleaning and maintenance activities at long term intervals. 2) Principal inspections, typically more extensive than visual inspections, resulting in some maintenance activities at long term intervals. 3) Special inspections on request, which are principal inspections combined with special measurements and taking of samples. This may result in larger rehabilitation activities, test loadings, mathematical predictions of the lifetime etc.

These approaches are not sufficient as they give their results by far too late, only after damage occurred. OSMOS has developed a very powerful, permanent monitoring tool that can be operated remotely. It can be used for all kind of structures, e.g., bridges, highways, tunnels, dams, geo-technical sites, constructions, etc. OSMOS can accompany the structure to be analyzed from the very beginning, the construction phase or any later point in time. A set of sensors is installed at the monitoring site and is connected to an evaluation unit. This unit comprises an opto-electronic part for the fiber-optic OSMOS sensors and standard inputs for signals from other sensors, e.g., pressure, moisture, chloride, etc. A data processing system is comprised in the unit as well as a communication tool to allow for the remote operation via modem by point-to-point access or Internet. The full set of static and dynamic data is available from the monitored structure as all sensors allow for static and dynamic measurements.

2 THE OSMOS MONITORING SYSTEM

The OSMOS monitoring system was developed for structural analysis and therefore gives the most complete set of information that is thinkable. Using the OSMOS fiber-optic sensors, the following data is collected or derived: dynamic data, static data, and statistical data. To illustrate the power of the OSMOS monitoring system and the OSMOS sensors, the following self-explaining 10 examples of the obtained data are given, fig. 1 to fig. 10.

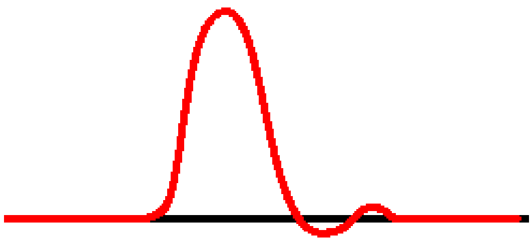

Fig. 1: Proof of the elastic behavior of the monitored structure, no offset after the event.

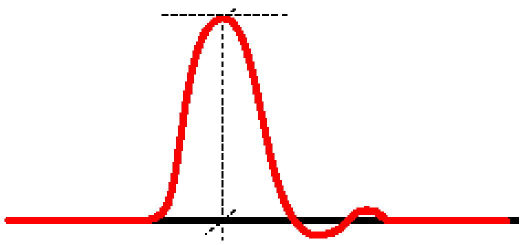

Fig. 2: Measurement of the amplitude of the event, e.g., load or intensity.

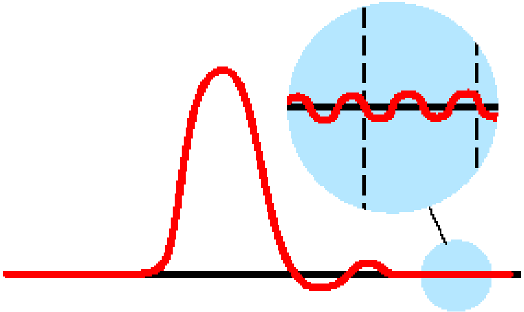

Fig. 3: Analysis of the eigen-period of the structure.

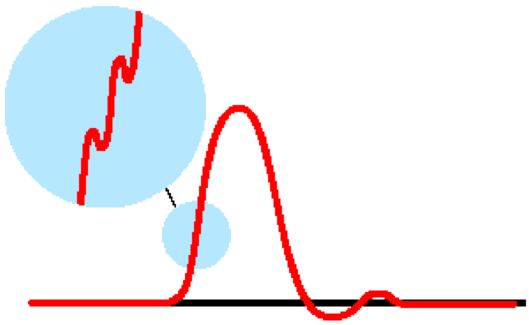

Fig. 4: Analysis of the higher harmonics of the structure.

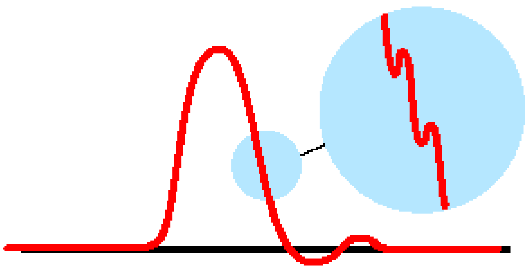

Fig. 5: Detection of micro cracks or hair cracks or shock effects of the structure.

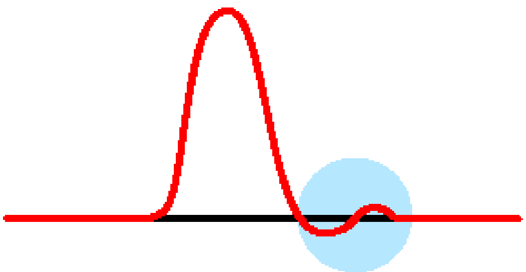

Fig. 6: Analysis of the visco-elastic behavior of the structure.

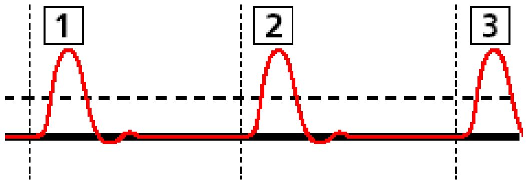

Fig. 7: Counting of events.

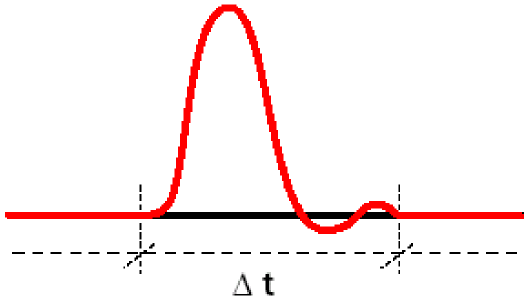

Fig. 8: Calculation of the speed of a single event.

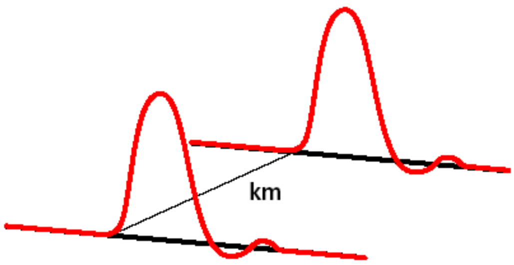

Fig. 9: Simultaneous measurement of multiple events.

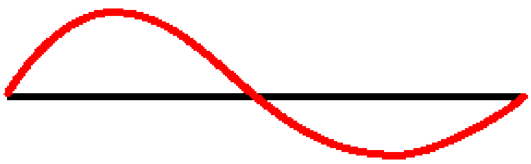

Fig. 10: Detection of extra-low frequencies, scale is minutes to hours.

3 FIBER-OPTIC DEFORMATION AND DISPLACEMENT SENSORS

OSMOS developed, based on the patented micro bending principle, fiber-optic deformation sensors with a long measurement base that can be up to 10 m long. The long measurement base is ideally suited for the integral monitoring of large constructions, e.g., bridges, tunnels, etc. If measurements over a short distance are required an OSMOS displacement sensor can be used, the optical extensometer. All sensors can be used for static and dynamic measurements of deformations or displacements in real time with high accuracy and high resolution on the order of 1 µm. The system allows a sampling frequency of 100 Hz, so that the static and dynamic behavior of a structure can be recorded. Laboratory and filed tests have proven an excellent long-term stability of the whole system with its components.

4 EXAMPLES

4.1 Skovdiget Bridge, next to Copenhagen, Denmark

OSMOS installed eight sensors at the Skovdiget Bridge to measure longitudinal deformations in the girders and transversal deformations in the ribs. Fig. 11 shows a picture from the installation.

Fig. 11: Mounting a 5-m long OSMOS fiber-optic deformation sensor under a girder, mid-span.

Fig. 12 gives the dynamic results measured in two directions as the response from the bridge to a heavy truck passing the bridge. The deformation of the girder is ~28 µ strain and the deformation of the rib is ~75 µ strain, due to the asymmetric loading of the bridge in this case.

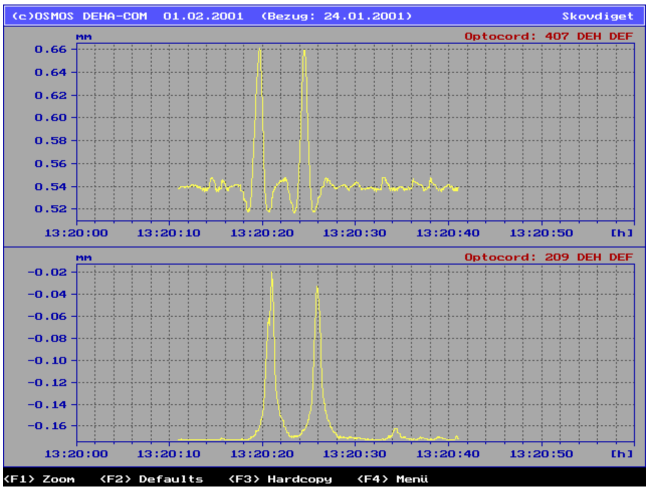

Fig. 12: Results from a 5-m long OSMOS fiber-optic deformation sensor under a girder (upper half), mid-span and from a 2-m long OSMOS fiber-optic deformation sensor under a rib (lower half), mid-span.

4.2 Herrenbrücke, Lübeck, Germany

The Herrenbrücke, a pre-stressed concrete bridge built in the late 1960, needs careful monitoring due to the heavy corrosion of the tensioned cables. OSMOS carries out the monitoring and the deformation analysis and also provides information about the traffic passing the bridge. This is one of the crucial factors for the lifetime of the bridge; hence OSMOS classifies the weight and the amount of traffic on that bridge. Fig. 13 shows a photo of a weak part of the Herrenbrücke.

Fig. 13: Position of four 5-m long OSMOS fiber-optic deformation sensors on the side of the girder in the weak part of the Herrenbrücke, Lübeck.

Fig. 14 shows the results from the traffic analysis for two weeks in the summer of 2001 starting on Sunday July 1st, 2001. Three different categories are displayed: 25 µm/5m deformation corresponding to loads over 12.5 t, 50 µm/5m deformation corresponding to loads over 25 t, and 75 µm/5m deformation corresponding to loads over 37.5 t. The load count is displayed on the ordinate as the number of events passing the threshold for a category in an hour versus time on the abscissa. On Sunday night, there is a small traffic peak due to the beginning of the permitted truck traffic time. The weekdays, days and nights, and the weekends can clearly be seen.

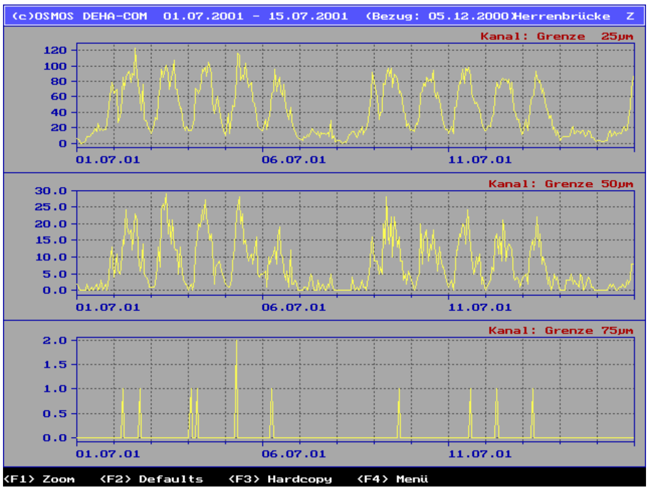

Fig. 14: Traffic counts and weight categories of the Herrenbrücke, Lübeck.

4.3 Wittenberg-Bridge, Wittenberg, Germany

The Wittenberg-Bridge, a pre-stressed concrete bridge built in the beginning of the 20th century, needs careful monitoring due to the increase of traffic, due to the poor shape of the surface of the beams and girders, and due to the absence of the construction plans. OSMOS carries out the monitoring and the deformation analysis.

A trial loading was carried out to analyze the structural integrity of the Wittenberg-Bridge on July 10, 2000. Hydraulic presses had been used to impose the load on the bridge. In this manner the bridge could be loaded and relaxed to the original position. Stepwise loading and unloading was done slowly to study the response of the bridge in detail. It was important to see, if the bridge stays elastic. Any inelastic behavior could lead to the formation of severe cracks and to the destruction of the bridge; hence this would have been the end of the tests – and the bridge.

Fig. 15 shows the results from the trial loading for loads up to 120 t. The bridge stays elastic all the time. In the beginning of the test, the temperature of the bridge is sinking; hence the sensors become a little bit shorter. The baseline therefore is not a straight line.

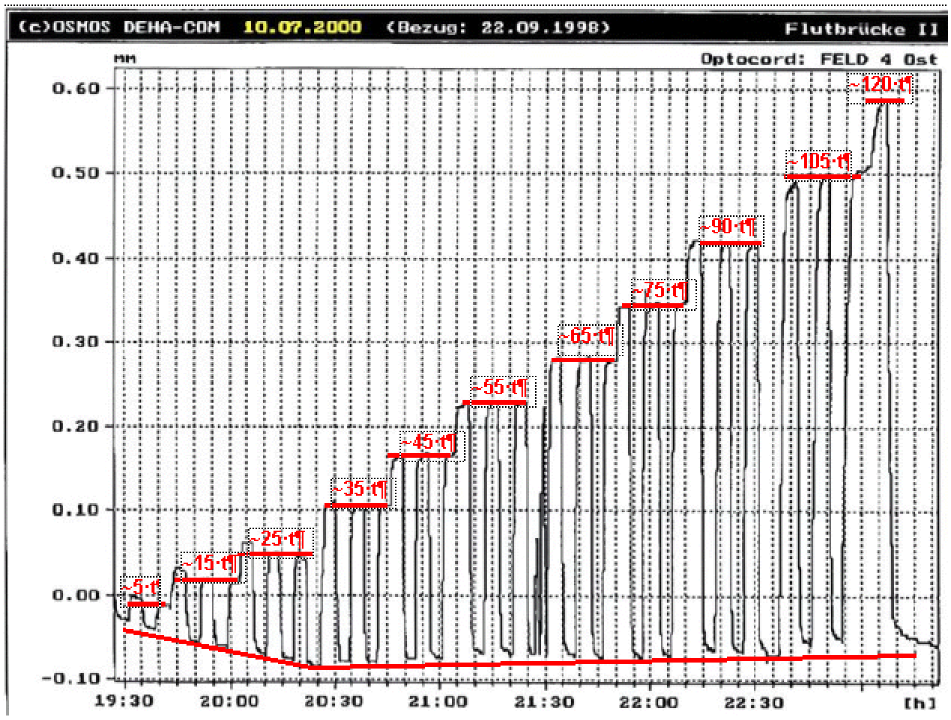

Fig. 15: Trial loading of the Wittenberg-Bridge on July 10, 2000. The load is increased from 5 t to 120 t.

4.4 Hohenzollern-Bridge, Cologne, Germany

The Hohenzollern-Bridge is a steel construction bridge with two parallel bridges on the same foundations with multiple spans crossing the river Rhine. It needs careful monitoring due to the increase of traffic. OSMOS carried out the deformation analysis due to the train traffic. The impact of different passenger trains was investigated on March 14, 2001 with a 2-m long deformation sensor. A photo of the bridge and the sensor location are given in fig. 16.

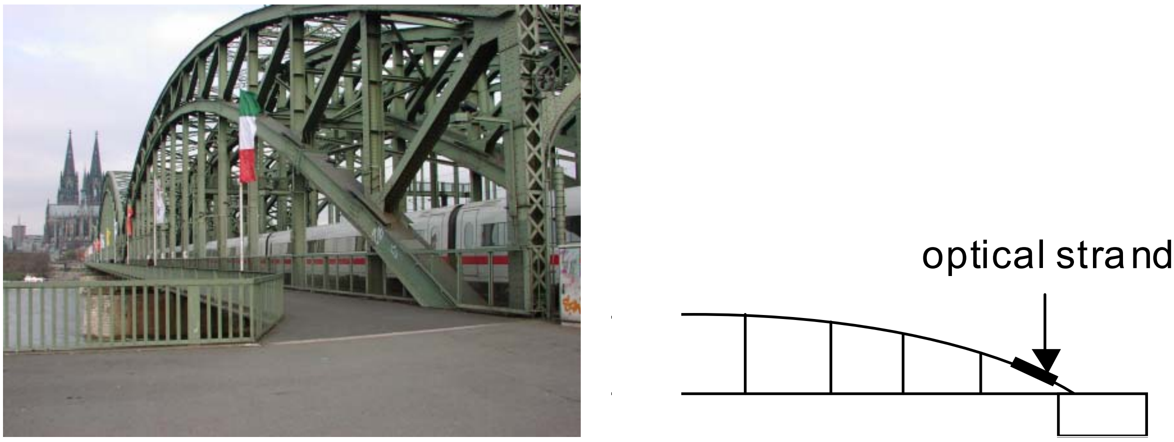

Fig.: 16: Photo of the Hohenzollern-Bridge with 2x2 tracks and position of the 2-m long optical strand.

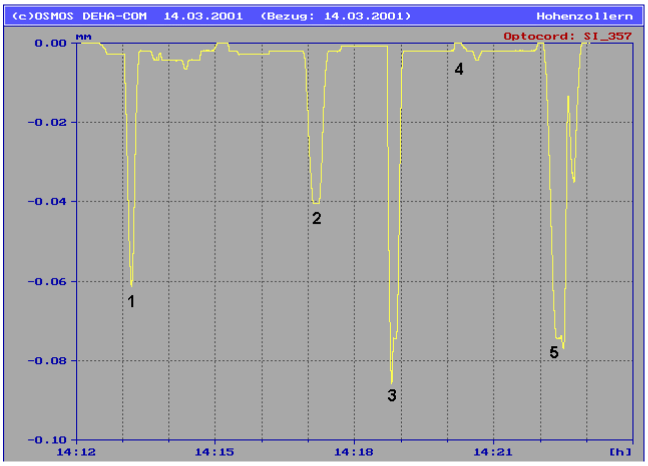

Fig.: 17: Deformation measurements with a 2-m long optical strand on the Hohenzollern-Bridge.

Fig. 17 shows the measured results with the 2-m long optical strand for five events within 11 minutes. Events 1 – 3 and 5 represent trains passing the bridge on track 1 or 2, whereas event 4 represents a train passing on track 3, on the parallel bridge on the same foundation. Event 4 shows that the foundations are quite strong because they lead to a clear separation between the two bridges. Therefore, the impact of the traffic on the neighboring bridge is barely measurable. The largest measured deformation is for event 3, a regional train, with a value of 90 µm/2 m = 45 µ strain. Event 6 represents two trains passing the bridge almost parallel on tracks 1 and 2.

5 CONCLUSIONS

OSMOS developed and introduced a novel powerful tool for the monitoring of all kind of structures. In particular, with the high accuracy and high resolution OSMOS fiber-optic deformation and displacement sensors the full power of the tool can be exploited. It allows for the early detection of structural problems. The monitoring data provide information about the status of an object, its usage, and they enable lifetime predictions. The OSMOS monitoring system leads to the reduction of the maintenance cost and facilitates significantly the management of a structure.

6 ACKNOWLEDGEMENTS

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