European Perspective on Monitoring-Based Maintenance

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ABSTRACT: The recent development of reliable short and long-term instrumental monitoring systems has opened new possibilities and challenges for the management of bridges and other civil engineering structures. These systems can provide quantitative information on the state of a structure and on its evolution. On the other hand, the large quantities of raw data that these systems often produce must be reduced to a small number of significant indicators that can be used for decision-making purposes. For this reason, we are currently facing a shift of interest from the development of new sensors systems to the design of data analysis and reduction strategies. This paper will discuss the current European trends in the domain of computer-aided data analysis and their integration into monitoring-based maintenance. The general discussion will be illustrated by a few application examples.

1 INTRODUCTION

2 SOFO DYNAMIC SYSTEM

The SOFO Dynamic system is designed to allow a full compatibility with the SOFO sensors already installed in several structures (Glisic & al. 1999, Inaudi & al. 1994). This also guarantees the possibility of using the same sensors with the standard SOFO reading unit, optimized for long-term stable measurements. Its performances are resumed in the following table:

Table 1: SOFO Dynamic system performances

Bandwidth	0 to 10 kHz
Resolution	0.01 µm
Measurement Range	± 5mm
Velocity range	max 10'000 µm /s
Drift	<0.003 µm/s <0.5 µm/day with compensation
Max number of channels	8 (7 with drift compensation)
Acquisition	Simultaneous
Digital readout	USB 2.0, 1kHz, 32 bits
Analog output	8 channels, 10kHz, 20 bits, adjustable gain

The SOFO Dynamic reading unit is therefore adapted for measurements down to static and has no low-frequency roll-off typical of accelerometers, for example. It can be used for static measurements over hours and days. However, the absolute zero point is lost when the sensors are disconnected or the system is powered off (Cekorich, 1999, Guaita 2000). Therefore the system is not adapted for long-term (year long) monitoring.

The following table resumes the main features and differences between the SOFO V static reading unit and the SOFO Dynamic reading unit.

Table 2: Comparison of SOFO V and SOFO Dynamic characteristics

	SOFO V Static Reading Unit	SOFO Dynamic reading unit
Application	Short and long-term static monitoring	Dynamic and short-term static measurements
Type of measurement	Self-referenced relative	Incremental relative
Sensor compatibility	Compatible with all SOFO sensors	
Output	SDB monitoring database	Digital output Analog output
Number of channels	Unlimited	8 per module
Acquisition	Sequential	Simultaneous
Data Logging	Yes, integrated	Through software or 3rd party DAQ

3 RECENT APPLICATIONS

3.1 *Bolshoi Moskvoretskiy Bridge, Russia*

Bolshoi Moskvoretskiy Bridge was built in 1936-37, over the Moscow River. It is situated in the centre of Moscow, next to the Kremlin, and leads the one of the main traffic lines of city to the Red Square. The bridge consists of three parallel 100m long reinforced concrete arch hidden behind stonewalls. The cross-section of each arch contains three merged boxes. The superstructure of the bridge is supported by columns. Four traffic lanes cross the bridge in each direction. Two types of the degradation are noticed on the bridge. Settlement in the centre of the arch which provoked the cracking of the stone walls near abutments on both sides of the bridge, and chloride diffusion that practically transverses the upper wall of the arch boxes in some sections, and penetrates inside the boxes. The condition of the bridge after nearly 70 years of service and its functional and historical importance have led the authorities to decide to continuously monitor structural behaviour of the bridge.

The aim of monitoring is to increase the knowledge concerning the structural behaviour of this very old structure, to increase safety and reduce maintenance costs. Total of 16 standard SOFO sensors are installed in order to continuously monitor average strain along the arch, curvature in both, horizontal and vertical direction and the deformed shape using the SPADS software. In order to distinguish thermal influenced 6 thermocouples are also installed. In a later stage the pre-warning and warning system will be set using the SOFO VIEW software. The data is sent remotely to the control room using a telephone line. The installation of all the SOFO equipment was completed in June 2003. The long-term monitoring started.



Figure 1: Bolshoi Moskvoretskiy Bridge: general view, cracking of the stone walls confirms the settlement in the middle of the arch; penetration of chlorides is visible in the interior of the arch boxes. Courtesy of Triada Holding, Moscow

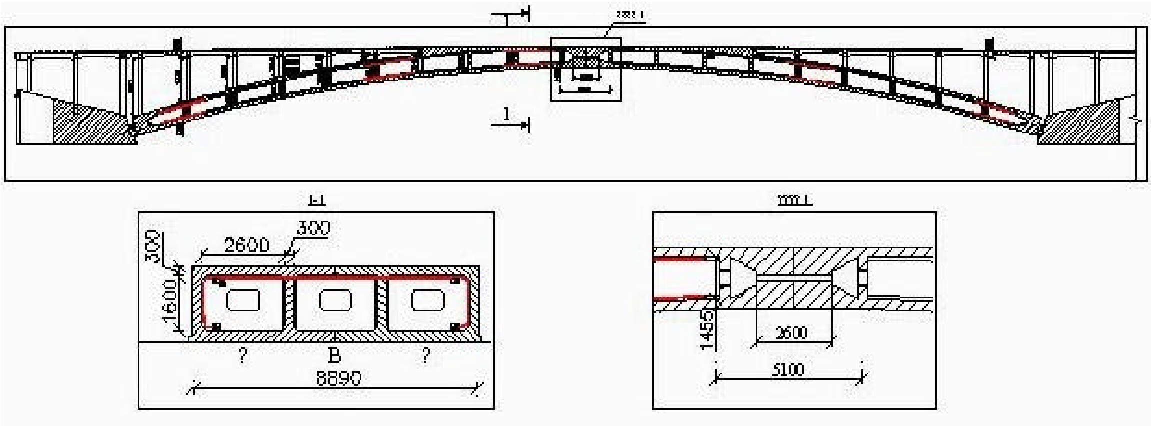

Figure 2: Bolshoi Moskvoretskiy Bridge: Longitudinal and cross sections, position of the sensors. Courtesy of Triada Holding, Moscow

Figure 3: Bolshoi Moskvoretskiy Bridge: SOFO sensor before and after the protection is installed, and a view to the intermediate connection box. Courtesy of Triada Holding, Moscow

3.2 *Schladming Bridge, Austria*

A new bridge construction for the widening of roads on alpine slopes is used in Austria for the first time. The new bridge construction is based on a continuous concrete slab that is tightly connected to concrete columns. The structure has no expansion joints and no bridge bearings. Temperature induced strain cannot dissipate and will lead to stresses within the bridge deck. Therefore, a monitoring program was established to measure internal deformations using eight fiber optical sensors of type SOFO.

Existing roads in alpine regions are very often too narrow for today's requirements. Common techniques for their widening like retaining walls are very expensive and difficult to apply in steep terrain. A new bridge construction was developed by the Consulting Engineers Office Eisner, Graz. A prototype of the new design was built near Schladming, Austria in 2002. The bridge is about 150 m long and supported by 30 concrete columns. A cross section shows that two thirds of the concrete bridge deck rest on existing ground whilst the remaining third cantilevers out (Figure 4).

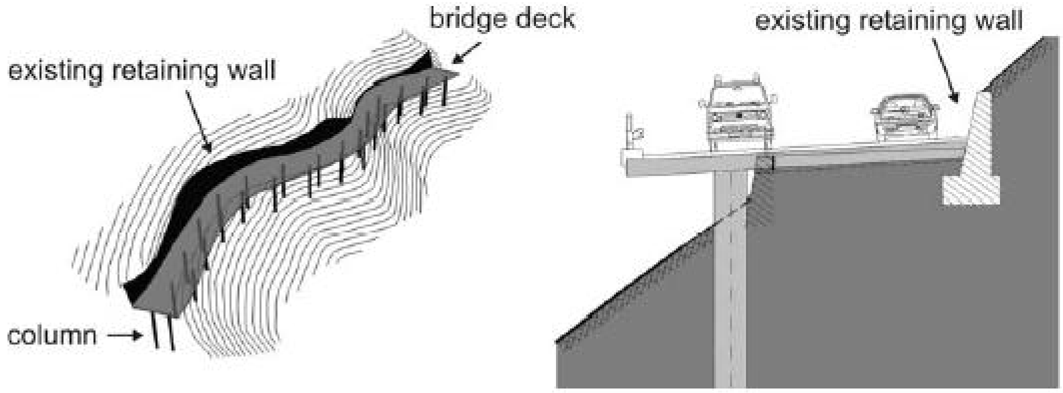

Figure 4: New bridge construction for the widening of roads in steep terrain, (Högler & Lienhart 2003)

Th results of one measurement profile are shown in Figure 5 (Lienhart, & al. 2003). In this profile four fiber optical sensors were embedded but only sensor 4 (figure 7-left) is in the cantilevered part of the bridge. Due to the low stiffness of the sensors it is possible to observe the hardening of the concrete at its initial phase. Figure 7-right shows the behavior of the concrete during the first 48 hours after pouring. Measurements started after all sensors were entirely covered with concrete.

The swelling of the concrete lasted 10 to 12 hours with an elongation between 0.05 mm and 0.13 mm for the 5 m sensor length. Remarkable is the smoothness of the curves. Especially if considering that for every single measurement the respective sensor was connected to the measurement unit and then disconnected again.

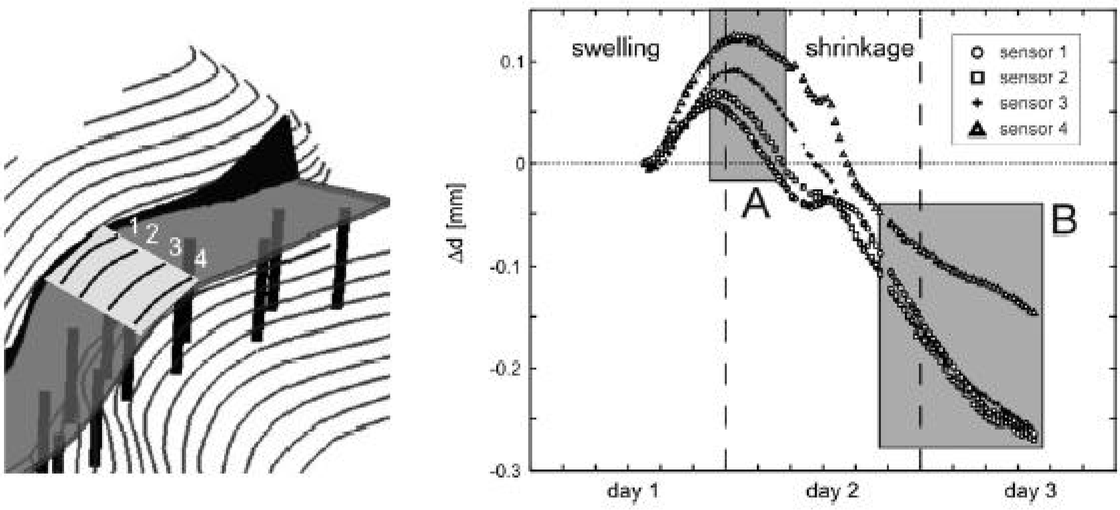

Figure 5: Measurement profile 3 (left), hardening of the concrete during the first 48 hours (right). Courtesy of Werner Lienhart and Fritz K. Brunner.

Due to the low stiffness of the sensors and the high precision of the system it is possible to measure phenomena like hardening of concrete that can hardly be observed using traditional geodetic techniques. The in-field precision of the system has been verified as 2.2 µm. Lienhart & Brunner have shown that a combination of fiber optical sensors and temperature sensors allows separating thermal expansion effects from other sources. The monitoring of the structure is being continued. A comparison of the measured deformations with simulations by FE models is planned as the next step of the investigation.

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