Monitoring of Civil Infrastructure – Techniques and Results

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Summary

Monitoring continuously the decisive parameters of an existing structure provides the quantitative basis for analytical modelling and the condition assessment in order to ensure the safety of highway bridges with regard to life extension and replacement strategies. In this paper the authors discuss the instrumentation and first results of the monitoring system installed on the Colle Isarco viaduct.

Keywords: structural health monitoring; instrumentation; data acquisition; sensing technologies; condition assessment.

1. Introduction

To a continuously growing degree, we observe an increasing shift from investments in the construction of new infrastructures to the maintenance and lifetime extension of the existing ones. In Europe, e.g., the annual upkeep for bridges amounts from 0.8% to 2.5% of the construction costs [4]. The continued use of existing systems is, due to environmental, economical and socio-political assets, of great significance growing larger every year. Considering modified loading requirements, aging of materials and environmental actions, performance of many of these in-service structures has decayed over the years of utilization and the inherent level of safety may be inadequate relative to current design standards.

In front of this background we find the necessity to identify the key parameters and procedures to verify and update the knowledge about the present condition of a structure with respect to a number of aspects. A visual inspection may yield a first qualitative, maybe purely intuitive impression. A better judgment would be based on the evaluation of acquired quantitative information. Recent progress in the development of sensing and data processing technologies combined with material/structure damage characterization have resulted in a significant interest in diagnostic tools to monitor structural integrity and to detect structural degradation. The definition of the objective of the instrumentation program usually follows the realization that something about the structure is not known well enough and that measurements of a number of quantities at a certain location would be desirable for the sake of economy or safety. Adequate monitoring techniques provide qualitative and quantitative knowledge that facilitates a more precise condition assessment and efficient maintenance interventions [4].

This paper is intended to discuss the experiences gained by the authors in the application of the monitoring system installed on the Colle Isarco Viaduct (Fig. 1). The overall length of the instrumented section of this massive prestressed concrete structure is 378 m. The maximum height of the box girders near the supports number 8 and 9 is 11 m, having a uniform width of 6 m. the arrangement for each roadbed is approximately 11 m wide. The height of the 4 supporting piles No. 7, 8, 9 and 10 varies between 33 and 60m. The bridge was built in 1969 and was upgraded through an essential rehabilitation intervention in 1999 – 2000 (Fig. 2).

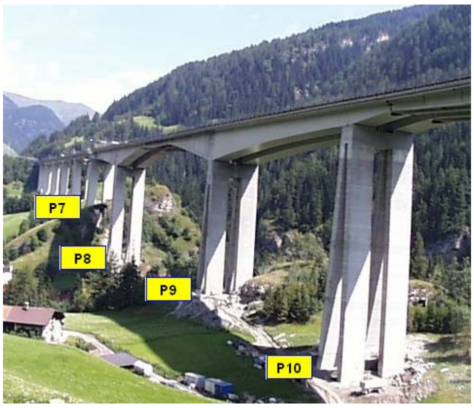

Fig. 1 Instrumented section of the viaduct

Fig. 2 Rehabilitation of the piles

2. Deformation Monitoring

Recent advances in fibre optic sensing has led several technologies to become an alternative to classical electrical, mechanical or vibrating wire strain gages. Among them, Bragg grating and Fabry-Perot sensors are available to provide local strain measurements, the fibre optical extensometers SOFO provide a very accurate and reliable measurement of the relative displacement of any two points chosen in a structure at distances from 20 cm to 30 m. The SOFO sensor, developed by Inaudi et Al. [2], consists of a pair of single-mode fibres installed in the structure to be monitored. The measurement fibre is in mechanical contact with the structure itself and will therefore follow its deformations in both elongation and shortening. The second fibre, called reference fibre, is installed free in the same pipe. All deformations of the structure will then result in a change of the length difference between these two fibres. To make an absolute measurement of this path unbalance, a low-coherence double Michelson interferometer in tandem configuration is used. The first interferometer is made of the measurement and reference fibres, while the second is contained in the analyzer unit. This second interferometer can introduce, by means of a scanning mirror, a well-known path unbalance between its two arms. Because of the reduced coherence of the source used, interference fringes are detectable only when the reading interferometer compensates the length difference between the fibres in the structure. This type of sensor has a resolution of 2 microns and is, like most fibre optic devices, insensitive to temperature, humidity, vibration, corrosion, and electromagnetic fields.

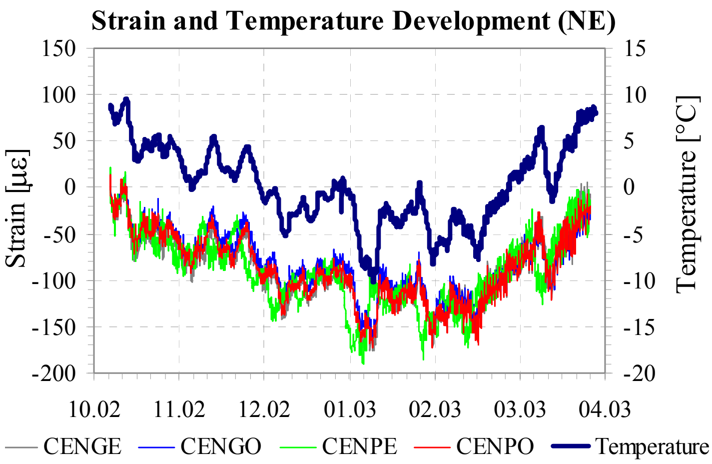

Fig. 3 Prestressing members - strain and temperature

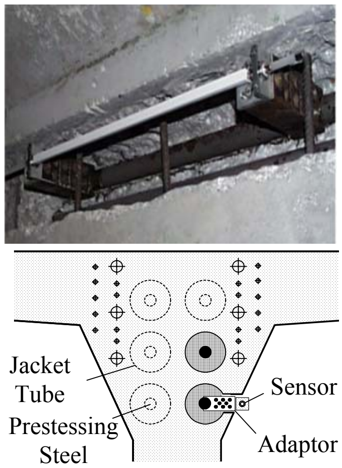

Fig. 4 Installation scheme

In the present monitoring system, a network of this type of sensor was installed for strain and deformation measurements. 96 fibre optical SOFO-Sensors with a base length of 10 m were installed on the concrete surface parallel to the neutral axis of the box girders in order to determine the vertical, horizontal, and torsional deformations (Fig. 5). Sensors with a base length of 0.5 m were used to measure the strains of 16 selected prestressing members (Fig. 3 and Fig. 4). Another 24 sensors with a base length of 8 and 10 m were installed on the piles P7 and P8 (Fig. 7). Each sensing fibre is addressed separately and subsequently multiplexed to a readout unit that performs the necessary interpretation of the optical effect to a discrete signal (Fig. 6). The measurement intervals are scheduled by a PC-Software and the results are archived in a relational data base repository.

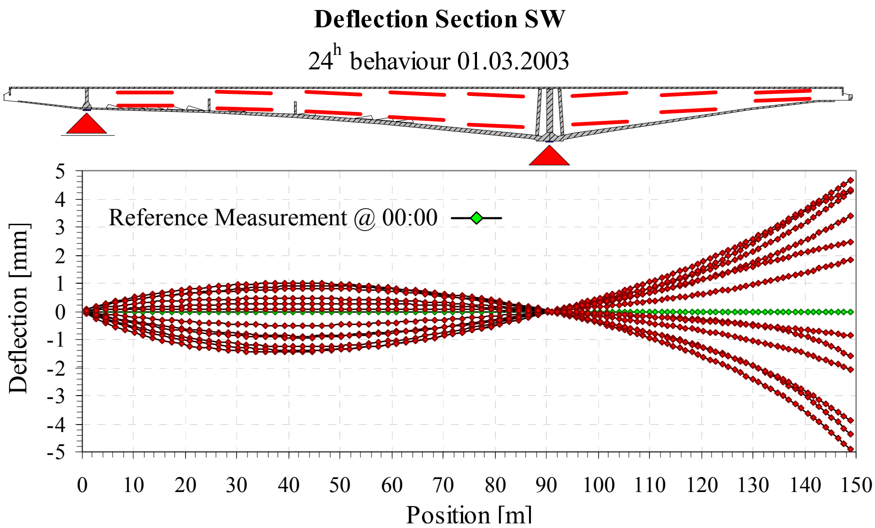

Fig. 5 Vertical deflection behaviour of bridge SW

Fig. 6 Central measurement unit

Fig. 3 shows the strain and temperature evolution for the period of approximately 6 months. By a continuous observation of the strain evolution, eventual prestressing losses and associated failures should be detectable in the domains of both short and long-term stresses. The same evaluation of strain can be made for the 96 sensors installed parallel to the neutral axis on the concrete surface of the box girders as well as for the 24 sensors installed on the piles P7 and P8.

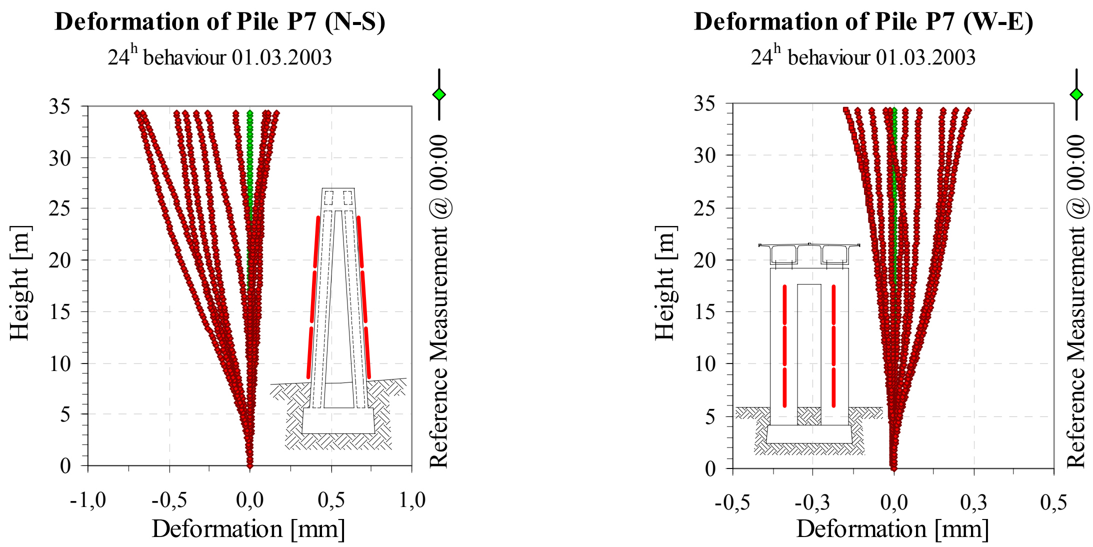

Fig. 7 24h deformation behaviour of pile P7 in North-South and West-East direction

In an advanced evaluation step the strain measurements of this network of sensors build the basis to calculate the displacement and curvature profiles by an algorithm described in [1]. Fig. 5 shows the exemplary 24^h deflection behaviour of one out of 4 instrumented bridge sections. The extreme values for vertical deflection over the whole measurement period (since 01.06.2001, always referenced to the zero campaign on 01.03.2003) range from -6.3 mm to +7.7 mm at mid-span (l=45m), and from -31.1 mm to +27.5 mm at the end of the cantilever beam (l=150 m). These values include both traffic and environmental loading.

The same calculus concept is applied to the piles. Fig. 7 shows the corresponding deformation of pile P7. Over the whole period the displacements accumulate to 8.5 mm in the longitudinal and 3 mm in the transversal direction. Additionally, 10 LVDTS have been installed to instrument the relative displacements between piles and girders on the bearings. Another approach that found application in the present monitoring system was the installation of 36 highly accurate inclinometers. On the one hand, these devices complete the fibre optical network with information on the rigid body displacements of the structure. On the other hand, vertical deflections can alternatively be determined by a similar algorithm as described above [1]. In order to separate the influence of thermal gradients in the structure and other agents (traffic, snow, wind), 96 thermocouples (T-Type, embedment depth 200 mm) have been installed in the girders and another 16 on the piles P7 and P8. The microclimate in the 8 chambers of the bridge is monitored by transducers for air temperature und relative humidity. Due to the large spatial distribution of the installation spots, all electrical sensors are read by a distributed data acquisition network consisting of 12 local nodes which are connected to one central control unit with remote access capability (Fig. 6).

3. Durability Monitoring

On 4 selected columns of the Colle Isarco viaduct 12 electrochemical multiprobes have been installed to determine the concentration of free chlorides, corrosion current, concrete resistivity, temperature, and electrochemical potentials at different embedding depths. These multiprobes have been developed at the IBWK/ETHZ by Zimmermann, Schiegg, Elsener, and Böhni. A more detailed description can be found in [3]. Prior to any instrumentation, potential field measurements were performed to determine whether the reinforcement of the columns is in an active or passive state. This and a laboratory chloride analysis led to the identification of representative installation locations for the sensing elements. The central chloride sensitive element in the electrochemical sensor is a silver wire coated with electrochemically deposited silver chloride (AgCl).

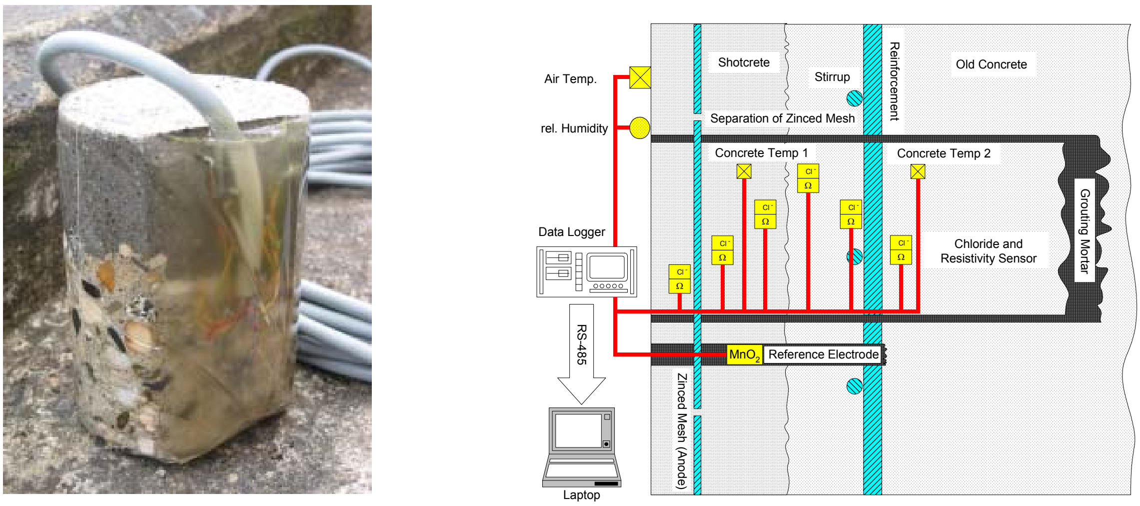

Fig. 8 Corrosion sensing multiprobe and installation scheme

The main resume after 2 years of monitoring is essentially, that the applied rehabilitation concept (cathodic protection through a zinced mesh, Fig. 2) proves to work in the expected way, which means that we observe generally a positive corrosion current flow between zinced mesh (anode) and the reinforcement (cathode). The concrete resistivity was not significantly influenced by precipitation, whereas the sensors captured drying and hydration of the young shotcrete after rehabilitation. As the concrete resistivity is affected by temperature to a greater extend as initially assumed, an exacter instrumentation of the temperature distribution would be desirable. Chloride measurements yielded only in part reasonable and stable values as they were influenced by other corrosive processes, however the concentrations found were in the expected range (< 0.01 mol/l). A more detailed discussion can be found in [4].

4. Conclusion and Future Work

Accompanying to the measurement activities, the monitored structure was analyzed with SARA [5], a software package based on the 3D nonlinear FE program ATHENA and the probabilistic reliability analysis tool FREET. The probability distribution functions for the basic input variables are obtained from stochastically models and, related to the present monitoring program, from the comparison with the recorded structural monitoring data. Comparison and combination of measured and analytically modelled behaviour is useful to calibrate and tune the mechanical and numerical model assumptions in order to facilitate analytical prediction and to support decision-making for maintenance and repair interventions. A detailed description can be found in [6].

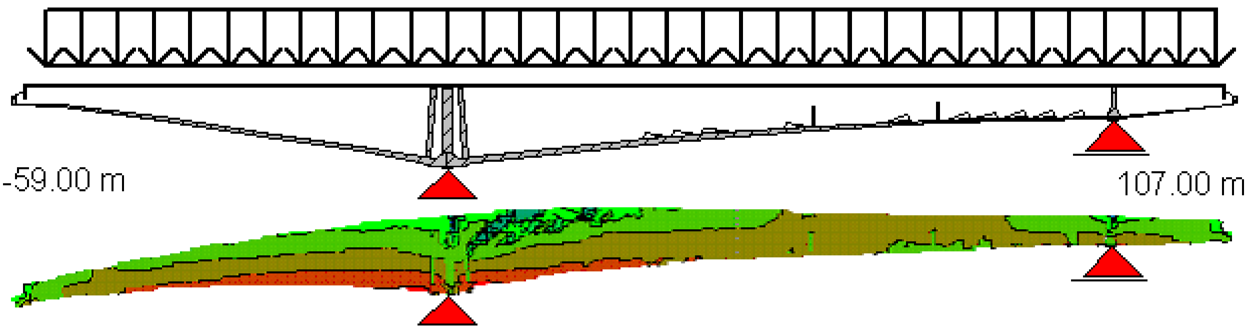

Fig. 9 Reliability analysis of the Colle Isarco bridge with SARA [6]

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