STRUCTURE ASSESSMENT BY CONTINUOUS MONITORING – APPLICATION TO SORRAIA RIVER BRIDGE

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SUMMARY

During the scope of a research project a prestressed concrete structure, Sorraia River Bridge, is being continuously monitored with the purpose of performing it assessment. Concrete structures when exposed to hard environmental conditions, tend to deteriorate. Such deterioration is the principal cause for them to become anesthetic and unsafety. Is also responsible for rising the costs related with it maintenance. The developed continuous monitoring system intends to help owners to achieve a better structure maintenance by controlling the long term structural behaviour and so reducing it degradation. In this paper a brief description of the bridge and of the instrumentation plan is realized. A methodology that intends to perform the structural assessment is also explained and some results presented.

1. INTRODUCTION

Civil engineering structures are submitted to stresses and climate factors that can result in physical and chemical material changes. With time such modifications, in case are not detected, may cause the structural degradation and eventually it collapse resulting in considerable economic and social costs.

The concrete structures deterioration, reflected by cracking, spalling, etc., is the principal cause for the high costs dispended by owners in it maintenance. This degradation also turns such structures more anesthetic and, as a result, other materials are being chosen in detriment of concrete.

Traditional techniques for inspection and maintenance of structures are inefficient when applied isolatedly. These techniques are very demanding in terms of time and human resources, are subjective and need expensive equipment. Such techniques are useful in a first analysis of the structure condition (Bergmeister and Santa, 2001).

To minimize the costs with inspection and maintenance of structures, a continuous monitoring system can be used. This system is innovative, performs the on time behavior control of structures, is objective and is more efficient and less expensive than traditional techniques. With such system, deterioration is minimized and more aesthetic concrete structures can be obtained.

A research project, with the objective of developing and implementing a continuous monitoring system, is being developed in Portugal. This project, that joins Portuguese research laboratories and infrastructure owners, has as main objective to prove owners the
advantages of such system. The continuous monitoring system will be first applied and tested in a highway pre stressed concrete bridge (Sorraia River Bridge).

2. SORRAIA RIVER BRIDGE

2.1 Structural description

The analyzed structure is a pre stressed concrete bridge, with a total length of 270 m, constructed by the cantilever process (Fig.1). The structure is divided into three spans, being the end spans 75 m length and the central span 120 m length. The bridge section is of box girder type. The section height varies from 2.55 m at mid span to 6.00 m at the support region (Figueiras et al., 2004).

The hollowed type columns, in reinforced concrete, are 7.5 m high. They are connected to the bridge deck by unidirectional bearings. Each column is supported by a cap pile of five piles each. The piles, with a diameter of 2.00 m, are cast “in situ” and about 30 m long.

![Fig.1 Sorraia River Bridge a) General view. b) Cantilever Construction.](image)

2.1 Instrumentation plan

To facilitate the implementation of this automatic and remote continuous monitoring system, the whole sensor network will be measured from two easily accessible locations (Observation Point – OP) according to Fig.2. The main sensor network is composed by 42 fiber optic Bragg grating sensors (temperature and strain sensors) and 42 electrical strain gages embedded in the bridge deck (deck sections S1 to S7), by 8 fiber optic Bragg grating sensors and 8 electrical strain gages placed in the bridge piles (pile 2 and 4), and by 2 fiber optic Bragg grating sensors and 2 electrical strain gages located in concrete shrinkage prove inside and outside the bridge. Additionally, there exist 2 humidity and 2 external temperature electrical sensors positioned in the interior and in the exterior of the bridge deck to observe the environmental conditions. All the embedded sensors are protected from physical and chemical attacks by special sensor holders developed in laboratory (Figueiras et al., 2004).

In each section, and for each sensor, there will be one local junction box that facilitates the cable connections after the concreting. In each Observation Point (OP) there will be one central box, which includes a reading unit, an optical switch, a portable PC and a modem to monitor the bridge remotely. In Fig.3 it is possible to observe the “in situ” application of sensors in bridge pile and deck (section S6). All the application was done with careful and some practical considerations were always taken in account. The obtained sensor survival tax is greater than 95% which is a real success.
3. METHODOLOGY

To realize the structural assessment two independent but integrated systems were developed. The Database System Consultation (DSC), that contains a remote communication module with the Observation Points (OP), is responsible for the storage and process of data. The Structural Behaviour System Visualization (SBSV) performs its visualization (Fig. 4).

During the construction of those systems, several technologies and languages were used and integrated together, such as: SQL, PHP, C++, LabVIEW, Flash and HTML. The access to such systems is made by Internet allowing the entrance in a restricted environment. The appropriate SBSV operation will depend fundamentally of the correct work of four components, responsible for the routines namely below (presented according to the following execution order):

- Reading input data;
- Execution of the visualization model;
- Graphic construction of the bridge deformed;
- Output generation.
Fig. 4 shows the SBSV and DSC components and display the relationship among them. As is possible to verify from the scheme, the process and storage of SBSV input data is done in the DSC, which should allow the user, if has interest, to filter the measurements from a selected period. The obtained and previously treated results (DSC output data) are used to interpret the global behaviour of the bridge (SBSV input data), but contain temperature, shrinkage and creep effects and also the influence of loads or actions on the bridge (Equation 1). To decompose and to interpret the sensor measurements, it is used a C++ algorithm, combined with LabVIEW code (National Instruments, 2003).

\[ \varepsilon(t) = \varepsilon_T(t) + \varepsilon_{cs}(t) + \varepsilon_{cc}(t) + \varepsilon_{el}(t) \]  

With the measurement of the temperature on the bridge, shrinkage prisms and knowing the creep law of the concrete, it is possible to decompose the value of the strain measured by the sensors as illustrated in Fig. 5. If the long term effects as the temperature effects, shrinkage and creep are well calibrated, every significant difference is probably an elastic strain induced to the structure. This methodology permits at this point to identify anomalies on the bridge (assessment support or cracking for example).

![Fig.5 Decomposition of the measured strain by the sensor.](image)

At a second stage it is calculated the seven monitored sections (deck sections S1 to S7) curvature and it temporal variation by the least squares method as illustrated in Fig. 6. Statistical parameters are considered to evaluate the goodness of the fit as the chi-square merit function - \( \chi^2 \). With that it is possible to verify the existence of any sensor that has an atypical behaviour. If it exists, that can be due to a sensor problem or a local problem on the concrete section.

![Fig.6 Curvature estimation based on the strain sensor measurement.](image)
This procedure it’s not applied to the strain value obtained by the sensor, but to the different types of strain (temperature, shrinkage, creep and elastic) detailed before. Knowing the curvature and other conditions that restrain the behaviour of the bridge, it is possible to estimate the global deformation of it by a polynomial function. Knowing the fractions of the temperature, shrinkage and creep strains it is possible to estimate the global deformation as a sum of partial deformations according to Fig. 7.

Fig. 7 Global deformation bridge estimation.

4. OBTAINED RESULTS

In this point, it will be presented some preliminary results based on strains and temperatures obtained in the section S6 (Fig. 8), located on the pile P2 (Fig 2). The measurements from the sensor S6-3I, with and without filtering (G1), are presented in Fig 9. Fig. 10 (a) displays the records of environmental and inside section temperature, while Fig. 10 (b) brings two graphics, one of them is the graph of strains G1 without the hyperstatic component of temperature, and other, is the reference graph, whose visualization is optional that, in this case, corresponds to the deformations from G1 after application of a median filter.

Fig. 8 Sensors in S6 section, highlighting the S6-3I, TS6-AE and TS6-AI sensors.

Fig. 9 Strains in S6 section (S6-3I sensor).
5. CONCLUSIONS

This paper describes the application of a continuous monitoring system developed during a research project in Portugal to a real concrete prestressed bridge, Sorraia River Bridge. The purpose of such monitoring system is to perform the long term assessment of the bridge controlling it deterioration by accompanying it behaviour.

This long term monitoring system when placed in a concrete structure is responsible for growing the structural safety, which is important for users, and for minimizing the maintenance costs, important for owners. It is also very significant in increasing the structures life cycle by controlling the deterioration processes and so phenomena’s like cracking, spalling, etc. Such control turns concrete structures more aesthetic and the concrete material more interesting.

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7. REFERENCES