INTRODUCTION

Civil infrastructures health monitoring should have the potential for the on time detection of possible anomalies or critical situations, diminishing costs related to inspections and simultaneously growing structural and users’ security. Inserted in a research project – SMARTE project – a new surveillance technique for prevention and support of civil infrastructures maintenance and management was applied into a real prototype structure – Sorraia River Bridge.

The civil infrastructures inspection programme has as main objective the eventual detection of anomalies that might compromise the structural safety and consequently of their users. In this way, traditional surveillance techniques, although important are expensive, slow in time and subjective. Considering such panorama, within a national research project - SMARTE project - a new technique for management and maintenance of structures was developed and implemented in a real structure, a pre-stressed concrete bridge (Sorraia River Bridge). The developed technique, long term structural health monitoring, has as a final purpose the execution of structural maintenance in an objective and efficient way. The evaluation of the structural behavior during whole life cycle is performed in an “on line” continuous way, allowing the on time detection of existent damages.

1 INTRODUCTION

Civil infrastructures health monitoring should have the potential for the on time detection of possible anomalies or critical situations, diminishing costs related to inspections and simultaneously growing structural and users’ security. Inserted in a research project – SMARTE project – a new surveillance technique for prevention and support of civil infrastructures maintenance and management was applied into a real prototype structure – Sorraia River Bridge.

The civil infrastructures inspection programme has as main objective the eventual detection of anomalies that might compromise the structural safety and consequently of their users. In this way, regarding what was previously stipulated within the grant established with the Portuguese State, the firm BRISA (Portuguese Highways) defined a huge long term periodic inspection program to all civil infrastructures inserted on their highway network. At present date, within all network it exist more than 1600 civil infrastructures that are in service. To perform such objective BRISA implemented new civil infrastructures management systems, having developed since January 2003 a specific service that focus this theme, designated by GOA (Gestão de Obras de Arte). So, supported by an exhaustive data base where all information related to the respective infrastructures is stored, this system possess, within other applications, a specific inspection module where it is registered all executed inspections indicating the structural state and the eventual necessity of rehabilitation and / or reinforcement.

Such inspections are essentially visual ones being in some cases, when the circumstances claim that, also used specific and elementary Non Destructive Tests (NDT). The periodicity on inspections that BRISA defined for their highway network, and namely the ones related to the set of civil infrastructures that integrate it, is in general of 3 years for common structures and 6 years for more specific ones (bridges and viaducts). This methodology is explained by the fact that most of the structures being relatively recent, namely the ones related to the conclusion of
SMARTE project, which consist in the development and implementation of a system for monitoring and remote management of civil infrastructures, allow the acquisition of real time information with the possibility of visualizing graphics and schemes where the establishment of limit security values for the different measured parameters will permit the alarm generation always when fixed levels are reached, is considered as one more value for the actual civil infrastructures management program of BRISA (GOA).

2 SMARTE PROJECT

2.1 Project Description

SMARTE project was essentially based in the development and installation of a long term remote structural health monitoring scheme in a prototype structure, Sorraia River Bridge, which belongs to the highway A13 (Portugal). This bridge is composed by two continuous parallel decks with three spans each. As it is possible to observe in Fig. 1 such bridge has a total length of 270 m being, respectively, 120 m and 75 m length the midspan and the end ones. The transversal profile of each deck comports two roads for one direction of traffic only.

Each deck is supported by two central and two transition piers that realize the connection between the bridge and the North and South access viaducts, respectively, with 487 m and 909 m length. A dilatation joint is inserted between the bridge and each viaduct. The longitudinal and transversal pre-stressed deck consists in one single box girder with 14.45 m width and a height that varies from 6.00 m over the piers to 2.55 m in midspan centre and in end span extremities. Central columns are rectangular and hollowed (6x3.5 m section) with a 0.60m thick and 8.00 m height walls. Such piers are founded in a cap with five piles of 2.0 m diameter and 35.0 m length. The necessity to cross Sorraia River in an oblique way and the impossibility of executing intermediary supports were the main reasons for using the cantilever constructive process with “in situ” concreting of dowels (GRID 2003).

The instrumentation plan of Sorraia River Bridge, basis of the long term structural health monitoring scheme, is presented in Fig. 1. In order to ease the implementation of automatic and remote monitoring, the whole sensor network will be measured from two accessible locations (Local Station - LS). There are 42 fibre Bragg grating temperature and strain sensors (FBG) and 42 electric strain gages located in bridge deck (instrumented sections S1 to S7), 8 FBG and 8 electric strain gages placed in bridge piles (instrumented piles 2 and 4), and 2 FBG and 2 electric strain gages placed in concrete shrinkage proves inside and outside box girder. Additionally, there are 2 humidity and 2 external temperature electric sensors, also placed inside and outside the bridge deck (Figueiras et al. 2004, Matos 2005a).

Figure 1. Sorraia River Bridge instrumentation plan.

2.2 Main Objectives

SMARTE project has two main objectives. The first one is related to the installation of the sensory system in the bridge, which should be liable and robust. This component, based on sensors that were placed in special locations according to a previously established criteria, will allow the readings and storage of most important parameters for a correct interpretation of the struc-
ture behaviour during its whole life cycle. The second main objective is related to the development of a component for data processing and archiving. Such system should translate the obtained data in more objective information that could be used as decision criteria for civil infrastructures management.

In Fig. 2 the scheme of the developed long term structural health monitoring is present. The sensory system is constituted by electric and fibre optic sensors (fibre Bragg grating sensors - FBG) installed in specific structural sections. Selection of the most appropriate data acquisition algorithm is an important role of the data acquisition system. This selection depends on the volume of stored data and on the type of diagnostic information that can be obtained. This algorithm is introduced either in a data logger, for electric sensors, and in a demodulation equipment for FBG. Both equipments are connected to a CPU device by a digital cable (RS232). In such CPU all data, from electric and FBG, is automatic conditioned. The communication system function is to send all information from the civil infrastructure to a central station where it is finally processed and stored. In this case the data is remotely sent via Modem (GSM – Global System for Mobile Communications). Data processing and archiving system, responsible for the storage and treatment of all collected data, and damage detection and modelling system, responsible for the structural behaviour analysis, are placed in such central station (Figueirais et al. 2004, Matos 2005a).

![Diagram of the developed long term structural health monitoring scheme.](image)

Figure 2. Long term structural health monitoring scheme.

3 STRUCTURAL HEALTH MONITORING

3.1 Sensory System

In long term structural health monitoring the used sensors are expected to perform reliably for the entire lifetime of the structure. Therefore, special attention has to be paid to the development of an appropriate technique of sensor application.

For the instrumentation of new structures sensor holders that can be placed in fresh concrete, covering the sensor, are recommended. However the measurement of strains in concrete oblige such holders to have proper characteristics, which are: (i) offer an adequate robustness against possible damages that can occur during the structure execution process; (ii) protection to chemical attacks during the structural life; (iii) guarantee an equal deformation of the involving concrete; (iv) measure any deformation induced to the holder; (v) preventing that the constituent material rigidity do not modify the local deformation of concrete.

Having this into account a new type of sensor holder, to be embedded in new concrete structures for long term monitoring, was developed within SMARTE project. The respective I type holder is in composite material (epoxy resin), being it extremities condensed with carbon fibres. Such holders present a very good behaviour when submitted to compression and tension.
stresses with or without cracking. Their life cycle is also very long as the sensors are inserted in a composite material with high durability. At the same time they are more economic than other holders as it is not necessary to use sensors which integrate the deformation throughout the whole length, more expensive. Usually the used sensors in these holders are typical metal resistance gage or fibre optic Bragg grating sensor that measure localized strain and temperature. The developed holders were applied in Sorraia River Bridge according to the previously established instrumentation plan (Fig. 1). Such structure was executed by the cantilever process (Fig. 3) and so the holders’ placement was realized having the construction timings into account. Conventional strain gauges were placed near developed holders to evaluate their behaviour as it is presented in Fig. 3. During construction some procedures were taking into account in order to obtain a robust and liable sensory system, proper for long term monitoring. Each cable end was protected, during respective dowel concreting, by metallic junction boxes developed for the purpose. After this phase the respective boxes were open and a connection with a cable, that links the holder to the data acquisition equipment, was so executed (Sousa 2004).

Figure 3. Sensory system and Sorraia River Bridge execution process.

3.2 Data Acquisition System

This system, which main objective is to acquire all monitored data, is composed by special equipment. While for electric sensors data is collected by a data logger unity, for fibre optic sensors a demodulation equipment is used. The connection between each electric sensor and the logger is established by a RS232 cable type. For fibre optic Bragg grating sensors (FBG) the multiplex property was used and a switch of 32 optic fibres, each with 4 to 8 FBG, is previously installed. A connection between the switch and the demodulation equipment is also made. The data loggers (Data Taker – Fig. 2a) are placed in both LS1 and LS2 while the demodulation equipment (Micron Optics – Fig. 2b) is only located in LS1. A CPU, as it is possible to observe in Fig. 2c, that congregates all information acquired by the three data acquisition equipments, is also positioned in LS1. The connection between data loggers and demodulation equipment with such CPU is made by a RS232 cable, except for the logger placed in LS2 where a RS485 cable is used in order to transmit all data with the minimum noise.

Software for data acquisition is implemented in the CPU device. While for data loggers (Data Taker) De Transfer software is used, for demodulation equipment Labview is considered to be the most appropriate one. Both softwares were updated, namely the frequency of acquisition and the position of each channel, having this specific long term structural health monitoring scheme into account.
3.3 Communication System

After data being stored in CPU device it is remotely sent to a central station located in FEUP. This remote and versatile communication assume a particular importance not only for the logistic facilities that makes possible, as it is not necessary to go so often to the structure site, but also for the establishment in the near future of a global access platform to the information obtained from all monitored civil infrastructures.

The communication system is materialized, in this case, by modems (Siemens TC35i) with transmission velocity of 9600 bps, being the established communication of GSM type. To perform data transmission between the bridge site and the central station one modem is connected to the CPU device, placed in the structure, being the other linked to a CPU device (server) placed in the central station. Java language is the basis of this system being used to develop proper algorithms that were introduced in both computers with the main objective of remote control each modem features (Perdigão et al. 2004).

3.4 Data Processing and Archiving System

Within the CPU device (server), placed in central station, the obtained data is archived and processed. A Database System Consultation (DSC), responsible for the storage and management of such data and of whole important information, was developed and implemented in the server. To develop it SQL (Structured Query Language) was used, which is a relational data base management system with a transactional mechanism and an Object Data Base Connection (ODBC) access type that accepts requests in SQL. This characteristic makes the whole system proper to regular changes.

Two filters to process the obtained data were developed using PHP language (Hypertext Processor), namely one media and one media with variations filter. An internet web site was also developed with the main objective of allowing the consultant of both the raw and the processed data. The access to this system is made by Internet, being inserted in a very restricted environment where users are authenticated via HTTP (Hypertext Transfer Protocol). To perform it, code in PHP language was developed and inserted in the server (Apache server).

For this bridge structural behaviour real time accompaniment a Visualization Module was implemented. It executes the structural deformed shape having into account the data obtained from the seven continuous monitored sections. This module, developed also in PHP and C++ language, has the main objective of presenting the obtained monitored data in a user friendly way. It is possible to designate all these modules as Structural Behaviour System Visualization (SBSV) according to Fig. 5 (Matos 2005b).
The accompaniment of structural behaviour may be done via web site. In Fig. 6, at left, it is possible to visualize the set of diagrams that constitute the involving of all bridge vertical displacements, obtained during the developed static load field test for low speed vehicles passage. The diagram positioned at right presents the transient displacements variation in one of the seven instrumented sections (in this case section S1 according to Fig. 1).

3.5 Damage Detection and Modeling System

This structure was modelled in a Finite Element Program for the construction, static load field test and service phase. The developed model was also updated with the obtained data and particular conclusions about this structure behaviour, as the high influence of the sub-structure piers plus cap piles and piles, were obtained.

More recent and having into account the developed FE model, calibrated for long term structural health monitoring, reliably based techniques that consider uncertainty on both obtained data and model parameters are being implemented. This warranties a consistent comparison between obtained and calculated data (Garcia et al. 2004).

Deterioration is identified as a change into a system, which affects its current or future performance. However, the concept of damage is not meaningful without a comparison between the two different states of this system, one of them representing the undamaged one. Methods for damage identification, also identified as structural assessment techniques, can be classified as dynamic or static-based (Hu 2002). In this case, static-based ones are being developed and implemented within the long term structural health monitoring scheme (Casas et al. 2005).
4 STATIC LOAD FIELD TEST

Before the Sorraia River Bridge exploration phase a load test was conducted to verify its conformity, and to calibrate the already installed long term structural health monitoring scheme. The load test consisted in a set of procedures using vehicles with an approximate weight of 25t. Figure 7 illustrates the load test with the vehicles located in midspan (Sousa et al. 2005).

![Figure 7. Static load field test with vehicles located in midspan.](image)

One of the procedures consists in a low speed passage of two vehicles side by side in direction North – South of the bridge. Fig. 8 presents two pair of deformation sensors placed in section S7 (Fig. 1). Each pair consists in a conventional strain gauge and a developed sensor holder as it can be observed in Fig. 3. One of the respective pairs is located in upper fibbers (S7-1S), being the other placed in bottom ones (S7-1I).

![Figure 8. Measured strains during static load field test.](image)

Some results obtained by the calculus of the structure deformed shape for loads located at midspan (Fig. 7) are presented in Fig. 9. In the same figure a comparison between these results with the measured vertical displacements in instrumented sections is executed. From this comparison, and also having into account Fig. 8, it is possible to conclude about the quality of obtained data and so of the implemented long term structural health monitoring scheme.

![Figure 9. Measured and calculated vertical displacements during static load field test.](image)
5 CONCLUSIONS AND FUTURE DEVELOPMENTS

In this article the SMARTe research project is described. This project has already finished and it main objective, the development and implementation in a real prototype structure (Sorraia River Bridge) of a new auxiliary technique for maintenance and management of civil infrastructures, was achieved. This technique is based in a long term structural health monitoring scheme composed by five systems (sensory, data acquisition, communication, data processing and archiving and damage detection and modeling).

A static load field test was executed to verify the structure and all systems behaviour. The obtained results were very interesting and promising. However some difficulties, that need to be overtaken, were identified. A new research project was so established by BRISA with FEUP – LABEST which aim is to manage the developed system during one year facing and surpassing those problems.

It is expected with this long term structural health monitoring to execute the real time analysis of all data, giving a contribute for a deeper knowledge of civil infrastructures behaviour, avoiding possible accidents, minimizing maintenance costs and improving the service quality.

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