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**DIAGNOSTIC, CONSERVATION AND BRIDGE MONITORING – APPLICATION TO THE BRIDGE
 OVER THE KWANZA RIVER**

**DIAGNÓSTICO, CONSERVAÇÃO E MONITORAMENTO DE PONTES – APLICAÇÃO NA PONTE
 SOBRE O RIO KWANZA**

**DIAGNOSTICO, CONSERVACIÓN Y MONITOREO DE PUENTES – APLICACIÓN AL PUENTE
 SOBRE EL RÍO KWANZA**

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ABSTRACT

Structural monitoring significantly contributes to greater and better knowledge of the real behavior of structures, having positive consequences both from an economic and social point of view. Currently, observation and monitoring is increasingly based on measurement systems that are an integral part of the structure. Sustainable engineering is something we have to keep in mind throughout the project, from planning and design to execution and operation. The Article will also mention 10 guidelines from the National Directive on Sustainable Development and Environmental Management of Professional Engineers, which was produced by Engineers Canada in 2016. The aim of these guidelines is to encourage Engineers to be proactive in protecting and managing a responsible environment. part inherent to the duties assumed by all engineers: researchers, academics, consultants, regulators or managers.

KEYWORDS: Structures. Monitoring. Sustainability. Bridges. Sensors

RESUMO

A monitorização estrutural contribui significativamente para um maior e melhor conhecimento do comportamento real das estruturas, tendo consequências positivas tanto do ponto de vista económico como social. Atualmente, a observação e o monitoramento são cada vez mais baseados em sistemas de medição que são parte integrante da estrutura. A engenharia sustentável é algo que devemos ter em mente durante todo o projeto, desde o planeamento e projeto até a execução e operação. O artigo também mencionará 10 diretrizes da Diretiva Nacional sobre Desenvolvimento Sustentável e Gestão Ambiental de Engenheiros Profissionais, que foi produzida pela Engineers Canada em 2016. O objetivo destas diretrizes é encorajar os engenheiros a serem proativos na proteção e gestão de um ambiente responsável, parte inerente aos deveres assumidos por todos os engenheiros: pesquisadores, académicos, consultores, reguladores ou gerentes.

PALAVRAS-CHAVE: Estruturas. Monitoramento. Sustentabilidade. Pontes. Sensores

RESUMEN

El seguimiento estructural contribuye significativamente a un mayor y mejor conocimiento del comportamiento real de las estructuras, teniendo consecuencias positivas tanto desde el punto de vista económico como social. Actualmente, la observación y el seguimiento se basan cada vez más en sistemas de medición que forman parte integral de la estructura. La ingeniería sostenible es algo que debemos tener en cuenta durante todo el proyecto, desde la planificación y el diseño hasta la ejecución y operación. El Artículo también mencionará 10 lineamientos de la Directiva Nacional sobre Desarrollo Sostenible y Gestión Ambiental de Ingenieros Profesionales, que fue elaborado por Ingenieros de Canadá en 2016. El objetivo de estos lineamientos es alentar a los Ingenieros a ser proactivos en la protección y gestión de un entorno responsable. ambiente. parte inherente a las

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funciones asumidas por todo ingeniero: investigadores, académicos, consultores, reguladores o directivos.

PALABRAS CLAVE: Estructuras. Vigilancia. Sostenibilidad. Puentes. Sensores

1. INTRODUCTION

The actual knowledge of the behaviour of pre-endeavoured reinforced concrete structures is complex and depends on multiple variables. These have a huge diversity, being able to identify, for example, both the characteristics of structural materials and the environmental effects on the structure. A correct interpretation of structural behaviour requires that the effect of the different variables be determined and quantified. The monitoring of structures is, then, a valid means with the potential to ensure a correct interpretation. On the other hand, monitoring, through real-time monitoring of the integrity of structures, is an efficient means of management for the competent authorities, thus resulting in a socio-economic benefit. It is therefore expected that their use by their entities will grow in the near future, significantly altering existing management systems.

2. STRUCTURAL MONITORING

Observation and monitoring is currently based on measurement systems that are an integral part of the structure. Figure 1 shows a possible integrated monitoring system. It is organized into three subsystems (ISIS, 2001; MUFTI, 2002):

- Sensory subsystem;
- Communication subsystem;
- Data processing subsystem.

The sensory subsystem has as its function the acquisition of data consisting of electrical resistance and fiber optic sensors that measure deformations and temperatures. This system should be robust and durable in itself.

The collection of the information provided by the various sensors installed in the structure should not be scarce, as a minimum is necessary for a correct interpretation of the behaviour of the structure, nor bulky, because the fact that there is too much information does not lead to a better interpretation of this behaviour, besides providing a greater weight in the processing of the data obtained. The selection of the acquisition system depends on the volume of information to be stored and the type of diagnosis to be made, both in the Data Logger in the case of electrical sensors and on the optical signal interrogation equipment in the case of fibre optic sensors.

The conduction of the information obtained by the electrical sensors for the Data Logger, placed at the observation post, is carried out by electrical cables. In the case of fiber optic sensors, the information obtained is carried out by optical cable to the inter-rogation equipment located at the observation post.

The junction box, whose function is to protect the connectors of the optical fibers and the



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ends of the electrical cables during the execution phase, is placed in the same section of the sensors. After construction all optical and electrical cables are connected to a longitudinal cable with similar characteristics which establishes the communication between each instrumented section and the observation post.

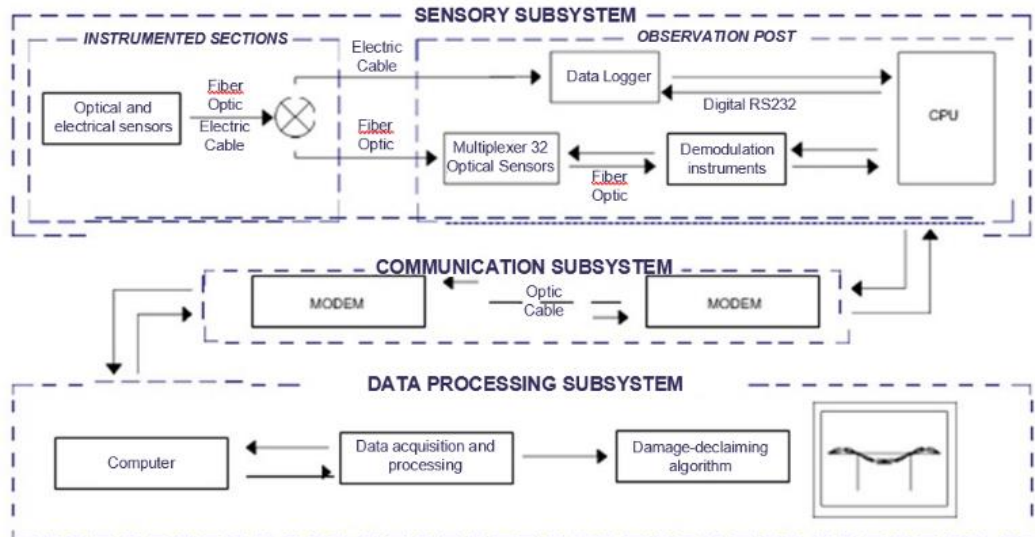


Figure 1 – Integrated monitoring system

2.1. Guideline on Sustainable Engineering

Here, we're going to introduce to 10 guidelines in National Guidelines on sustainable Engineering and Environmental stewardship for professional engineers. Which was produced by Engineers Canada in 2016:

- The first guideline is maintaining and improving knowledge and competency;
- Guideline number 2 is working with multi-disciplinary teams;
- The third guideline is considering social impacts. We've already seen that social impacts are one of the three pillars of sustainable development. Engineers should incorporate global, regional and local societal values applicable to their work;
- The fourth guideline is designing and evaluating sustainability outcomes and environmental stewardship;
- Guideline number 5 is costing and economic evaluation;
- The sixth guideline is about planning and management;
- Guideline number 7 is seeking and disseminating innovation;
- Eighth, we have leading, communicating and consulting;
- The ninth guideline is complying with regulatory and legal requirements;
- And finally, guideline number 10 is about managing risk. Engineers should implement risk mitigation measures in time to minimize environmental degradation where there are threats of serious



or irreversible damage but a lack of scientific certainty.

3. DEFORMATION AND TEMPERATURE SENSORS

3.1. Electrical Resistance Sensors

Electrical resistance sensors remain one of the most widely used and reliable sensors in structural monitoring. When pulled or compressed, the metal that constitutes the electrical resistance undergoes a variation in resistance ΔR as a result of the variation in length L , variation of cross-section A and resistivity ρ . Taking into account the Poisson ν coefficient and the gf electrical resistance sensor factor, the variation in ΔR resistance is proportional to the axial de-formation ϵ in the direction of the conductor shaft.

Equation 1 translates the relationship between the respective axial filament deformation and the variation of electrical resistance.

$$GF \cdot \epsilon = \frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} c(1 + 2 \cdot \nu) \quad (1)$$

Although this type of sensors are widely used, they have some disadvantages that highlight the influence of cable length on signal loss and susceptibility to electromagnetic effects (BUFFENBARGER et al., 2014, FIB, 2003).

It is also possible to measure temperature with electrical resistance sensors. These sensors utilize the physical principle of the variation of electrical resistance with temperature. Platinum is the most widely used metal due to the linearity of the variation between these two quantities. These sensors are commonly referred to as RTD's – Resistance Temperature Detector (BUFFENBARGER et al., 2014, FIB, 2003).

3.2. Fiber Optic Sensors

3.2.1. Operating Principle

Physical or environmental changes generally cause variations in the phase, intensity, wavelength and polarization of light propagated through an optical fiber, from which it is possible to extract information about the parameters to be measured. This characteristic of optical fibers has been applied in the development of sensors that allow the measurement, among others, of mechanical deformation, temperature, PH level in fresh concrete or moisture inside the concrete mass.

Bragg's fiber optic network technology originated in the discovery of optical fiber photosensitivity by Hill. It was found to be possible to photoinduced a permanent periodic modulation of the refraction index in the core of a photo-sensitive optical fiber, which acts essentially as a selective mirror in wavelength. It should be said that the manufacturing techniques of these devices have experienced great development in order to obtain durable sensors and at reasonable costs.

As mentioned, Bragg networks in fiber optics function as a selective mirror for incident light from a broad-spectrum source (Figure 2). The reflected light consists of a narrow spectral band, centered at a certain wavelength λ_0 . Transmitted light can in serial multiplexing schemes be used in the interrogation of other sensor elements installed along the same optical fiber. The λ_0 resonance wavelength of the reflection spectrum is established by Bragg's condition:

$$\lambda_0 = 2 \cdot n_{eff} \cdot \Lambda \quad (2)$$

where n_{eff} is the effective index of the guided mode and Λ is the modulation period of the Bragg network.

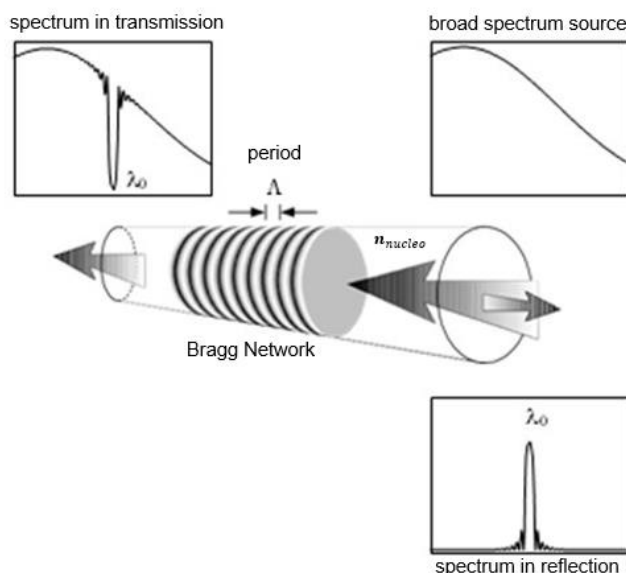


Figure 2 - Schematic representation of the principle of functioning of Bragg networks, illustrating the spectral response in reflection and transmission.

The variation $\Delta\lambda$ the resonant wavelength of a Bragg sensor may result from induced changes in the modulation period of the network Λ or disturbances of the effective index of the guided mode n_{eff} . Any of these changes are related to deformation variations or temperature variations to which the sensor is subjected (MAASKANT et al., 1997). For practical applications you can write:

$$\frac{\Delta\lambda}{\lambda_0} = GF \cdot \varepsilon_1 + \beta \cdot \Delta T \quad (3)$$

where ε_1 is axial deformation, ΔT is the temperature variation and GF and β are coefficients that depend on the characteristics of the optical fiber used.

Bragg network-based fiber optic sensors (SBFO) are particularly attractive as it is possible to integrate multiple sensors into the same fiber, simply by defining different modulation periods for each sensor. The reflection spectrum associated with each network thus presents different



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wavelengths, allowing to identify which sensor concerns. This property makes it simple to multiplex bragg sensors. (FELIX et al., 2004).

3.3. Main Advantages

SBFO offer, from a theoretical point of view, a unique set of advantages when compared to conventional electrical resistance sensors. In particular they are insensitive to electromagnetic fields, can be small, have reduced signal loss and high corrosion resistance. The use of Bragg's networks also has the advantage of installing an almost unlimited set of sensors along the same optical fiber. The wavelength of reflected light is a function of the quantities to be measured, i.e., axial deformation and temperature (Equation 3), independent property of losses that may exist along the fiber. One of the most attractive peculiarities of SBFO is the fact that the optical fiber on which the sensor is printed is also the means of transmitting the signal.

4. EXPERIMENTAL STUDY OF SENSORS

4.1. Introduction

In order to know more efficiently the behaviour of the two measurement systems and anticipate difficulties that can be encountered in the application at work, a pre-endeavoured reinforced concrete gantry - demonstrator was built in the laboratory. This, being instrumented with the two monitoring systems put to work, was subjected to specific tests, allowing a comparison between them.

This laboratory application also demonstrated the potential of Bragg networks in structural monitoring through comparison with the results of conventional instrumentation (electrical resistance sensors).

4.2. Geometry

The pre-hard reinforced structure is shaped like a gantry with exterior dimensions of 1.50m high, 3.20m wide and 0.50m deep (Figure 3). Amounts and baker, with 0.20m thickness, are equipped with circular negatives of 0.10m in diameter for the passage of steel rods for the application of various actions that may have a permanent or variable character.

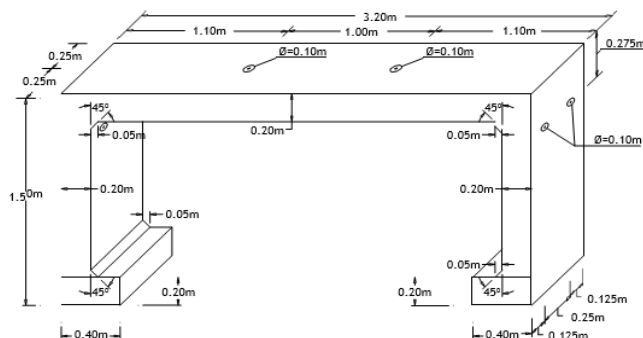


Figure 3 - Sampler Geometry



Five sections are instrumented with straps, 3 on the baker and 2 in the amounts designated by S1 to S5. In each of these sections, electric tensiometers of heat extraction are placed in close positions, electrical resistance extenders glued to the armor, and optical extensions of 3 different types (Bragg net glued to an aluminum body), OB (Bragg network glued with epoxy resin to a ribbed steel rod) and OC (Bragg net glued to a matrix composed of fibers of carbon and resin of small thickness).

All sensors installed on the outer contour of the structure are identified by an odd number, while all sensors installed on the inner contour are identified by an even number. The optical extensions, consisting of Bragg nets, are concentrated in the sections of the baker, doubling their number in the half-span section.

5. CONSERVATION

5.1. Conservation Notes

The main objectives of conservation management are to minimize conservation costs and increase safety and functionality. It integrates the results of inspections (conservation index) and structural assessments (safety index) over the life of bridges.

Due to the complexity of the model and the numerical errors associated with simulation tools, Genetic Algorithms prove to be an excellent option.

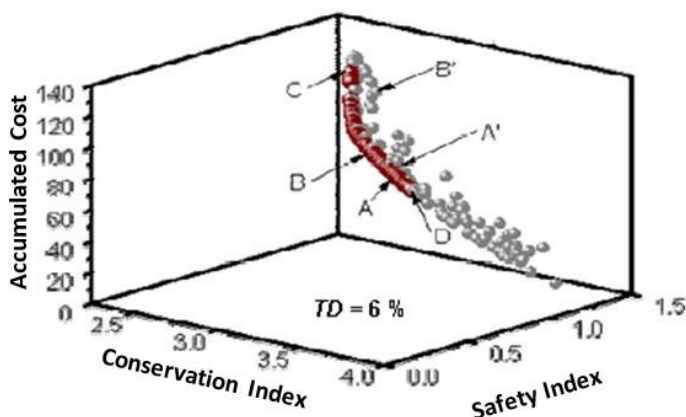


Figure 4 – Conservation index and security

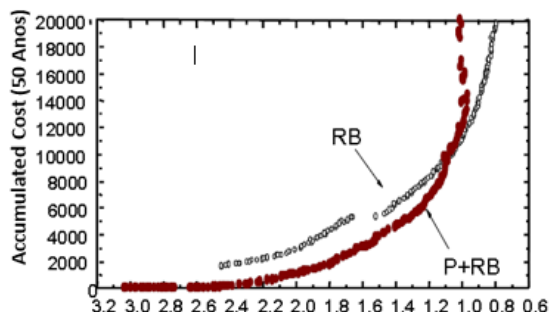


Figure 5 – Index Conservation Graphic

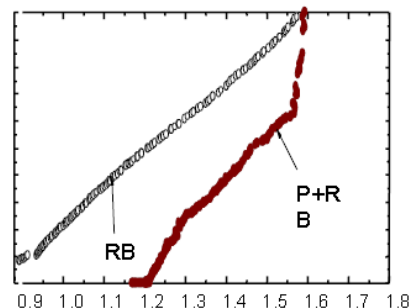


Figure 6 – Index Safety Graphic

Preventive Maintenance is not sufficient to ensure safety and functionality. The only recourse to rehabilitation leads to higher costs. The combination of both leads to better results and lower cost.

6. DIAGNOSTIC

Due to the fact that the reparations require significant costs and periods of time, there is a growing need to restore bridges and viaducts using specialists and professionals in the field who master the innovative technique of Industrial Mountaineering. This method allows you to perform repair work without reducing the intensity of traffic in the structure.

After a Diagnostic to the state of the bridge, a thorough plan to carry out repair work is executed, including:

- Removal of damaged concrete elements and steel structures;
- Application of anticorrosive coating on steel structures (pe. rebars);
- Repair or replacement of steel and degraded concrete elements;
- Structural reinforcement (if necessary);
- Waterproofing;
- Sealing of joints and welds;
- Repair of damage caused by the impact of ad-verse weather effects and subsequent protection.

Often these bridges have a load-carrying capacity that does not meet the requirements and needs of to-day's transport networks:

- Unexpected increase in traffic;
- Sucking up damage and defects;

In addition, over time, it is necessary to carry out reparations to restore the aesthetic aspect of the bridge.



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7. BRIDGE OVER THE KWANZA RIVER (CABALA BRIDGE)

7.1. Geometry

The Bridge over the Kwanza rive named as the 17 of September bridge is part of the EN110 road, crosses the Cabala, on the road that connects Catete to the Shrine of Muxima, Bengo Province, Re-public of Angola. It has a total length of 3643m, of which 1534m correspond to the bridge and access viaducts. The Tracing is predominantly rectilinear in the bridge area, presenting however some curved areas in the extreme areas of the viaducts. The cross-sectional profile includes two lanes for 1 traffic lane and has a width of 14.60m.

Thus, the first module of the super-structure has an access viaduct on the north side, with 1 extreme section of 24m and 6 sections of 30m, the bridge with two extreme branches of 68m and a central section of 120m, followed by an access viaduct on the south side with 10 sections of 30m. The meso-structure was built in situ, reinforced and pre-worked concrete, being supported on pillar/piles. The central foundations consist of massifs of nine moulded piles with 1.5m in diameter.

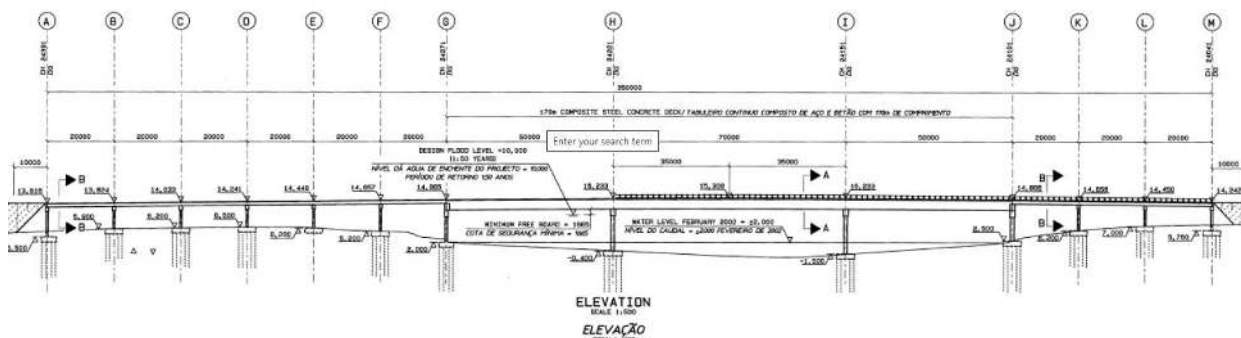


Figure 7 - Longitudinal profile of the bridge over the kwanza river

7.2. Instrumentation Plan

On the Bridge over the Kwanza River (Cabala Bridge) two foundation piles of the P8 pillar (E1 and E2) and two foundation piles of the P9 pillar (E3 and E4) are instrumented. In total of four sections, for the bridge tray, seven cross sections (S1 and S7) are instrumented, as illustrated Figure 6.

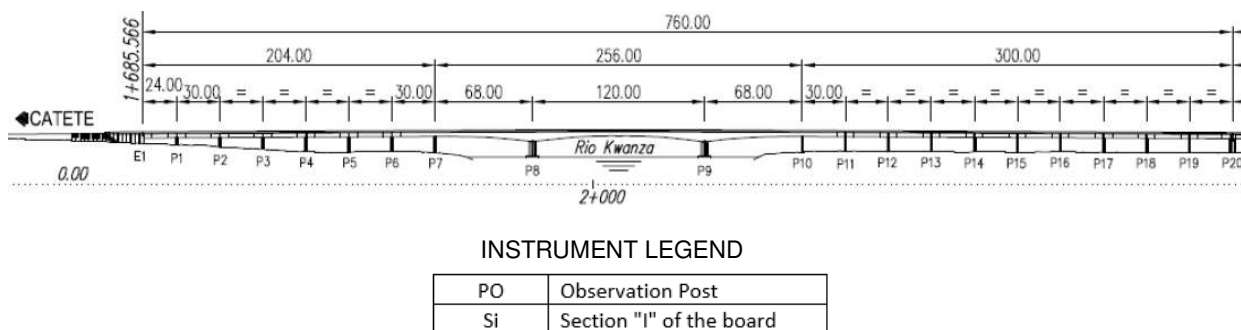


Figure 8 - Instrumentation plan of the Kwanza River Bridge



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The bridge will be instrumented with 42 fiber optic sensors (temperature and deformation) and 42 electrical resistance sensors distributed in the seven sections of the tray. Four piles of the two central pillars of the bridge will be instrumented with 8 fiber optic sensors and 8 electrical resistance sensors. For the quantification of the re-traction of the concrete placed on the bridge, two interior specimens and two exterior specimens with a fiber optic sensor (temperature and deformation) and an electrical resistance sensor will be instrumented. Additionally, to monitor environmental conditions, 2 pairs of humidity and temperature sensors placed inside and one inside the bridge tray are installed. Thermometers will be collated inside the concrete and automatic sonar for the recording of localized edits, placed in the P8 pillar header massif.

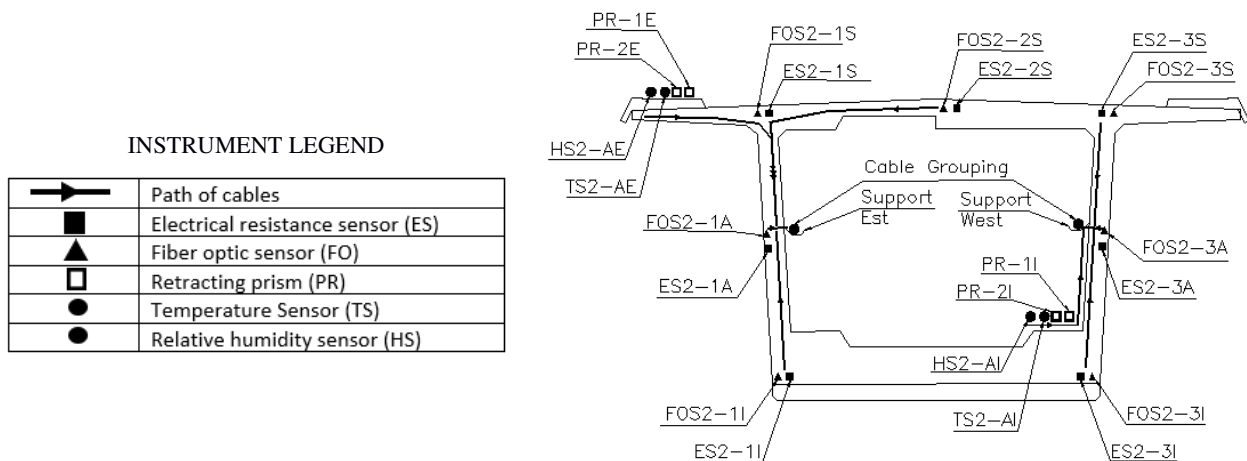


Figure 9 - Instrumentation plan – Cross Section of the Bridge

7.3. Sensors designed for the bridge on the Kwanza River

In structural monitoring, in particular where it is an integral part of the structure, the sensory system must meet minimum quality and operating requirements during the lifetime of the structure. Thus, specific care must be taken in the design and commissioning of the monitoring system.

As far as the way in which the sensors are applied to concrete structures we may have:

- Direct application of the sensor in the structure reinforcement.
- Application of the sensor on the concrete surface.
- Application of a sensor head inside the structure before the concrete.

For new structures, it is recommended to place sensor heads inside the structure, in this case being the chosen option. This type of application, whenever possible, allows the measurement of deformations and temperatures inside the structure.

The sensor head is the sensor casing and aims to protect it from mechanical damage that may occur during installation as well as against chemical attacks, thus providing efficient protection. On the other hand, the shape and stiffness of the sensor head must be such that it is minimal disturbance in the field of local deformations (FIB 2003). Typically, low-length sensor heads are used for measuring compression deformations, while in the case of traction deformations, where the



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concrete-levelling phenomenon usually occurs, longer sensor heads are preferred in order to capture this same traction. In this case, two types of sensor heads were developed inside which electrical resistance sensors and Bragg network sensors were installed.

The solution adopted for the piles of the bridge foundation consists of pairs of steel rods connected at the ends, with an electrical resistance sensor glued to a rod and a Bragg network sensor glued to the other (Figure 10).

For the tray was adopted a sensor head consisting of a shaft in epoxy resin where carbon fibbers were added at the ends. A numerical analysis by the finite element method (MEF) allowed optimizing the de-sired mechanical properties as well as the geometry of the sensor head, so that the deformation measured by it is representative of the actual deformation of the surrounding concrete (Figure 11).



Figure 10 – Sensor applied in Piles



Figure 11 – Sensor applied to the tray of the bridge

7.4. Application of sensors on site

In the present work two important aspects to be taken into account for good instrumentation and structural monitoring are the robustness of the sensory system during the installation and construction phase of the bridge and the durability of the same system in the long term.

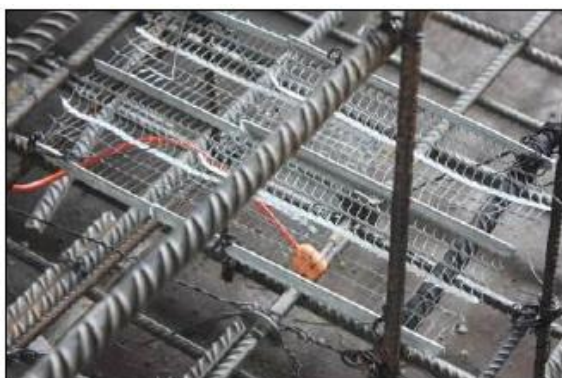


Figure 12 – Concrete interior stemometer



Figure 13 – Thermometers inside concrete



8. CONCLUSION

The New Bridge over the Kwanza River, also known as Ponte da Muxima or even baptized, the 17 de September Bridge crosses the town of Cabala, on the road that connects Catete to the Sanctuary of Muxima, Province of Bengo, Republic of Angola. The main objective of this work is to cross the main bed of the Kwanza River, as well as the entire length of the flood bed on the left bank of the river. The bridge over the Kwanza River significantly improved road traffic conditions in the territory, creating adequate conditions for crossing the river. The bridge's original execution project was calculated taking into account the regional context in which it is inserted, that is, being part of the SADC countries, the standards used to establish the regulatory overloads imposed on the structure and the combinations of actions were those of the SATCC. The other criteria for the dimensioning and safety verification of the elements that make up this work took into account the provisions of REBAPE and EC2 and EC7 (Eurocodes).

The 17 de September Bridge in Angola, opened to traffic in 2012 with a span of 3643m, was the first bridge with a record span in Africa in Angola. These technologies have advanced significantly in bridge construction and have been successfully applied in the construction of many bridges in Angola and is currently the record span in Africa for concrete bridges.

Regarding the future, as mentioned above, the Bridge is being monitored by LNEC, the data is sent to Lisbon via GSM, with monitoring on the ground by the LEA and periodic visits by LNEC technicians. On the other hand, it will be possible to evaluate the evolution of the shrinkage and creep of the concrete and the consequent redistribution of efforts, the monitoring of the outside temperature and the temperature inside the concrete, the variations in air humidity, erosion in the river bed near piles, river water levels and wind speed. It is therefore essential that special attention be paid to the maintenance of installed equipment, thus promoting a continuous collection and analysis of essential data for this type of works, which will continue to be built in Angola given the mobility needs in such an extensive territory.

Important aspects to be highlighted are the ease of installation of the system and the fact that it is an economically competitive solution compared to more traditional monitoring techniques. Another aspect of highlighting is the speed of the task of installing the sensors, thus being minimal the interference of the installation of the sensors in the normal process of bridge construction.

The integrated monitoring system applied to the bridge over the Kwanza River can be extended to other types of bridges, such as metal bridges. Only the sensor subsystem should be adapted depending on the type of intervention and work you want to monitor. The sensors can be of the type of soaking in concrete, or else, of application to the surface. The latter can be applied to metal structures or existing structures. In this specific case, soaking sensors were used. To this end, the development of sensor heads was used, whose objective is to give greater robustness and durability to the sensor subsystem.



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Some laboratory tests have shown that the sensors applied to the site have an appropriate behaviour.

The integrated system presented is, in itself, a potential and future means for better management and supervision of civil engineering structures, thus being possible to evaluate the degree of performance of them in real time.

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