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SENSORS FOR BRIDGE STRUCTURAL HEALTH MONITORING

BY

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Abstract. The use of continuous monitoring systems for the structural degradation of bridges has witnessed a rapid development in recent decades. This development meets the need of the administrators to know the technical condition of the bridges for making the best decisions regarding the maintenance and repair work. Over time, both materials and bridges are fully aged, suffering degradations that may affect the safety of both structure and traffic. With SHM systems, degradations are discovered from the earliest stages of development, thus lowering the cost to resolve them. In this paper, the authors deliver a short presentation of a various types of sensors required for the implementation and long-term use of modern SHM-type systems. The article provides information on the units responsible for capturing the most important data on the structure of the bridge under consideration and the types of sensors.

Keywords: bridge; Structural Health Monitoring; sensors; maintenance; monitoring.

1. Introduction

The degradation of the bridge structures has a wide variety of causes, such as elements failure due to the fatigue caused by repetitive loads in traffic,

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the effects of the environment on the materials used to build the structure, the exceedance of the maximum weight allowed by the vehicles engaged in crossing the bridges, and extreme events like accidents, earthquakes and floods. In order to pursue the evolution and maintain an acceptable level of traffic quality and safety, various systems and approaches in charge of assessing and monitoring the technical condition of the bridges have been implemented. However, the effectiveness of the inspection and maintenance programs implemented by the administrator is limited by the effectiveness of the inspection and repair methods used to discover the occurrence and evolution of degradation in the shortest possible time (Seo *et al*., 2015). For these reasons, a significant number of road and bridge authorities from various countries have switched to automatic tracking systems, initially using them for the most important structures in society, then extending this approach to as many bridges as possible (Brownjohn, 2007).

The data from the monitoring systems is obtained as accurately as possible, depending on the arrangement of the sensors on the structure. This information is used in assessing structural reliability, updating the numerical models of bridges and examining how to meet the safety conditions required for good traffic development. Depending on the evaluation requirements, various types of data acquisition systems may be used, some them being briefly presented in the article. Data capture systems need to be appropriately chosen to reflect the physical conditions of structure operation as accurately as possible (Sung *et al*., 2016).

The main aim of this paper consists in presenting the components of the system responsible for the continuous or periodic monitoring of bridges, called Structural Health Monitoring (SHM). In the second chapter of the paper the types of units responsible for data capturing are described. In the fourth chapter, authors make a review of the systems that transmit data from the structure.

2. Sensors Specializing in Recording Different Types of Data from the Structure

2.1. Local Voltage Sensors

The main use of local voltage sensors is to measure, as the name implies, the stresses that occur in certain areas of the bridge components. These tensions are caused by the response to the actions to which the structure is subjected (Boacă & Ionescu, 2010).

The local voltage sensors are arranged in two ways, depending on the moment when the voltage trend is monitored. They may be available from the construction stage, being anchored by the reinforcement and covered in concrete, or disposed on the surface of the element already in use. This latter mode of layout is used for structures that already have some degree of degradation.

As soon as the value of the elasticity of the building material from which the bridge is made is known, based on the data provided by the local voltage sensors, the value of the element's distortion can be easily assessed. However, in the case of concrete elements, specialists must also take into account the effects of temperature and sliding on the behavior of the concrete.

2.2. Deformation Monitoring Sensors

The sensors in charge with deformation monitoring can record data on the deformations suffered by the entire structure or an element thereof, depending on the area in which the devices are positioned, both during execution and operation. The deformations of a bridge provide valuable information on how the structure behaves in different situations (Boacă & Ionescu, 2010).

Deformation monitoring sensors are arranged in the characteristic sections of the structure. The main monitored data is the arrow and elongation.

Deformations occur when the structure is subject to different loads. Of these, the most important causes of deformation are traffic, the weight of the bridge and temperature variation. Traffic deflections considered to be live loads have an important disadvantage as they may interfere with the structure's load-bearing ability when overtaking permissible axle loads or imposed tonnage restrictions are frequently violated. Over time, these deformations lead to the complete degradation of the structural element and later of the entire structure, mainly due to the fatigue effect.

2.3. Crack Detection Sensors

The technology used by sensors detecting the presence and spread of cracks in the structure is based on the determination of the stress distribution pattern in the monitored elements. Based on this information, the cracks occurring in the most requested areas of the elements are determined (Boacă & Ionescu, 2010).

The dimensions of a surface crack at reinforced concrete elements are influenced by the presence and density of the reinforcements that are designed to take up most of the effort in that element.

In order to provide the most accurate information about the areas of interest, the sensors must be disposed in the characteristic sections with the greatest possibility of cracks or where cracks already exist. This latter approach is used when it is desired to track the evolution of a crack that may affect the safety of the bridge.

2.4. Position Sensors

Position sensors are specially designed to provide the necessary data on the behaviour of the monitored structure joints and the evolution of the existing cracks discovered after the last technical revision or information from other sensors. Data captured by position sensors refers to the movements of the elements on the surface on which they are disposed. Most often, they are used to track the behaviour of the infrastructures, especially when there is suspicion of instability of the foundation ground or the element in general (Boacă & Ionescu, 2010).

To monitor global deformations, the most accessible approaches refered to by researchers are the topographical methods (Hann, 2012). These methods consist in periodically measuring the position of specific points, namely reference points arranged on the structure. The landmarks are either mobile or fixed. The mobile landmarks are located on the monitored bridge, or on the superstructure if the arrow is being tracked, or on the infrastructures for the quantification of compacts. The fixed landmarks are placed on the field outside the construction area of influence.

In addition to the approaches outlined above, Feng and Feng (2017) propose a modern but promising method due to the ease of its implementation. A video camera, a zoom lens and a laptop are used to capture video frames of the structure. The first captured image is defined as a template and used as reference. In this way, the pixel shift is obtained using a specific scaling factor, which results in physical displacement in millimetres.

2.5. Vibration Measurement Sensors

Some of the most used sensors in the SHM systems are the sensors responsible for measuring the vibration level generated by a structure. They have experienced rapid development because they have been found to be able to quickly detect the presence and evolution of degradations by merely analysing the evolution of the vibrations. Measurements are of two kinds: short duration, carried out through a mobile device placed on the bridge or continuous, by placing the sensors at the most important points of the structure and recording the vibrations according to the load level (Boacă & Ionescu, 2010).

The measurement of vibrations is achieved primarily by measuring their amplitude, frequency and wavelengths. Based on the recorded data, they evaluate their action on the structure, along with its response (Hann, 2012). Kim and Lee (2014) stated that the detection of vibration degradation has an error margin of about 0.5%, a value that ranked the method first in the top of the systems used to detect the degradation occurrence and evolution.

2.6. Temperature Sensors

In the life of a bridge structure, temperature variation occupies an important place because a whole series of degradations are the main cause of multiple variations of this parameter. Therefore, when analysing the behaviour of the bridge, in addition to loadings from own and traffic weights, one should also take into account the variation of both daily and yearly ambient temperature (Hann, 2012; Boacă & Ionescu, 2010).

To take into account the specific temperature variation calculations, when a continuous monitoring system of the technical condition of the bridge is designed, a temperature measurement sensor is also available. This sensor is located on the surface of a bridge element or near the site under standard conditions to avoid recording errors.

According to other approaches (Xiao *et al.*, 2017), the temperature can be recorded by the same devices that are also responsible for data on the stresses in the construction elements. An example of such devices is optical fibre sensors that can measure voltages, temperatures, displacements, or provide the data needed to achieve accelerograms. At the same time, the optical fibre has high durability in extreme environments and is suitable for use in monitoring structures located in low temperature areas (*e.g.* Alaska).

2.7. Concremote Sensors

The Austrian Doka Company has developed a new technology to measure the resistance of concrete put into operation in various construction structures, including bridges, called Concremote (Fig. 1). For the greater accessibility of this technology, 2 types of sensors, wireless and wired, were made. Wireless sensors are used to monitor concrete strength in tiles, for tunnels and bridge resistance elements. The sensors to which data is transmitted via cables are used to monitor concrete in columns, bridges and tunnels, and massive concrete structures (Woof, 2016).

The operating principle of Concremote sensors is based on the measurement of concrete temperature intervals. By means of a specialized program, the recorded value is compared to a set of reference data and, based on a calculation algorithm, the resistance of the concrete in that moment is obtained. The method has a number of advantages, the most important being that the strength of the concrete is measured directly at the site, easily and quickly, without the need for sampling and subsequent testing.

Fig. 1 – Concremote sensors (Woof, 2016).

3. Capture and Transmission Technologies

3.1. Nanosensors

Nanosensors (Fig. 2) represent the most recent research in the field of the development of systems tracking the behaviour of bridge structures over time. Some of the most important studies were conducted by the American researchers at the US Department of Transportation – Federal Highway Administration. At the same time, researchers at Polytechnic University of Hong Kong (PolyU) created and developed nanosensor networks that can be installed on the surface of the structure by spraying (Marin, 2017).

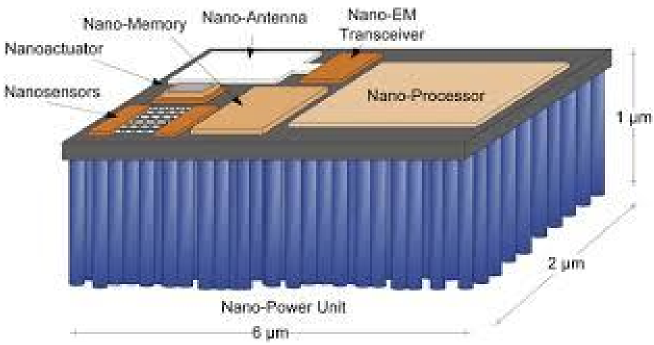

Fig. 2 – Nanosensors (Akyildiz *et al*., 2010).

These types of sensors are used to detect cracks in the early stages of their development, especially in metal structures, cracks resulting from repetitive loads in traffic. Due to the importance of these cracks and the way their presence and expansion affect the resistance of the bridge, administrators from developed countries have concluded that it is necessary to develop systems and tools capable of detecting cracks from the early stages of their development. The main purpose is to minimize the costs of carrying out maintenance and rehabilitation work.

The nanosensors used are made by printing on a conductive ink on a flexible material. The operation is done using specially designed inkjet printers. Thus, a very thin film with a conductive role is formed. The newly built tools make up a wireless radio frequency sensor capable of monitoring the appearance and development of real-time cracks.

Because of their ease of construction, researchers believe that this technology will not require high cost of supply and assembly. Another advantage is represented by the ease of distribution of data capture and storage units across the whole structure, with the most vulnerable points being targeted.

3.2. Piezoelectric Sensors

Piezoelectric sensors (Fig. 3) are considered to be some of the most commonly used sensors in SHM, mainly due to the interest of bridge operators in the use of ElectroMagnetic Impedance (abbreviated EMI in the literature). An *et al*. (2014) presents the most important advantages of using these types of sensors, such as: multifunctionality, nonintrusivity, low cost of production, assembly and maintenance, reduced size, low response time and the possibility of reuse.

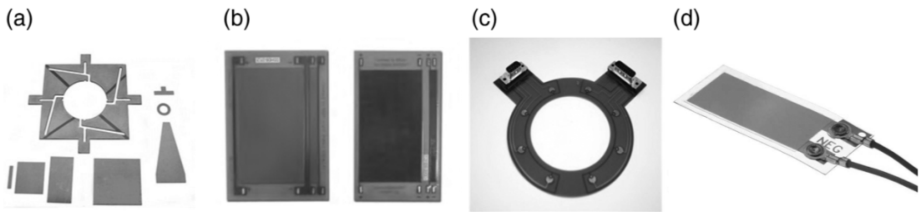

Fig. 3 – Piezoelectric sensors (An *et al*., 2014).

The sensors used in EMI bridge degradation monitoring are made of a high-strength titanium-zirconium-lead alloy, called PZT sensors. These sensors are disposed on the surface of the existing structures or are incorporated if installed during construction in the case of the new structures (Yang & Soh, 2009). Thanks to their versatility, the sensors have been used mainly for monitoring bridge structures built from innovative materials or those with revolutionary designs.

The technology used by the PZT sensors is based on the idea that any changes occurring within the impedance of the bridge structure under consideration are caused by changes in its mechanics. By measuring these changes and comparing them with different specific values of the monitored parameters, the engineers responsible for managing the structure can make various predictions regarding the evolution of the identified degradations or the possibility for new ones to emerge.

From the point of view of the materials of which PZT sensors are built, quartz has been, for many years, the most used element due to increased mechanical strengths that can reach up to 2,...,3 GPa, high sensitivity to high voltage and increased resistance at extreme temperatures (greater than 400°C – an important feature in their use in monitoring the nuclear power plant degradation). Another material used is Rochelle salt due to its high piezoelectricity (An *et al*., 2014).

A special type of piezoelectric sensors are the acoustic emission sensors (AE – Acoustic Emission in the literature), frequently used in the assessment of the technical condition of bridges. The operation of these sensors is based on the idea that the degradation emergence and development leads to the release of an acoustic wave energy that travels through the structure and can be intercepted by the AE technology (Yapar *et al*., 2015).

3.3. Wireless Sensors

A fully operational SHM-type system must be capable of detecting the degradation occurrence and localization with considerable accuracy. In order to meet this challenge, the structure manager or the staff responsible for designing the automated time tracking system must install a dense sensor network, which leads to high financial efforts (Swarts & Lynch, 2009).

Wireless sensor SHM systems are mainly used for tracking bridges, especially because of their ability to automatically record data directly from the structure. The design of a wireless sensor system involves the integration of the following types of components and technologies: communication between the sensors installed at different strategic points on the bridge and the central data storage system via electromagnetic waves, sensors able to capture the information needed to characterize the structure and the computers used in data storage and processing (Liu *et al*., 2014). The sensors used in these special networks are of the same type as those that are part of the classic SHM systems, the main difference between the two approaches being the mode of data transmission.

One of the most important advantages of the extensive deployment of this type of sensor is the high speed of installation and dismantles (Winter and

Swartz, 2017). For this reason, wireless sensors are ideal for emergency situations when it is necessary to determine in the shortest possible time the technical condition of the bridges affected by the occurrence of extreme events such as floods, earthquakes, etc. That could result in compromising the safety of the structure.

Although the SHM systems with wireless sensors have a number of important advantages, they are not free of disadvantages. The main disadvantage is the high cost of implementing these sensors. Therefore, researchers around the world have developed different research programs to optimize the sensor network, reduce system power and the related costs (Liu *et al*., 2014).

Another disadvantage was presented by researchers Webb *et al*. (2015), who state that some of the most important issues of SHM systems using wireless sensors are radio frequency propagation and the need for the regular change of sensor batteries, which have a limited lifetime. This downside can be reduced by introducing battery recharge systems via solar panels.

3.4. Magneto-Elastic Sensors

To find out the level of tension in the cables and the stands of suspended or horseshoe bridges, researchers have developed automated systems to determine these values. The SHM systems mounted on such structures also have ElectroMagnetic sensors (abbreviated EM in the literature or referred to as vibration sensors) (Wang, 2009).

The operating principle of the EM sensors is based on the idea of measuring the resonant frequency of the output signal generated by the monitored cable. This signal is produced by traffic vibrations or external loads, travelling through the structure cable and being captured by the EM sensors located on it. One of the most important advantages of Vibration Sensor Technology is the extremely low level of disturbance that can occur within the frequency signal.

The EM sensors are also used to analyse voltage variations in pre-tensioned reinforcements in bridge structures. In this case, the sensors can be incorporated directly into the concrete structures, being placed on the reinforcements in the time of the execution of the structure or attached to the cables in the resistance structure (Wang, 2009).

3.5. Fiber-Optic Sensors

In the case of composite structures, the most commonly used sensors in the SHM type automated time tracking systems are FOS (Fibre Optic Sensor) sensors (Dilena *et al*., 2015).

The operating principle of FOS is based on the fact that they transmit pulses at regular intervals through fibre optic cables, measuring the return time of that signal at source. With the onset and development of a degradation and its intersection with FOS cable, the cable section changes, resulting in significant changes in the propagation time of the propagated signal (Fig. 4) (Collins *et al.*, 2014).

Fig. 4 − Schematic diagram of the functional principle of FOS sensors.

Bridging researchers chose FOS implementation due to their unique set of properties. Of these, the most important are their small diameter (250 micron order), adaptive geometry for any type of structure and neutrality to electrical and electromagnetic interference. Other uses of FOS are elements of remote sensing technology or as a means of transmitting information (Ko & Ni, 2005).

In addition to the main advantages outlined above, Brownjohn (2007) has other five features: high precision, even after a large number of measurements, immunity to magnetic interference, high versatility in application, material stability and good operability under extreme climatic conditions.

3.6. Optical Detection Sensors

Optical detection sensors (ODS) are a type of special sensors used in SHM-type systems due to their main advantage – they do not require direct physical control of the monitored structure. These sensors are capable of capturing images of the structure and, following the automatic analysis of those images, the presence and extent of degradation are detected (Shinozuka & Mansouri, 2009). SHM Bridge Monitoring Systems using ODS have the following elements: an optical telescope (mounted at a fixed point near the structure), an image capture unit, a data recording and storage unit and an image processing and degradation detection unit.

In the research field, ODS sensors have been created and developed as a core element in Remote Sensing Technologies (RST). RST include, in addition to the ODS sensors, both hardware and software components responsible for the remote monitoring of structures (civil and bridges) based on image processing. These technologies have been developed primarily for structures located in urban area, where classical monitoring would be more difficult to achieve. RST are currently used in emergency situations to quickly estimate degradations resulting from natural disasters (Shinozuka & Mansouri, 2009).

3.7. GPS

One of the technologies used to develop the SHM systems is GPS (Global Position System), which is used when there is high chance of interference due to the external environment. These interferences mainly affect the transmission of data on the exact location of the recorded structure and degradation. The data captured by the GPS systems depend only on the time of transmission of radio waves from the satellite to the receiver (Brownjohn, 2007); it is not subject to bad weather, except in extreme situations (Hann, 2012). According to more recent research (Lepădatu & Tiberius, 2014), the SHM-GPS systems can also be used to determine the vibration modes of the structure. For this purpose, the devices installed on the structure are used, the data being transmitted in the same way as the location information.

The GPS systems are used to measure any movement of the monitored structure. For some researchers, the main disadvantage of these time tracking systems is their limited accuracy, with tolerances between 5 and 10 mm. Therefore, various solutions to this problem have been sought, the most reliable being monitoring through total stations. For this solution, the measuring accuracy increases to about 0.2 mm (Ribeiro *et al*., 2014).

In terms of composition, a SHM-GPS system comprises a base antenna, two GPS logger elements and a rover antenna. In order to monitor a bridge, the system components are arranged as follows: the base station and a GPS logger antenna at a fixed location near the structure and a rover antenna and a second GPS logger on the bridge. Measurements provided by such a system are also called kinematic measurements in real time, being used due to the fact that the structural position data are relatively accurate with 1 cm tolerances at rates up to 10 Hz according to Brownjohn (2007).

When it comes to monitoring a bridge of significant length, the SHM-GPS systems are considered to be a highly effective solution for measuring the deflection of the analysed structure (Ko & Ni, 2005). However, the authors also present the two most important limitations of this monitoring solution: the accuracy of the measurement is limited compared to the requirements imposed on large structures and the access is difficult when monitoring all the beams of the structure.

3.8. PVDF Sensors

One of the main causes of bridge degradation is represented by the tasks to which they are subjected. For this reason, overtaking the permissible axle loads by the vehicles engaged in crossing the bridges is a pressing issue for the managers in the field. However, under the current legal conditions, the static verification of vehicle loads on the road network implies a number of drawbacks, such as slowing traffic or weighing only a limited number of users. Taking these disadvantages into account and wishing to limit them, researchers have developed a dynamic vehicle registration method. The method is based on installing sensors in the road pavement.

The SHM system used in dynamic vehicle registration records consists of PVDF (PolyVinyliDene Fluoride) sensors, also called frontal sensors, data amplification and filtering circuit, A/D conversion circuit, central processing unit data, communication system and alarm system. When a vehicle enters the range of the sensor network, the analogy signals will be converted into digital signals by the A/D drive. Prior to the conversion, they have an amplification and then a reduction until all types of disturbance are eliminated. Information from the sensors will be processed by a CPU unit, giving accurate data on the dynamic load of vehicles. When the permissible limit value is exceeded, the alarm system sends the necessary data to a central unit where further analysis is carried out on how the bridge structure is affected by the passage of such a vehicle (Yu *et al*., 2013).

The main properties of the PVDF sensors are exploited especially when it comes to determining the stresses, accelerations, forces and different physical properties of both the bridge structure and the vehicles involved in its crossing. The following are the most important features of this type of sensors, as presented by researchers Yu *et al*. (2013):

– the PVDF sensors have superior characteristics in terms of dynamic response compared to those offered by general voltage sensors;

– the PVDF sensor work mode is based on an alternate force to provide a current-flow measurement circuit between the sensors. This force helps to determine the weight of moving vehicles with greater accuracy;

– the information is transmitted by cables, the location of the CPU being at a convenient distance from the roadside.

In the SHM systems using PVDF sensors, measurements are initiated when the first input signal is produced, which occurs when the front wheels of a vehicle come in direct contact with the sensors. The second row of signals is recorded when the sensor is touched by the rear wheels. This results in vehicle-to-clothing pressure, which is calculated on the basis of sensor data. The main drawback of this technology is that the number of axles of a vehicle can vary, each axle transmitting a different pulse. To minimize this disadvantage, an induction coil was implemented. When the vehicle passes over these coils, the magnetic flux undergoes changes, and an electrical signal is transmitted to the traffic sensor to start the recording.

These sensors can also be used to measure the number and type of vehicles using the road sector on which the bridge is located, achieving the proper road classification and the efficient allocation of budget funds.

4. Conclusions

From the desire of administrators and researchers in the field to use new methods and technologies to identify as accurately and easily the technical state of the bridges, different SHM systems have been developed and implemented. They capture data from the structure, passing them to a data bank where they are processed and the results show the degradation occurrence and development. After processing, the information is stored in the data bank.

The main components that vary in the composition of a SHM system are the sensors, also called the units responsible for capturing data. For this reason, the authors of this article decided to make a brief review of the most commonly used sensors together with their main features.

This paper is structured in 4 chapters. The first is an introduction to the systems used for tracking bridge behaviour over time. The second chapter presents the types of units responsible for capturing data from the structure. The third chapter presents the sensors specialized in recording different types of data from the structure and the technologies used for capturing and transmitting information. The last chapter is reserved to the conclusions.

This work is part of a complex research program on implementing systems to study the behaviour of bridges in time. The program is being developed at the Faculty of Civil Engineering and Building Services at “Gheorghe Asachi” Technical University of Iaşi.

REFERENCES

Akyldiz I.F., Jornet J.M., *Electromagnetic Wireless Nanosensor Networks*, Nano Communications Networks, **1**, 3-9, 2010.

An Y.K., Kim M.K., Sohn H., *Piezoelectric Transducers for Assessing and Monitoring Civil Infrastructures*, In M.L. Wang, J.P. Jynch, H. Sohn (Ed), Sensor Technologies for Civil Infrastructures, Vol **1**: Sensing Hardware and Data Collection Methods for Performance Assessment, Woodhead Publishing, Cambridge, UK, 86-120, 2014.

Boacă G., Ionescu C., *Bridge Instrumentation,* Intersections/Intersecții, **7**, *1*, 94-100 (2010).

Brownjohn J.M.W., *Structural Health Monitoring of Civil Infrastructure*, Philosophical Transactions of The Royal Society A, **365**, 589-622, 2007.

Collins J., Mullins G., Lewis C., Winters D., *FHWA-HRT-09-040 – State of Practice and Art for Structural Health Monitoring of Bridges Substructures*, US Department of Transportation Federal Highway Administration, Georgetown, US, 2014.

Dilena M., Limongelli M.P., Morassi A., *Damage Localization in Bridges via the FRF Interpolation Method*, Mechanical Systems and Signal Processing, 52-53, 162-180, 2015.

Feng D., Feng M.Q., *Experimental Validation of Cost-Effective Vision-Based Structural Health Monitoring*, Mecanical Systems and Signal Processing, **88**, 199-211, 2017.

Hann F.E.I., *Comportarea in situ a construcțiilor şi aptitudinea lor pentru exploatare*, Bucureşti, România, 2012.

Kim M.H., Lee J.M., *Sensing Solutions Dor Assessing and Monitoring Offshore Structures*, In Wang M.L., Lynch J.P., Sohn H. (Ed), Sensors Technologies for Sivil Infrastructures, Volume **2**: Applications in Structural Health Monitoring, Woodhead Publishing, Cambridge UK, 550-564, 2014.

Ko J.M., Ni Z.Q., *Technology Developments in Structural Health Monitoring of Large-Scale Bridges*, Engineering Structures, **27**, 1715-1725, 2005.

Lepădatu A., Tiberius C., *GPS for Structural Health Monitoring – Case Study on the Basarab Overpass Cable-Stayed Bridge*, Journal of Applied Geodesy, **8**, *1*, 65-85 (2014).

Liu Z., Yu Z., Liu G., Wang J., Mao X., *Design of a Wireless Measurement System Based on WSNs for Large Bridges*, Measurement, **50**, 324-330, 2014.

Marin C., *O nouă tehnologie revoluționară. Senzori aplicați prin pulverizare pentru monitorizarea structurilor în timp real*, Drumuri şi Poduri, 169 (238), 13, 2017.

Ribeiro D. Calçada R., Ferreira J., Martins T., *Non-Contact Measurement of the Dynamic Displacement of Railway Bridges Using an Advanced Video-Based System*, Engineering Structures, **75**, 164-180, 2014.

Seo J., Cyaplewski T.M., Kimn J.H., Hatfield G., *Integrated Structural Health Monitoring System and Multi-Regression Models for Determining Load Ratings for Complex Steel Bridges*, Measurement, **75**, 308-319, 2015.

Shinozuka M., Mansouri B., *Synthetic Aperture Radar and Remote Sensing Technologies for Structural Health Monitoring of Civil Infrastructure Systems*, In V. M. Karbhari, F. Ansari (Ed), Structural health monitoring of civil infrastructure systems, Cambridge CRC Press, Cornwall, UK, 113-151, 2009.

Sung Y.C., Lin T.K., Chiu Y.T. Chang K.C., Chen K.L., Chang C.C., *A Bridge Safety Monitoring System for Prestressed Composite Box-Girder Bridges with Corrugated Steel Webs Based on in-situ Loading Experiments and a Long-Term Monitoring Database*, Engineering Structures, **126**, 571-585, 2016.

Swartz Y.C., Lynch J.P., *Wireless Sensors and Networks for Structural Health Monitoring of Civil Infrastructure Systems*, In V. M. Karbhari, F. Ansari (Ed), Structural health monitoring of civil infrastructure systems, Cambridge CRC Press, Cornwall, UK, 72-112, 2009.

Wang M.L., *Magnetoelastic Stress Sensors for Structural Health Monitoring of Civil Infrastructure Systems*, In V. M. Karbhari, F. Ansari (Ed), Structural health monitoring of civil infrastructure systems, Cambridge CRC Press, Cornwall, UK, 152-176, 2009.

Webb G.T., Vardanega P.J., Middelton C.R., *Categories of SHM Deployments: Technologies and Capabilities*, J. Bridge Eng., **20**, *11*, 04014118 (2015).

Winter B.D., Swartz R.A., *Wireless Structural Control Using Stochastic Bandwidth Allocation and Dynamic State Estimation with Measurement Fusion*, Structural Control Health Monitoring, e2014, 2017.

Woof M., *Doka's Concremote Gives Exact Measurement*, bauma 20166 show preview, 58, 2016.

Xiao F., Hulsez J.L., Balasubramanian R., *Fibre Optic Health Monitoring and Temperature Behavior of Bridge in Cold Region*, Structural Control and Health Monitoring, e2020, 2017.

Yang Y.W., Soh C.K., *Piezoelectric Impedance Transducers for Structural Health Monitoring of Civil Infrastructure Systems*, In V.M. Karbhari, F. Ansari (Ed), Structural health monitoring of civil infrastructure systems, Cambridge CRC Press, Cronwall, UK, 43-71, 2009.

Yapar O., Basu P.K., Volgyesi P., Ledeczi A., *Structural Health Monitoring of Bridges with Piezoelectric AE Sensors,* Engineering Failure Analysis, **50**, 150-169, 2015.

Yu Y., Zhao X., Shi Y., Ou J., *Design of a Real-Time Overload Monitoring System for Bridges and Roads Based on Structural Response,* Measurement, **46**, 345-352, 2013.

SENZORI PENTRU MONITORIZAREA STĂRII TEHNICE A PODURILOR

(Rezumat)

Utilizarea sistemelor de monitorizare continuă a degradărilor structurale a podurilor a cunoscut o dezvoltare rapidă, mai ales în ultimele decenii. Această dezvoltare răspunde nevoii administratorilor de a cunoaşte starea tehnică a podurilor în scopul luării celor mai bune decizii privitoare la momentul oportun de realizare a lucrărilor de întreținere şi reparații. Cu timpul, atât materialele, cât şi podurile în general sunt supuse procesului de îmbătrânire, suferind degradări care pod afecta siguranța structurii şi a traficului. Utilizând sistemele SHM, degradările sunt descoperite de la primele etape de dezvoltare, reducând astfel costul de remediere a lor. În această lucrare, autorii prezintă o scurtă prezentare a diferitelor tipuri de senzori necesari pentru implementarea şi utilizarea pe termen lung a sistemelor moderne de tipul SHM. Articolul oferă informații despre unitățile responsabile de captarea celor mai importante date privind structura podului în cauză.