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Bridge management system within the strategic roads as an element of smart city

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Abstract. A permanent increase of population in large urban centres - both in Poland and in the whole world - causes environmental pollution, demographic changes and, most of all, the growth of the traffic volume. A way to deal with all problems of cities is the performance of the Smart City conception, which allows to build intelligent solutions improving transport, energy technology, tourism and many other fields that constitute the economy. The basis of the operation should be an efficient communication infrastructure, because the dynamics of the economic development is significantly dependent on the efficiency and the reliability of the communication system. It can be also stated that the development of the transport networks, including those on highly urbanised areas, is essential to ensure proper functioning of economic and social life. Correctly conducted monitoring and the diagnostics of the bridges should help the road administration with managing these objects and with extending the lifetime period, so it should allow to optimise the completion period and the scope of possible renovation, repair or enforcement, and in the case of discovering that there are damages that endanger the safety of the construction, it should ensure justified removal from service.

The article presents an example of the use of acoustic emission method for the assessment of the condition of My Thuan cable-stayed bridge by the Tien Giang river. The application of AE technique enables monitoring and following the processes occurring in the total volume of the structure, regardless of stress and deformations, but depending on the integrity of the construction, and this is of key importance for the durability of use and safe work of the bridge. Thanks to this, it enables the performance of the Smart Cities concept in relation to the intelligent infrastructure and ensuring a proper level of safety.

1. Introduction

Objects made of reinforced concrete dominate in industrial, hydrotechnical, municipal construction, and especially in bridge infrastructure. Ensuring the safety of the construction requires doing a range of diagnostic activities in all life phases of a structure. As a result of the influence of external factors on the construction, including the environmental factors and operational loads that change during long-time exploitation, the structures degrade. Undertaking diagnostic activities thus concerns particularly old buildings that should be controlled during the exploitation [1,2].

The basic elements of cyclic monitoring are inspections that should be supported by non-destructive diagnostic tests that confirm the visual examination and make it possible to evaluate objectively the technical condition of the structure including the damages occurring in inaccessible places. Early and precise detection of damages developing during the use allows to adopt reasonable measures, including repair works ensuring uninterrupted exploitation of the structure. On this account, especially in the recent time, a lot of attention has been paid to the topic of diagnostics and monitoring of the exploited building structures, and this issue is connected with the notion of stability and ensuring the reliability of these structures.

In the case of bridges, the problem of monitoring is particularly important because the development of road systems is dependent on their technical condition. Temporary exclusion of flyover or bridge from the exploitation causes the occurrence of significant economic, social and environmental losses, thus it is legitimate to undertake the works oriented on the development of technology and procedures of proper maintenance of road structures, as well as the methods of their diagnostics and monitoring. Monitoring systems should particularly focus on recording two factors, i.e. the changes that occur in the structure of load and the accumulation of damages. Properly conducted monitoring and diagnostics of bridges should help the road management with managing these structures and with prolonging the exploitation time, thus it should make it possible to optimize the time of realization and the range of possible renovation, repair or reinforcement, and in the case of the occurrence of damages threatening the safety of the structure, it should help with ensuring justified exclusion of the structure from exploitation [3].

The development of new diagnostic and monitoring methods for concrete structures is significant for the increase of road infrastructure management quality.

It has become essential to develop a procedure of bridge evaluation based on an objective analysis of destructive processes, including the entire supporting structure of the object. This procedure should be non-destructive, its range should include the entire supporting structure or at least its entire element and it should make it possible to detect and localize active damages that occur there, and it should allow to monitor the development of the damages over time as well [4-7].

These requirements are met by the method of acoustic emission which consists of comparative analysis of acoustic emission signals registered during the examination of the structure with the created base of standard signals of destructive processes, which enables the identification and localization of these active destructive processes. It can be applied to reinforced concrete (IADP), prestressed (RPD) and steel structures, allowing for global monitoring including the entire analyzed element and for registering only active damages developing in conditions that are present during the monitoring (in the conditions of real loads) [8-10].

The purpose of the article is to present the monitoring systems of the My Thuan bridge that use the global system of health evaluation (SHMS), which is based on the acoustic emission method.

2. Materials and methods

The My Thuan cable-stayed bridge (Figure 1) connects the banks of the Tien Giang river, which goes between two large provinces of the basin of Mekong. The structure is located along the national road no. 1A which is the main traffic route. The bridge was developed between July 1997 and May 2000. The structure with two planes of suspension was designed on the basis of Australian AUSROADS-92 standard, then it was verified with the H30 – XB80 operational load and Vietnamese 22 TCN 18-79 standard.

The bridge, the total length of which is 1535.2 m, consists of three continuous spans of 150÷350÷150 m. It is based on two main pylons. The main spans are made of prestressed concrete with characteristic strength amounting to 50 MPa. They consists of two main girders connected by cross-beams that are bridge decks. These elements were made with the use of cantilever method. The main spans are 1760 mm high and they have width variable from 1200 to 1400 mm, the thickness of the bridge deck is 250 mm. The outer spans are suspended on 4 X 32 cable stays, every cable stay includes from 22 to 29 cable splices of diameter amounting to 15.2 mm from seven separate cables. On every side of the cable stay, a vibration damping system was used. H-type pylons with the height of 123.5 m (starting from the foundation base), 84.43 m (starting from the deck) were made of concrete of characteristic strength amounting to 50 MPa. Every pylon is founded on 16 bored piles of 2.5 m in diameter extending to a depth of 90 m (the northern pylon) and 100 m (the southern pylon).

During the design and construction of the My Thuan bridge, no monitoring system (SHMS) was developed apart from devices monitoring weather conditions around the bridge (anemometer for measuring the direction and speed of the wind and a device for measuring air humidity, located in the middle of the main span and on the top of one pylon), a camera for monitoring the level of water in the river and a camera for monitoring the traffic volume on the structure. However, there is no information about the current condition of these devices.

Figure 1. My Thuan Bridge.

Acoustic Emission (AE) is a transient elastic wave being an effect of rapid release of energy stored in material because of micro-damages that are propagating. The transience of the wave is the result of absorption - the transformation of the elastic strain energy into the heat energy. This is why the occurrence of AE is the signal of degradation of material property in comparison with its properties at the moment prior to the emission. Hence the AE phenomenon indicates the destruction of the material, thus the destruction of the element made of it [11,12].

The released elastic wave (AE) is registered by the sensors of acoustic emission located on the structure, then it is analyzed with the use of a computer. In the presented method, an acoustic wave is determined with the use of the following twelve parameters: counts, counts to the value of maximum amplitude, the duration of the signal, the rise time of the signal, the amplitude of the signal given in mV or dB, the energy of the signal, the power of the signal, average root mean square of the signal, absolute energy of the signal, average frequency of the signal, reverberation frequency and initial frequency. In reinforced concrete structures, the identification of the type of the destructive process and its intensity requires comparative analysis with the base of standard signals, in a similar way as in the case of prestressed structures [13,14].

The base of standard signals was created by conducting a range of tests on different types of reinforced concrete beams and samples, with the realization of different load programmes, including cyclic load, modelling the movement of a car, in order to achieve the domination of one of the destructive processes that can occur at the time of reinforced concrete structures tests during their exploitation. The base was also verified on real structures [15-17]. Standard databases were classified on the basis of 12 parameters of AE and they were marked for reinforced concrete structures as Classes:

- Class 1 Initiation of micro-cracking in the grout,
- Class 2 Initiation of micro-cracking at the grout-aggregate interface and development of micro-cracks,
- Class 3 Initiation of micro-cracks on the element surface,
- Class 4 Growth of cracks,

- Class 5 Loss of adhesion in the crack vicinity,
- Class 6 Buckling of compression bars / crushing of compressed concrete / rebar rupture.

On the basis of the conducted examination of the development of the cracks in reinforced concrete elements put under repetitive, cyclic and dynamic load, the following criteria of the destruction level of the structure were proposed for the evaluation of technical condition of reinforced concrete structures, in relation to the identified destructive processes (signal classes):

- Classes 1 and 2 - safe operation of the structure,
- Class 3 - warning,
- Class 4 - hazard to durability,
- Class 5 - hazard to bearing capacity,
- Class 6 - loss of structural reliability.

The My Thuan bridge is a large cable-stayed object with reinforced concrete structure. The main spans of the bridge, the pylons and the places where the cable-stays are anchored are exposed to significant dynamic loads. These elements, during a dozen or so years of exploitation, have undergone some displacements and deformations. Cracks on these elements are also visible (Figure 2). An important aspect is therefore the measure of and monitoring the values of stresses, displacements, as well as the changes of temperature of bridge structure elements at the time of further exploitation.

Figure 2. Cracks of bridge support elements.

This is why it is so important to use an NDT method which allows for global evaluation of the entire examined structure (SHM). The proposed method was based on the analysis, identification and localisation of active destructive processes that are accompanied by acoustic emission (AE). It allows to monitor the destructive processes in the entire structure under operational loads without the need for local analysis of stress or deformation state, or interaction of the damages that occurred whilst taking into consideration external influences such as: external loads, temperature, humidity, etc.

AE measuring system consists of measuring method using the technique of acoustic emission along with data analysis, databases allowing to classify the destructive processes and procedures allowing to localise active destructive processes.

Selecting the acoustic emission as measuring method was mainly determined by its advantages. These are:

- the possibility to localise these damages, that were not detected by traditional methods,
- AE registers only active destructions, and these are the ones that develop in conditions in which the monitoring is conducted,
- monitoring can be conducted in various conditions, for example during the exploitation of the structure, relatively under test load, and the results are gained on an ongoing basis,
- AE is able to identify all types of developing destructions, while the majority of methods only focuses on selected types of defects,
- AE characterises the intensity of the development of the damages during the use of the object in a good manner,
- AE allows to characterise the sources generating the signals.

3. Results

Two complete measuring systems constituting the elements of the system are shown below, and this system allows to evaluate the technical condition of the bridge, thus it allows to make decisions concerning the exploitation and repairs.

Accelerations measuring system (Figure 3): the purpose is to measure the dynamic characteristics of the span under the influence of activation caused by the wind (monsoon area and strong winds), rain and operational load. The number of "vibrations", the size of the amplitude, etc. can also be used for fatigue analysis. The task is to measure the accelerations of the centres of the spans (bidirectional accelerometer - 100Hz), vertically (z) and across (y) the structure, to develop the thresholds for recording the data on account of the speed of the wind, rain and acceleration jumps caused by heavy vehicles (this initiator should be developed after approximately 12-24 months of observation of the bridge and comparison with the assumptions and results from calculation model). The system consists of 3 measuring points, each with 2 sensors.

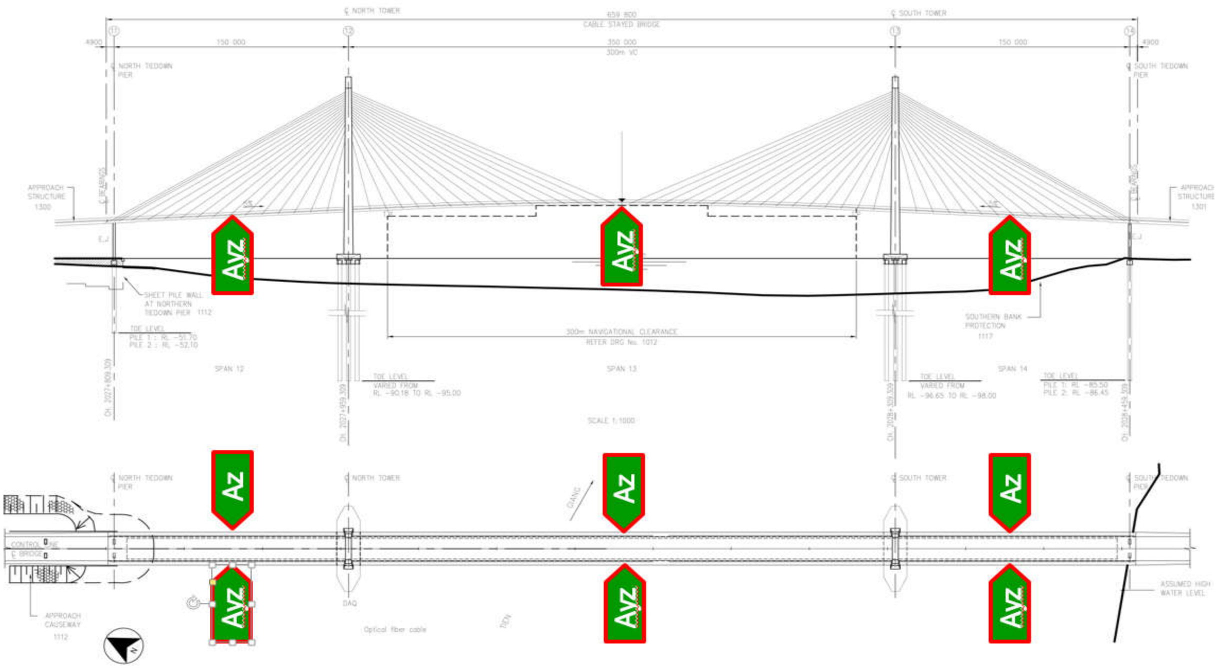

Figure 3. Distribution of measurement points in the accelerations measuring system.

System for measuring displacement (Figure 4): the purpose is the diagnostics of the technical condition and long-term modifications occurring in the structure of the spans and determination of the settlement of supports and their influence on the change of span's grade line. The task consists of the measurement of vertical and horizontal displacements of the centres of the spans and supports. There is a possibility to conduct static measurement, for example 1/h, every 30 minutes, and/or dynamic activated measurement, for example at the moment of A1 accelerometers system initiation, passing the thresholds established on the basis of calculations or "on request". The system consists of 7 measuring points along the span and, alternatively, 4 on the tops of the pylons. Hydroprofilometer, liquid levelling system (GEOKON) or GNSS can be used in a span, GNSS can be used on the tops of the pylons.

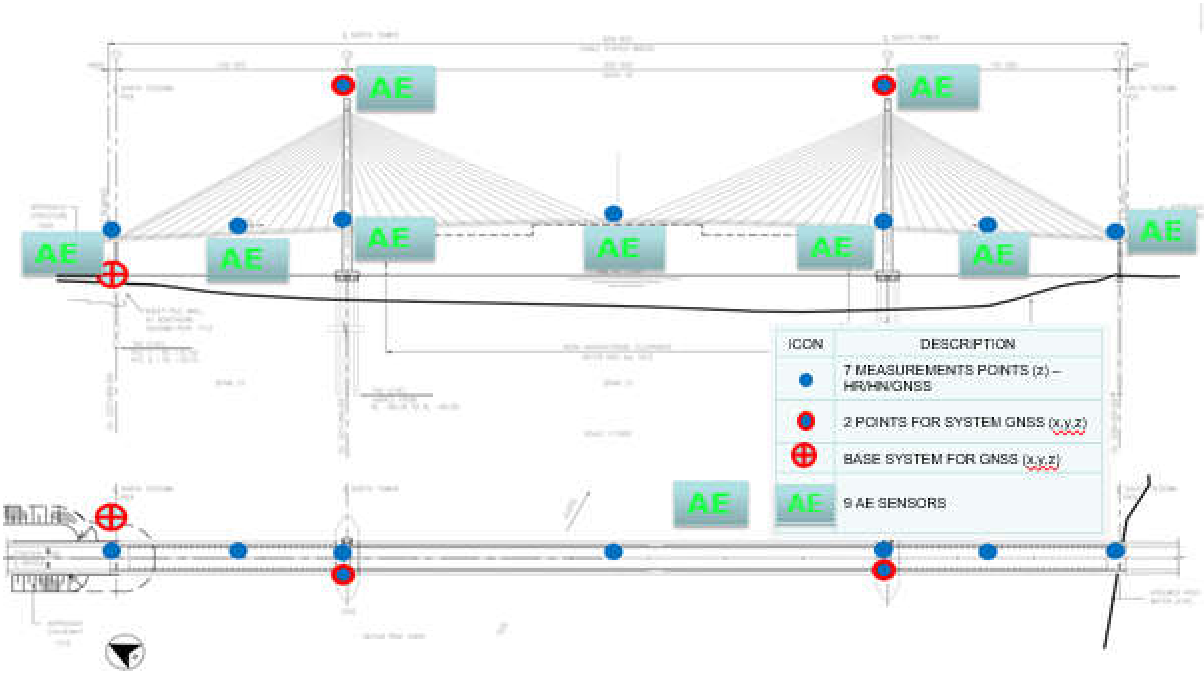

Figure 4. Distribution of measurement points in the system for measuring displacement.

4. Conclusions

The proposed system of global evaluation and monitoring of concrete structure, on the basis of the measurement of acoustic emission accompanying the destructive processes, includes the entire element that is examined or its selected part and it allows to localize and identify active destructive processes and to determine their dynamics in real time. The data that are collected can be the foundation for determining the structural condition of the structure.

The presented system can be used to:

- evaluate the condition of the structure and possible hazards,
- conduct constant or periodic controls of the condition of the structure, in particular to observe the dynamics of destructive processes,
- automatically limit or stop the traffic when signals indicative of the occurrence of destructive processes creating hazard to the safety of the users are registered,
- evaluate the quality of the previous repairs,
- evaluate the efficiency of the decisions about limiting the traffic on a given structure or decreasing its capability, decisions that have been subjective and impossible to verify so far, hence too conservative,
- monitor the movement of non-standard vehicles (for example, on the basis of the data obtained by the system, it was stated that slow movement of non-standard vehicle creates

significantly lower danger than rapid movement of three lorries of lower weight than allowable weight).

On the basis of the information presented in the article it is stated that the presented examples of global systems for monitoring the structure condition in relation to the My Thuan bridge allow for full control of the condition of the structure. Thanks to this, the presented conception makes it possible to fully implement the Smart Cities concept in relation to the intelligent infrastructure and it ensures a proper level of safety. Properly conducted monitoring and the diagnostics of the bridges significantly support road management in the management of these objects and prolonging the time of exploitation.

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