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New non-destructive diagnostic method of bridges

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Abstract

Currently, on the base of foreign experience the Bridge Management System of the Czech Republic is created and progressively implemented. In connection with this process the requirements for non-destructive testing realized directly during the bridge structure inspections are on the increase.

In the past it was sufficient to realize only visual examination of defects. Now the prognosis of a future behaviour of the structure and determination of a residual life-time are required. The new bridges are more frequently equipped with monitoring facilities including data acquisition systems. As a part of the bridge inspection is commonly used carbonation depth survey, content of chloride and extent of reinforcement corrosion. The most frequent methods for determination of corrosion extend are ultrasound, sonar, infra-red camera, radar, electric potential measurement, radiography, vibration analysis, etc.

Next potential methods, which can be used in this area are modal analysis and acoustic emission method. The application of these methods on bridges is at the beginning.

The Czech Ministry of transport supports research and development (R&D) projects dealing with these two promising methods.

The article is dealing with R&D project, which is focused on usage of acoustic emission method as a tool for non-destructive testing of bridge structures, with a view to an assessment of reinforcement corrosion.

The measurement realized on laboratory samples and bridge structure will be mentioned, including information about equipment and measurement technique.

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1. INTRODUCTION

Concrete and prestressed structures condition is affected by varied factors. One of the most negative factors is reinforcement corrosion. At present time, CDV - Transport Research Centre and Physical Department of Faculty of Civil Engineering at Brno University of Technology are dealing with development of a diagnostic method based on the principle of acoustic emission. This method should be used for structural defects monitoring of concrete and prestressed structures, especially bridges, where defects were caused by reinforcement corrosion.

2. ACOUSTIC EMISSION

Mechanical energy appears whenever any object or structure is stressed. The energy is emitted in the form of elastic waves. This phenomenon is generally called Acoustic Emission (AE). Normally operated bridges are affected by dynamic actions caused by transport, wind etc. That gives rise to the acoustic emission. The research is trying to find the characteristic frequencies ("unhealthy sound") that are generated by corroded reinforcement of bridges while they are stressed.

3. STATE OF THE ART

The research focused on usage of AE method in the field of testing of reinforcement corrosion and prestressed structures is currently in progress at some research centres all around the world [2]. It include mainly testing of laboratory samples or testing of reduced girders, which are placed on the laboratory premises.

Canadian company Pure technologies has patented monitoring technology called Sound Print, which is able detect and localize wire breaks of prestressed cables with the accuracy of 0,5 m. The system uses an array of sensors, which monitor a part or whole supporting structure of bridges and similar structures. These sensors are connected with 32 channels acquisition unites. Signals are treated on-line and presented at Web pages. The provider of this technology in Europe is the company Advitam [3].

At Polish Kielce university they are dealing with a development of diagnostic method for testing of bridges based on AE principle. Loading of structures is realized by the help of heavy lories, statically or dynamically. AE signals are analyzed in time domain. They execute a zonal localization of areas of defects. To determine the condition of girders parts is used AE parameters analysis. On the base of these parameters they count other indicators called historic index and

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severity, whose combination indicates the degree of defects of individual parts of a structure, mainly girders [4].

The other possibility is to measure acoustic response during using of the bridge. At University of Edinburgh they realized in-situ long term monitoring of bridge condition with the view of detecting crack growth and determining position of the crack tips. They worked with time domain of the signal. The compared parameters were number of detected evens (their hits) and their energy [5].

4. MEASURING EQUIPMENT

For the measurement purpose we have used four channel acquisition system containing of a efficient personal computer, 12-bit sampling card NI 6115, amplifiers AMP 22 and 31, preamplifiers PA 15 and broadband piesoelectrical sensors (up to 1 MHz). Recorded signals were processed by the composed CDV software and the results were presented by the help of NI Diadem software. Connection diagram for one channel of the measuring system is shown in figure 1. The basic parameters, which are count from the time domain of the signal are presented in figure 2. The other parameters are energy, root mean square, average signal level, average frequency, etc.

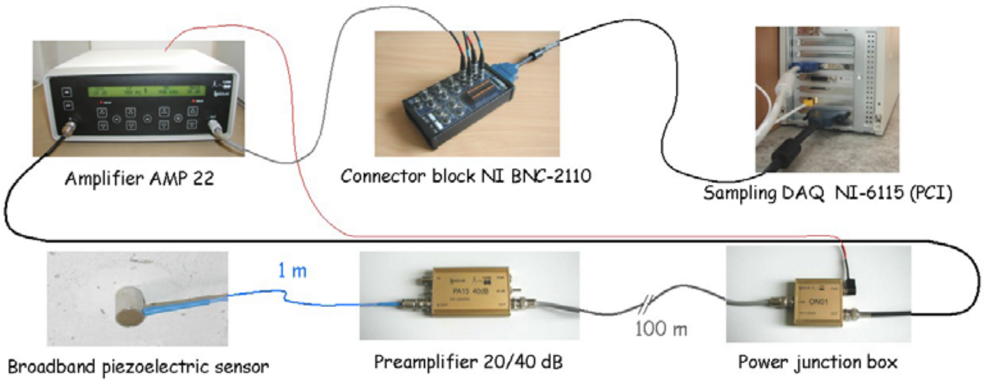

Fig. 1: Connection diagram for one channel of the measuring system

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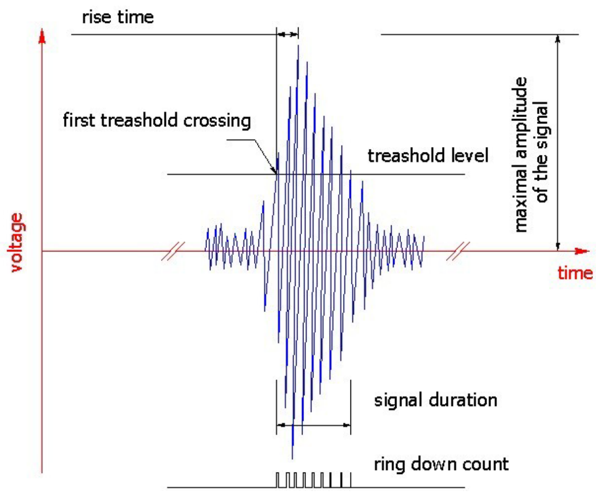

Fig. 2: Basic AE parameters counted from a time domain of the signal

5. OWN RESEARCH

The aim of our research is to propose methodology for preparation and realization of measurement of reinforcement defects of concrete and prestressed structures, with a use of AE method. One-time measurements will be carried out with a help of mobile equipment. The proposed measurement system is supposed to allow repeated measurements of more structures because it is not fixed to one construction for a longer period of time. The results and conclusions will form a base for the proposal of monitoring, repair and maintenance system of concrete road bridges.

6. LABORATORY MEASUREMENTS

Laboratory measurements were aimed to study an acoustic signal with the reinforcement corrosion correlation. The response signal to actuating pulse and AE signals recorded during the time when the samples were exposed to bending tension were analyzed.

In the first phase, the correlation of signal frequency spectra (response to actuating pulse on a reinforcement surface) for both corroded and partly corroded rebar was studied. There was an apparent shift of marked frequency components into lower frequency range in the case of partly corroded reinforcement.

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In the second phase, the samples exposed to accelerated corrosion were repeatedly monitored. The response of these samples on the actuated pulse was processed again. The response was recorded simultaneously on the reinforcement and on the concrete surface of the sample. With increasing corrosion, in the frequency spectrum marked frequency components shift into lower frequency areas, see figure 3.

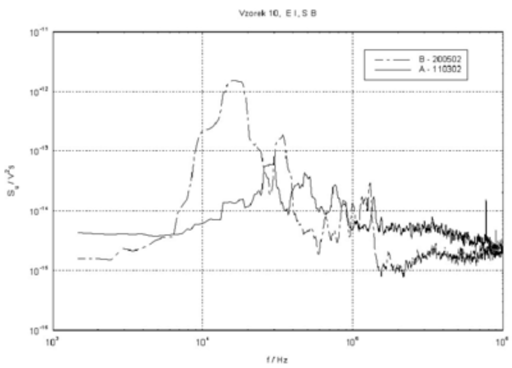

Fig. 3: Frequency spectra comparison

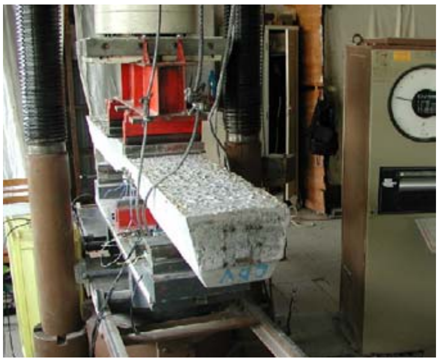

Fig. 4: Bending tension test

In the third phase, two sets of reinforced beams were monitored. One set aged in laboratory conditions while the other in an aggressive corrosive environment. Tested beams were repeatedly exposed to bending tensions according to European Standard EN 12390-5, see figure 4. Frequency spectra of the acoustic emission and the pulse frequency rate were processed.

The laboratory measurements proved correlation of changes in frequency spectra with structural changes caused by reinforcement corrosion. Satisfactory correlation was reached especially in the case of monitoring the proceeding corrosion by repeated sample measurements.

6. MEASUREMENTS ON THE BRIDGE

After verification of the possibility to detect corrosion of in-build reinforcement in laboratory conditions we started measurements in situ.

During the reconstruction of 20-year old bridge: 7-012 Brandysek, I73 bridge beams (prestressed I-beams) were tested by AE method. The bridge consisted of three spans with 9 beams, 30 m long each. Consecutively, when the beams were demolished, a condition of prestressed cables and construction reinforcement were checked.

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6.1 Process of measurement

The bridge profile is shown in figure 5. Eighteen I 73 beams were measured with the AE method. Sensors were fixed at the ceiling of each beam in the middle of its length. AE signals were generated by the lorry travelling over a 15 cm high wooden chock. The chock was placed on the road surface exactly above the point of measurement. The measuring system was powered by a generator. The use of the platform is shown in figure 6, AE signals generated by the lorry travelling over the chock is shown in figure 7.

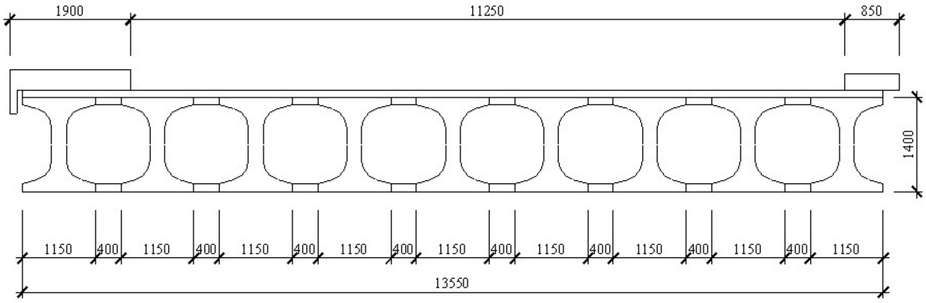

Fig. 5: Brandysek bridge profile

During the whole time the lorry travelling over the chock AE signal was continually recorded (approx. 15 seconds). Sampling frequency was selected at 1 MHz. Each beam was measured repeatedly, three times.

Fig. 6: Sensors placement process

Fig. 7: Lorry travelling over the chock

6.2 Beams demolition

Even before our measurement a decision was taken that the existing I73 beams would be removed and replaced with steel beams. The beams demolition was

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carried out on the spot with a help of a pneumatic hammer and hydraulic cutting shears. With the help of this equipment the concrete was broken, construction and prestressed reinforcement separated and taken away to be recycled. A visual examination was carried out both at the point of measurement and also along the whole length of the beam including the anchors and Sandrik steel pipes. The examination was aimed to all prestressed reinforcement consisting of 20-wire cables of 4.5 mm in diameter.

There was no significant effect of corrosion on the reinforcement section. For the evaluating purposes, the corrosive attack extent was divided into 4 groups (k1 up to k4).

Fig. 8: Four groups of corrosion

The reinforcement basally untouched by corrosion was put into the first group k1. The reinforcement close to the anchors, which was weakened by corrosion up to 0.5 mm and with initial signs of penetrating corrosion was placed into the fourth group k4, see figure 8.

6.3 The beams evaluation

FFT (Fast Fourier Transformation) was used to transform the acoustic signal from the time domain to the frequency spectrum.

The typical recorded signal is shown in figure 9. The arrows indicate events occurred when the lorry wheels hit the road surface. The arrow 1 corresponds to the front axle, the arrows 2 and 3 correspond to the wheels of the rear axle.

The time domain corresponding to the second and third wheel hitting were selected to analyze signals of individual beams. In figure 10, there is shown a time domain

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corresponding to hitting the second wheel of the rear axle to the road surface. Figure 11 represents its frequency spectrum.

There were found no significant differences when all frequency spectra were compared, in a range between 1 kHz and 500 kHz. In the scope of performed measurements, no frequency was found that would indicate some significant construction defect caused by the reinforcement corrosion. That corresponds to the visual examination of the reinforcement at the points of measurement. It proved that both the prestressed and the construction reinforcement were in suitable condition concerning to the corrosion.

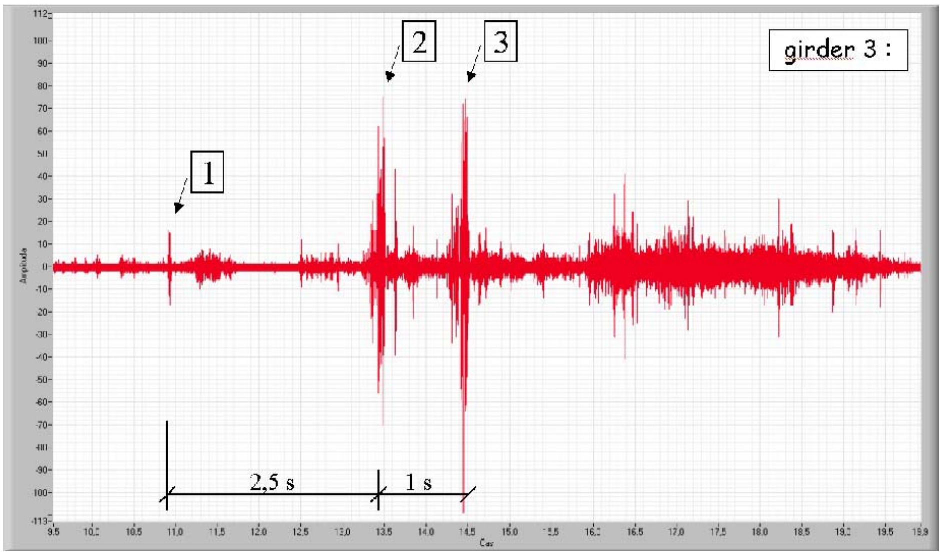
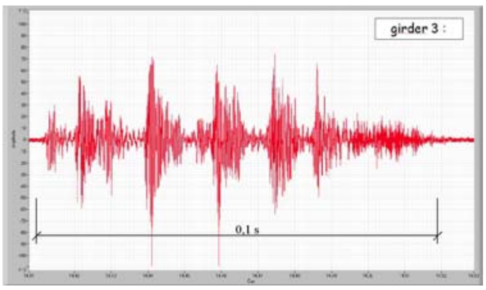


Fig. 9: Whole signal in time domain



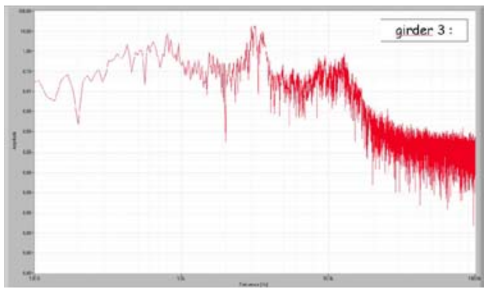


Fig. 10: Wheel 2 - time domain

Fig. 11: Wheel 2 – frequency spectrum

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7. CONCLUSION

The significant advantage of the AE method is the fact that it indicates the unstable and dangerous defects, which are active at the given structure stress. In comparison with the other non-destructive diagnostic methods AE method can give global information about the examined object condition. According to the AE measurement results, it is possible to aim a diagnostic checking to those points where the emission sources were detected preferentially. Thus the AE method becomes a useful supplement to the common diagnostic methods.

Acknowledgements

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