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Experimental validation of concrete crack identification and location with acoustic emission method

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ABSTRACT

The work aims to experimentally validate the identification and location of destructive processes in reinforced concrete structures using the method based on the measurements of acoustic emissions generated by those processes. The system that employs the method was presented in works Gołaski et al. (2010) [3], Gołaski et al. (2006) [4] and Świt (2008) [11]. As it is very difficult to document the results obtained with the acoustic emission (AE) method, the validation of the process was conducted. The tests involved reinforced concrete beams loaded until failure. The measurements of acoustics emission were taken continuously, at the same time the strains in the beam lateral surface were recoded using 3D optical scanner (Aramis). The comparison of the results demonstrated that the recorded acoustic emission signals really correspond to the process of crack initiation and development. It was shown that the AE method not only identifies the process of formation of cracks, but also makes it possible to locate them.

1. Introduction

Recently much attention has been paid to diagnostics and monitoring of building structures in service, which is related to their durability and reliability [9,10,12,13]. In particular that refers to bridges because the development of road network depends on their technical state. Additionally, over 50% of bridges were designed and constructed in the years 1946–1980. The mean value in the evaluation of bridges and overpasses in national roads in Poland [2] amounted to 3.64. The evaluation was based on the guidelines of the so-called bridge management system, in which the grades ranged 1–5 (1 denoted a failure condition, 5 denoted an excellent condition). Temporary bridge shutdowns lead to substantial economic, social and environmental losses; therefore, currently many works are geared towards developing technologies and procedures that aim at ensuring the proper maintenance of road structures, which includes monitoring and diagnostics [1,9,10,12,13]. In accordance with [5], monitoring systems should focus on two issues, namely the changes taking place in the structure of loads, and also damage accumulation. Properly conducted bridge monitoring and diagnostics are intended to help relevant road management bodies to supervise those structures and prolong their service life. Thus, to optimise the schedule and scope of renovation works, repairs or strengthening, and in case damages that threaten the structural safety are revealed, to decide to shut down the structure if justifiable. The monitoring system presented in works [3,4,11] makes it possible to carry out objective, i.e. independent of the inspector's experience, assessment of the technical state of

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Table 1 – Characteristic signal classes and the corresponding symbols, colours and codes.

Colour/shape								
Class no.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8

concrete structures. The system is based on measurements of acoustic emissions generated by active (developing) destructive processes.

Acoustic emissions (AE) are vanishing elastic waves generated due to a rapid release of the energy accumulated in the material by propagating micro-damages (micro-crack growth, the movement of vacancies and dislocations, grain boundary sliding, coalescence of dislocations, crack initiation and development, phase changes in the crystalline structure) [7,8].

The received AE signals are characterised by a number of parameters such as e.g. counts, duration, signal rise time, signal amplitude, signal energy, average effective voltage, average signal level, initial frequency, etc.

The processes that generate AE signals accompany only active damages, i.e. those that are initiated or develop under the conditions that prevail while the measurements are taken.

For pre-stressed concrete structures the following destructive processes, which are also AE sources, can be differentiated [4]: microcracks [6], friction between crack surfaces, initiation and growth of cracks in the concrete, the loss of adhesion at the concrete–reinforcement interface, concrete spalling, friction at the reinforcement–concrete interface, corrosion, plastic deformation and fracture of prestressing cables and other reinforcement.

In the presented system, the signals characteristic of each destructive process constitute the reference databases, which makes it possible to identify such a process. Thus, e.g. a database which comprises selected parameters of the acoustic emission signal is ascribed to the initiation of cracks in the concrete.

Databases for individual processes (or groups of those) are determined using material specimens and models in specially designed laboratory tests, in which a given destructive process, or a group of processes, dominates.

Reference databases, eight of which were compiled for pre-stressed elements, were classified on the basis of twelve parameters (number of counts, number of counts to peak, duration, rise time, amplitude in mV or dB, energy, strength, root mean square, mean level, mean frequency, reverberation frequency and initial frequency) of the AE signal and denoted as classes [11]:

1. Micro-cracking in the concrete at the boundary of the small-sized ($\Phi \leq 2$ mm) aggregate and the cement paste.
2. Micro-cracking in the concrete at the boundary of the medium-sized ($\Phi \leq 8$ mm) aggregate fraction and the cement paste.
3. Cracks initiation in the concrete tension zone.
4. Cracks growth.
5. Cracks at the concrete–reinforcement interface.
6. Plastic deformation of steel and concrete.

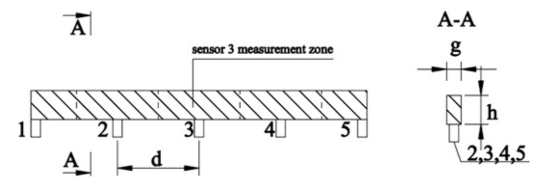

Fig. 1 – Measurement zones covering the whole examined item.

7. Concrete separation from the reinforcement (delamination).
8. Rupture of prestressed tendons.

In the investigations conducted for the present work, the first seven classes were found to occur in reinforced concrete elements. Signal classes and the corresponding symbols and colours are presented in Table 1.

For instance, a signal corresponding to Class 1 reference is caused by a destructive process that involves the formation of micro-cracks in the concrete at the boundary of the small-sized aggregate fraction and the cement paste.

By means of appropriate spacing of acoustic sensors [3] and taking measurements of AE signals (Fig. 1), and also having a database of reference signals at one's disposal, it is possible to identify and monitor active destructive processes that occur within the whole volume of the examined material.

Signals were recorded, identified and analysed with zone accuracy in the manner described above. The results were applied to the technical evaluation [11] of the examined structures (mainly pre-stressed concrete bridges) in service. The possibility of documented validation of the results obtained in the tests (the identification and location of a destructive process) on real structures and in investigations was much restricted. For instance, it was possible to identify Classes 3 and 4 signals (cracks initiation and development) only when the crack was clearly visible.

The paper aims at experimental validating of the identification and location of Classes 3 and 4 signals related to the initiation and development of cracks.

2. Location of AE sources

Acoustic emission sources are located on the basis of the difference in the time that AE generated signal reaches the sensors with known (experimentally determined) wave velocity.

2.1. *Linear zone location*

In the beam tests [3,11], linear zone location was applied, with an accuracy to the measurement zone in which a destructive process occurs.