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Application of the SiGMA analysis to the stress evaluation of the cracking structures

Introduction

The technique of the measurement of acoustic emissions is divided into two methods: classical and quantitative. Generally applied in the research of whole constructions e.g. bridges, is the classical method. All the data occupying the favourable volume and the interpretation of results, is in real-time. The qualitative method, however, enables the interpretation of results only after the execution of the measurement, thus it is labour-consuming [Grosse, Linzer 2008: 53–99].

The classical measurement relies on the registration of acoustic emission signals and the analysis of parameters. Most often applied parameters are the number of signals, counts, the duration, the rise time, the amplitude and the energy. This method was successfully applied to the diagnosis of bridges made of pre-stressed concrete beams [Świt 2011: 2], to the evaluation of elements strengthened with composite material [Świt 2004: 414–418] and currently, in the research work for the assessment of reinforced concrete beams [Goszczyńska, Świt, Trąmpczyński, Krampikowska, Tworzewska, Tworzewski 2012: 77–85].

The quantitative measurement relies on the registration of wave shapes of acoustic emission signals and the parameters. This method enables interpretation of local damage in the form of three-dimensional locations and provides information on structural changes of material [Grosse, Linzer 2008: 53–99]. Thus, during recent years interest has grown in respect of these methods of processing and analysing of acoustic emission signals, e.g. the wavelet analysis [Kim, Melhem 2004: 347–362], the analysis of the waveform [Teodorczyk 2013: 359–366] and the Sigma analysis [Ohtsu, Isoda, Tomoda 2007: 21–32].

The Sigma analysis allows the signal source to be located and to evaluate the reason and the direction of an elastic wave propagation. Cracking of the concrete is a source of the elastic wave. The Sigma procedure can determine the stresses which caused the cracking e.g. tensile stress, shearing stress or both simultaneously. The factor responsible for the interpretation of stresses is the moment tensor, describes the importance of acoustic emission signals, on the basis of waveform, size and the propagation direction [Ono 2010: 317–341].

This work presents an experimental approach to the Sigma analysis and the moment tensor, for the reinforced concrete element under load.

1. The Experimental Study

The purpose of the investigation was to carry out the Sigma analysis on the basis of registered waveforms, as results of the cracking reinforced concrete element.

1.1. The Testing Element

An experimental investigation was conducted out on the element 150 × 150 × 600 mm, from the precast concrete plant. The average concrete compression strength was 61.22 MPa after 120 days. The element reinforcement was made from a single smooth bar, S235JR steel grade (fig. 1).

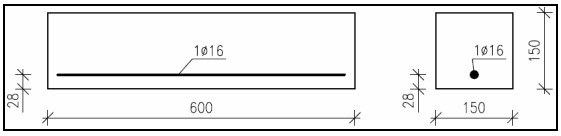

Fig. 1. Reinforced concrete element performed to the test (own elaboration)

1.2. Research Work

The testing element was loaded onto a strength machine in the range of the load-bearing capacity 250 kN. The machine consists of two work spaces: the upper part enables the testing of steel bars during axial tension, however the bottom, test of elements on the compression and the three-point bending (fig. 2). The strength machine was bought within the framework of the project „MODIN II – Modernizacja i rozbudowa infrastruktury edukacyjno-badawczej Politechniki Świętokrzyskiej w Kielcach".

Fig. 2. The strength machine constructed to carry out the investigation (own elaboration)

1.3. The Load Programme

The reinforced concrete element was loaded with force in the middle of span, monotonically with temporary stoppage. The strength machine conducted 19 levels of the load with intervals of 3 kN and 4 minutes stoppage time. The test was finished after a 57 kN force was achieved. The cracking of the element was observed on every level of the load.

1.4. Sigma Analysis

An acoustic emission is a transient wave caused by the liberation of energy in material. The experimental study is directed on the realising of the energy in the concrete as result of structure deterioration. Thus, the transient wave gets to the surface of the element and is recorded by sensors. The equation of the elastic wave movement describes Green's function, proposed by [Ohtsu 2008: 175–200]. Thereby, the longitudinal wave of acoustic emission has the greatest velocity, reaches sensors as first.

The Sigma analysis requires the waveform of a longitudinal wave, the time of the arrival and the amplitude of the first movement. It is necessary to record the wave by a minimum of six sensors. On this base, the analysis can locate the areas of the concrete deterioration and to evaluate the reason. The procedure designates six components of the moment tensor (tension and shear) and determines the stress which causes cracking of the element and the direction of the longitudinal wave propagation [Ohtsu 2008: 175–200].

The acoustic emission test was conducted using the industrial apparatus, equipped with two eight-channel-cards of Samos and specialistic software. The software enables registration of wave shapes of acoustic emissions together with their parameters. Piezoelectric sensors with the flat characteristics were used in the 20–80 kHz frequency range. They were placed on three sides of the element (fig. 3).

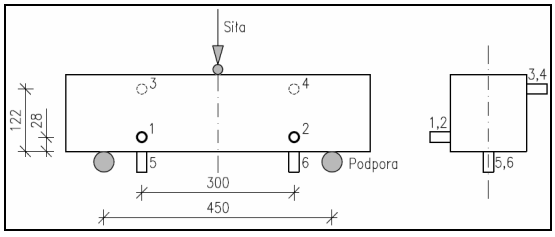

Fig. 3. The spacing of measuring-sensors to the Sigma analysis, numbers 1–6 are sensors (own elaboration)

2. Results

The Sigma analysis was performed by AEWin SiGMA3D software equipped with a moment tensor module. The programme enables three-dimensional location and the analysis of acoustic emission signals. The place of

the signal's location was compared with the place of the cracking appearing on the element. Only one crack arose in the middle of span which was developed gradually towards the load (fig. 4); the image of the crack was underlined with a black line.

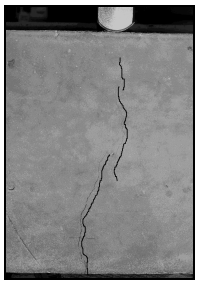

Fig. 4. The image of cracking of the reinforced concrete element in the range of the 57 kN force (own elaboration)

To the SiGMA3D programme were chosen signals registered by six sensors and classified as events of acoustic emissions. Every event is highlighted with a colour, assigned to the arising stress (fig. 5), but for the purpose of the article, the use of colour was eliminated. During the study were registered tensile stress, shearing stress and both simultaneously.

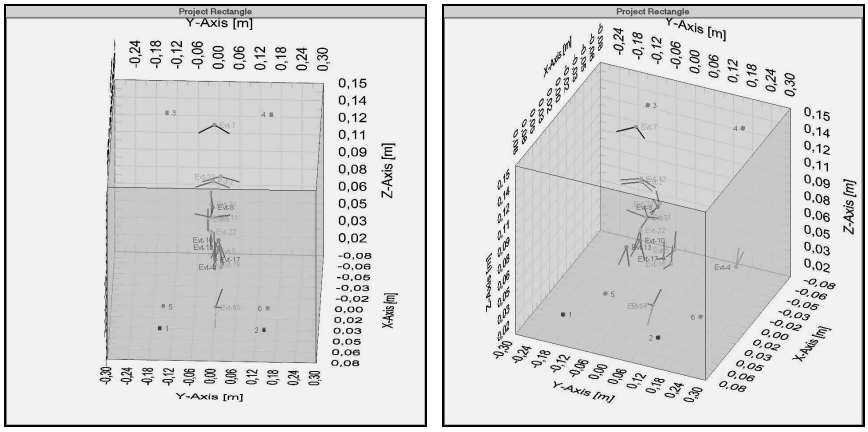

Fig. 5. The Sigma analysis of the reinforced concrete element under load in the AEWin SiGMA3D programme (own elaboration)

Conclusions

The Sigma analysis was applied to the investigation of the reinforced concrete element during three-point bending. On the basis of this experimental study the following conclusions were established.

a) The analysis of Sigma identified tensile stress, shearing stress and both simultaneously, as deterioration of the reinforced concrete element under load.
b) The location of acoustic emission signals occurred in the area of cracking of the element, what confirms the correctness of the analysis.
c) The Sigma analysis is useful in the early detection of the micro-cracking of concrete appearing outside the element, what can be essential in the diagnosis of reinforced concrete constructions.
d) The development of the measuring apparatus and computational algorithms, enables the progress of quantitative methods for the acoustic emission analysis, on the basis of registered waveforms.

Literatura

Goszczyńska B., Świt G., Trąmpczyński W., Krampikowska A., Tworzewska J., Tworzewski P. (2012), *Zastosowanie metody emisji akustycznej do analizy procesu zarysowania belek żelbetowych*, „Zeszyty Naukowe Politechniki Rzeszowskiej", Seria: „Budownictwo i Inżynieria Środowiska", nr 59 (3/2012/II).

Grosse C.U., Linzer L.M. (2008), *Signal-Based AE Analysis* [w:] *Acoustic Emission Testing*, red. C.U. Grosse, M. Ohtsu, Springer.

Kim H., Melhem H. (2004), *Damage detection of structures by wavelet analysis*, "Engineering Structures", vol. 26.

Ohtsu M. (2008), *Moment tensor analysis* [w:] *Acoustic Emission Testing*, red. C.U. Grosse, M. Ohtsu, Springer.

Ohtsu M., Isoda T., Tomoda Y. (2007), *Acoustic emission techniques standardized for concrete structures*, "Journal of Acoustic Emission", vol. 25.

Ono K. (2010), *Application of acoustic emission for structure diagnosis*, 56 Konferencja Naukowa Komitetu Inżynierii Lądowej i Wodnej PAN oraz Komitetu Nauki PZITB, Kielce–Krynica, 19–24 września 2010: „Diagnostyka, monitoring i modernizacja eksploatowanych obiektów budowlanych", Kielce.

Świt G. (2004), *Evaluation of compliance change in concrete beams reinforced by GRP using AE*, "Journal of Materials in Civil Engineering", vol. 16, no 5.

Świt G. (2011), *Analiza procesów destrukcyjnych w obiektach mostowych z belek strunobetonowych z wykorzystaniem zjawiska emisji akustycznej*, Kielce.

Teodorczyk M. (2013), *Tłumienie fali akustycznej w belce żelbetowej z wykorzystaniem podręcznego urządzenia do pomiaru emisji akustycznej* [w:] *Aktualne badania i analizy z inżynierii lądowej*.

Abstract

The paper presents the method for the elastic wave processing and propagation analysis applied to the reinforced concrete element under load. The quantitative method gives information about structural changes within the material and enables three-dimensional location of local damage. The Sigma analysis based

on a waveform of longitudinal waves was chosen for the study. On this base the analysis can locate the place of the concrete deterioration and evaluate the stress which causing cracking. The acoustic emission test was conducted by the industrial apparatus and six piezoelectric sensors. The waveforms of acoustic emission signals were analysed using computer software. The experimental study confirmed the correctness of the analysis on the base of cracking appearing. The Sigma analysis identified tensile stress, shearing stress and both simultaneously. The method can be useful in the early detection of the micro-cracking of the reinforced concrete elements.

Key words: Quantitative methods, SiGMA analysis, longitudinal acoustic wave, cracking, reinforced concrete.