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Conference Paper

Author(s):
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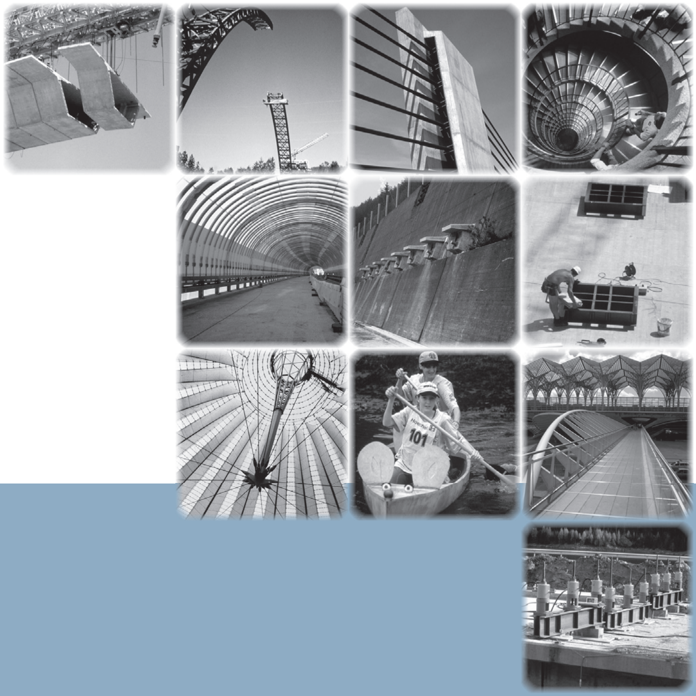
Publication date:
2010

Permanent link:
https://doi.org/10.3929/ethz-a-006962352



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Publisher:
Technical University of Denmark, Dept. of Civil Engineering

Publication Place:
Kgs. Lyngby, Denmark

Publication Date:
2010

Start Page:
611

End Page:
616

Language:
English

Editor(s)
Fisher, Gregor; Geiker, Mette; Hededal, Ole; Ottosen, Lisbeth; Stang, Henrik

Book Title:
8th International PhD Symposium in Civil Engineering

Event Name:
8th International PhD Symposium in Civil Engineering

Event Location:
Kgs. Lyngby, Denmark

Event Date:
June 20-23, 2010

Assigned Organisational Unit(s):
03353

Acoustic Emission in Structural Health Monitoring - corrosion detecting in post-tensioned girders

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Abstract
The aim of this work was applying the acoustic emission monitoring technique for evaluation of corrosion processes of steel tendons in post-tensioned concrete girders. Deteriorations and especially wire breaks, caused by corrosion of tendons, may result in disintegration of a whole structure. Detection and evaluation of corrosion processes in concrete girders is technically difficult and appropriate methods are still under development.

1. Introduction

Corrosion of reinforcement is a serious problem in engineering structures and is most difficult to discover in its early stage of development, especially because early initiation and development appear inside of a structure, out of visibility. We are not aware of consequences, when it is not possible to discover products of corrosion. Corrosion causes the deterioration of concrete and reduction of steel reinforcement's cross section As a result a collapse of a structure may occur. Detection and evaluation of an early stage corrosion processes is complicated and mostly destructive.

The experiments presented in this paper were executed at University Paul Sabatier in Toulouse, France during a master project. These tests were carried out to determine a more sufficient detection technique for recognition and evaluation of corrosion initiation processes. Acoustic Emission (AE) has been applied as a main monitoring method. AE is the elastic energy spontaneously released by materials when they undergo deformation [1]. AE signals are generated during deterioration initiation and development. This non-destructive method has been chosen due to many advantages like damage/deterioration localization, global monitoring covering the whole structure, only active damage/deterioration registration, monitoring under service conditions and finally damage/deterioration development intensity evaluation. AE monitoring was performed to detect the acoustic signals corresponding to accelerated corrosion processes.

In this study the corrosion processes of reinforcement of post tensioned tendons in concrete beams were examined. The laboratory tests have been performed on two post tensioned girders, which were of the same geometry. In one of beams, the tendon was treated with an acid attack for two weeks prior to the bending tests, while the second served as a reference without an acid treatment. Both of the beams were loaded in cycles up to failure in four point bending. The recorded data has been analysed with NOESIS Pattern Recognition Analysis. The results gained from this analysis provide some information considering sources of AE, which are the destructive processes.

1.1 Testing samples

For the purpose of this research, two 3 m long post tensioned concrete beams (see Figure 1a) were constructed. The rectangular cross section of the beams measures 15x28 cm. Both tendons were tensioned with the same force of 75 kN. In each girder, a plastic hollow box (90x80x30 mm) had been encased on tendons to aggravate the corrosion process (see Figure 1b). Only one of the girders was treated with an acid (NH_4SCN) for two weeks. Bending tests were undertaken on both girders i.e. P1 without acid treatment and P2 with the corroding tendon. During all of the experiment' stages, AE monitoring was carried out.

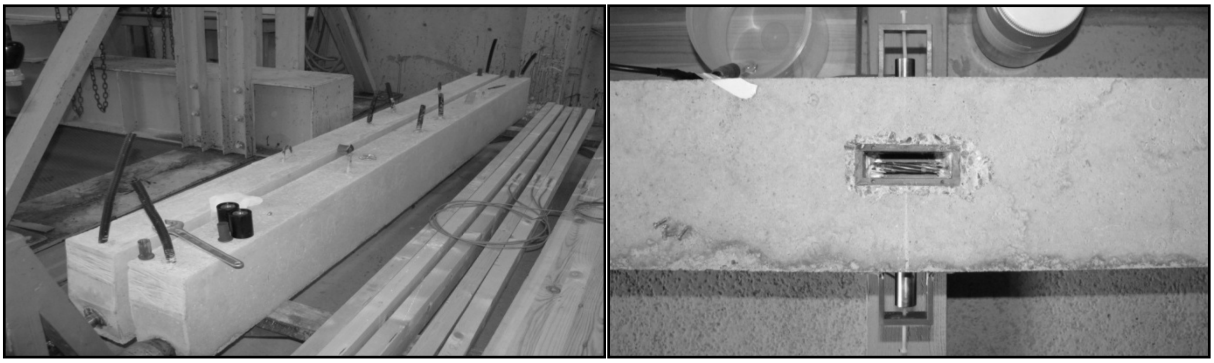

Figure 1: (a) Post tensioned 3 m long beams after 28 days of maturing; (b) The P2 beam with the exposed tendon before applying the acid, during acid treatment.

1.2 Monitoring equipment

As the main monitoring system the µSAMOS was used, which is a sensor based acoustic multichannel operation system containing a PCI-8 card [2].

For the monitoring, two types of AE piezoelectric sensors were used. On concrete surface, the Vallen Systems GmbH [3] VS30-V sensors with the mean frequency value of 55 kHz, high sensitivity low frequency were applied. This type of AE sensors are optimized for testing tank floors and other engineering structures as well as for leak detection. At the surface of the tendons, WD low sensitivity high frequency PAC Ltd. [2] AE sensors were positioned.

For the parametric measurements, a displacement sensor and a load cell were connected to the µSAMOS system.

For data acquisition, the AEWin, fully compatible with PACs standard (DTA) data files, Data Acquisition and Replay program was utilized [2].

The bending tests were performed on a testing stand SINTCO with a loading capacity up to 600 kN.

1.3 Experiments stages

The experiment of two geometrically similar beams was performed to discover the influence of an aggressive chemical environment on the development of acoustic signals. The experiments were carried out in three main stages i.e. bending test of beam P1, corrosion monitoring of beam P2 followed by bending test. Both beams were loaded in cycles up to failure in four point bending.

1.3.1 Corrosion monitoring (P2)

This part of the experiment was undertaken to discover initiation and development of corrosion processes on post-tensioned tendon by AE monitoring. The moment of corrosion initiation is very difficult to recognize.

During the corrosion monitoring, the tendon of beam P2 was treated with an acid with two different chemical solutions: NH_4SCN (200 g/800 ml) i.e. solution 1, during the first week and NH_4SCN (400 g/800 ml) i.e. solution 2, during the second week of the monitoring. During the test, AE was acquired and no load was applied.

1.3.2 Bending tests (P1, P2)

The beams P1, P2 were loaded up to failure in seven cycles (see Figure 2):

- Cycle 1: 0 – 35 kN
- Cycle 2: 0 – 40 kN
- Cycle 3: 0 – 40 kN
- Cycle 4: 0 – 50 kN
- Cycle 5: 0 – 50 kN
- Cycle 6: 0 – 60 kN
- Cycle 7: 0 – 105 kN.

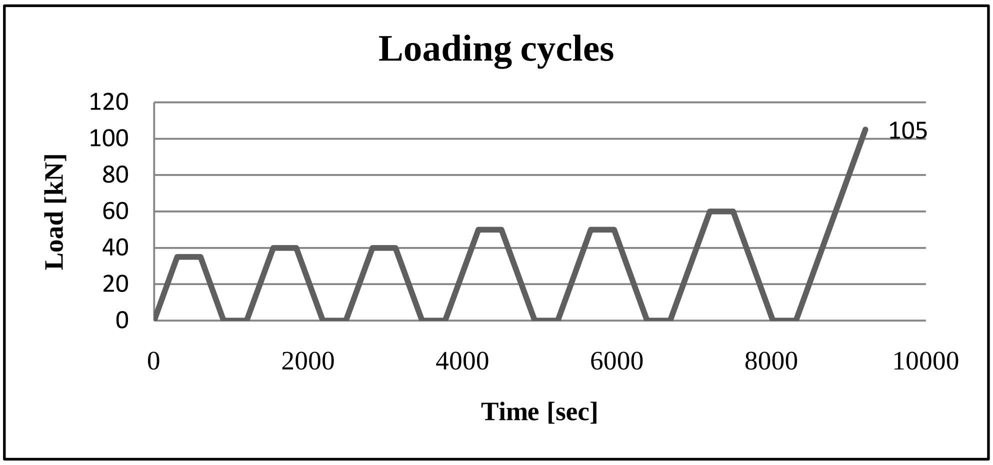

Figure 2: Bending test: Loading cycles vs. Time.

The loading levels 40 kN and 50 kN were repeated to study the Kaiser Effect i.e. an effect, in which acoustic emissions are not observed during the reloading of a material until the stress exceeds its previous high value.

2. Analysis of the acoustic signals

The following analysis focuses on the AE signals' classification to recognize destructive processes in post-tensioned concrete girders. For the AE signal analysis, the NOESIS Unsupervised Pattern Recognition (UPR) analysis was used. Signals, collected during the mechanical and chemical parts of the experiments, were filtered i.e. removing correlated parameters, and classified by the unsupervised k-Means statistic with a different purposed number of classes.

In the presented signal patterns, results with an assumed number of classes (see Figure 3 - 4), which represent different destructive processes taking place during the bending tests and corrosion monitoring, are revealed. The results from the tests of the two post tensioned concrete beams, which were loaded up to failure under neutral environmental conditions (laboratory conditions), are presented in the next diagrams i.e. signal strength vs. time. It should be noted, that in the higher load cycles, the activity of acoustic emission was registered during both loading and unloading. High activity during unloading proves the presence of concrete cracking i.e. opening and closure of cracks. In regular service of structures, this defect allows corrosive agents to penetrate a structure.

The failure of beam P1 revealed plastic deformations and tendon break and is represented by AE signals in the last loading cycle 7. The development of destructive processes in the concrete took place during prior loading cycles (see corresponding signals to the loading cycle 4, cycle 5 and cycle 6 on the Figure 3, 4). Beam P2, which was treated previously with a corrosive component, was loaded up to failure in the same loading cycles as beam P1. The results, which are shown on Figure 4, do not show any larger variation (compared to beam P1 bending tests' results), which could clearly indicate the degradation of the tendon's state due to corrosion.

Beam P2 reached its ultimate load by transfer cracking of the concrete and yielding of the tendon. These events produced high signal energy.

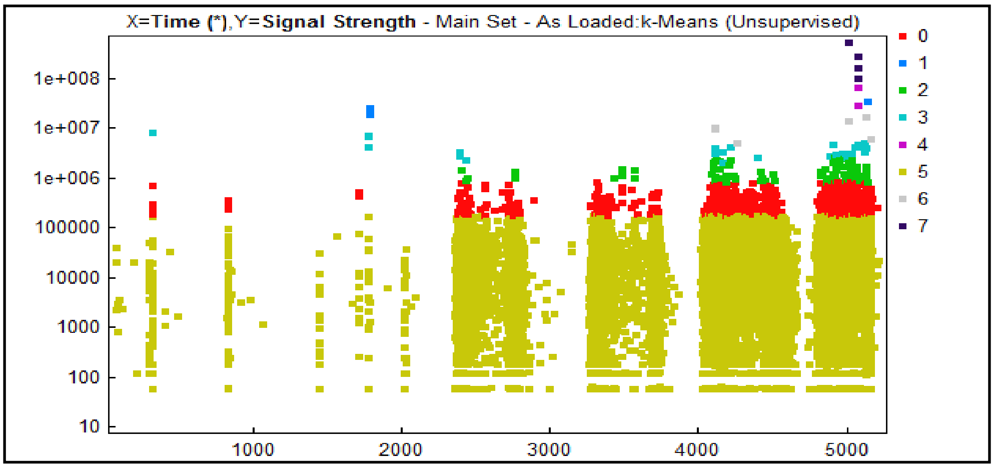

Figure 3: Beam P1 - AE classified signals during the loading cycles 1 to 7. AE signal classification by the UPR method with 8 classes. AE signals not normalized.

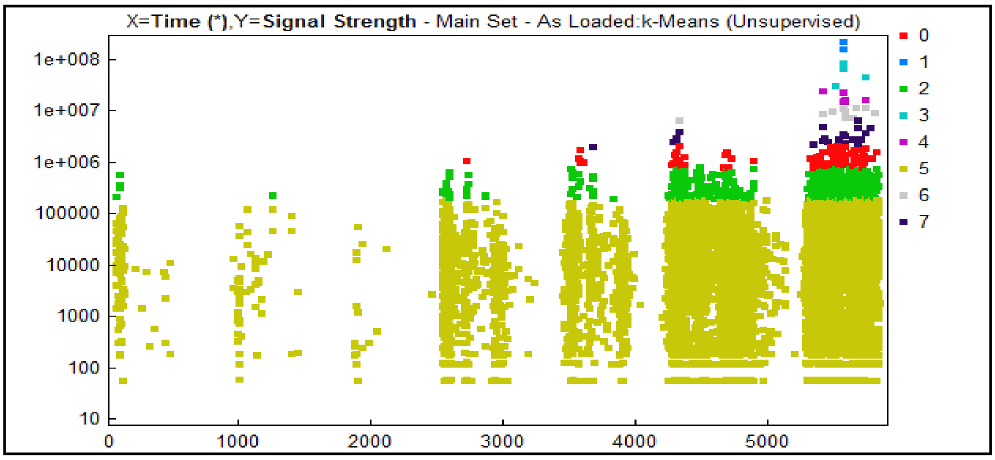

Figure 4: Beam P2 - AE classified signals during the loading cycles 1 to 7. AE signal classification by UPR method with 8 classes. AE signals not normalized.

The tendon of beam P2 was treated with an aggressive corrosive component prior to the bending test. During the corrosion monitoring, acoustic signals were registered. The results from Day 8 are presented on Figure 5. The stronger AE activity appeared periodically, approximately every 50 000 sec. Between bursting events, registered signals appeared to have a regular and weak emission above the established threshold. The level of signal strength during bursts of corrosion products is nearly two times lower than the signals registered during the bending tests.

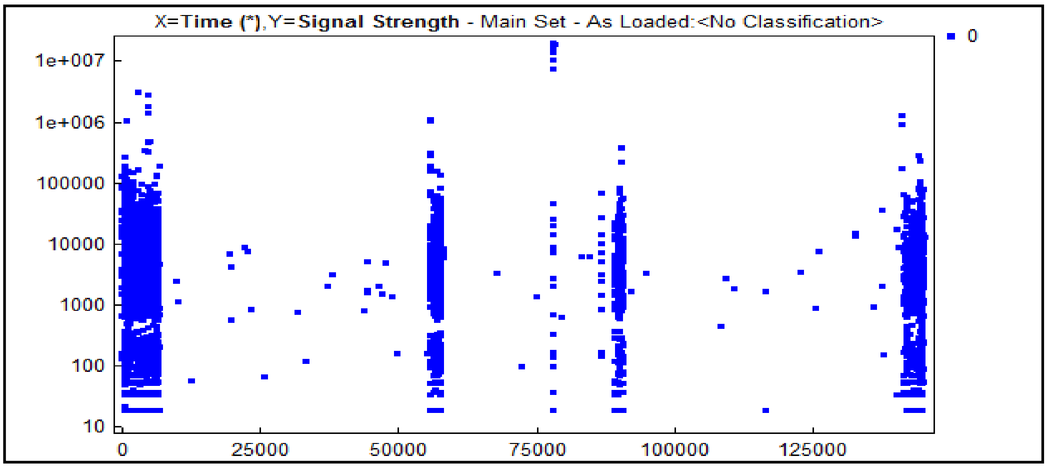

Figure 5: Beam P2, Day 8 – Corrosion monitoring. AE signals strength vs. time; data not classified.

After seven days of monitoring, the corrosive solution was increased. The monitoring was continued during the following week. The energy of signals has not increased significantly, which means that raising the intensity of corrosive component did not result in an increase of the signals' energy. Periodical emission's activity may be caused by two main processes: bursting of corrosion products, which was previously observed during monitoring of steel tanks by Kielce University of Technology (KUT) in Poland, and/or caused by displacement of tendon due to loss of steel bar cross section in the corroded area.

3. Conclusions

Signals registered during initiation and development of corrosion processes show an intermitted nature. The corrosion intensity variation is detectable based on the AE activity. However, the signal strength of the registered data during corrosion monitoring is at least twice lower than the signal strength produced by the destructive processes during the bending tests. Due to a short term of an acid treatment of the tendon, the aggressive environment did not clearly influence the beam's strength in this experiment.

As assumed at the beginning, AE has clearly detected signals coming from corrosion initiation and development, which produces weak signals, compared to processes like concrete cracking or wire breaking. However, this phenomenon has been detected in controlled laboratory conditions without any external loading. It would be very difficult to separate corrosion signals from so called noise signals in regular field monitoring conditions. Due to this fact, further AE is not preferred for corrosion in-situ monitoring.

4. Future research

These experiments have been performed as a part of a research on structural health condition monitoring by acoustic emission. The main aim is to discover and recognize the acoustic signals leading to failure/collapse of a structure. This research has been studied previously at KUT, where laboratory tests on samples, beams, full scale girders and field monitoring on prestressed concrete bridges have been performed [4, 5].

The next step of the research would be developing an overall structural health monitoring for prestressed and post-tensioned concrete bridges. The monitoring should also concern an influence of loading/traffic variation, and environmental conditions on acoustic signals activity.

Acknowledgements

I would like to thank Professor Leszek Gołaski from Kielce University of Technology for great support and fruitful discussion.
I would also like to thank Professor Jean-Paul Balayssac from University Paul Sabatier, Toulouse, who as my advisor supported this research at the Laboratory LMDC Toulouse.

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