Pullout Experiments on Bonded Anchors Monitored via Acoustic Emission Techniques

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Abstract. Fastening techniques are nowadays widely used in civil engineering to fix hybrid components and to enable for efficient structures. One of the major concerns is the sustainability of the fastening techniques and – in regard to anchors – the bond between the anchor and the cementitious matrix. The understanding of bonded anchors and their behaviour under long-term load is essential for their proper usage. Therefore pull-out experiments, monitored with acoustic emission techniques, where conducted. The localization of the acoustic emissions provides insight into the mechanics of bonded anchors and particularly the failure of the bond. Data processing was done using Matlab. For onset picking the AIC picking procedure was implemented and the Bancroft algorithm was used for 3D localization. To verify the localization results obtained with the Bancroft algorithm the Geiger Method was utilized.

Results show, that the location of acoustic emission sources is changing with increasing load. Comparing these results with finite element simulations a correlation could be found, indicating that the bond stress is spreading along the anchor with increasing load.

1. Introduction

Developed in the 1950s, bonded anchors where first used for the preliminary support in mining and tunnel construction. In the following years the usage in construction industry became more important (Lehr 2003). Nowadays, bonded anchors are mostly used for fastening heavy loads onto concrete structures. Since the introduction of bonded anchors into the construction industry design rules where developed and therefore the short term behaviour is quite predictable. In contrast, the long term behaviour is still a topic of scientific interest. Especially since severe accidents, resulting from failure of bonded anchors happened, the topic draw the attention of the scientific community (Ross 2007). In this context some pull-out experiments, partially monitored with acoustic emission equipment, were conducted at the chair of non-destructive testing. The results obtained by acoustic emission methods are the main topic of this contribution.

2. Bonded anchors and experimental Setup

Bonded anchors consist mostly of three components, which are anchor rod, injection resin and anchor base. The force is transferred to the anchor ground mostly via mechanical interlocking between anchor rod and injection resin. Force transmission from injection resin into anchor base is then enabled by adhesion and capillary forces (Lehr 2003). This study excludes cementitious bonded anchors and covers only chemically bonded anchors. Nevertheless, the presented methods could be used also on other types of dowels. A diagrammatic drawing of the used specimens is given in fig 1.

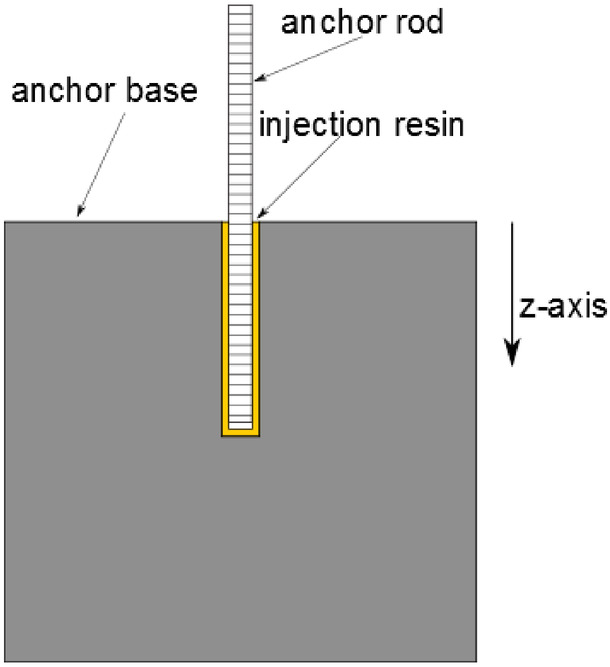

Fig. 1. Schematic diagram of the used specimens.

Mounting the anchors involves the borehole drilling, a cleaning procedure, squeezing the adhesive into the drill holes and placing the anchor rod in to the drill holes. Usually, there are specifications regarding the cleaning procedure given by the manufacturer (Lehr 2003). For the Anchor base, a concrete cube with 0,20 m edge length and a 28 days pressure strength of 32 MPa was used. After drilling and cleaning the boreholes the FIS-V-360-S injection resin was injected into the borehole. This was followed immediately by placing the anchor rod in the borehole. Excess material was then removed with a paper towel. Within a few minutes the injection resin hardens out. After a few days the injection resin is completely cured and the specimens are ready for pull-out experiments.

A Roell & Korthaus tensile test machine was used for the pull-out experiments. The load curve, which is shown in fig. 1 was applied for measuring the reversible part of the displacement. An evaluation of this data is not part of the presented work.

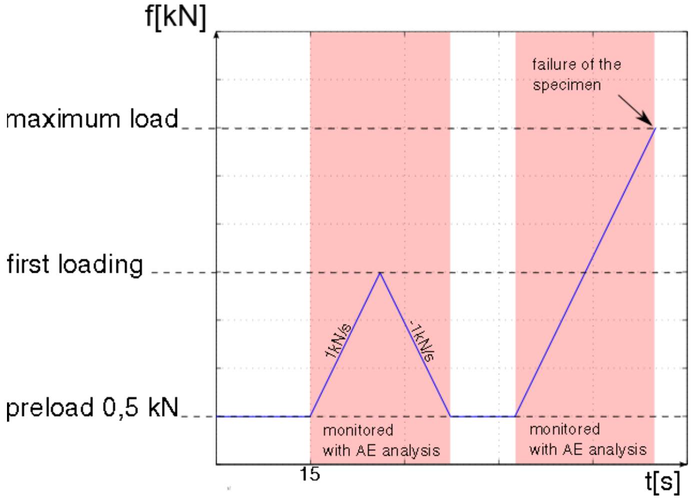

Fig. 2. Schematic diagram of the used load curve.

A total number of 14 experiments were conducted and monitored via acoustic emission sensors. Due to faulty settings and hardware problems 10 experiments could be evaluated properly.

The Panametrics V103 sensors from Olympus where used to record the acoustic emissions. A SmartPreDig amplifier was utilised to amplify the signals and a band pass filter was applied to reduce low frequency noise and to avoid aliasing artefacts. Data acquisition was done with Elsys data acquisition cards. The data processing was entirely done with MATLAB.

3. Methods used for source localisation

Locating the source of an acoustic emission is an inversion problem. This means, that location and time of the acoustic emission are computed from the sensor coordinates and the corresponding onset times. Onset times are determined using a combination of a threshold picker and an AIC-Picker (Kurz, Grosse et al. 2005). The 3D-localisation is done with the Bancroft algorithm. Due to the limitation of the Bancroft algorithm to four sensors a permutation approach is necessary (Kurz 2006) (Bancroft 1985). Therefore a localisation for each permutation of 4 sensors is computed. To estimate the accuracy of the localisation short ultrasonic pulses where transmitted into the anchor base on different positions. In addition to the accuracy estimation, the prevailing ultrasonic velocity can be determined. An exemplary result of the velocity determination is given in fig. 3a. The prevailing velocity is approximately 4850 m/s.

Source localisation of the ultrasonic pulses allows calculating a mislocation vector. By calculating the length of this vector, the achieved accuracy is determined. An example is given in fig. 3b. As shown in fig. 3b, the mislocation vector never rises above 2 cm. The differences in accuracy and the overall error could be explained by inhomogeneity in the material or by poor picking. An additional source of errors results from the two-dimensional extension of the coupling surface.

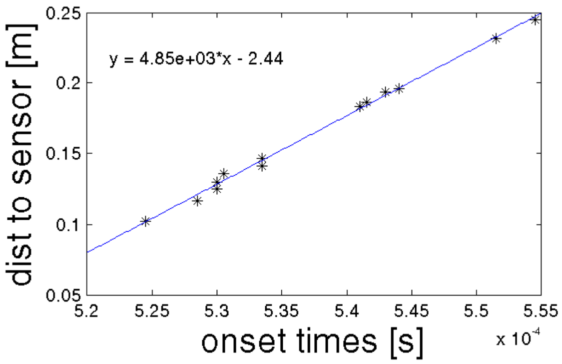

Fig. 3a. Velocity determination.

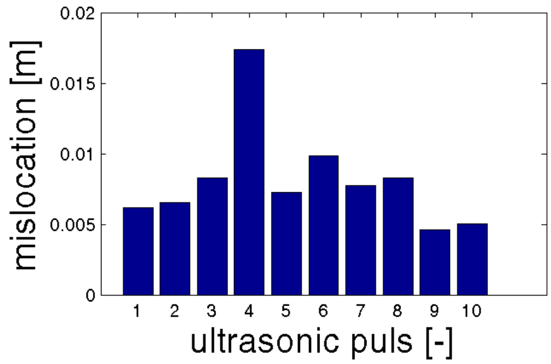

Fig. 3b. Length of mislocation vectors.

As a result of the permutation approach, one location is obtained by each permutation. The cloud diagram in fig. 4a shows the results obtained by the permutation approach. The light red patch represents the margin of the specimen. Sensors are shown as numbered blue circles. To determine the most likely position the median coordinate of every direction is calculated. Starting from this point the mean of a predefined window is calculated. This step is illustrated in fig. 4b.

The accuracy estimation of localisation results of acoustic emissions without known source is based on the linear relationship between onset times and the epicentral distance. To measure the quality of the linear relationship the correlation coefficient can be used. A value between 0,9 and 1 indicates a very strong correlation and therefore the localisation can be considered as certain.

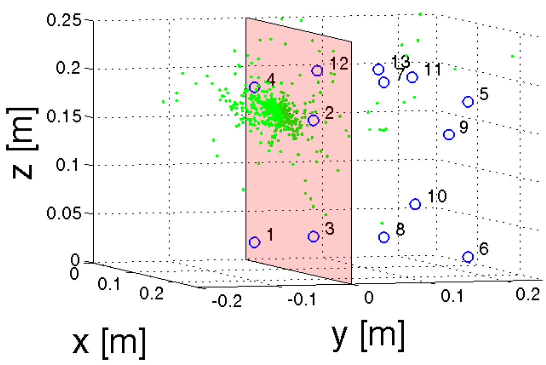

Fig. 4a. Cloud diagram.

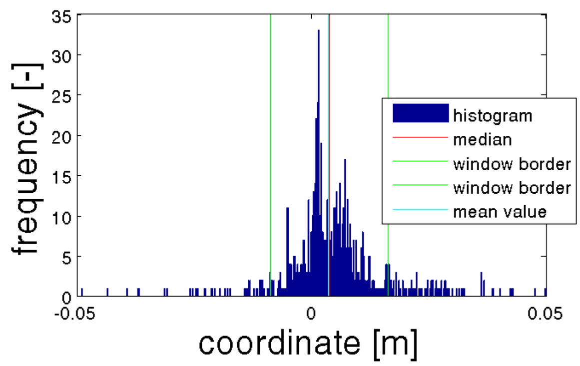

Fig. 4b. Distribution of permutation results.

4. Results

In the past, experiments and numerical simulations regarding bonded anchors were carried out. The main task of these experiments was the development of designing rules for bonded anchors. One of the results was the bond stress distribution within the boundary surface between anchor rod and anchor base (Lehr 2003). An example for the bond stress distribution for different loading stages is given in fig. 5. Additionally the bond stress spreading along the connection length is shown.

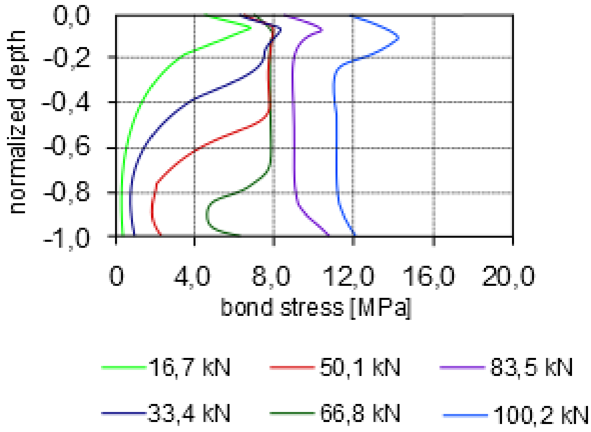

Fig. 5. Bond stress at bonded anchors under different loading (modified after Lehr 2003).

These findings are confirmed by the results obtained by acoustic emission analysis. Especially the source location changes with increasing load towards the centre of the specimen. The point z=0 is located on the surface of the specimen as shown as in fig. 1. If only the most accurate localized emissions are taken into account the spread of the acoustic emission sources in z direction is quite visible (Raith 2013). An example for the change in the z-coordinate due to increasing load is given in fig. 6.

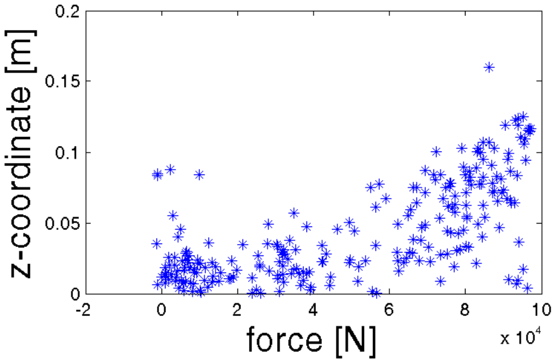

Fig. 6. Change in the z-coordinate of the acoustic emissions while increasing load.

5. Discussion

As shown in the results chapter, the onset determination is only for a certain proportion of events accurate enough to calculate a reliable source localisation. In this way, a preselected number of events is used to show the above stated facts. Additionally, some recorded events comprise of more than one acoustic emission, thus they were not taken into account. If all events where evaluated, it is uncertain whether the trend shown in fig. 6. will preserve.

Moreover the localisation accuracy is limited due to the inhomogeneity of the anchor base. The mislocation vectors in fig. 3b indicate a maximum error at approximately 0,015 m, so a maximum error is considered to reach this value. Transferability to actual acoustic emissions is assumed but cannot be guaranteed due to different source mechanisms. Despite these restrictions the link between bond stress spreading and acoustic emission locations seems to be strong.

6. Outlook

To increase the predictive significance of the measurements, it is necessary to enhance the onset determination and thus the localisation accuracy. Therefore the experimental setup has to be changed. To reduce the amount of acoustic emissions that occur at the support it is necessary to insert a Teflon layer between anchor base and support. Furthermore it makes sense to use path-controlled instead of force-controlled loading so that a uniform damage development can be achieved. An improvement of the signal processing may also lead to more accurate localisation results.

7. Acknowledgements

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