

# **ACOUSTIC EMISSION SIGNAL PROPAGATION THROUGH WELDED STEEL BRIDGE JOINTS**

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## **Abstract**

The main focus of this research was recognition and evaluation of the acoustic signals being modified by travelling through a 3D full scale model of a steel bridge joint. The aim is to develop a monitoring system for steel trusses, mainly bridges, based on the acoustic emission technique. This system should be capable of detecting early signs of processes leading directly to sudden failures/collapses, which for steel bridges, is a common type of failure.

The experiment considered the analysis of the acoustic signal propagation in a 3D joint. For this purpose, a number of reference mine breaks has been performed. Signal analysis including waveform pattern identification has been completed. Various phenomena have been discovered regarding the behaviour of acoustic signals transferred through different structural elements.

## **1. Introduction**

During the last years, some structural failures have concerned the public's and government's opinion. The first example is the collapse of the I-35W steel bridge over the Mississippi River in Minneapolis, USA in 1<sup>st</sup> of August 2007 (see Figure 1). National Transportation Safety Board (NTSB) identified a design flaw as the likely cause of the collapse, and asserted that additional weight on the bridge at the time of the collapse triggered the failure [1]. The second example is the collapse of the trade steel hall in Katowice, Poland in 28<sup>th</sup> of January 2006. The collapse of the hall, which took place during an exhibition of pigeons, occurred due to poor design and snow load exceeding the design value. Both of these failures were sudden and unexpected. Could these tragic events, where many people died or were injured, be avoided? The solution for sudden failures/collapses is to develop a warning system, which could detect critical destructive events early enough and could automatically forward notices to responsible bodies, as well as to structure users. The necessity of developing warning monitoring systems against failure has been highlighted by responsible authorities around the world. The clear directions to equip civil engineering structures with continuous monitoring systems have been established, of which the decree of the Moscow City Mayor is an example [2].



Figure 1: I-35W Bridge over The Mississippi River, USA: (left) before [3] and (right) after the collapse [4] courtesy to Mr. Tim Davis, Consolidated Photo, USA.

Acoustic Emission (AE) monitoring technique seems to be suitable as the base method of the system. According to the Nondestructive Testing Handbook's definition, AE is the elastic energy spontaneously released by materials when they undergo deformation [5]. AE signals are generated during defects/deterioration initiation and development. This method has been chosen due to many advantages. Main is the possibility of performing the global monitoring in a non-destructive manner covering the whole structure or structural element. The registration covers only active damage/deterioration processes monitoring under service. And finally the development of damage/deterioration processes is evaluated based on the signal intensity. Similar researches have been carried out on prestressed concrete structures with positive results [6, 7]. Although, AE monitoring of steel structures requires a different approach due to significant differences of acoustic signals propagation between steel and concrete.

Two main destructive processes have been recognised in steel structures that both produce low energy acoustic signals. These are the fatigue crack propagation and the corrosion, which appear in elements exposed to continuously recurring dynamic load and/or aggressive environment. It is possible to monitor the development of these processes exclusively by AE monitoring, under the condition that their approximate location has previously been established. The "clear" signals

should then be separated from the external influences by the guard sensors, which are mounted to reject events from disturbing sources outside of the area of interest. This monitoring allows recording the signals, which carry the information about the speed of the fatigue crack development [8, 9]. Since only localized processes are monitored, the sudden overall structural failure may not be necessarily expected.

The main focus of this part of the research is the analysis of the high energy acoustic signals propagation in structural elements of spatial steel bridge joints, which are produced during cracking including brittle cracking of welded and riveted joint elements. Considering the low signals attenuation in steel, acoustic signals can propagate over long distances through long structural elements. However, it should be noted that the parameters that characterise AE signals i.e. amplitude, energy and frequency are varying when the waves propagate through welded/riveted truss elements. Better understanding of the character of the signal propagation will help recognizing the localization and identification of the sources of the high energy acoustic signals. This knowledge could then possibly serve as a base for establishing structural safety and also as a tool for warning against sudden failures/collapses.

The experiments presented in this paper have been undertaken in the Laboratory of Strength of Materials at the Kielce University of Technology in Poland while the analysis of the results has been performed at the ETH Zurich in Switzerland. The signals propagation has been analysed in a full scale model of a spatial steel bridge joint (see Figure 2 and Figure 3).



Figure 2: Full scale model of a steel bridge joint.

## 2. Introduction to the experiment

The bridge joint contain a two-plane truss (front and back) assembled of parallel steel profiles (lower band 2xC 160x2000, upper band 2xC 100x2000, cross band 2xC 160x530 and joint plate 640x400x8) connected by welded braces (steel plates 60x210x8 mm). To obtain the desired “clear” AE signals, the set of reference pencil mine breaks have been performed at previously selected points on the front plane of the joint. These points are marked as triangles in Figure 4 (MB1, MB2 and MB3). Each set of mine breaks (MB) consisted of ten single events. For comparison, each MB was repeated several times. Normally, the average amplitude of a mine break varies between 90 and 95 dB. These AE signals are short and produce high energy, which corresponds to the AE signals generation during an initiation of brittle cracking of welded truss joints.

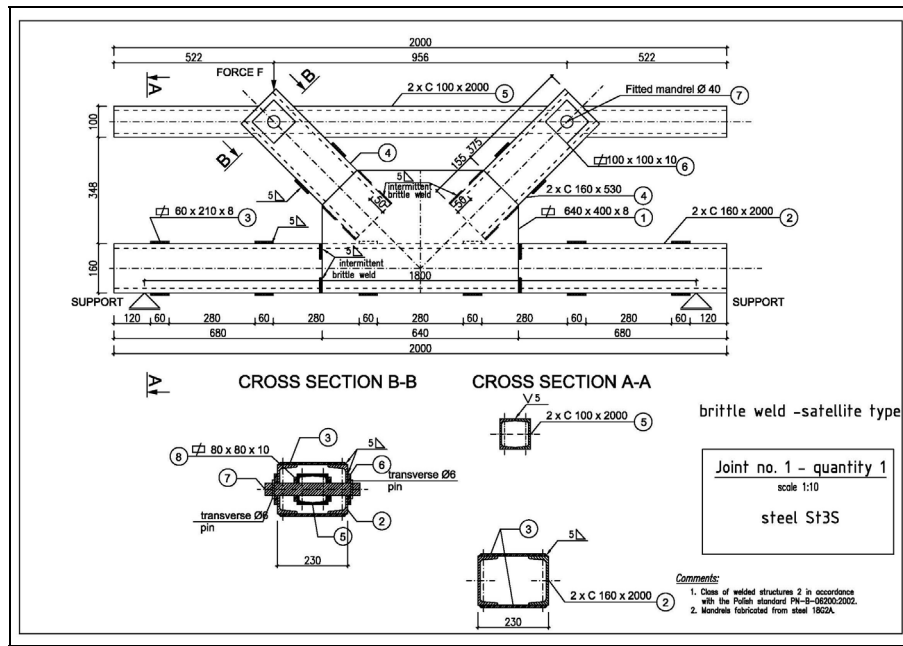


Figure 3: Geometry of the steel bridge joint.

AE monitoring provides detection and localization of destructive processes, which are described by hit domain and/or time domain parameters and are registered by AE piezoelectric sensors. There are no guidelines concerning the type of sensors, which should be applied on steel truss structures. Due to low signal attenuation in steel, generated signals may travel long distances. The signals may also be reflected several times by material discontinuities i.e. defects and damages. It is assumed that signals emitted by sources, which are located within one element, may be fully or partially transmitted through joints to neighbour elements. The signal transfer may result in deviation of signal parameters, which comes from full/partial reflections. Therefore, the signal acquisition and analysis should be accurate and appropriate sensors should be applied.

To do this, prior to the experiment on the joint, four types of sensors have been tested on a rectangular steel plate:

- WD – wideband sensor with a flat frequency response in the range 100 – 1000 kHz,
- DECI SE55-R – resonant sensor with a peak frequency response at 55 kHz,
- VS150-RI - resonant sensor with a peak frequency response at 150 kHz,
- VS30-V – high sensitivity low-frequency sensor with a flat frequency response in the range 25 – 80 kHz.

The reference signal source was Langevin's probe type HEC-45282 (Figure 4).

The DECI SE55-R, characterized by low frequency and high sensitivity at 55 kHz (see Figure 4) were chosen for monitoring of the steel bridge joint because of their low signal damping [11]. For the experiment, six sensors of this type were mounted symmetrically on the bridge joint (see Figure 2, 3, 5) i.e. three on Plane 1 (front) and three placed symmetrically on the Plane 2 (back).

As the main monitoring system, the  $\mu$ SAMOS was used, which is a sensor based acoustic multichannel operation system containing a PCI-8 card [12]. For data acquisition, the AEWin that is fully compatible with PACs standard (DTA) data files, Data Acquisition and Replay program was utilized [12]. The converted DTA to PRI results have been analysed with Visual AE, which is a statistical analysis software [13].



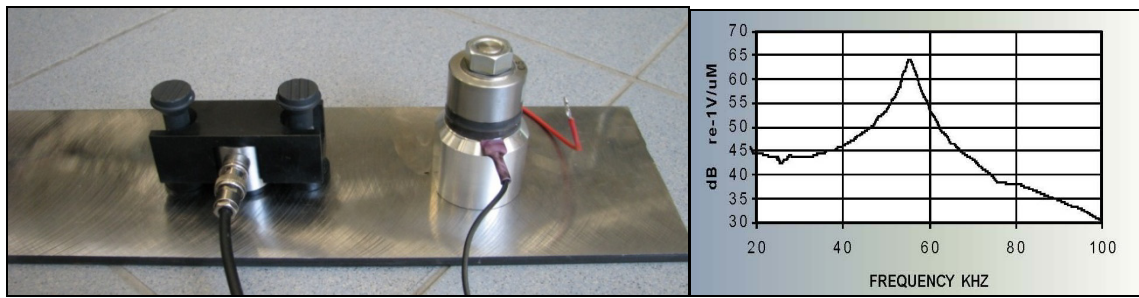


Figure 4: (left) DECI SE55-R sensor and Langevin's probe type HEC-45282; (right) SE55-R characteristic frequency response.

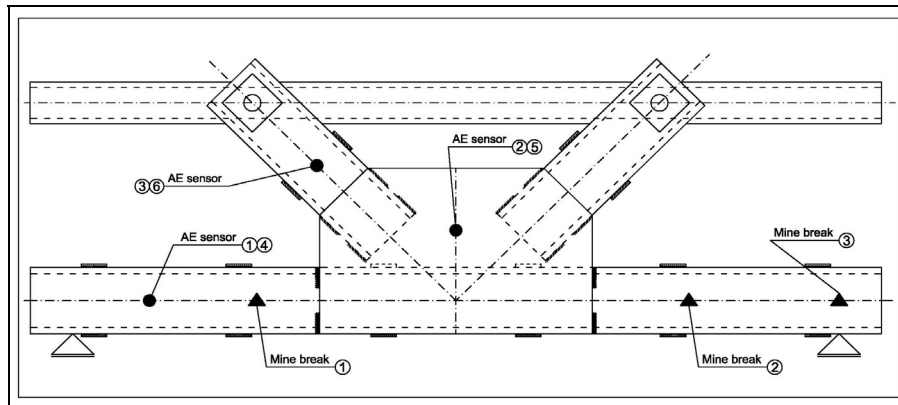


Figure 5: Scheme of distribution of AE sensors on the joint. Triangles indicate the mine break points.

### 3. Analysis of the acoustic signals

The pencil mine breaks served as AE reference source signals. Each set of mine breaks (MB – see triangles MB1, MB2 and MB3 in Figure 5) consisted of ten single events and was repeated several times for comparison. AE signals generated by the reference MBs in plane P1 have been registered by all of the AE sensors (Channels CH-1 – CH-6), localized on both planes P1 and P2. The transformation of the AE signals through the welds and the lacings resulted in a change of the signal shape and value of AE parameters i.e. loss of energy and amplitude (see Figure 6), where the differences reached 15 dB up to 30 dB. The level of loss depends on the position of the reference source and the receiver. Only a small number of hits reached a high level of amplitude. Most of the recorded AE signals exhibit a long duration i.e. three times longer and maintain a low amplitude (see Figure 7, 8 (right)). The character of these signals is showing some similarities to continuous signals i.e. noise and fatigue or corrosion processes. In case of analysing of unknown and not localized sources, this phenomenon could be easily misinterpreted and classified as a different process.

The variation of signals' pattern and parameters at the low energy level is to be investigated in the complicated structural form. The characteristics of the material itself allow continuous reflections, signals interference and overlapping. The Fast Fourier Transformation (FFT) of the AE signals taken from both planes has revealed hardly any divergences in signal patterns (see Figure 7, 8 (left)). In both presented signal examples (CH-1 and CH-5), there are visible low amplitude peaks at different frequencies despite the fact that only one type of resonant sensors with characteristic peak at 55 dB has been applied.

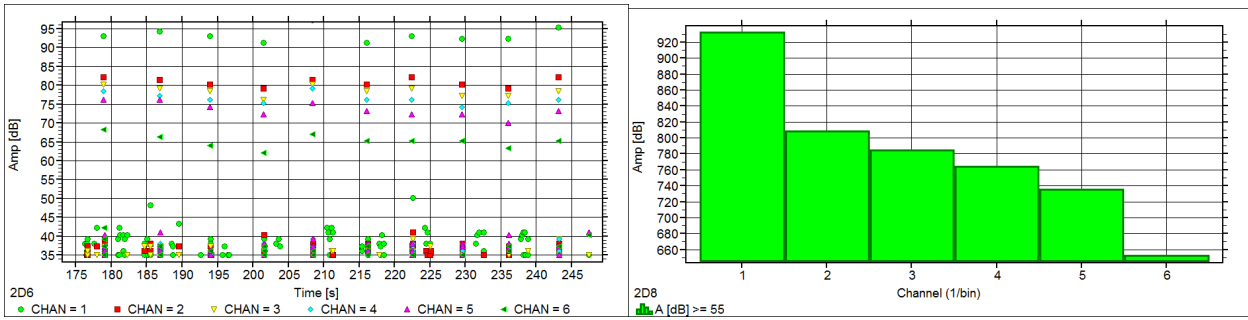


Figure 6: MB1: AE activity during 10 mine breaks; (left) amplitude vs. time correlation diagram, (right) bar distribution summary of amplitudes above 55dB in separate channels.

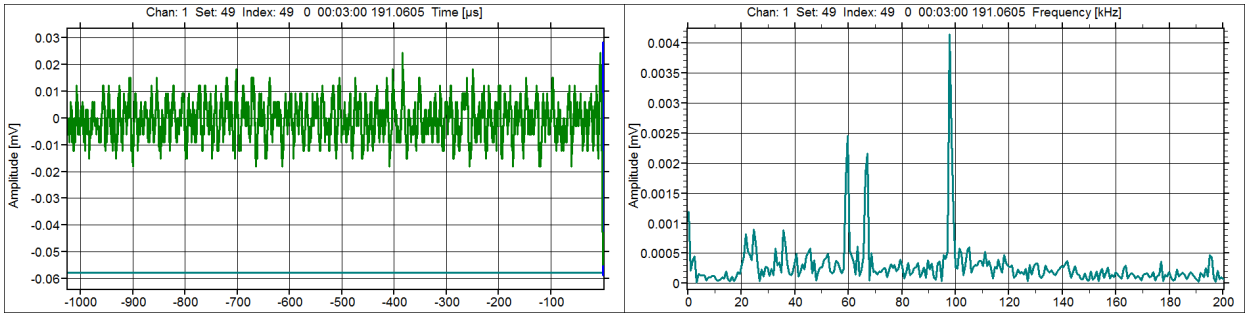


Figure 7: MB1 P1: Waveforms of a single mine break at high amplitudes in channel 1: (left) Sample signal, (right) FFT.

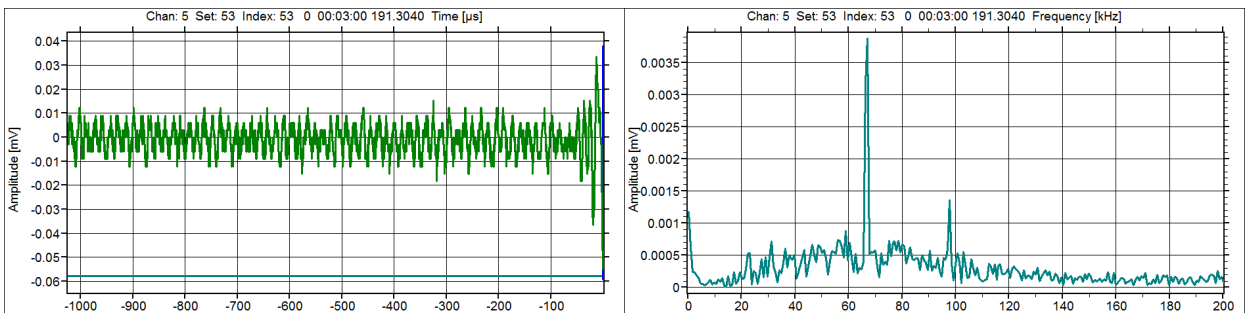


Figure 8: MB1 P2: Waveforms of a single mine break at high amplitudes in channel 5: (left) Sample signal, (right) FFT.

This type of signals does not provide any straight forward information about the destructive processes, which are dangerous for the structural integrity. Due to the multiple signal reflections and interferences, the registered waveforms' patterns are modified and it is difficult or even impossible to distinguish the primary signal parameters characterizing the clear sources i.e. destructive processes. Among the registered signals, only a few sample waveforms could be recognized as "references" (see Figure 9, 10) and could refer to the dangerous processes. Their amplitude is estimated to be between 50 and 95 dB and their duration is relatively short. The unexpected is the high amplitude at the frequency of 20 kHz in the FFT analysis, which still needs to be further studied.

Based on the performed data investigation, the further analysis should be executed with a signal parameter study with a reduced amount of data. FFT analysis should serve as a pre-test validation of a previously chosen sensor type.

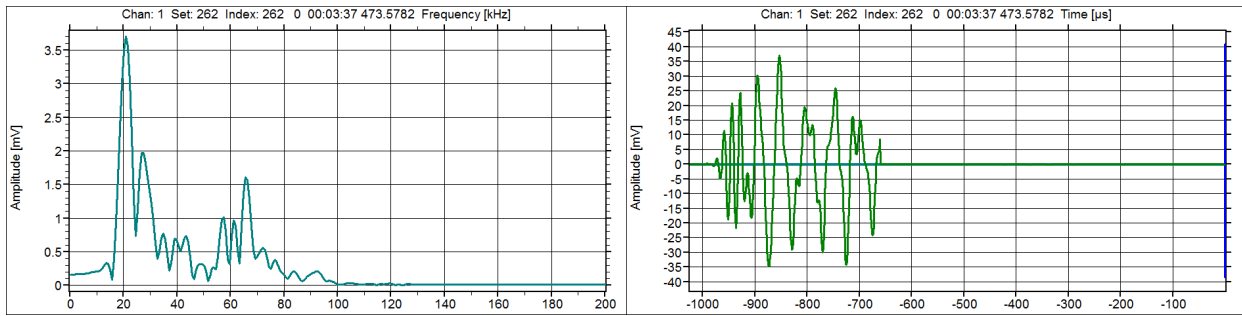


Figure 9: MB1 P1: Waveforms of a single mine break at low amplitudes in channel 1: (left) FFT, (right) Sample signal.

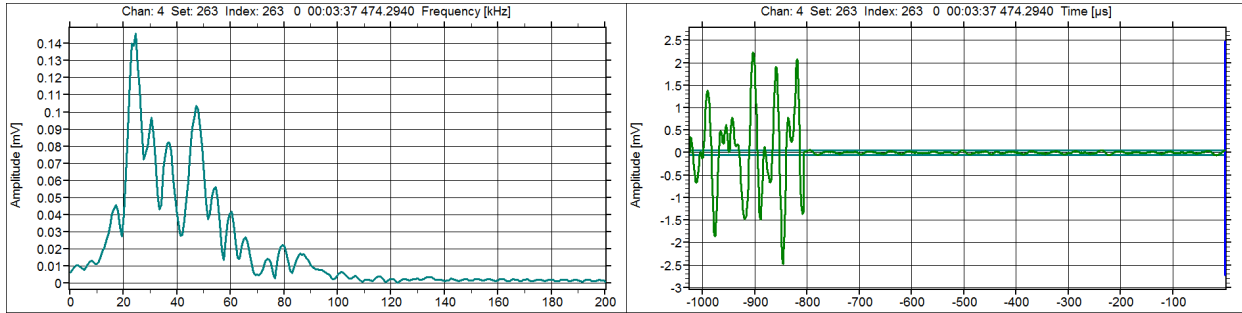


Figure 10: MB1 P2: Waveforms of a single mine break at low amplitudes in channel 4: (left) FFT, (right) Sample signal.

#### 4. Conclusions

Most of the AE signals registered during the reference mine breaks on both front and back planes are signals of long duration and low amplitude. These signals seem to come from signal reflections and overlapping during the propagation. The describing parameters show similarities to the parameters of signals generated during propagation of fatigue cracks, friction or corrosion processes. Some “clear” signals have also been recognized at both front and back planes, which appear to be not modified by either reflection or overlapping. These signals could correspond to strong destructive processes i.e. initiation of brittle cracking. The study of these waveforms has shown that only the nearest sensor from the impact point (MB1) contained high amplitude peak reaching the level 40mV (CH-1), other sensors (CH-2 – CH-6) would not exceed 2mV. These signals are also of relatively short duration and appear to have similarities in the pattern of the FFT waveform. These “reference” waveforms could be separately analysed through the filtration process from the whole network of the registered data.

Identification of the signal propagation and distinguishing the “reference” waveforms could be the basis for developing a procedure suitable for recognition of the dangerous processes leading to decrease of structural safety and serviceability.

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