MONITOROVANIE STAVU KONŠTRUKCIE MOSTA

BRIDGE STRUCTURE STATE MONITORING

P. PETRÁSEK, V. SVOBODA[1]

Abstrakt

Mosty sú veľmi špecifickým druhom konštrukcie a ich diagnostika je tiež veľmi špecifická. Každá mostná konštrukcia je unikátna, ale všetky majú jeden spoločný rys. Ak chceme diagnostikovať celú konštrukciu mosta, reprezentuje to veľkú oblasť. Je nemysliteľné skontrolovať celý most najbežnejšími kontrolnými metódami ako sú magnetická metóda, RTG, atď. Veľmi účinným nástrojom pre diagnostiku mostných konštrukcií je metóda akustickej emisie. Dá sa ňou prehliadnuť celá konštrukcia ľubovoľného tvaru rýchlo a v celom svojom objeme. Metóda akustickej emisie je tiež veľmi vhodná pre kontinuálny monitoring. V kombinácii s tenzometrickým meraním a meraním vibrácií nám dáva výbornú informáciu o stave mostnej konštrukcie. V práci sú uvedené niektoré experimentálne výsledky z merania na oceľovom moste. Na základe merania je urobené vyhodnotenie zvyškovej životnosti mosta.

Kľúčové slová: Diagnostika, akustická emisia, tenzometrické meranie, vibrácia.

Abstract

Bridges are very specific kind of structures and their diagnostics is also very specific. Each bridge structure is unique but all these structures have one identical character. If you want to diagnose whole bridge structure it represents to inspect big area. It is inconceivable to inspect whole bridge by the most common NDT inspections like magnetic method, RTG etc. Very powerful tool for the bridge structures diagnostic is acoustic emission method. You can inspect whole construction of any kind of shape quickly and in all volume. Acoustic emission method is also very convenient for continuous monitoring. In combination with strain-gauge measurement and vibration measurement you have perfect information about state of the bridge structure. Some experimental results are presented from measurement on steel bridge. On the base of measurement the residual life time evaluation of bridge is made.

Keywords: Diagnostics, acoustic emission, strain gauge measurement, vibration.

ACOUSTIC EMISSION

The acoustic emission is a phenomenon characterized by generating elastic stress waves due to various processes taking place in material. These waves propagate through a body and it is possible, by their detection and analysis, to obtain information on the course of the process detected. For detection of propagating stress waves, i.e. acoustic emission, sensitive resonance piezoelectric sensors are used. They are fixed at the surface of a structure and they transform elastic stress waves into electric signal.

The position and significance of the AE method among other NDT consist first of all in their mutual supplementing. The AE method presents on principle a different information than other NDT methods.

[1] P. PETRÁSEK, V. SVOBODA, Preditest Ltd., Prague, preditest@preditest.cz,
Lektoroval: prof. Ing. Pavol JUHÁS, DrSc., KkaDR, SvF TU v Košiciach, pavol.juhas@tuke.sk

The operation of typical NDT methods aims at "a suitable illumination and thus visibility" of the presence of defects in the material of a structure (e.g. ultrasound, capillary method, etc.). Typical NDT methods search for the presence of defects in a structure, usually gradually in steps. They provide information on the pressure, size, orientation, and geometry of defect.

The AE method operates with the aim "to monitor" the warning activity of processes arising in material due to loading of a structure. The AE method detects defects, which are active acoustically. The defects become active due to a complex of causes, as are high stresses, structural damage, corrosion attack, etc. The AE method thus detects not only the presence of defects but also the presence of conditions for their development. The AE method is an integral method. The network of sensors monitors the structure or its region as a whole in a real time of loading, and that is also in service. The AE method gives the evidence on the presence, course, and development of acoustic emission of detected processes, as well as on the presence of defects together with conditions for their development.

Processes and Phenomena Detected by the AE Method

- movement of dislocations
- decohesion and fracture of structural components of material
- decohesion of grains, formation of micro cracks
- crack growth
- crack opening and closure
- leakage of pressurized medium due to a crack

UTILIZATION OF AE METHOD ON STEEL BRIDGE ACROSS THE RIVER ELBE

Continuous truss bridge consists of three sections with lengths 30, 48 and 30 m (Fig.1). Bridge construction is assembled with 2x36 spans each per 3 m length and 3,12 m height. Spans connections on upper and lower flanges are realized by means of pin connections, verticals are mounted with special bolts. Orthotropous flooring with 7,8 width has two lines.

During visual and capillary method testing defect type crack was find out in connection between crossbeam and Orthotropous flooring. Due to this reason diagnostics by means of AE method was concentrate only on behaviour of these cracks not on diagnostics of the whole structure during bridge loading by trucks crossings.

Fig.1 General view on the bridge

Extent of measurement

Acoustic emission measurement was performed in the area of welded joints between the longitudinal chute-shaped reinforcements and transversal bridge beams by means of altogether 15 sensors. Thirteen sensors were placed near the detected crack-type defects, two sensors in the area of uncracked welds. There are AE sensors position on places 0, 1, 2 (32th span) on the Fig.2.

Instrumentation used

During measurement, the following instrumentation was used:

- Multichannel AE measuring system SAENV-16
- Piezoelectric AE sensors, type VS-E-1F
- Preamplifiers with gain G=35 dB, f_h = 100 Hz
- Control computer with Pentium II (160 MHz) processor
- Interconnection coaxial cables

The analog signal from the sensor is amplified in preamplifier, then led by a coaxial cable to the measuring unit SANV-16. There it is amplified again and envelope analysis of the signal is performed - i.e. the following parameters are measured:

- Number of threshold crossings (Ne)
- Pulse width (Width)
- Signal amplitude (Ampl)
- Rise time to maximum amplitude (R.time).

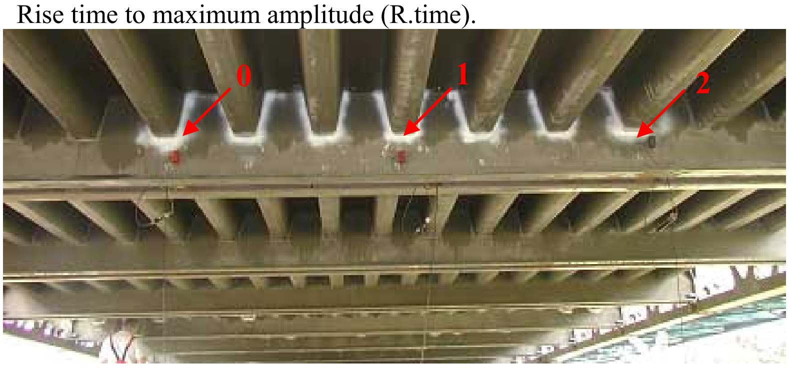


Fig.2 AE sensors position on places 0, 1, 2 – 32th span

During the measurement in the mode of plane location or linear location, the sequence of times when the signal is registered by the individual sensors of the measuring network including delays (delta T) is registered. Taking into account the distribution of sensors and the conditions of signal propagation, a real-time location of signal source is performed.

The setting of instrumentation and data acquisition are performed by means of a control computer (notebook). The data measured are displayed in tabular or graphic form and simultaneously stored on the hard disk of the control computer to enable further processing.

Course of measurement

The AE measurement was performed in two phases. In the first phase, the measurement was performed in the zone location mode (detection of AE signals by the individual sensors), i.e. without the measurement of delta T and the sequences of times when the signal is registered by the individual sensors. The measurement took place during 14 bridge crossings by trucks. In 7 cases, the trucks were loaded with ashes, in 7 cases they were empty. In this phase, the masses and velocities of the trucks were not known.

In the second phase, the measurement was performed in the mode of linear location of AE sources. That means, during the individual crossings the sequences of times when the signal was registered by the pairs of adjacent sensors and delta T values were measured. In this phase, the measurement took place during the crossing of the bridge by a 42 ton truck moving at various speeds. The measurement took place during 7 crossings.

Measurement evaluation – first phase

In the Fig.3 and Fig.4 there is the comparison of total and filtered emission activity in the most active point 11 during bridge crossing by a loaded and empty truck is shown.

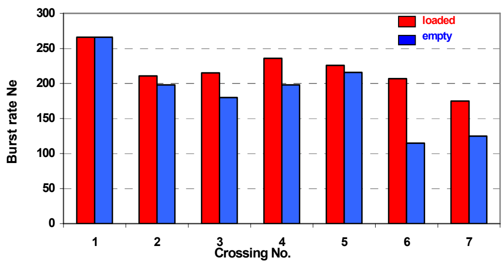


Fig.3 Total emission activity

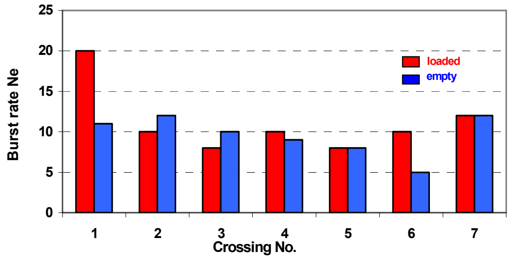


Fig.4 Filtered emission activity

Measurement evaluation – second phase

In this phase, the measurement was performed in linear location mode. It means that the control and measurement program allowed only the detection of emission events for the corresponding sensor pairs and filtration based on delta T times was performed already during data acquisition. This filtration was determined by the maximum completion time for the individual sensor pairs. Taking the distribution of acoustic emission sensors into account, the completion of emission events was permitted for the following measurement point pairs: 0-1, 1-2, 3-4, 4-5, 6-7, 8-9, 9-10, 10-11, 11-12, 13-14.

The bridge construction was loaded by one fully loaded truck (total mass 42 tons) traveling at speeds 20 km/h, 30 km/h and 40 km/h respectively, crossing the bridge in both directions.

The measurement in this phase confirmed increased emission activity in measuring points 6-7, 8-9 and 11-12. It corresponds with the measurement in the first phase (zone location). As the filtered emission events contain only emission events from the area of defects, it is necessary to distribute the emission activity on the basis of the sequence of times when the signal is registered by the individual sensors for a given pair of sensors and to determine the contribution of the individual defects to the total emission activity detected by the given pair of sensors.

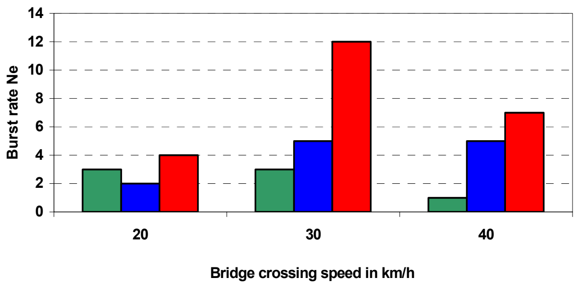


Fig.5 Filtered emission activity in defect area from sensors 7, 8, 11

As apparent from the sum of total emission activity during the individual bridge crossings, the highest emission activity was detected in measuring point 7, 8 and 11. In spite of the fact that the numbers of emission events during the individual crossings are relatively low, these areas with crack-type defects can be evaluated as active, due to the cyclic loading of the bridge by moving trucks. Most detected emission events from measuring points 7, 8 and 11 exhibit low amplitudes of signal, only exceptionally exceeding 50 dB. Amplitudes higher that 50 dB but lower than 60 dB were detected in measuring points 8 and 11 at crossing speed 40 km/h. Relatively low number of detected emission events indicate low level of material degradation processes in the crack-type defects.

Results from AE testing

The results of acoustic emission (AE) measurement on MMT bridge across the Elbe during bridge crossing by loaded and empty trucks can be summarized as follows:

1. The AE measurement has to be performed with sensor arrangement allowing the measurement in plane or linear location mode. The measurement in zone location mode (detection by the individual sensors) exhibits higher sensitivity but in this case it is adversely affected by considerable interference (background) emission events without the possibility of their location.
2. The AE measurement in two phases combining zone and linear location confirmed after data filtration a relatively low but repeated emission activity during the individual loading cycles in measuring points 7, 8 and 11 (i.e. in measuring points close to crack-type defects).
3. This emission activity exhibits symptoms (parameters of the individual emission events) of active material degradation process. Although a low number of emission events and low amplitudes of emission signal indicate a low level of degradation process and insignificant propagation of the individual defects during loading cycles, these three defect areas are nonetheless to be evaluated as emissively active.
4. Taking into account practical experience in the applications of acoustic emission during cyclic loading testing, an increase in emission activity in measuring points 7, 8 and 11 corresponding to the faster propagation of these defects can be expected during further loading cycles.
5. The AE measurement at various speeds of bridge crossing confirmed the detection of larger number of emission events at 30 km/h and 40 km/h if compared with the speed 20 km/h.

STRAIN GAUGE MEASUREMENT

According to the bridge construction, its supports, possibilities of sensor installation and extent of measurement, following positions for sensors were selected (Fig.6).

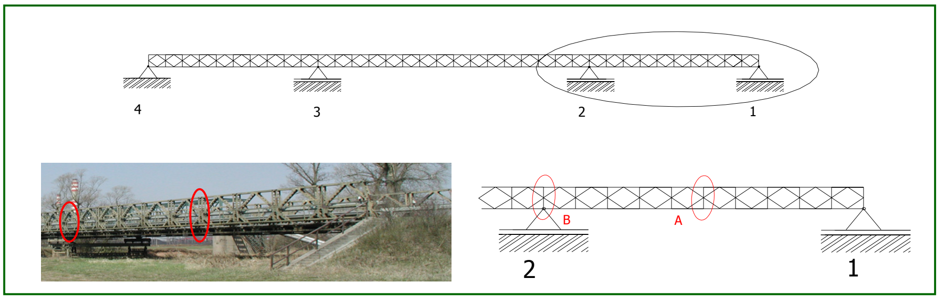


Fig.6 Sensors displacement

The strain gauges were placed as shown in the Fig.7.

a) Pin connections of longitudinal beams of the bridge.

b) Transversal beams of running surface of the bridge (always central parts).

Course of loading and measurement

The loading of the bridge was performed by a four-axle truck moving across the bridge.

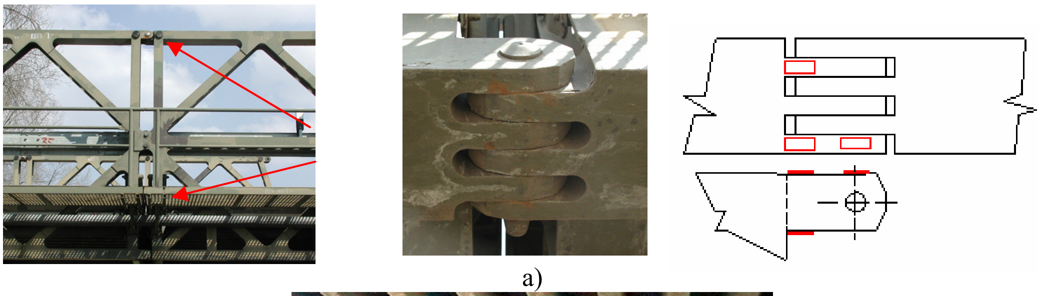
Two different loading masses were used:

a) Empty truck (14,5 tons)

b) Fully loaded truck (42 tons)

The following truck speeds were used: 20 km/h, 30 km/h and 40 km/h.

Both directions of bridge crossing were used.



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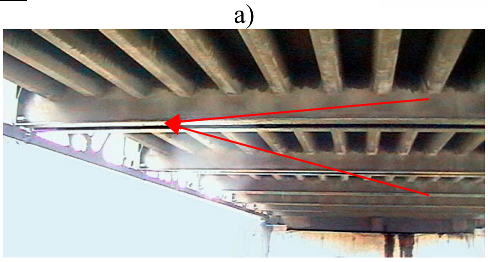


b)

Fig.7 Strain gauge displacement: a) pin connectors, b) crossbeams center, lower flange

Results evaluation – cross beams

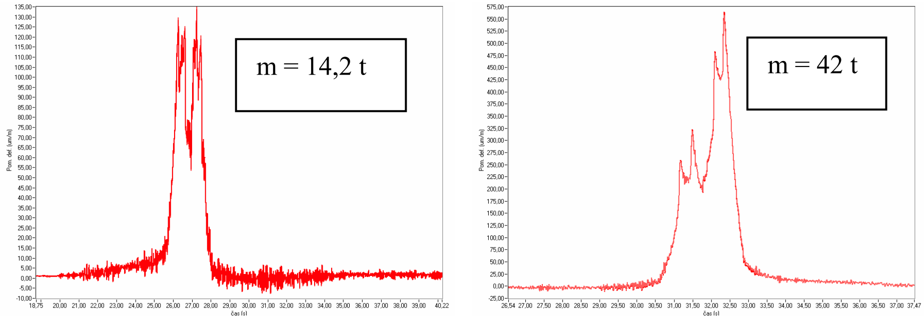


Fig.8 Comparison of strain course during crossing of empty and loaded truck

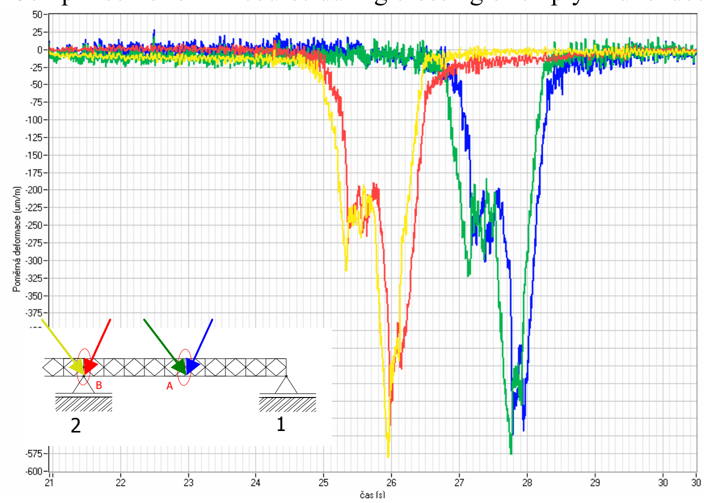


Fig.9 Strain course during crossing of loaded truck with speed 40km/h

Results evaluation – main beams

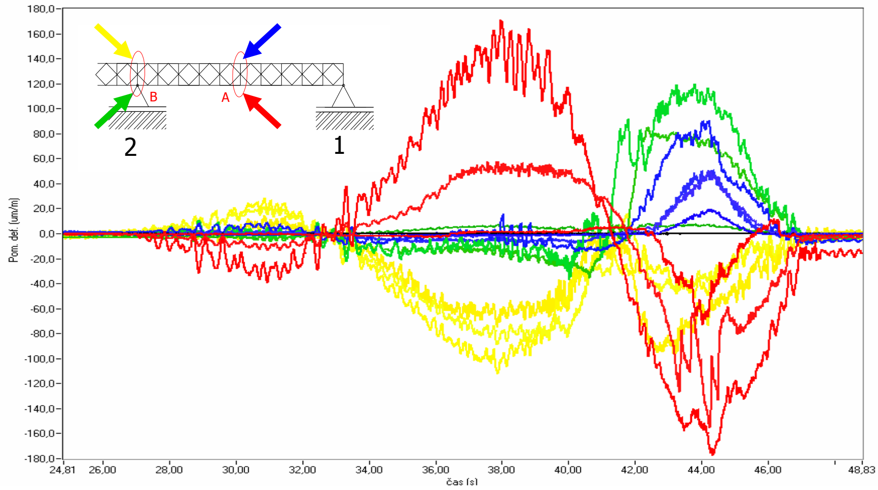
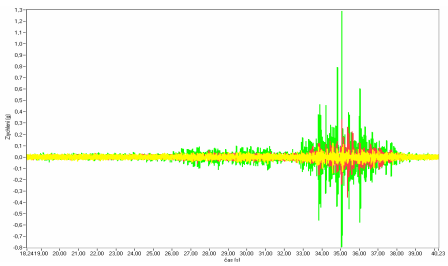


Fig.10 Strain course during crossing of loaded truck with speed 40km/h

VIBRATION MEASUREMENT



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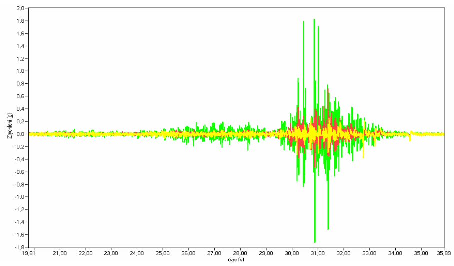

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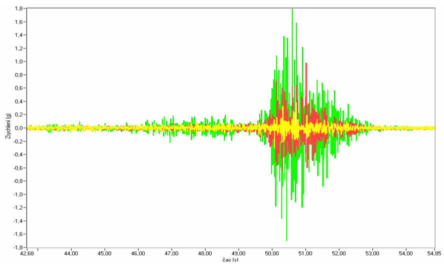
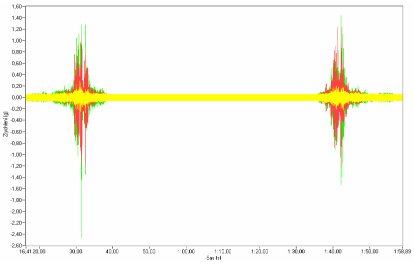


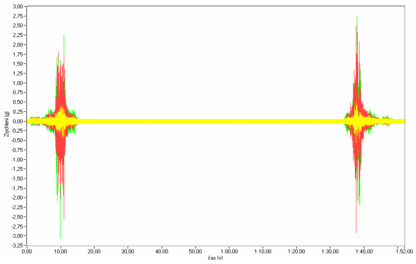
c)

Fig.10 Vibration course on crossbeam (section A): a) speed 20km/h, b) speed 30km/h, c) speed 40km/h

Yellow colour = direction x (horizontal, perpendicular to the direction of vehicle velocity)
Red colour = direction y (horizontal, parallel with the direction of vehicle velocity)
Green colour = direction z (vertical)



a)



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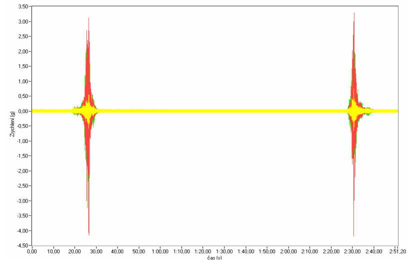

c)

Fig.11 Vibration course on main beam (section B): a) speed 20km/h, b) speed 30km/h, c) speed 40km/h

Yellow colour	= direction x	(horizontal, perpendicular to the direction of vehicle velocity)
Red colour	= direction y	(horizontal, parallel with the direction of vehicle velocity)
Green colour	= direction z	(vertical)

CONCLUSION

Combination of these three kinds of measuring methods (Acoustic Emission measurement, strain gauge measurement and vibration measurement) gives completely information about state of the structures. AE method gives information concerning defects and their activity, strain gauge measurement gives information concerning course of stress especially of level and orientation and vibration measurement gives information about dynamic behaviour of the construction.

Each method is specifying information from the other methods for example in the place where AE detect emission source responding with some defect (crack), strain gauges can confirm this information by measuring higher strain level. Another example of these method supplementation is following. Strain gauge measurement do not confirm influence of speed during crossing the bridge but results from vibration measurement shows big speed influence.

Each method individually gives a lot of information about processes happening in the construction but by combination of these methods we obtain very powerful diagnostic tool.