IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

# Application of the Acoustic Emission Method in the Assessment of the Technical Condition of Steel Structures

# Application of the Acoustic Emission Method in the Assessment of the Technical Condition of Steel Structures

**Anna Adamczak - Bugno [1], Grzegorz Swit [1], Aleksandra Krampikowska [1]**

[1] Kielce University of Technology, Aleja Tysiąclecia Panstwa Polskiego 7, 25-314 Kielce, Poland

aadamczak@tu.kielce.pl

**Abstract**. In accordance with applicable international regulations, construction products and elements should have appropriate physical and strength features to meet the required limit states of load-bearing capacity and serviceability in the construction objects designed by them throughout their entire lifetime. The non-destructive methods should be used to assess physical and strength features at various stages of implementation and operation.
The complexity of security problems, reliability and durability in the conditions of use of modern building structures therefore requires the development and improvement of specialized research methods. Diagnostics and assessment of building objects requires the use of optimal "in situ" research methods that allow for the assessment of the boundary states of buildings with sufficient accuracy over the entire lifetime.
The article presents application the acoustic emission signal (AE) in the diagnosis of technical facilities. The equipment used for signal acquisition is described. An example area of application of the AE method in technology is presented - monitoring of the technical condition of steel structures. Recording and analyzing the AE signal proved to be an effective tool in the diagnosis of this type of construction.

## 1. Introduction

Two different aspects can be distinguished presently, regarding the determination of durability of building structures. The first of these is related to the analysis of existing structures designed according to the standards previously in force. The second one concerns the assurance of the assumed period of use, taking into account mechanical characteristics and construction durability. Problems of durability, strength and environmental impact in accordance with the current approach are interrelated. This is because the use of materials with lower strength and durability parameters makes it necessary to perform repairs or replacement of elements, which should then be disposed of. This causes environmental pollution by landfilling, recycling, waste disposal as well as additional energy consumption [1].

Durability can be defined as the ability of a structure to meet a minimum of its functions for a period of planned use and under the intended conditions, without having to incur excessive repair and maintenance costs.

The durability of the structure, next to safety and usability, is analysed as one of the three pillars of structural reliability. These elements - today practically equally important in terms of significance -

were expressively differently considered in the past in terms of creating rules for their recognition in design.

Steel belongs to the group of basic construction materials. Steel constructions are used in industrial, communication, agricultural, public and housing construction, and engineering constructions. In industrial construction steel is used for making: roof trusses, lattice or full-wall trusses (most often girders), purlins, columns, frame constructions, halls and sheds, girders and overpasses, chimneys, telecommunication towers, masts, industrial galleries, tanks, pipelines, bridges, energy-intensive barriers. In general, construction, steel is used for making: beams, ribs, lintels, pillars, roof trusses, structures of tall buildings, domes, arches, structural coverings, hall structures (entertainment, sports, and commercial), roofs, poles. Roofs and facades generally cover steel roofing products. Steel should be selected due to strength conditions, fracture toughness, joint design, and corrosion resistance. The basis for ensuring the durability of the steel structure in the design period of use are: appropriate design, construction, protection against corrosion and proper maintenance [2, 3].

In the reality surrounding us, one can see a number of buildings that were either incorrectly designed or materials with too low resistance to an aggressive environment were used. However, the most important problem that can be noticed is the lack of renovation policy for building structures. While there are legal conditions requiring the performance of current, annual and extended reviews, it is not possible to enforce a correct (in line with construction art and knowledge development) implementation of them. It is related to two aspects. The first one is caused by the desire to spend the smallest amounts for the required inspections, which in turn leads to the second aspect, namely the performance of inspections and diagnostics of the technical condition of the structure by people who do not have sufficient knowledge, professional experience and technical capabilities. Inspection documents prepared in this way cannot be a reliable and credible source of information used to determine the remaining period of use [4].

The durability of a structure or element can be determined in requirements when starting an investment process or assessed in relation to existing objects, while materials show the variability of properties over time as results of aging and the impact of various factors. The significance of changes in these properties depends on the intended use of the material, the method of use in the construction and, above all, the type of construction. The same material with a characteristic property development over time may be appropriate for the construction and completely unsuitable for another. However, it was accepted to talk about the durability of building materials, understanding precisely this variability. Particular importance is to determine the beginning of destruction in materials and construction elements, because many of the initiated processes lead to destruction almost without being able to stop them in an efficient and economical way [5].

Therefore, the concept of linking the limit state of durability was established not with a predetermined degree or scope of damage to the structural element, but with the initiation of the destruction process, which inevitably leads to the occurrence of one of two traditional limit states. For this reason, it is so important to develop methods that would detect the beginning of the destruction process as well as track its development and course in the entire volume of the structure, and not only in the areas selected in a subjective way.

Such method may be the acoustic emission method. Acoustic emission (AE) is one of the non-destructive methods and more often practically used in the diagnostics of building structures. In various research centers around the world, many publications about its use are prepared annually.

The term acoustic emission (AE) is used for describing the phenomenon of the generation of elastic waves in solids and liquids. Generation source of these waves are both processes of micro cracks development, development and annihilation of dislocations or mutual displacement of fragments of the studied element combined with friction. Almost all materials, including metals, emit elastic (resonant) waves when they are under load. There is big amount of phenomena that, thanks to the fact that they generate elastic waves, can be tested by the Acoustic Emission (AE) method.

Among them are:

- plastic deformation, i.e. dislocation slip or twinning;

- crack formation and growth and destruction process;
- phase transition, especially very fast (e.g. martensitic).

One of the main sources of AE in metals is dislocation movement, especially movement with significant accelerations or delays. With very high external loads, the maximum dislocation speed is close to the speed of sound. At moderate loads, it is much smaller, 1 - 50% of the sound speed. On the other hand, accelerations and delays of dislocations are very large and take place in very short time intervals: 10 -11 ÷ 10 -10s and on very small sections of 1 - 50 parameters of the crystal lattice. Due to the dependence of AE on the degree of plastic deformation, its growth speed and the volume of metal in which this deformation develops, even with uniaxial stretching, there are several typical variations of the acoustic emission characteristics as a function of RMS. As far as the metal deformation itself produces a not very intense AE, the formation and growth of cracks is usually accompanied by strong AE, especially in more brittle materials, i.e. less deformability and higher strength [6, 7].

## 2. Basic research

Basic research on steel objects and elements (beams, roof girders, bridges, viaducts) by acoustic emission method (monitoring) is carried out on objects loaded during normal operation of the facility (in exceptional cases, a test load) [8, 9].

Research during normal operation of the facility is aimed at:

- determining whether there is active damage in the analysed object, i.e. damages that increase (develop) under operating conditions,
- identification and location of damage;
- estimation of the hazard degree, hazard degree that is the endanger for the object.;
- etermining, what extends the facility safety in danger during normal operation.

### *2.1. Criteria for damage assessment of steel structures*

All of selected load-bearing elements of the structure are subjected to testing. The assessment of the degree of object damage is carried out based on the analysis of the acoustic emission signals parameters recorded during bridge or structure loading. Damages generating AE signals are detected by the zone or surface localization method.

In the case when the zone covers the support area and there is a risk that some of the signals result from friction between the support and the structure, then in this zone a surface location should be used with "guarding" sensors that cut off signals coming from the outside (the contact points of the support with the tested element). Every zone is evaluated and then, on the basis of the degree of damage determined for each zone compared with reference signals, the whole element is evaluated [10].

### *2.2. Criterion of technical condition*

The assessment consists of the analysis of changes in the acoustic emission intensity generated in specific structural elements particular zones. Registered AE signals are grouped into classes, which are assigned to various destructive mechanisms that take place during the use of the analyzed buildings. The number of registered AE signals parameters must be consistent with the parameters used to build the base of reference signals [11,12].

The grouping and classification of AE signals should be carried out using a learning-based method. The degree of threat posed by generating processes within one class is determined by the so-called intensity code of destructive processes. These processes are best illustrated by scatter plot, where one AE signal is assigned to each point. The color and shape of the point indicate the class, to which the given AE signal belongs. The discussed classes, symbols and codes are presented in Table 1.

**Table 1.** Classes, symbols and codes of AE signals

| **Colour** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Class number** | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 |
| **Danger code** | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 5 |

The individual signal classes mean:

Nr 1 – rupture;
Nr 2 – friction;
Nr 3 – crack propagation;
Nr 4 – crack initiation;
Nr 5 – perforation / deformation;
Nr 6 – material losses;
Nr 7 – surface corrosion;
Nr 8 – work in the elastic range.

Their appearance signals the presence of dangerous destructive processes in structural elements, which were defined as degrees of danger.

**Table 2.** Degrees of danger

| **Colour** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Class number** | No. 1 | No. 2 | No. 3 | No. 4 | No 5 | No. 6 | No. 7 | No. 8 |
| **Code of destruction** | 0 | 1 | 1 | 2 | 3 | 3 | 4 | 5 |
| **Degree of danger** | Very high | High | High | Average higher | Average higher | Average | Low | No risk |

In assessing the extent of damage, we use the results of the zonal location and the classification of AE signals in the zones.

## 3. Results and discussions

Two steel poles (Fig. 1a, 2a) constituting the cable car's support structure were tested. As a result of visual inspection of poles, surface corrosion of most steel elements was found. It has been found deformations of some of them as well as pitting corrosion and fatigue cracks on fragments of the tested elements (Fig. 1b, 2b). Corrosion is intensified on the middle surfaces of the column construction supporting strips, in particular in the area of gusset plates where welded and bolted joints occur. Corrosion was also found at the interface between profiles and sheets of multi-branch elements, i.e. posts, diagonals and belts, as well as at the place where the angles were connected to the webs and belts.

Because of the corrosion processes and the loosening of bolts securing the column elements, the friction phenomenon of some steel elements between them, was also found.

The described damages are caused by the action of corrosive factors due to the impact of rainwater and insufficient protective and anti-corrosive agents (non-painted coatings or strongly developed corrosion centers). Observing the photographs, one can be noticed changes in the structure of the material, from which the columns are made. It causes additional destructive processes in the form of delamination of the steel structure and inter granular corrosion, which causes that due to the working environment of posts, the supervision of their technical condition should be additionally increased.

a) b)

**Figure 1.** a) View of the examined column No. 1 together with the safety bridge b) View of the anchor block and the sheets connecting the column No. 1 with the foundation, traces of surface and pitting corrosion.

a) b)

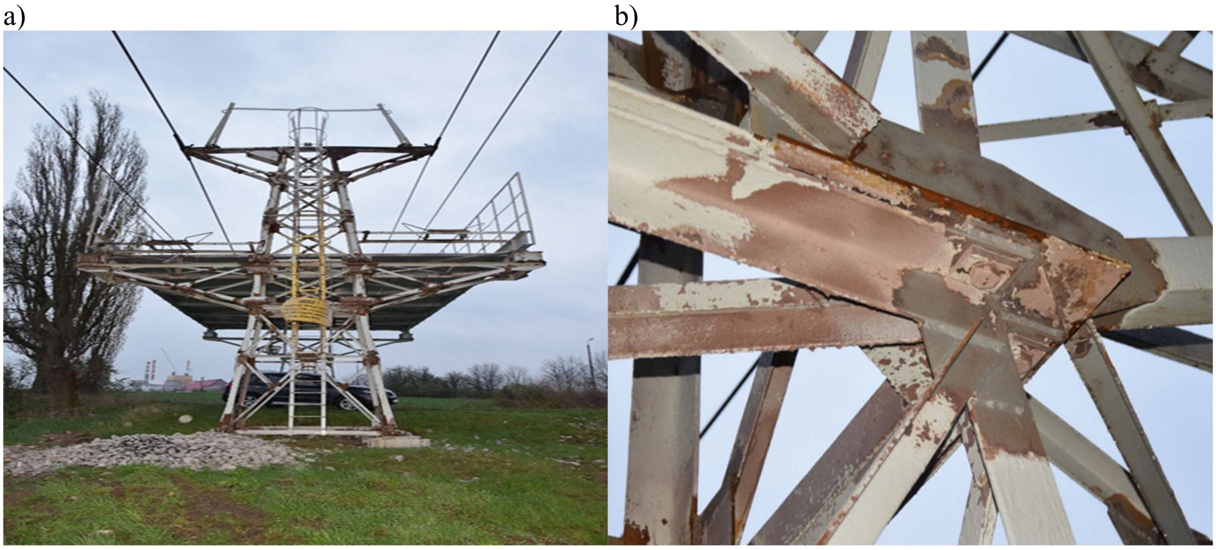

**Figure 2.** a) View of the examined column No. 2 from the side b) View from the outside on the top node, visible traces of surface corrosion of the structural elements of the truss.

Twelve sensors were located on the pole No. 1. On the basis of the spatial location, it was indicated that the pole of the supporting structure works in the range that may cause a threat in the future for the safety of the whole cable car. The tests were carried out during cable car stoppage, as well as during normal operation. During the stoppage no processes generating hazardous phenomena were found, however, when the cable car started (working in the operational scope), it revealed the destructive processes described in 4 classes, which indicates the development of micro cracks on structural elements. This indicates that some elements are exposed to destructive processes caused by material fatigue. Spots of surface corrosion were also located. The most strenuous places were located in the places of screw connections and in the middle of the vertical elements of the column.

Based on the recorded AE signals analysed using the reference signal base, it can be noticed that we receive class signals in the analysed node from 5 to 2. It should be noted that the duration and rise time of these signals are long and up to 350,000 µs and up to 65,000 µs, respectively, while the energy of signals is high and reaches 65,000 eu. It is worth noting that the acoustic emission signals are generated continuously and initiated by passing carriages weighing approximately 2,500 kg, which indicates the existence of places with fatigue and overload cracks, as well as corrosion centers.

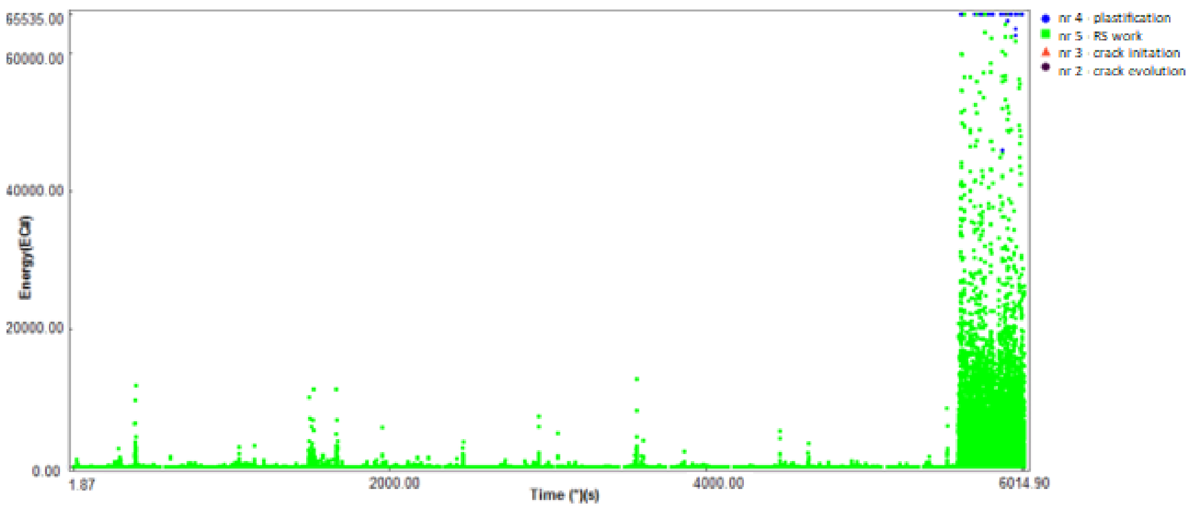


**Figure 3.** Graph of energy in a function of time for sensors 1-12 for column No. 1.

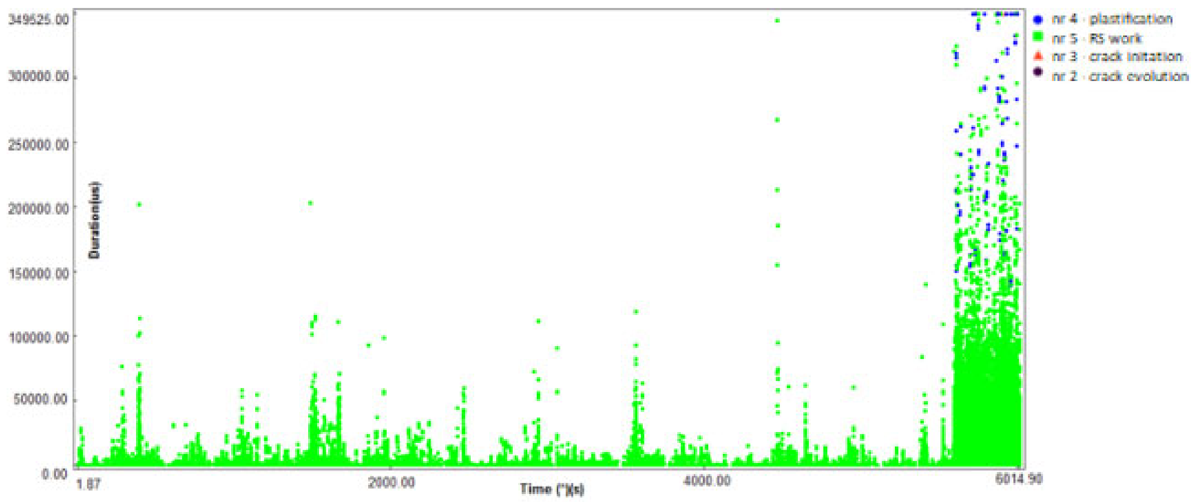


**Figure 4.** Graph of AE signal time versus time for sensors 1-12 for column No. 1.

Welded and screw connections, within nodes due to significant surface corrosion and in some places and pitting, can potentially be a place of loosening screws (sheets). Due to the occurring destructive processes, observation of this column and the establishment of spacers between the column and the

IOP Conf. Series: Materials Science and Engineering 471 (2019) 032041 doi:10.1088/1757-899X/471/3/032041

safety platform was recommended. A part of the damage may result from the additional load caused by the movements of the platform causing material fatigue.

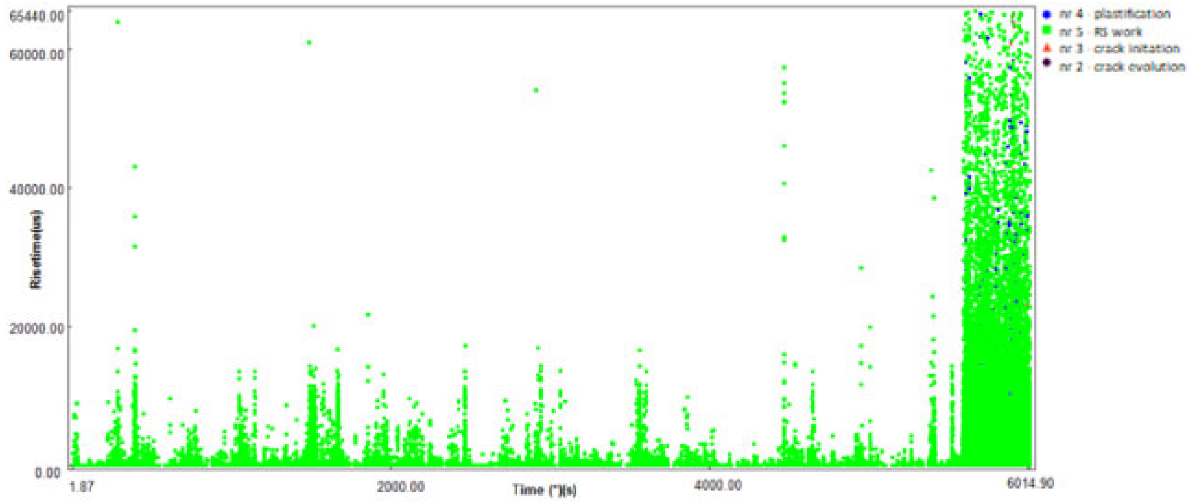


**Figure 5.** Graph of AE rise time in a function of time for sensors 1-12 for column No. 1.

Twelve sensors are located on pole No. 2. On the basis of the spatial location, it was indicated that the pole of the supporting structure works in the range that may cause a threat in the future for the safety of the whole cable car. The tests were carried out during normal operation. During the work, two processes were found that generated work-related phenomena in the elastic range, i.e. assumed in the calculations and the place where the local steel became plasticized, described by the 4th class. This phenomenon may have a different ground, but as in the case of pole 2, the additional load probably causes it, induced by vibrations of the steel platform securing the road.

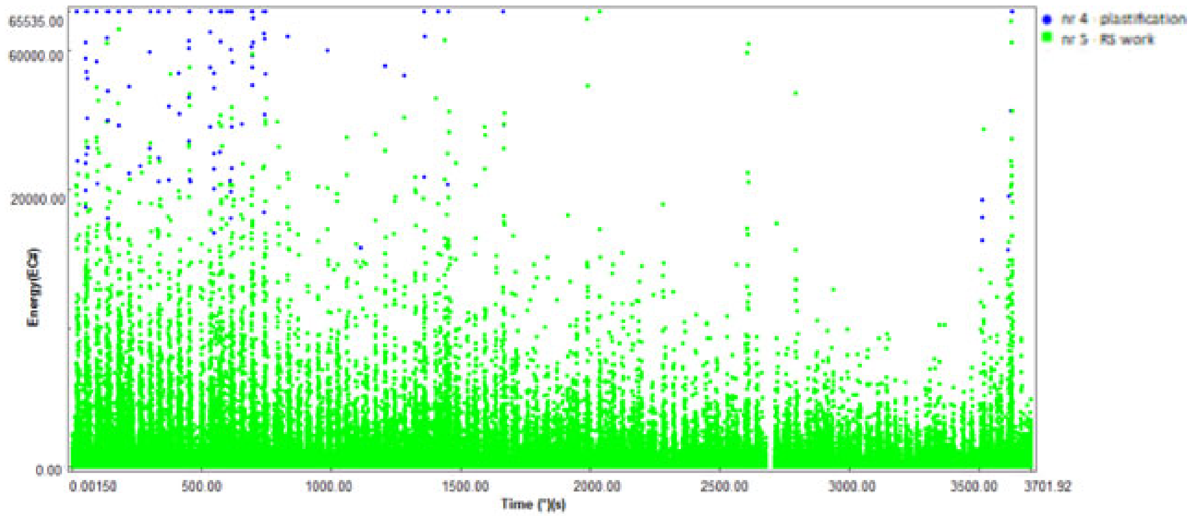


**Figure 6.** Graph of energy in a function of time for sensors 1-12 for column No. 2.

The lack of spacers at the combination of these two structural elements may cause the plasticization of steel and, therefore, fatigue micro cracks and consequently cracks. This indicates that some elements are exposed to destructive processes caused by material fatigue. Spots of surface corrosion were also located. The most strenuous places are located in the places of screw connections and in the middle of the vertical elements of the column.

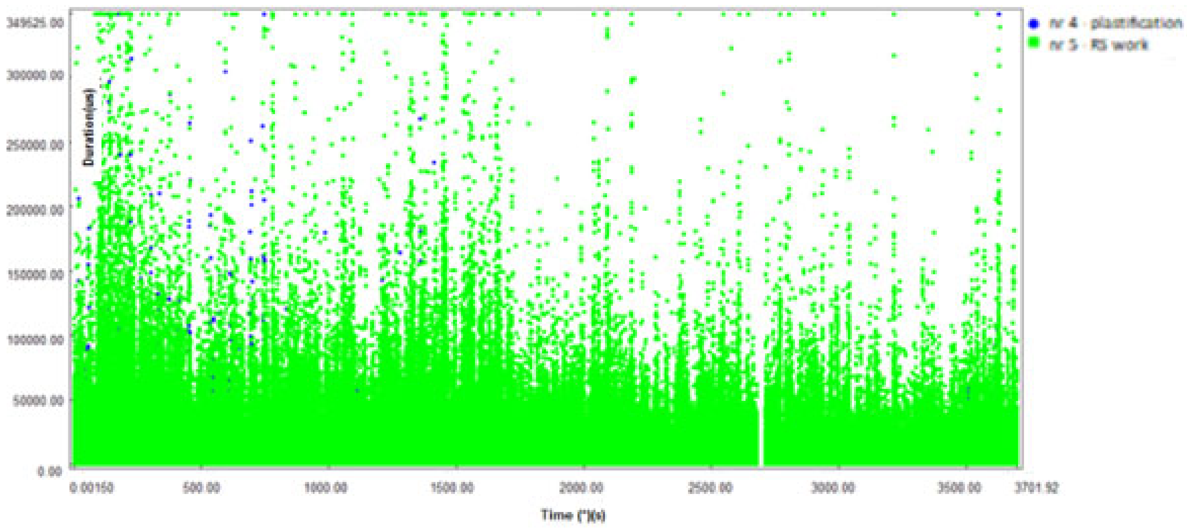


**Figure 7.** Graph of AE signal time versus time for sensors 1-12 for column No. 2.

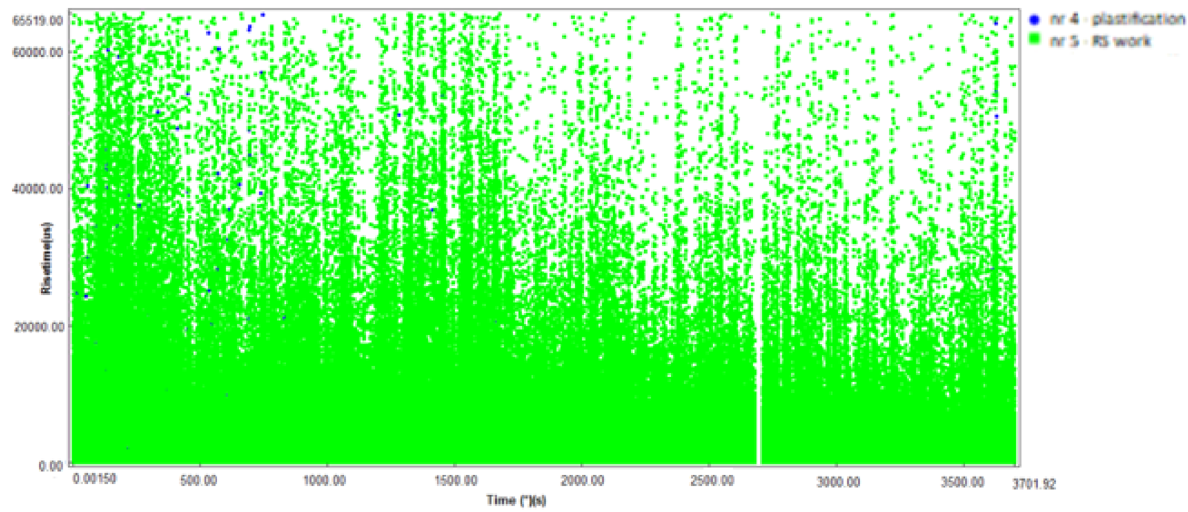


**Figure 8.** Graph of AE rise time in a function of time for sensors 1-12 for column No. 2.

Based on the recorded AE signals analysed using the reference signal base, it can be noticed that in the analysed node only 5 to 4 class signals appear. Please note that the duration and rise time of these signals are long and appropriate are up to 350,000 µs and up to 65,000 µs, while the energy of signals is low and on average rises up to 20,000 eu, and occasionally it reaches a high value up to 65,000 eu. It is worth noting that the acoustic emission signals are generated discontinuously and they are not initiated by passing carriages weighing approximately 2,500 kg, which indicates the existence of places with plastic deformations, which may degenerate into fatigue micro cracks and corrosion centers. Welded and screw connections within nodes due to surface corrosion and in some places may potentially be the place of loosening screws (sheets). Due to the occurring destructive processes, it was recommended to conduct observation of this column and the establishment of spacers between the column and the safety platform. A part of the damage may result from the additional load caused by the movements of the platform causing material fatigue.

## 4. Conclusions

The analysis of the column tests results using the base of reference signals shows that:

- it is possible to determine the destruction mechanisms in steel structure elements;

- it is possible to monitor individual destructive processes during construction work;
- analysis using a reference file is susceptible to structural changes in steel;
- processes described as not threatening or slightly affecting the technical condition of the structure, run in a stable manner over time (no sudden jumps in their course).

When assessing the structure, consideration should be given to the interaction of various structural elements as well as the interaction of defects present in the facility. Therefore, current procedures based on precise load control make it difficult to carry out diagnostics of large building objects in field conditions. The methods and procedures currently used are expected to provide information enabling them to infer the effect of the recorded defects on the load capacity and durability of the structure in the conditions in which bridges, buildings and structures work. Such a possibility is created today by the application of the acoustic emission technique using the analysis of destructive processes taking place in elements of building structures. Each destructive process is a source of acoustic emission, which is characterized by the descriptors of the recorded signal. These sizes allow the classification of signals and thus destructive processes. Thanks to the combination of destructive processes with the extent of damage as well as their impact on safety, it is possible to conduct observations of the technical condition of the structure on a regular basis and forecast changes in the durability of the facility. The association of AE signals with destructive processes provides the basis for further work on the development of statistical, probabilistic models describing changes in the durability of the structure, taking into account the actual working conditions, and intensity of damage development of structures measured "in-situ".

**References**

[1] R. M. Lawson, “Sustainability of steel in housing and residential buildings (P370)”, *The Steel Construction Institute*, 2007.
[2] R. M. Lawson, K. Francis, “Energy Efficient Housing using Light Steel Framing (P367)”, *The Steel Construction Institute*, 2007.
[3] Y. Lu, J. Michael, “A methodology for structural health monitoring with diffuse ultrasonic waves in the presence of temperature variations”, *Ultrasonics*, vol. 43, pp. 717–731, 2005.
[4] B. Goszczyńska, G. Świt, W. Trąmpczyński, “Monitoring of Active Destructive Processes as a Diagnostic Tool for the Structure Technical State Evaluation”, Bulletin *of the Polish Academy of Sciences, Technical Sciences*, vol. 61(1), pp. 97-109, 2013.
[5] Z. Su, L. Ye, Y. Lu, “Guided Lamb waves for identification of damage in composite structures: A review”, *Journal of Sound and Vibration*, vol. 295, pp. 753–780, 2006.
[6] G. Świt, A. Krampikowska, L. Minh Chinh, “A Prototype System for Acoustic Emission-Based Structural Health Monitoring of My Thuan Bridge”, *Proceedings of 2016 Prognostics and System Health Management Conference (PHM-Chengdu)*, pp. 624-630, 2016.
[7] J. Balageas, C. Fritzen, A. Guemes, “Structural Health Monitoring Systems”, *ISTE*, 2006.
[8] L. Minh Chinh, A. Adamczak, A. Krampikowska, G. Świt, “Dragon bridge - the world largest dragon-shaped (ARCH) steel bridge as element of smart city”, *E3S Web of Conferences*, vol. 10, p. 5, 2016.
[9] G. Świt, A. Krampikowska, L. Minh Chinh, A. Adamczak, “Nhat Tan Bridge - The Biggest Cable-Stayed Bridge in Vietnam”, *Procedia Engineering*, vol. 161, pp. 666-673, 2016.
[10] D. Adams, Health Monitoring of Structural Materials and Components, Willey, New York, 2007.
[11] P. Olaszek, G. Świt, J. R. Casas, “On-site assessment of bridges supported by acoustic emission”, *Proceedings of the Institution of Civil Engineers - Bridge Eng.*, vol. 169(2), pp. 81-92, 2016.
[12] B. Goszczyńska, G. Świt, W. Trąmpczyński, A. Krampikowska, “ Application of the Acoustic Emission Method of identification and location of destructive processes to the monitoring concrete bridges”, *7th Int. Conf. on Bridge Maintenance, Safety and Management (IABMAS)*, pp. 688-694, 2014.