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Testing of Railway Prestressed Concrete Sleepers Using Acoustic Emission

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Summary

The article describes the tests of prestressed concrete sleepers made according to the method specified in the requirements of the European standards (EN 13230-2:2009 Railway applications – Track – Concrete sleepers and bearers – Part 2: Prestressed monoblock sleepers) and WTWiO regulations, and an additional measurement method was used – acoustic emission (AE). The purpose of the tests using the acoustic emission method was to verify the results obtained using other test methods described in the European standard. The use of this method in sleeper tests enables obtaining precise data from the sleeper load test and determination of the characteristic parameters based on the recorded AE signals. Due to the variety of existing sleepers and the development of products in this area: wooden sleepers, composite sleepers, steel sleepers (type Y), the use of the acoustic emission method in research will be a good support and will enable proper assessment of these elements of the railway road.

Keywords: test sleepers, acoustic emission, crack

1. Introduction

The requirements for prestressed concrete sleepers with regard to the method of testing, strength and material criteria, marking, etc. are specified in the WTWiO "Technical conditions for the production and acceptance of prestressed concrete sleepers and turnout sleepers Id-101" developed by PKP PLK [1] and in the European standards EN 13230-2:2009 (Railway applications – Track – Concrete sleepers and bearers – Part 2: Prestressed monoblock sleepers" [2].

Prestressed concrete sleepers are important elements of a railway road, which should maintain their structural parameters for decades (more than 30–40 years) while being subjected to operational loads and changing weather conditions. Prestressed concrete sleepers are important elements in the structure of a railway road and have a direct impact on the safety of passenger and freight transport. Depending on the planned operating conditions on the railway routes in question (classification of the railway lines, expected track operating loads, maximum speed), different types of prestressed concrete sleeper structures are used. Prestressed concrete sleeper designs include PS-94 and PS-93 sleepers, which are most often used in the development of main railway routes – trunk lines, where passenger train speeds are above 160 km/h, with a predicted load of 22.5 tonnes per axle (225 kN/axle) [3]. Sleepers of this type are also used on freight railway lines where the highest volumes of freight are carried (above 25 Tg/year – trunk lines) [4].

The acoustic emission method is already known and has been used for many years in various industrial fields. In the last ten years, there has been a significant development of this method as a result of the integration of electronic circuits, their miniaturisation, higher performance and the development and design of software and applications that enable faster analysis of data streams (e.g. during a single test of prestressed concrete sleepers, AE equipment can record hundreds and thousands of AE events in 1 second). This has resulted in acoustic emission becoming a research and measurement tool increasingly used in many industries. Acoustic emission has already been used for many years in the refining industry for monitoring and evaluation of industrial installations, refinery tanks, pipelines and other important structural facilities. There are many papers dedicated to the acoustic emission method used for the assessment of bridge and viaduct structures, also often used in the assessment of concrete or reinforced concrete structures [5, 6, 7].

In the field of strength testing, sleepers are subjected to different load variants: static, dynamic and

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fatigue loading. The aim of the tests carried out on selected objects from production is to determine characteristic strength parameters, such as: Fr_r – appearance of the first crack, $Fr_{0.05}$ – appearance of a 0.05 mm wide crack after removal of the load, F_{rB} – destructive force of the sleeper.

Full testing applies to new structure, new technology or technological changes, in which case the full range of tests described in the above-mentioned documents is required: PN-EN 13230 standard – in the case of European requirements, and WTWiO [2] in the case of PKP PLK requirements. The scope of WTWiO [2] for prestressed concrete sleepers largely coincides with the requirements of PN-EN 13230. In the case of checking tests, this area of testing, required by PN-EN 13230, is usually carried out to a limited extent. Full and periodic tests should be performed by independent research units that have research methods accredited by PCA (Polish Center for Accreditation) [1, 2].

The Materials & Structure Laboratory of the Railway Institute has accredited test procedures for testing prestressed concrete sleepers, according to which the tests described in this article were performed. The additional scope of acoustic emission tests is a method not described in the mentioned documents, and this method is used as an additional, independent assessment of the condition of prestressed concrete sleepers. The article describes tests performed on prestressed concrete sleepers of the PS-94 type, which are built on main railway lines. Other types of sleepers are also used for railway construction: steel (Fig. 1a) wooden (Fig. 1b) or composite sleepers. In particular, the latter area of composite sleepers is developing rapidly. For the aforementioned sleepers, the same standard requirements do not apply as for prestressed concrete sleepers.

The acoustic emission method as one of the group of NDT (*Non-Destructive Testing*) methods is increasingly being used in various areas of industrial research as an effective method of monitoring important industrial facilities, e.g. in the refining industry, as evidenced by the increasing number of scientific papers that describe tests carried out using this method. As a result of the research carried out with the AE method, the scientific basis for the implementation of its applications in new industries is expanding. Also in the area of the evaluation of various types of railway sleepers or other railway infrastructure objects, there is potential for the application of this research method.

MISTRAS Group has been a world leader in the development and manufacture of acoustic emission equipment for industrial control and monitoring applications since 1978. These tests on prestressed concrete sleepers were carried out using MISTRAS AEWinWXO8 control and measurement equipment.

2. Acoustic emission signals

Acoustic emission is a method from the NDT group of tests, where elastic waves are recorded using special equipment, defined in the standards in question – e.g. PN-EN 13477-1 [8], PN-EN 13477-2 [9], PN-EN 13554:2011 [10] and the Users Manual [11]. Waves that are released in a material that undergoes micro deformation as a result of various factors, events, e.g. changes in microstructure, fracture of crystal lattice, deformation of crystal lattice, friction, corrosion. The acoustic emission method is a passive method that involves listening for signals created in the material or on its surface (as opposed to the ultrasonic method, which involves sending ultrasonic signals and receiving them). The wave originating from defects or damaged areas propagates through the material and reaches the acoustic emission sensor, where the analogue signal is converted into digital data in the measuring device by appropriate processing of the voltage signal by means of electronic circuits ADC (*Analog to Digital Convert-*

a) b)

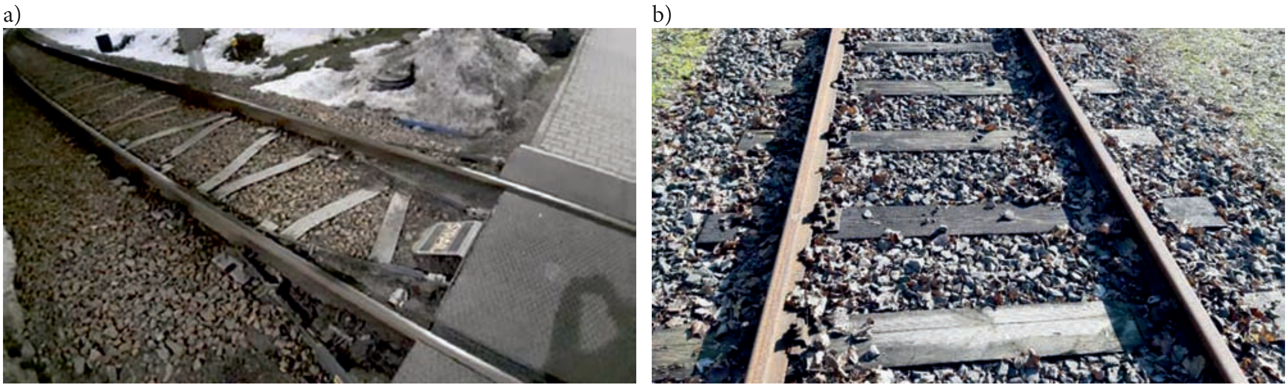

Fig. 1. Steel sleepers (a) and wooden sleepers (b) used in the construction of the railway track [photo D. Kowalczyk]

er) is an analogue-to-digital converter[2]. The conceptual AE signal and its characteristic features are shown in Figure 2, while the actual AE signal recorded during testing is shown in Figure 3.

Based on the collected events, the characteristic parameters are evaluated, thereby determining the significance of the event, which has a direct bearing on the assessment of the condition of the object (structure) under load. The most relevant acoustic emission parameters are: *rise time* – the time it takes for the signal to reach maximum amplitude, *duration* – the duration of the signal above the defined noise level, *energy* – the energy of the AE event, *amplitude*, *counts* – the number of counts of the maximum during the AE event, *threshold* – the defined noise level. These parameters are shown in Figures 2, 3.

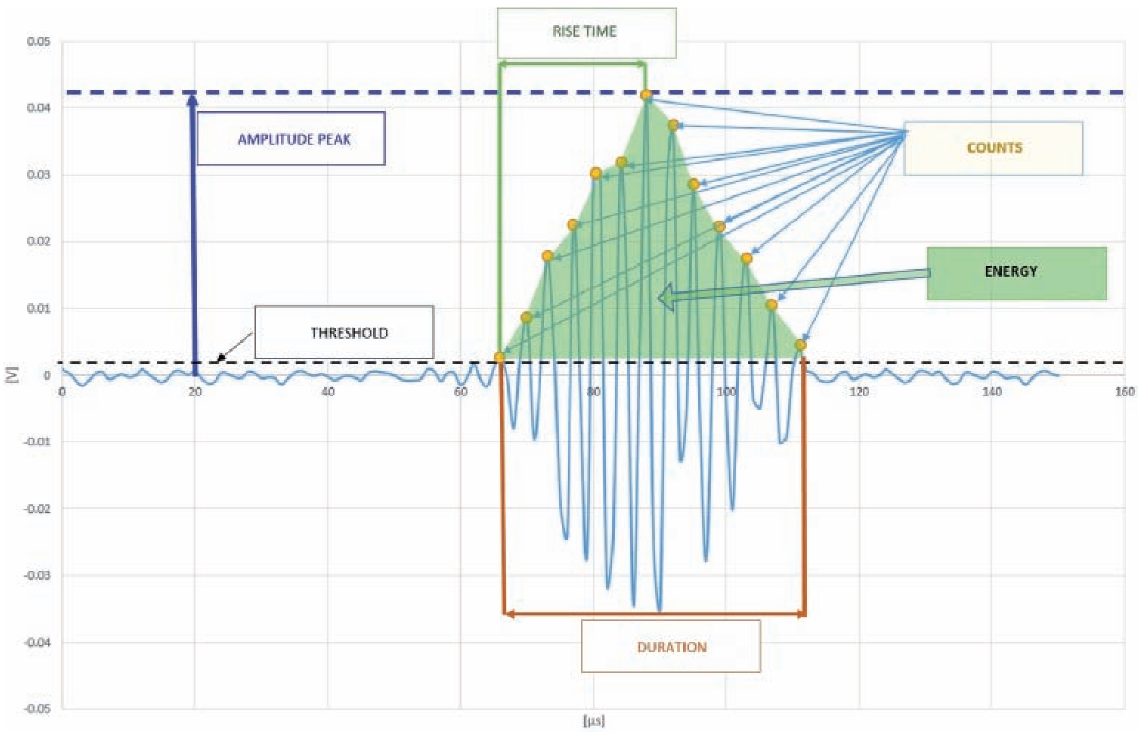

Fig. 2. An example of an acoustic emission signal [the author's own compilation]

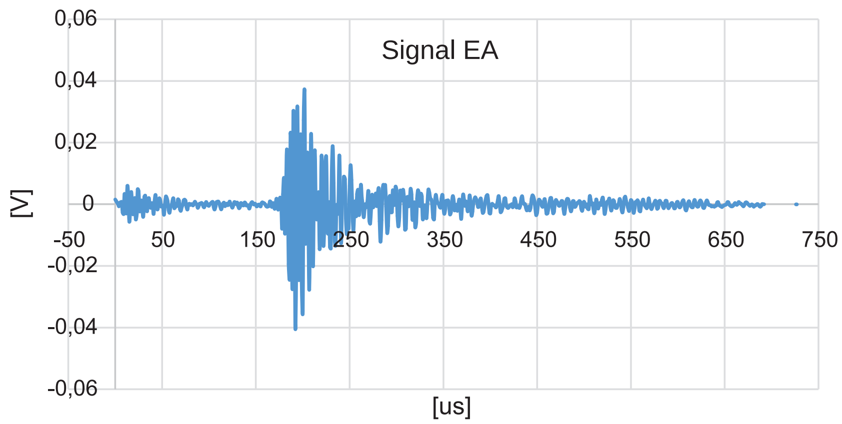

Fig. 3. An example of a real acoustic emission signal (AE) [the author's own compilation]

[2] Analog Digital Converter is sometimes abbreviated as A/C converter or A/D converter (*Analog to Digital*).

Detailed requirements for acoustic emission testing equipment are described in EN 13477-1 [8], and definitions are detailed in the acoustic emission standards EN 1330-9:2017 – Non-destructive testing – Terminology – Part 9: Terms used in acoustic emission testing [12]. Formula (1) for the dynamic range of acoustic emission, AE signal formula of the designation as described in ASTM E976 [12], DR – *Dynamic Range*, is shown below.

$$\mathrm{DR} = 20\log\left[\frac{V\ peak\ signal}{V\ peak\ electronic\ noise}\right]. \qquad (1)$$

Before the strength tests of the prestressed concrete sleepers were carried out, the correctness of the control and measurement equipment for recording acoustic emissions was checked, the attenuation of the signal was measured and the velocity of wave propagation in the prestressed concrete sleepers was determined. The equipment was also checked in accordance with accredited test procedures for all necessary equipment for testing prestressed concrete sleepers.

3. Attenuation tests (AE)

Tests were carried out to determine the attenuation of the acoustic emission signal in prestressed concrete sleepers The acoustic emission control and measurement equipment used in the tests met the guidelines and requirements of the PN-EN 13554:2011[10] and PN-EN 13477-2 [9] standards. Measurements and signal recording, together with their analysis, were performed on a Mistras device equipped with an 8-channel AE signal card with EAwinEXP8 software. For this purpose, an acoustic emission sensor of the PKI6 type (with integrated preamplifier) was placed in the zone under the rail of the sleeper, and reference AE signals were generated at specific distances from the sensor (distance from the sensor 500 mm, 1000 mm, 1500 mm, 2000 mm, 2500 mm).

The PK6I sensor used in the tests is a resonant mid-frequency acoustic emission sensor with an integrated ultra-low noise preamplifier. The sensor is equipped with an AST (integrated automatic sensor test function). The detection threshold of the acoustic emission signal was set at a value above 40 dB.

AE signal attenuation tests were performed using the AE signal reference source – Hsu-Nielsen according to the requirements described in PN-EN 1330-9:2017 point 2.5.21 and ASTM E976. For the placed AE sensor of the PKI6 type shown in Figure 4, reference signals were triggered at 0 mm, 500 mm; 1000 mm, 1500 mm, 2000 mm, 2500 mm.

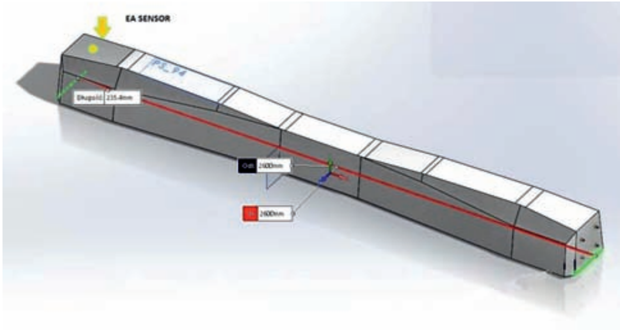

Fig. 4. The method of measuring the attenuation of the AE signal in the PS-94 prestressed concrete sleeper [the author's own compilation]

The aim of the tests carried out was to determine whether AE event signals originating from one extreme of the sleeper were recorded by the sensor on the opposite side of the sleeper. As the tests showed, for an initiated AE signal at a distance of approximately 2.5 m from the sensor, the signal was detected by the acoustic emission system (Fig. 5). This indicates that any important AE signal that is generated in the sleepers during the test can be recorded by the AE sensor (if the system settings are correct and the correct noise threshold is specified).

Additional tests were also carried out to determine the level of attenuation of the AE signal in prestressed concrete sleepers, in this case the same EAwinEXP8 recording measurement system equipped with four PKI15 sensors (with preamplifier circuits integrated in the sensors) was used in the tests. The sensors were placed on the prestressed concrete sleepers as shown in Figure 6 (in one axis). AE events were generated close to sensors 1 and 4 at distances of approximately 5 mm from the sensor.

The resulting acoustic emission signal of the same event, recorded by individual sensors located at different distances from the source, is shown in Figure 7.

Figure 8 shows the acquired AE signals (collected from the individual sensors) on a single time axis. Due to the large voltage difference in the amplitude of the signals recorded at the individual sensors, the signal from sensor 1 is shown in a limited range (from −0.1 V to +0.1 V) – in order to better illustrate them. The differences in the onset times of the acoustic emission signal recorded for the individual sensors are due to the travel time of the wave in the substrate from the AE source to the respective sensor. This is determined by formula (2) for the attenuation of the signal depending on the distance of the sensor from the source (AE).

$$\alpha_t = \frac{20}{D}\log_{10}\left(\frac{A1}{A2}\right) = \frac{A_r}{D}, \qquad (2)$$

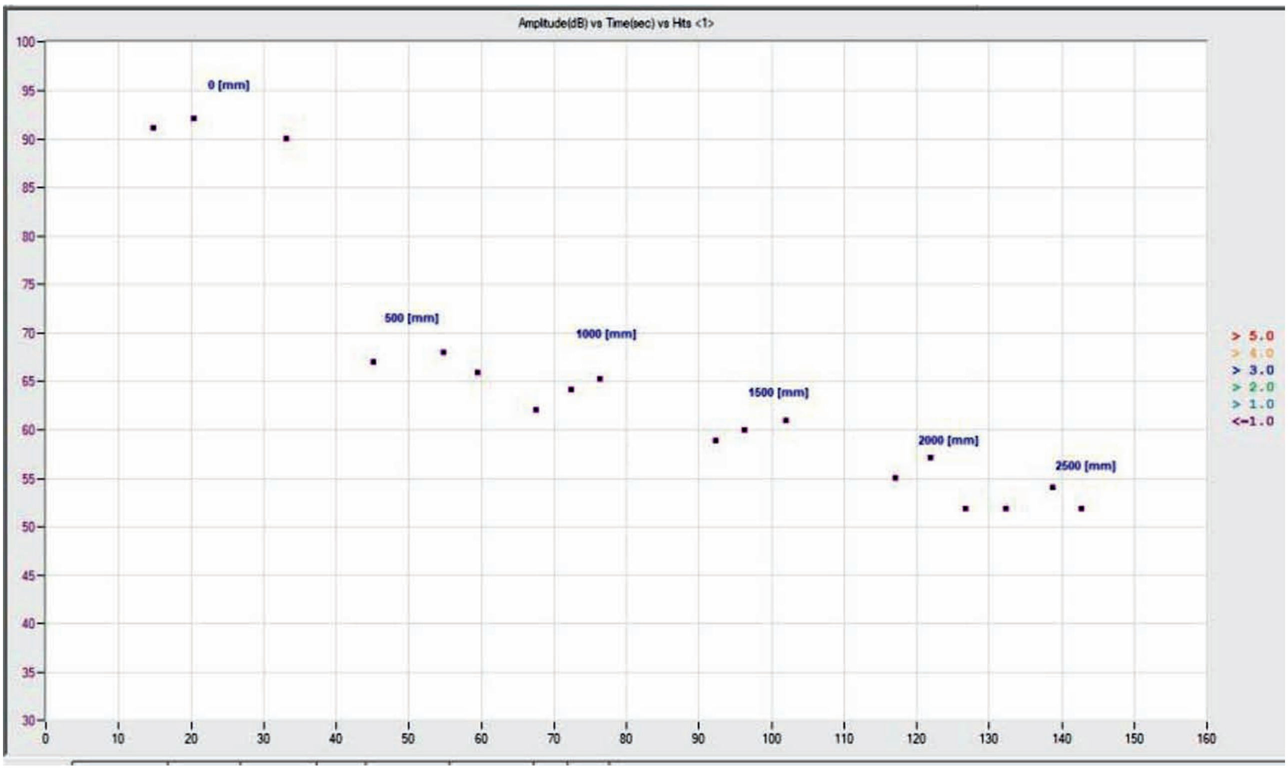

Fig. 5. Attenuation results of reference AE signals (Hsu-Niesen) [the author's own compilation]

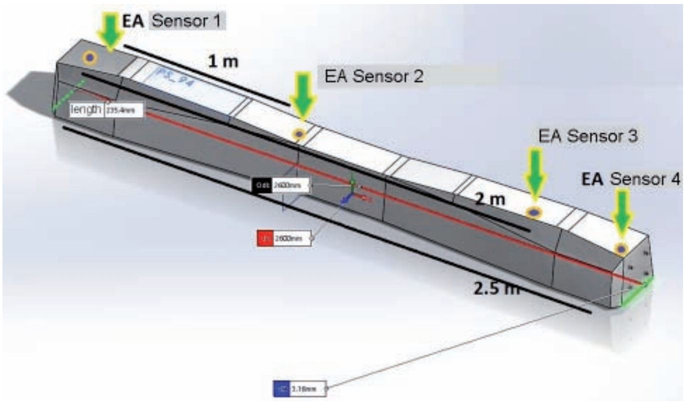

Fig. 6. The location of the sensors on the prestressed conrcete sleeper during the determination of the attenuation of the AE (Hsu-Niesen) signals [the author's own compilation]

where:

α_t – attenuation w (dB/m),

$A1$ – amplitude of the signal at Sensor 1 (V),

$A2$ – amplitude of the signal at Sensor 2 (V),

D – distance between Sensor 1 and Sensor 2 (m),

A_r – relative amplitude,

A – Maximum measured signal amplitude (V) at a receiver sensor at distance x from the source,

A_0 – Maximum reference amplitude (V) at the source position.

$$A_r = 20\log_{10}\left(\frac{A}{A_0}\right). \quad (3)$$

Based on the test results and analysis of the data for the individual sensors, signal attenuation values

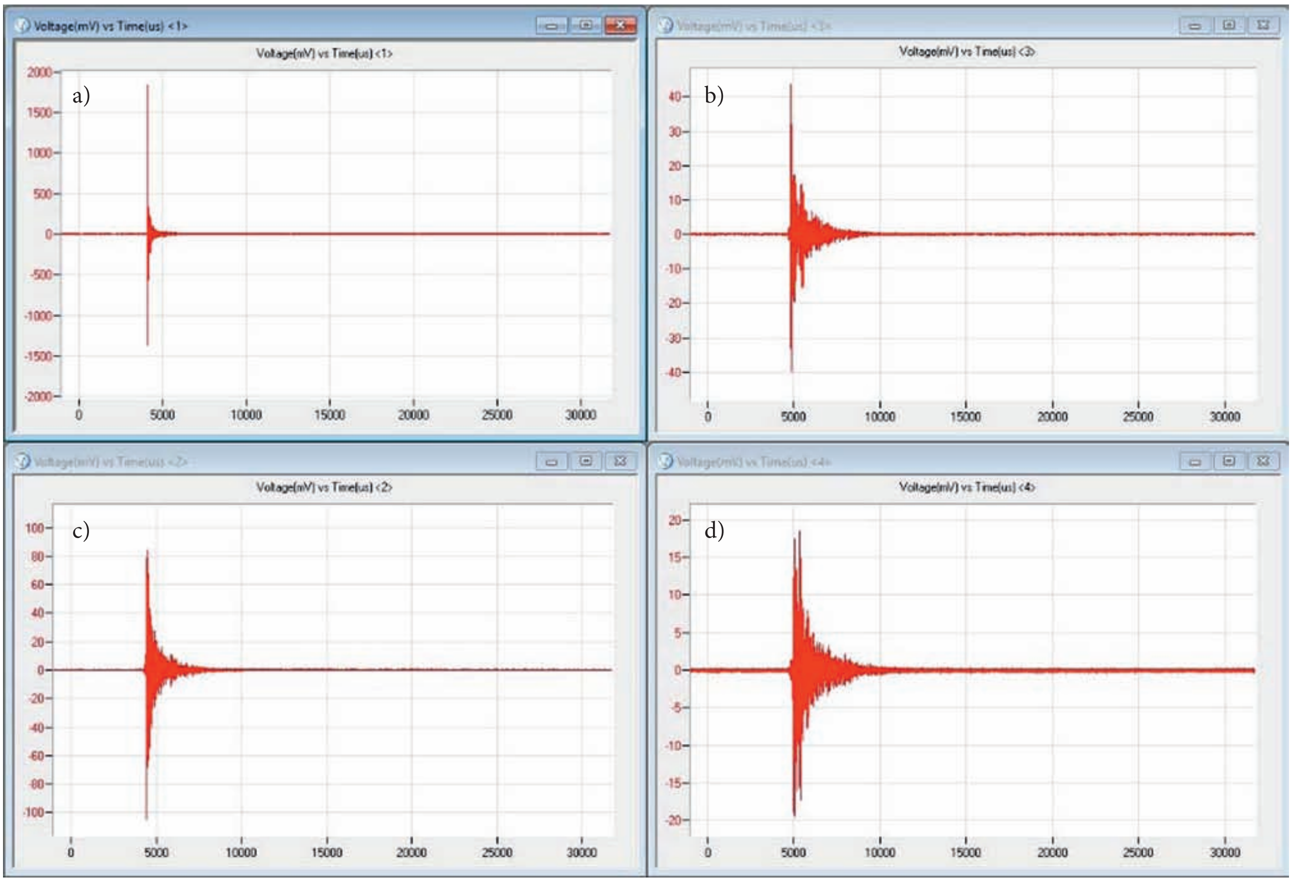

Fig. 7. Acoustic emission signal recorded on sensors of the same type located at different distances from the source (AE event site): a) 2.5 [m], b) 2 [m], c) 1 [m], d) 0.1 [m]; graph (Y-axis – voltage signal [V], X-axis – time [μs]; [the author's own compilation]

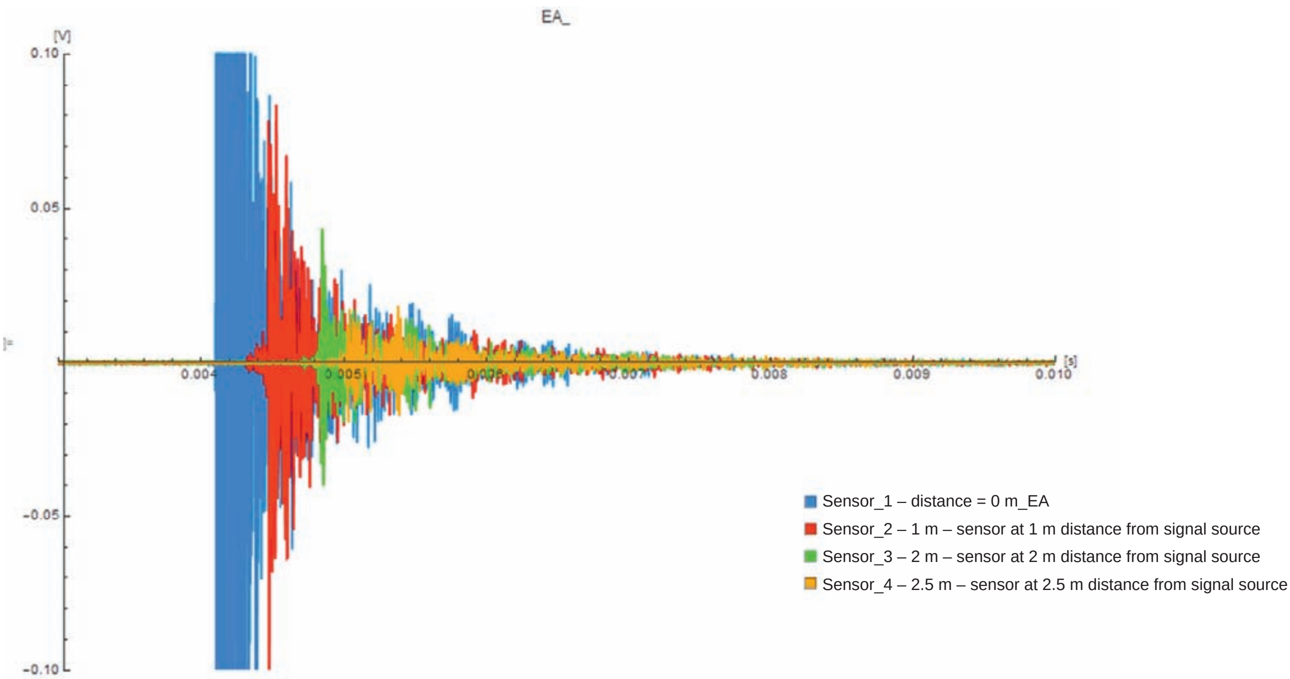

Fig. 8. Acoustic emission signals obtained on individual sensors at defined distances (according to Fig. 5) from the source of the AE event [the author's own compilation]

were calculated from formula 2 and 3 and the results are shown in Tables 1, 2.

Table 1

Determination of signal attenuation values in the tested material – prestressed concrete sleepers

Sensor	Signal amplitude [V]	Distance [m]	Signal attenuation [dB/m]
4	1.82	0.01	–
3	0.105	1	24.7
2	0.044	2	16.16
1	0.0194	2.5	15.77

Tests conducted on the attenuation of AE signals have shown that the sensors can detect acoustic emission events even at distances of more than 2.5 metres. In the case of destructive testing, this is important because the sensors can be located at a greater distance from where the object is predicted to be destroyed, without risking damage to the testing equipment. The determination of "signal attenuation in acoustic emission testing" plays an important role - this data is used to localise AE events [14], and thus to identify critical areas in structures. Accurate determination of this parameter enables the precise location of such areas. Due to many different factors, such as the size of the fraction (aggregate grain size), the type of aggregate material, the composition of the concrete mix, etc., the determination of the attenuation parameter locally may vary in the tested object. This is also due to the fact that objects such as prestressed concrete sleepers have an additional complex geometry and steel reinforcement, which is an additional factor affecting the wave propagation velocities in the material and thus the attenuation of the acoustic emission signals in the material. Additional factors affecting attenuation are the stresses that also occur in Prestressed concrete sleepers. A more extensive description of the effect of factors on the attenuation of signals in concrete is presented in publication [15].

4. Tests on the velocity of elastic wave propagation in concrete (foundation of PS-94 type)

Tests were carried out to determine the velocity of elastic wave propagation – the AE signal in prestressed concrete sleepers of the PS-94 type. Measurements and recording of signals, along with their analysis, were carried out on an AE equipment (Mistras system equipped with an 8-channel AE signal card with EAwinEXP8 software). For this purpose, two AE sensors of the PKI6 type (with integrated preamplifier) were placed: one sensor in the area of the end of the sleeper and the other on the opposite side of the sleeper (as shown in Figure 9), the distance between the sensors was 2560 mm. To test the determination of the elastic wave velocity, sources of the reference AE signal (Hsu-Nielsen) were used and three signals were generated at the direct position of sensor 2. The results obtained are shown in Table 3.

Table 2

Obtained characteristic parameters of AE signals of the same event on the same type of sensors at different distances from the signal source (according to Figure 6)

SS.mmmuuun	CH	EA signal rise time [ns]	Counts	Energy [aJ]	AE duration [ns]	Amplitude	ABS-ENERGY	Distance
02.3520760	4	10	233	388	4435	97	34	0
02.3521715	3	103	204	141	3933	74	55	1 m
02.3524495	2	176	149	84	3558	65	99	2 m
02.3528555	1	260	121	57	3741	58	100	2.5 m
SS.mmmuuun	**CH**	**EA signal rise time [ns]**	**Counts**	**Energy [aJ]**	**AE duration [ns]**	**Amplitude**	**ABS-ENERGY**	**Distance**
52.1478750	4	14	375	750	5253	95	53	0
52.1479695	3	107	311	259	5965	76	71	1 m
52.1482475	2	284	216	162	5801	65	99	2 m
52.1486535	1	1154	185	133	5492	62	100	2.5 m

Explanations: "SS.mmmuuun" indicates time respectively: s – second, m – milliseconds [ms], u – microseconds [μs], n – nanoseconds [ns]; Energy 1[J] = $1\cdot10^{18}$ [aJ]; [own elaboration]

Table 3

Results obtained for the elastic wave propagation test in the PS-94 type sleeper

SS.mmmuuun	Sensor	EA rise time [ns]	Counts	Energy [aJ]	AE duration [ns]	Difference in EA signal time recorded by sensors 1 and 2 [ns]	Distance [mm]	velocity V [m/s]
52.6657873	2	4	121	179	4211	–	–	–
52.6666072	1	711	115	128	5032	0.000819	2560	**3122.3**
59.1154292	2	4	128	234	3176	–	–	–
59.1162463	1	714	128	179	5244	0.000817	2560	**3133.0**
69.1372473	2	4	136	233	3312	–	–	–
69.1380673	1	712	125	150	5242	0.000820	2560	**3122.0**

[Authors' own elaboration].

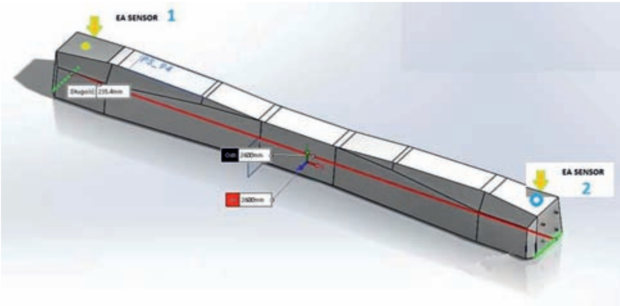

Fig. 9. Attenuation results of reference AE signals (Hsu-Niesen) [the author's own compilation]

On the basis of the tests carried out and the analysis of the article on the effect of the stress level on the changes in the ultrasonic wave propagation velocity in selected types of concrete [15], it was concluded that in the case of prestressed concrete sleepers, where there is a technological production of compressive stresses and a complex geometry and material heterogeneity, it is difficult to obtain an accurate, repeatable wave propagation velocity. However, the values obtained coincide with literature data for this type of material. Tests described in the article [15] indicate that, with an increase in stresses up to 60% of the concrete strength properties, there can be a decrease in wave propagation velocity of up to about 40%.

5. Testing the strength of prestressed concrete sleepers

The purpose of testing prestressed concrete sleepers is: to assess the structure, to check the correctness of the meanings, to assess for the presence of defects (or the absence of defects) in production faults, to check the dimensions for conformity with the design documentation, to assess the materials used for production and, in terms of structural strength, to test the sleepers and subject them to static, dynamic and fatigue loads with reference to the criteria specified in standards [1, 2].

In terms of static tests, prestressed concrete sleepers are subjected to loads in the section under the rail (Fig. 10), the middle section in the normal position (Fig. 11) and in the negative position (Fig. 12). In dynamic tests, the structure is loaded in the section under the rail (see Fig. 10), and the fatigue test consists of loading the sleeper structure in the section under the rail until a crack appears, and then the sleeper is subjected to loads of a defined force amplitude for 2,000,000 load cycles.

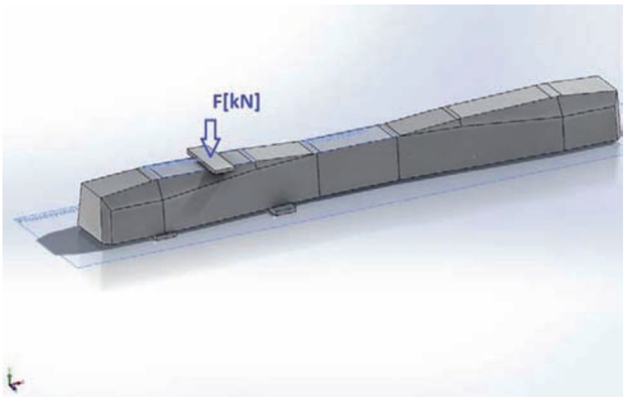

Fig. 10. Diagram of sleeper loads in the rail section [the author's own compilation]

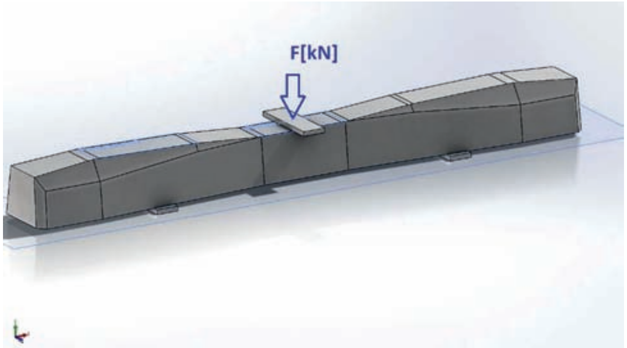

Fig. 11. Diagram of sleeper loads in the middle part in the normal position [the author's own compilation]

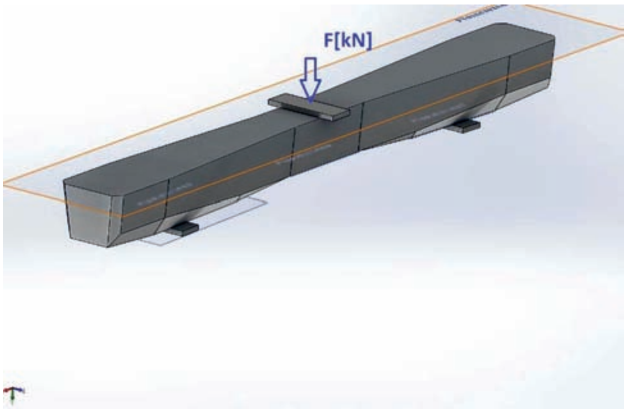

Fig. 12. Scheme of sleeper loads in the middle part in the inverted position [the author's own compilation]

As described, each type of test requires appropriate test rig preparation. Below are the results of static negative load test at the centre section (Figure 10), where the loading diagram shown in Figure 13 was implemented and acoustic emission signals were recorded during the test.

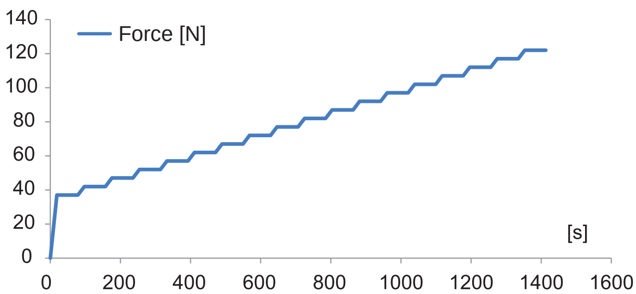

Fig. 13. Scheme of the sleeper load during the test in the middle part in the inverted position [the author's own compilation]

The sleeper, loaded with an initial force of 37 kN, was then subjected to progressive loading, increasing the force by 5 kN (Fig. 13). During the loading, an inspection was carried out, and any cracks or fractures that appeared were observed. An example of the inspection results (crack detection) is shown in Figure 14.

Fig. 14. The result of the visual inspection – finding the appearance of a crack during the loading of the sleeper [own elaboration]

Prestressed concrete sleeper testing in the negative central position simulates the most extreme case of poor support in the operation of the sleeper in the central section. Three AE sensors, two PKI6 sensors and one WDI sensor were used during the loading of the sleepers in the middle section in terms of the AE method.

The tests included the EAwinEXP8 system [11] for recording acoustic emission signals, which also allows the input of external analogue signals. The input of external signals from other measuring devices enables better correlation of the test course with acoustic emission events and the condition of the test object. Prestressed concrete sleepers were tested on the LFV fatigue testing machine (Fig. 15), which is equipped with a first-class load cell. A force signal was derived from the LFV testing machine and fed into the AEwinEXP8 system via an additional channel – this enabled the AE events to be recorded directly, along with information on the load to which the sleeper was subjected.

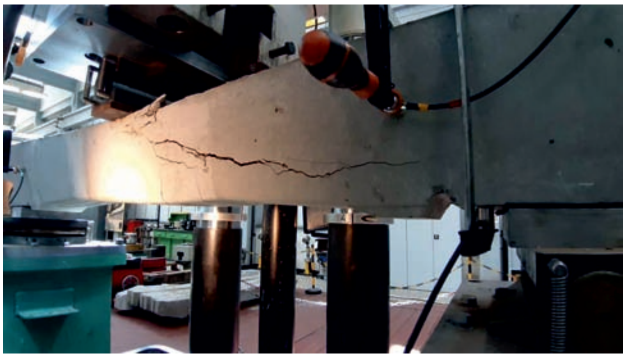

Fig. 15. Examination of a prestressed concrete sleeper on the LFV strength testing machine, load in the central part in an inverted position [photo D. Kowalczyk]

The sensors were placed away from the immediate area of cracks and highest stresses to protect the sensors from unpredictable fracture of the prestressed concrete sleepers. Since the tests are carried out up to the complete destruction of the object (determination of the Fr force) [1, 2], thus the course of such a test would expose the AE sensors to damage. In the case of the test in the middle section, the destructive forces reach up to 130 kN, in the case of the test in the section under the rail – up to 600 kN. Placing the sensors as proposed (positioning them in the area of the sections under the rail of the sleeper) allowed an additional analysis of the crack progression (crack development in the sleeper from the first AE events to its destruction), as shown in Figure 16.

The example AE signals from the final stage of the test, presented here, more accurately identify the correct destructive force and relate it to the acoustic emission events.

Example AE signals from the final stage of the test shown, which more accurately allow the determination of the correct damage force and relate it to acoustic emission events. Data for the descriptions in Tables 4 and 5. SSS notation. mmmuuun – test time [ms] – millisecond, – microsecond [μs], n – nanosecond [ns], time measured from the start of the test, force signal [kN], CH1 – sensor 1, PKI6, CH2 – sensor 2, PKI6; CH3 – WDI sensor, Rise time – signal rise time, Counts – number of counts, Energy – energy, duration – signal duration, AMP – amplitude; see standard [12] for detailed signal descriptions and explanations.

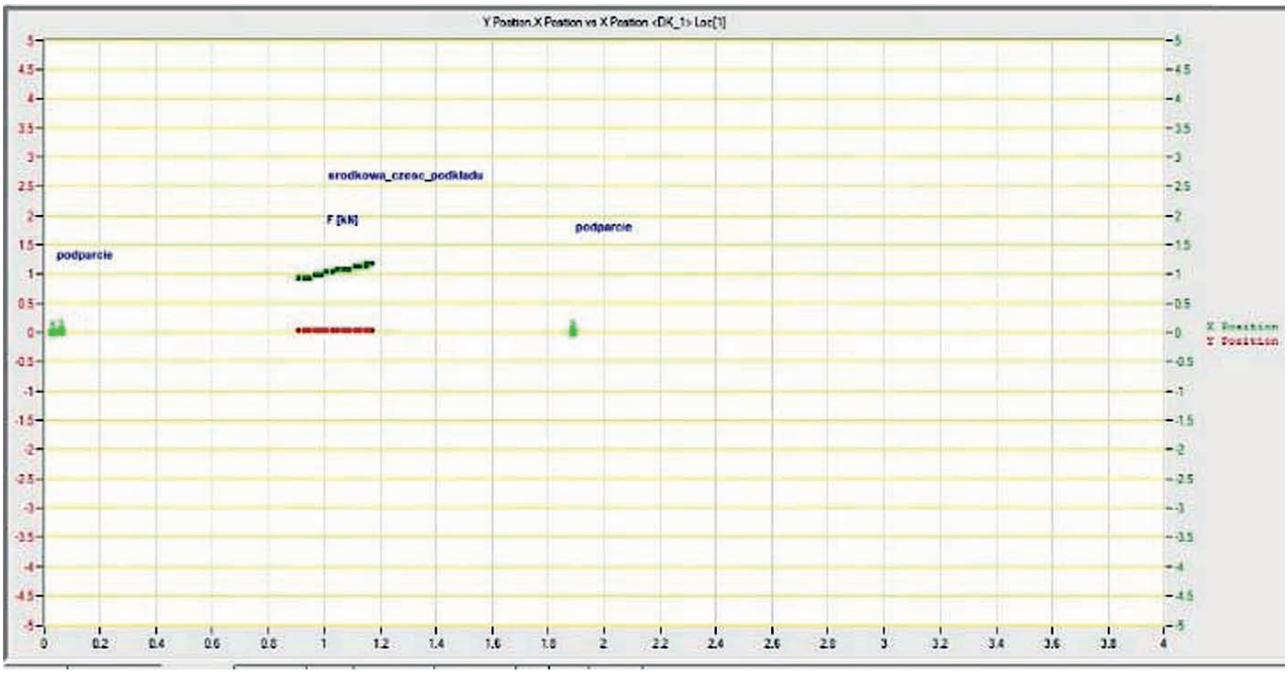

Fig. 16. An example of the occurrence of AE events in the sleeper in terms of loads for visual inspection of cracks (cracks) on the sleeper surface (about 63 kN – load in the middle part of the sleeper) [the author's own compilation]

Table 4

Excerpt from AE data collected during testing of PS-94 sleeper designated as podkład_strunobetonowy_2_9, subjected to sorting analysis against the Energy column [12]

SSSS.mmmuuun	Force [kN]	Sensor number	EA rise time [ns]	EA counts	Energy [aJ]	AE duration [ns]	Amplitude [dB]
635.815	–111.084	2	17570	6164	65535	1E+06	99
636.134	**–112.457**	**1**	**25914**	**3795**	**65535**	**1E+06**	**97**
636.816	-110.016	2	12307	8572	65535	999996	95
637.135	-110.931	1	41080	5903	65535	999941	99
637.817	-110.169	2	15208	12613	65535	1E+06	99
638.136	-109.711	1	47477	6910	65535	1E+06	99
638.818	-107.88	2	21949	13214	65535	999999	99
639.137	-108.795	1	4664	9664	65535	1E+06	99
639.819	-108.49	2	2034	10540	65535	1E+06	99

Table 5

Excerpt from AE data collected during the testing of the Ps-94 sleeper designated as podkład _strunobetonowy_1_14, subjected to analysis sorted against the energy column [11]

SSSS.mmmuuun	Force [kN]	Sensor number	EA rise time [ns]	EA counts	Energy [aJ]	AE duration [ns]	Amplitude [dB]
718.532	–119.324	1	9664	6599	65535	1E+06	96
719.533	**–121.46**	**1**	**38150**	**10576**	**65535**	**1E+06**	**92**
720.399	–121.002	2	978	4658	65535	1E+06	89
720.534	–120.697	1	62076	16551	65535	1E+06	99
721.4	–116.272	2	5090	7717	65535	1E+06	90
721.535	–114.594	1	11147	16557	65535	1E+06	99
722.401	–111.694	2	52077	9935	65535	1E+06	95
722.536	–114.594	1	47165	17751	65535	1E+06	99
723.402	–97.1985	2	63222	8621	65535	1E+06	99
723.537	–92.6208	1	58454	17232	65535	1E+06	99
723.679	–87.5854	3	47739	4725	65535	809082	99
724.403	–47.9126	2	30170	30387	65535	885564	97

Analysis of the acoustic emission signals and the force parameter makes it possible to determine the destructive moment of the sleeper. In the light of the analysis of the recorded AE events, it can be concluded that the destructive force of the sleeper in the middle part was 121 kN (for podkład_strunobetonowy_1_14).

During the testing of the prestressed concrete sleeper in terms of detecting the first crack (visual inspection), EA signals were also recorded. The results of the acoustic emission tests are shown in Figures 17, 18.

EN 13260 describes how to carry out load tests on sleepers to determine when the first crack appears

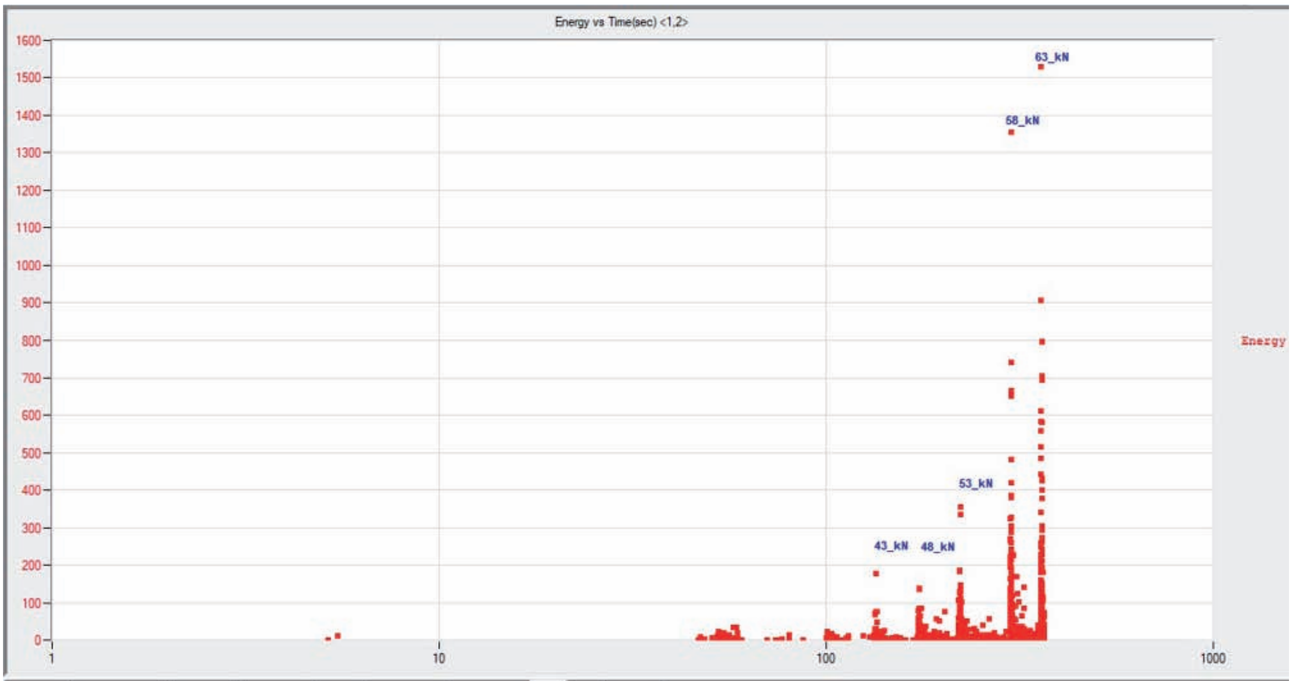

Fig. 17. The course of the load on the prestressed concrete sleeper _1_14 during the crack detection stage (time energy of events AE diagram) [the author's own compilation]

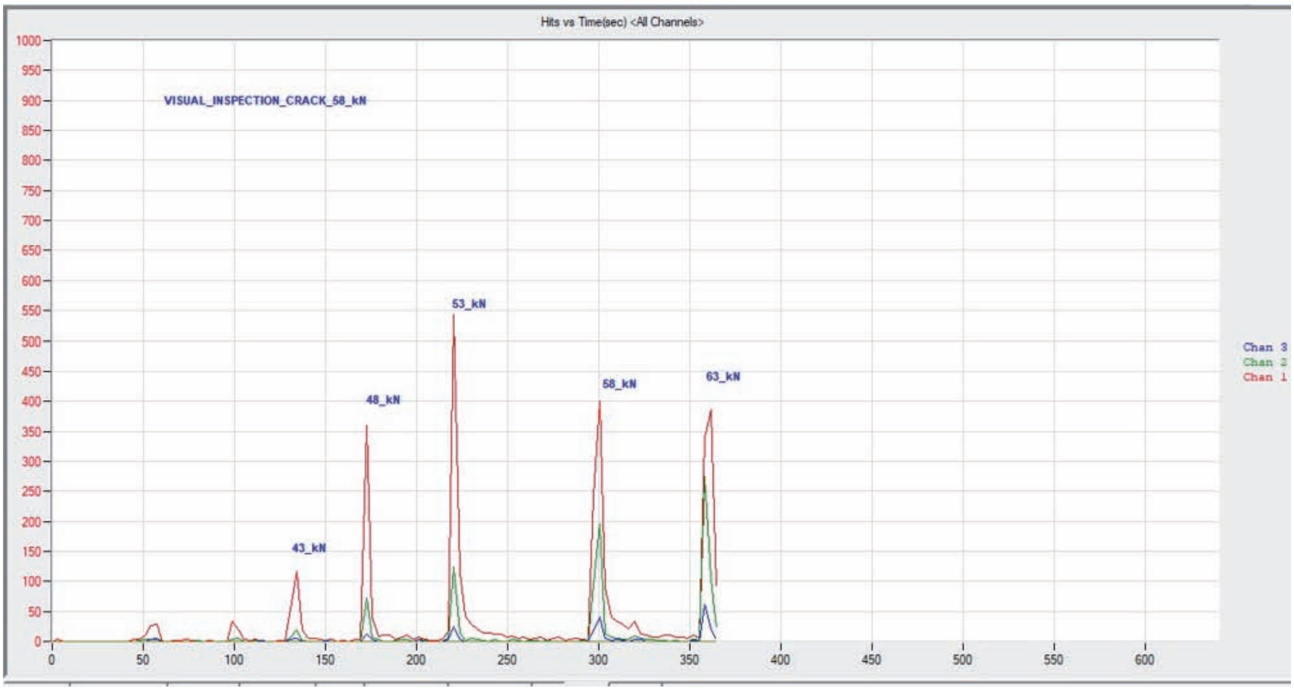

Fig. 18. The course of the load on the prestressed concrete sleeper marked as N_1_14 during the crack detection stage (number of AE events recorded on each sensor) [the author's own compilation]

(determination of the Fr_0 parameter), as detailed in this article. As prestressed concrete sleepers are solid objects (shown in 3D in the drawings), visual inspections are, however, not precise in determining the Fr_0 parameter. Crack propagation takes place in the area of least strength. Assuming that such a location may occur in the inner part of the sleeper (e.g. a material defect), the inspection may not detect such a defect. In the light of the test results presented here, acoustic emission could be an important support for the research. On the basis of more test investigations, it would be necessary to identify and define the signal levels that are considered to be the appearance of scratches/cracks in prestressed concrete sleepers and to supplement the provisions in the standards.

Based on the obtained results of the crack detection inspection tests, it was found that they occurred at a load of 58 kN (as described in Figure 19). With reference to the AE signals obtained and the analysis of these data, at the earlier load thresholds of the sleeper, it can be concluded that, for the sleeper designated N_1_14, the Fr_0 parameter could be determined for a load force of 48 kN or 53 kN. On the basis of the tests carried out, it can be concluded that visual inspections determine the test parameter Fr_0 quite well, but that the recording of the AE signals determines this parameter more accurately.

Prestressed concrete sleepers must be assessed at various stages of loading, such as the occurrence of the so-called first crack or the determination of the F_r/F_{rB} failure force, when carrying out the test according to EN 13230 [1]. As has been shown, the acoustic emission method can be a great additional support in the conducted tests on sleepers, it can be helpful in the conducted inspections for the detection of cracks, as well as, with the defined parameters of AE events, it would make it possible to determine the critical load state of the tested object (Fig. 19).

6. Conclusions

The acoustic emission method, as one of a group of NDT methods, is increasingly used in various areas of industrial tests. As shown in the article, it can also serve as an additional method for assessing the structural condition of prestressed concrete sleepers (or referred to in standards, as an alternative way of assessing damage and technical condition). The advantage of this method is that the damage signals come from the entire 3D object under test and also information can be obtained about the nature of the damage that dynamically occurs during the test (determination of event energy). The recorded signals even indicate the critical state before complete failure of the sleeper and allow the determination of the F_{rB} parameter - the force that destroys the sleeper (requirements of PN-EN 13230).

Research and scientific work on the implementation of the acoustic emission method in the assessment of all types of decks should still proceed. The implementation of the acoustic emission method as

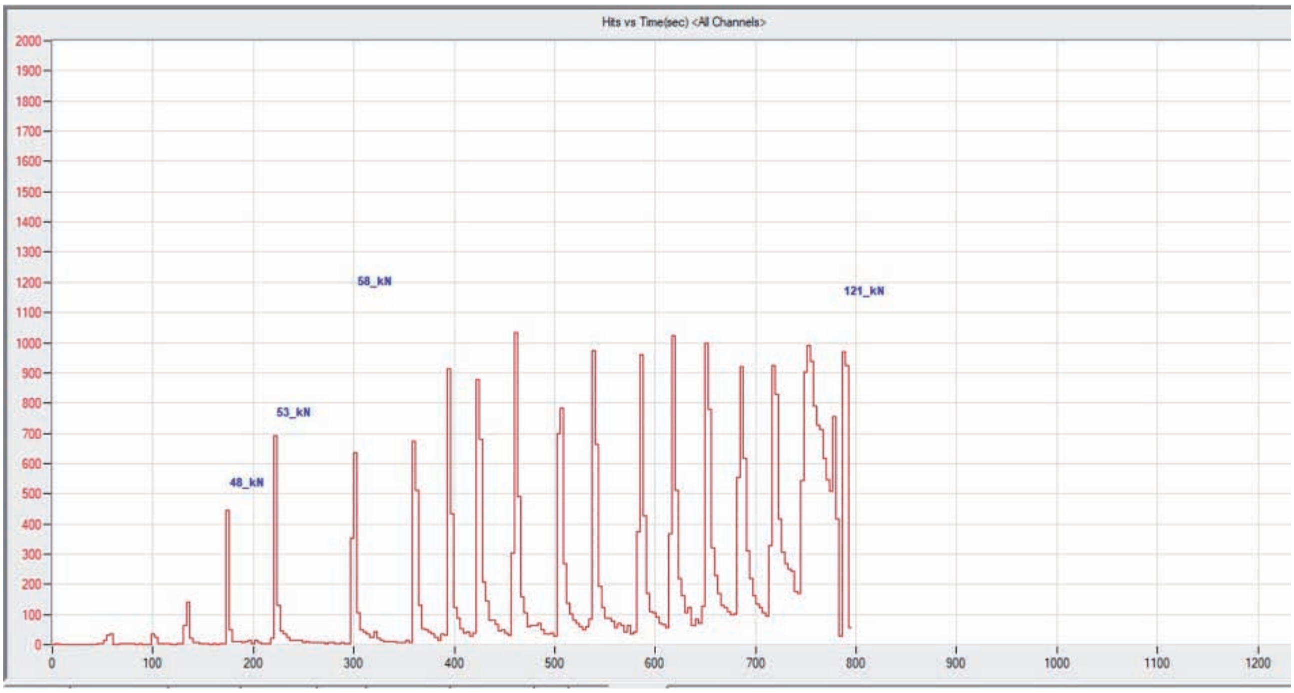

Fig. 19. Chart total energy [aJ] recorded on the basis of AE events until the destruction of the sleeper [the author's own compilation]

an alternative evaluation of the condition of sleepers, due to the fact that different types of material are used for their construction, is a complex issue. Prestressed concrete sleepers and wooden, steel sleepers (the so-called "Y-type" sleepers) are used on the Polish railway market, but composite sleepers made of various base materials, additives, fibre and reinforcing materials, or more and more often various recycled materials are also used in Europe and the world. In such cases, determining common evaluation criteria for such different material groups (with different mechanical properties and material characteristics) or even for the composite sleeper group itself is a difficult issue.

However, even for testing prestressed concrete sleepers, the acoustic emission method is a great support in research and additional verification of the condition of the structure against current requirements. Further development of research work in this area can also support the assessment of structures under operational conditions (e.g. monitoring of the condition of sleepers in the track under operational conditions).

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