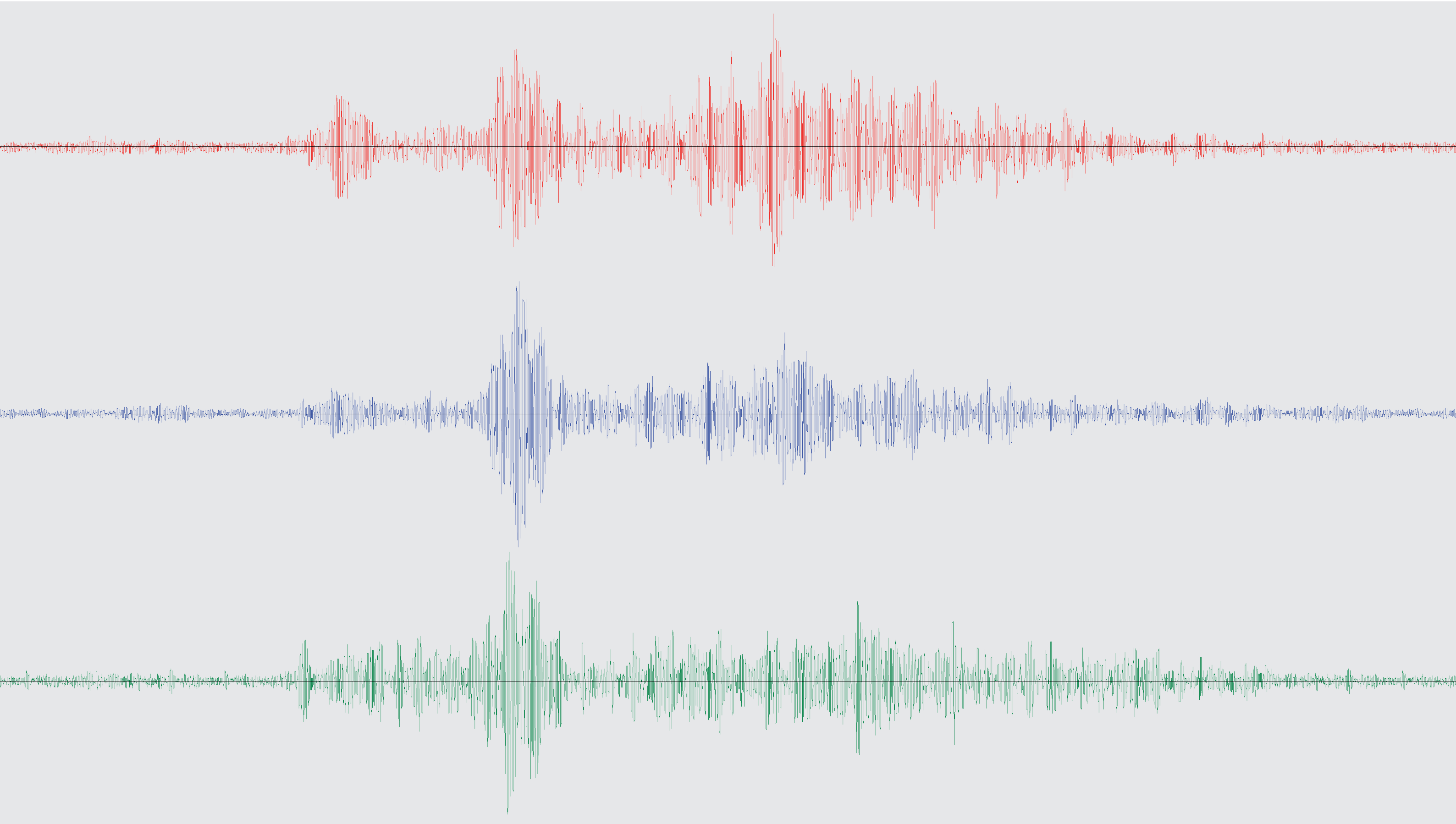
Environment and exploration of shale gas

THE RESULTS OF SEISMIC MONITORING



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Environment and exploration of shale gas

THE RESULTS OF SEISMIC MONITORING

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SUMMARY

The seismometric studies have been done in following areas:

- Syczyn-OU2K well in Syczyn, Wierzbica Commune, Chełmski Poviat, Lubelskie Voivodeship,
- Zwierzyniec-1 well in Zawada, Jarczów Commune, Tomaszewski Poviat, Lubelskie Voivodeship,
- Gapowo-1 well, Stężyca Commune, Kartuski Poviat, Pomorskie Voivodeship.

The study consisted of continuous observation of seismic vibrations at four measuring stations around each exploratory well. Measuring stations were located around the wells, in the localities presented in Annexes 1–3. Seismometric network was installed to register potential seismic vibrations caused by hydraulic fracturing in the wells. The range of observations depends, inter alia on noise level at the measuring stations , energy of seismic events, the distance between the measuring positions and seismic events and the sensitivity of the apparatus. A circle with a radius of about 10 km with a centre located at seismic sensor installation point was adopted as an observation area for seismic events that could potentially affect the development on the surface.

During the monitoring period no vibrations coming from seismic events associated with the process of rock mass cracking caused by hydraulic fracturing were registered. Recorded level of seismic background during hydraulic fracturing in the well did not exceed 2mm/s. Registered vibrations did not exceed the permissible vibration levels according to the standards for the evaluation of the harmfulness of vibrations transmitted through the ground onto the buildings: Polish Standard PN-85 / B-02170 and the German Standard DIN 4150/3.

1. INTRODUCTION

Under the agreement No. 16 / GDOŚ / 2013 entered into by and between the Minister of the Environment represented by Mr Michał Kiełsznia – General Director of Environmental Protection on the basis of a power of attorney No. 86, dated August 29, 2011., and the Central Mining Institute in Katowice – "Environmental risks assessment of the prospecting, exploration and exploitation of unconventional reservoirs of hydrocarbons ", the staff of Mining Geophysics Laboratory has designed and installed seismometric networks to measure the seismic vibrations in the regions:

- Syczyn-OU2K well in Syczyn, Wierzbica Commune, Chełmski Poviat, Lubelskie Voivodeship,
- Zwierzyniec-1 well in Zawada, Jarczów Commune, Tomaszewski Poviat, Lubelskie Voivodeship,
- Gapowo-1 well, Stężyca Commune, Kartuski Poviat, Pomorskie Voivodeship..

The purpose of those networks was to carry out continous digital recording of seismic background and seismic events with their automatic detection in designated areas around the well and analysis of recorded seismograms. The task of seismometric networks was to register of any vibration caused by work carried out in the wells. The possibility to detect seismic tremors of a minimum energy of 10^3 J (0.6 magnitude) for a hypocentral distance of 4–5 km was assumed. This gives the vibration amplitude at 4–6E-5 m / s level. The vibrations of this size can be registered with the installed apparatus, and the expected noise level in the research area. Vibrations from the tremors with energy of 10^4 J (1.2 magnitude) could be recorded up to a distance of about 10 km (vibrations amplitude of about 4E-5 m/s).

- Seismic monitoring included the following works:
- preparation: determination of the installation sites, installation of equipment,
- seismic background measurement before hydraulic fracturing,
- measurement during hydraulic fracturing,
- measurement after hydraulic fracturing.

2. DESCRIPTION OF SEISMOMETRIC NETWORK

Within the project a seismometric network was installed to measure the seismic vibrations in the following areas:

- Syczyn-OU2K well in Syczyn,
- Zwierzyniec-1 well in Zawada,
- Gapowo-1 well.

4 measuring stations were installed in every area at the points listed in Annexes 1–3. The periods of hydraulic fracturing in particular wells were provided in Table 1, while operating times of the individual stations in Table 2.

Table 1 Summary of hydraulic fracturing periods in particular areas of research.

Well	The beginning of hydraulic fracturing	The end of hydraulic fracturing
Syczyn-OU2K	21.06.2013	11.07.2013
Zwierzyniec-1	6.07.2013	11.07.2013
Gapowo-1	9.05.2014	23.05.2014

Table 2 List of measuring stations in the area of the wells with their operating time.

The name of the station – locality	The beginning of the measurement	The end of the measurement
Syczyn-OU2K well area		
Syczyn 1– Bekisza	10.04.2013	13.08.2013
Syczyn 2 – Syczyn	10.04.2013	13.08.2013
Syczyn 3 – Syczyn	10.04.2013	13.08.2013
Syczyn 4 – Syczyn	11.04.2013	12.08.2013
Zwierzyniec-1 well area		
Zawada 1 – Wielącza Kolonia	12.06.2013	6.09.2013
Zawada 2 – Kolonia Siedliska	12.06.2013	6.09.2013
Zawada 3 – Zawada (north)	12.06.2013	6.09.2013
Zawada 4 – Zawada (south)	12.06.2013	6.09.2013
Gapowo-1 well area		
Recorder 1 – Żuromino	19.03.2014	4.08.2014
Recorder 2 – Żuromino	19.03.2014	4.08.2014
Recorder 3 – Borowiec	18.03.2014	4.08.2014
Recorder 4 – Dubowo	18.03.2014	4.08.2014

Table 3 Operating time and failure rate of measuring apparatus

Station	No. of working days	The number of out of service days	The period of correct recording, %
Syczyn-OU2K well area			
Syczyn 1 – Bekisza	125	7	94,4
Syczyn 2 – Syczyn	125	2,5	98,0
Syczyn 3 – Syczyn	125	1	99,2
Syczyn 4 – Syczyn	123	0,5	99,6
Zwierzyniec-1 well area			
Zawada 1 – Wieląnza Kolonia	71	0	100,0
Zawada 2 – Siedliska Kolonia	71	21	70,0
Zawada 3 – Zawada (north)	71	1	98,6
Zawada 4 – Zawada (south)	71	5	92,3
Gapowo-1 well area			
Recorder 1 – Żuromino	138	0	100%
Recorder 2 – Żuromino	138	0.4	99,7%
Recorder 3 – Borowiec	139	0.2	99,8%
Recorder 4 – Dubowo	139	0.1	99,9%

Locations of installed stations were selected so as to – as far as technically possible – encircle the area of the works conducted in the wells and to record the lowest seismic background. Therefore it was possible to register even weak seismic tremors from the well area and their location. The main criteria when choosing the location of measuring stations were:

- availability of power supply and the ability to safely leave the apparatus on site,
- location of stations around the well in different directions,
- distances differentiation of station locations in relation to well locations.

Seismic background and possible seismic events were measured continuously with with the option of an automatic triggering for each measuring station. Automatic triggering algorithm was based on the ratio of the average value of the vibration amplitude in a short time window STA (300 ms) to the average value of the vibration amplitude in a long time window LTA (3000 ms), and the STA / LTA value at 2–5 level, after which automatic triggering of recording on the hard disk of the recorder was taking place. Sampling frequency of apparatus was set at 250 Hz, which allows to register events with a frequency of up to 125 Hz. Recording events with frequency of 125 Hz is sufficient to evaluate their impact on the buildings and people. Standards used to evaluate the vibrations (see Table 4 on p. 9 and Fig. 3 on page 10) include vibration frequencies up to 100 Hz. Additionally, due to recording conducted in a continuous manner in each of the four recording apparatus, a special data buffer was configured, allowing to record all vibrations in the period of 3 to 12 months. In this way it was possible to analyse all the vibrations recorded by the seismometric stations, even if the running process of automatic detection of events did not detect any signals.

Each station of seismometric network working in the test site consisted of a digital AMAX recorder equipped with three component DLM3D self-constructed sensors measuring velocity in three orthogonal directions or Kinemetrics seismometers Model SS-1 (list of measuring stations and the types of sensors used are listed in Annex 1–3). The sensors were calibrated on the table of Bruel & Kjaer company using the reference sensor. Sensitivity of DLM3D probes ranged 20–24 V / (m / s), while seismometers in the range of 310–340 V / (m / s). The resonant frequency of seismometers was 1 Hz. GPS modules were used to synchronize the time in the apparatus and in emergency to synchronize time from the web servers. Picture of measuring station and exemplary mounting method of the sensor were shown in Fig. 1, 2 and 2a.

Fig. 1 AMAX Digital recorder

Fig. 2 Exemplary mounting method of geophone sensor of AMAX apparatus in the ground

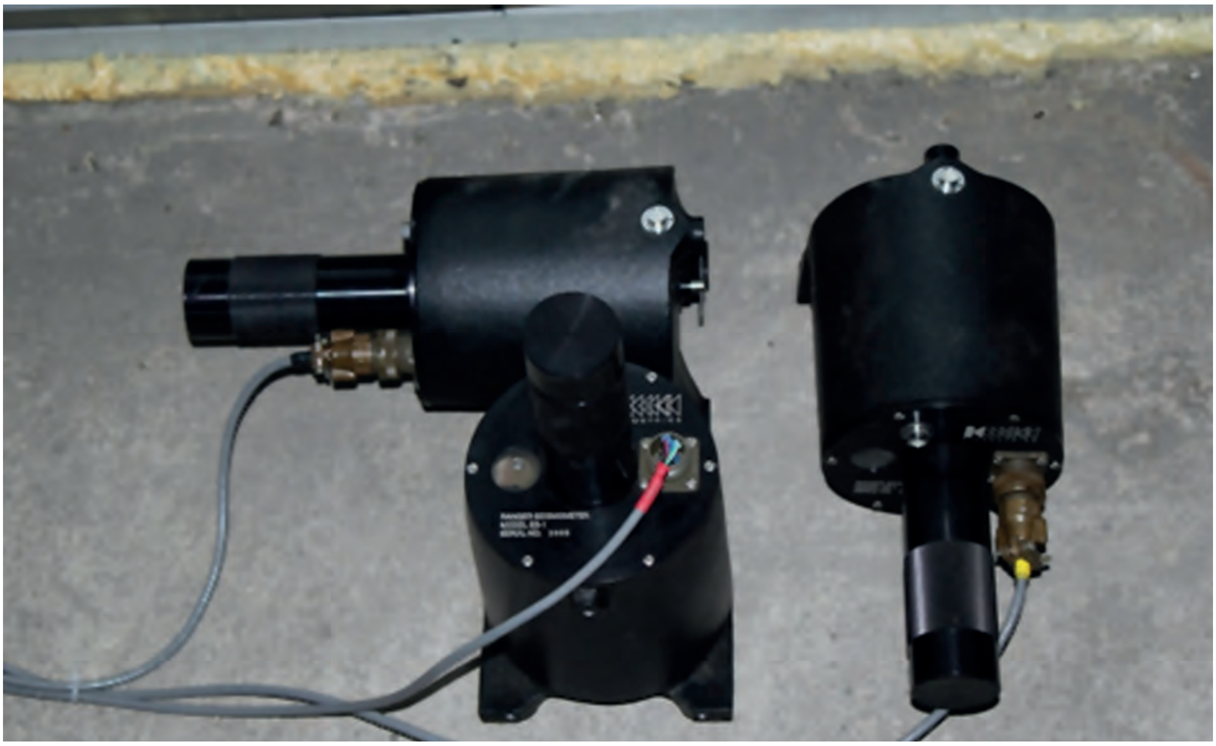


Fig. 2a Exemplary mounting method of Kinemetrics seismometers of AMAX apparatus on the building foundation.

Digital vibration recorder is a 64-channel device based on 16-bit A/C converter, with input voltage range of ± 10V. The signal from the sensors was amplified a 100 times in the case of DLM3D probes and a 10 times in the case of Kinemetrics seismometers. To register vibrations in DLM3D probes low-frequency vertical and horizontal geophones type 11D made by American company GeoSpace were used. These geophones with resonance frequency of 4.5 Hz measure ground velocity. In order to register vibrations of 1 Hz, electronic circuit rectifying characteristics of each sensor in the range of 1–5 Hz was used. Each three component vibration sensor was mounted by placing it in permanent manner in the ground, which is illustrated on Fig. 2. In addition, each measuring station was equipped with a mobile router and connected to the Internet through the mobile network with a static IP number. Such configuration allows for current (online) observations of recorded vibrations and allows remote control of devices from anywhere in the world.

Opportunities of recording of seismic tremors by the apparatus depend mainly on factors such as the level of noise in the measuring station, energy of the tremor, hypocentral distance. In the event of seismic tremors with the energy in the order of 10^4 J (magnitude:1.2) amplitude of vibrations caused by this type of event should be in the order of 4E–5 m / s, assuming a hypocentral distance of 10 km. The values of such amplitudes should be visible in the recorded seismograms, because the seismic background in this area has maximum amplitude in the order of 1E–6 m / s. This makes it possible to detect tremors in the area of the well much weaker than those that could be sensed by human or buildings.

Operating times together with the number of out of service days presented in Table 3 indicate that:

- **In the area of Syczyn-OU2K well** seismometric apparatus has worked properly and there were no periods of simultaneous downtime at all measuring stations. While breaks in the recording of individual stations were short – a few hours at most – and were due mostly to lack of power at the measuring stations, which is typical for energy networks located in rural areas. One longer break in recording in Bekisza station (Syczyn 1) took place in the period from 04.11.2013 to 04.17.2013. This was the start-up period before the hydraulic fracturing. The apparatus has failed – defective power supply adaptor – and it had to be replaced.
- **In the area of Zwierzyniec-1 well** the seismometric apparatus has worked properly and there were no periods of simultaneous downtime at all measurement stations. Three longer breaks in recording in Zawada 2 station were caused by equipment failures, i.e. damage to recorder power supply adaptor and the main board. Failures were due to large fluctuations in the mains voltage. The three-day long breakdown on Zawada 4 station in the period from 06.18.2013 to 06.22.2013 was caused by accidental switching off of the measuring apparatus by a third party. The other breaks in the recording were short, one-day long and mostly caused by the lack of power at the measuring station, which is typical for energy networks located in rural areas.
- **In the area of Gapowo-1 well** the seismometric apparatus has worked properly and there were no periods of simultaneous downtime at all measurement stations. Breaks in recording were short, a few hours long at most and mostly caused by the lack of power at the measuring station, which is typical for energy networks located in rural areas.

A description of all measuring stations installed on the following ranges: Syczyn-OU2K, Zwierzyniec-1 and Gapowo-1, as well as their locations are shown in Annexes 1–3.

3. STANDARDS USED TO ASSESS SEISMIC VIBRATIONS

German standard DIN 4150/3 distinguishes short-term and long-term vibration and is quite commonly used in Europe. The decisive criterion for analysis of the harmfulness is the peak value of vibration velocity and the dominant vibration frequency read from Fourier spectrum. Table 4 shows the corresponding allowable vibration velocities of short-term tremors, depending on the type of building, and for different frequency ranges.

Table 4 Guideline values for vibration velocity when evaluating the effects of short-term vibrations on structure according to DIN 4150/3

Category	Description of the category (structure)	Guideline values for velocity in mm/s			
		Vibrations at the foundation at the frequency of			Vibrations at horizontal plane-at all frequencies
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz*)	
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15
3	Structures with particular sensitivity structures that cannot be included in the above two categories, and of great intrinsic value i.e.: buildings under conservation protection, equipped with special electronic or mechanical devices	3	3 to 8	8 to 10	8

*) At the frequencies of above 100 Hz, values from this column may be used as minimum values.

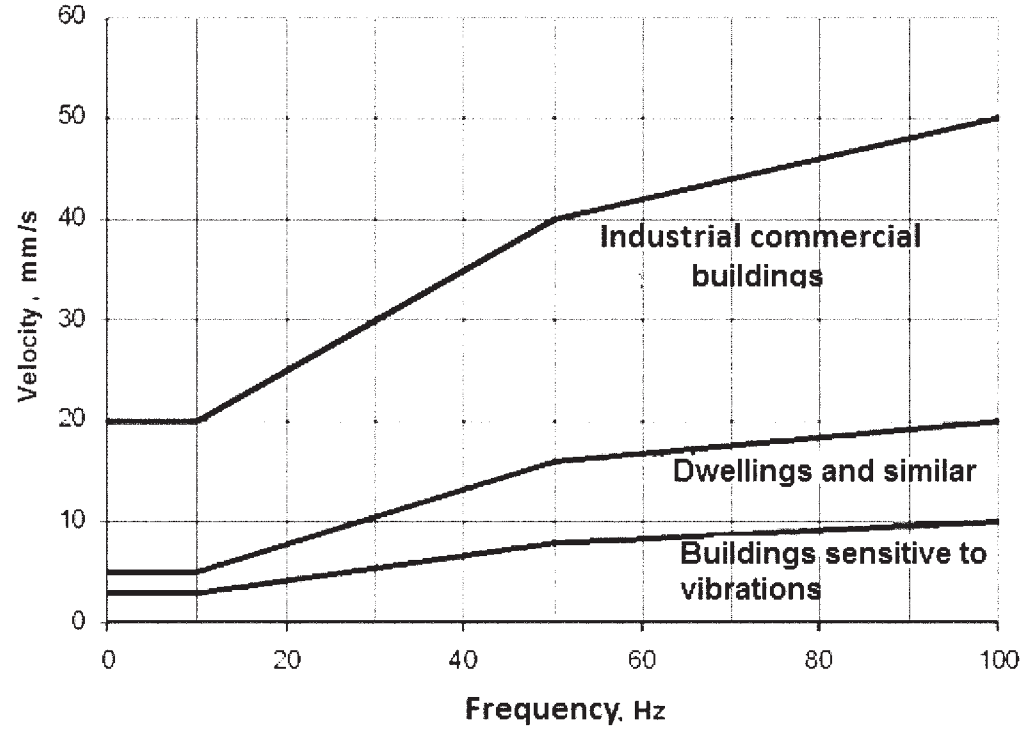


Diagram of DIN 4150/3 standard

Annexes 4–15 include threshold value of 5 mm/s marked with red horizontal line , for which the impact of seismic and paraseismic vibrations should be eventually considered in accordance with DIN 4150/3 for frequencies from 1 Hz to 10 Hz. For higher frequencies threshold value increases

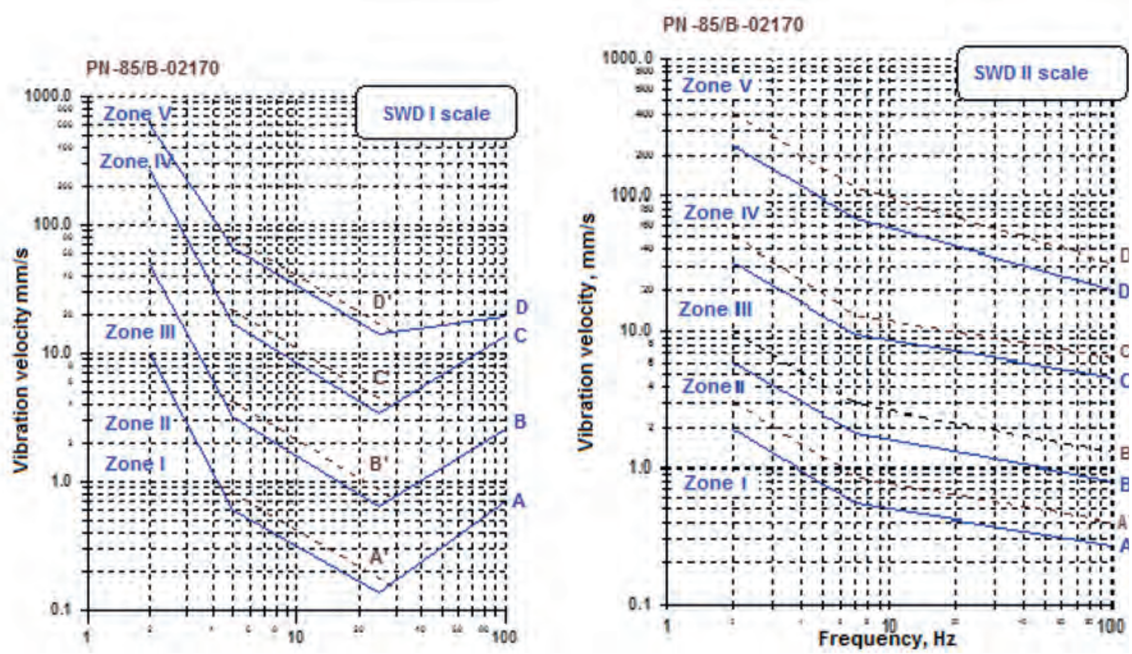


Fig. 3 The scales of dynamic influences SWD-I and SWD-II according to Polish standard PN-85/B-02170 in logarithmic coordinates of the frequency and vibration velocity.

In Poland, during assessment of the harmfulness of ground vibrations transmitted to buildings the PN-85/B-02170 standard is used, which includes SWD I and SWD II scales for the engineering assessment of the effects of vibrations in certain classes of buildings. This standard is used to evaluate acceleration amplitude or the velocity of the ground vibrations for specific frequencies obtained from seismometric measurements.

SWD I scale is used for buildings with small-size horizontal floor plans (not exceeding 15 m), one- and two-storey high, and with height of not more than any of the dimensions of the horizontal floor plan.

SWD II scale is used for buildings not higher than five storeys, whose height is less than twice the minimum width of the building, and for the low buildings (up to two storeys high), but not meeting the conditions for SWD-I scale. Both SWD scales are developed in the form of nomograms, in which maximum vibration accelerations are placed on vertical axis, while centre frequency of the vibration band is placed on the horizontal axis.

Objects in the area of research are eligible for assessment in accordance with SWD I scale.

SWD scales reflect five zones of vibration influance on buildings:

- **zone I** – vibrations imperceptible to the building,
- **zone II** – vibration perceptible to the building, but harmless to the structure; only accelerated wear of the building can occur, and the first cracks in plaster coating,
- **zone III** – vibrations harmful to the building structure causing localized scratches and cracks; flaking of plaster and coating may occur,
- **zone IV** – highly hazardous vibrations to the building, numerous local cracks, destruction of walls, etc. appear.
- **zone V** – vibrations leading to failure of the building.

Limit A – the lower limit of perceptibility of vibrations by the buildings, full dynamic resistance of buildings.

Limit B – igidity limit of buildings, the lower limit of the formation of unacceptable – in view of building standards – scratches and cracks in structural elements.

Limit C – tensile strength limit of individual elements of the building, the lower limit of heavy structural damage.

Limit D – the limit of the building stability, above which the damage to the wwell building may occur.

In the evaluation SWD scales relate to the continuous vibrations (of above 30 minutes a day in total), wherein the zone boundaries are shown in two options according to the assessment of the building condition, type of ground and the type of vibration. Classification into proper option occurs according to the overwhelming number of relevant features listed in Table 4 included in the PN-85/B-02170.

The construction objects in the area where measurements were performed shall be eligible for evaluation according to the SWD I scale.

4. ANALYSIS OF THE RESULTS OF MEASUREMENTS

Seismic background around the Syczyn-OU2K, Zwierzyniec-1, and Gapowo-1 wells was measured continuously at four measuring stations before hydraulic fracturing, during hydraulic fracturing, and after hydraulic fracturing. During measuring process the recorded background underwent changes, which are represented in diagrams of the maximum amplitude distributions presented in Annexes 4 to 15 (maximum amplitude was determined for a 40s long window). For each seismometric station the maximum vibration amplitudes of the seismic background were isolated for the individual X, Y and Z components, and cumulatively for XYZ components. The resultant vibrations XYZ is calculated as the vector length with X, Y and Z components according to the proportion: $XYZ(t) = \sqrt{X(t)^2 + Y(t)^2 + Z(t)^2}$ where XYZ means a resultant vector, X, Y and Z – following components, t – time.

Presented maximum amplitude of vibration velocities of recorded background can be used to assess its impact on residential buildings and people. In Poland, the assessment of impact of vibrations on buildings is made based on the PN-85 / B-02170 standard. This standard allows the assessment of the vibration impact from both the velocity and acceleration seismograms. To assess the impact of vibrations the German standard can also be utilised, i.e.

DIN 4150/3, which is used to assess the impact of vibrations on buildings based on velocity seismograms. German standard is quite commonly used in the assessment of the impact of vibrations in Europe.

The exemplary seismograms presented in the following chapters were not digitally processed, nor filtered to remove interference.

4.1 Test site in the area of the Syczyn-OU2K well

Seismic background around Syczyn-OU2K well was continuously measured at four measurement stations in the period from 04.11.2013 to 08.11.2013 Measurements in the period from 04.11.2013 to 20.05.2013 were performed before hydraulic fracturing, from 05.21.2013 to 10.07.2013 during hydraulic fracturing, and from 07.11.2013 to 11.08.2013 – after hydraulic fracturing.

The results of measurements of seismic background in the area of Syczyn-OU2K well in the measurement period at the individual stations are described in Annexes 4, 5, 6 and 7 Their analysis and description are as follows:

Syczyn 1 station

The maximum amplitude of the vibration velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each observation period:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	18.04.2013, 10.59	17.06.2013, 16.39	31.07.2013, 18.35
Resultant XYZ	3.18E-3	1.00E-3	9.81E-4

The variability of the maximum amplitudes over time is shown in Annex 4. Exemplary vibration recording and its Fourier spectrum are represented in Fig. 4 and 5. Exemplary recording of the background and its Fourier spectrum are presented in fig. 6 and 7. Seismic background shown in Fig. 6 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Syczyn 1 station it was possible to register the vibrations with amplitude greater than 2.0E-5 m/s. Seismograms shown in Fig. 4 are an example of registered vibrations the amplitude of which exceeds the background level. Vibrations registered on 18.04.2013, at 10.59 with maximum amplitude of 3.18 mm/s were the result of strikes in the sensor or its vicinity.

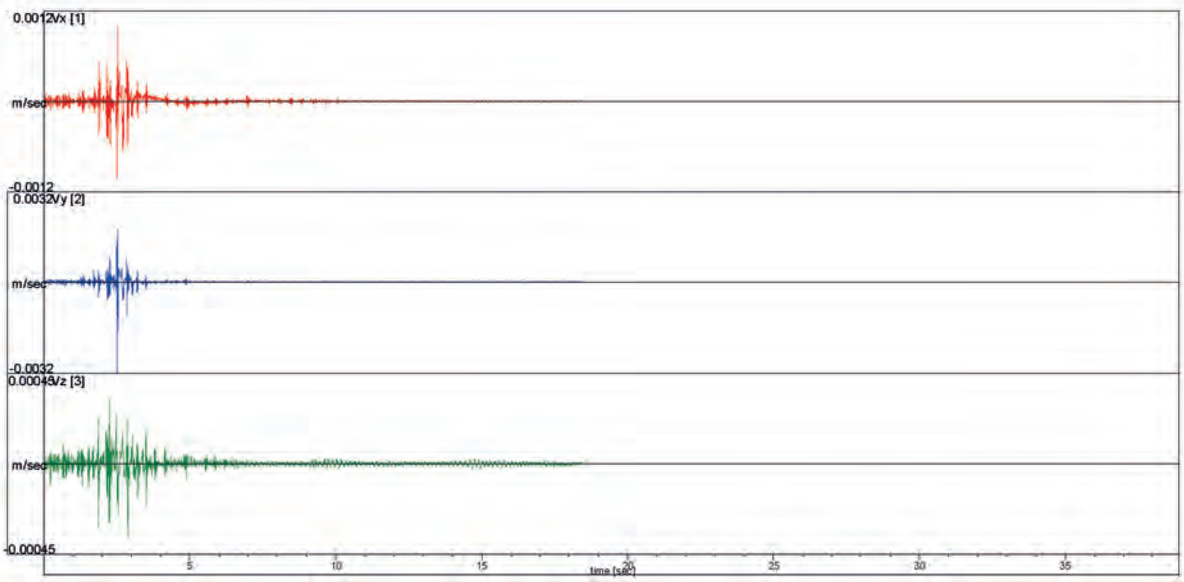


Fig. 4 The example of vibrations registered at Syczyn 1 station on 04.18.2013; at 10.59 (the highest recorded amplitude of vibrations)

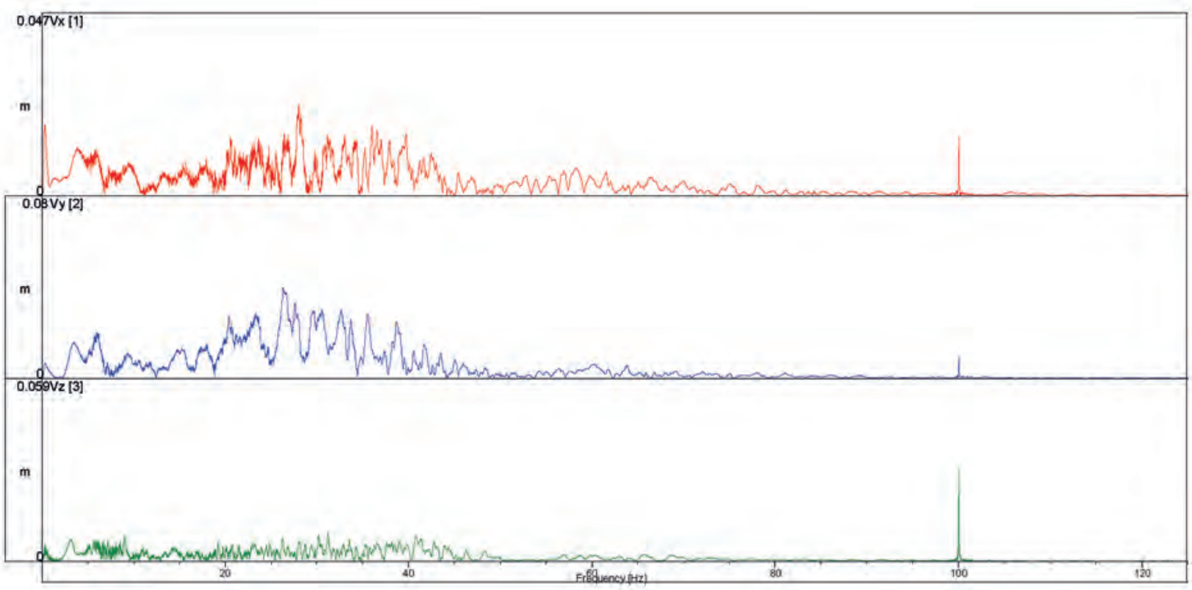


Fig. 5 Fourier analysis (amplitude spectrum) of recording from Fig. 4

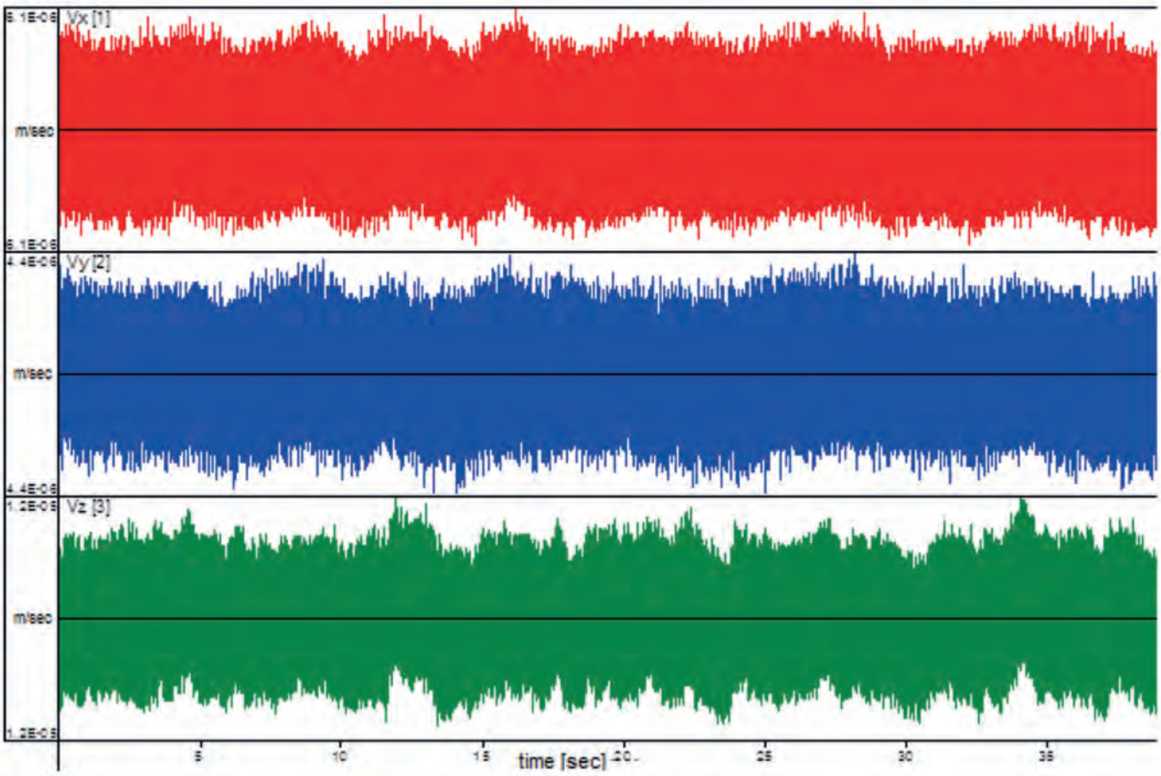


Fig. 6 Example of seismic background recorded at Syczyn 1 station.

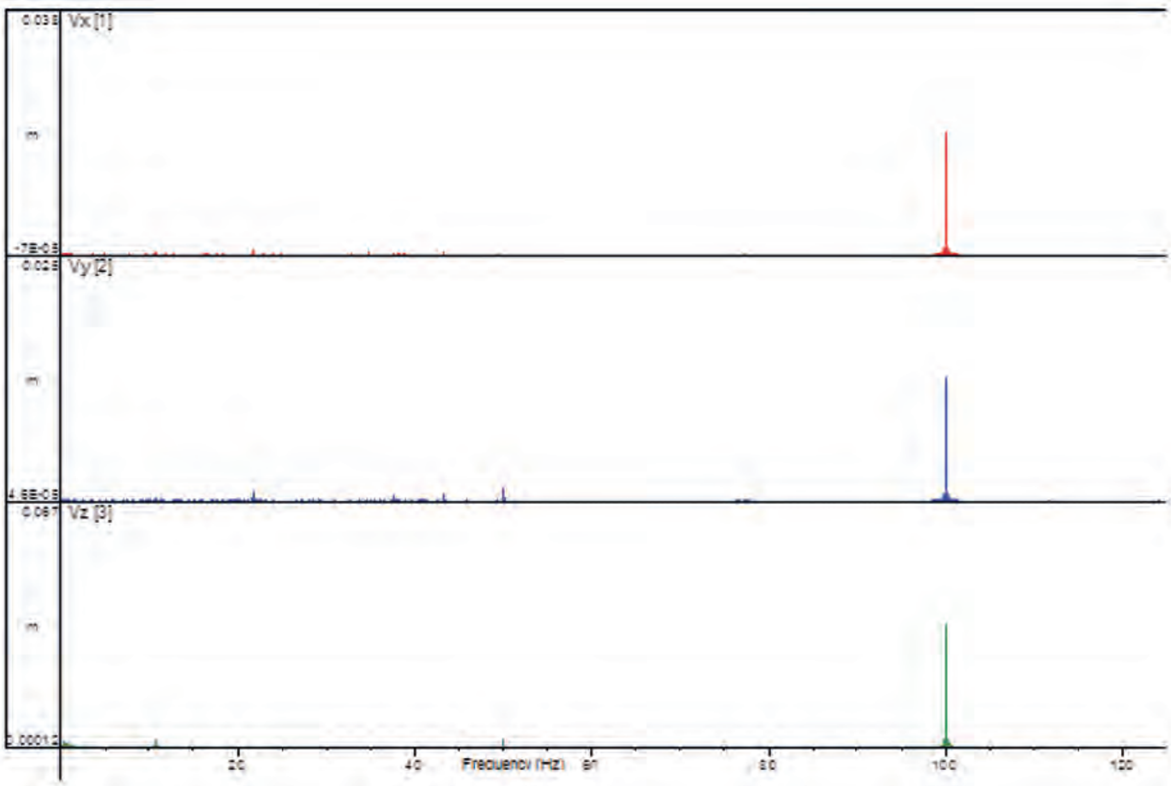


Fig. 7 Fourier analysis (amplitude spectrum) of recording from Fig. 6

Syczyn 2 station

The maximum amplitude of the vibration velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each observation period:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	09.05.2013, 12.36	27.05.2013, 10.03	11.07.2013, 13.14
Resultant XYZ	8.98E-4	1.04E-3	3.12E-4

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 10 and 11. Seismic background shown in Fig. 10 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Syczyn 2 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 8 are an example of registered vibrations the amplitude of which exceeds the background level.

The highest vibration amplitudes were recorded on 05.27.2013, at 10.03, when equipment was operating (pumps) at the Syczyn-OU2K well. This recording is shown in Fig. 8.

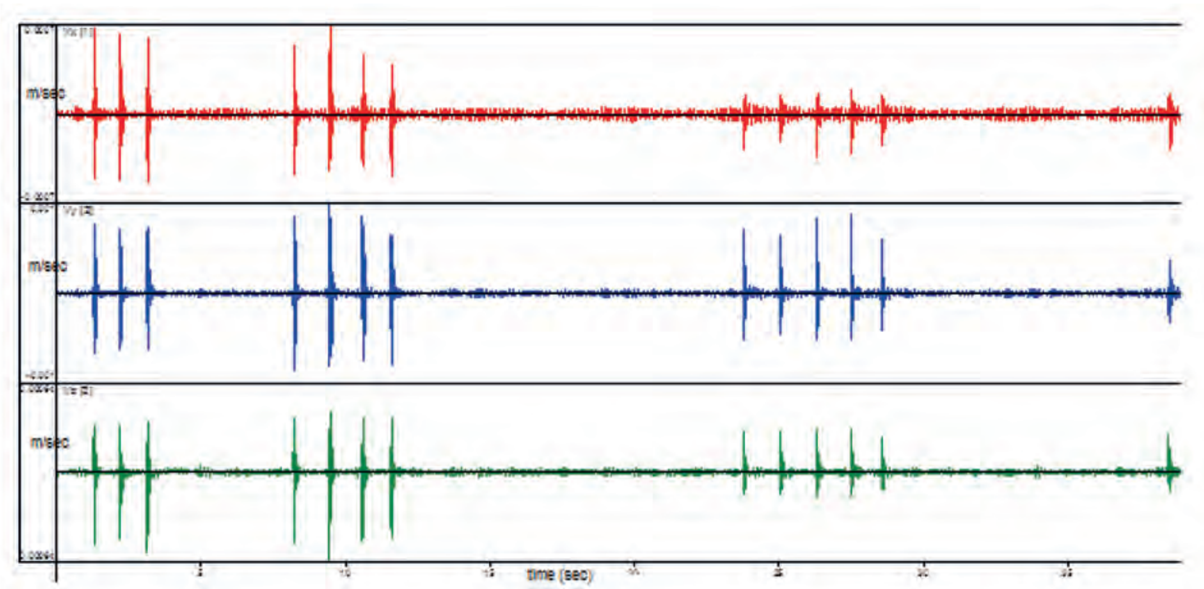


Fig. 8 Vibrations recorded on 27.05.2013, at 10.03 when equipment was operating

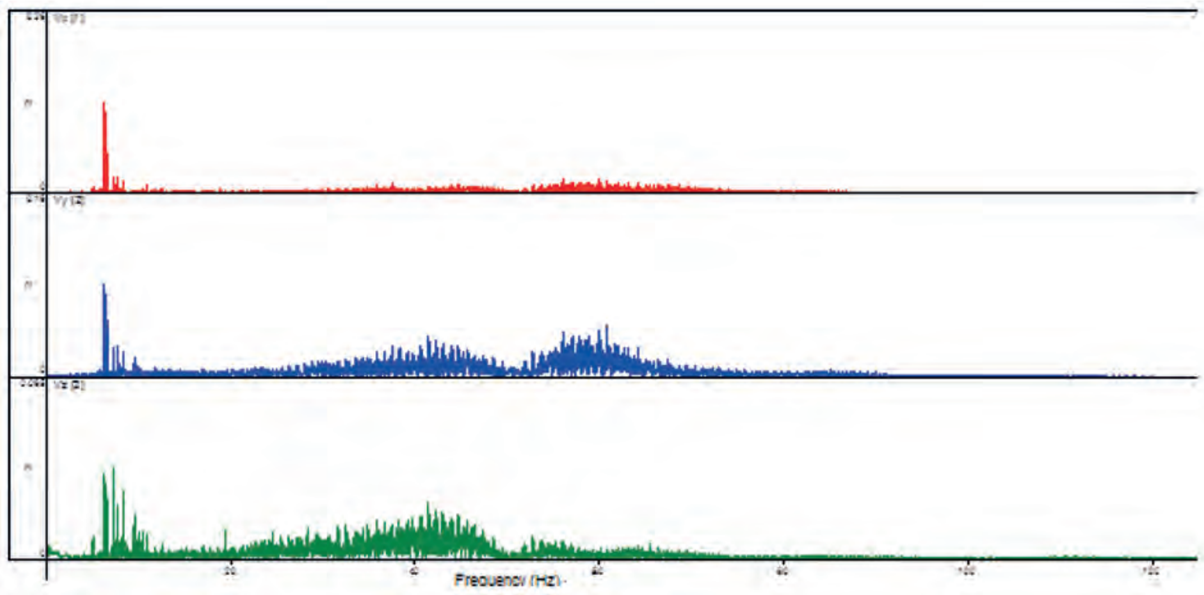


Fig. 9 Fourier analysis (amplitude spectrum) of recording from Fig. 8

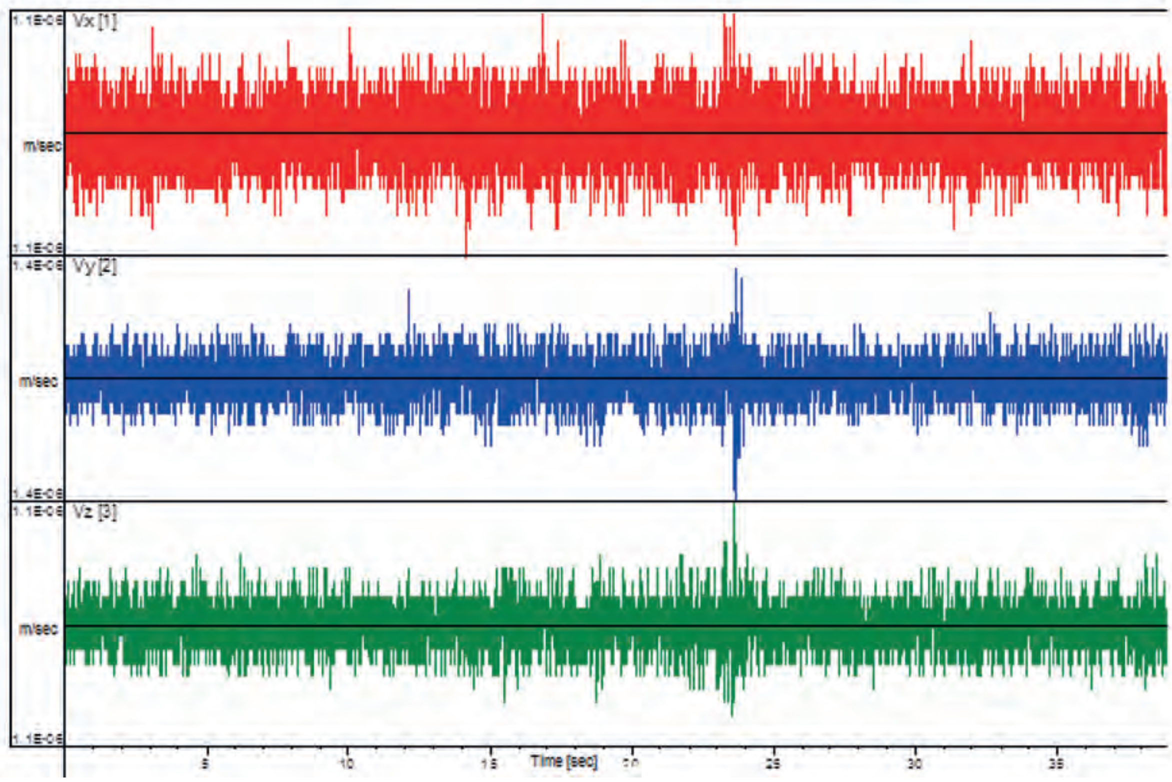


Fig. 10 Example of seismic background recorded at Syczyn 2 station

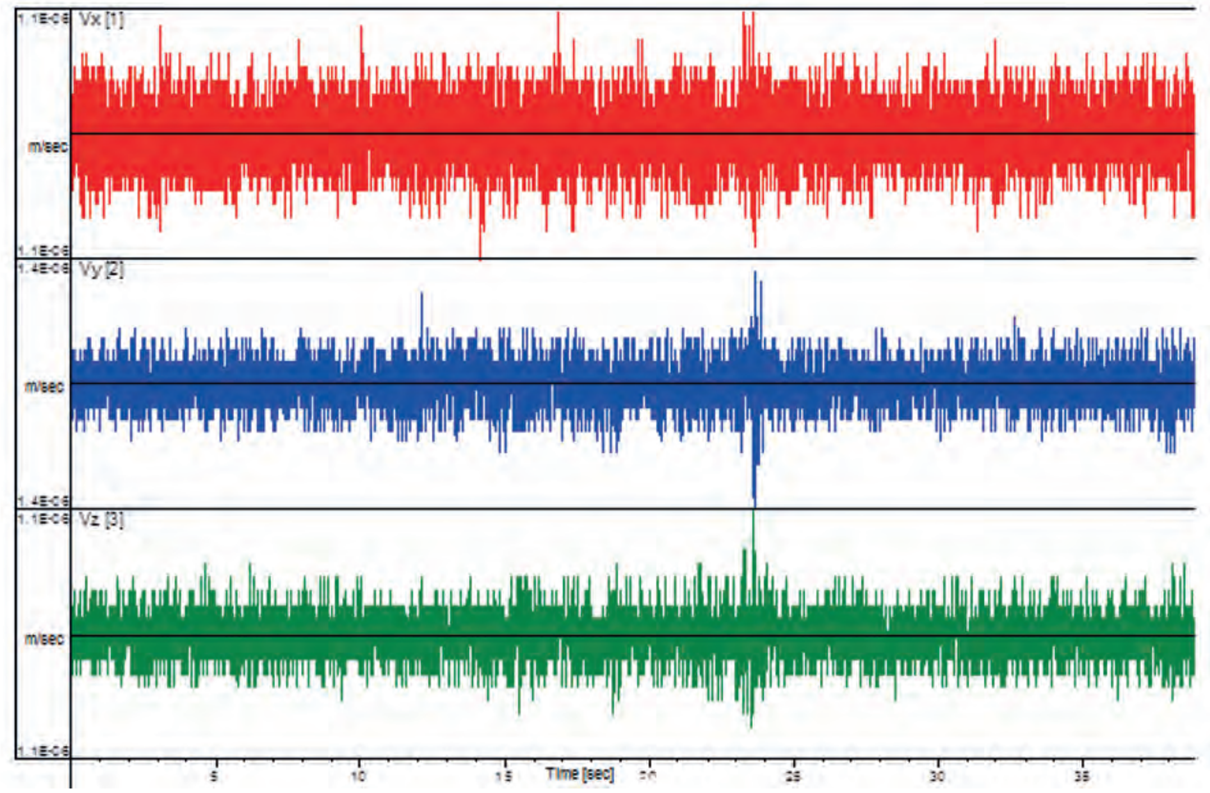


Fig. 11 Fourier analysis (amplitude spectrum) of recording from Fig. 10

During the considered period, at the studied measurement site paraseismic vibrations on the surface coming from the works related to hydraulic fracturing (working pumps) have been found. Works conducted in the period from 21.05.2013 to 10.07.2013 have been recorded by AMAX apparatus installed at the Syczyn 2 station. It was a place located in the nearest distance from conducted works. Those works are visible on recordings coming from the Syczyn 2 station from 22.05.2013 to 06.05.2013 The distribution of the maximum ground vibration amplitudes in the period from 20.05.2013 to 07.06.2013 for the station Syczyn 2 is shown in Fig. 12. During that time, there is a clear indication of periods of operation of the hydraulic fracturing equipment (see arrows in Fig. 12) in which the level of maximum amplitudes is higher compared to the period during which those machines where not operating. The maximum recorded resultant vibration amplitude was 1.04E-3 m/s. Recorded vibrations were classified as paraseismic vibrations (not being the result of fracturing of rocks during hydraulic fracturing). Vibrations at this level can be felt by the people, but are harmless to the buildings (according to the SWD I scale it is a zone II: vibration perceptible to the building, but harmless to the structure, only accelerated wear of the building may occur, and the first cracks in coatings and plasters).

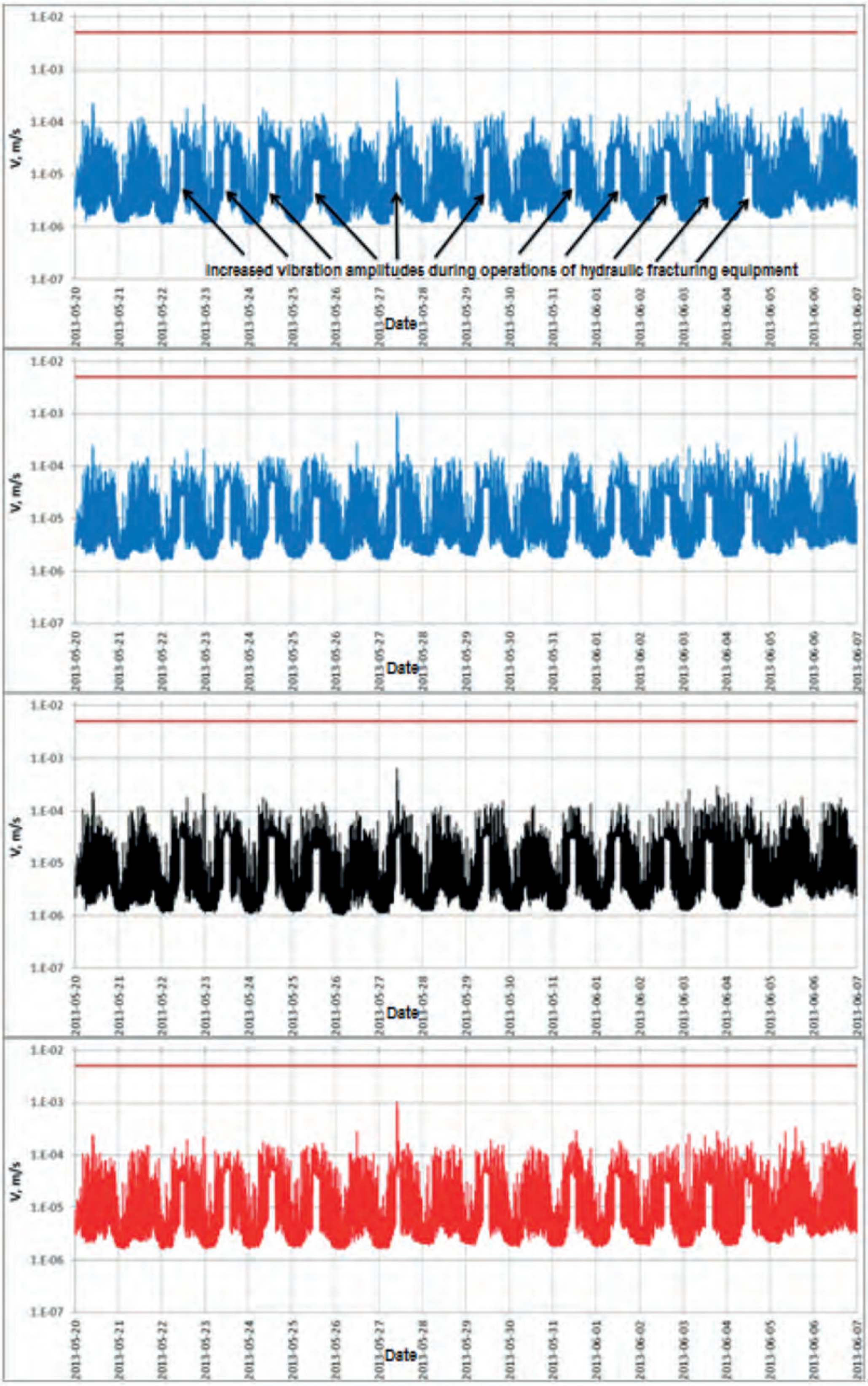


Fig. 12 The distribution of the maximum ground vibration amplitudes in the period from 05.20.2013 to 07.06.2013 at the Syczyn 2 station. Component X, Y, Z, and the resultant XYZ respectively.

Syczyn 3 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	14.04.2013, 10.43	22.05.2013, 13.53	10.07.2013, 14.23
Resultant XYZ	4.10E-3	4.10E-3	2.45E-3

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 15 and 16. Seismic background shown in Fig. 15 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Syczyn 3 station it was possible to register the vibrations with amplitude greater than 4.0E-6 m/s. Seismograms shown in Fig. 13 are an example of maximum vibrations registered 22.05.2013 at 13.53 being the result of strikes in the sensor or its vicinity.

The variability of the maximum amplitudes over time for the studied period is presented in Annex 6. Records of the event relating to maximum amplitudes, and its amplitude spectrum are shown in Fig. 13 and 14.

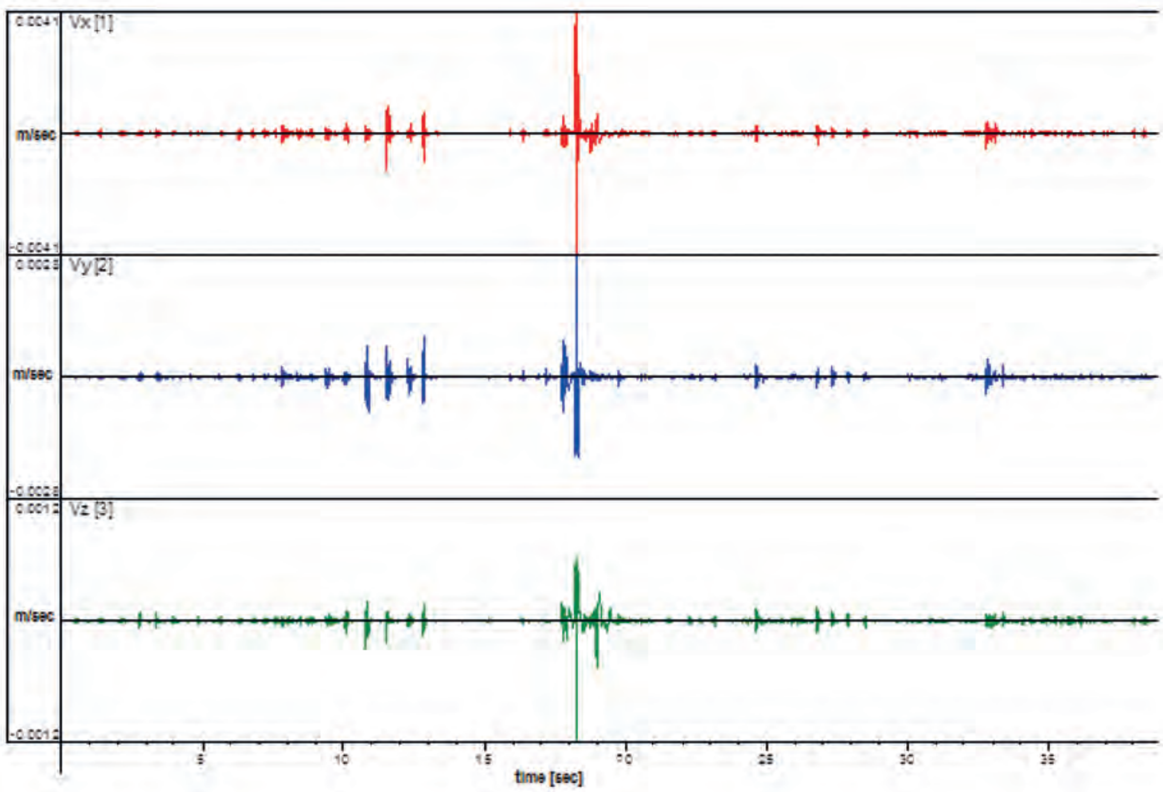


Fig. 13 Example of vibrations recorded at Syczyn 3 station on 05.22.2013 at 13.53 with a maximum amplitude.

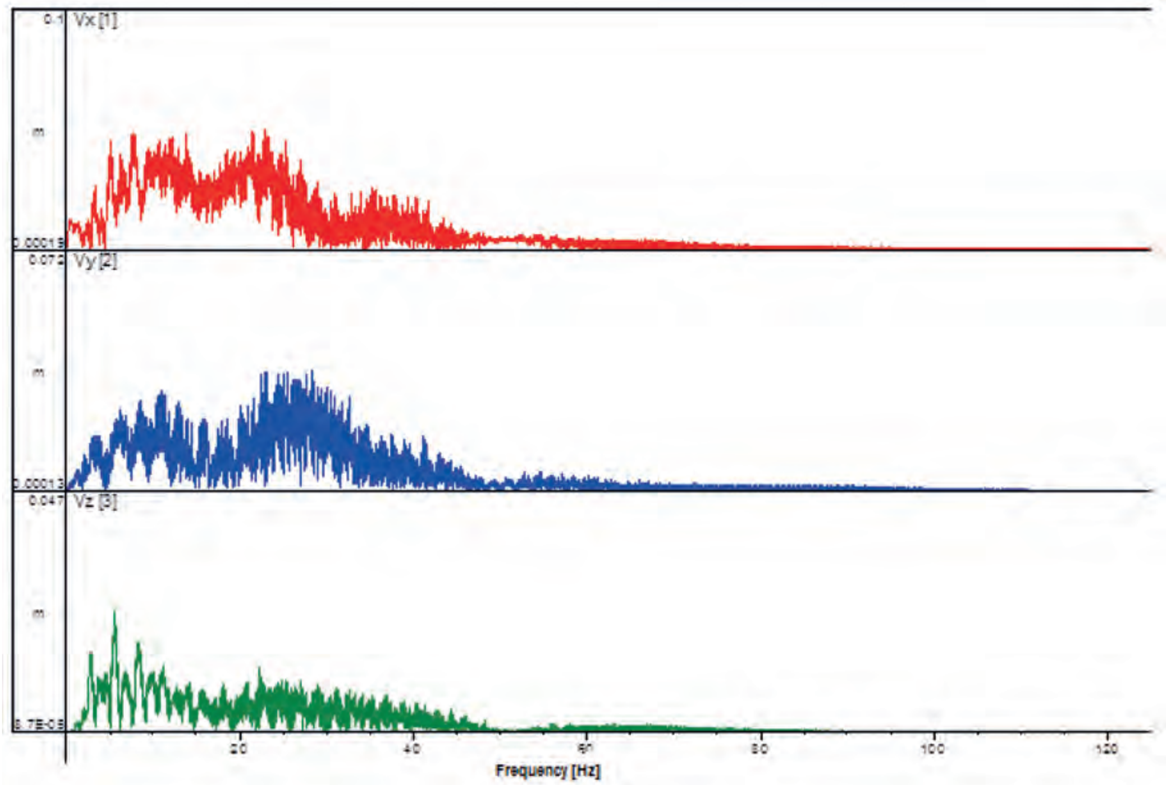


Fig. 14 Fourier analysis (amplitude spectrum) of vibrations from Fig. 13

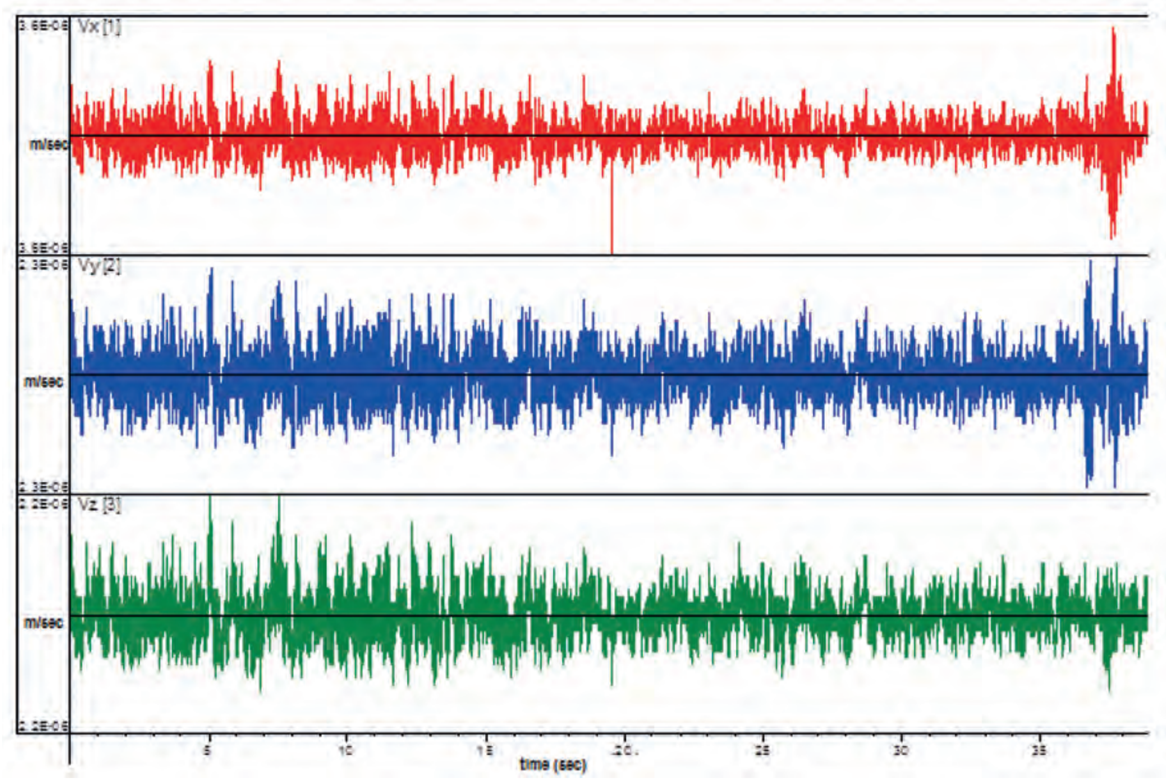


Fig. 15 Example of seismic background recorded at Syczyn 3 station.

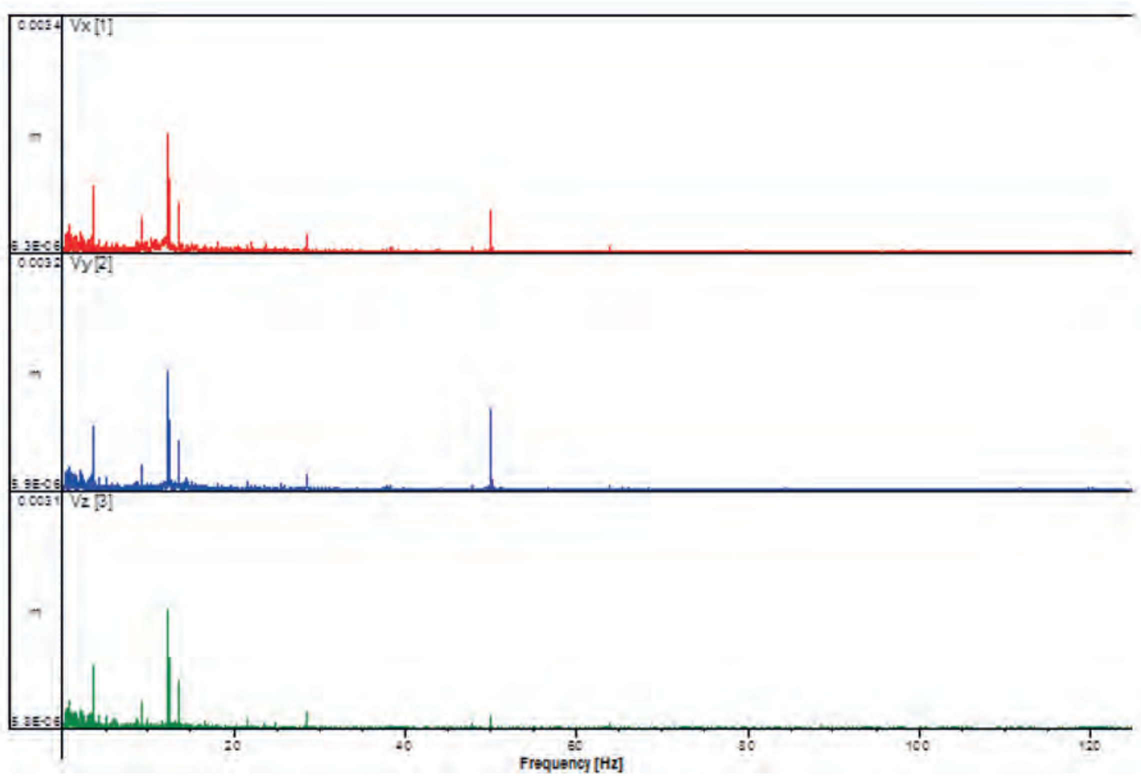


Fig. 16 Fourier analysis (amplitude spectrum) of vibrations from Fig. 15

The sensor at the Syczyn 3 station registered number of events with an amplitude exceeding 1 mm/s. These vibrations were similar in type – short pulses, similar to those shown in Fig. 12. They originated from vibrations induced near the sensor by the people, for example children playing football, jumping, strikes, etc.

Syczyn 4 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	During hydraulic fracturing	After hydraulic fracturing
Date and time	09.05.2013, 09.51	04.07.2013, 06.38	08.08.2013, 10.59
Resultant XYZ	5.06E-4	1.28E-3	8.34E-4

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 19 and 20. Seismic background shown in Fig. 15 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Syczyn 4 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 17 are an example of registered vibrations the amplitude of which exceeds the background level.

The variability of the maximum amplitudes over time is presented in Annex 7. Records of the event relating to maximum amplitudes from 4.07.2013 at 6.38 are presented in Fig. 17 and 18.

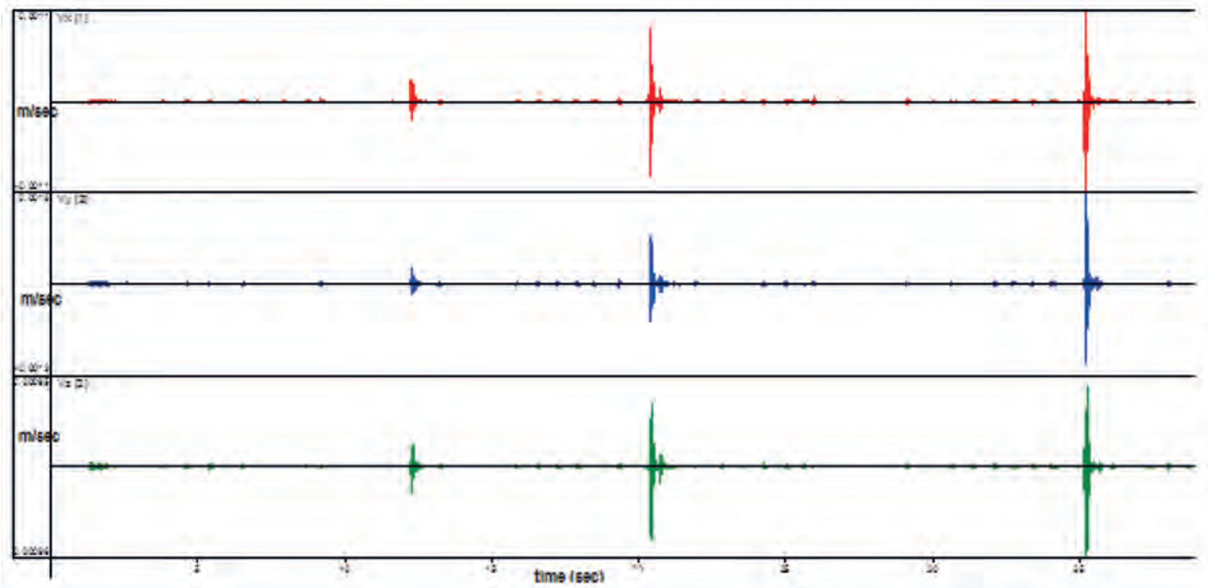


Fig. 17 Example of vibrations recorded at Syczyn 4 station on 04.07.2013, at 6.38 with a maximum amplitude.

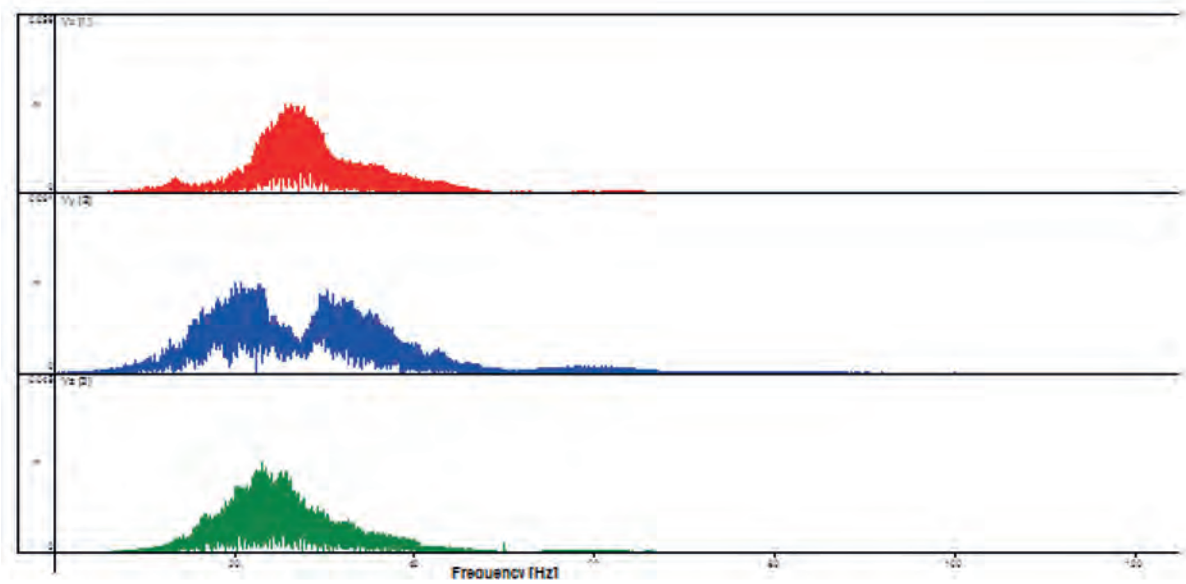


Fig. 18 Fourier analysis (amplitude spectrum) of the background from Fig. 17

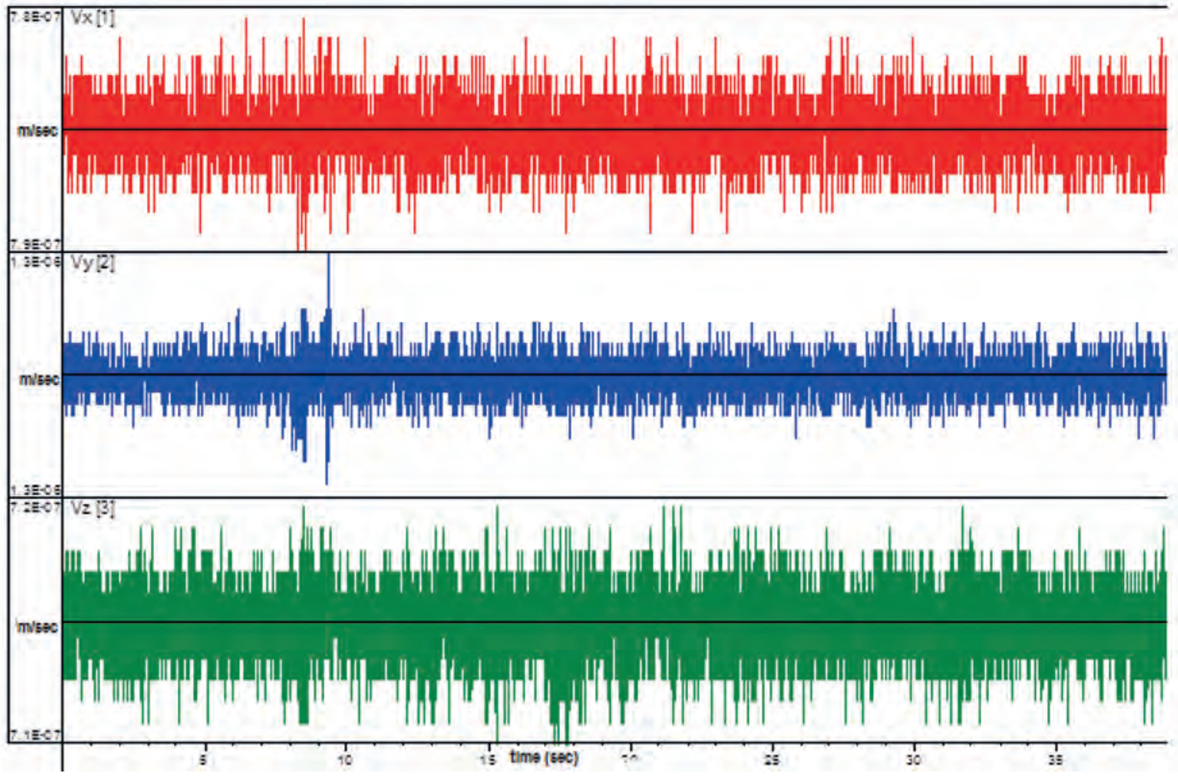


Fig. 19 Example of seismic background recorded at Syczyn 4 station

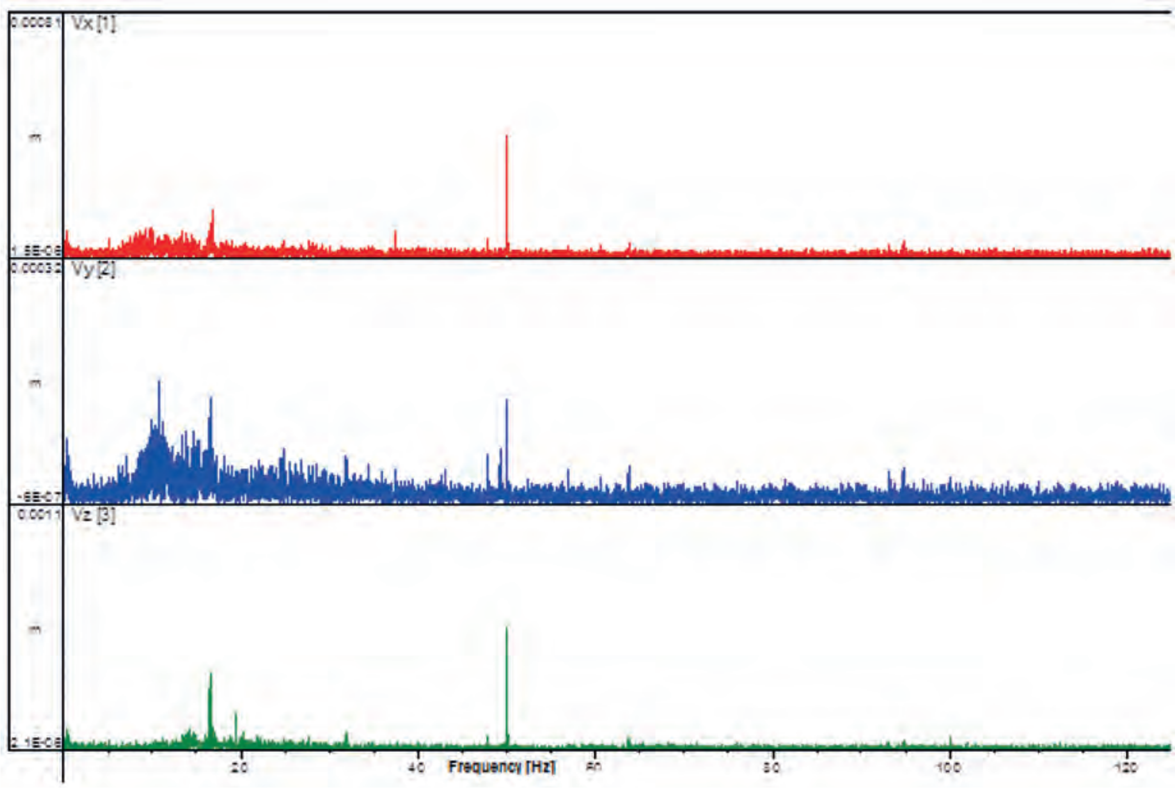


Fig. 20 Fourier analysis (amplitude spectrum) of vibrations from Fig. 19

The sensor at the Syczyn 3 station registered number of events with an amplitude exceeding 1 mm/s. These vibrations were similar in type – short pulses, similar to those shown in Fig. 16. They originated from vibrations induced near the sensor by the people, for example children playing football, jumping, strikes, etc.

In the course of measurements on the ground surface in the vicinity of the Syczyn-OU2K wells no vibrations coming from seismic events associated with the process of cracking the rock caused hydraulic fracturing were registered.

4.2. Test site in the area of the Zwierzyniec-1 well

Seismic background around Zwierzyniec-1 wells was continuously measured at four measurement stations in the period from 12.06.2013 to 6.09.2013 Measurements in the period from 12.06.2013 to 5.07. 2013 were performed before hydraulic fracturing, from 6.07.2013 to 11.07.2013 during hydraulic fracturing, and from 11.07.2013 to 6.09.2013 – after hydraulic fracturing. Registered background underwent changes during the course of the measurement, which is included in the figures presenting distribution of maximum amplitudes listed in Annexes 8, 9, 10 and 11.

The results of measurements of seismic background taken at the respective stations are described in Annexes 8–11. Their analysis and description are as follows:

Zawada 1 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	20.06.2013, 10.44	09.07.2013, 17.29	15.07.2013, 11.22
Resultant XYZ	6.10E-04	7.91E-05	4.51E-04

The variability of the maximum amplitudes over time is presented in Annex 8. Exemplary recording of vibrations, and their Fourier spectrum are presented in Fig. 21–24. Exemplary recording of the background, and its Fourier spectrum are presented in Fig. 25 and 26. Seismic background shown in Fig. 25 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Zawada 1 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 21 and 23 are examples of registered vibrations the amplitude of which exceeds the background level. Recording from Fig. 23 is the result of a strike in the sensor or its vicinity.

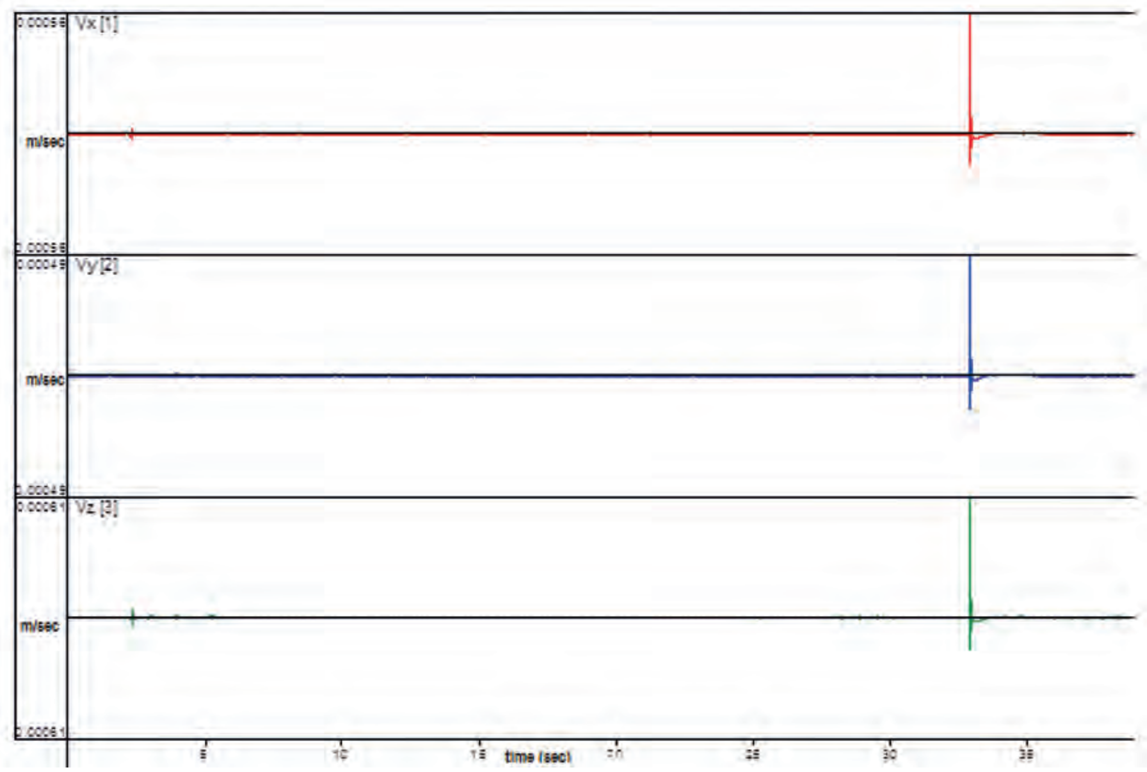


Fig. 21 Recording from 20.06.2013 at 10.44 with maximum amplitude at Zawada 1 station

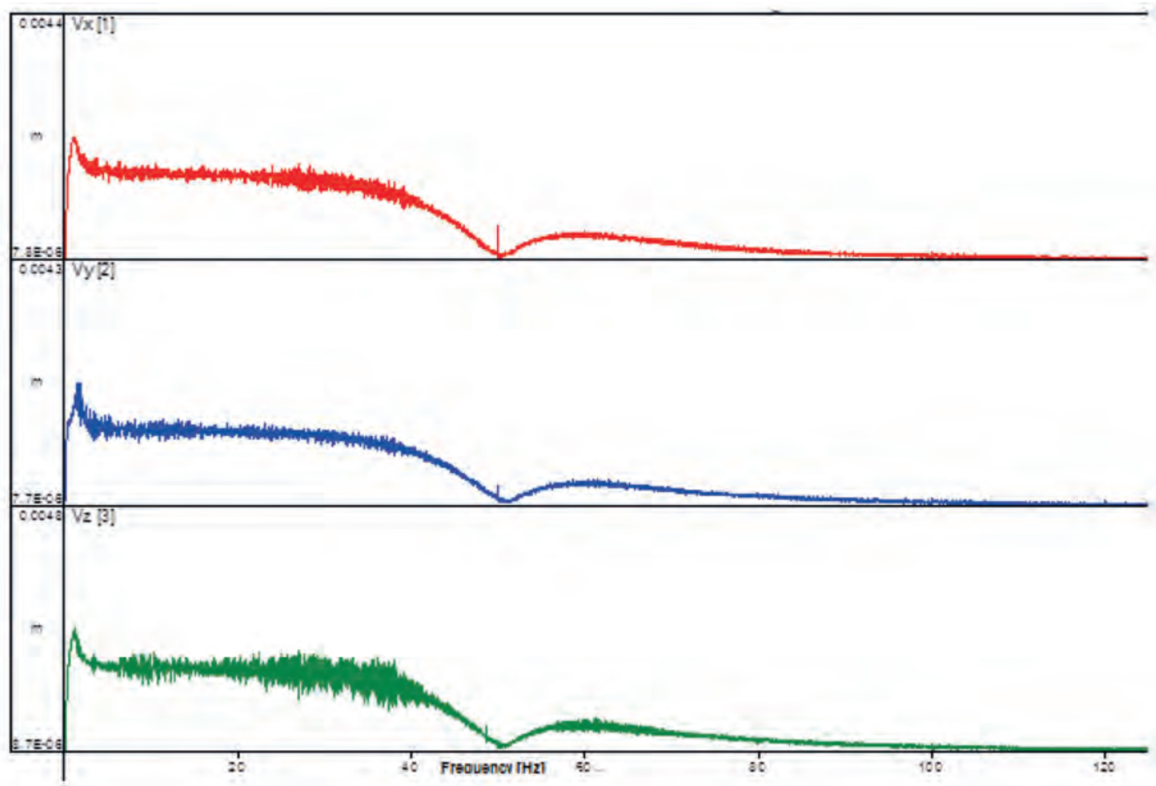


Fig. 22 Fourier analysis (amplitude spectrum) of recording from Fig. 21

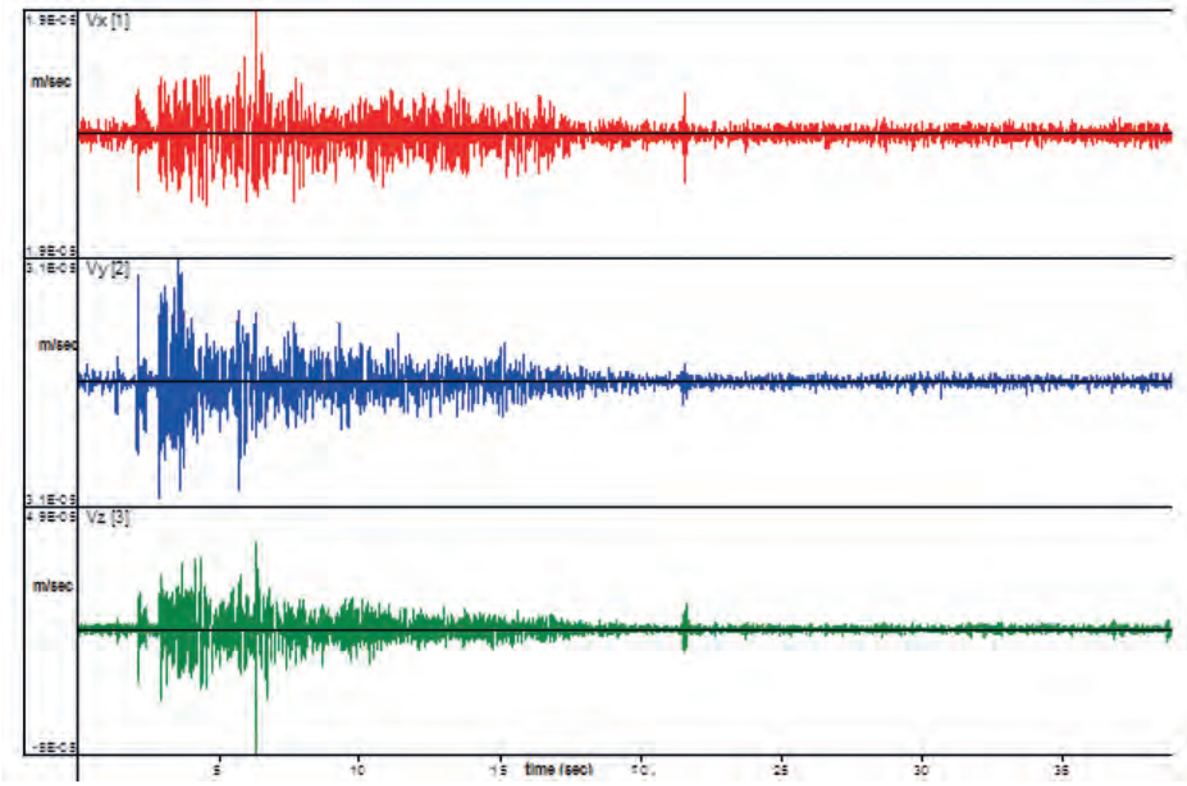


Fig. 23 Exemplary recording of vibrations registered at Zawada 1 station

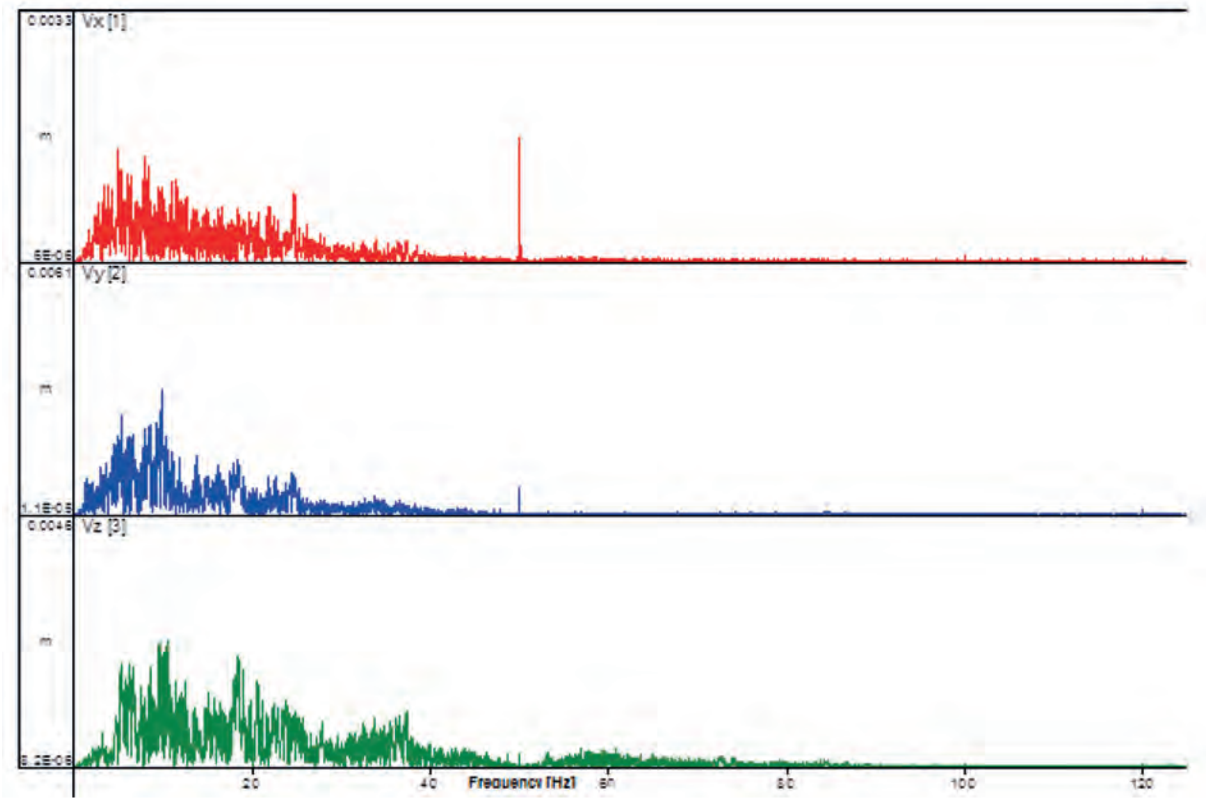


Fig. 24 Fourier analysis (amplitude spectrum) of recording from Fig. 23

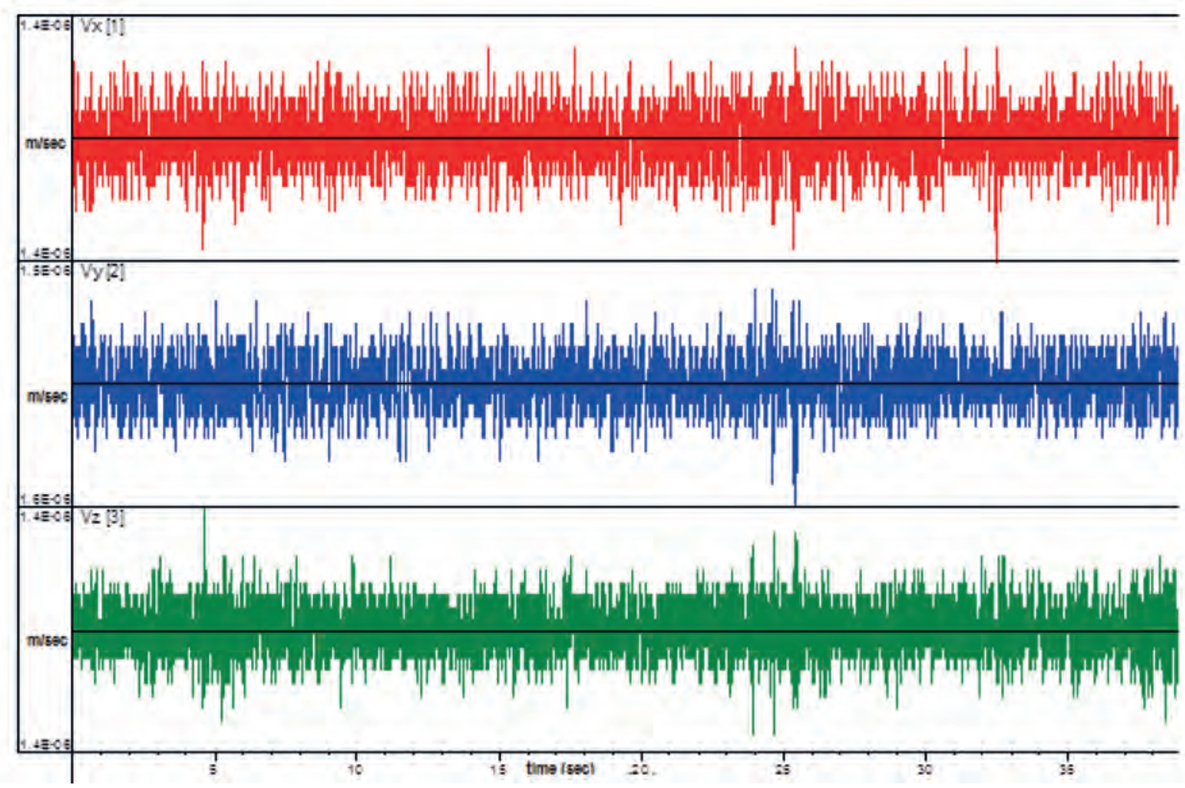


Fig. 25 Exemplary recording of seismic background registered at Zawada 1 station

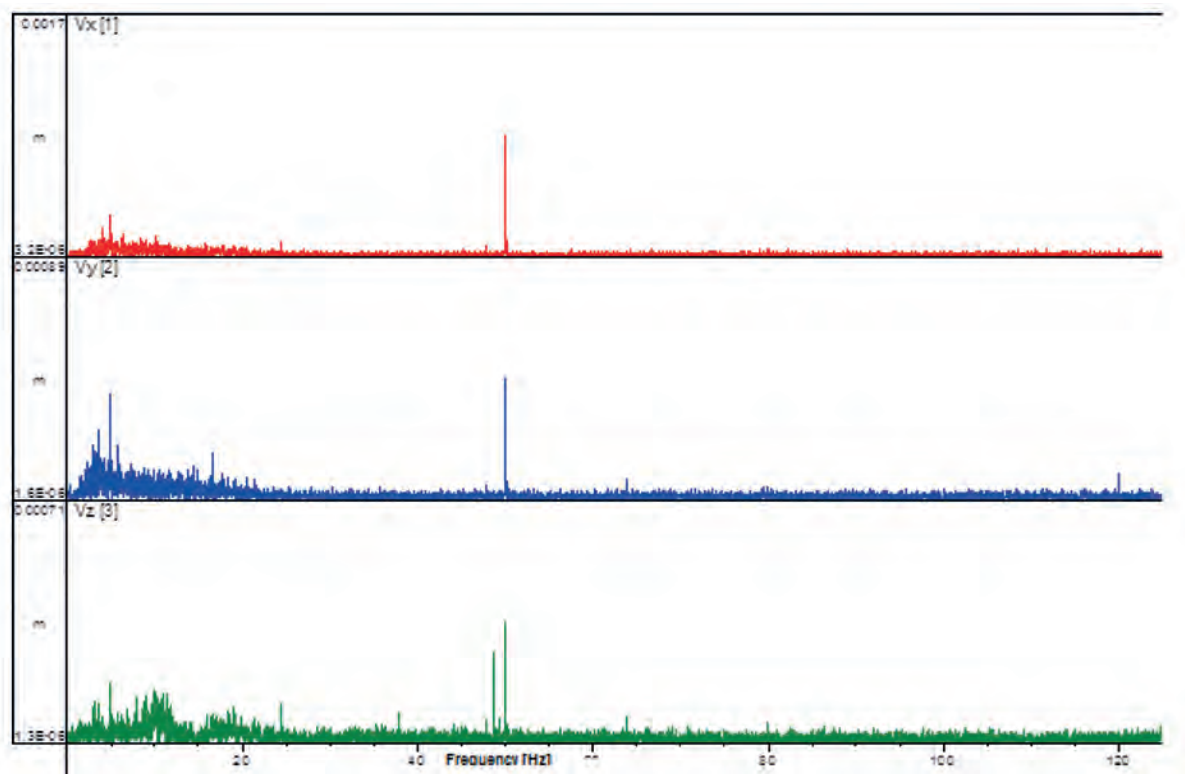


Fig. 26 Fourier analysis (amplitude spectrum) of recording from Fig. 25

Zawada 2 station

Zawada 2 station located in the Siedliska-Kolonia has experienced a series of breakdowns, and it hasn't worked for 21 days in total. Recording computer failed there three times. One of the breakdowns occurred in the period from 07.06.2013 to 12.07.2013, i.e. while performing hydraulic fracturing. Failures were probably due to significant fluctuations in the mains voltage.

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	During hydraulic fracturing	After hydraulic fracturing
Date and time	22.06.2013 r., 23.39	–	27.08.2013 r., 04.39
Resultant XYZ	5.06E-04	–	9.67E-05

The variability of the maximum amplitudes over time is presented in Annex 9. Exemplary recording of vibrations, and their Fourier spectrum are presented in Fig. 27-30. Exemplary recording of the background, and its Fourier spectrum are presented in Fig. 31 and 33. Seismic background shown in Fig. 31 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Zawada 1 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 27 and 29 are examples of registered vibrations the amplitude of which exceeds the background level.

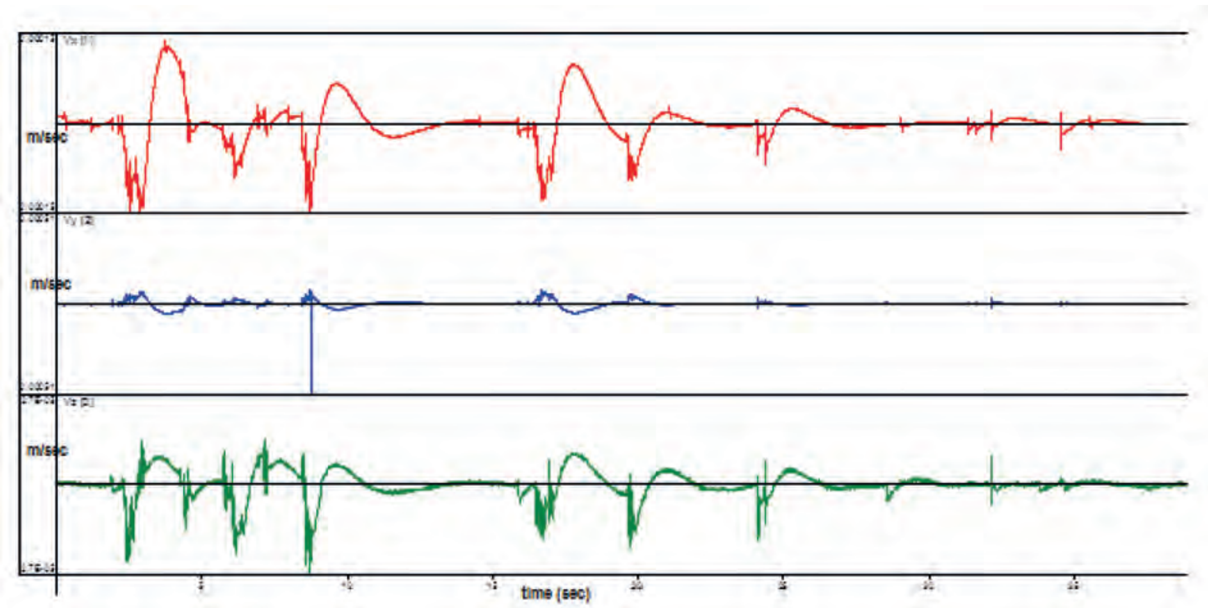


Fig. 27 Exemplary recording of vibrations with maximum amplitude registered at Zawada 2 station at 23.39

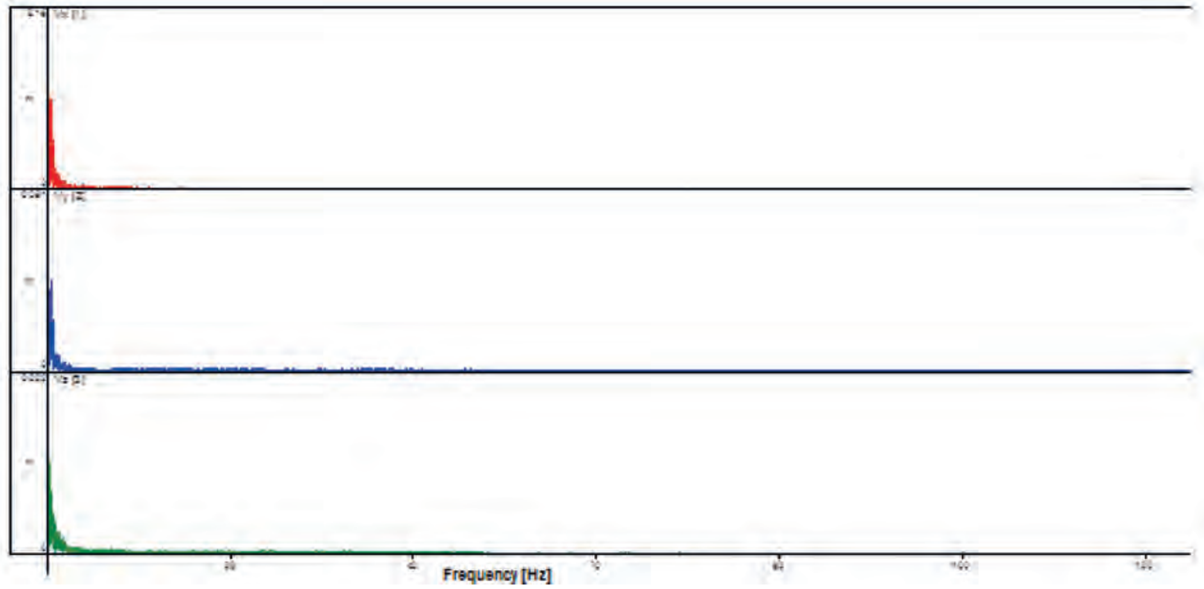


Fig. 28 Fourier analysis (amplitude spectrum) of recording from Fig. 27

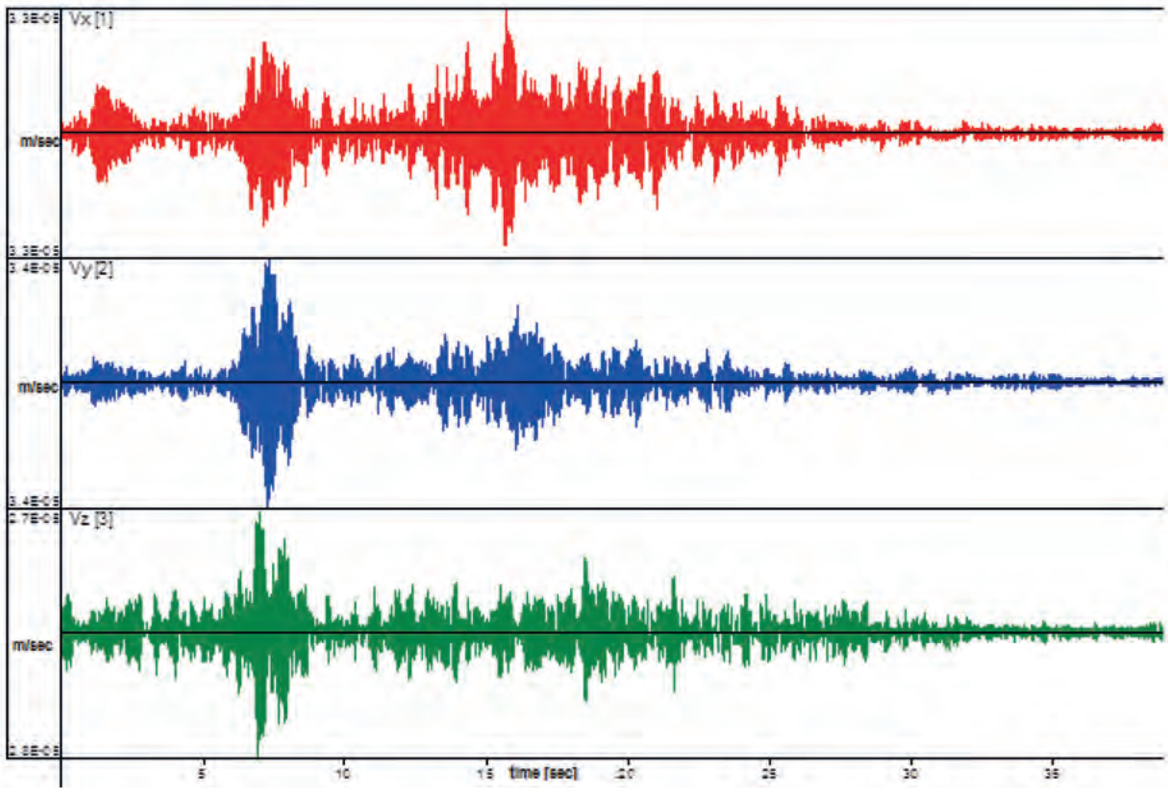


Fig. 29 Exemplary recording of vibrations registered at Zawada 2 station

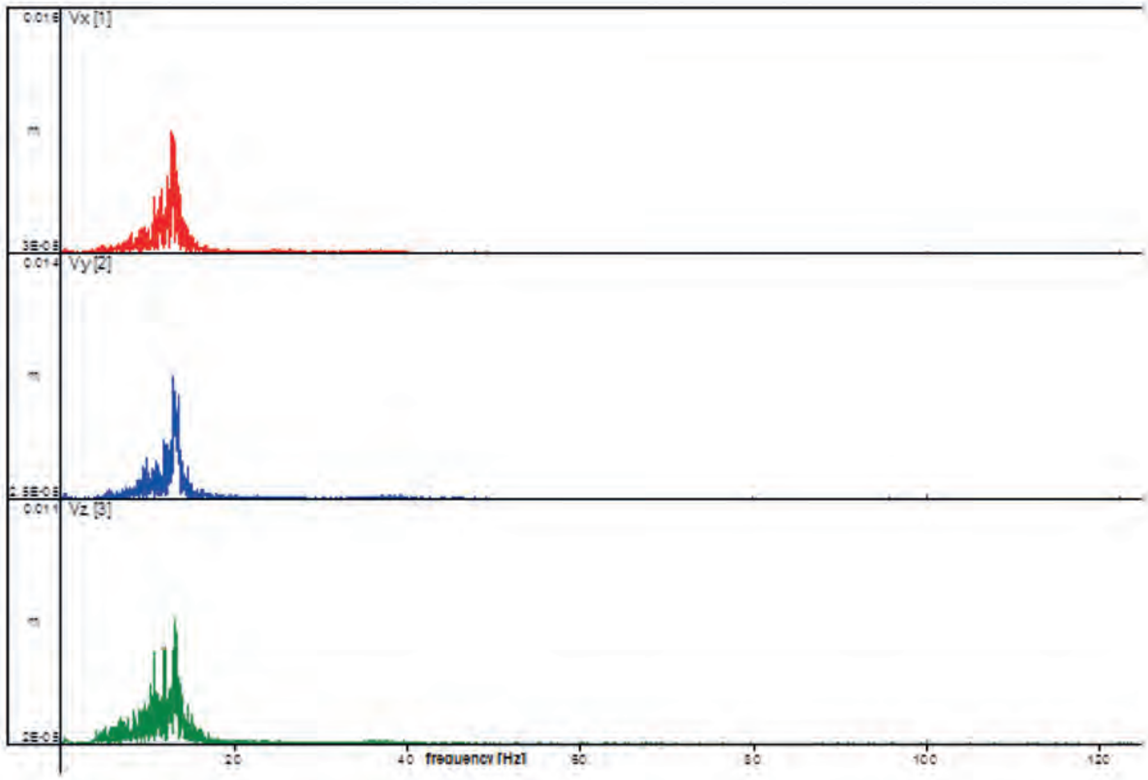


Fig. 30 Fourier analysis (amplitude spectrum) of recording from Fig. 29

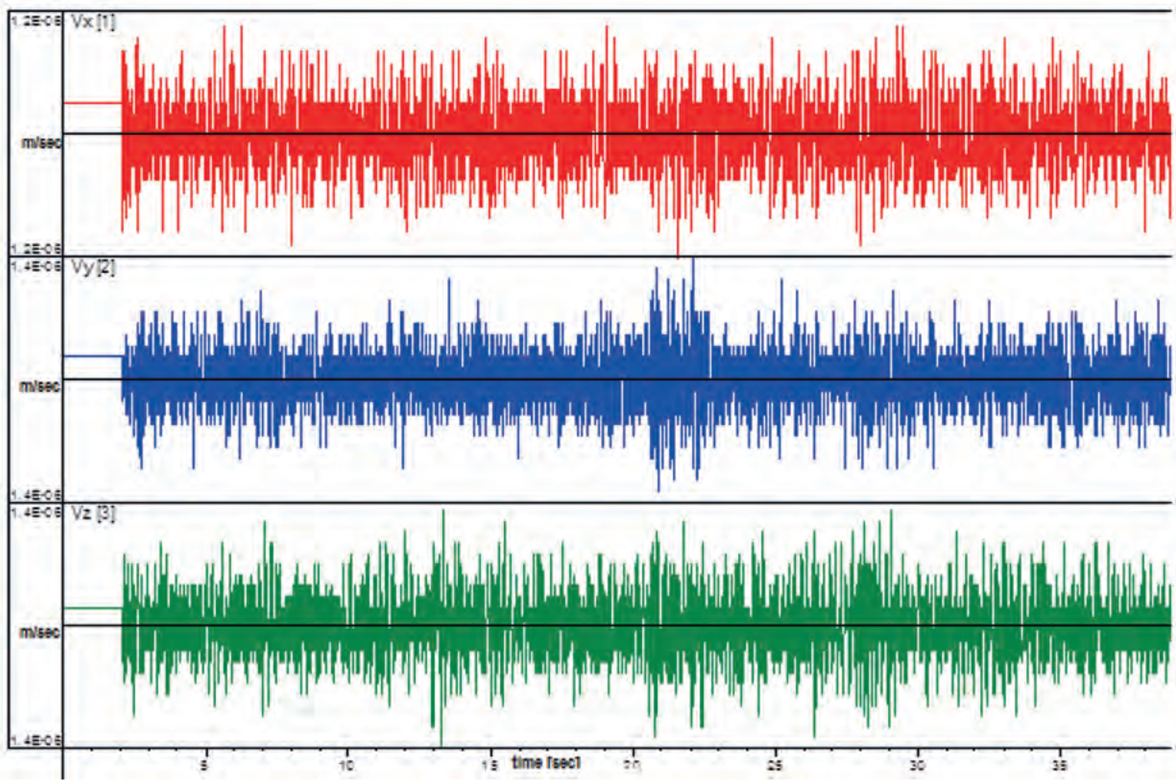


Fig. 31 Exemplary recording of seismic background registered at Zawada 2 station

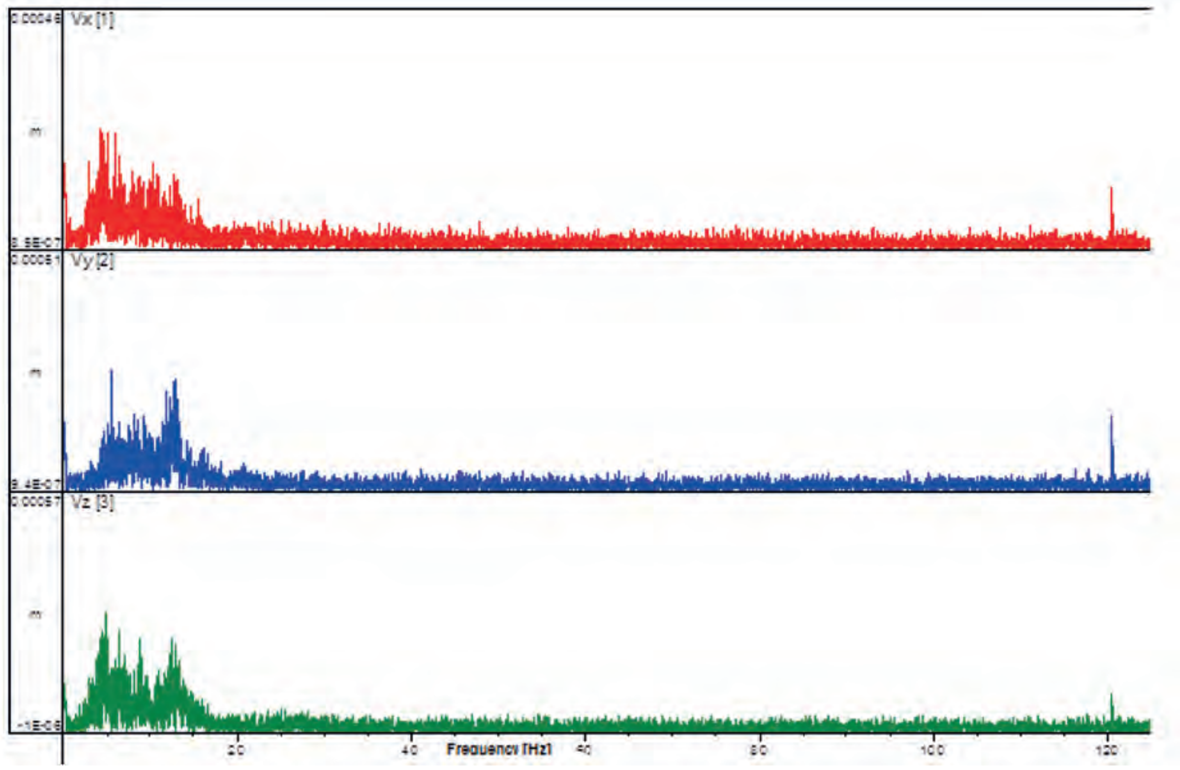


Fig. 32 Fourier analysis (amplitude spectrum) of recording from Fig. 31

Zawada 3 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	During hydraulic fracturing	After hydraulic fracturing
Date and time	13.06.2013, 17.55	06.07.2013, 21.39	04.09.2013, 18.33
Resultant XYZ	5.55E-04	2.28E-04	8.38E-04

The variability of the maximum amplitudes over time is presented in Annex 10. Exemplary recording of vibrations, and their Fourier spectrum are presented in Fig. 33–36. Exemplary recording of the background, and its Fourier spectrum are presented in Fig. 37 and 38 Seismic background shown in Fig. 37 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Zawada 3 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 33 and 35 are examples of registered vibrations the amplitude of which exceeds the background level. Recording from Fig. 23 is the result of a strike in the sensor or its vicinity.

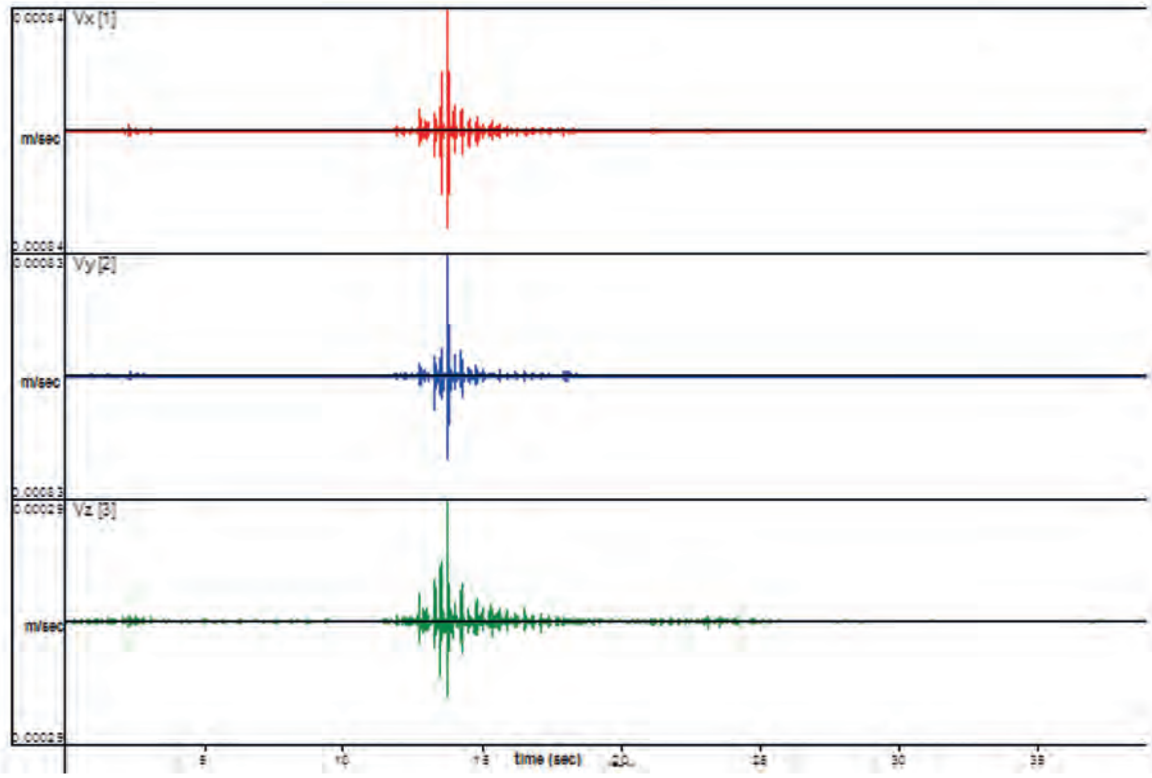


Fig. 33 Exemplary recording of vibrations with maximum amplitude registered at Zawada 3 station on 04.09.2013 at 23.39

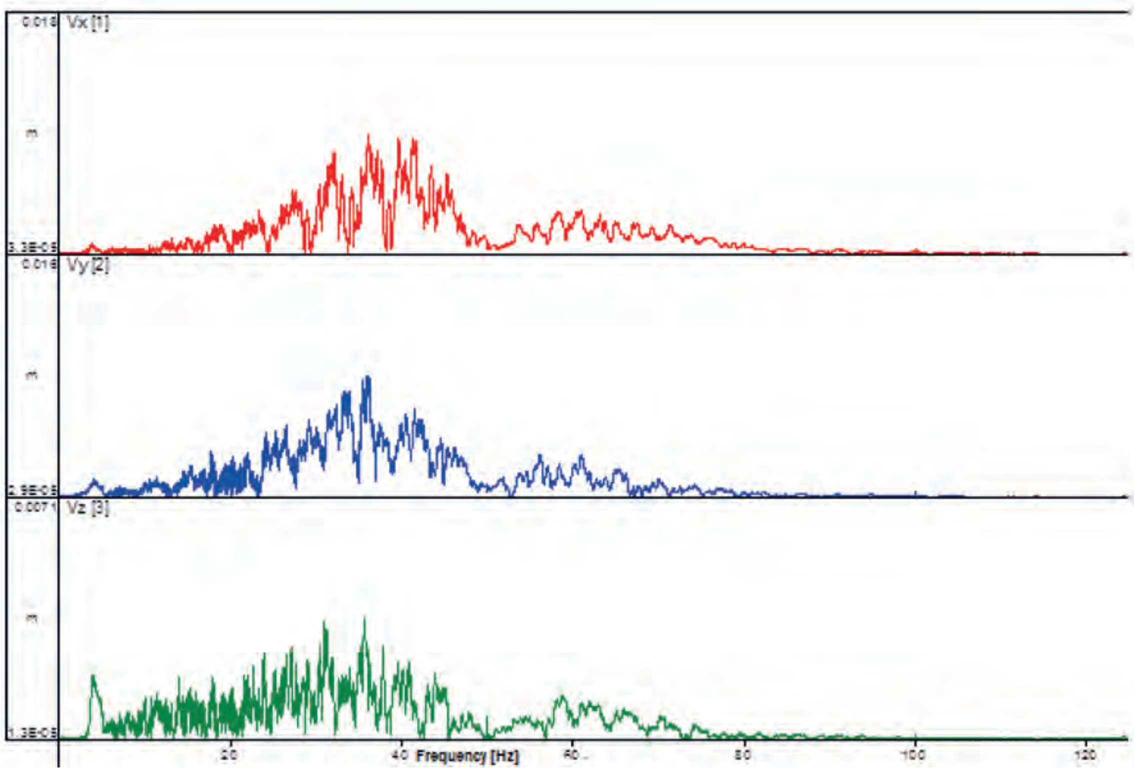


Fig. 34 Fourier analysis (amplitude spectrum) of recording from Fig. 33

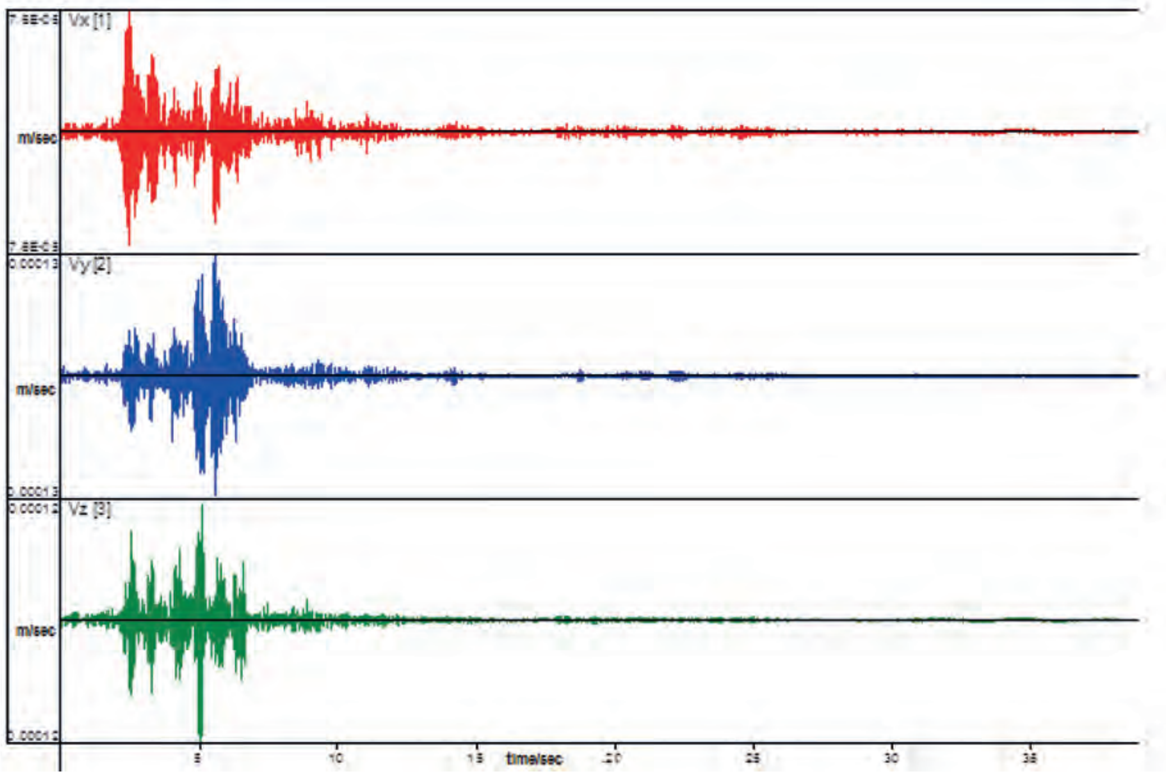


Fig. 35 Exemplary recording of vibrations registered at Zawada 3 station

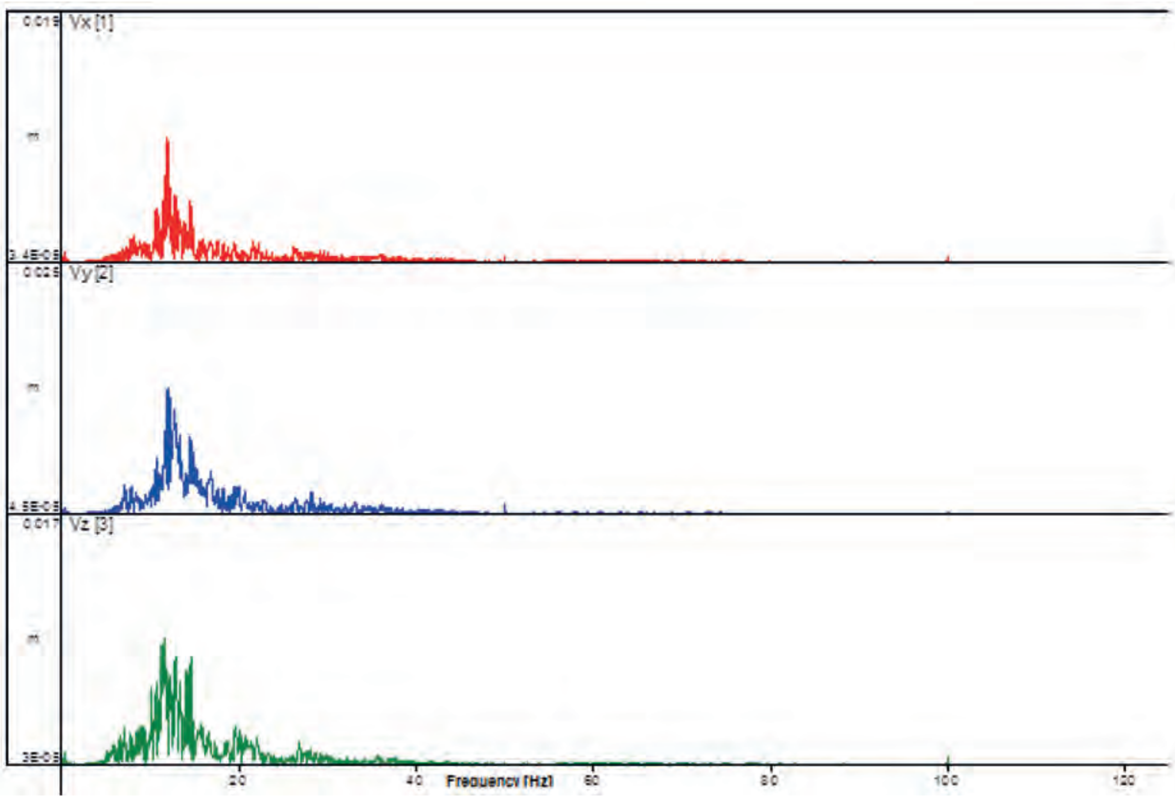


Fig. 36 Fourier analysis (amplitude spectrum) of recording from Fig. 35

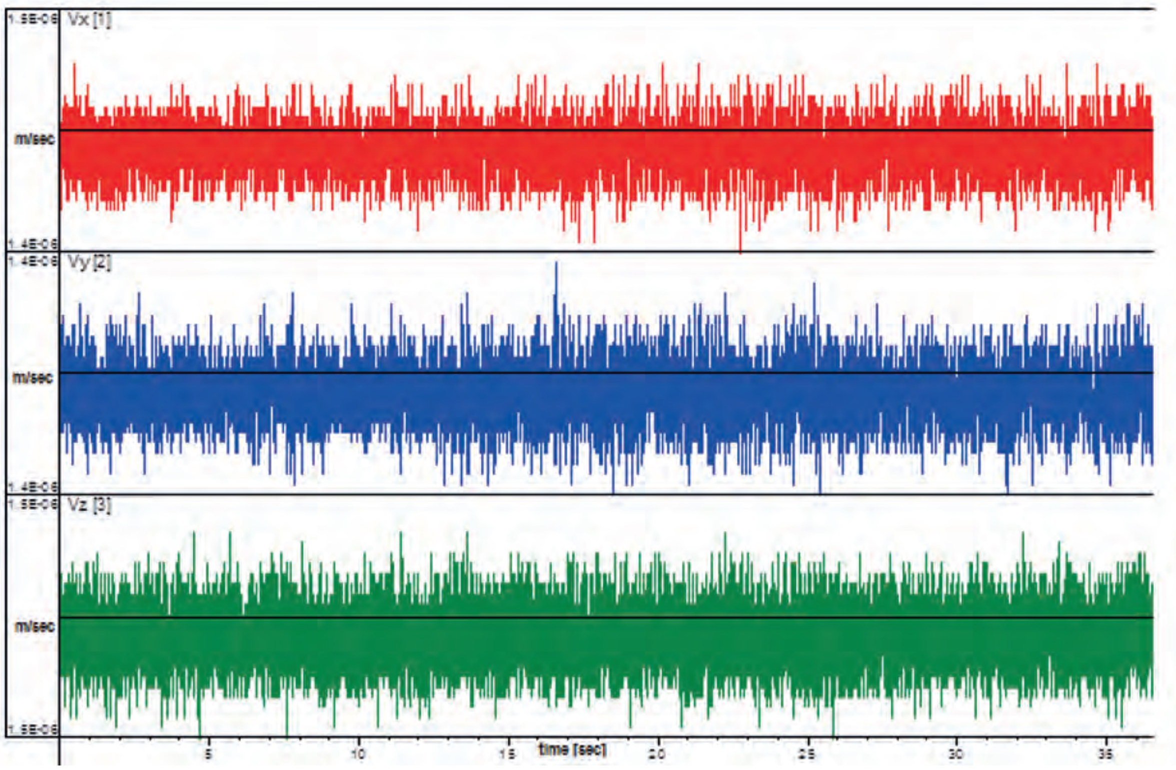


Fig. 3 Exemplary recording of seismic background registered at Zawada 3 station

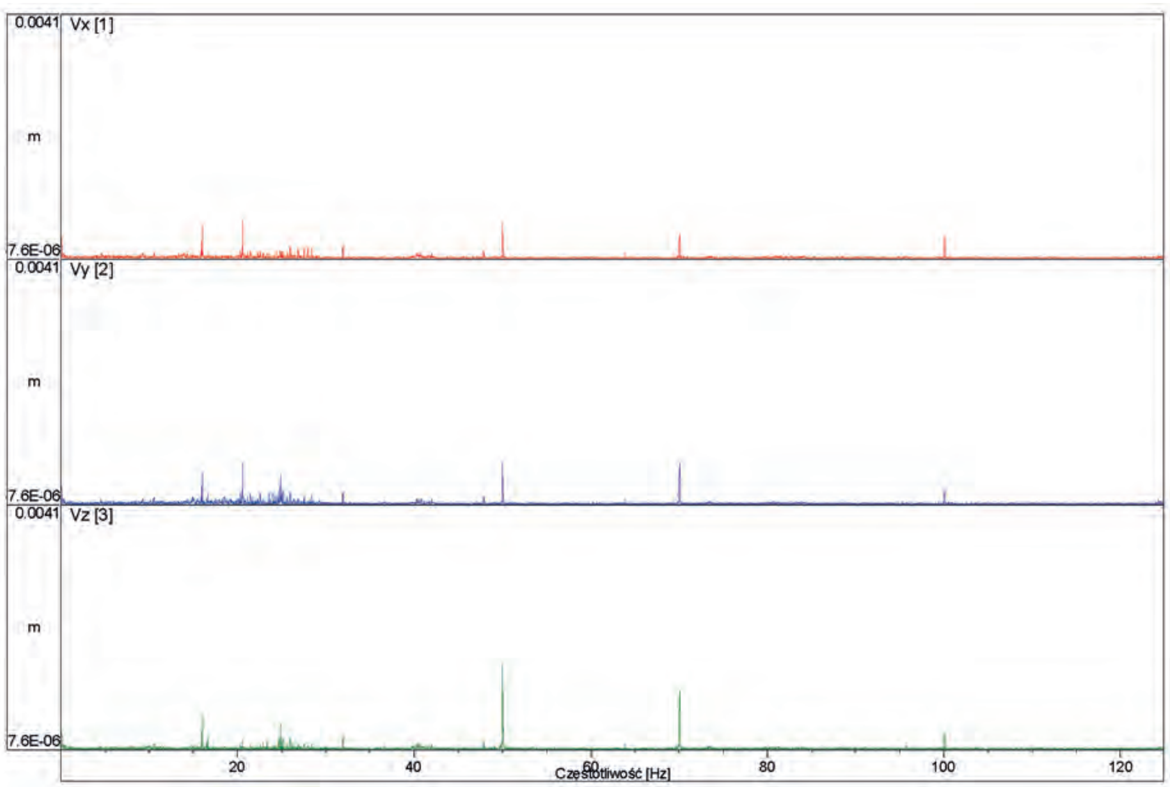


Fig. 38 Fourier analysis (amplitude spectrum) of recording from Fig. 37

Zawada 4 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	During hydraulic fracturing	After hydraulic fracturing
Date and time	29.06.2013, 21.16	06.07.2013, 00.31	06.08.2013, 22.9
Resultant XYZ	1.37E-03	5.64E-04	1.30E-03

The variability of the maximum amplitudes over time is presented in Annex 11. Exemplary recording of vibrations, and their Fourier spectrum are presented in Fig. 39–42. Exemplary recording of the background, and its Fourier spectrum are presented in fig. 43 and 44. Seismic background shown in Fig. 43 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Zawada 4 station it was possible to register the vibrations with amplitude greater than 3.0E-6 m/s. Seismograms shown in Fig. 39 and 41 are examples of registered vibrations the amplitude of which exceeds the background level. Recording of maximum amplitude presented in Fig. 36 is the result of a strike in the vicinity of sensor (or in the sensor).

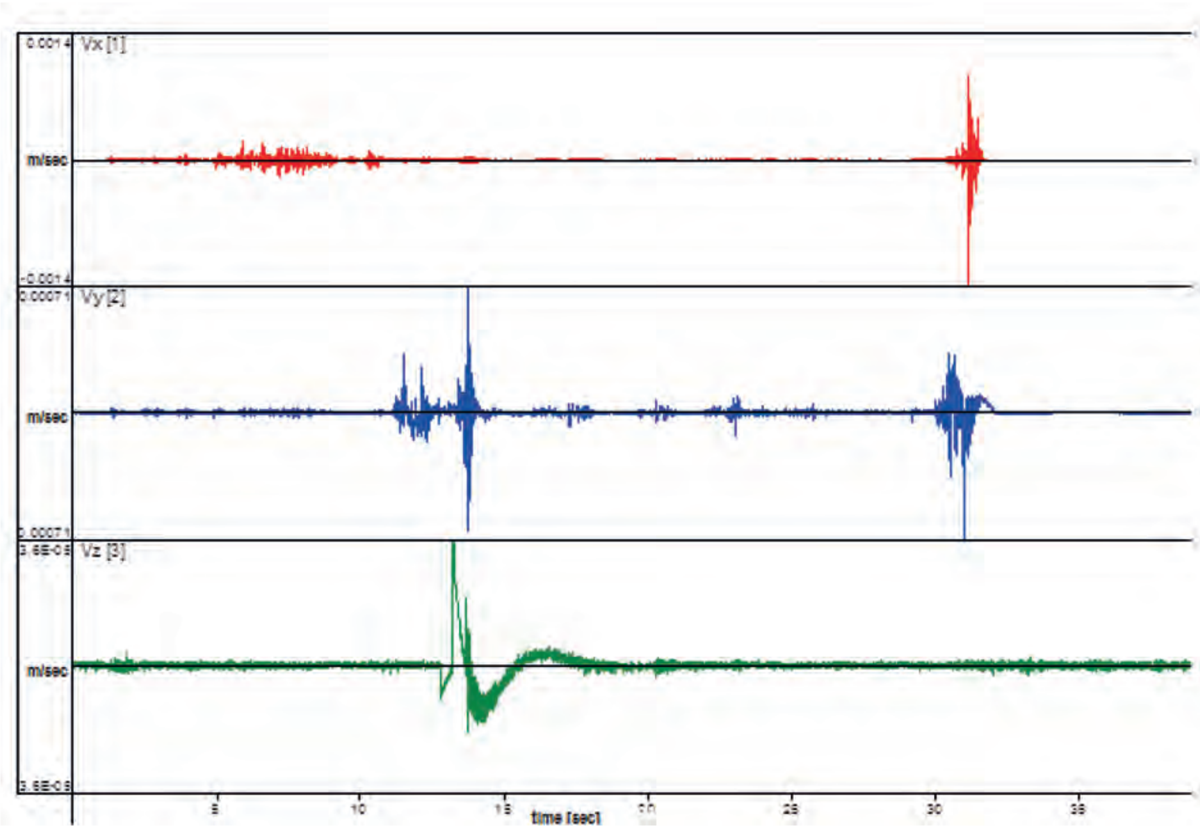


Fig. 39 Recording of maximum vibrations registered at Zawada 4 station on 29.06.2013 at 21.16

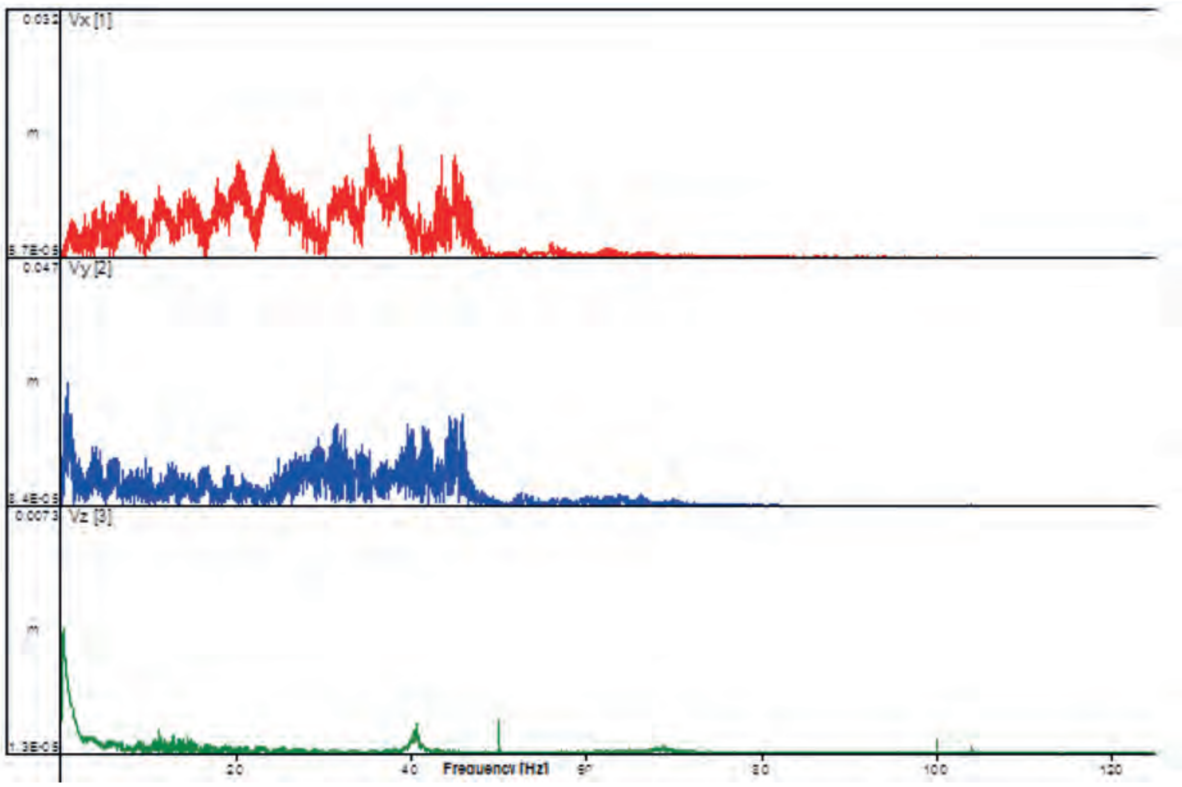


Fig. 40 Fourier analysis (amplitude spectrum) of recording from Fig. 39

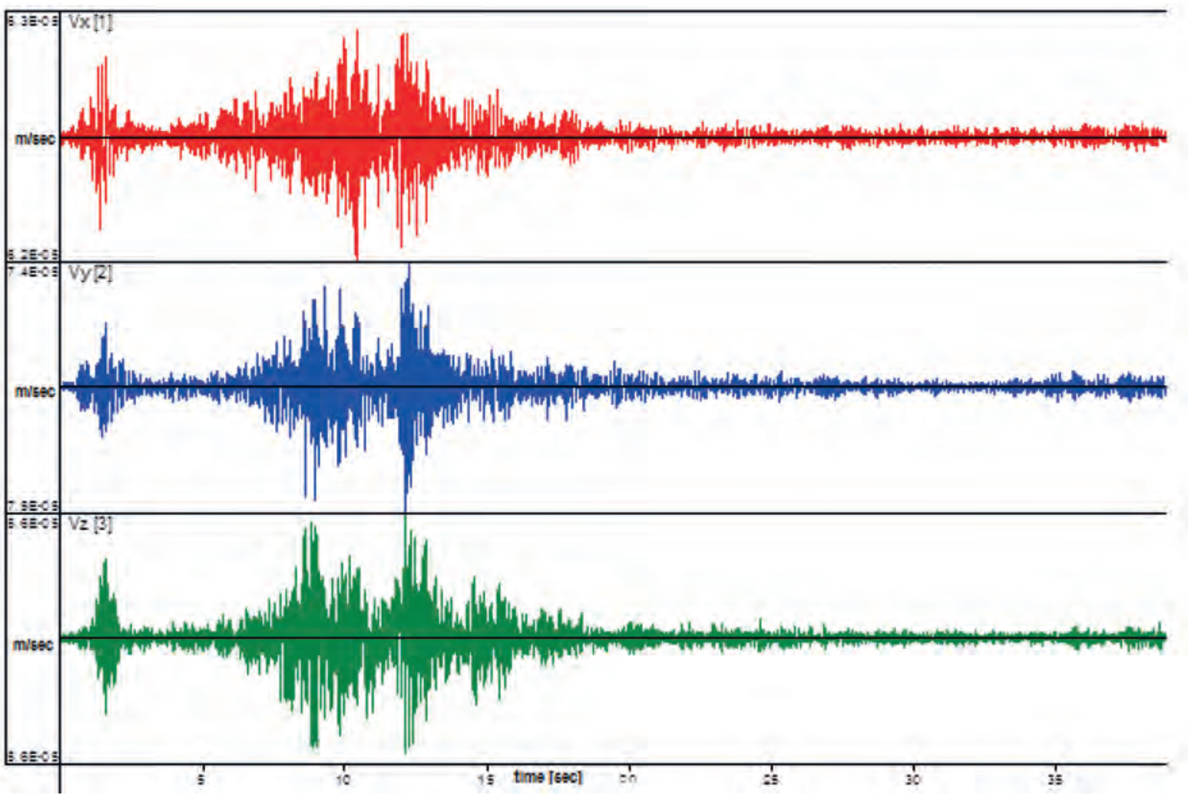


Fig. 41 Exemplary recording of vibrations registered at Zawada 4 station

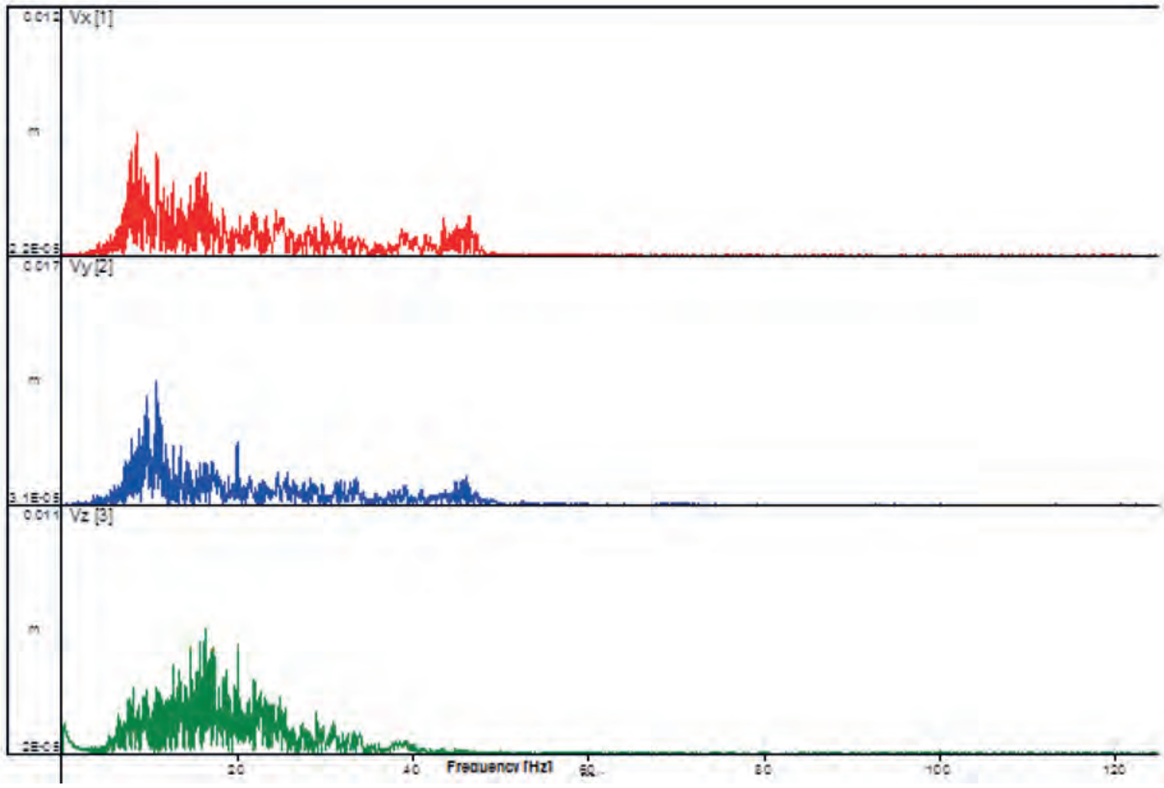


Fig. 42 Fourier analysis (amplitude spectrum) of recording from Fig. 41

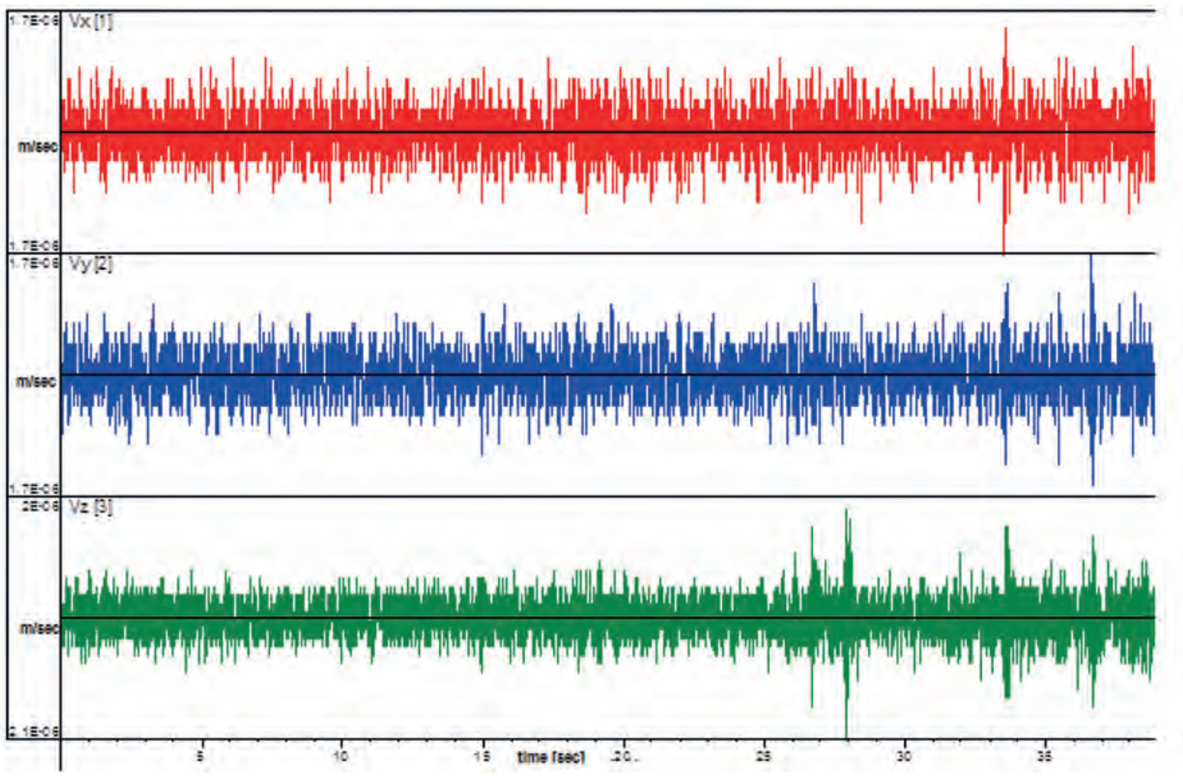


Fig. 43 Exemplary recording of seismic background registered at Zawada 4 station

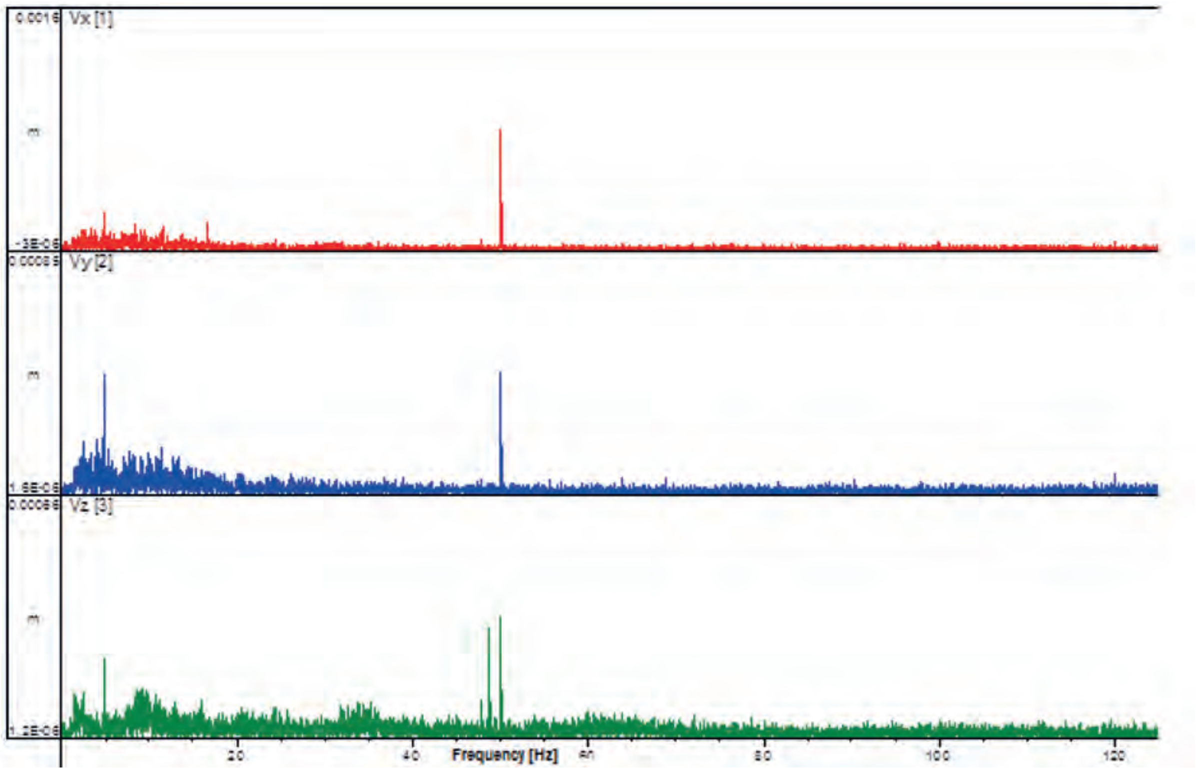


Fig. 44 Fourier analysis (amplitude spectrum) of recording from Fig. 43

The maximum amplitudes of vibrations recorded around the Zwierzyniec-1 well were the result of events taking place around the sensors, probably strikes in the ground in the vicinity of the sensor (or in the sensor itself). Also recorded were machinery movements in farms and road traffic.

In the course of measurements on the ground surface in the vicinity of the Zwierzyniec-1 wells no vibrations coming from seismic events associated with the process of cracking the rock caused hydraulic fracturing were registered.

4.3. Test site in the area of the Gapowo-1 well

Seismic background around Gapowo-1 wells was continuously measured at four measurement stations in the period from 18/19.03.2014 to 4.08.2014 Measurements in the period …to 9.05.2014 were performed before hydraulic fracturing, from 9.05.2014 to 22.05.2014 during hydraulic fracturing, and from 22.05.2014 r. do 4.08.2014 – after hydraulic fracturing. Registered background underwent changes during the course of the measurement, which is included in the figures presenting distribution of maximum amplitudes listed in Annexes 12–15

The results of measurements of seismic background taken at the respective stations are described in Annexes 12–15. Their analysis and description are as follows:

Recorder 1 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	27.04.2014, 14.51	09.05.2014, 9.38	13.06.2014, 15.16
Resultant XYZ	3.28E-04	4.69E-04	6.79E-04

The variability of the maximum amplitudes over time is presented in Annex 12. Exemplary recording of vibrations, and their Fourier spectrum are presented in fig. 45 and 48. Exemplary recording of the background, and its Fourier spectrum are presented in Fig. 49 and 50. Seismic background shown in Fig. 49 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Recorder 1 station it was possible to register the vibrations with amplitude greater than 2.0E-6 m/s. Seismograms shown in Fig. 45 are an examples of registered vibrations the amplitude of which exceeds the background level (the first maximum and the second selected randomly).

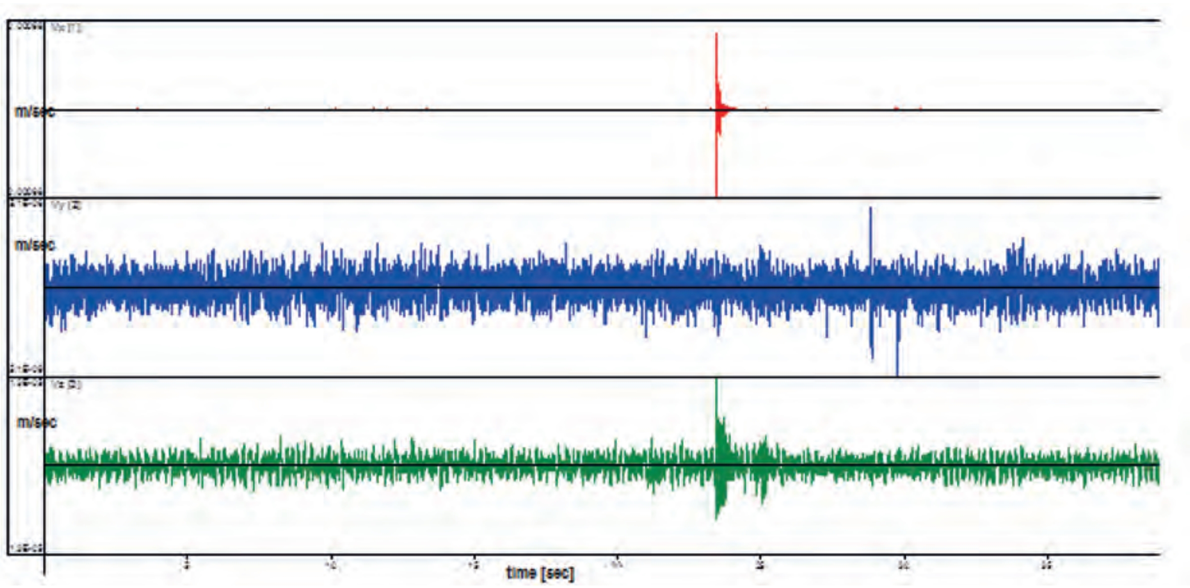


Fig. 45 Recording of maximum vibrations registered at Recorder 1 station on 13.06.2014 at 15.16

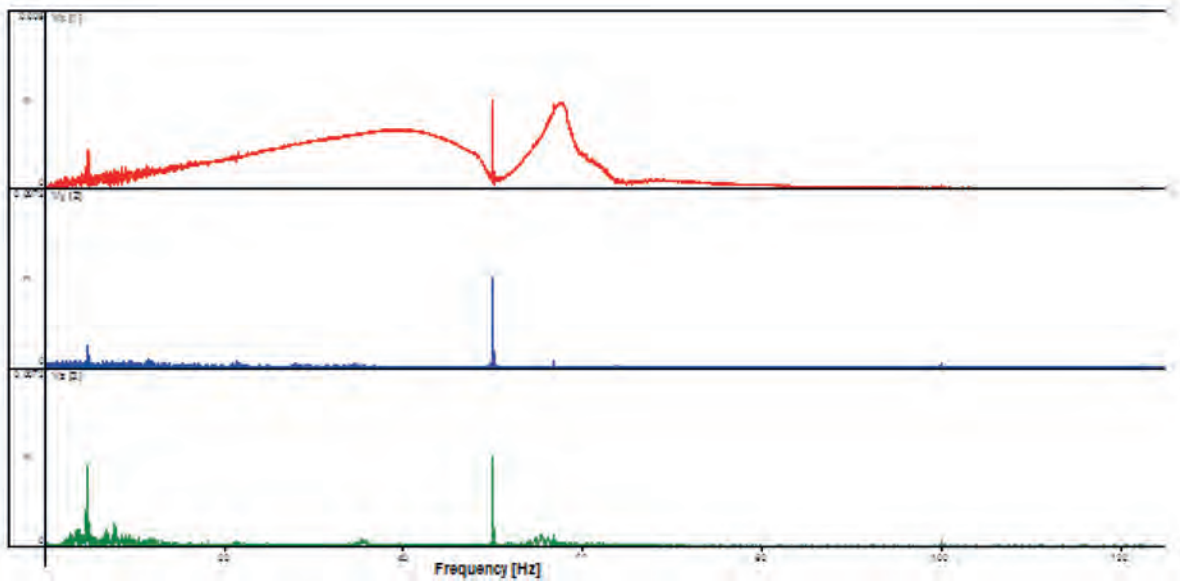


Fig. 46 Fourier analysis (amplitude spectrum) of recording from Fig. 45

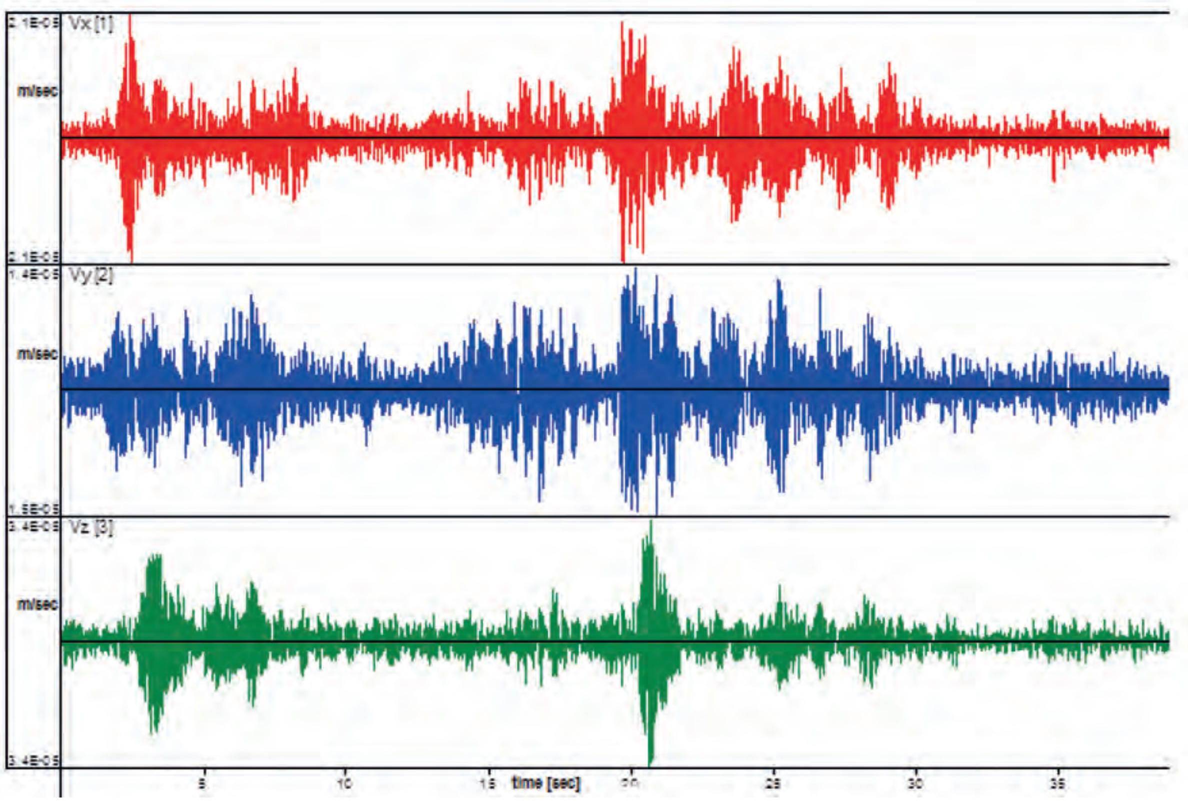


Fig. 47 Exemplary recording of vibrations registered on 01.04.2014 at 13.30 at Recorder 1 station.

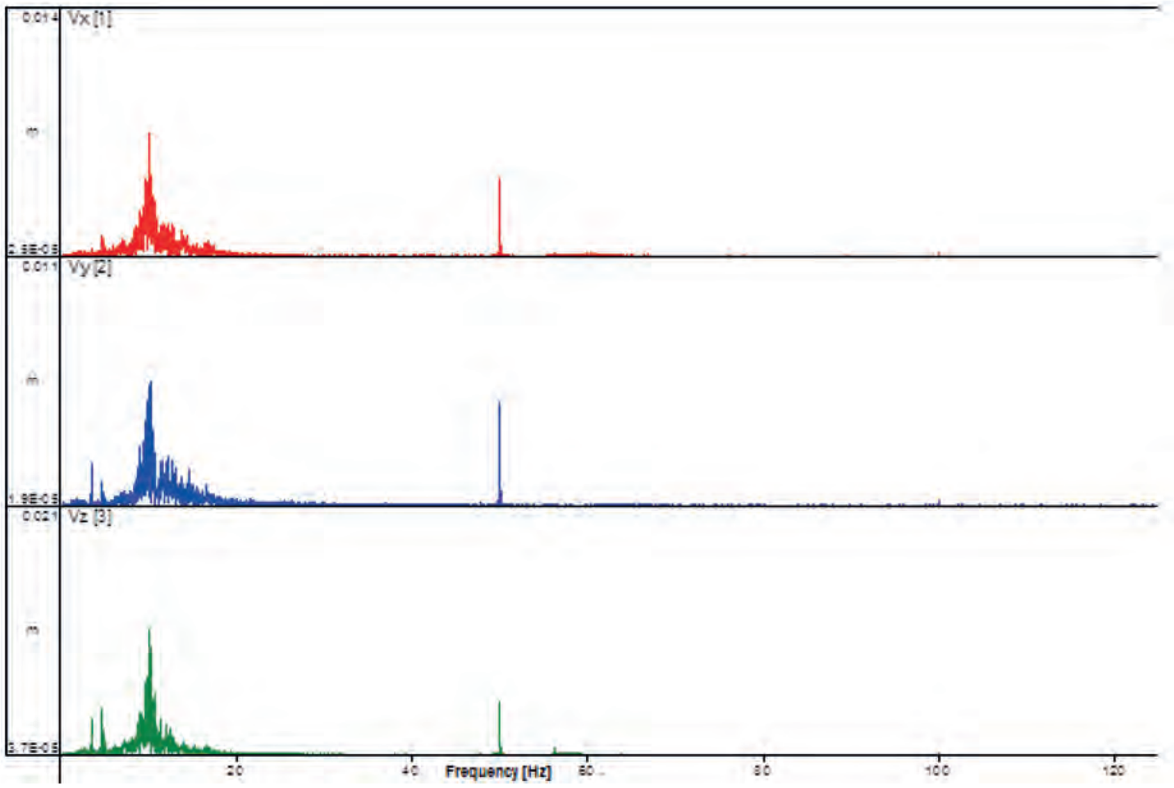


Fig. 48. Fourier analysis (amplitude spectrum) of recording from Fig. 47

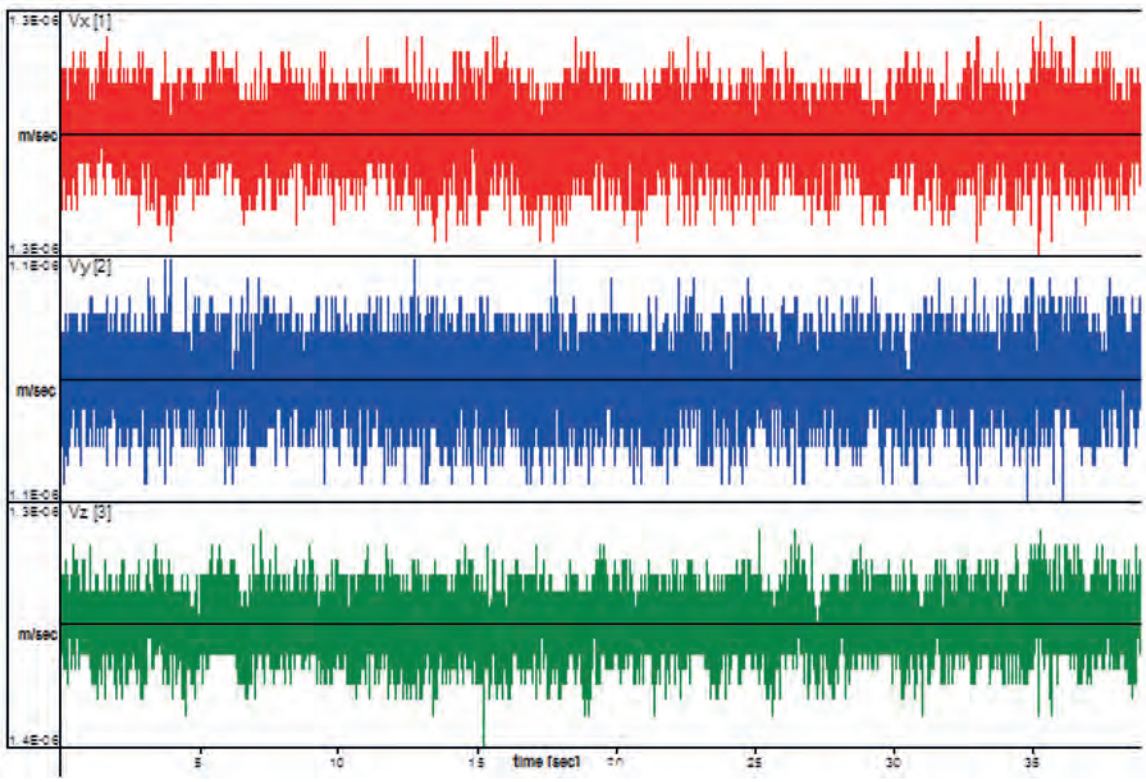


Fig. 49 Exemplary recording of seismic background registered at Recorder 1 station

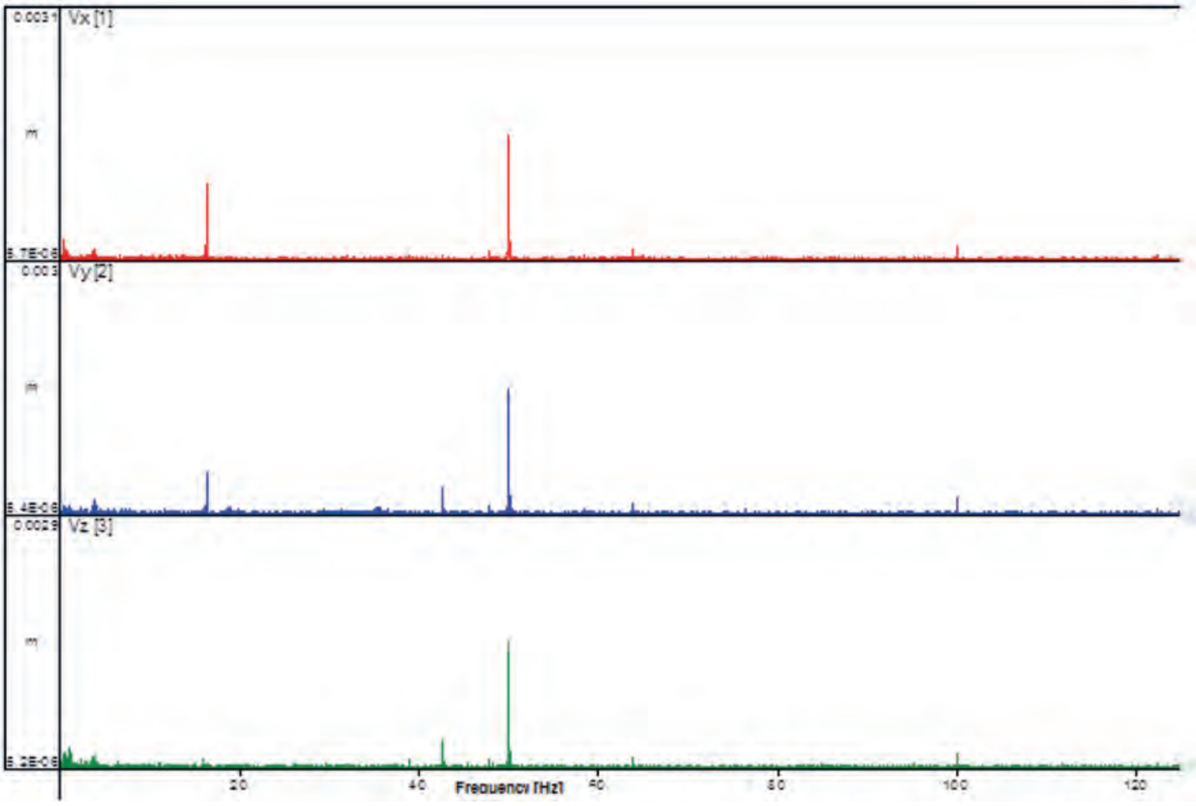


Fig. 50 Fourier analysis (amplitude spectrum) of recording from Fig. 49

Recorder 2 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	During hydraulic fracturing	After hydraulic fracturing
Date and time	03.04.2014, 17.56	13.05.2014, 17.39	23.06.2014, 16.21
Resultant XYZ	8.97E-04	7.75E-04	7.82E-04

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 55 and 56. Seismic backgrounds shown in Fig. 61 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Recorder 2 station it was possible to register the vibrations with amplitude greater than 4.0E-6 m/s. Seismograms shown in Fig. 51 and 53 are an example of registered vibrations the amplitude of which exceeds the background level (the first maximum and the second selected randomly).

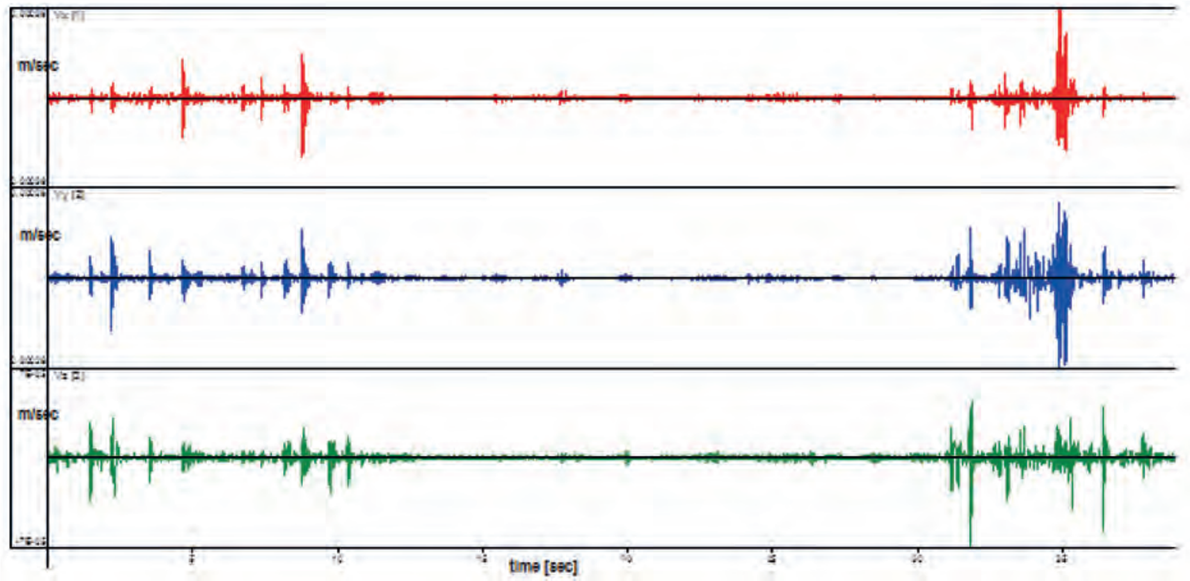


Fig. 51 Recording of maximum vibrations registered at Recorder 2 station on 03.04.2014 at 17.56

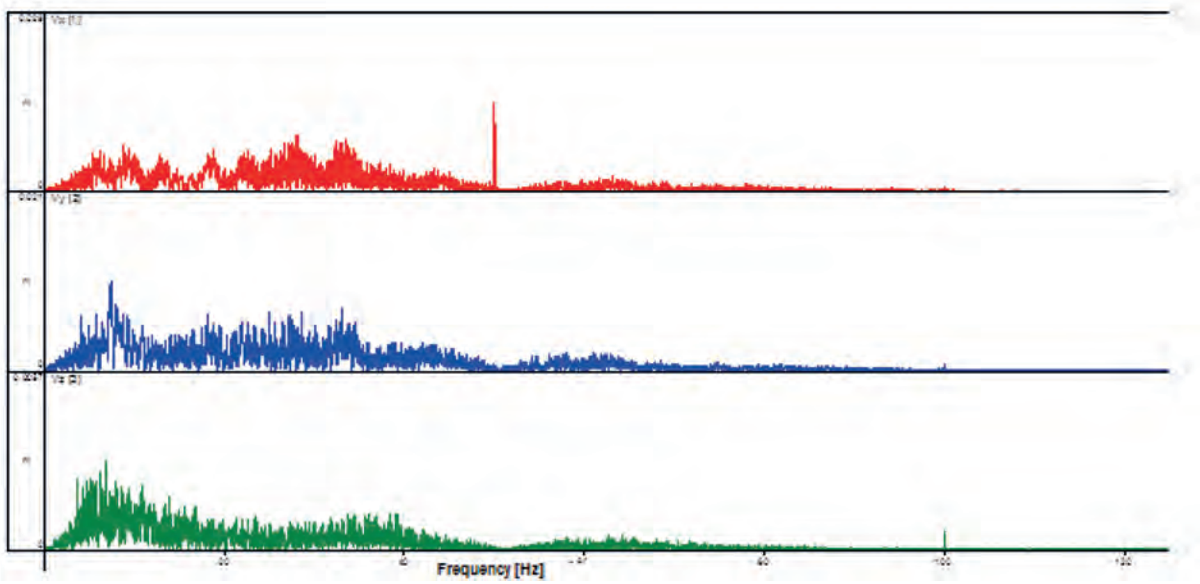


Fig. 52 Fourier analysis (amplitude spectrum) of recording from Fig. 51

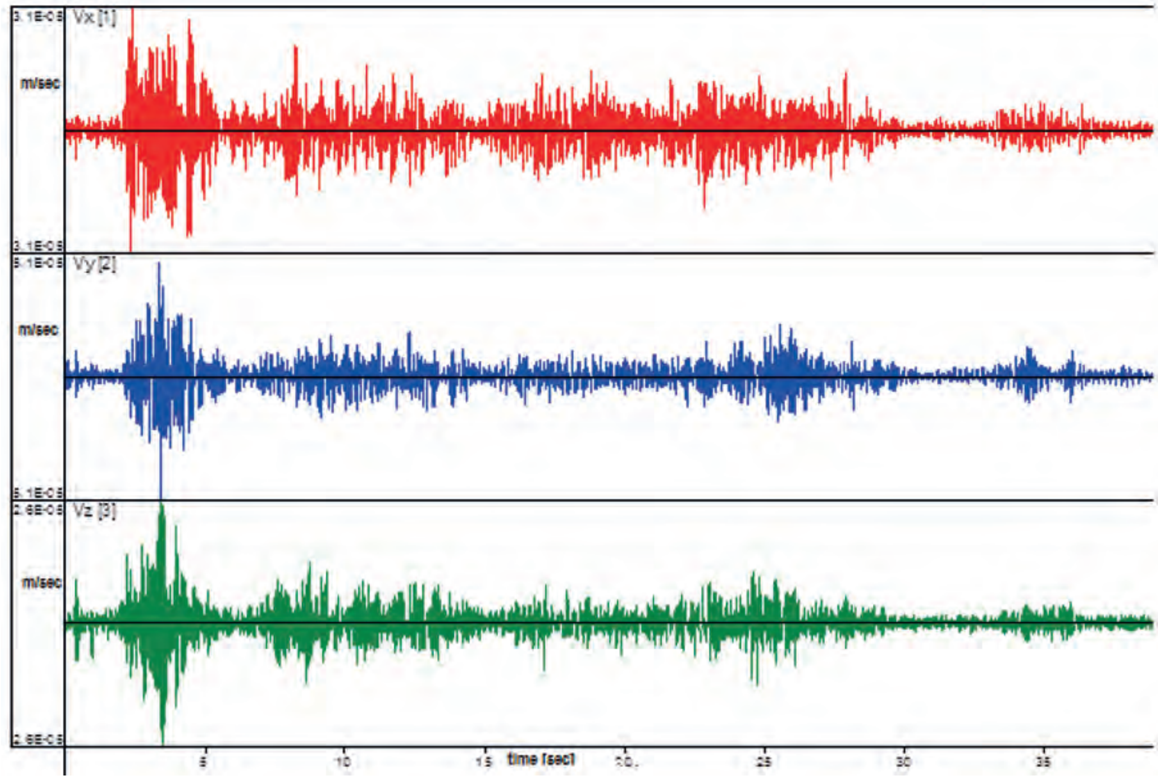


Fig. 53 Exemplary recording of vibrations registered on 19.03.2014 at 14.33 at Recorder 2 station.

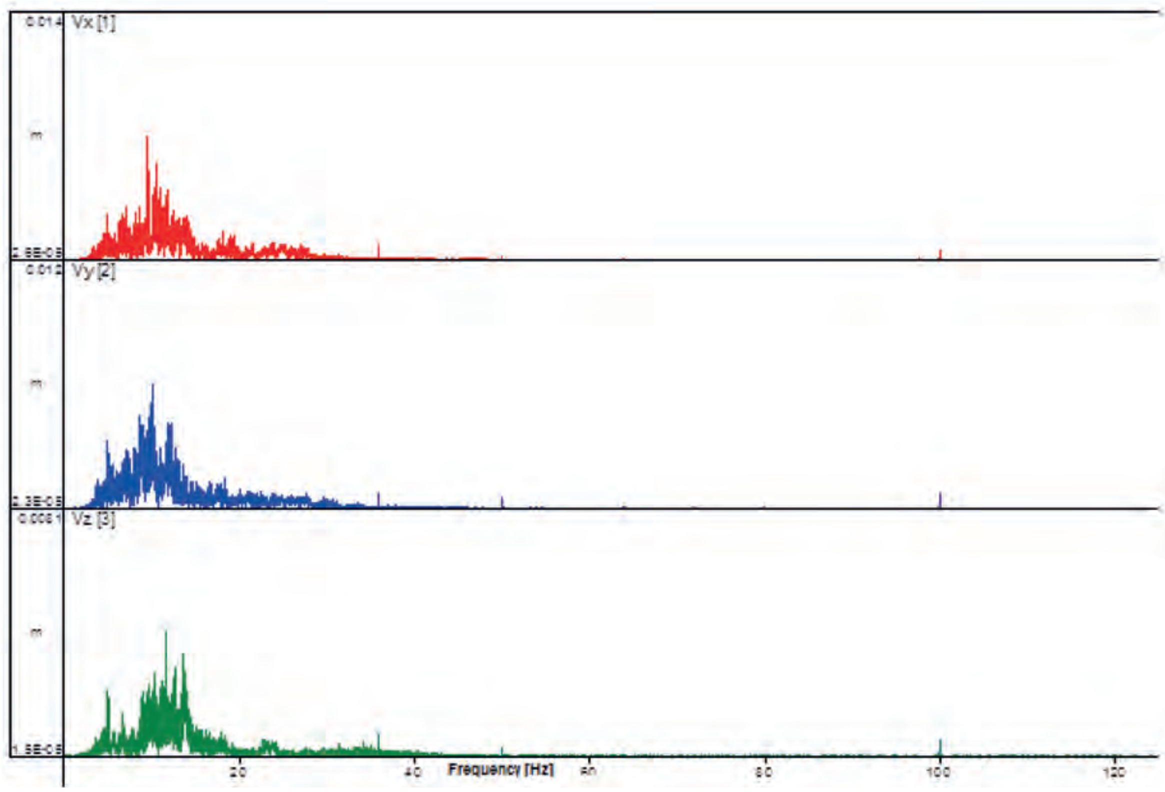


Fig. 54 Fourier analysis (amplitude spectrum) of recording from Fig. 53

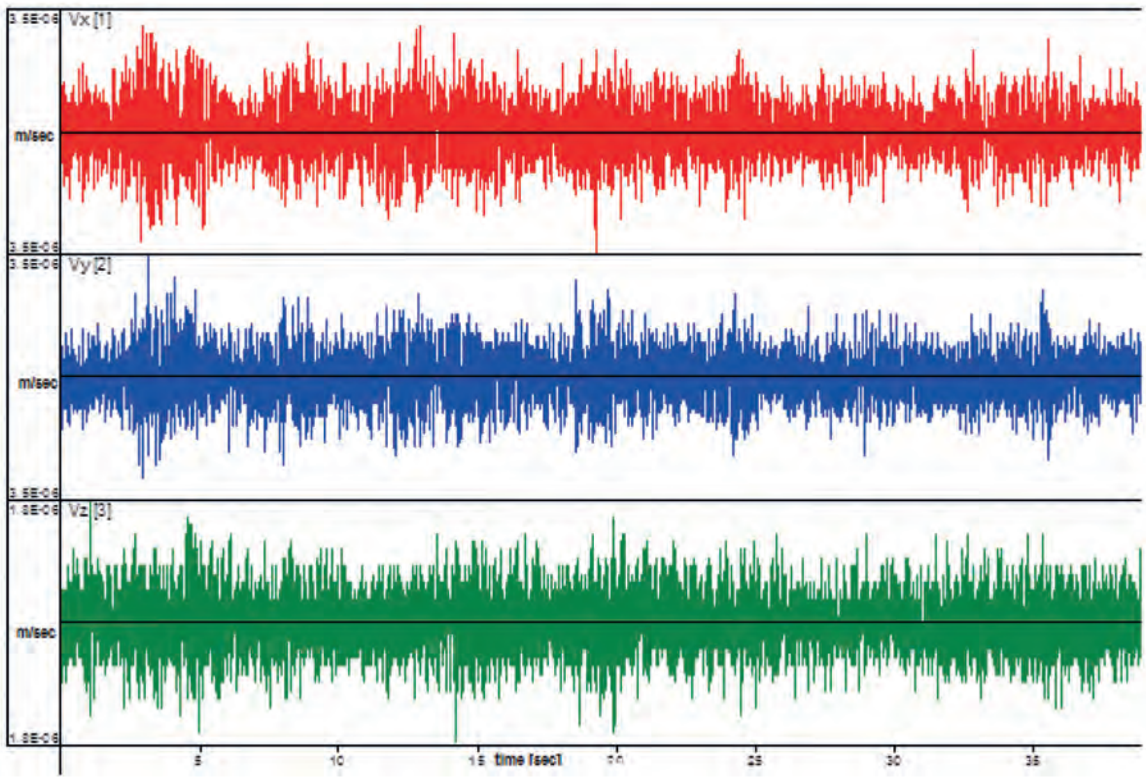


Fig. 55 Exemplary recording of seismic background registered at Recorder 2 station

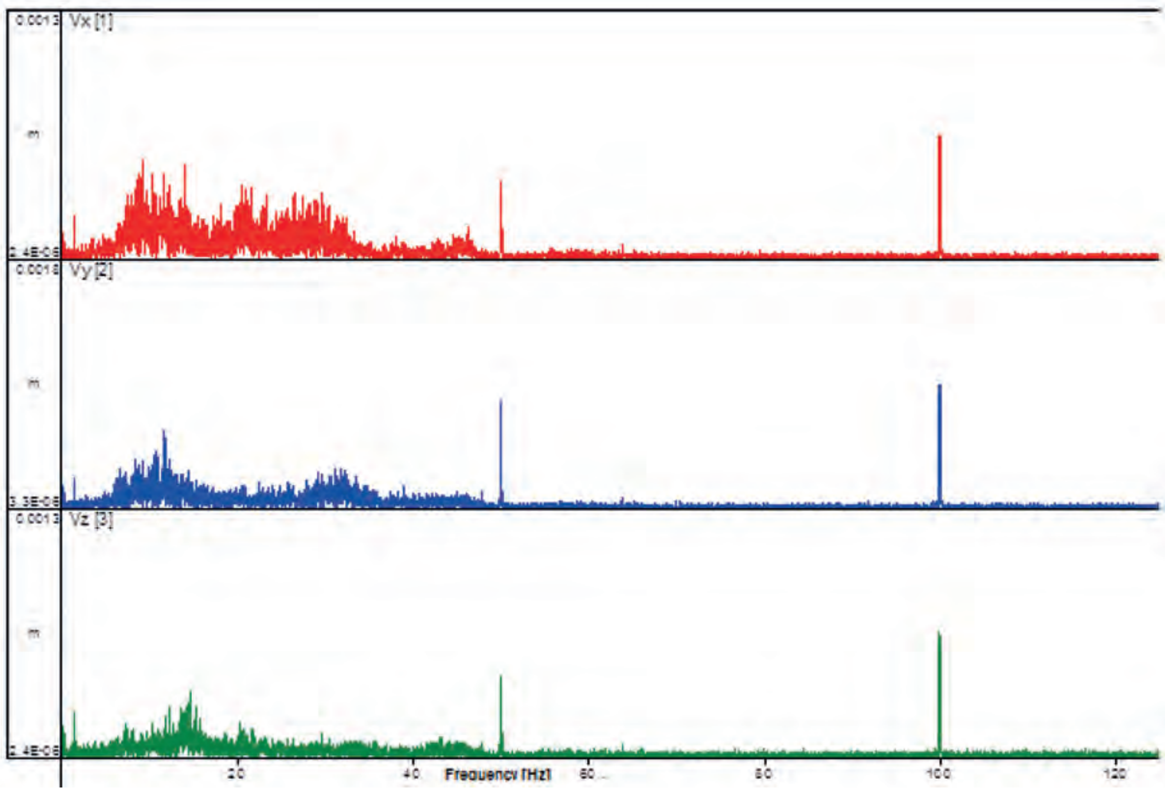


Fig. 56 Fourier analysis (amplitude spectrum) of recording from Fig. 55

Recorder 3 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	18.03.2014, 18.31	16.05.2014, 18.32	28.05.2014, 15.44
Resultant XYZ	9.18E-04	3.76E-04	8.46E-04

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 61 and 62. Seismic backgrounds shown in Fig. 61 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Recorder 3 station it was possible to register the vibrations with amplitude greater than 6.0E-6 m/s. Seismograms shown in Fig. 57 and 59 are an example of registered vibrations the amplitude of which exceeds the background level (the first maximum and the second selected randomly).

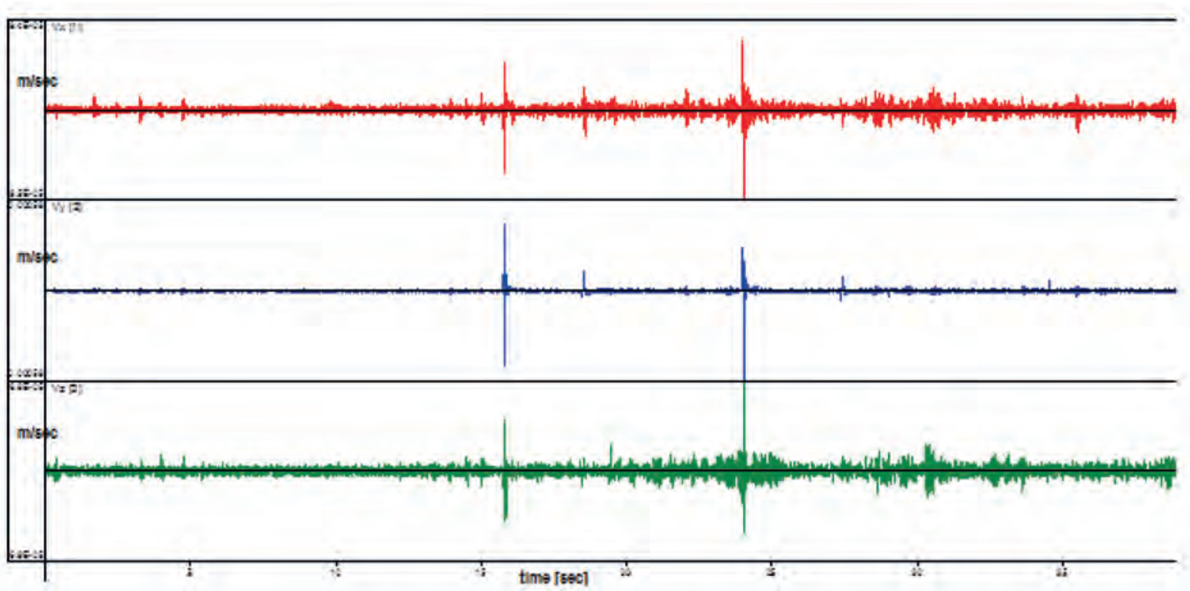


Fig. 57 Recording of maximum vibrations registered at Recorder 3 station on 18.03.2014 at 18.31

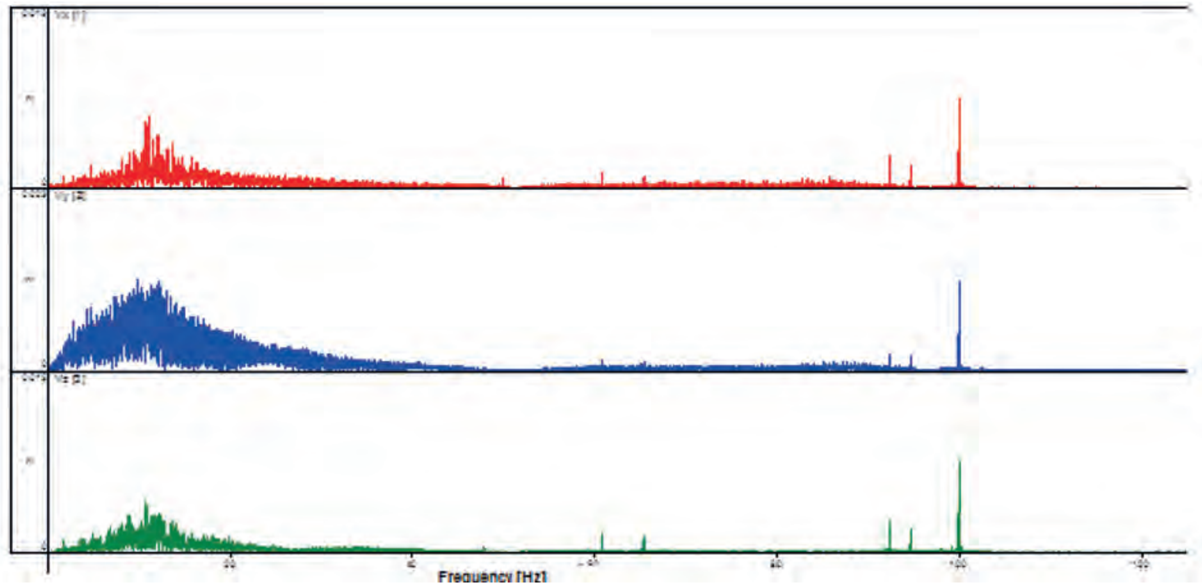


Fig. 58 Fourier analysis (amplitude spectrum) of recording from Fig. 57

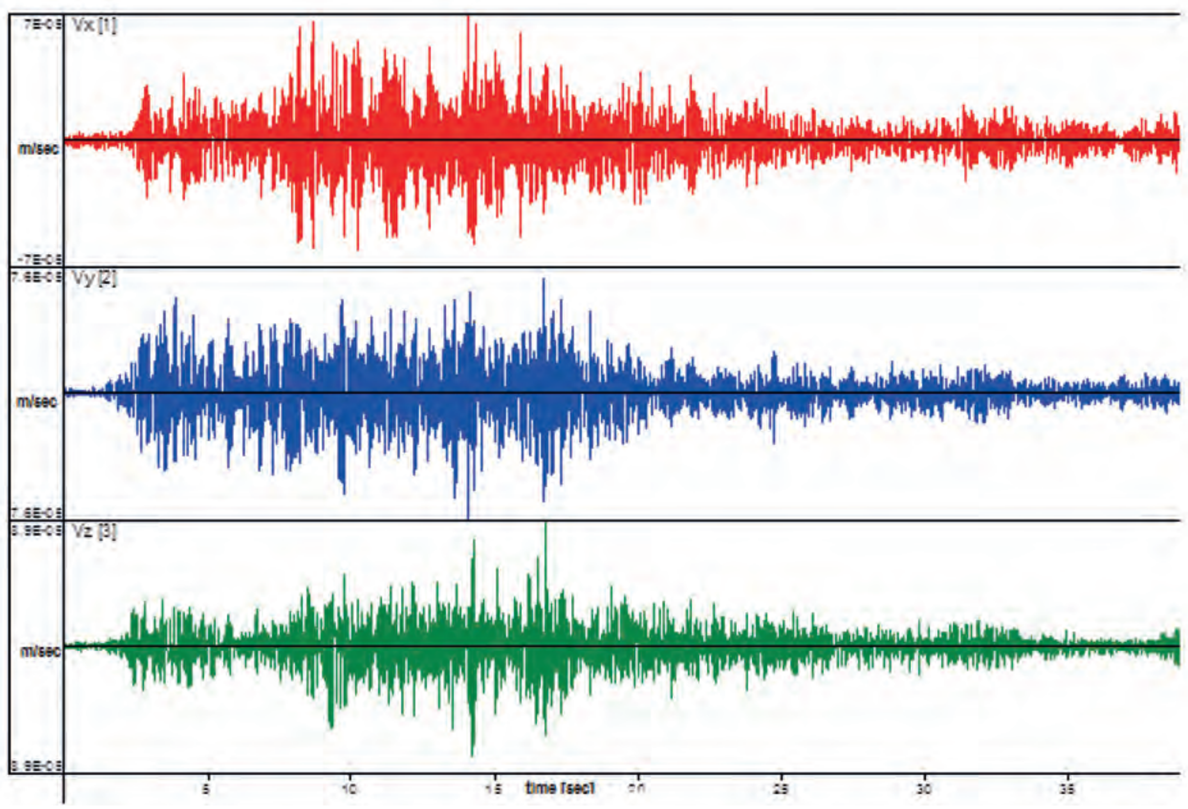


Fig. 59 Exemplary recording of vibrations registered on 19.03.2014 at 17.12 at Recorder 3 station

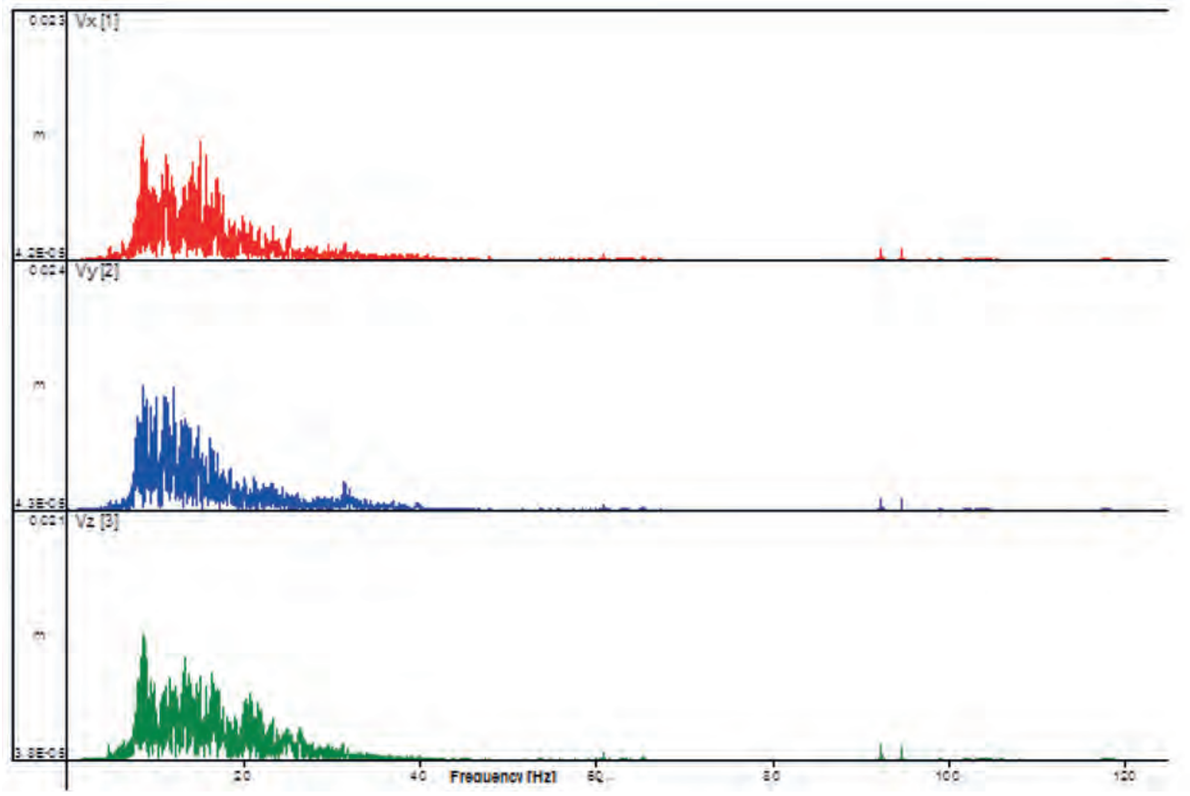


Fig. 60 Fourier analysis (amplitude spectrum) of recording from Fig. 59

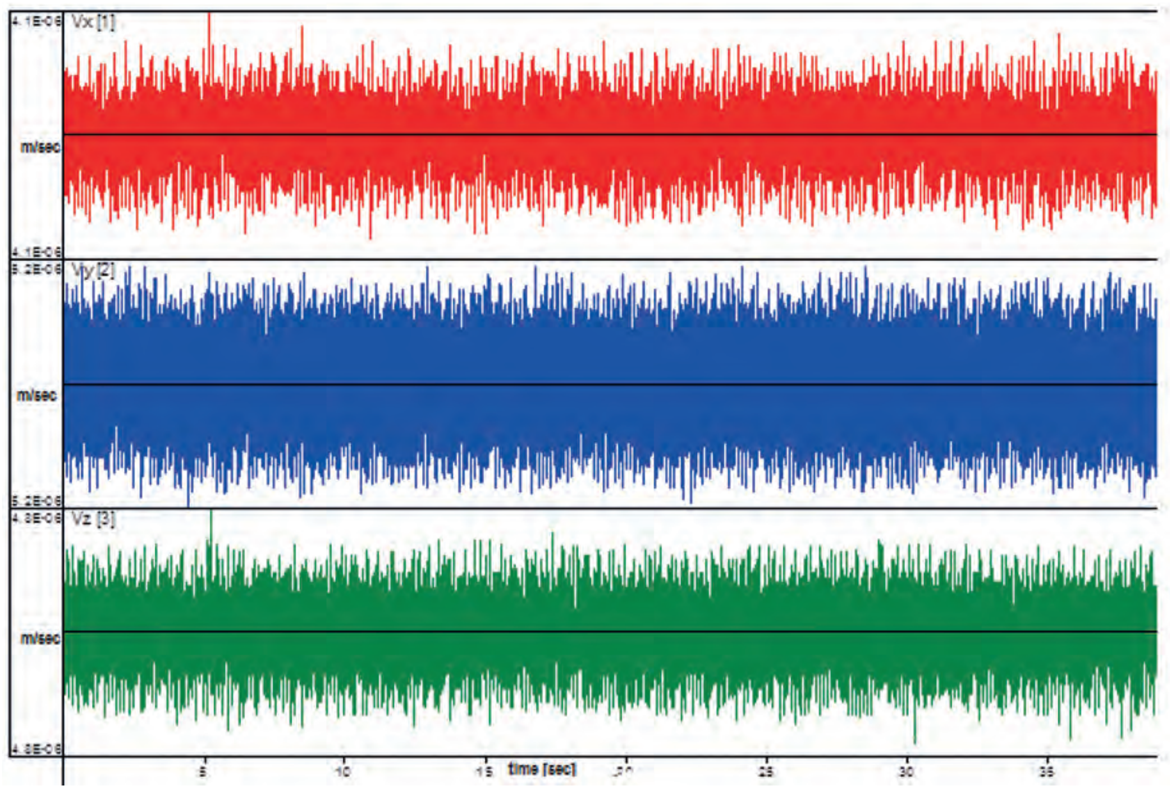


Fig. 61 Exemplary recording of seismic background registered at Recorder 3 station

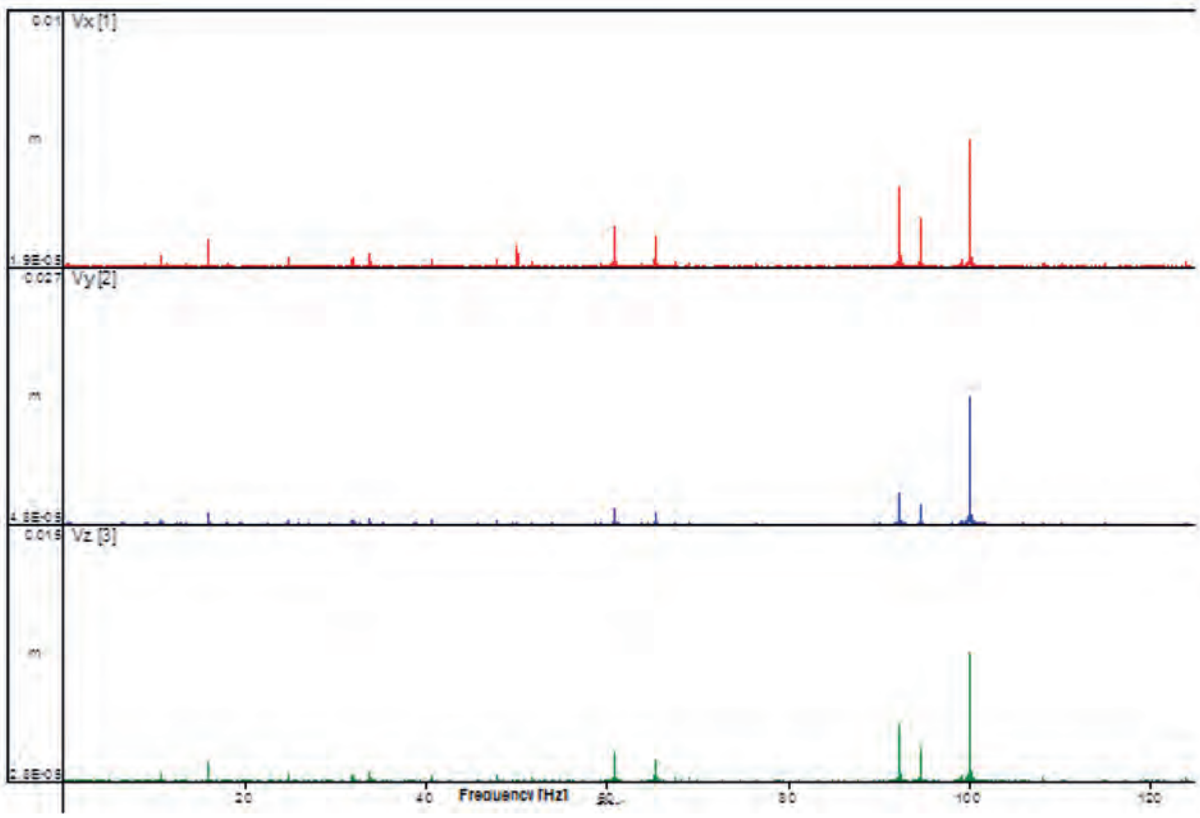


Fig. 62 Fourier analysis (amplitude spectrum) of recording from Fig. 61

Recorder 4 station

The maximum amplitudes of the vibrations velocity (m/s) for the background throughout the frequency range (up to 125 Hz) in each period of observation:

	Before hydraulic fracturing	**During hydraulic fracturing**	**After hydraulic fracturing**
Date and time	21.03.2014, 13.49	22.05.2014, 15.46	22.07.2014, 18.05
Resultant XYZ	9.92E-04	9.01E-04	7.83E-04

Exemplary recording of the background and its Fourier spectrum are presented in Fig. 67 and 68 Seismic background shown in Fig. 61 illustrates lower limit of sensitivity of the recording apparatus, i.e. the minimum values of vibration amplitudes that can be distinguished against the background noise. At the Recorder 4 station it was possible to register the vibrations with amplitude greater than 7.0E-6 m/s. Seismograms shown in Fig. 63 and 65 are an example of registered vibrations the amplitude of which exceeds the background level (the first maximum and the second selected randomly).

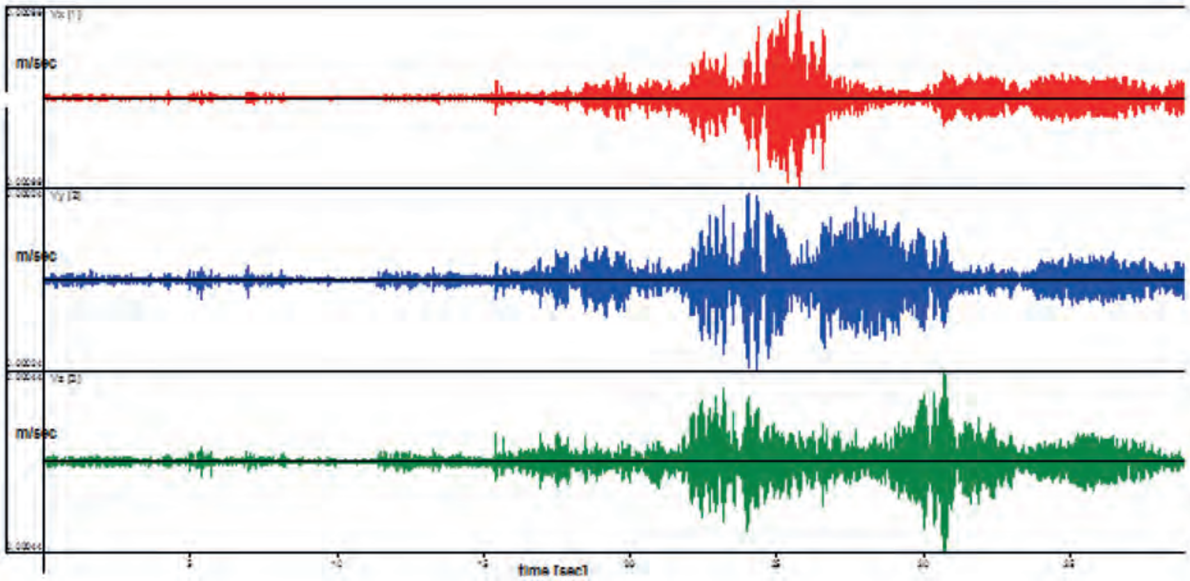


Fig. 63 Recording of maximum vibrations registered at Recorder 4 station on 21.03.2014 at 13.49

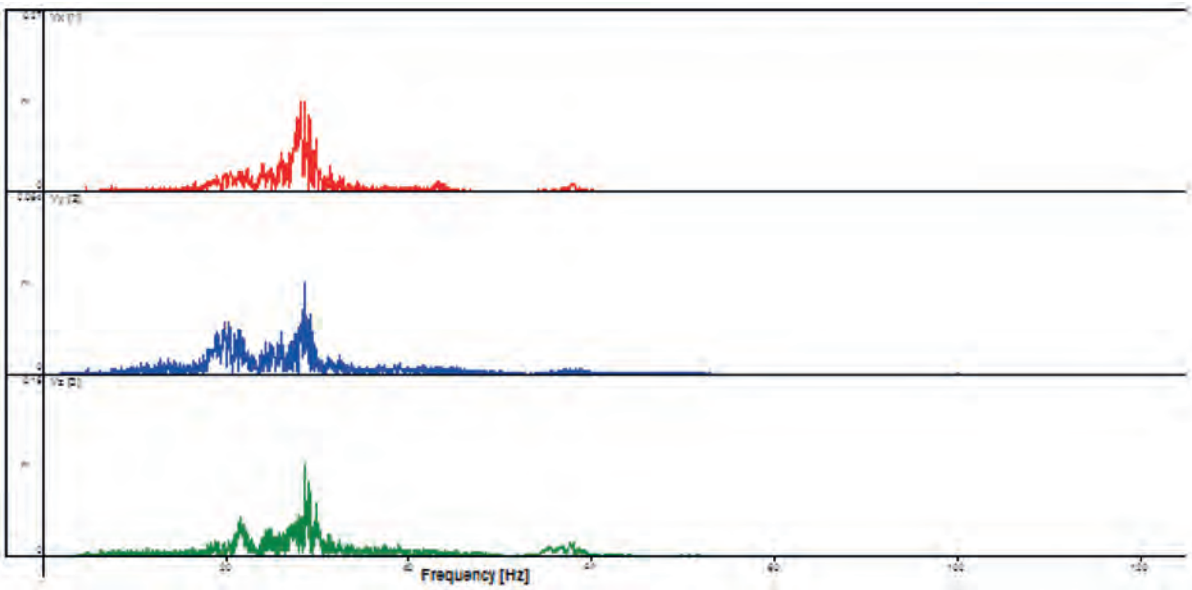


Fig. 64 Fourier analysis (amplitude spectrum) of recording from Fig. 63

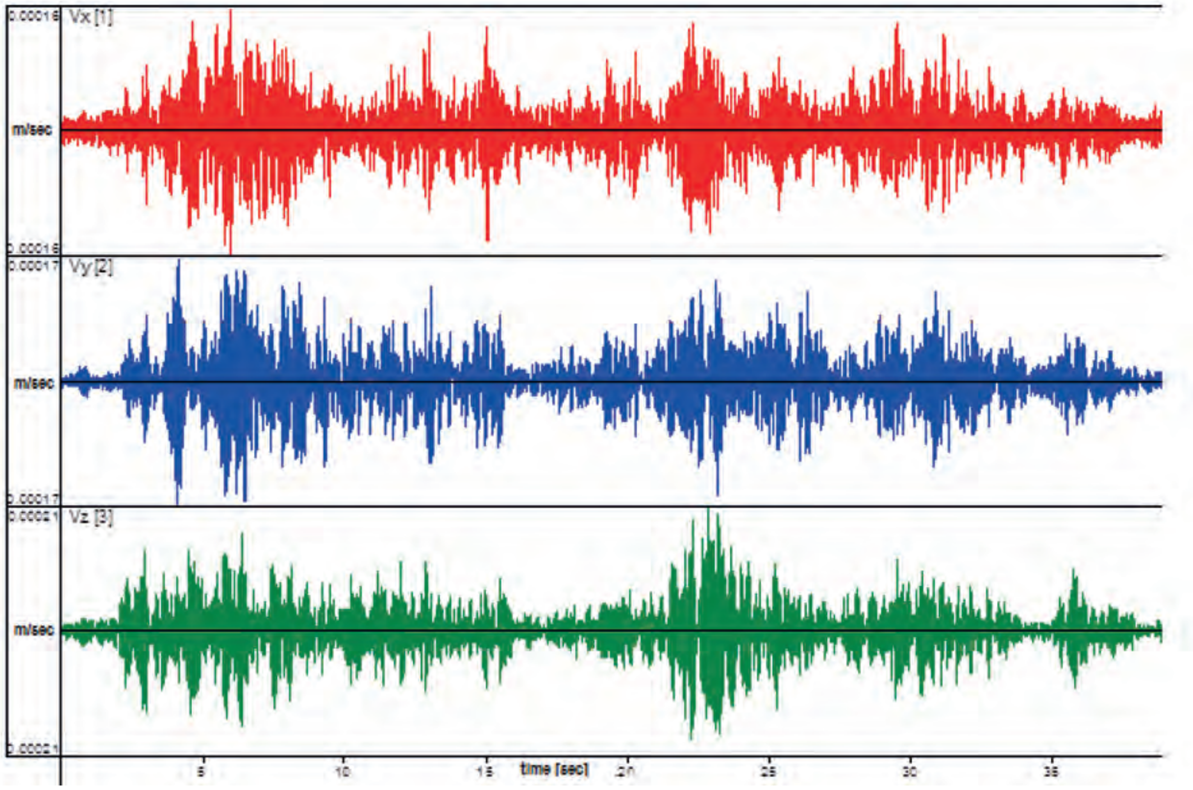


Fig. 65 Exemplary recording of vibrations registered on 16.04.2014 at 17.12 at Recorder 4 station.

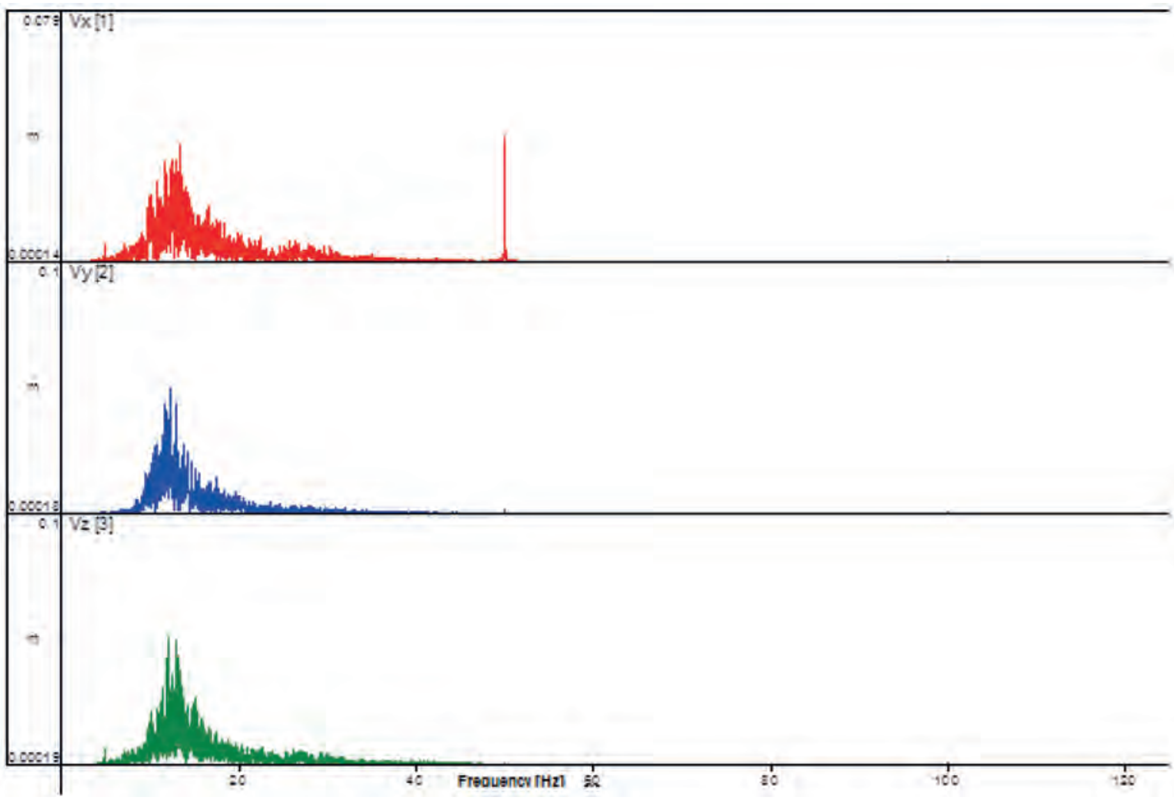


Fig. 66 Fourier analysis (amplitude spectrum) of recording from Fig. 65

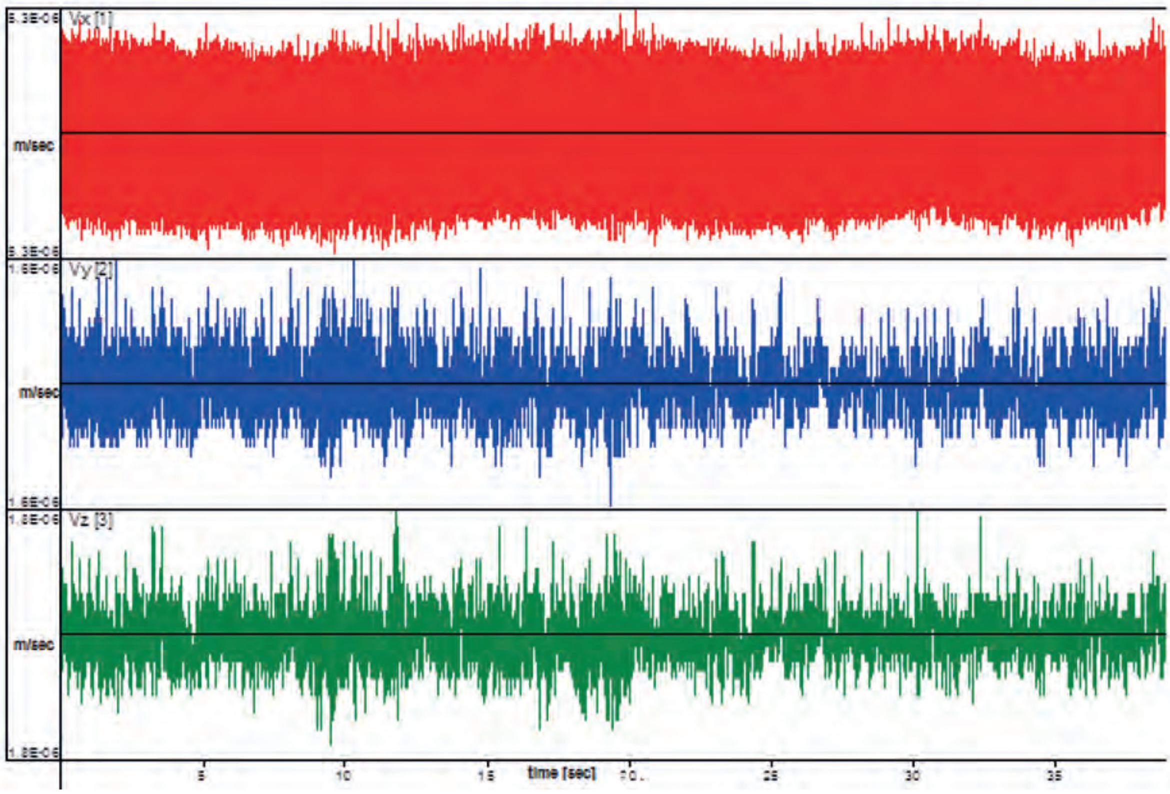


Fig. 67 Exemplary recording of seismic background registered at Recorder 4 station

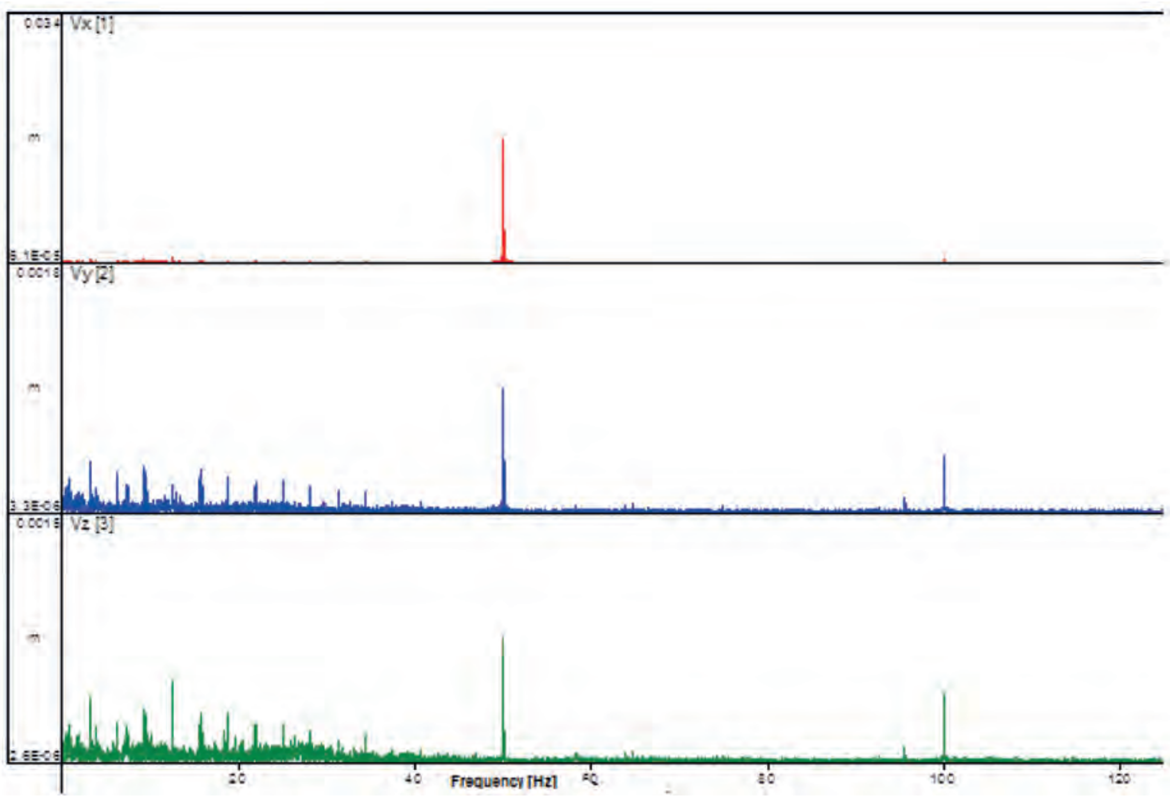


Fig. 68 Fourier analysis (amplitude spectrum) of recording from Fig. 67

The maximum amplitudes of vibrations recorded around the Gapowo -1 well were the result of events taking place around the sensors, probably strikes in the ground due to the e.g. chopping wood in the farm. Also recorded were machinery movements in farms and road traffic.

In the course of measurements on the ground surface in the vicinity of the Zwierzyniec-1 wells no vibrations coming from seismic events associated with the process of cracking the rock caused hydraulic fracturing were registered

5. EVALUATION OF REGISTERED VIBRATIONS

Maximum velocity values listed in Annexes 4–15 did not exceed 2 mm/s. Events with amplitude vibration greater than 0.5 mm/s were associated with the vibrations caused by human activity near the sensor, e.g. earthworks on the farm. Their classification and identification was possible on the basis of the nature of the recording (duration, dominant frequencies). Distinguishing this type of events from potential shocks was also possible by the fact that these events were recorded by only one measuring station. Exemplary evaluation of this type of vibrations is presented in Fig. 69 and 70 (for maximum vibration recorded at Syczyn 4 station on 07.04.2013, at 6.38, and at Zawada 3 station registered on 04.09.2013, at 18.33). These evaluations are for information purposes only, intended to show interpretation method according to the SWD scale. In addition, according to the standards the measurements should be carried out on the building foundation (at each test site, one station was mounted on the building foundation and three in the ground). Points placed on nomograms presented in Fig. 69–72 were calculated using octave filtration in accordance with PN-85 / B-02170.

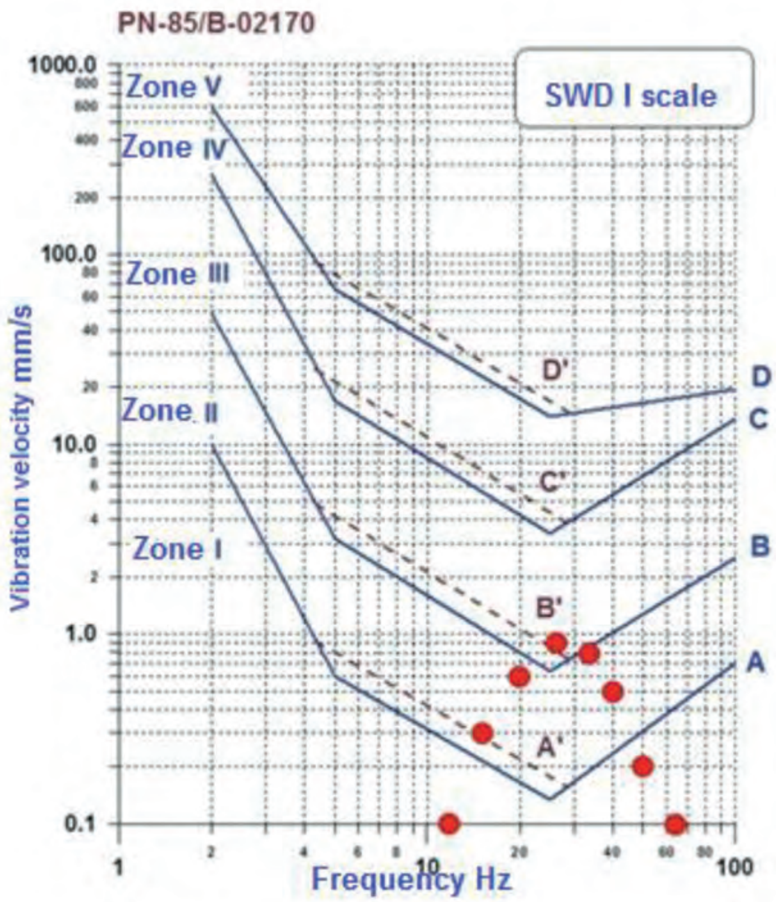


Fig. 69 Evaluation of vibrations registered at the Syczyn 4 station on 04.07.2013, at 6.38 according to the Dynamic Influence Scales SWD-I of Polish standard PN-85 / B-02170; vibrations were caused by people working in the vicinity of the sensor.

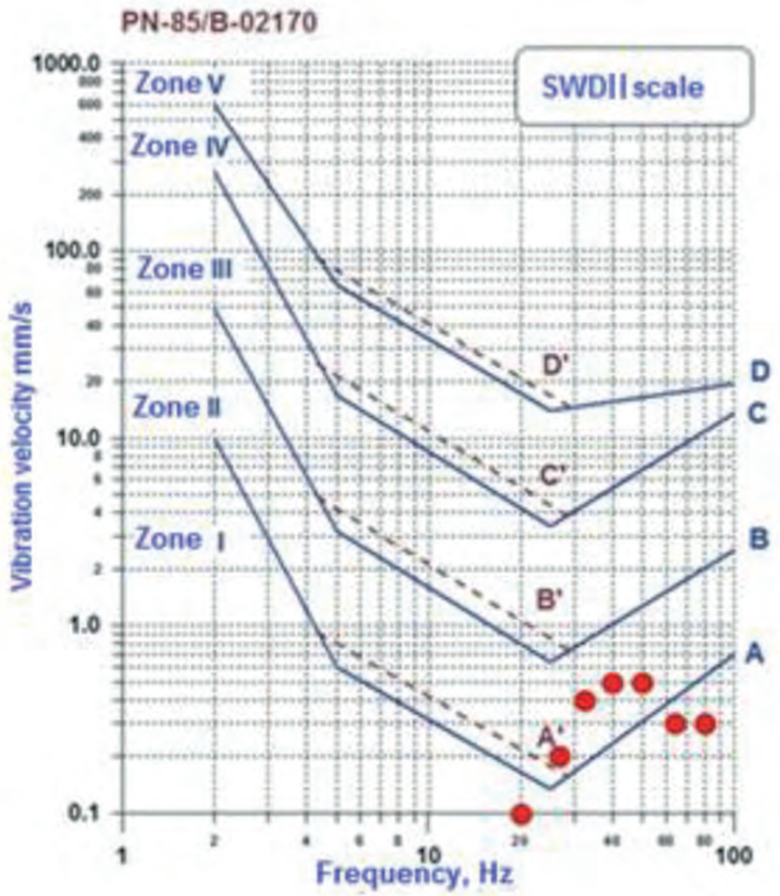


Fig. 70 Evaluation of vibrations registered at the Zawada 3 station on 4.09.2013, at 18.33 according to the Dynamic Influence Scales SWD-I of Polish standard PN-85 / B-02170; vibrations were caused by people working in the vicinity of the sensor

The vibrations with the largest amplitudes (Fig. 69–70 marked with red dots) were the results of striking the sensors or striking caused by work carried out in their vicinity (construction of a fence, chopping wood). It is known because of to the frequency characteristics of these vibrations. This type of vibration according to PN-85 / B-02170 can be classified into Zone II (vibrations perceptible to the building, but harmless to the structure, only accelerated wear of the building may occur and the first cracks in coatings and plasters), or even III (vibrations harmful to the building that can cause local scratches and cracks, peeling of plaster and coatings may occur). However, these vibrations are derived from sources located very close to the sensor, which was located in the ground, and not on the building, and therefore the real impact of vibration on the building is smaller.

Registered vibrations associated with the work conducted in the wells include the following:

- vibrations recorded at the Syczyn 2 station from 05.22.2013 to 11.07.2013, i.e. during operations of the hydraulic fracturing equipment at the Syczyn-OU2K well. The assessment of these vibrations in relation to the SWD I scale is shown in Fig. 71,
- vibrations from passing cars delivering materials necessary for hydraulic fracturing process. The assessment of these vibrations in relation to the SWD I scale is shown in Fig. 72.

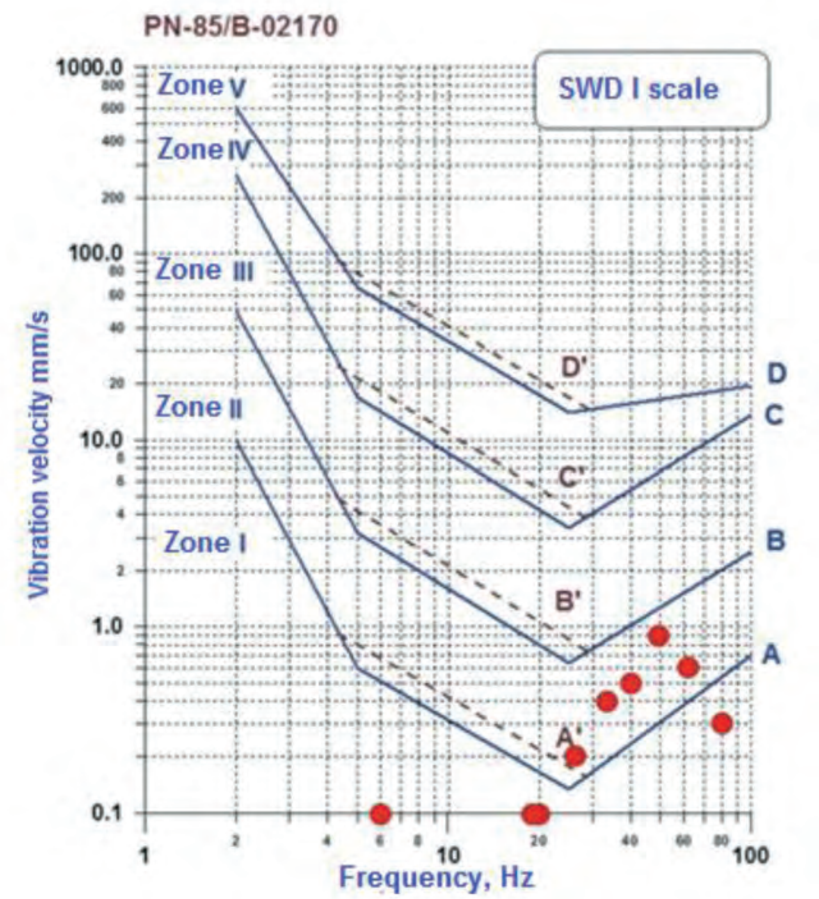


Fig. 71 Evaluation of vibrations registered at the Syczyn 2 station on 27.05.2013, according to the Dynamic Influence Scales SWD-I of Polish standard PN-85 / B-02170; vibrations were caused by hydraulic fracturing equipment operating in the vicinity of Syczyn-OU2K well.

The vibrations recorded during hydraulic fracturing in the area of the Syczyn-OU2K well according to the PN-85 / B-02170 can be classified into Zone II (vibration perceptible to the building, but harmless to the structure, only accelerated wear of the building may occur, and the first cracks in coatings and plaster). It is shown in Fig. 71, in which the red dots indicate the vibration frequency in individual frequency intervals.

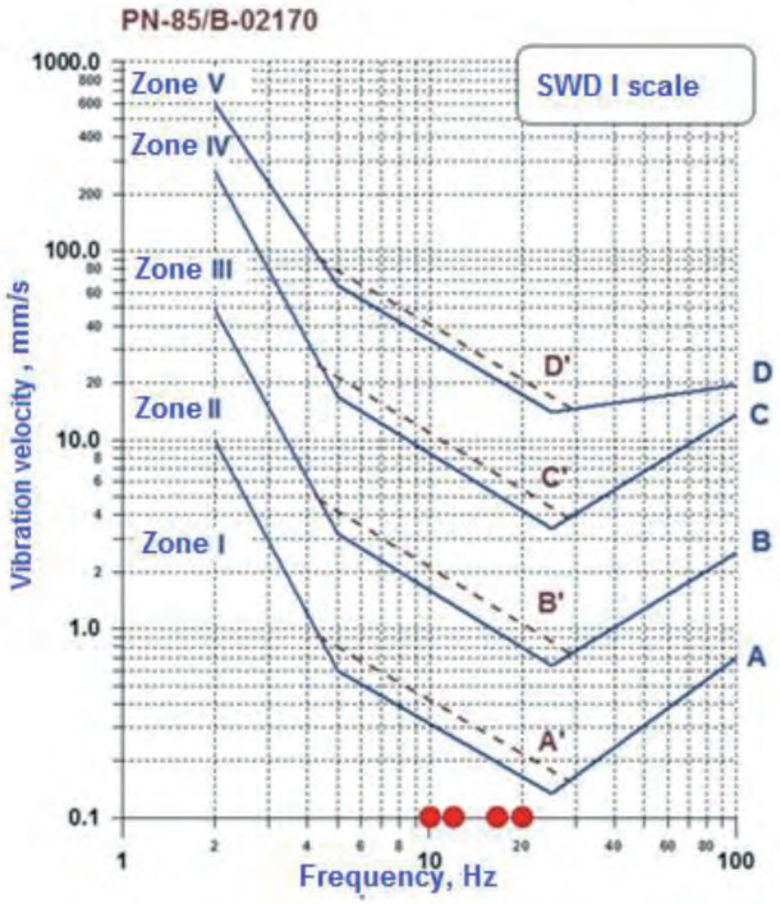


Fig. 72 Evaluation of vibrations registered at the Gapowo 4 station on 2.05.2014, at 9.50 according to the Dynamic Influence Scales SWD-I of Polish standard PN-85 / B-02170; vibrations were caused by road traffic related to hydraulic fracturing (delivery of materials)

Vibrations from the road traffic recorded during the measurements on all the wells according to PN-85 / B-02170 can be classified into the zone I (vibrations imperceptible to the building). An example of evaluation is shown in Fig. 72.

Measured vibration values are below the threshold values, if evaluation of vibrations includes standard DIN 4150/3 (see Table 4), which is commonly used in the assessment of the impact of seismic vibrations in Europe. In Annexes 4–15 the threshold value of 5 mm/s is marked with red line, a starting point from which it may be appropriate to consider the impact of paraseismic vibration according to German standard DIN 4150/3. Paraseismic vibrations constitute vibrations emanating from the events such as: detonation of explosives, road traffic, working machines. This concept was created to distinguish such vibrations from the seismic vibrations emanating from earthquakes.

The above vibration analysis in accordance with SWD-I scale included in Fig. 69–72 was made with use of 1/3 octave filters, and can also be related to the PN-88 / B-02171 scale, to assess the impact of vibration on people in buildings. For this purpose, the adjusted, acceptable vibration velocity limits should be defined separately for component z, and x–y. Adjusted, acceptable vibration velocity limits specified for residential buildings for the vertical component of the vibration with equal 3.2 mm/s and for the horizontal components x–y equal to 9.28 mm/s. From the Fig. 69–72, it is clear that the recorded vibrations do not reach this level, which means that they had no effect on the people in the buildings.

6. TELESEISMIC EVENTS

In the course of the measurements the number of teleseismic events was recorded, i.e. distant earthquakes. Below are presented few of recorded seismograms. The figures are for information purposes only, while recordings of the entire earthquake last longer, usually several or more minutes.

The earthquake of 24/05/2013 located on the Sea of Okhotsk (see Fig. 73–80).

Characteristics of this tremor are as follows:

Magnitude	M=8,3
Region	Sea of Okhotsk
Time	24.05.2013, at 05.44 UTC
Location	54.91 N; 153.34 E
Depth	598 km

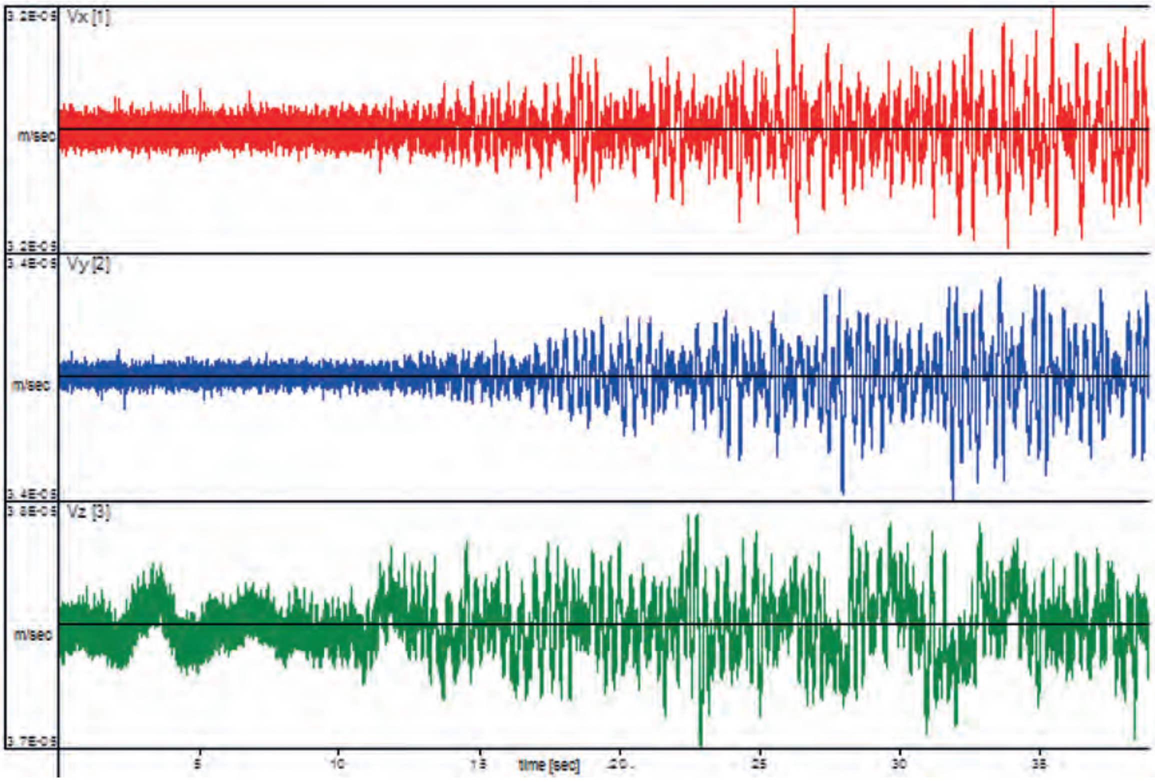


Fig. 73 Record of the earthquake in the Sea of Okhotsk dated 24.05.2013 at Syczyn 1 station in Bekisza (area of Syczyn OU2K well). Start of recording 7:54:27.127 local time

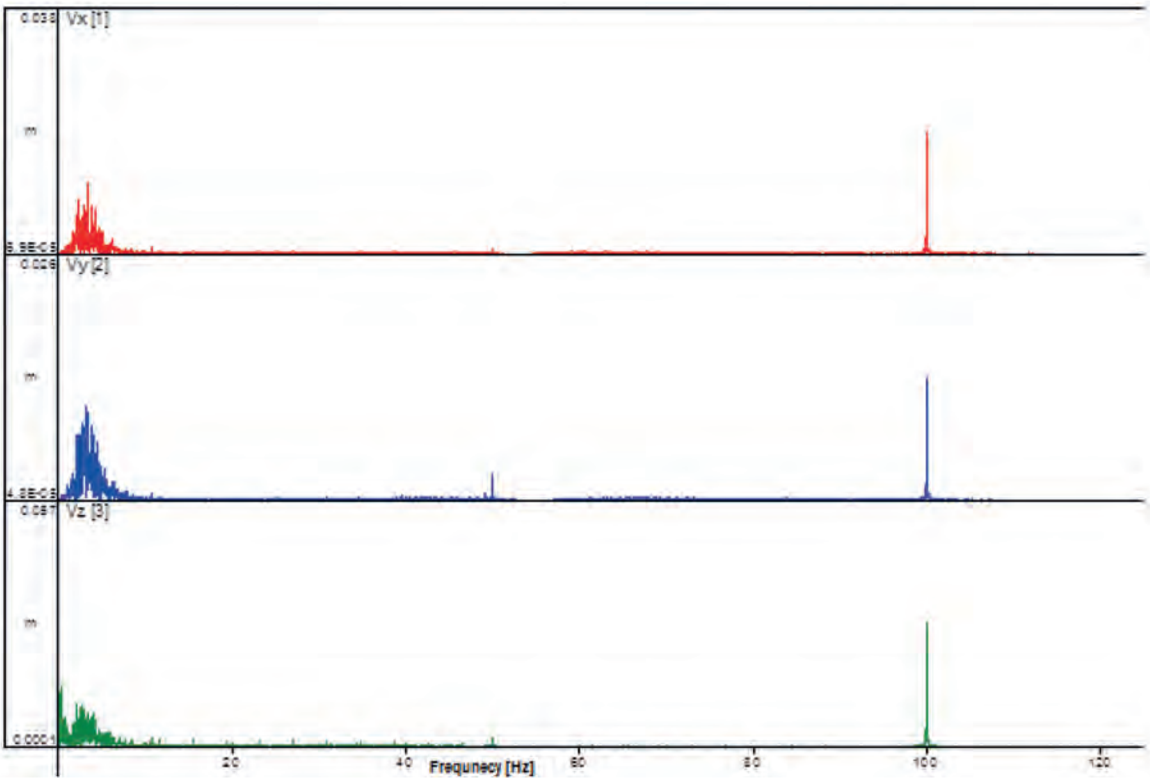


Fig. 74 Fourier analysis (amplitude spectrum) of recording from Fig. 73

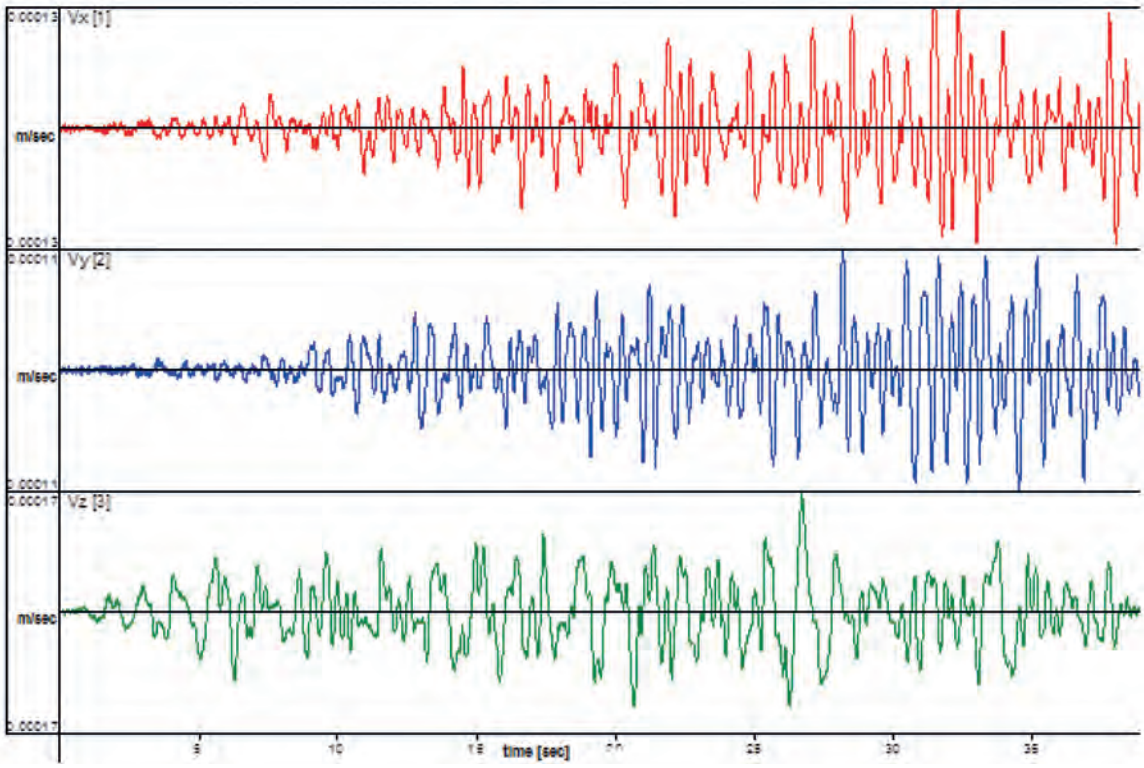


Fig. 75 Record of the earthquake in the Sea of Okhotsk dated 24.05.2013 at Syczyn 2 station in Syczyn (area of Syczyn OU2K well). Start of recording 7:54:33.478 local time

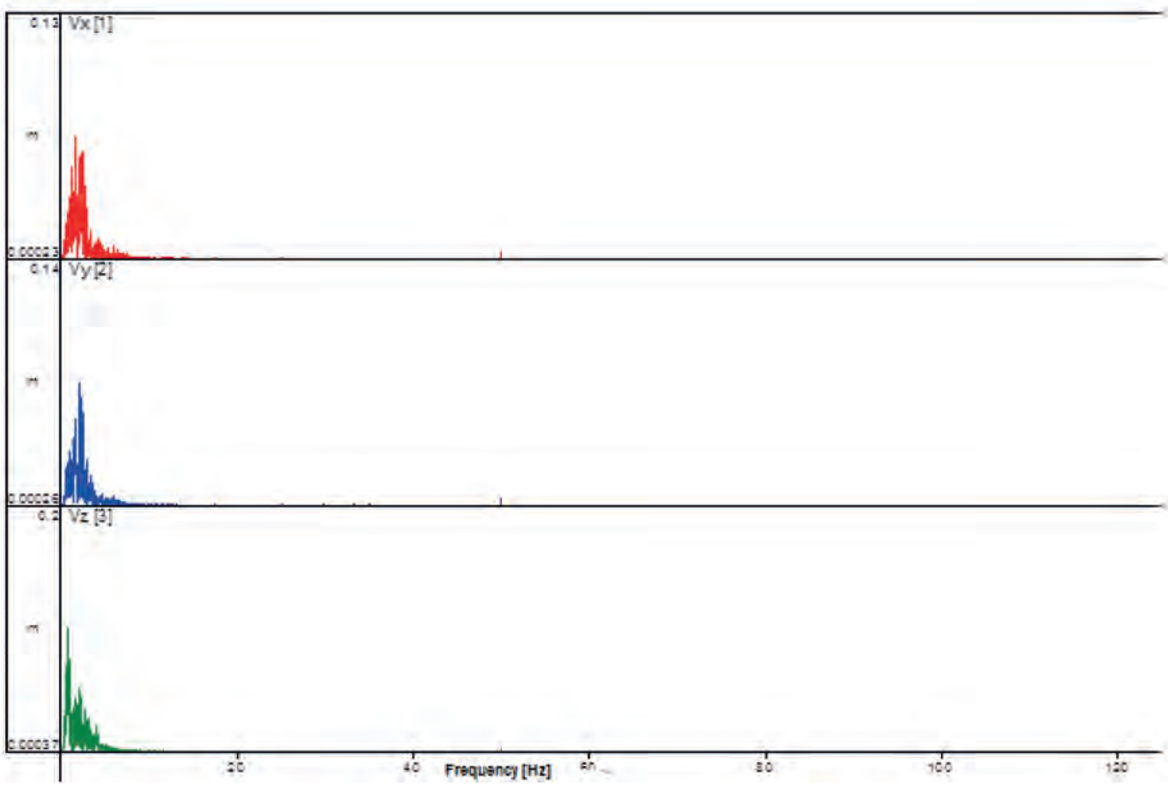


Fig. 76 Fourier analysis (amplitude spectrum) of recording from Fig. 75

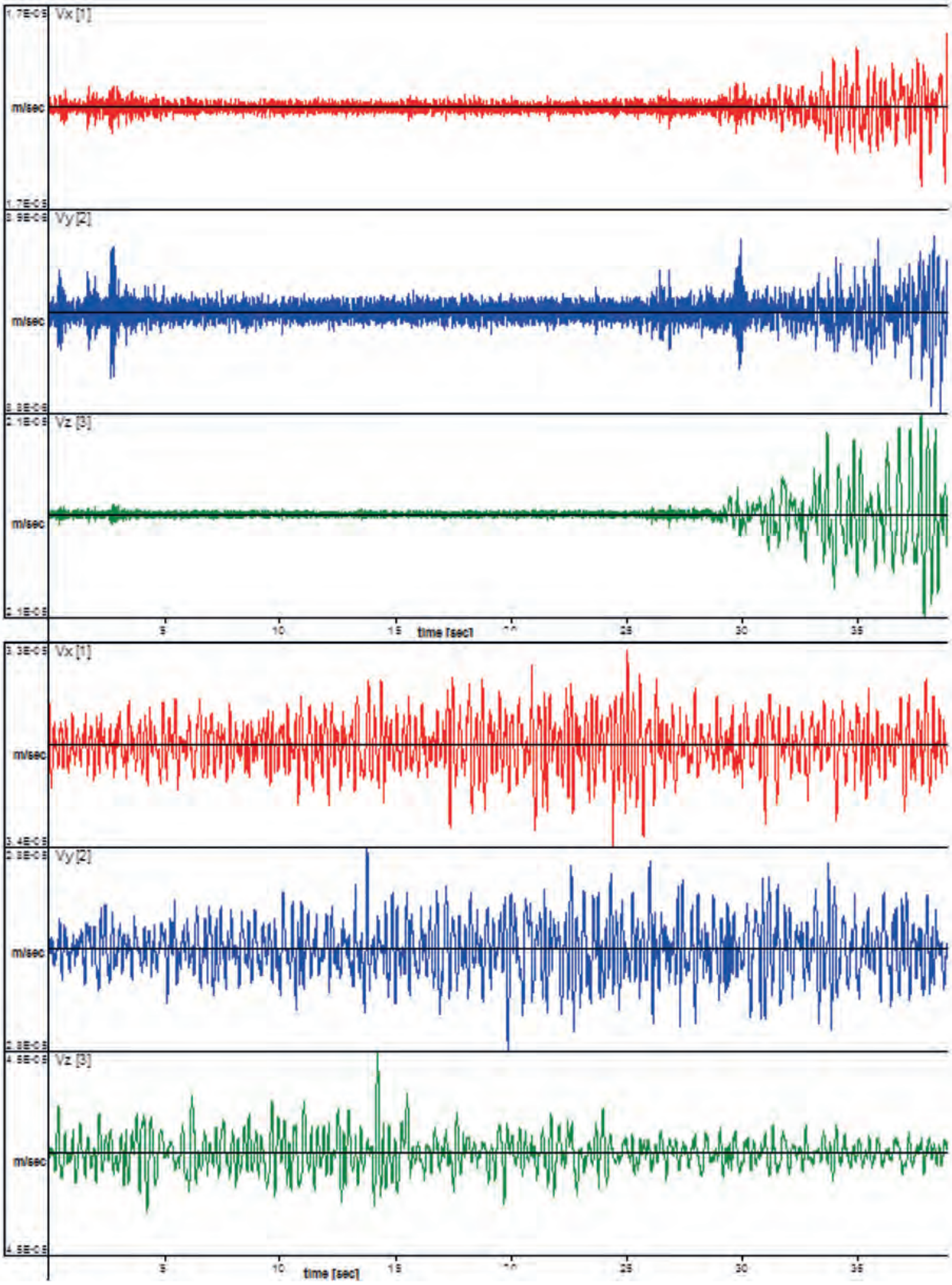


Fig. 77 Record of the earthquake in the Sea of Okhotsk dated 24.05.2013 at Syczyn 3 station in Syczyn (area of Syczyn OU2K well), two consecutive windows 40 sec. long. Start of recording 7:54:02.586 local time.

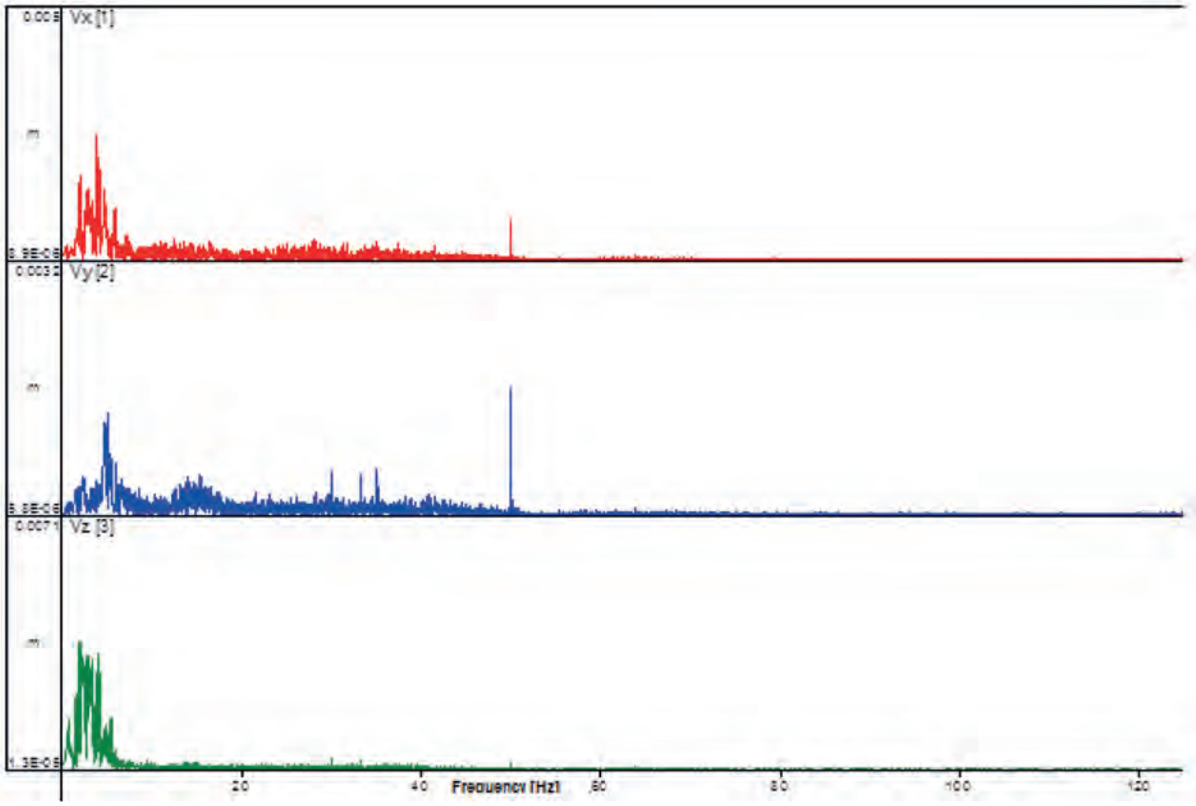


Fig. 78 Fourier analysis (amplitude spectrum) of recording from Fig. 77

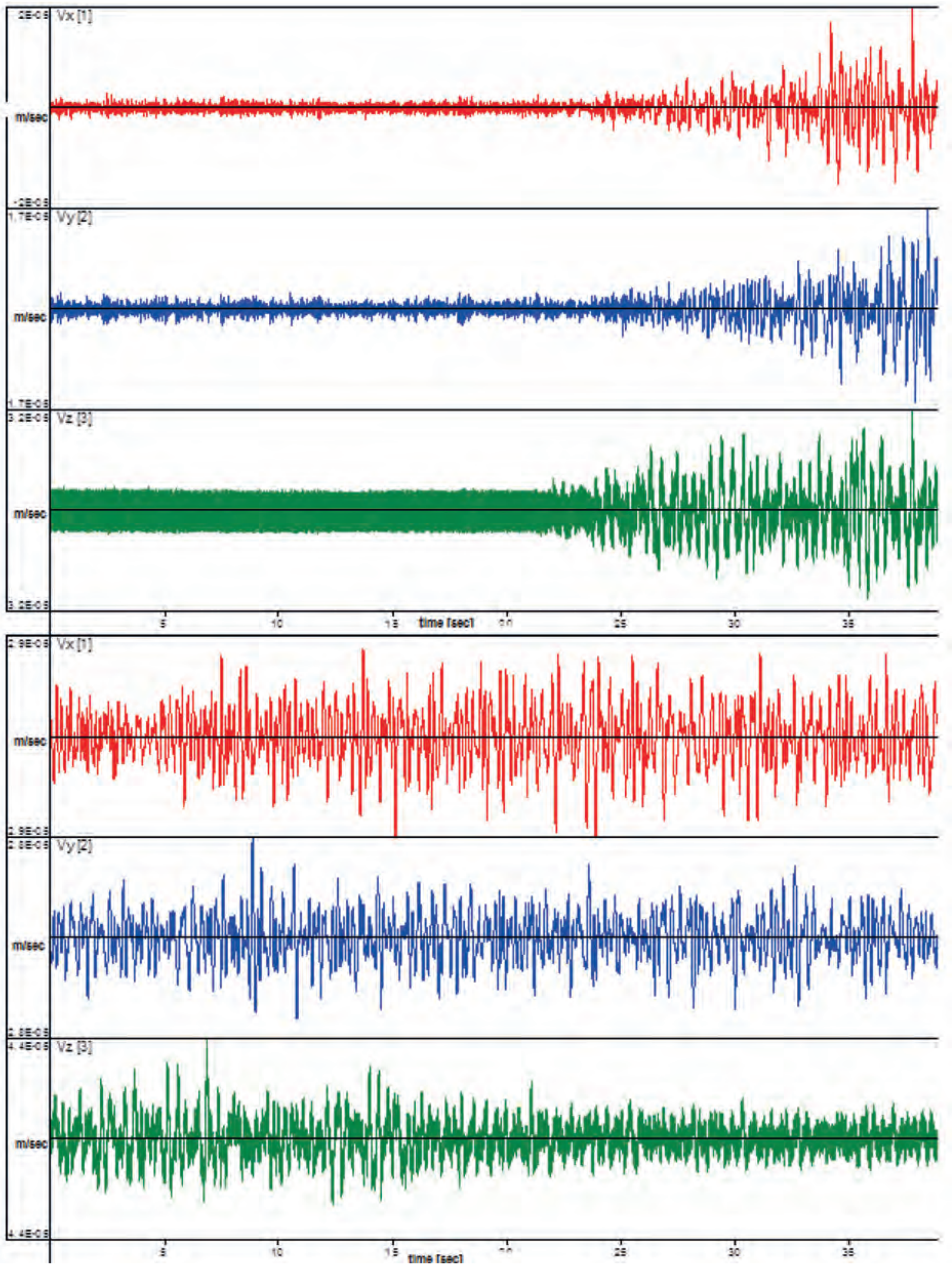


Fig. 79 Record of the earthquake in the Sea of Okhotsk dated 24.05.2013 at Syczyn 4 station in Syczyn (area of Syczyn OU2K well), two consecutive windows 40 sec. long. Start of recording 7:54:11.325 local time.

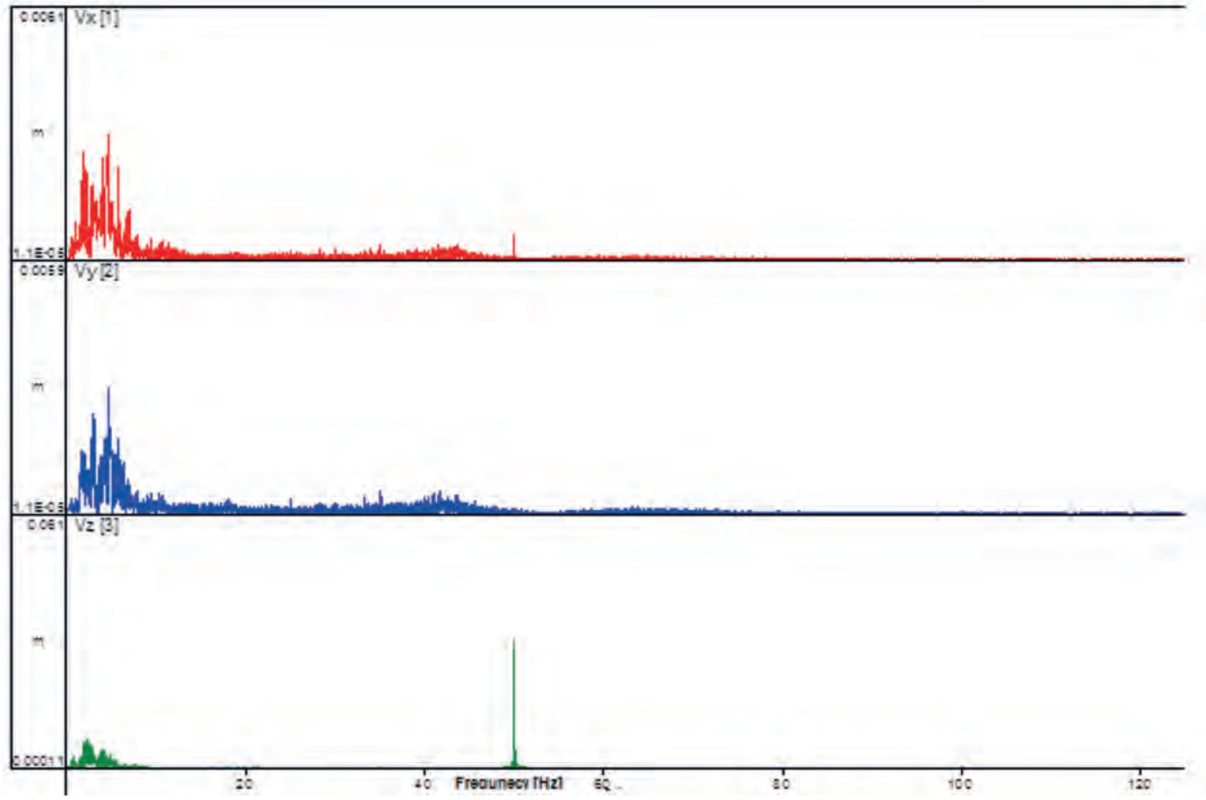


Fig. 80 Fourier analysis (amplitude spectrum) of recording from Fig. 79

The earthquake of 06/15/2013, located on the island of Crete (see Fig. 81–84). Characteristics of this tremor are as follows:

Magnitude	M=6.2
Region	Crete, Greece
Time	15.06.2013, at 16.10 UTC
Location	34.23 N; 25.00 E
Depth	10 km

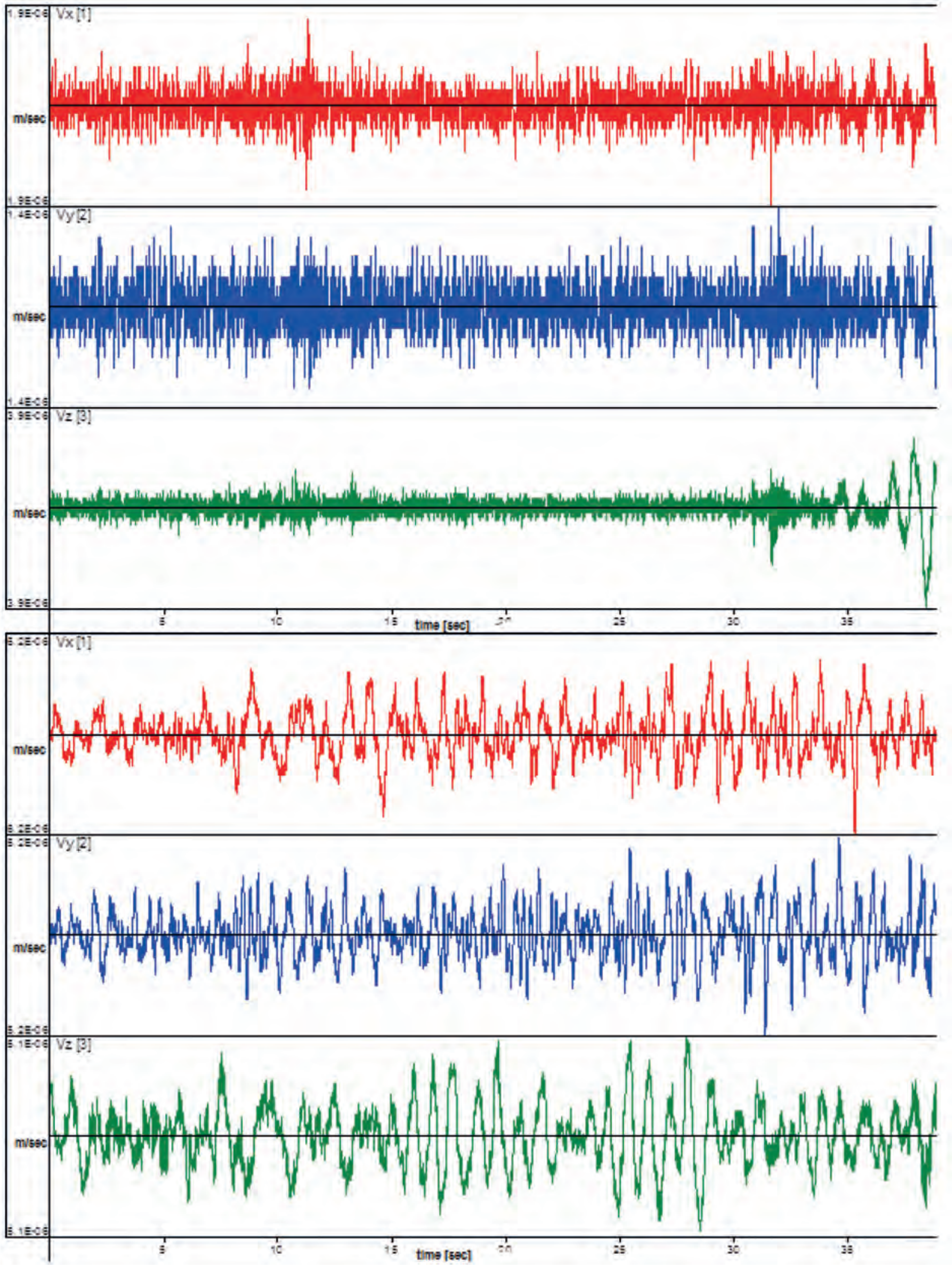


Fig. 81 Record of the earthquake in Crete dated 15.06.2013 at Zawada 1 station in Wielącz Kolonia (area of Zwierzyniec-1 well), two consecutive windows 40 sec. long. Start of recording 18:14:15.117 local time.

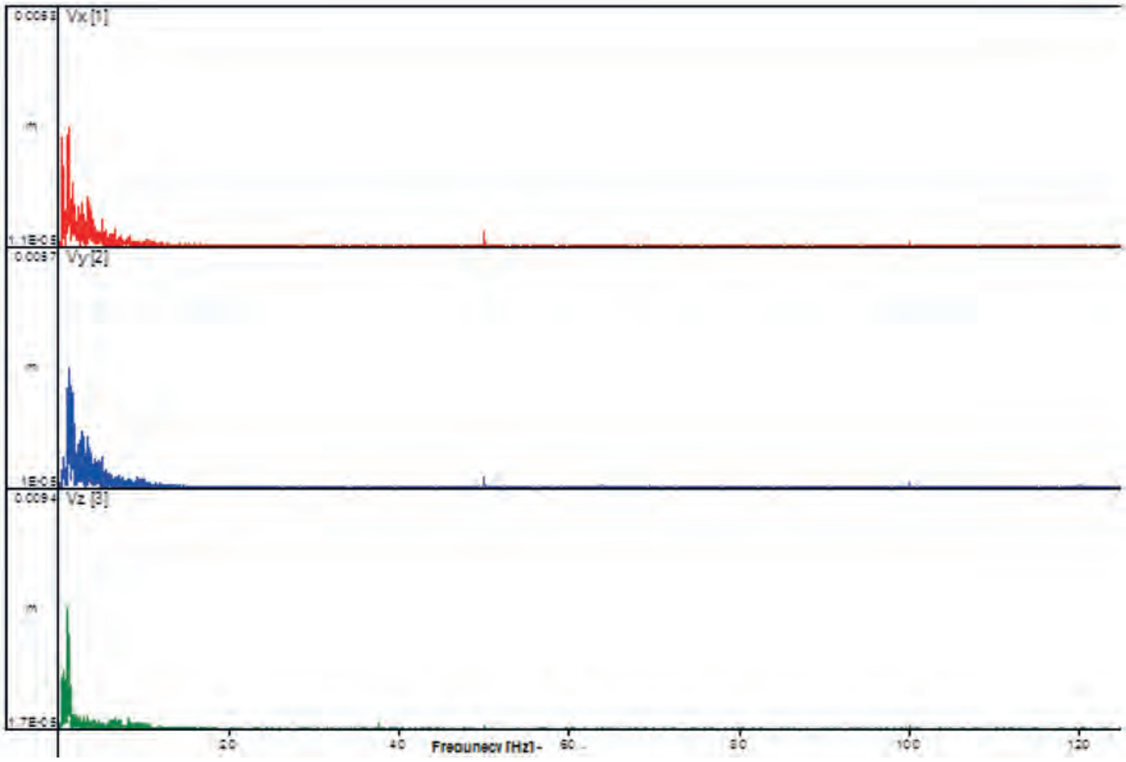


Fig. 82 Fourier analysis (amplitude spectrum) of recording from Fig. 81

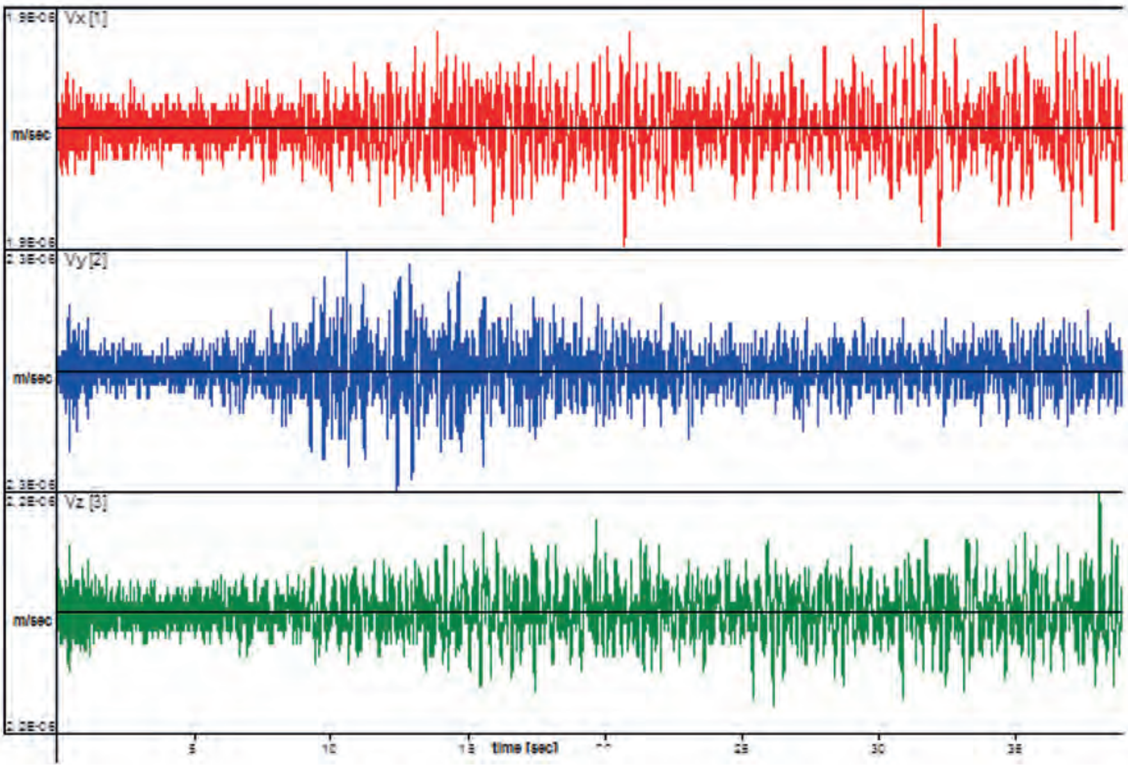


Fig. 83 Record of the earthquake in Crete dated 15.06.2013 at Zawada 2 station in Siedliska Kolonia (area of Zwierzyniec-1 well). Start of the recording 18:14:45.067 local time.

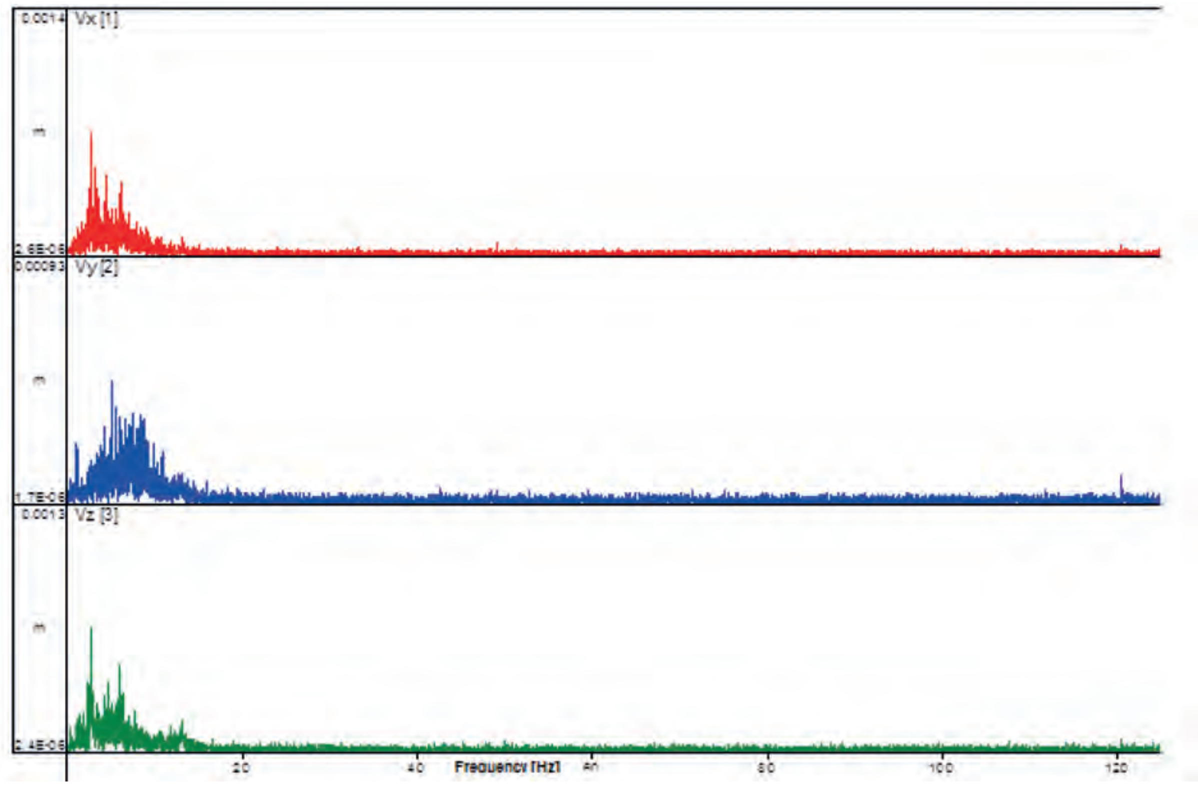


Fig. 84 Fourier analysis (amplitude spectrum) of recording from Fig. 83

The earthquake of 23/06/2014, located in the Bering Sea (Rat Islands) (see Fig. 85–86). Characteristics of this tremor are as follows:

Magnitude: M=7.9
Region: Rat Islands group of the Aleutian Islands
Time: 23.06.2014, at 20.53 UTC
Location: 51.85 N; 178.76 E
Depth: 106 km

Seismograms for this earthquake is presented collectively for all stations in the Gapowo-1 well area in Figure 85 (using a low pass filter with a cut-off frequency of 10Hz to eliminate some of the distortions).

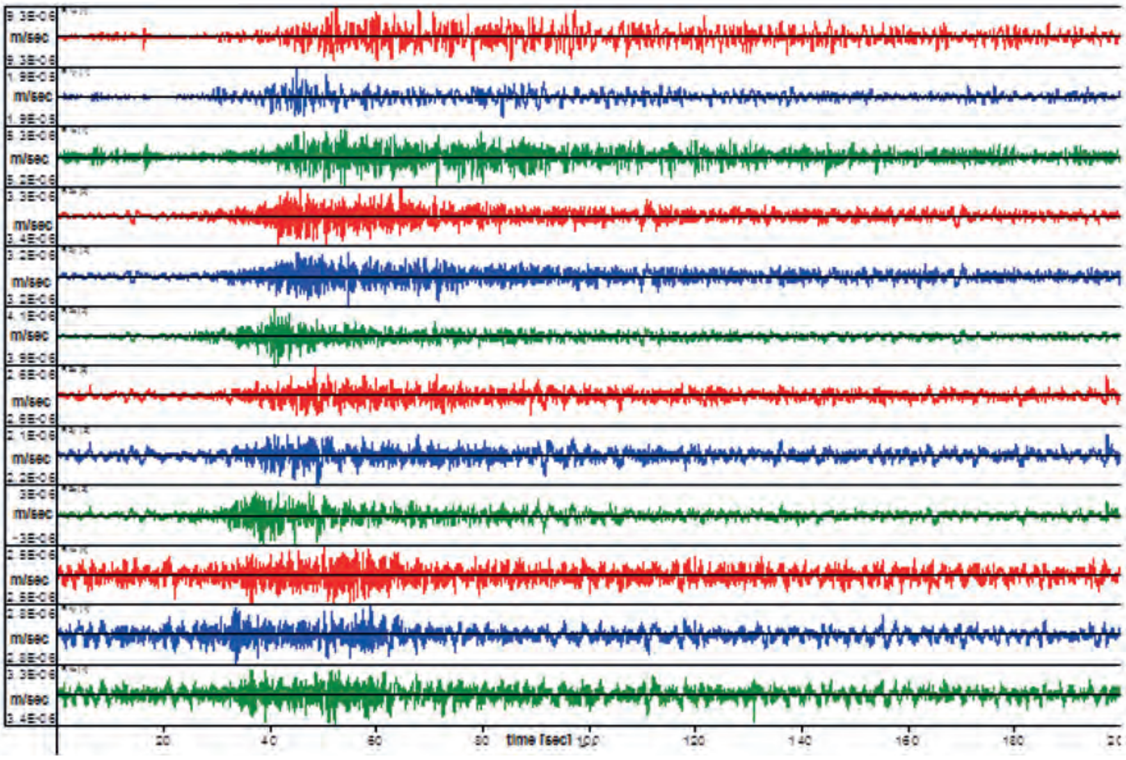


Fig. 85 Record of the earthquake in the Bering Sea on 06.23.2014, onstations in the Gapowo-1 well area. Recorder 1 (channel 1–3), Recorder 2 (channel 4–6), the Recorder 3 (channel 7–9), Recorder 4 (channel 10–12). Start of recording 23:04:30.702 local time.

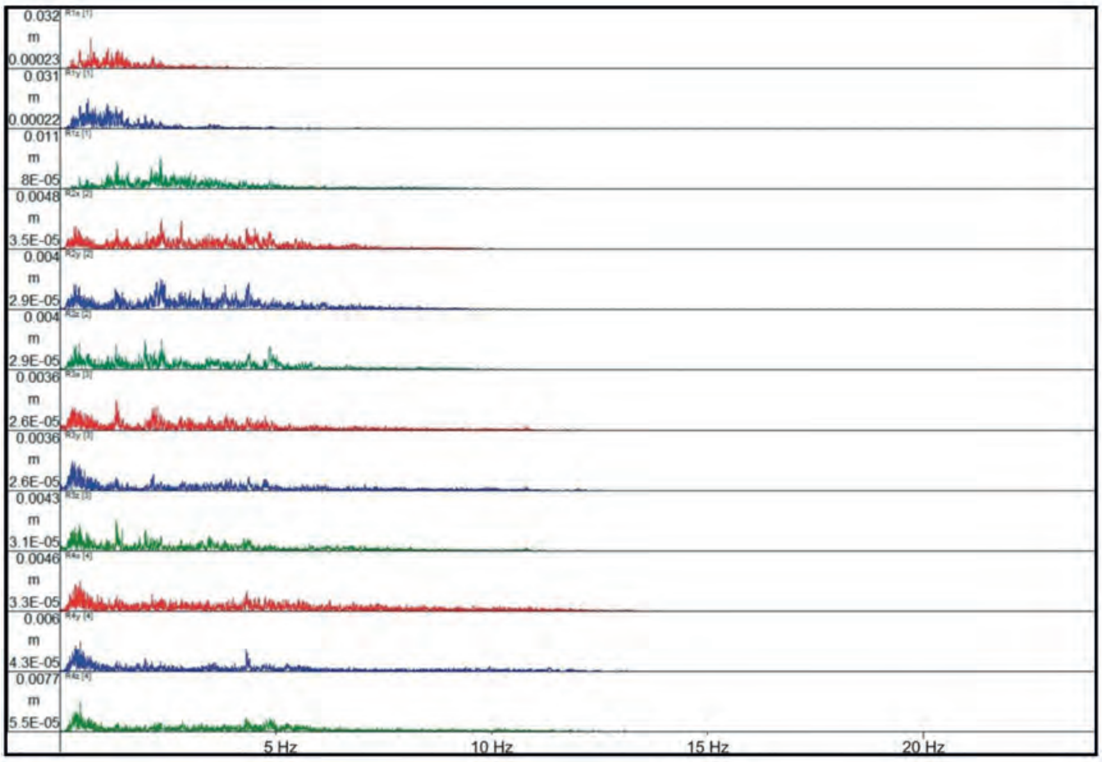


Fig. 86 Fourier analysis (amplitude spectrum) of recording from Fig. 85

7. SUMMARY AND CONCLUSIONS

1. As part of the measurement carried out, a continuous monitoring of seismic vibrations in the three areas was made:
   - In the period from 10.04.2013 to 13.08.2013 at 4 measuring stations around Syczyn-OU2K well,
   - In the period from 12.06.2013 to 5.09.2013 r. at 4 measuring stations around Zwierzyniec-1 well,
   - In the period from 18.03.2014 to 4.08.2014 r. at 4 measuring stations around Gapowo-1 well.
   - In the course of the measurements on the ground surface in the vicinity of the Syczyn-OU2K, Zwierzyniec-1 and Gapowo-1 wells, no vibrations emanating from the seismic events associated with the process of cracking the rock caused by hydraulic fracturing were recorded.
2. In the area of the Syczyn-OU2K well a paraseismic vibrations on the ground surface caused by operation of hydraulic fracturing equipment (pumps) were found. These vibrations were registered only at the station closest to the well (Syczyn 2 station in Syczyn), and the maximum amplitudes have reached a value of 1 mm/s. Registered vibrations did not exceed the permissible vibration levels according to Polish Standard PN-85 / B-02170 and the German standard DIN 4150/3 and had no impact on building infrastructure at the measuring station.
3. Registered paraseismic vibrations did not exceed the permissible vibration levels according to the Polish standard PN-88 / B-02171 and had no impact on people in buildings.
4. In the course of the measurements a paraseismic vibrations related primarily to the road traffic were found. Their level does not exceed the value of 2 mm/s.
5. Conducted monitoring also enabled registration of the teleseismic events, i.e. registration of vibrations emanating from distant earthquakes, which did not affect the building infrastructure in the area of study.

8. LIST OF ANNEXES

Annex No. 1 Location map of Syczyn-OU2K test site

Annex No. 2 Location map of Zwierzyniec-1 test site

Annex No. 3 Location map of Gapowo-1 test site

Annex No. 4 The area of Syczyn-OU2K well. The distribution of the maximum ground vibration amplitudes in the period from 10.04.2013 to 08.13.2013 for the Syczyn 1 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 5 The area of Syczyn-OU2K well. The distribution of the maximum ground vibration amplitudes in the period from 10.04.2013 to 13.08.2013 for the Syczyn 2 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 6 The area of Syczyn-OU2K well. The distribution of the maximum ground vibration amplitudes in the period from 10.04.2013 to 13.08.2013 for the Syczyn 3 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 7 The area of Syczyn-OU2K well. The distribution of the maximum ground vibration amplitudes in the period from 11.04.2013 to 12.08.2013 for the Syczyn 4 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 8 The area of Zwierzyniec-1 well. The distribution of the maximum ground vibration amplitudes in the period from 12.06.2013 to 6.09.2013 for the Zawada 1 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 9 The area of Zwierzyniec-1 well. The distribution of the maximum ground vibration amplitudes in the period from 12.06.2013 to 6.09.2013 for the Zawada 2 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 10 The area of Zwierzyniec-1 well. The distribution of the maximum ground vibration amplitudes in the period from 12.06.2013 to 6.09.2013 for the Zawada 3 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 11 The area of Zwierzyniec-1 well. The distribution of the maximum ground vibration amplitudes in the period from 12.06.2013 to 6.09.2013 for the Zawada 4 station. Component X, Y, Z, and the resultant XYZ respectively.

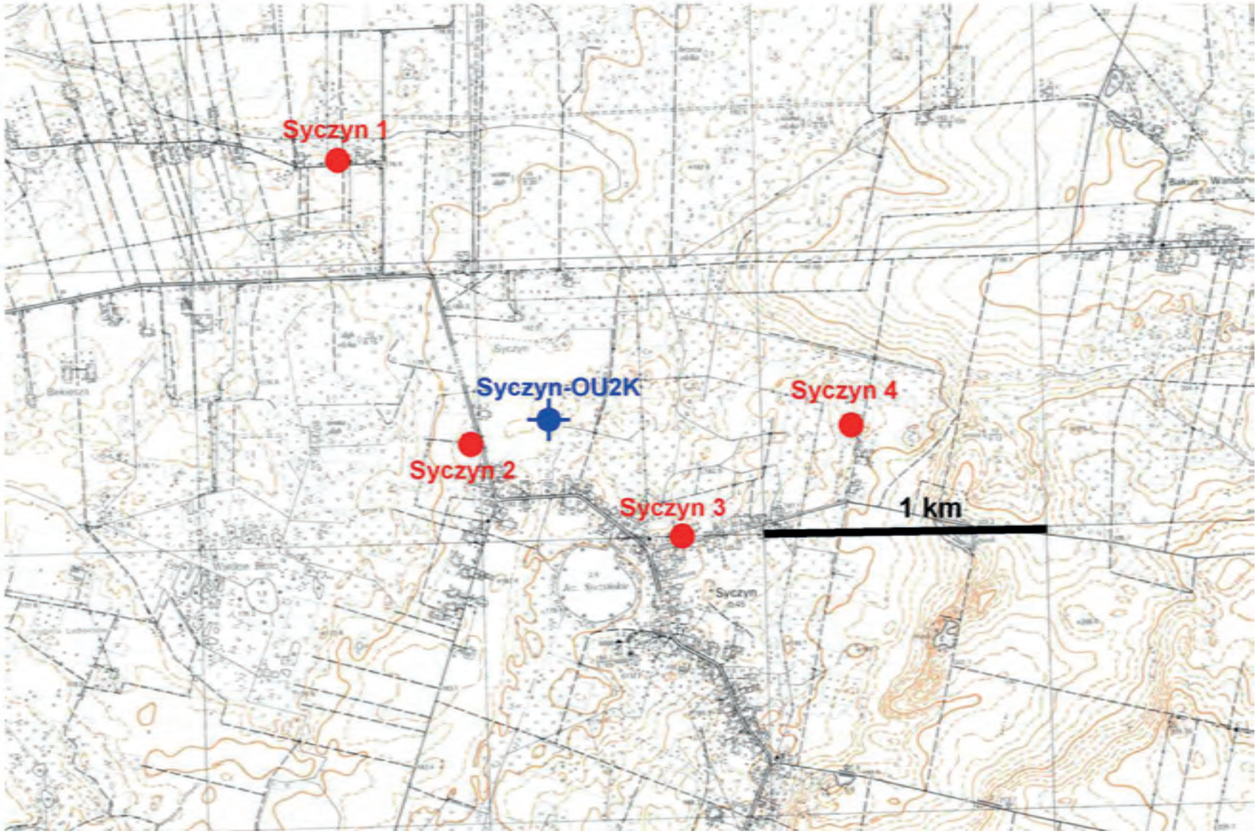
Annex No. 12 The area of Gapowo-1 well. The distribution of the maximum ground vibration amplitudes in the period from 19.03.2014 to 4.08.2014 for the Recorder 1 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 13 The area of Gapowo-1 well. The distribution of the maximum ground vibration amplitudes in the period from 19.03.2014 to 4.08.2014 for the Recorder 2 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 14 The area of Gapowo-1 well. The distribution of the maximum ground vibration amplitudes in the period from 18.03.2014 to 4.08.2014 for the Recorder 3 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex No. 15 The area of Gapowo-1 well. The distribution of the maximum ground vibration amplitudes in the period from 18.03.2014 to 4.08.2014 for the Recorder 4 station. Component X, Y, Z, and the resultant XYZ respectively.

Annex 1 Location map of Syczyn-OU2K testing ground



Description of measuring stations:

Syczyn 1 – located in Bekisza, geographical coordinates: /at. 51°18.046′, long. 23°13,573′
Station in the ground, DLM3D probes

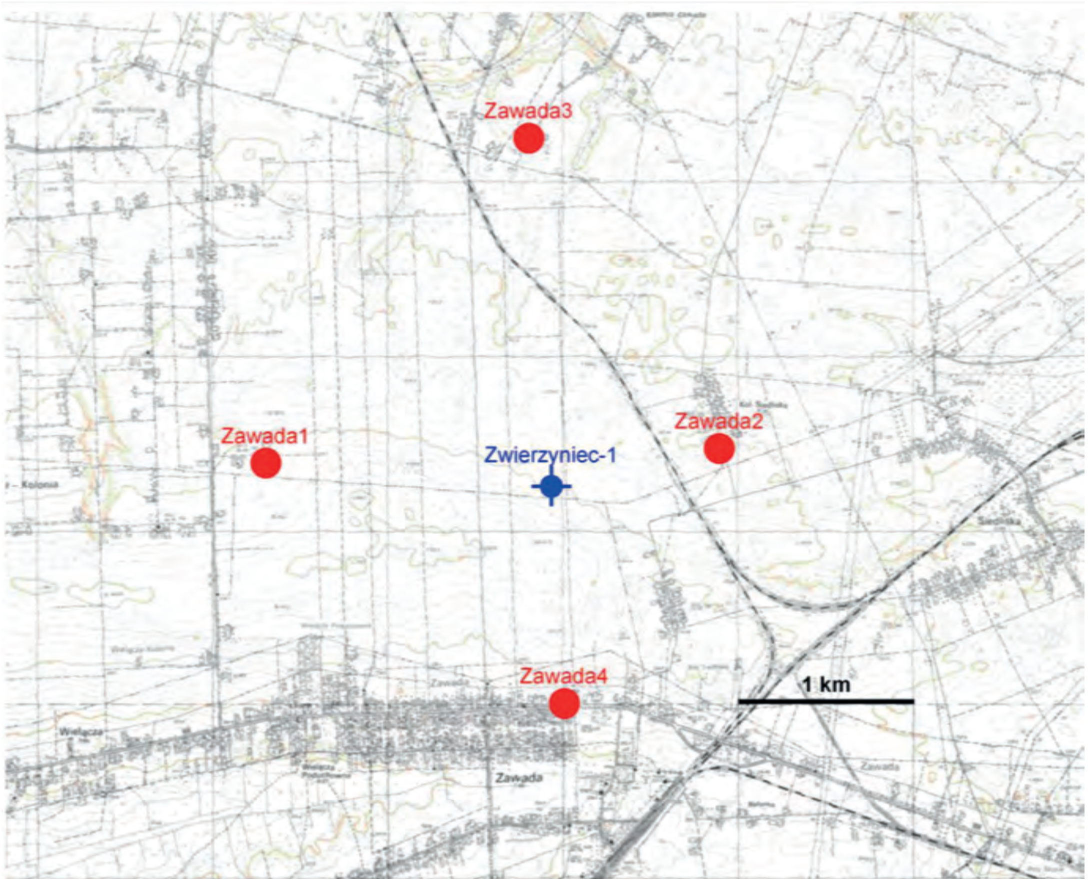
Syczyn 2 – located in the village Syczyn, geographical coordinates: lat. 51°17.504′, long. 23°13.936′
Station on the building foundation, Kinemetrics seismometers.

Syczyn 3 – located in the Syczyn, geographical coordinates: lat. 51°17.286′, long. 23°14.540′
Station in the ground, DLM3D probes

Syczyn 4 – located in the Syczyn, geographical coordinates: lat. 51°17.495′, long. 23°15.069′
Station in the ground, DLM3D probes

Individual geophones mounted in the following manner:
X – horizontal component, NS
Y – horizontal component, EW
Z – vertical component

Annex No. 2 Location map of Zwierzyniec-1 testing ground



Description of measuring stations:

Zawada 1 – located in the Wieląсza Kolonia, geographical coordinates: lat. 50o44.203′, long. 23o05,868′
Station in the ground, DLM3D probes

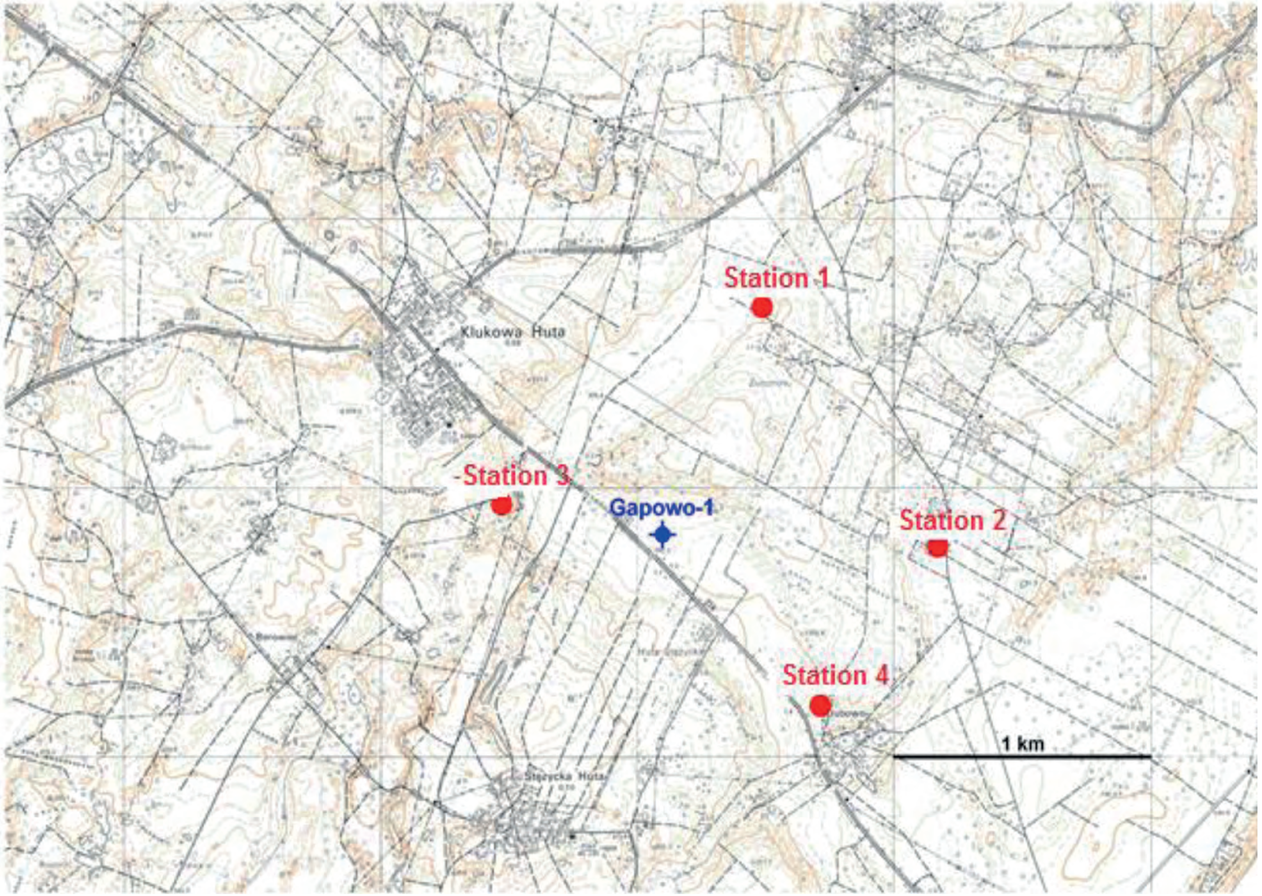
Zawada 2 – located in the Siedliska Kolonia, geographical coordinates: lat. 50o44.185′, long. 23o08,089′
Station in the ground, DLM3D probes

Zawada 3 – located in the Zawada (north), geographical coordinates: lat. 50o45.197′, long. 23o07.183′
Station in the ground, DLM3D probes

Zawada 4 – located in the Zawada (south), geographical coordinates: lat. 50o43.469′, long. 23o07.350′
Station on the building foundation, Kinemetrics seismometers

Individual geophones mounted in the following manner:
X – horizontal component, NS
Y – horizontal component, EW
Z – vertical component.

Annex No. 3 Location map of Gapowo -1 testing ground



Description of measuring stations:

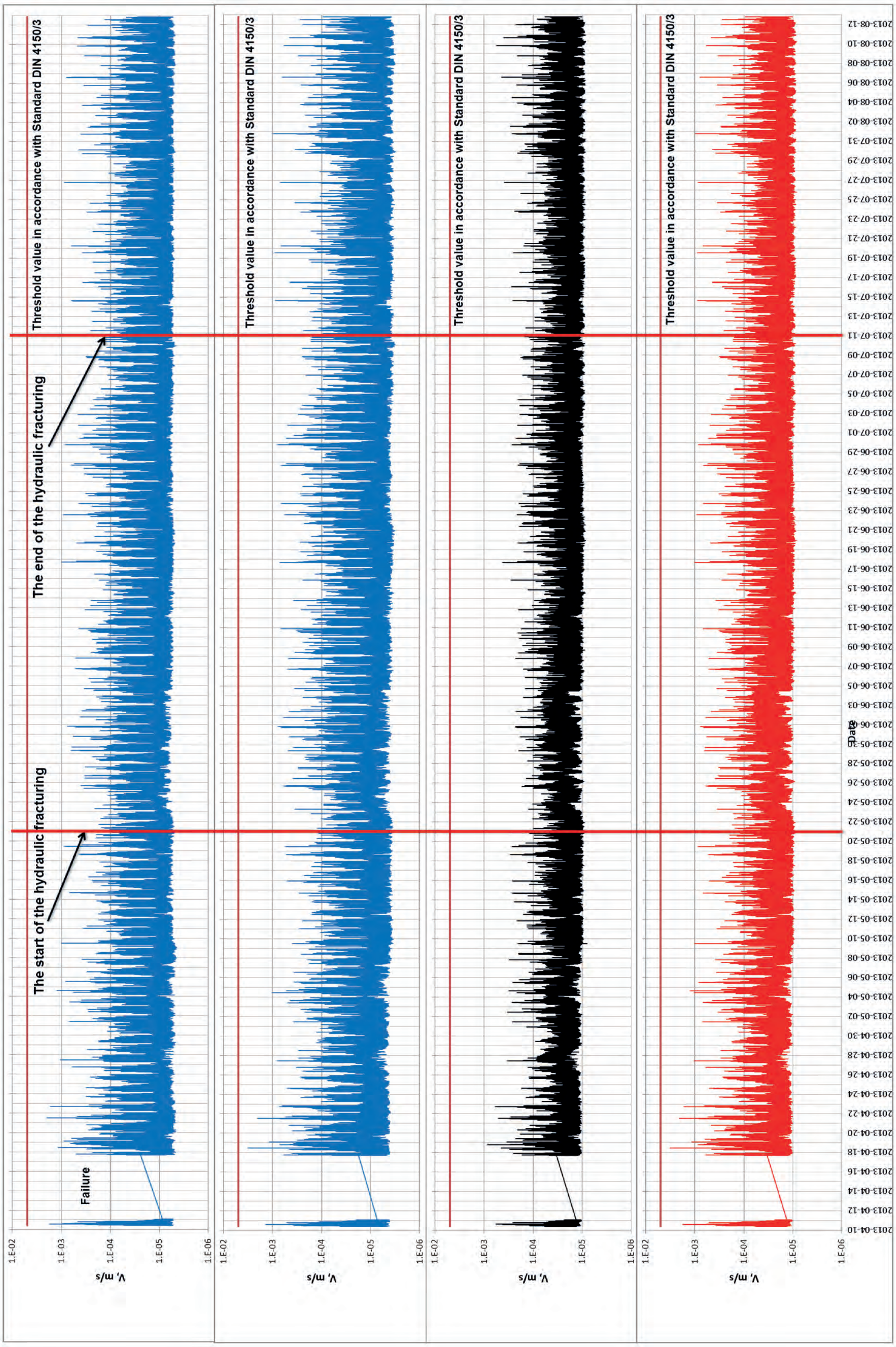
Station 1 – located in Żuromino, geographical coordinates: lat. 54°14.494′N, long. 17°55.141′″E.
Station on the building foundation, Kinemetrics seismometers

Station 2 – located in Żuromino, geographical coordinates: lat. 54°14.013′N, long. 17°55.758′E
Station in the ground, DLM3D probes

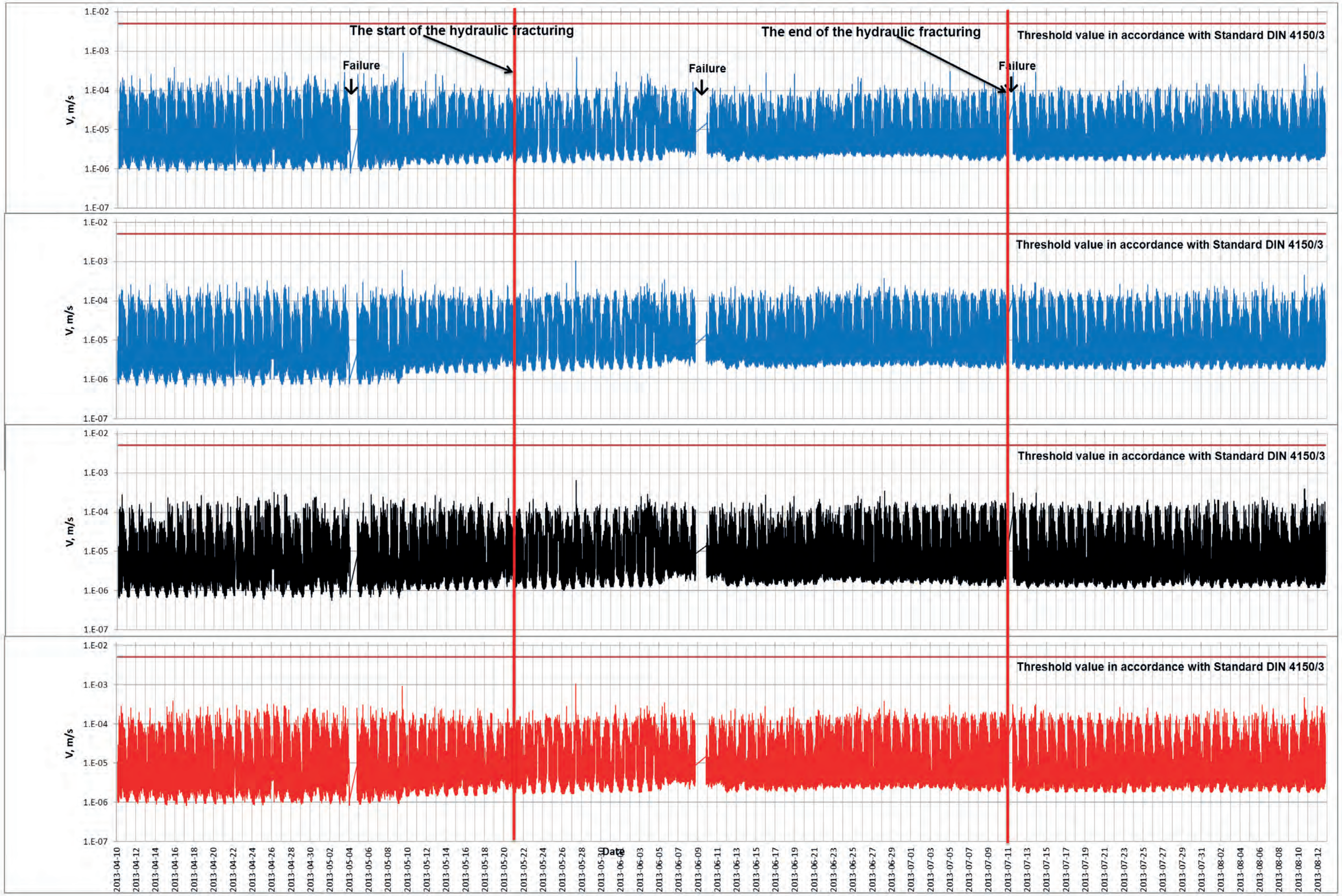
Station 3 – located in Borowiec, geographical coordinates: lat. 54°14.107′N, long. 17°54.193′E
Station in the ground, DLM3D probes.

Station 4 – located in Dubowo, geographical coordinates: lat. 54°13.707′N, long. 17°55.321′E
Station in the ground, DLM3D probes.

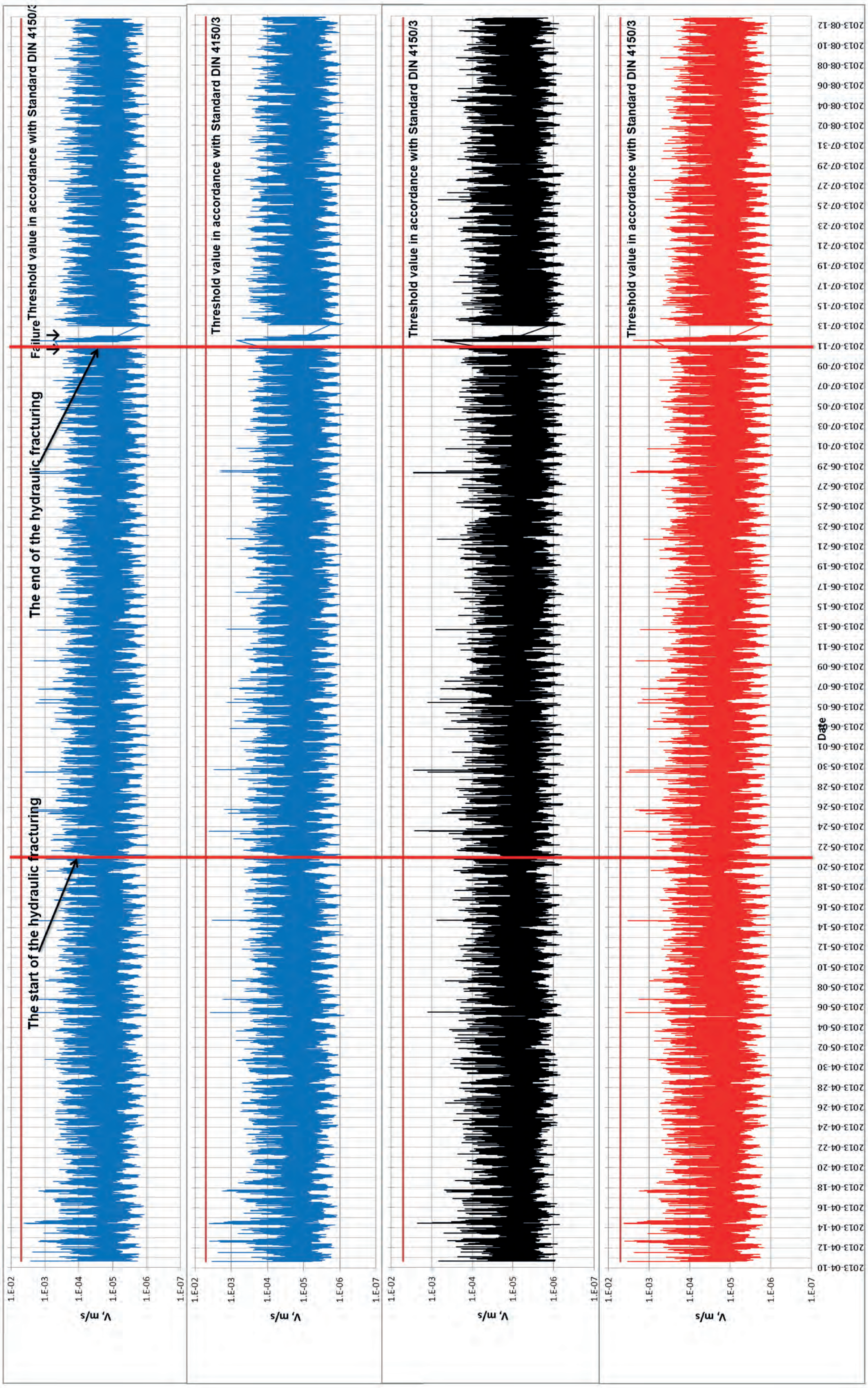
Individual geophones mounted in the following manner:
X – horizontal component, NS
Y – horizontal component, EW
Z – vertical component.



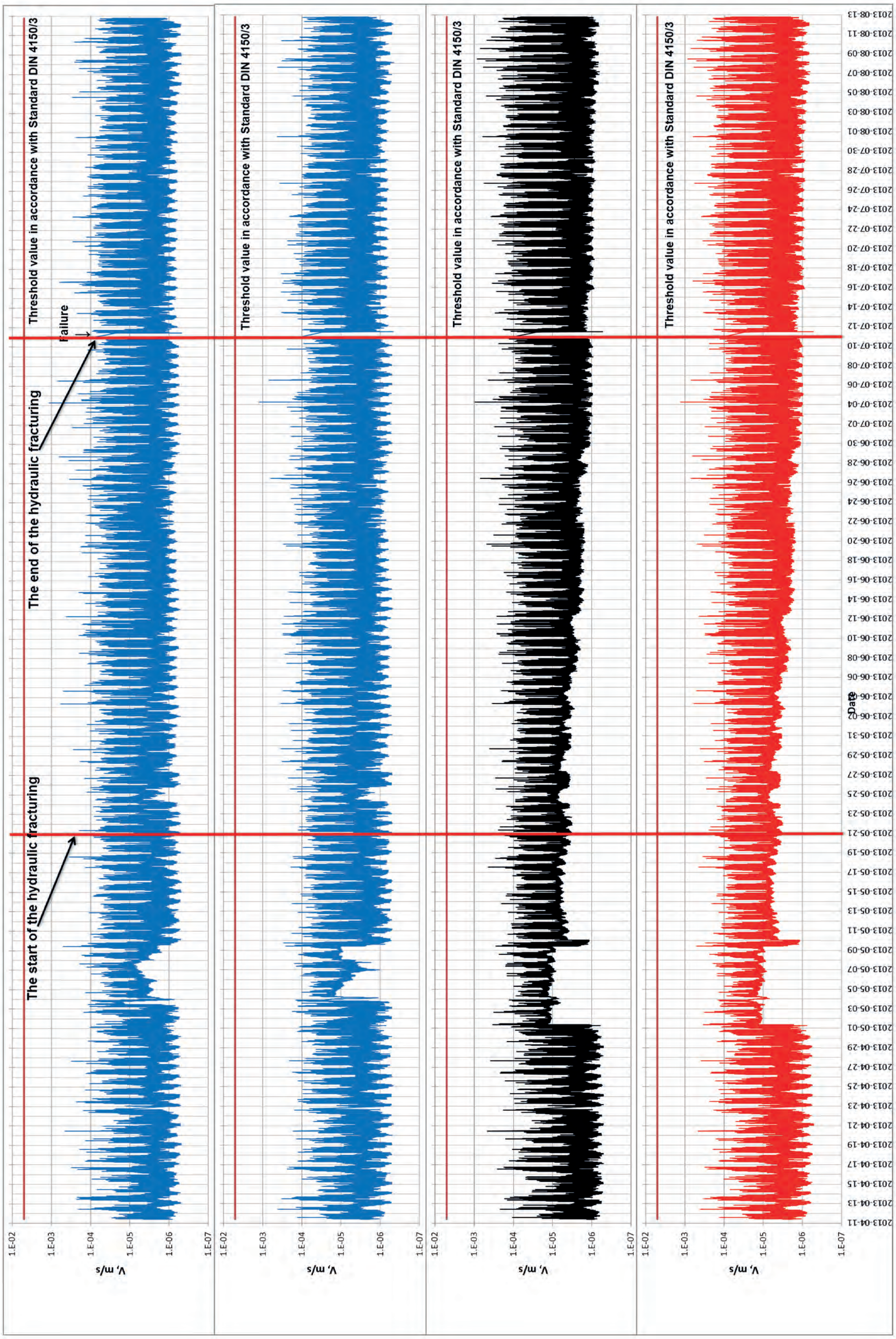
Annex No. 4 Region of Syczyn-OU2K hole. The distribution of the maximum ground vibration amplitudes in the period 12.06.2013 to 6.09.2013 for the Syczyn 1 station. Component X, Y, Z, and the resultant XYZ respectively.



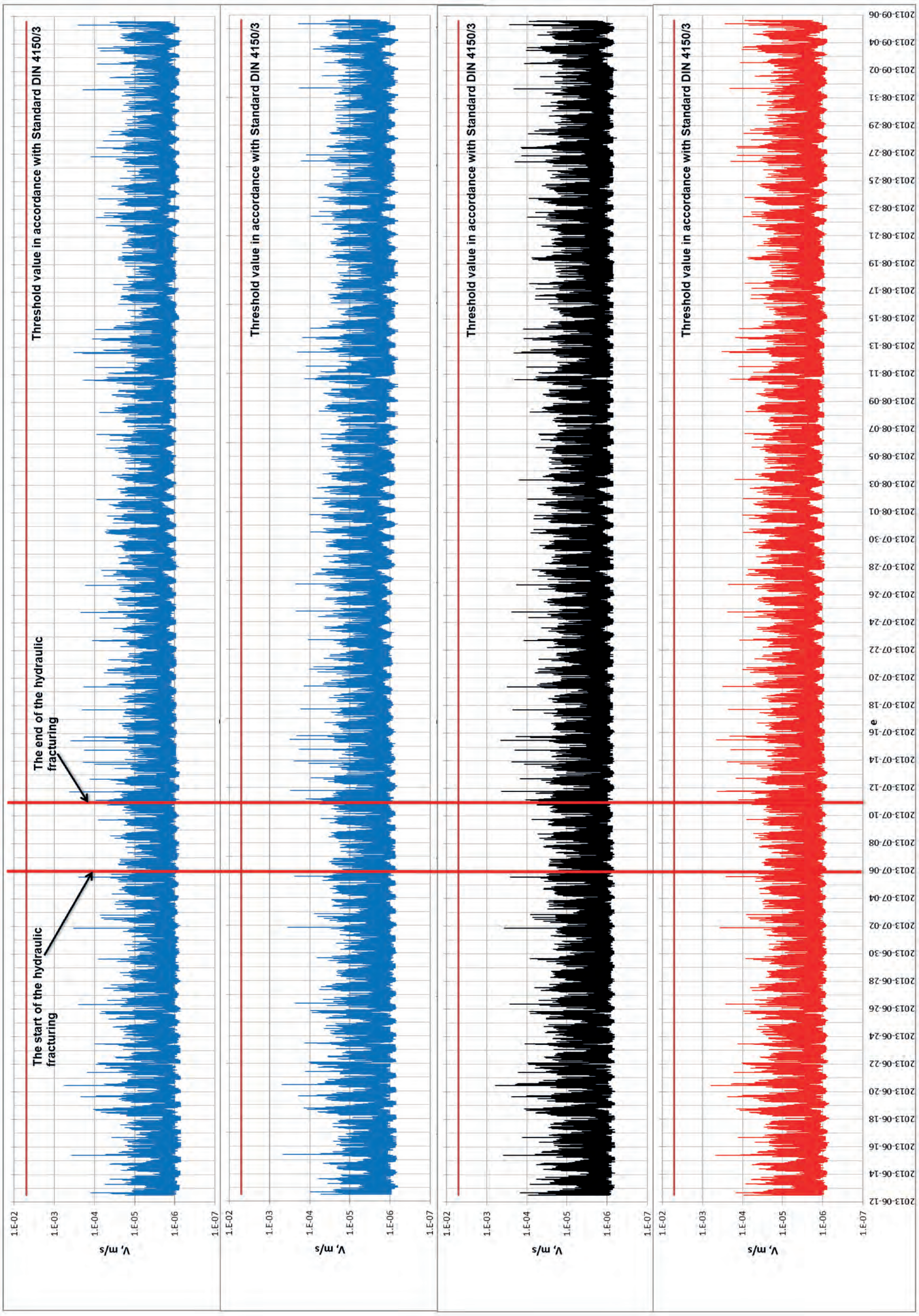
Annex No. 5 Region of Syczyn-OU2K hole. The distribution of the maximum ground vibration amplitudes in the period 10.04.2013 to 13.08.2013 for the Syczyn 2 station. Component X, Y, Z, and the resultant XYZ respectively.



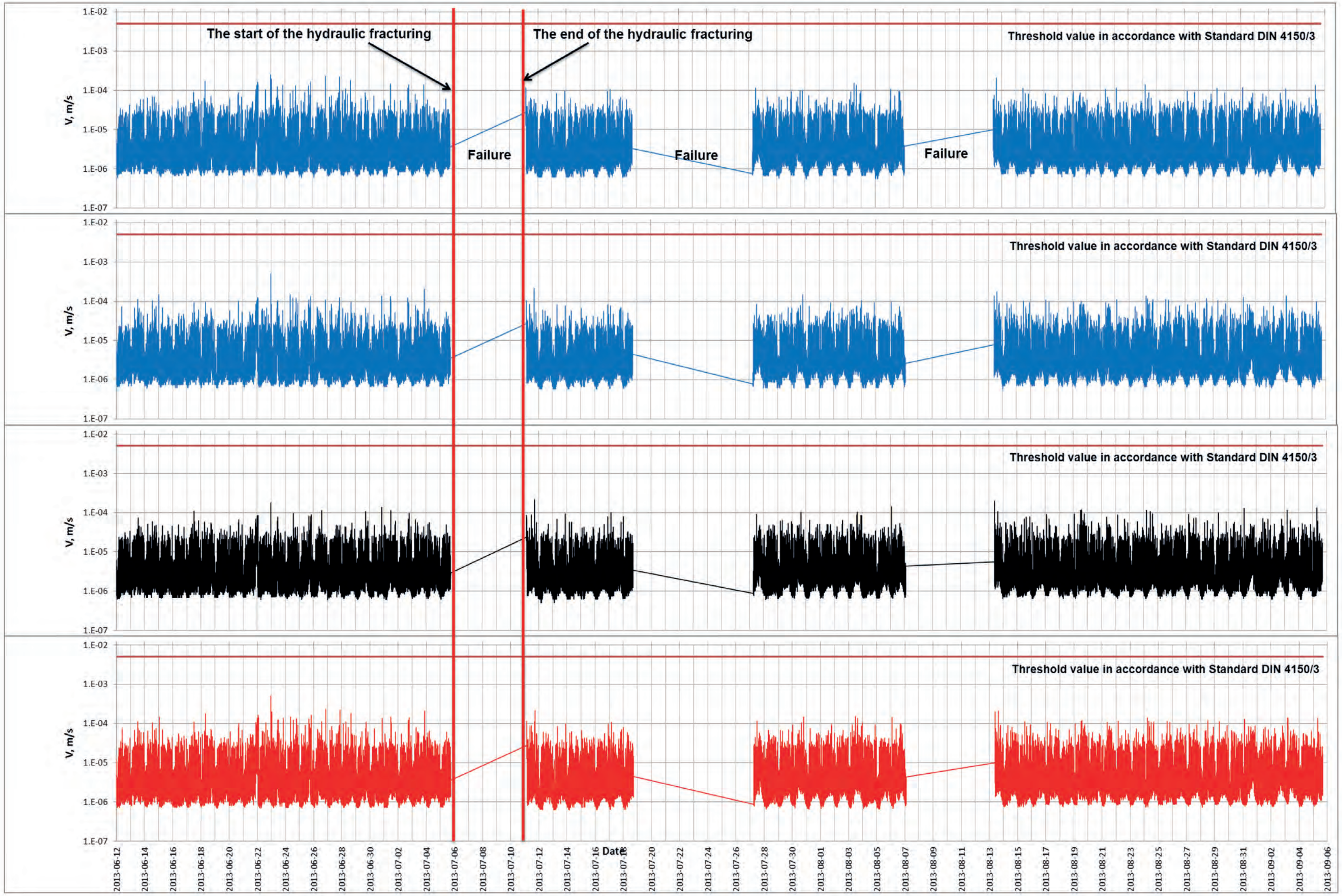
Annex No. 6 Region of Syczyn-OU2K hole. The distribution of the maximum ground vibration amplitudes in the period 10.04.2013 to 13.08.2013 for the Syczyn 3 station. Component X, Y, Z, and the resultant XYZ respectively.



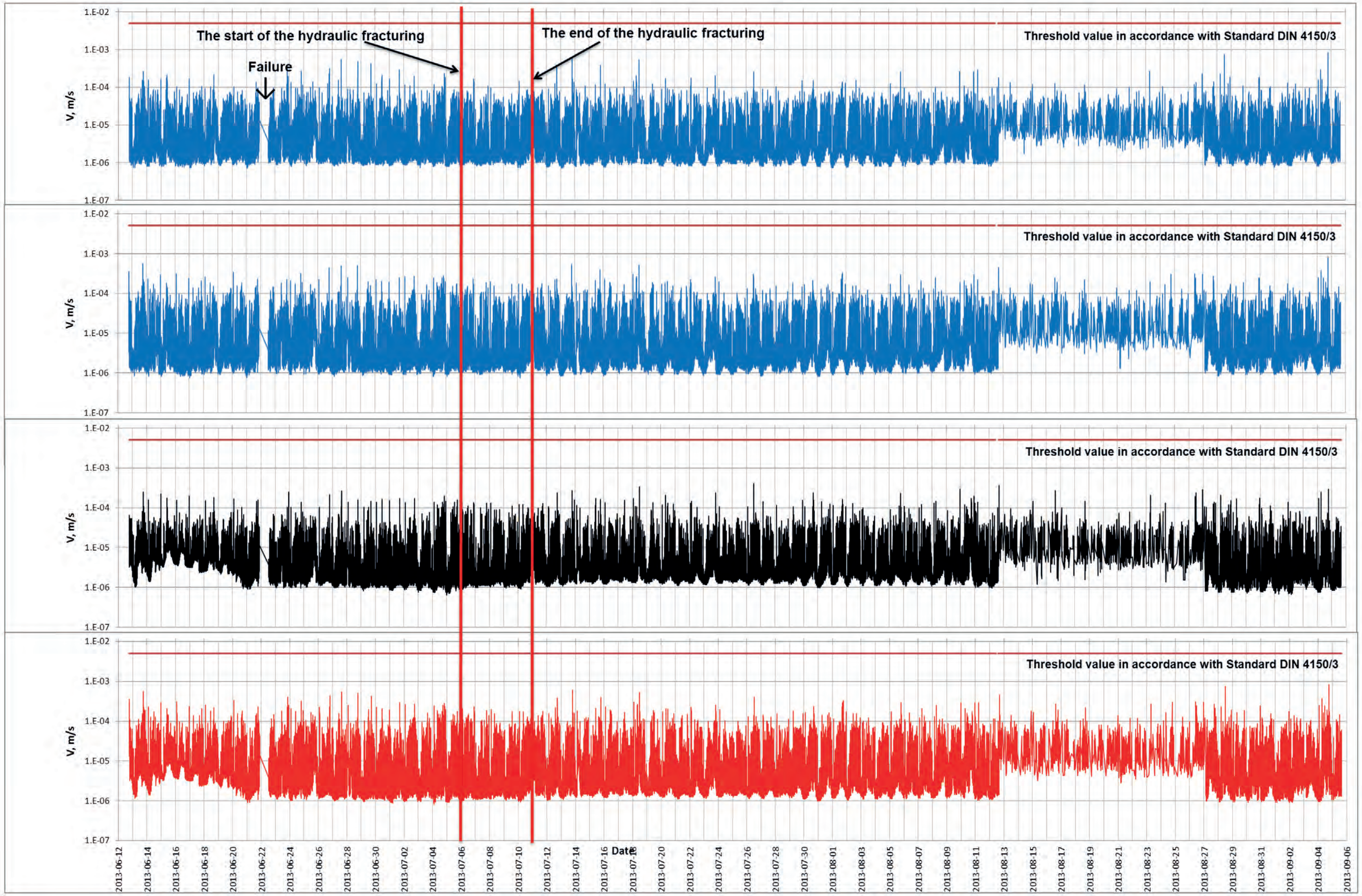
Annex No. 7 Region of Syczyn-OU2K hole. The distribution of the maximum ground vibration amplitudes in the period 11.03.2013 to 12.08.2013 for the Syczyn 4 station. Component X, Y, Z, and the resultant XYZ respectively.



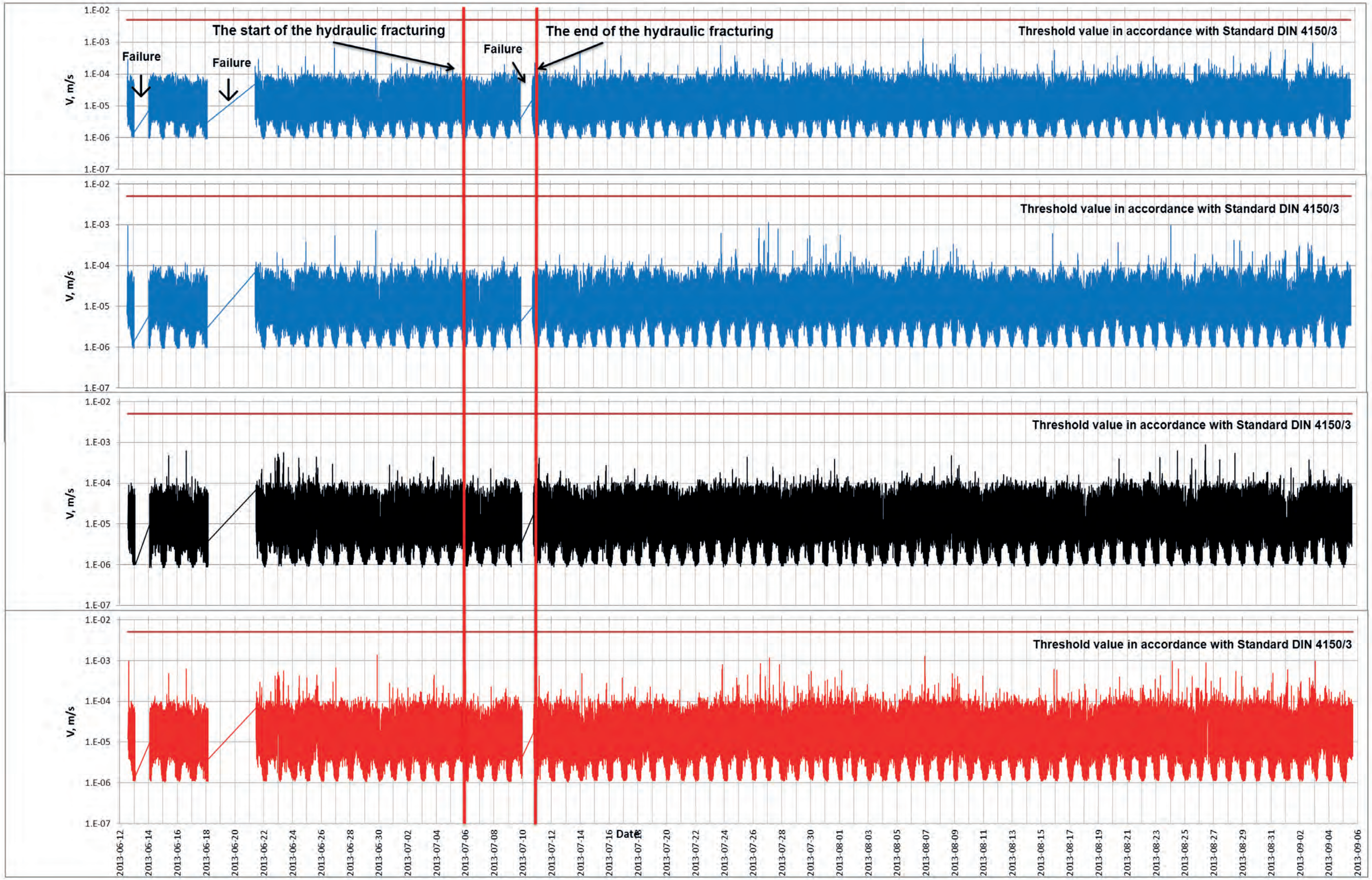
Annex No. 8 Region of Zwierzyniec-1 hole. The distribution of the maximum ground vibration amplitudes in the period 12.06.2013 to 6.09.2013 for the Zawada 1 station. Component X, Y, Z, and the resultant XYZ respectively.



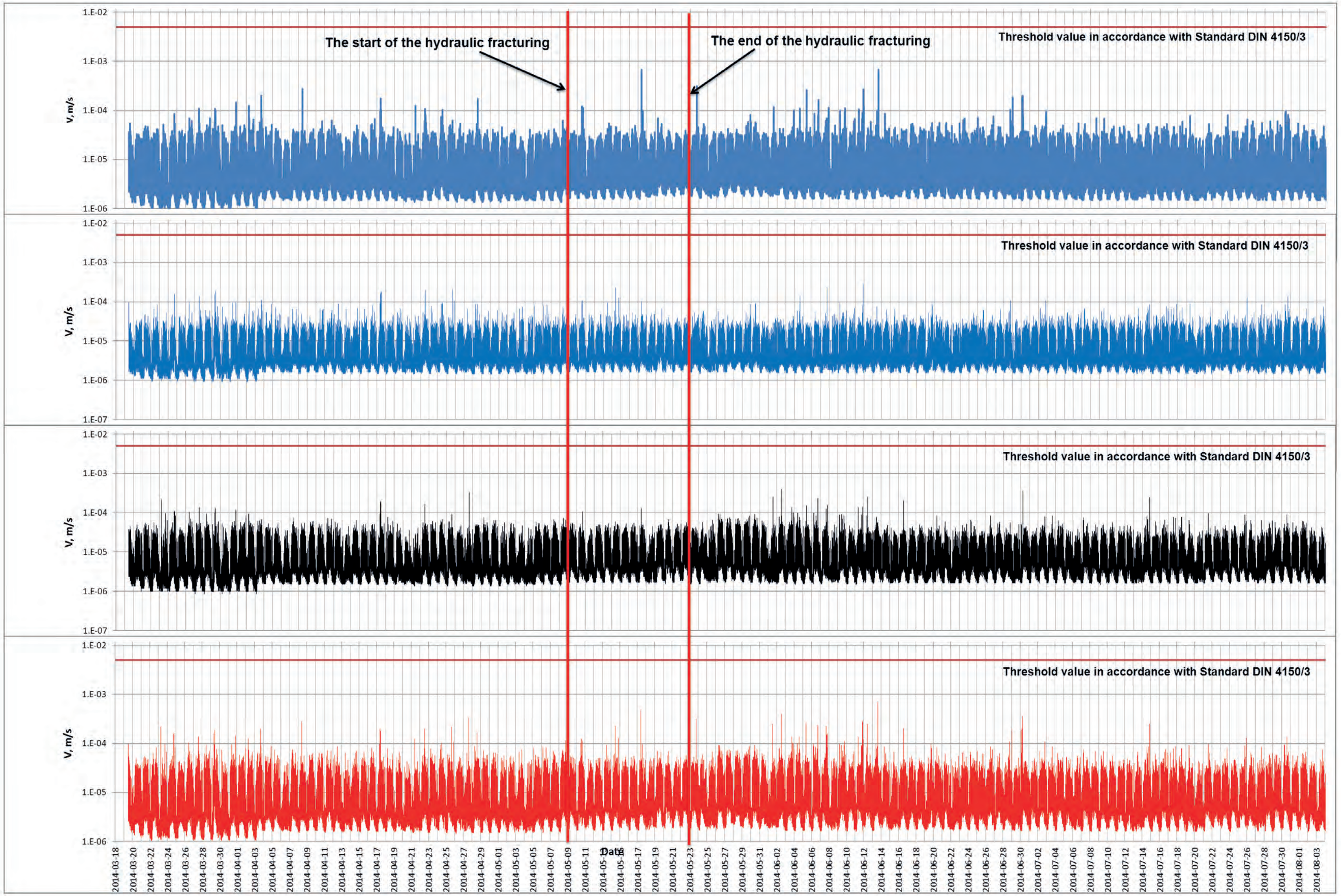
Annex No. 9 Region of Zwierzyniec-1 hole. The distribution of the maximum ground vibration amplitudes in the period 12.06.2013 to 6.09.2013 for the Zawada 2 station. Component X, Y, Z, and the resultant XYZ respectively.



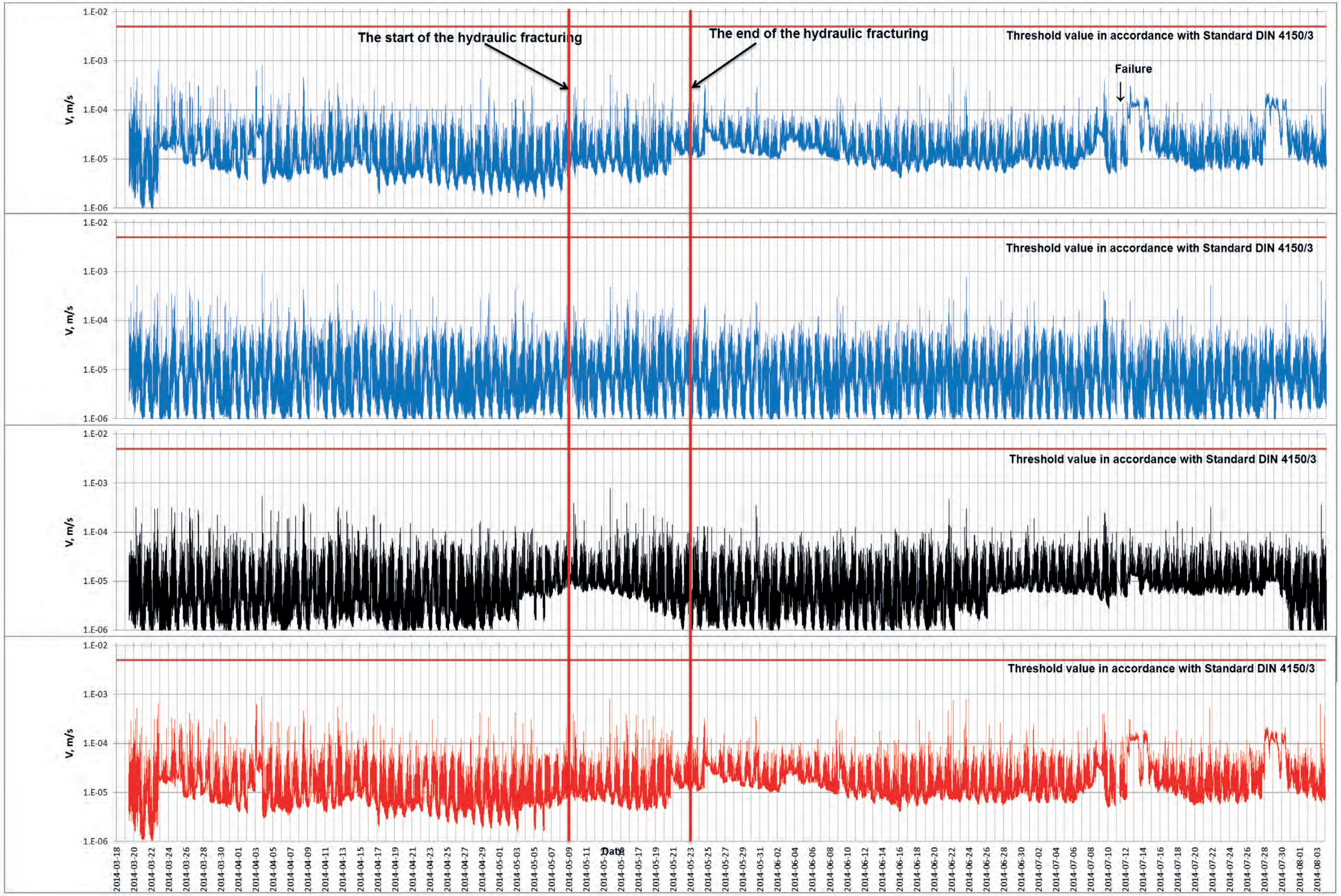
Annex No. 10 Region of Zwierzyniec-1 hole. The distribution of the maximum ground vibration amplitudes in the period 12.06.2013 to 6.09.2013 for the Zawada 3 station. Component X, Y, Z, and the resultant XYZ respectively.



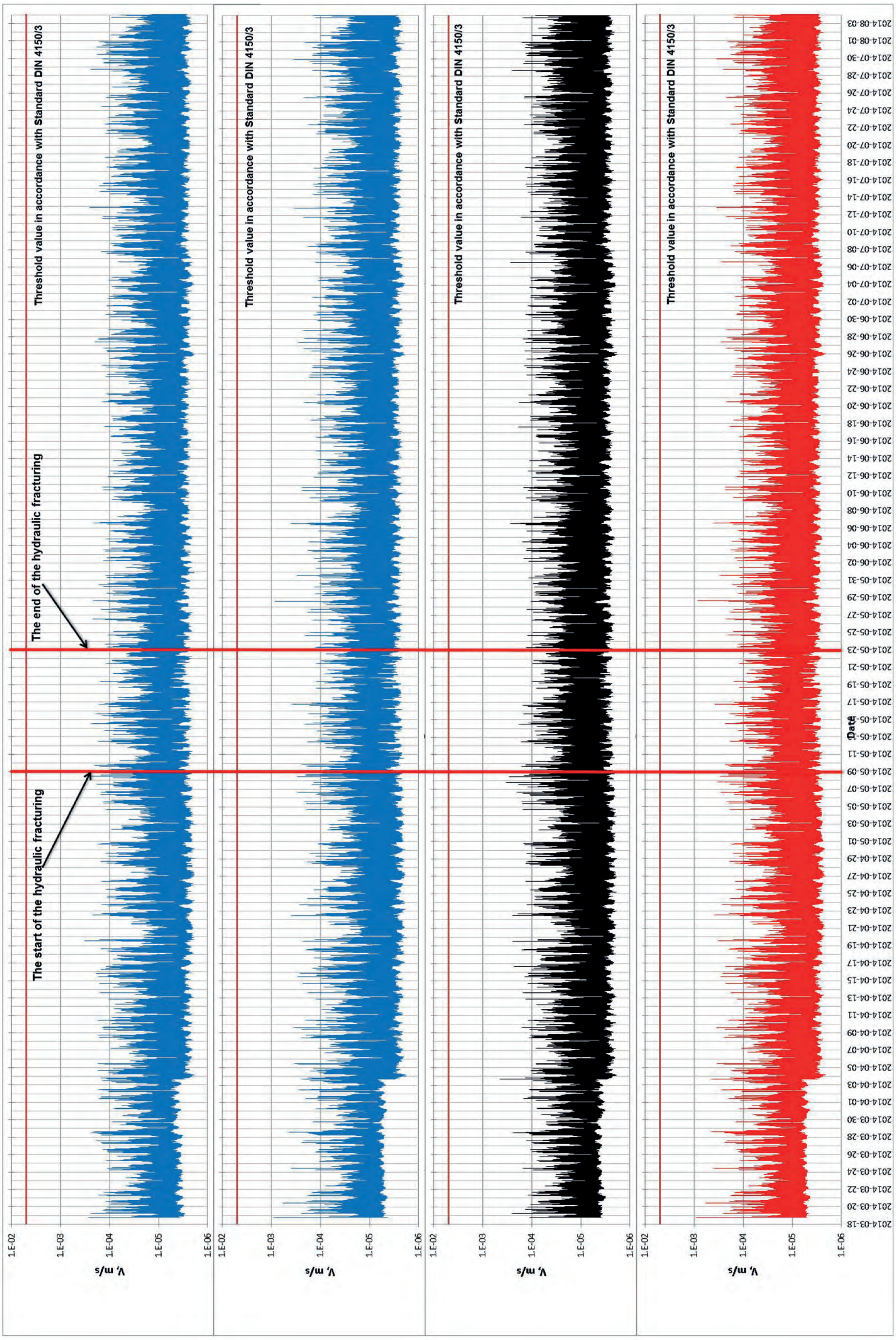
Annex No. 11 Region of Zwierzyniec-1 hole. The distribution of the maximum ground vibration amplitudes in the period 12.06.2013 to 6.09.2013 for the Zawada 4 station. Component X, Y, Z, and the resultant XYZ respectively.



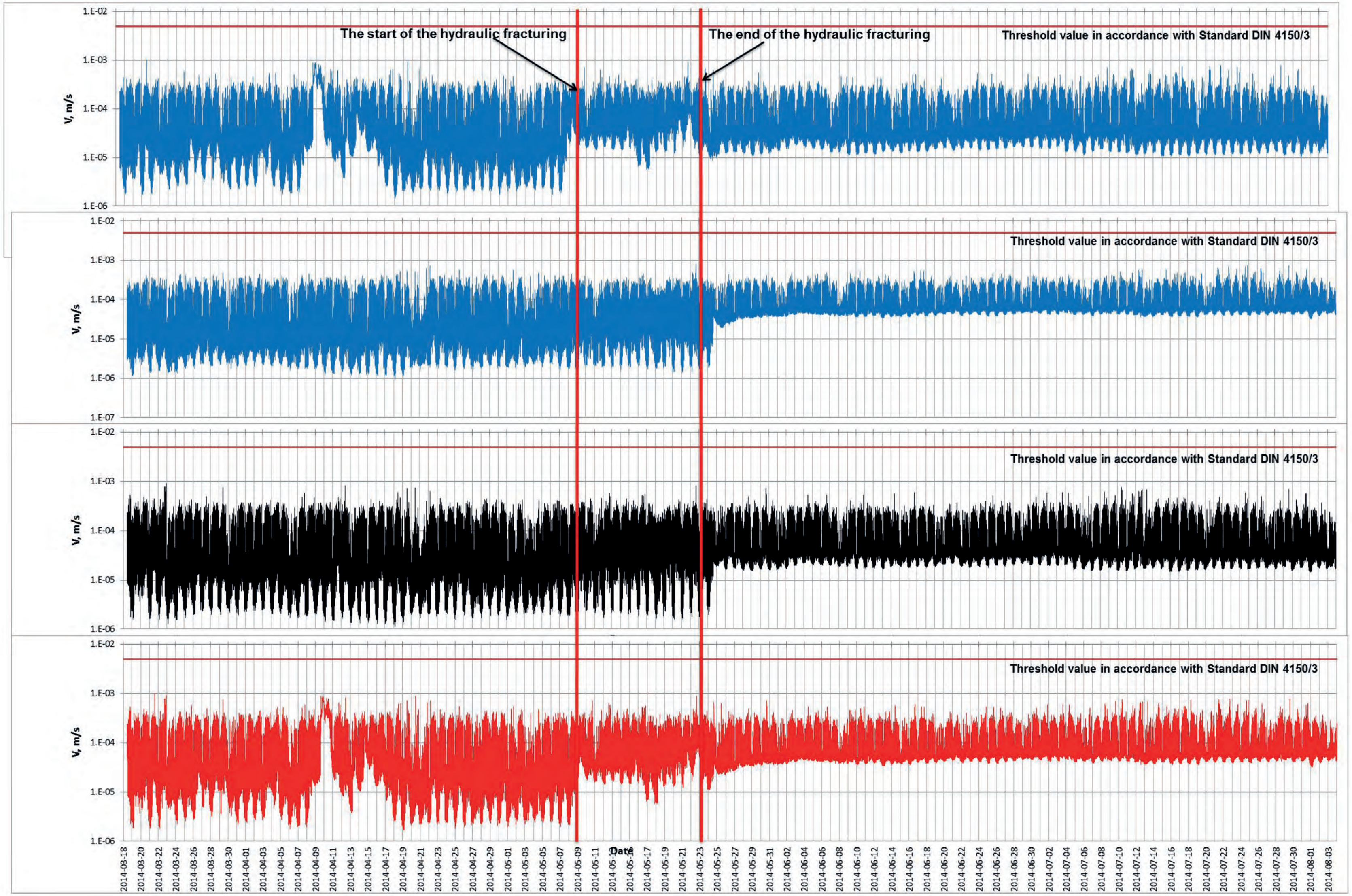
Annex No. 12 Region of Gapowo-1 hole. The distribution of the maximum ground vibration amplitudes in the period from 06.12.2013 to 06.09.2013 for the Recorder 1 station. Component X, Y, Z, and the resultant XYZ respectively.



Annex No. 13 Region of Gapowo-1 hole. The distribution of the maximum ground vibration amplitudes in the period from 06.12.2013 to 06.09.2013 for the Recorder 2 station. Component X, Y, Z, and the resultant XYZ respectively.



Annex No. 14 Region of Gapowo-1 hole. The distribution of the maximum ground vibration amplitudes in the period from 06.12.2013 to 06.09.2013 for the Recorder 3 station. Component X, Y, Z, and the resultant XYZ respectively.



Annex No. 15 Region of Gapowo-1 hole. The distribution of the maximum ground vibration amplitudes in the period from 06.12.2013 to 06.09.2013 for the Recorder 4 station. Component X, Y, Z, and the resultant XYZ respectively.