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LOCAL EFFECTS IN PEAK ACCELERATIONS CAUSED BY MINING TREMORS IN BYTOM SYNCLINE REGION (UPPER SILESIA)

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ABSTRACT

This paper shows how the local effects can change the value of maximum accelerations from mining-induced tremors. The analysis was carried out basing on data collected from acceleration stations installed in Bytom Syncline region (Upper Silesia). The estimation of the local effects was obtained on the basis of deviations from the attenuation relation. The accelerograms were recorded from the mining tremors in low seismic energy range and in epicentral distances in the range from 500m to 5000m. The obtained results were correlated with results from Horizontal to Vertical Spectral Ratio (HVSR) technique. This method is based on simple theoretical foundation and is commonly used in natural seismicity studies. Our results show that the H/V ratio technique gives a reasonable estimate of the surface amplification for frequency range between about 2 and 8 Hz. In case of simple geology and when the signal to noise is adequately high the results are the best. All the results show that there occur local effects.

KEYWORDS: amplification of vibration, HVSR technique, local effects, attenuation relation

INTRODUCTION

On the surface one can observe many negative results of underground mining which have influence on infrastructure. These effects have relation to tremors, their epicentral distance, depth of occurrence of shock, energy of shock and geological structure.

Some of the regions that are mostly damaged by the effects are Bytom and Piekary Śląskie, located in the Upper Silesia region. In this area there are situated two still active coal mines, namely “Bobrek - Centrum” and Zakład Górniczy “Piekary”. In the paper the variations of the acceleration amplitude of recorded mining tremors are analyzed. One of the parameters describing this change is the amplification factor. The amplification factor increases when velocity decreases of the seismic wave in superficial layer (Olszewska and Lasocki, 2004). This can be related exactly with variety of geological formation of the superficial layers and their thickness. The size of amplification is known as local effect.

In this work amplification factor was calculated using HVSR (Horizontal to Vertical Spectral Ratio) method. The HVSR method is based on the ratio of the horizontal and vertical components of amplitude spectra of ground accelerations.

ANALYSIS OF GEOLOGICAL CONDITIONS

In the Bytom Syncline area the mining is connected with occurrence of lead and coal deposits. Locally there occur triasic and quaternary layers deposited above the carboniferous formation. The thickness of triasic formation changes significantly. The roof of triasic formations occurs sometimes already at small depths, depending on site where the accelerometers were installed. Therefore the thickness of quaternary sediments changes, reaching at some sites up to 50 m. Quaternary sediments are mainly formed by sands and clays. The earlier research of the analyzed area has been done by means of analytical methods. The amplification was assessed basing on analytical methods assuming the specific geological cross-section and therefore calculated amplification had little precision. In the presented article the estimated amplification factor was correlated with conclusions from the analysis of the attenuation relation of recorded accelerograms. Additionally the results were compared to geological profile of the site.

HVSR METHOD

The best calculation of the amplification factor is when we have data from borehole seismographs. Because the installation of borehole seismographs is costly and difficult one can use data from acceleration stations installed at the surface. We have analyzed records from four automatic stations with three component recordings installed by the coal mines.

The HVSR method is based on ratio between the horizontal to vertical components of acceleration amplitude spectra (Nakamura, 1989). This method gives the best results when the factor is assessed from S wave. Because the epicentral distances were small, it was not possible to identify S waves so we have calculated spectral ratio from the whole signal. We take the time window for all data and calculate

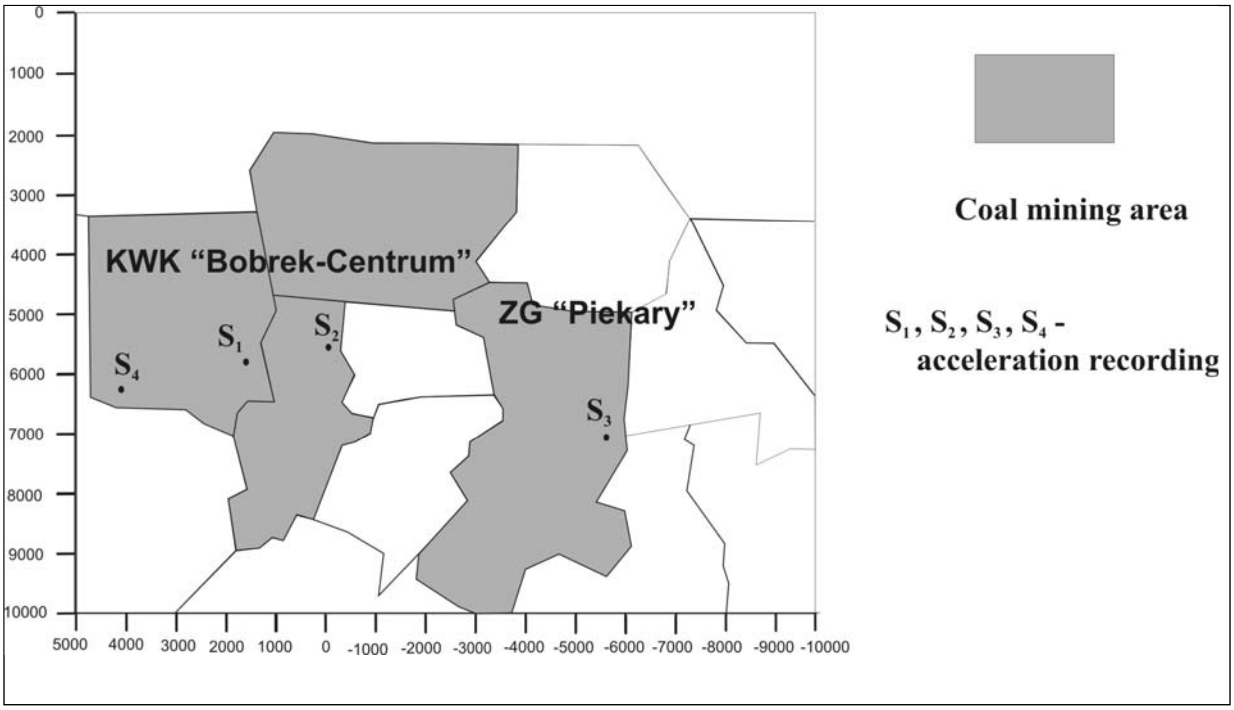

Fig. 1 Location of recording stations in Bytom Syncline.

spectrum by using fast Fourier transformation. Then the spectral ratio between the horizontal and the vertical component (H/V ratio) is estimated by:

$$\frac{H}{V} = \frac{A_H \cdot G_H + R_H}{A_V \cdot G_V + R_V} = \frac{G_H}{G_V} \cdot \frac{\left[A_H + \frac{R_H}{G_H}\right]}{\left[A_V + \frac{R_V}{G_V}\right]} \tag{1}$$

where:

A_H, A_V – amplification factor of horizontal and vertical components of vertically incident body wave

G_H, G_V – spectra of horizontal and vertical motion in the solid basement

R_H, R_V – spectra of horizontal and vertical components of Rayleigh waves,

It was observed (Nakamura, 1989) that the vertical component cannot be amplified around the frequency where horizontal component receives large amplification ($A_V = 1$). There is no influence of Rayleigh wave where the amplification peak is observed ($R_H/G_H = 0$ and $R_V/G_V = 0$). Amplitude spectra of horizontal and vertical component of accelerations are similar ($G_H/G_V = 1$). Then H/V ratio is equal:

$$HVSR = \frac{H}{V} = A_H \tag{2}$$

Next H/V ratio is calculated and smoothed taking a median from set of accelerograms. In this way H/V ratio and the peak of resonance's frequency is obtained. Dominating peak have information about amplification and the frequency is related to principal frequency of the cover. The spectral peaks should be selected from the frequencies above 2 Hz and below 6 - 7 Hz. In this range energy of Rayleigh wave is almost zero. This method gives the best results when the geological layers of the cover are horizontal (Atkinson and Cassidy, 2000).

The HVSR method was checked through theoretical and empirical analyses (Lachet and Bard, 1994; Konno and Ohmachi, 1998; Tsuboi et al., 2001).

EXPERIMENTAL DATA

Analyzed data come from four stations located in Bytom Syncline region, Upper Silesia, (Fig. 1). In this stations are installed recorders, which automatically record changes of acceleration vibration of ground surface. All stations have three component accelerometers which are mounted on building foundations. Such install does not interfere analysis of records because the vibrations of foundations for small buildings are similar to records observed on earth surface (Maciąg and Tatara, 1999; Lasocki et al.,

Table 1 Analysed data.

L.P.	Recording station	No of analyzed recordings	Station coordinates		
			X	Y	Z
1	S_1	215	5807	1626	285
2	S_2	211	5960	4	270
3	S_3	108	7242	- 5982	289
4	S_4	50	6255	- 4064	283

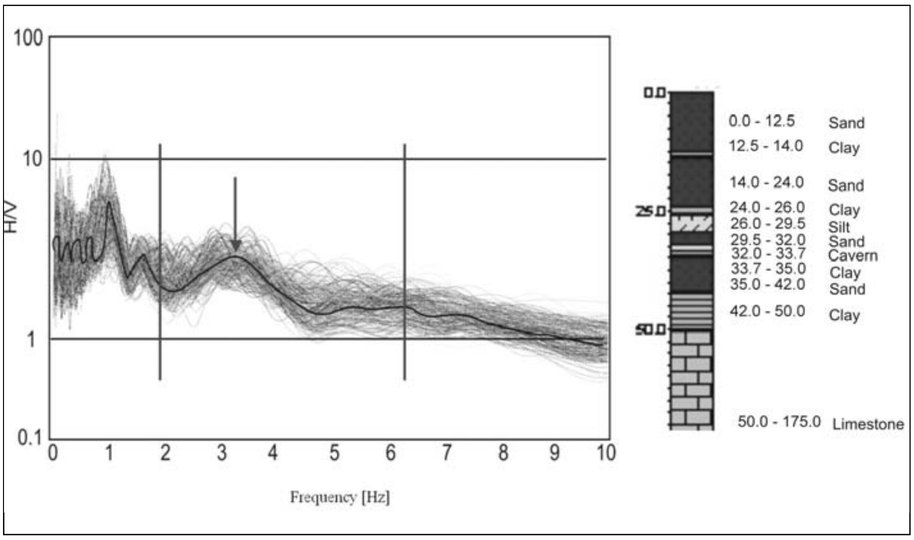

Fig. 2 Spectral ratios of mining tremors recorded at S_1 station with geological profile of the site (right).

2000). The frequency range of flat transfer function was from about 1-2 Hz to 100-200 Hz (Markowski et al., 2002). The records used in analysis come from the period 1997 - 2004.

ANALYSIS OF ACCELEROGRAMS

The software JSESAME Version 1.08 was used for the analyses which allow the calculations of H/V ratio. The analysis of all accelerograms and their spectra show that the H/V ratios for individual station have approx. linear character for each station in selected frequency range. The results of H/V ratio calculations for each station are presented in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. denoting the median value by thickened line. The received results are compatible with the earlier results of research which led in GZW area. The maximum value of H/V ratio for S_1 station is observed at 3.5 Hz what was marked by arrow (Fig. 2), the frequency and the value of the peak of the H/V ratio give information about the value of amplification of the ground vibration, which for S_1 site is equal 3.5. The size of amplification was correlated with geological structure presented in form of the geological profile (Fig. 2). Quaternary strata with thickness of 50 m show, that they can increase the amplitude of vibrations induced by mining tremors.

The H/V ratio for S_2 station (Fig. 3) is more disturbed however the course of average values is clearer. The HVSR curve for this station has two maxima for frequencies of 2.8 Hz and 4.2 Hz. Occurrence of more than one maximum give us information about complicated structure of the quaternary strata what was confirmed by the analysis of geological profile in area of recording site. The value of the maximum at peak of H/V ratio is 3.1. Quaternary thickness reaches in this place 22 m and is represented mainly by sands and clays. Additionally there occurs silt with 11.4 meter thickness, which could also influence the amplification of vibration.

The analysis of H/V spectral ratio for S_3 station (Fig. 4) shows that there occurs one main peak of amplification situated at frequency 3.1 Hz. The peak value is equal 2.0 . The value of amplification can by related with occurrence of quaternary clays, sands and silt to depth of 29 meters below the surface.

Considering recordings from S_4 station (Fig. 5) the one dominating peak of H/V ratio is occurring at

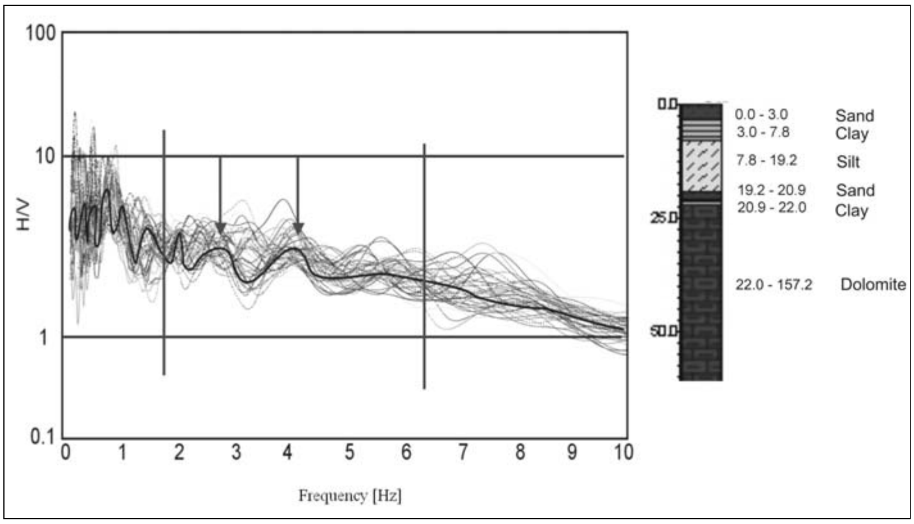

Fig. 3 Spectral ratios of mining tremors recorded at S_2 station with geological profile of the site (right).

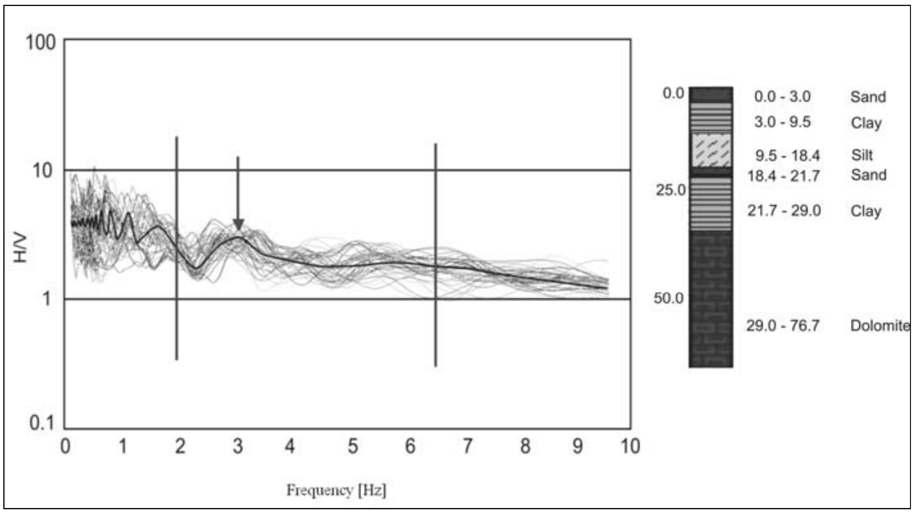

Fig. 4 Spectral ratios of mining tremors recorded at S_3 station with geological profile of the site (right).

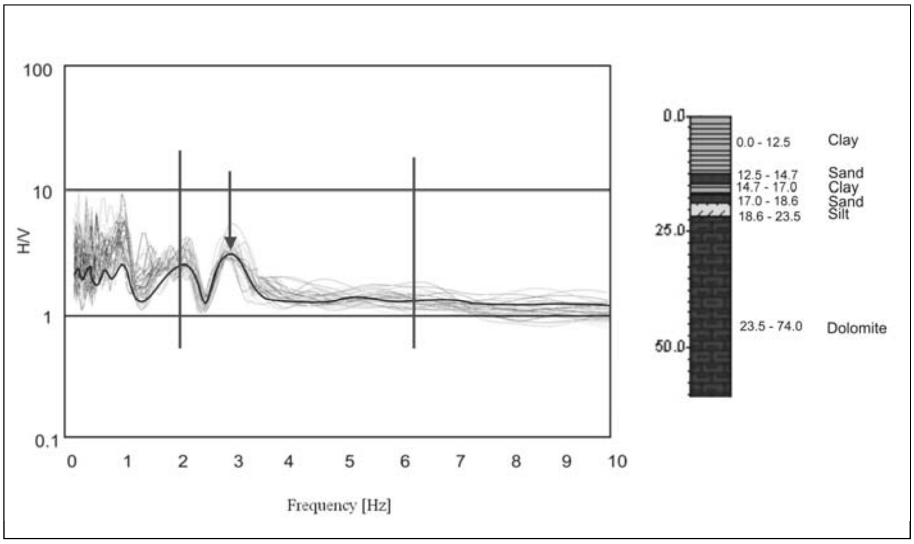

Fig. 5 Spectral ratios of mining tremors recorded at S_4 station with geological profile of the site (right).

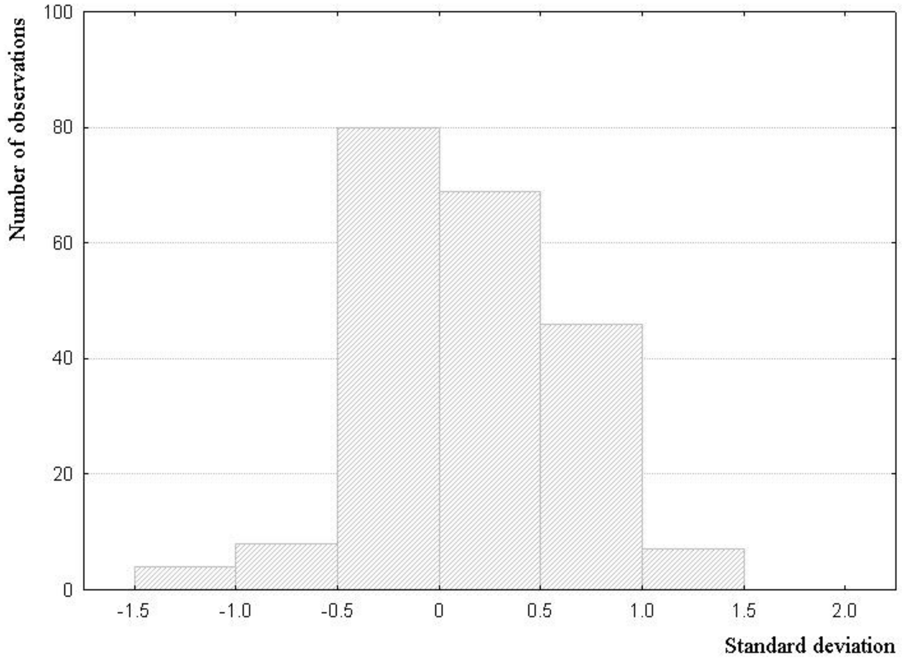

Fig. 6 Histogram of residuals of recorded data from attenuation relation for S_1 station.

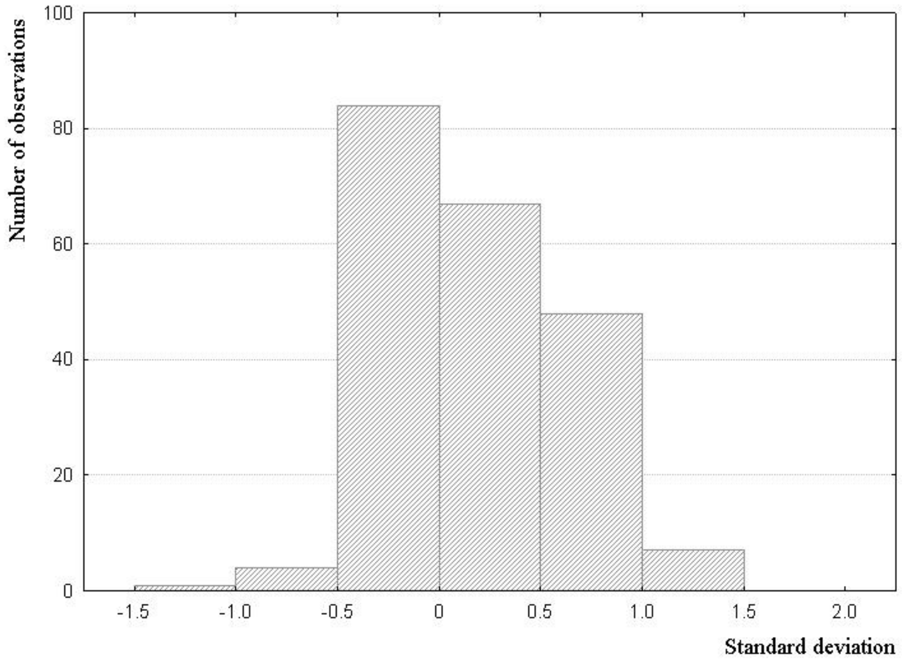

Fig. 7 Histogram of residuals of recorded data from attenuation relation for S_2 station.

frequency 3 Hz. This frequency can be considered as a principal frequency of the cover. The amplification value is estimated on 2.4. The quaternary strata are there observed to the depth of 23.5 m. These structures are represented by sands, clays and silt. Below there are dolomite, marl, limestone and sandstone.

The results show that with exception of S_2 station, the frequencies of HVSR peaks increase with the increase of thickness of the quaternary deposits. Because in Bytom Syncline region the epicentral distances are small so it was not possible to identify the individual phase of signal therefore we calculated spectrum from whole signal. This causes that we

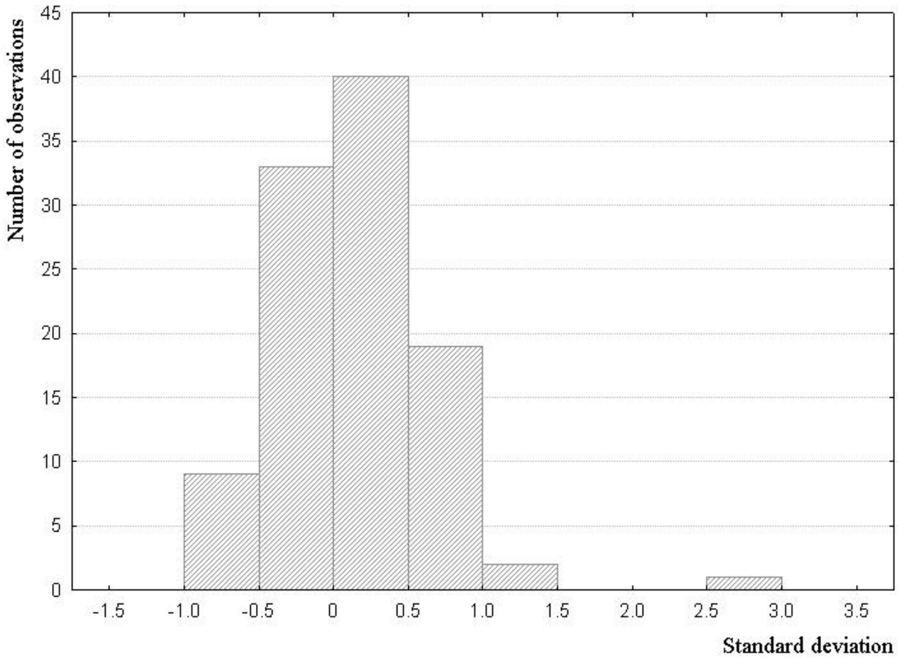

Fig. 8 Histogram of residuals of recorded data from attenuation relation for S_3 station.

observe the increase of influence of surface waves and noise contents in the traces, what may disturbed the usual relation of nature frequency and cover thickness.

From the data we have calculated the attenuation relation of A_{xyz} = f (log E, R) using the least squares procedure.

$$\log A_{XYZ} = 1.2981 + 0.1579 \log E + 0.0001 R \qquad (3)$$

Standard error of estimation is S = 0.210, coefficient of correlation R = 0.408. This form of attenuation relation does not include the amplification (local effects) at analysed stations. Because it was calculated for all recordings it includes the average value of amplification at analysed stations. Therefore for stations with higher amplification the residuals should indicate positive shift and for those with lower amplification the shift should be negative one. Using the positions of points relative to the surface of attenuation relation we calculate the residuals for all stations. At Fig. 6 the histogram of residuals from S_1 station is presented and the following figures (Figs. 7, 8 and 9) are illustrating the residuals from stations S_2, S_3, S_4 respectively.

Considering station S_1, S_2, S_3, S_4 the observed that residuals correlate with amplification estimated by HVSR method. For S_4 station occurs weak correlation, it can be connected with small number of available data (only 50 records). The effect of distribution of the residuals can give us information about the possibility of occurrence of amplifications. But the sizes of residuals aren't equal of the values of amplification.

Obtained results show that the values of the amplification factor can be connected with the geology of quaternary strata and their thickness. The calculated residuals of observed data from the attenuation relation for each recording station show that in some places the amplification of ground vibrations may occur. But we can see that the residuals agree with the amplification estimates in ordering an excess of positive residuals is noted in two stations S_1, S_2 where the estimated amplification is the largest. Also we see for S_3, S_4 station where is least amplifications that the excess of the negative residuals occurs. But histograms of the residuals show that the observed relations are not unique and should be further tested.

CONCLUSIONS

1. The analysis of the H/V ratio from accelerograms recorded in Bytom Syncline shows that in this region the amplification of the ground vibrations occurs.
2. The occurrence of amplification can by deduced from the H/V ratio analysis and from the attenuation relation.
3. It looks that the estimated amplification value of vibration can be related to the geological structure of the cover at the recording site, although the relation between natural frequency and quaternary thickness is disturbed.

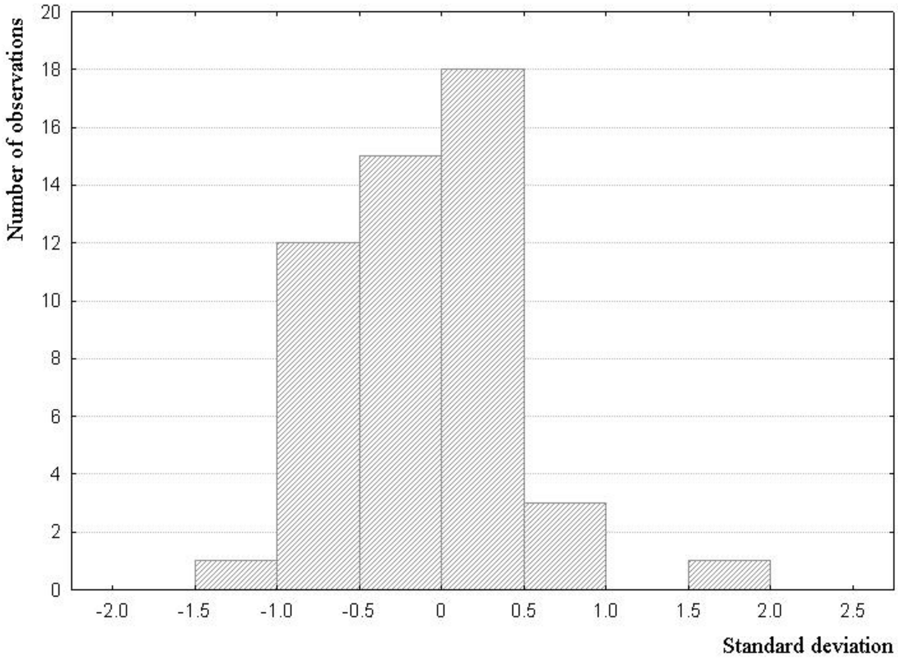

Fig. 9 Histogram of residuals of recorded data from attenuation relation for S_4 station.

Table 2 Summary of the results.

L.P.	Recording station	Amplification from H/V	Principal frequency at max of H/V	Thickness of quaternary strata [m]	Predominant structur of geology
1	S_1	3.5	3.5	50	Sand
2	S_2	3.1	4.2	22	Sand, silt
3	S_3	2.0	3.1	29	Sand, clay
4	S_4	2.4	3.0	23.5	Sand, clay, silt

4. The courses of observed H/V spectral ratio for mining tremors are similar to typical courses for natural seismicity. The estimated amplification factors (from H/V ratio peak values) and observed natural frequencies are realistic. It can be stated that the HVSR method can be used to calculate the amplification in Bytom Syncline area.

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