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TIME-SPECTRAL CHARACTERISTICS OF PARASEISMIC KINEMATIC EXCITATIONS, TAKING INTO ACCOUNT DIFFERENTIATION OF THE OROGEN AT POLKOWICE

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Abstract

The paper presents the results of an analysis of nonstationary kinematic excitations generated by quakes due to mining activities taking into account differentiation of the orogen at Polkowice in the Copper-Mining District of Legnica and Głogów. Based on essential differences in the time-spectral characteristics of excitations two types of them may be distinguished. Most mining quakes in the region generates the first one. The aim of the analysis was to compute, how much the structure of orogen modifies values of parameters characterized the first type of excitations. The analysis was based on the results of seismological measurements of the 64 mining quakes which had occurred in the years 2000-2002 and 2004-2005 at Polkowice. Parameters characterizing the time-spectral properties of the excitations were calculated based on Gabor's representation. The effect of differentiations of the orogen into the values of these parameters was checked based on three tests of goodness of fit of the probability distribution for the three housing estates in Polkowice. It has been assumed that the positive results in two tests prove decisively that there is no reason to reject the hypothesis about identity of the compared distribuants concerning the respective parameters. There is a distinct differentiation in the results, depending on the parameter and on the given region of the town. Corrections of the values of parameters characterizing presented time-spectral properties of kinematic excitations have been displayed in figures.

Streszczenie

W artykule przedstawiono wyniki analizy niestacjonarnych wymuszeń kinematycznych generowanych przez wstrząsy związane z eksploatacją górniczą, w której uwzględniono zróżnicowanie górotworu w Polkowicach w Legnicko-Głogowskim Okręgu Miedziowym. Bazując na zasadniczych różnicach w czasowo-widmowych charakterystykach tych wymuszeń wyróżniono dwa ich typy. Większość wstrząsów górniczych w regionie generuje pierwszy z nich. Celem analizy było sprawdzenie w jakim stopniu budowa górotworu modyfikuje wartości parametrów charakteryzujących pierwszy z typów wymuszeń. Analiza bazowała na wynikach pomiarów sejsmologicznych 64 wstrząsów górniczych, które wystąpiły w latach 2000-2002 i 2004-2005 w Polkowicach. Parametry charakteryzujące czasowo-widmowe własności wymuszeń obliczono wykorzystując reprezentację Gabora. Efekt zróżnicowania górotworu w wartościach tych parametrów sprawdzono z wykorzystaniem trzech testów zgodności rozkładów prawdopodobieństwa z uwzględnieniem trzech osiedli w Polkowicach. Przyjęto, że pozytywny wynik w dwóch testach zdecydowanie wskazuje, że nie ma podstaw do odrzucenia hipotezy o identyczności porównywanych rozkładów odnoszących się do rozważanych parametrów. Istnieje wyraźne zróżnicowanie wyników zależnie od parametru i regionu miasta. Korekty wartości parametrów charakteryzujących przedstawione własności czasowo-widmowe wymuszeń kinematycznych zaprezentowano na rysunkach.

Keywords: **Mining quakes; Kinematic excitations; Time-spectral properties; Gabor's representation.**

1. INTRODUCTION

Publications [1, 2] present results of the time-spectral analysis of acceleration kinematic excitations generated by quakes due to mining activities in the region of Polkowice in the Copper-Mining District of Legnica and Głogów. Based on essential differences in the time-spectral characteristics of excitations two types of them may be distinguished. Most mining quakes in the region of the town generate the first one, the other one occurs only incidentally. In signals of the first type two segments have been distinguished, the initial (No. 1) and the fundamental one (No. 2), differing from each other. The latter one has been further divided into two subsegments, in Fig. 1 denoted as "a" and "b".

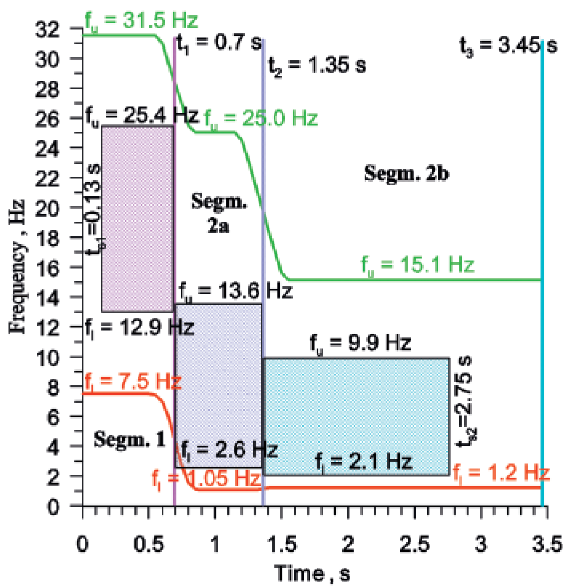

Figure 1.
Time-spectral characteristics of kinematic excitations in Polkowice

Every one of them was characterized by the bottom and upper frequency bands, their duration and zones (shaded rectangles in Fig. 1), in which most often the peak values of acceleration do occur. By means of such a segmentation of excitations their distinct non-stationarity could be taken into account. Thus, the question arises, how much the structure of the orogen modify the values of the calculated parameters. This has been characterized in table 1, concerning the housing estates Dąbrowskiego, Polanki and the city centre.

In these regions measuring stations have been installed, from which most accelerograms, recorded during the quakes are sent. The surface layers of the orogen differ from each other as follows: in the region of the housing estate Dąbrowskiego there is mid – grained sand with a depth of strata amounting to 2.2 m, or a layer of sandy clay with a strata thickness of 1.4 m, and deeper down coarse sand; in the city centre there are firm clays with a strata thickness of up to 2 m; and in the western part of the town sandy clays or coarse and mid – grained sand with a strata thickness of 0.5-2.5 m. Mentioned kinds of the layers occur in various configurations and thicknesses. It may be said that in the considered region the orogen does not display any essential differentiation, as far as the rocky material and the stratification are concerned. The analysis of the influence of soil characteristics on elastic waves propagation was the subject matter, among others, of complex investigations performed in situ [3], analyses of vibrations inside the buildings in the region of Polkowice [4,5] as well as of other publications, e.g. [6,7]. Much stress was laid on the effect of these conditions on the take-over of vibrations propagating in the subsoil under the buildings. This phenomenon has not been, however, assessed explicitly. According to [6] absorption of energy in the course of elastic waves propagation in the subsoil affects, among others, the spectrum of vibrations of the earth surface. Absorption is more intensive in case of components with higher frequencies. Just an opposite conclusion has been put forward by the authors of [3], presenting the results of investigation in situ concerning the surface refraction, comprising an analysis of vibrations of the surface, excited impulsively in the orogen at a depth of 0.5 to 2.0 m. Deeper source of excitations results in the spectrum of responses being shifted towards higher frequencies. The scope of seismic measurements carried out in Polkowice does not allow to formulate conclusions concerning the relationship between the structure of the orogen and the detailed characteristics of excitations caused by mining quakes. Therefore, attention was paid merely to the determi-

Table 1.
Characteristics of orogen in Polkowice

Housing estate	Quaternary		Tertiary	
	Thickness [m]	Type	Thickness [m]	Type
Dąbrowskiego	max. 30	Sands, gravels, sandy clay	~ 410	Silts, sands, gravels, layers of lignite
Polanka	~ 50	Sands, gravels	385	Sands, silts, gravels, mudstone, layers of lignite
City centre	30 -35	Sands, gravels, sandy clay	~ 400	Sands, gravels, silts

nation of the general regularities connected with the localization of the measuring stations. Based on rather slight differentiation of the orogen structure in Polkowice it is to be expected that the time-spectral properties of kinematic excitations depending on the town region will be rather little differentiated. The aim of the present paper is to find an answer to this question and to suggest corrections within the necessary range of the aforesaid parameters.

2. MEASUREMENT DATA AND RESULTS OF THE ANALYSIS

The analysis of the acceleration kinematic excitations of the first type [1] was based on the results of measurements, not quoted here in great detail. It ought to be mentioned, however, that the analyzed excitations had been generated by 64 mining quakes, recorded by six seismic stations. They have been chosen from among about 640 recorded accelerograms which had occurred in the years 2000-2002 and 2004-2005 in Polkowice and in the adjacent region. Selected accelerograms, providing an image of subsoil vibrations with two orthogonal horizontal components, have been characterized by the peak accelerations exceeding $a_g = 0.25$ m/s^2. Their entire duration was contained between the point on the time axis when the signal at the measuring station starts and the point after the last local extremum amounting to $a_g = 0.1$ m/s^2. Paraseismic kinematic excitations are non-stationary signals, and Gabor's time-frequency transformation was applied in their analysis. Coefficients of decomposition were calculated in compliance with the formula [1,8]

$$c_{m,n} = \int_{-\infty}^{+\infty} x(t)\gamma^*_{m,n}(t - m\cdot\Delta t)e^{j2\pi n\cdot\Delta f\cdot t} \qquad (1)$$

where:

$\gamma(t)$ – window function of the analyzed signal $x(t)$ shifted in time by $m\times\Delta t$, (the asterix denotes a complex conjugate function),

$e^{j2\pi n\cdot\Delta f\cdot t}$ – harmonic functions shifted in frequencies domain by $n\times\Delta f$,

Δt, Δf – preset shift in the domain of time and frequencies, respectively,

j – imaginary unit.

Transformation according to (1) may be interpreted as a set of Fourier's transforms, calculated for subsequent segments of signal $x(t)$, determined by the window of the analysis $\gamma(t)$ with the assumed length. This window moves along the axis of time by the period Δt, and separates in each new position the segment of signal, for which Fourier's transforms are then calculated. Coefficients of decomposition describe evolution of spectral power density [8], to which the modules of Gabor's transforms correspond, i.e. Gabor's time-frequency representations, determined by the formula

$$S_x(m\cdot\Delta t, n\cdot\Delta f) = \left|c_{m,n}\right|^2 . \qquad (2)$$

Parameters characterizing the time-spectral properties of kinematic excitations were calculated based on Gabor's representation expressed in the decibel scale. Assumed level of reference was Gabor's representation of the harmonic signal with an amplitude of $a_{ref} = 0.01$ m/s^2, adapted to the frequency of currently analyzed excitation component and length of the analyzed function. It has been assumed that the set of samples of the respective parameters, calculated in the suggested way [1], results statistically from general population with an unknown probability distribution. The influence of differentiation the structure of the orogen into the values of these parameters was checked for the housing estates Dąbrowskiego and Polanka, and also for the city centre of Polkowice. For this purpose parameters characterizing excitations were analyzed by means of a probabilistic model. Based on three tests of the goodness of fit of probability distribution it was checked whether the following hypothesis is feasible

$$H_0:\ F_I = F_{II}, \qquad (3)$$

where:

F_I, F_{II} – distribuants of the random variable characterizing kinematic excitations and corresponding to the site of the selected housing estate.

Distribuant F_I was determined successively for the housing estates Dąbrowskiego, Polanka and the city centre. The three quoted populations display a continuous distribution, being, however, unknown. There populations provided samples, viz. sets of data calculated based on recorded excitations. To each one of the three populations three tests of goodness of fit were applied: Smirnow's, Pearson's, and Wilcoxon's [9]. Each of them makes use of the probability distribution, viz. Kołmogorow's, chi-square and normal in approximation, respectively. Significance level of the tests was assumed to be 5%.

Table 2.
Results of tests of goodness of fit

No.	Random variable	City centre	Housing estate Dąbrowskiego	Housing estate Polanka
1.	End of duration, segm. 1	1	1	1
2.	End of duration, segm. 2a	3	1	-
3.	End of duration, segm. 2b	2	1	2
4.	Bottom frequency, segm. 1	2	2	1
5.	Upper frequency, segm. 1	3	-	2
6.	Bottom frequency, segm. 2a	1	3	2
7.	Upper frequency, segm. 2a	3	-	1
8.	Bottom frequency, segm. 2b	-	3	2
9.	Upper frequency, segm. 2b	2	1	2
10.	Time of peak value of acceleration, segm. 1	2	-	1
11.	Frequency of peak value of acceleration, segm. 1	2	2	1
12.	Time of peak value of acceleration, segm. 2a	2	1	1
13.	Frequency of peak value of acceleration, segm. 2a	2	3	3
14.	Time of peak value of acceleration, segm. 2b	1	1	1
15.	Frequency of peak value of acceleration, segm. 2b	2	3	3

Formulaes and technical details of their realization have not been quoted, because they were typical and complied with recommendations provided in handbooks. Comprehensive results concerning the number of tests, based on which a repudiation of the hypothesis H_0 about the identity of the compared distribuants according to (3) is not justified, have been gathered in Table 2.

It has been assumed that positive results in two tests prove decisively that there is no reason to reject the hypothesis H_0 concerning the respective parameters – random variables. Based on the results gathered in Table 2 we may say that there is a distinct differentiation in the results, depending on the parameter and on the given region of the town, which is concerned. As far as the city centre is concerned, in case of 11 parameters hypothesis H_0 is acceptable, in the housing estate Dąbrowskiego – 5 parameters, and in the housing estate Polanka – 7. For the end of duration of the segments the hypothesis can be accepted in three cases out of nine. For boundary frequencies the hypothesis is acceptable in four cases in segment No. 1, in 3 cases in subsegment No. 2a, and in 4 cases in subsegment No. 2b out of nine possible ones. Parameters determining boundaries of the zones in which the peak values of accelerations do occur, permit to consider hypothesis H_0 to be acceptable: times of occurrence - twice and the corresponding frequencies – 8 times out of 9. The specification indicates, that identity of the probability distribution of the parameters concerns merely some situations. An exception is the last mentioned group of parameters which in nearly all cases display this property. Considerable scattering of results in the tests of goodness of fit prove differentiation of the parameter values depending on the orogen structure. For this reason, their values had to be corrected in the analyzed regions of Polkowice, if the hypothesis H_0 was accepted in not more than one test. These results have been gathered in Fig. 2-4.

3. CONCLUSIONS

As we see in Fig. 1 and 2, corrections of the values of parameters characterizing the presented time-spectral properties of kinematic excitations concerning the city centre of Polkowice are inconsiderable. They concern merely the end of the duration of the initial segment and the zone of peak accelerations in the subsegment 2b, as well as the bottom boundary of the fundamental segment. In the regions comprising the housing estates Dąbrowskiego and Polanka changes are more distinct and concern most of the applied parameters. In case of the former one considered changes of the parameter are contained within the range from 8% to 57% versus their values plotted in Fig. 1, whereas those concerning the latter housing estate they are less and contained within the range from 4 to 36%. As far as the level of the dynamic

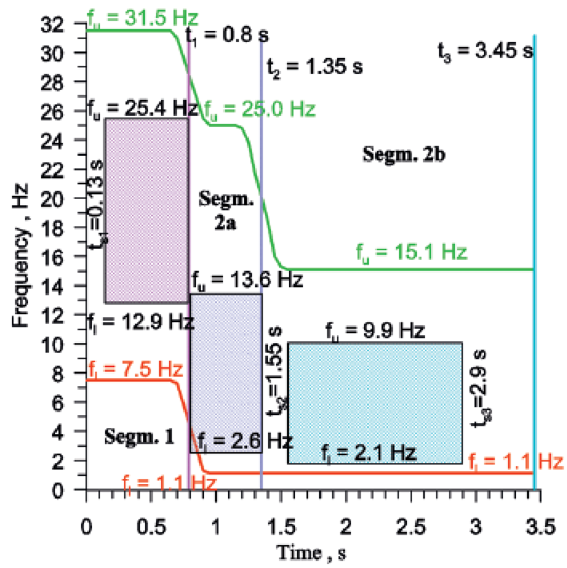

Figure 2.
Time-spectral characteristics of kinematic excitations in city centre of Polkowice

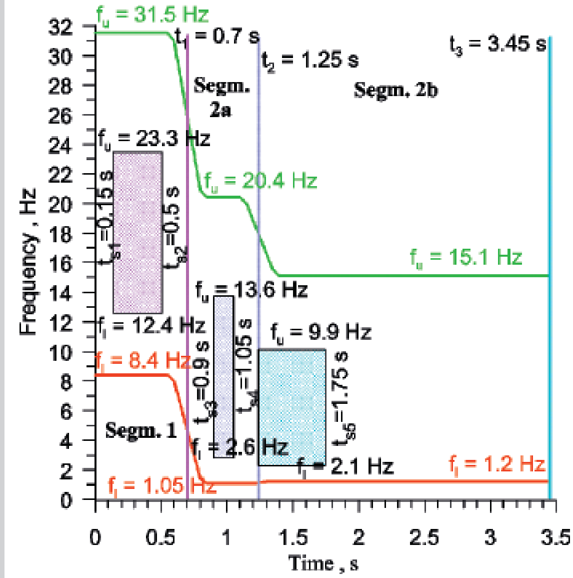

Figure 4.
Time-spectral characteristics of kinematic excitations in the housing estate Polanka in Polkowice

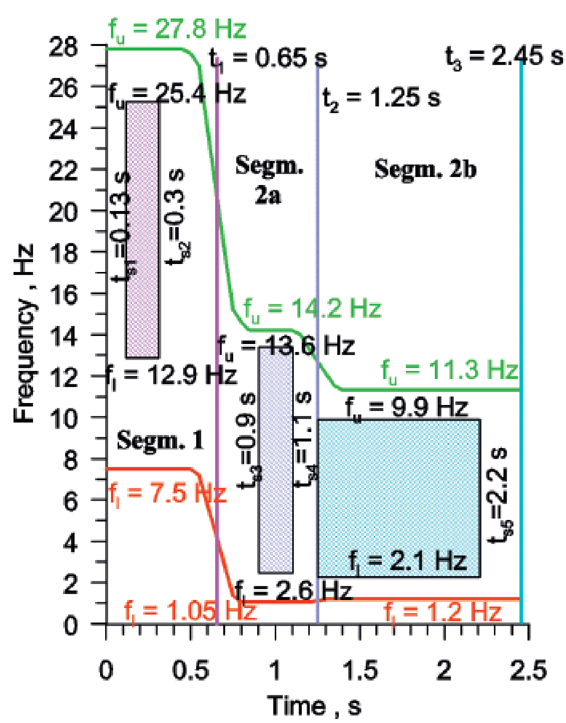

Figure 3.
Time-spectral characteristics of kinematic excitations in the housing estate Dąbrowskiego at Polkowice

response excited in the supporting structures of the buildings in the region of Polkowice is concerned, changes of the parameter values do not require any supplementing to the conclusions, which have been put forward in [2]. This response is unexpectedly low, mainly due to the short duration of excitations and high amplitudinal frequency spectrum in the initial segment, in which usually the peak values of accelerations occur. It also ought to be stressed that in case of detailed analyses of the effort of the supporting structures of buildings caused by quakes resulting from mining activities, confirmed by numerical calculations, it may prove to be significant that dynamic loads in the adjacent surrounding of the building are taken into account. Depending on the applied method of calculations, this concerns kinematic excitations and also the spectra of responses originating from quakes caused by mining activities.

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