ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 2/2011

RATIONALIZATION OF THE RANGE OF DYNAMIC CALCULATIONS IN THE DIAGNOSTICS OF PARASEISMICALLY LOADED BUILDINGS

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Received: 15.03.2011; Revised: 1.06.2011; Accepted: 15.06.2011

Abstract

The paper presents a way of assessing the intensity and rational duration of kinematic dynamic loads from the viewpoint of the ability to generate extreme dynamic responses of the supporting structure of the building. This procedure may be applied in the course of diagnostic analysis ofthe effort of the structure making use of the load history method based on kinematic excitations caused by mining activities. In the preliminary selection of paraseismic loads from among a numerous shocks which had occurred only some were chosen, i.e. those which resulted in extreme dynamic responses of the structure. Thus, their duration can be reduced to the time from their start to the moment of this response. Such a classification permits to restrict, and hence to rationalize the range of numerical calculations. This method is based on the time-spectral properties of paraseismic excitations in the region of Polkowice in the Copper Mining Basin of Głogów. Four criterial parameters were taken into account. The paper presents the results of validating this procedure, making use of seismological and dynamic measurement data gathered in Polkowice. It has been found that between the parameters of excitations and the dynamic response of the buildings exists an evident stochastic relation.

Streszczenie

W pracy przedstawiono sposób szacowania intensywności oraz racjonalnego czasu trwania kinematycznych obciążeń dynamicznych z punktu widzenia zdolności do generowania ekstremalnych odpowiedzi dynamicznych konstrukcji nośnej budynku. Może on być stosowany w trakcie prowadzenia diagnostycznej analizy wytężenia konstrukcji metodą historii odpowiedzi z wykorzystaniem wymuszeń kinematycznych pochodzenia górniczego. W trakcie wstępnej selekcji przypadków obciążeń parasejsmicznych należy spośród wielu zaistniałych wstrząsów górniczych wybrać tylko te nieliczne, które wywołają ekstremalne odpowiedzi dynamiczne konstrukcji. Można ograniczyć ich czas trwania do przedziału od początku do chwili wystąpienia tej odpowiedzi. Klasyfikacja taka umożliwia ograniczenie, a więc racjonalizację zakresu analizy numerycznej konstrukcji. Sposób bazuje na własnościach czasowo-widmowych wymuszeń parasejsmicznych z rejonu Polkowic w Legnicko-Głogowskim Okręgu Miedziowym. Wykorzystano w nim cztery parametry kryterialne. Przedstawiano wyniki walidacji sposobu z wykorzystaniem sejsmologicznych i dynamicznych danych pomiarowych z Polkowic w Legnicko-Głogowskim Okręgu Miedziowym. Stwierdzono istnienie wyraźnej zależności stochastycznej pomiędzy parametrami wymuszeń a odpowiedzią dynamiczną budynków.

Keywords: **Mining quakes; Diagnostic analysis of buildings; Load history method; Representative kinematic excitations.**

1. INTRODUCTION

A detailed diagnostic analysis of buildings exposed, among others, to paraseismic effects [1-3], due to mining activities, requires sometimes multi-variant numerical calculations in order to reproduce the past effort of the structures. Therefore, the incident generating an extreme state of effort must be identified. In such an analysis usually the load history method is applied. Its versatility involves important requirements, conditioning the credibility of the results of calculations. It is indispensable to take into consideration a sufficient number of paraseismic loads, i.e. kinematic excitations, recorded at the measuring stations during the mining quakes in the analyzed time interval. Available experience [4] indicates that the excitations ought to be recorded in the region in which the building is localized and comprise all the possible variants of time-spectral characteristics, as well as the intensity. This means that many cases of paraseismic loads must be taken into account, which involves a considerable amount of work connected with computer calculations and the analysis of the obtained results. Thus, the analysis must be necessarily restricted to those cases which are connected with extreme dynamic efforts of the structure. Further on the way of classifying a priori, i.e. previous to dynamic calculations, the intensity of paraseismic loads [5] has been presented, as well as the way of a credible assessment of their indispensable duration. This allows to reduce the range of dynamic numerical calculations of the building to absolutely essential cases of loading during the optimal length of time.

2. CHARACTERISTICS OF THE METHOD

The suggested method has two aspects. The first one consists in the classification of kinematic excitations in the entire set of the considered cases with respect to the intensity of the dynamic response to them in the analyzed building. The second aspect resolves itself into a restriction of the duration of the excitations to a minimum thanks to the assessment of the position of the point on the time axis, in which its extreme dynamic response occurs. In this method it was assumed that in the diagnostic analysis the kinematic excitation is determined by two orthogonal

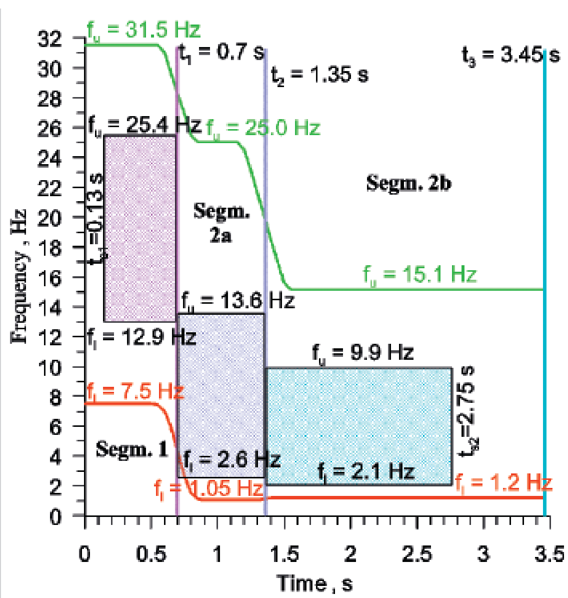

Figure 1.
Time – spectral characteristics of kinematic excitations generated by quakes at Polkowice

horizontal components. Also the non-stationary state of the excitations has to be taken into account [6,7], expressing it by the separation of the segment spectra of excitations [4]: No. 1 with a high-frequency characteristic, and Nos. 2a and 2b with properties of low – frequency signal, as shown in Fig. 1.

Fig. 1 shows the boundaries of the segments No. 1, No. 2a and 2b, as well as the boundaries of their bands. Inside the indicated intervals those ranges have been marked, in which the local extremes of the dominating components are localized. Their bottom and upper-band boundaries have been described, and also the boundary points on the time axis. The segmentation results also from the fact – ascertained in the course of dynamic calculations of the structures [3] – that the extreme dynamic response of the buildings, generated by mining quakes, principally occurred in the second segment. The division of the accelerograms may be assumed to be approximate based on Fig. 1. The boundary between the segments should be rather sought making use of the spectral power density function calculated after the excitation had been divided into two parts [5]. A repeated change of the position of the point of this division permits to localize exactly the boundary and the segment No. 2. In this method also the excitations were filtrated, separating from each of them the narrow-band component which may cause resonance of the considered building. For this purpose a digital filter is applied with a transfer band, whose boundary frequencies depend on the natural spectrum of the analyzed building:

$$\mathbf{F}_1 = [0.7 f_1 ; 1.2 f_3], \tag{1}$$

where

f_i – natural frequencies of the building.

In order to classify approximately kinematic excitations from the viewpoint of their intensity, two parameters [5] were used, calculated jointly for both horizontal components in the segments No. 2, according to the formulae:

Arias intensity

$$I_A = \sum_{j=0}^{N_s-1} \left(a_{xj21}^2 + a_{yj21}^2\right) \Delta t \ , \tag{2}$$

and the average power

$$P = \sum_{j=0}^{N_s-1} \left(a_{xj21}^2 + a_{yj21}^2\right) / N_s \ , \tag{3}$$

where:

a_{xk21} , a_{yk21} – values of the excitation horizontal components in the directions X and Y in j – th points on the time axis in the segment No. 2 and spectrum band No. 1,

N_s - number of samples of the excitation component,

Δt- signal discretization period.

The localization of the dynamic response extreme of the building on the time axis can be determined approximately basing on two quantities [5]according to the formulae:

Husid function

$$H_n = \sum_{j=0}^{n} \left(a_{xj21}^2 + a_{yj21}^2 \right) \Delta t / I_A \,, n = 0,1,2,\ldots, N_S - 1, \quad (4)$$

and evolutional average power

$$P_n = \sum_{j=n-n_w}^{n} \left(a_{xj21}^2 + a_{yj21}^2 \right) / n_w \;, \; n = n_W \,, n_W + 1, \ldots, N_s \;, (5)$$

where:

$n_W = T_W / \Delta t$ – number of excitation samples corresponding to the width of the rectangular time window, in which the power rating has been averaged,

T_W – averaging time interval, i.e. the width of the time window.

The latter function may be interpreted as the mean power of anexcitation fragment with the length T_W. The width of the time window ought to be equal to the fundamental natural period of the building, and the running value of the power rating refers to the end of the duration of the segment of averaging time.

Arias intensity and the mean power ratings are normalized by dividing them by the maximum values in the set of excitations. Making use of the normalized criterial parameters the set of excitations is put in some order by separating the subset $\mathbf{K}_{max}$ of the most intensive excitations. Theseloads usually occur in the interval 0.9-1.0 of the values of the criterial parameters with a probability of 98%, that the remaining excitations are beyond this range.

The dynamic extreme response arising in the structure due to a kinematic excitation is to be found near the end of the largest and steepest increment ofHusid function and maximum of the evolutional mean power. The distance Δ_{max} = 0.25 s must be added to the times of occurrence of these points, so that the duration of the kinematic excitation may be assessed credibly. The method algorithm is presented in Fig. 2 in the form of an organigram. The different tints indicate the stages of numerical calculations.

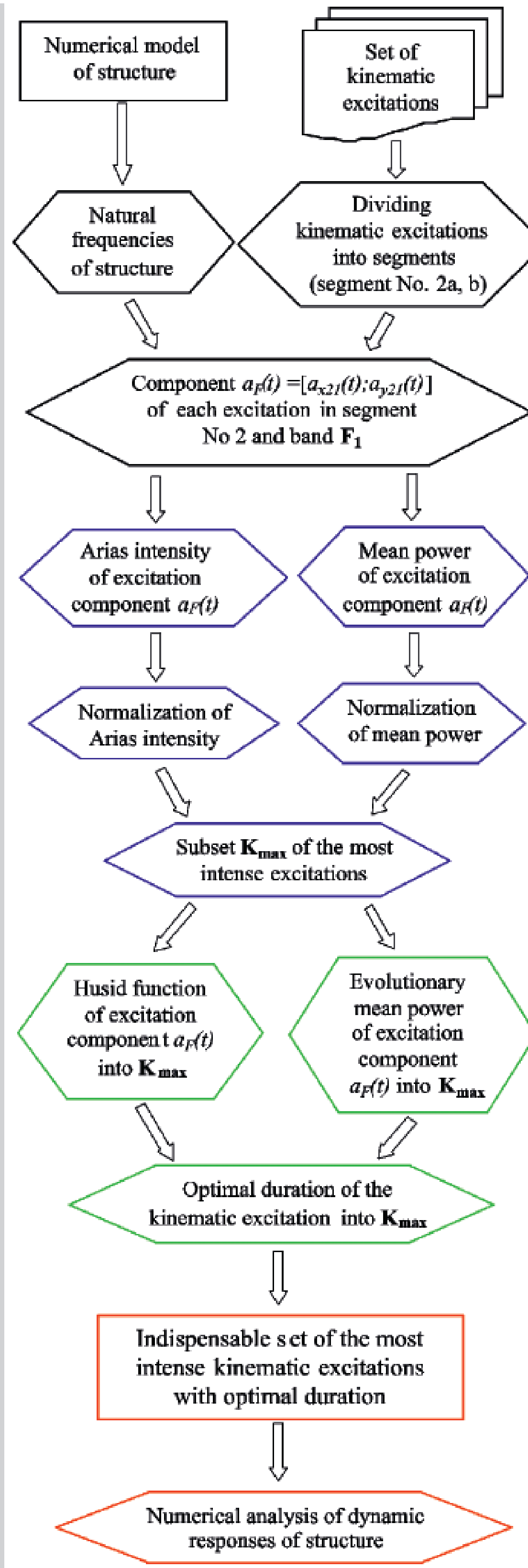

Figure 2.
General algorithm of the method

In only few cases [4] the kinematic excitations recorded in Polkowice have no high-frequency segment No. 1. In such cases the segmentation of the excitations is redundant. Rarely do occur excitations in which segments No. 1 are dominant, and they generate extreme dynamic responses of the structures. In these cases the presented method may be applied, taking, however, into account the time – spectral properties of the excitations.

3. VALIDATION OF THE METHOD

For the purpose of validating the suggested method, kinematic excitations were used, generated by mining quakes, recorded at four stations localized in Polkowice [5]. In each station the vibrations of the soil were measured in the vicinity of the buildings, and in two at the foundations and floors of their structures. From about 640 excitations such ones were selected which had been recorded in the years 2000-2002 and 2004-2005, characterized by peak accelerations exceeding 0.25 m/s^2. For these tests four actual buildings were chosen [5], exposed to these excitations. Two of them, No. 1 and No. 2 have two storeys and a masonry wall structure in a mixed system. Building No. 3 has five storeys and a lateral-large-size block structure.Building No. 4 has twelve storeys and a prefabricated lateral wall structure.

In the validation the non-stationarity of the excitations was taken into account by their segmentation. The susceptibility of the buildings to narrow-band and low-frequency components of excitations were investigated in the band $\mathbf{F_1}$ in compliance with (1) and the following ones in compliance with the formulae

$$\mathbf{F}_2 = \left[0.8 f_4 ; 1.2 f_6\right], \quad \mathbf{F}_3 = \left[0.8 f_7 ; 20\right], \tag{6}$$

with denotations similar to those in (1).

In the validation of the method a parameterized assessment of the extreme dynamic responses of the buildings, generated by excitations was applied, because it had been found [3] that extreme dynamic stresses in the structure occur more or less at the same time as the maximum relative horizontal dynamic displacements, as expressedby the relation

$$u_{\max}(t_0) = \sqrt{\left[u_{x2}(t_0) - u_{x1}(t_0)\right]^2 + \left[u_{y2}(t_0) - u_{y1}(t_0)\right]^2}, \tag{7}$$

where:

$u_{x1}(t)$, $u_{y1}(t)$, $u_{x2}(t)$, $u_{y2}(t)$ – horizontal components of displacements, respectively in the foundation (index 1) and in the highest storey (index 2),

t_0 – position of the maximum relative displacement on the time axis.

For the assessment of the responses of buildings Nos. 1 and 2 the results of a numerical analysis were used [3], performed by means of the software Ansys. In the buildings Nos. 3 and 4 the dynamic responses were assessed making use of the orthogonal horizontal components of the accelerograms recorded during the mining quakes, based on which the indispensable displacements could be calculated. The validation of the classification of the excitation intensity included, among others, the evaluation of the quality of the regression function, in which the parameters quoted in (2) and (3) are subsequently independent random variables, and the dependent variable is the dynamic displacement (7). The empirical regression function was expressed in the power (surd) form [5]

Table 1.
Correlation coefficients and square deviations of the regression functions of logarithmic variables: Arias intensities (ArI) or the average power (AP) and dynamic displacement

Criterial parameters	No. of segm.	No. of band	Correlation coefficients of buildings				Square deviation of buildings			
			1	2	3	4	1	2	3	4
ArI	1	1	0.75	0.66	0.79	0.21	0.45	0.27	0.69	0.68
AP	″	″	0.77	0.67	0.80	0.04	0.44	0.27	0.67	0.70
ArI	″	2	0.62	0.62	0.82	0.04	0.54	0.29	0.64	0.70
AP	″	″	0.62	0.62	0.81	0.02	0.54	0.29	0.65	0.70
ArI	″	3	0	0.05	0.66	0.01	0.69	0.37	0.84	0.70
AP	″	″	0.07	0.04	0.66	0.01	0.68	0.37	0.83	0.70
ArI	2	1	0.93	0.82	0.98	0.98	0.26	0.21	0.21	0.15
AP	″	″	0.89	0.84	0.98	0.98	0.31	0.20	0.21	0.13
ArI	″	2	0.55	0.23	0.88	0.74	0.57	0.36	0.52	0.47
AP	″	″	0.45	0.40	0.86	0.72	0.61	0.34	0.57	0.48
ArI	″	3	0.40	0.08	0.82	0.14	0.63	0.37	0.64	0.69
AP	″	″	0.29	0.04	0.72	0.18	0.66	0.37	0.78	0.69

$$y = ax^b, \tag{8}$$

where a, b – numerical coefficients.

As a measure of the stochastic dependence of the analyzed random values the correlation coefficient was applied, whereas the fit of the regression function was assessed based on the mean square deviation and confidence limits with the significance level 10%. Table 1 presents the results of measurements characterizing the stochastic relations of the sets of logarithmized random variables.

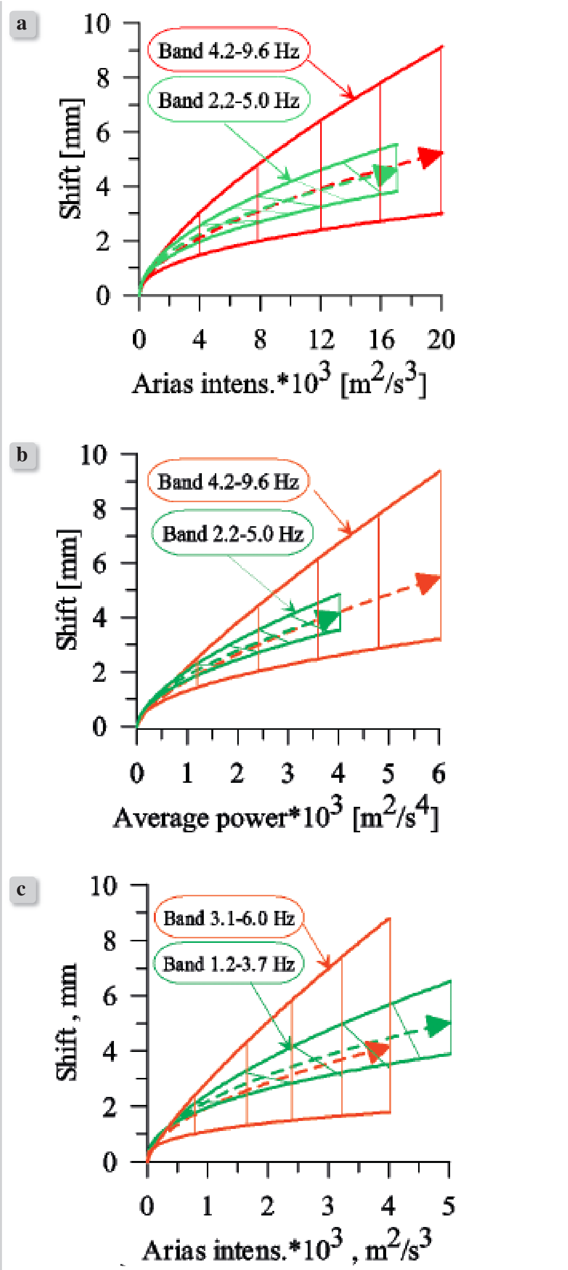

Figure 3.
Diagrams of the regression function of criterial parameters of the buildings No. 3 (a, b) and No. 4 (c)

Exemplary diagrams of the regression function (broken lines) with confidence limits (hachured fields) in the segment No. 2 and the bands Nos. 1 and 2 have been presented in Fig. 3.

The correlation coefficients concerning Arias intensity in segment No. 2 and band No. 1 are contained within the interval 0.82-0.98, in the band No. 2 within the interval 0.23-0.88, and in the band No. 3 they are still less. In the segment No.1 the values of the correlation coefficients are generally smaller than in the segment No. 2. The mean square deviation in the segment No. 2 amounts in the band No. 1 to 0.15-0.26 and increases in the subsequent bands. The correlation coefficients corresponding to the average power in the segment No. 2 are contained in the interval 0.84-0.98 in the band No. 1 and 0.40-0.86 in the band No. 2. The mean square deviation in the segment No. 2 and the band No. 1 is contained within the limits 0.13-0.31. The quality of matching the analyzed regression functions to the random variables is distinctly worse in each higher band than No. 1, and worse in the segment No. 1 than in the segment No. 2.The valuation of kinematic excitations intensities is the best in the segment No. 1 and band No. 1.

The method validation in its second aspect consisted in a statistic assessment of the time location accuracy of the occurrence of the structure extreme dynamic response. For this purpose the distances between the assessed and the calculated time of the occurrence of extreme parameterized dynamic responses (7) were applied concerning three buildings. The assessment was based on the two criterial functions (4) and (5). The distances were calculated by means of the formula

$$\Delta_t = t_{num} - t_{par}\ , \tag{9}$$

where:

t_{num}, t_{par} – calculated and assessed position of the extreme dynamic response of the structure on the time axis.

The average values of the distances and their right-hand confidence boundaries at significance level of 10% have been calculated. This boundary was considered to asses the position of the extreme dynamic response on the time axis. The time interval between the moment when the excitation began and the final point covered with a probability of 90% this extreme response. The results of these calculations have been gathered in Table 2.

Table 2.
The values of the calculated parameters of Husid function (HuF) and evolutional average power (EAP) and right-hand confidence boundaries of the parameter Δ_t (5)

No. of build.	Criterial function	No. of band	Mean value of intervals Δ_t	Standard deviation of intervals	Tolerance of mean value	Right-hand confidence boundaries of intervals
1	HuF	1	-0.192	0.366	±0.200	0.008
″	″	2	- 0.252	0.349	±0.191	-0.061
″	EAP	1	0.024	0.237	±0.129	0.153
″	″	2	0.221	0.411	±0.225	0.446
3	HuF	1	- 0.055	0.224	±0.084	0.029
″	″	2	- 0.297	0.349	±0.131	-0.166
″	EAP	1	0.046	0.165	±0.062	0.108
″	″	2	0.001	0.136	±0.051	0.052
4	HuF	1	0.050	0.258	±0.173	0.223
″	″	2	- 0.045	0.263	±0.176	0.131
″	EAP	1	0.009	0.250	±0.167	0.176
″	″	2	0.042	0.240	±0.161	0.203

The right-hand confidence boundaries of the distances in the criterial functions amount to 0.008-0.223 in the band No. 1 and 0.166-0.446 in the band No. 2. The assessment of the position of the extreme response is more pertinent in the first band than in the second one. No criterial function is characterized by a better assessment of the localization of the extreme response. The extreme of this response occurs at the end of the largest and steepest increment of Husid function with an accuracy of about 0.22 s and in the vicinity of the maximum mean power rating with an accuracy of about 0.18 s. The extreme response values are in the analyzed cases localized in the segment No. 2 of the excitation, mostly in the lowest band. Exemplary diagrams of Husid functions (broken lines) and the evolutional average power (full lines) in the segment No. 2 and the bands Nos. 1 and 2 can be seen in Fig. 4. The Husid function was evaluated using the Arias intensity calculated in the bands No. 1-3 of segment No. 2. The estimated position of the extreme dynamic response of the building has been indicated by an arrow.

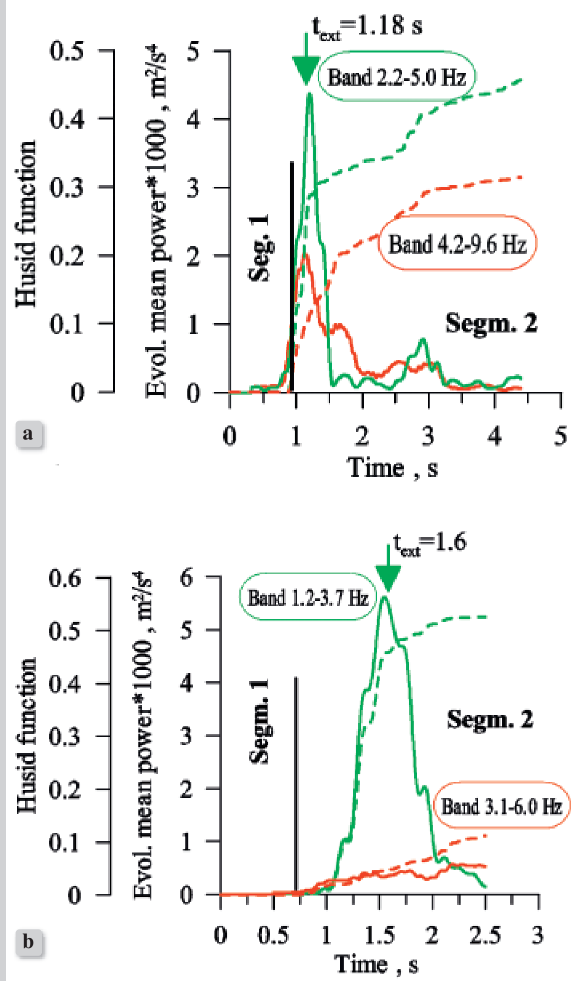

Figure 4.
Diagrams of the criterial functions of the buildings No. 3 (a) and No. 4 (b)

4. CONCLUSIONS

The presented method of assessing a priori kinematic loads was applied for the test building and a set of 36 mining quakes. This building [5] was made of brick, with a mixed system of load-bearing walls, four-storey high. Its numerical model was analyzed making use of the program Abacus. The kinematic excitations were taken from the set that had been used for the method validation from the viewpoint of their intensity characterized by the Arias parameter and average power. The maximum accelerations of one of the horizontal components were contained within the range from 0.3 to 1.37 m/s^2. The set was arranged according to the intensity of the generated dynamic response of the building. The sequence was verified by numerical calculations of the dynamic responses of the test building, exposed to six most intensive excitations. Based on the dynamic fields of extreme normal and shear stresses in the load-bearing walls of the building, it has been proved that the sequence of loads, assessed a priori, was correct. The analysis of available measurement data and the results of numerical calculations concerning several buildings exposed to the effect of kinematic excitations, generated by mining quakes, indicates that the suggested classification is reliable. It permits to select out of the set of excitations those ones which can give rise to the extreme dynamic response of the analyzed structure at the least expenditure of work. The application of the suggested way of classifying kinematic excitations seems to be possible also in case of classifying excitations of other origins than those to mining activities.

ACKNOWLEDGEMENTS

The presented investigations have been carried out based on the results of measurements carried out by the *Mining Plant "Rudna" KGHM "PolskaMiedź"* in Polkowice.

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