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CLASSIFICATION OF PARASEISMICAL VIBRATIONS OF THE SOIL AFFECTING THE BUILDING

Z. Lipski[1] and D. Mrozek[2]

Abstract

The paper deals with the application of two criterial parameters, viz. the Arias intensity and the average power, in the classification of dynamic loads exerted on a building due to mining quakes. This classification is based on the sensitivity of the construction to such quakes, with the dynamic purpose of detecting those loads which provoke the most extreme dynamic response of the building. The analyzed loads in the form of accelerating excitations were recorded in four seismological stations at Polkowice in the Copper Mining District of Legnica and Głogów. It has been found, that there exists a considerable relation between the aforesaid parameters characterizing these excitations and the dynamic response of the tested building..

1 INTRODUCTION

In the course of a numerical dynamical analysis of the supporting structures of building affected by loads due to vibration in the soil an important equivocal problem turns up concerning the proper choice of the load generating the extreme response in the considered construction, because in the load history method usually several, sometimes even some score of incident have to be analyzed, in the course of which vibrations are induced in the soil. Thus, for example, every intensive mining quake, earth quake, explosion of blasting material and passing of a heavy vehicle on an uneven road may be an impending danger for the building. The sensitivity of the analyzed construction to individual kinds of loads depends generally on the dynamic properties of the building and the spectral characteristics of the load in time. The former may be described, for instance, by means of a transmittance matrix of adequately selected inputs and outputs of the dynamic system. The properties of the load may be described in various ways. In the present paper dealing with the kinematic excitation caused by mining quakes it has been suggested to characterize these properties by criterial parameters, viz. the Arias intensity [2] and the average power. They were calculated separating from the excitation the components in the bands with boundaries depending on the own spectrum of the analyzed building [4]. The differentiation of the spectral properties of each excitation was also taken into account [3,5,6]. Basing on the matrix of the transition pulse functions of the tested building, the maximum horizontal dynamic differential displacement between the foundation and the roof of the highest storey was calculated. These displacements constituted the assessment [1,7] of the maximum dynamic response of the building to the analyzed excitations have been taken into account. They generate the components of the tensor of dynamic stresses, and thus condition the formation of possible damages in the supporting walls of the construction. In the comparative analysis of excitations both criterial parameters were treated as random independent variables, and the maximum dynamic displacements of the building as dependent ones. The existence of a regressive relation between them has been proved. Its existence permitted to assign a rank to each load in the analyzed set. The highest ranks denoted the most intensive loads

[1] Dr Zbigniew Lipski, Faculty of Civil Engineering, Silesian University of Technology Gliwice, Akademicka str. 5, Poland , (48) 32 237 19 97, zbigniew.lipski@polsl.pl.
[2] Mgr Dawid Mrozek, Faculty of Civil Engineering, Silesian University of Technology Gliwice, Akademicka str. 5, Poland , (48) 32 237 15 45, dawid.mrozek@polsl.pl.

exerted on the building. Excitations generating in the supporting structure extreme dynamic responses, being most dangerous from among all the analyzed loads, were to be observed in the subset of excitations. Nevertheless the dynamic responses of the tested building have been calculated numerically applying the method of the load history, making use of the chosen excitations.

2 PRINCIPLES OF THE ANALYSIS OF EXCITATIONS

The sensitivity of the structure of the tested building was analyzed for a set of realizations of stochastic processes constituting kinematic excitations. For this purpose a four-storey brick house with a basement was chosen. It has four external supporting walls and continuous footing of reinforced concrete. The dimensions of its horizontal projection were 6,0*8,0 m. The Young module of the material used for the walls amounted to E=0,5 GPa, the coefficient of soil reaction was assumed to be C=70 MPa/m, the dumping of the building was characterized by the coefficient of critical damping ξ=3 %. The numerical model of the building had 59700 quadrangle, shell four-nodes finite elements and 375000 degrees of freedom Fig. 1.

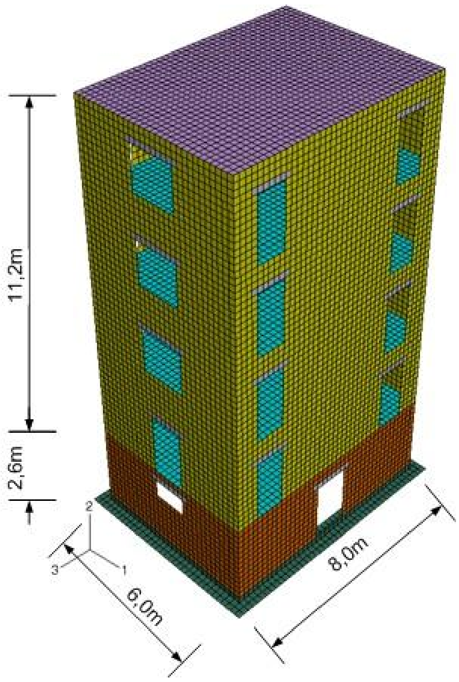


Fig. 1. View of the numerical model of the construction.

Its eigenfrequencies are to be seen in Table 1.

No.	Frequency [Hz]	Characteristic of eigenvectors
1	1.54	Strain in plane XZ
2	1.70	Strain in plane YZ
3	2.03	Rotation round axis Z
4	4.54	Composite strain state in plane XZ
5	4.58	Composite strain state in plane XZ
6	6.18	Composite strain state
7	6.81	Composite strain state

Tab. 1. Eigenfrequencies of the building.

The set of kinematic excitations affecting the building comprised 36 elements – the progress of acceleration in time, each of them consisting of two orthogonal components recorded by 4 seismologic stations. They were localized in various housing estates of Polkowice in the Copper Mining District of Legnica and Głogów, recording accelerations of the free surface of the soil. The vibrations were generated by quakes, which occurred

in Polkowice in the years 2000 – 2005. From among these were selected that, involved maximum accelerations of one of the horizontal components within the limits from 0.25 to 1.37 m/s^2. The frequencies of discretization in the accelerograms amounted to 200; 384.6 and 500 Hz depending on the devices used for recording them.
The Arias intensity was calculated in compliance with equation [8]

$$I_{Ak} = \sum_{j=0}^{N_s-1} \left(a_{xj}^2 + a_{yj}^2 \right) \Delta t \ , \ k = 1, 2, 3 \tag{1}$$

where: a_{xj} , a_{yj} – values (samples) of the horizontal components X and Y of kinematic excitation in the j-th point on the time axis,
$N_s = T_s/\Delta t + 1$ – number of samples of excitation,
T_s – duration of the analyzed excitation,
Δt – time of discretization of the signal.
The mean power of kinematic excitation was calculated according to the formula

$$P_k = \sum_{j=0}^{N_s-1} \left(a_{xj}^2 + a_{yj}^2 \right) / N_s \ . \tag{2}$$

The values of the Arias intensity and average power were calculated in selected bands of the frequency of kinematic excitations. Therefore, they were subjected to narrow – band filtration. Three narrow – band signals were chosen and again analyzed. The filtration was carried out by means of the Fourier transformation. In this way those components were separated from the excitations, which might influence the resonance of the tested building. The filtration was carried out in bands the position and width of which was adapted to its eigenfrequency. The boundary frequencies of the bands were assumed to display the three lowest eigenfrequencies in the first band, the next four eigenfrequencies in the second band and in the last one other values. From [1,4,7] it results that the level of the dynamic response generated by the paraseismic kinematic excitation in the buildings depends definitely on the components whose frequencies are close to the lowest eigenfrequencies. This sensitivity of responses to the component frequencies of excitation decreases with the increase of the values of the frequency. The boundary frequencies of the bands assumed in the analysis were 0.8 – 2.2 Hz in the first band, 2.2 – 7.5 Hz in the second and 7.5 – 20.0 Hz in the thirds. Each excitation was divided into two segments: the initial and the subsequent one, resulting from the separation of the spectra, e.g. the spectral power density. The former one lasts for 0,5 – 1 s second displaying a high – frequency character, the latter lasts longer and displays properties of a low – frequency signal. Thanks to that the objective analysis took into consideration the different spectral properties of each accelerogram in the course of its duration. The division was based on the function of the spectral power density.
As has already been mentioned in the Introduction, for the assessment of the dynamic response of the building the maximum resultants, relative dynamic horizontal displacements between the foundation and the highest storey were applied. The extreme stress fields, deciding about the degree of the dynamic effort of the supporting structure walls occur almost simultaneously with the mentioned displacement. They have been calculated by means of the formula

$$u_{\max}(t_0) = \sqrt{\left[u_{x2}(t_0) - u_{x1}(t_0)\right]^2 + \left[u_{y2}(t_0) - u_{y1}(t_0)\right]^2} \ , \tag{3}$$

where: $u_{x2}(t)$, $u_{y2}(t)$ – horizontal components of displacements the highest storey of the structure,
$u_{x1}(t)$, $u_{y1}(t)$ – horizontal components of displacements in the foundations of the building,
t_0 – position on the time axis of the maximum dynamic relative displacement of the building.
The components of displacements in (3) were calculated for all the 36 excitations applied in the analysis, making use of transition pulse function and convolution complying with the generally known formulas. The transition pulse functions were calculated numerically applying the load history method employing the model of the test building. It has been assumed that the accelerating impulsive kinematic excitation affected the building via the soil, whereas the horizontal components of its displacing dynamic response were calculated in the quoins of the roof the highest storey of the building and in the analogical points of the foundation.
The sets of maximum dynamic displacements of the building according to (3) and the Arias intensity according to (1) or the average power according to (2) of the excitations were used to investigate the regression between them. The parameters of excitations were an independent variable and the dynamic displacements of the building a dependent variable. The empirical regression function was assumed in the power form (surd), in other words linearly for these variables, rearranged by logarithmization. Thus, the function of linear regression could be expressed as

$$\ln y = a \ln x + \ln b \ , \tag{4}$$

or in the power form $y = bx^a$, (5)

where: *a, b* – coefficients of the regression function.

The values of the coefficients a, b were calculated by applying the standard procedure of the Matlab packet. As a measure of the stochastic relation of the analyzed random variables according to (4) the correlation coefficient was assumed, and the matching of the regression function (4) was assessed basing on the mean square deviation. As their typical estimators have been applied, no respective formulas need be quoted. In order to verify the results of the analysis of the sensitivity of the tested building to kinematic excitations numerical calculations have been carried out, basing on the highest excitations determined by the criterial parameters. The calculations were carried out by means of the load history method.

3 ANALYSIS OF THE RESULTS OF NUMERICAL CALCULATIONS

Table 2 presents ten kinematic excitations classified in the order of their intensity assessed basing on resultant horizontal relative dynamic displacements of the tested building. The displacements were inscribed in normalized form. To every one of them also values of Arias intensity and average power have been assigned. Utilizing the classification of excitations in the set, based on the values of these parameters, their rank could be determined. The ranking presented in this table permitted to indicate precisely the four most intensive excitations, which elicit in the structure of the tested building extreme dynamic responses.

No. of signal	Normalized comparatively dynamic displacement of building [ ]	Arias intensity*1000 in band			Average power *1000 in band		
		0.8 – 2.2 Hz	2.2 – 7.5 Hz	Signal rank in set	0.8 – 2.2 Hz	2.2 – 7.5 Hz	Signal rank in set
1	1.0	33.3	86.8	1	9.9	25.8	1
2	0.87	13.6	20.6	2	2.8	4.3	2
3	0.73	13.5	40.3	3	2.3	6.8	3
4	0.69	6.2	12.4	4	2.3	4.5	4
5	0.57	5.4	31.5	6	1.7	10.1	5
6	0.53	3.4	21.0	10	1.0	6.3	10
7	0.47	5.6	9.3	5	1.5	2.4	7
8	0.44	4.2	14.4	9	1.3	4.4	9
9	0.43	4.3	7.4	8	1.4	2.4	8
10	0.43	4.8	11.5	7	1.6	3.9	6

Tab. 2 Values of the Arias intensity and average power in segment No. 2 of the most intensive kinematic excitations.

Table 3 contains values of the parameters of linear regression function (4) calculated for sets of logarithmic variables and the mean square deviations and the correlation coefficient related also to the same variables. This table presents also the values of the coefficients of the power regression function (5) in the segment No. 2 together with their values corresponding to the confidence interval on the significance level ±10%. The correlation coefficients concerning the investigated stochastic relation amount to 0.93 0r 0.94 in segment No.2 and the lowest band , depending on the variable. In this segment and in the band No. 2 the correlation coefficient amounts to 0.81 or 0.69, and in the highest band its values are still smaller. In segment No. 1 the values of the correlation coefficient is generally smaller than their corresponding values in the segment No. 2. The mean square deviation amounts to 0,28 or 0,27 in the lowest band of the segment No. 2 and to 0,76 or 0,77 in the band No. 3. It may be said that the quality of matching the regression function to the random variables distinctly deteriorates in the case of calculating it for higher and higher bands, and that it is worse in the segment No. 1 than in the segment No. 2.

This statement is confirmed by Fig. 2 a and b, presenting diagrams of the regression functions for the sets of logarithmic independent variables: the Arias intensity or averages power, and the dependent variable – the normalized dynamic displacements of the building in the segment No. 2, both in the first and second band.

Fig. 2a concerns the Arias intensity and Fig. 2b the average power. The results corresponding to the first segment or to the highest band have been neglected because of the distinctly worse correlation of the random variables

No.	Linear function of regression						Power function of regression			
	Values of coefficients		Values of coefficients in confidence interval ±10%		Mean square devia-tions	Correla-tion coeffi-cient	Values of coefficients		Values of coefficients in confidence interval ±10%	
	a	lnb	a	lnb			a	b	a	b
Arias intensity										
1	0.435	1.528	0.402/0.467	1.291/1.765	0.28	0.93	0.435	4.608	0.402/0.467	3.64/5.84
2	0.620	1.526	0.497/0.742	0.912/2.139	0.45	0.81	0.620	4.60	0.497/0.742	2.49/8.49
3	0.171	-0.68	-0.033/0.37	-1.69/0.329	0.76	0.17	0.171	0.506	-0.033/0.37	0.184/1.39
Average power										
1	0.510	2.487	0.466/0.554	2.136/2.839	0.27	0.94	0.510	12.03	0.466/0.554	8.46/17.09
2	0.603	1.952	0.409/0.798	0.825/3.078	0.56	0.69	0.603	7.039	0.409/0.798	2.28/21.72
3	-0.018	-1.61	-0.235/0.20	-2.859/-0.36	0.77	0.07	-0.018	0.200	-0.235/0.20	0.057/0.696

Tab. 3 Values of the parameters characterizing the regression function

taken into account in the analysis and due to the poor matching of the regression function to the data. The symbol "x" denotes the location of the points corresponding to the analyzed data. Fig. 2 shows that the dissipation of the variables in the lowest band of the segment No.2 is distinctly less than in the higher band.

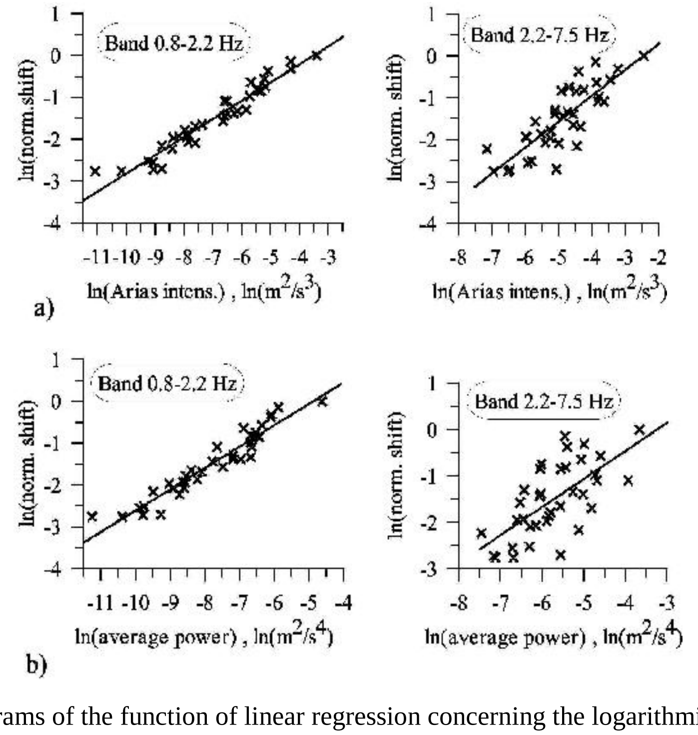
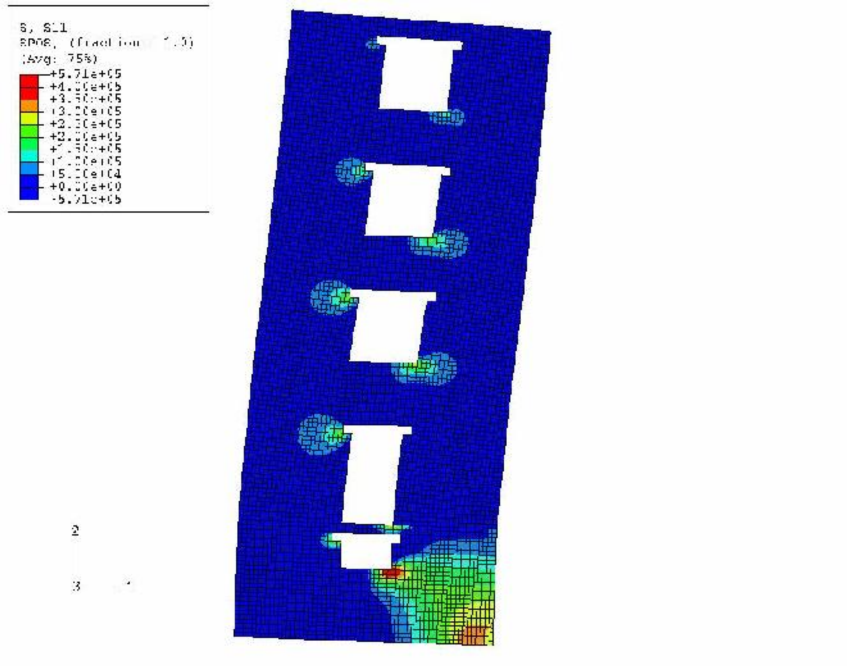
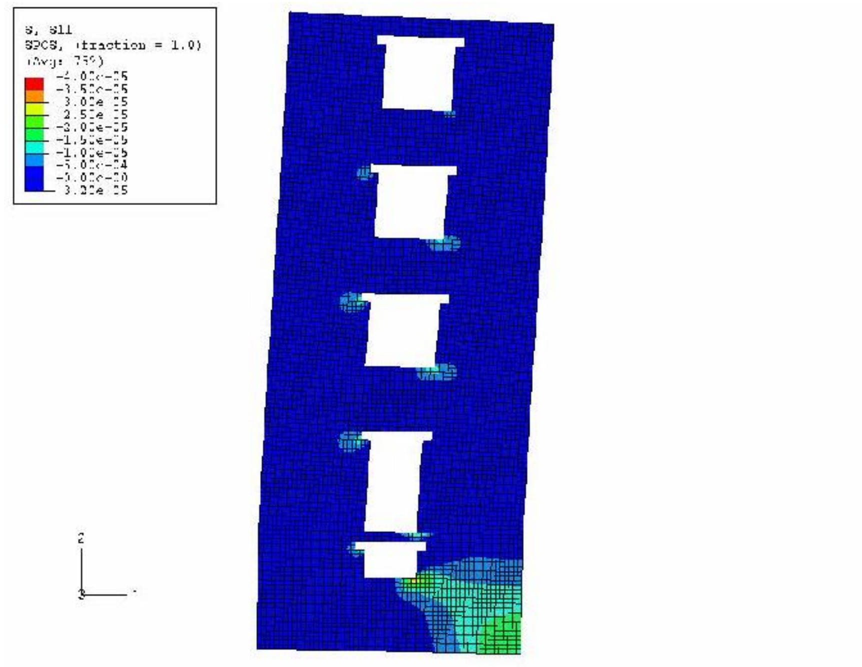


Fig.2 Diagrams of the function of linear regression concerning the logarithmic variables.

The assessed ranking of paraseismic loads was verified basing on the results of numerical calculations of the effect of excitations on the tested building in the course of their entire duration. Also relative displacements have been checked defining them analogically as in the case of the quantities applied in the assessment of the dynamic response of the building in compliance with item 2. For this purpose the numerical model presented in Fig. 1 was used. The calculations were carried out according to the load history method. As loads the kinematic excitations Nos. 1 – 6 in table 2 were assumed, which in the comparative analysis were considered to be responsible for extreme dynamic responses. The progress of the aforesaid relative displacements of the structure in time served as results of calculations, similarly the normal and shear stress fields. In principle the progress of relative dynamic displacements generated by the loads Nos. 1 – 6 in time, calculated by according to the finite element method and applying the transition pulse function are the same. This means that the assessment of dynamic displacements making use of the transition pulse function is the correct procedure. Fig. 3 a – c presents maps of normal horizontal dynamic stresses in the external transverse wall, caused by the loads Nos. 1 –2 (tab. 2).



a)



b)

Fig. 3 Maps of normal horizontal dynamic stresses in the transverse wall generated by the excitations: a) -nr 1, b) – nr 2.

The presented cases of the dynamic responses of the structure differ from each other in the extreme values of the stresses and keep the ranking of 1, 2, respectively, resulting from the analysis of the criterial parameters. It may be said that the ranking of loads determined on their basis is correct rendering a priori the adequate ranking resulting from the extreme values of the dynamic stresses of the structure, which constitute its dynamic response to the given load.

4 CONCLUSIONS

The analysis of the Arias intensity and average power of a set of 36 kinematic excitations generated by mining quakes and affecting the tested building indicates that there is some relation between these parameters and the extreme dynamic response of the building. Considering these parameters and the extreme dynamic displacements of building to be random variables, it may be maintained that they are stochastically dependent. The measure of this relation, i.e. value of the correlation coefficient increases distinctly in the case of excitations in the form of narrow – band signals with a band comprising the lowest eigenfrequencies of the tested building. Thus the conclusion may be drawn that each of the two selected parameters allows to assess the intensity of kinematic excitations reliably from the point of view of maximizing the dynamic response of the building. It is worth to be stressed that the matter is the maximization of the response of some definite construction, already existing or being designed. This results from a rather far reaching detailed definition of each quantity. Particularly important is the application of segmentation and narrow – band filtration of the excitations, thanks to which the dynamic properties of the building can be taken into account. This conclusion concerns the low – frequency segment of each excitation as well as the lowest band from among those determined in the present paper.

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