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ESTIMATION OF DYNAMIC RESPONSE OF BUILDINGS WITH LOAD BEARING WALLS USING RESPONSE SPECTRA AND NEURAL NETWORKS

Krystyna Kuźniar

Pedagogical University of Cracow

e-mail: kkuzniar@wsp.krakow.pl

The paper deals with application of neural networks and response spectra for estimation of dynamic response of medium-height buildings with load bearing walls. Averaged spectra are also used. Computed results are compared with experimental ones on actual structures. Results from the study show that effects of the neural network analysis are quite satisfactory.

Key words: neural network, response spectra, dynamic response

1. Introduction

The estimation of dynamic response of buildings (displacements and inertial forces) is a very important problem of structural dynamics. The dynamic response of buildings subjected to seismic-type excitations by tests on actual full-scale buildings was described e.g. in Ciesielski et al. (1995) and Maciąg (1986). However a theoretical structural dynamic analysis involves many complex tasks like creating an idealized model of a building and selection of ground flexibility parameters. Besides, the problem is relative to very complex structures as buildings, in particular – prefabricated buildings. Recently, some papers have dealt with using the neural network technique for dynamic problems (cf. e.g. Chen et al., 1995; Cheng and Popplewell, 1994). Earthquake response spectra are often used in analysis and design of structures. But both response spectra and neural networks are used for vibration problems e.g. in Ghaboussi, Lin (1998) and Cheng, Popplewell (1994). The problem related to simulation of the displacement response in the time domain of a building subjected to seismic-type excitations (one-step algorithm) was discussed in Kuźniar et al. (2000).

This paper is concerned with application of artificial neural networks for estimation of the dynamic response of medium-height buildings (five-storey buildings) with load bearing walls. They are prefabricated buildings erected using the panel or block technology, so they are particularly sensitive to dynamic effects. The sets of training and testing patterns were formulated on the basis of tests performed on real structures, that means – on actual full-scale buildings. Displacement response spectra are utilized here. The trial of estimation of averaged ground spectra and neural network usefulness to real building dynamic response calculations are also presented in this paper.

2. Analysed buildings

Typical residential, prefabricated, with load bearing walls, five-storey buildings were tested. Buildings of the WUF-GT84 type (one object), C/MBY/V (III) type (one object), DOMINO-68 type (one object) and WUF-T-67-S.A./V type (one object) were erected in the large panel technology and buildings of the BSK type (two objects) in large block technology. The walls constituting a transverse-longitudinal system are the vertical bearing elements in the buildings. Every storey is 2.7 m or 2.8 m high. All the buildings have basements and they are founded on different grounds with concrete strip foundations. In Fig. 1 a selected pattern of the plan and vertical section of the considered buildings are shown.

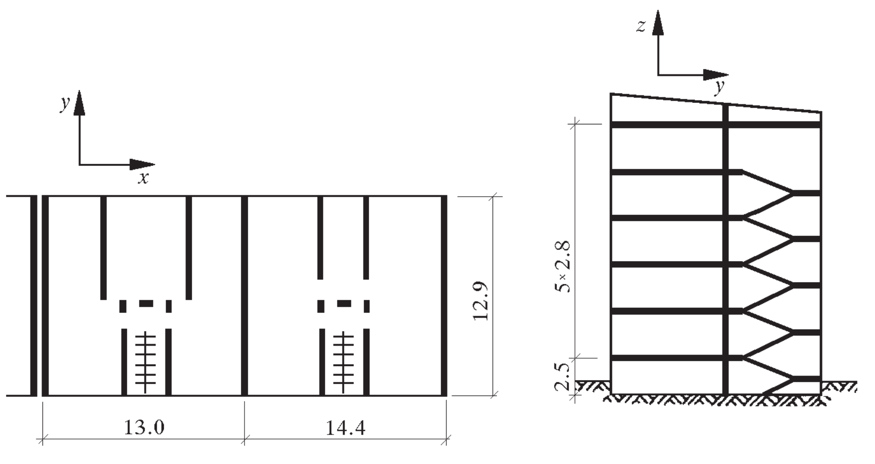


Fig. 1. Plan and vertical section of the BSK type building

3. Description of the tests on real buildings

Full scale tests were made many times for a period of a few years (Ciesielski et al., 1995). Firings of explosives in nearby quarries were the sources of the building vibrations. The investigated buildings were located at a distance of 300 m to 1200 m from the site of the explosions. The blowing charges were fired in different places on the walls of excavations. Hence, various distances and angles of the waves reaching analysed buildings were obtained. Explosions were carried out using the technology of long, almost vertical as well as horizontal holes. The amount of the explosives varied from 300 kg to 2100 kg in the case of vertical holes, and 45 kg in the case of horizontal ones. The main attention was devoted to measurements of horizontal vibration components in the directions parallel to transverse and longitudinal axis of the buildings. The seismographs were placed on the ground in front of the building, at the basement level and at the fourth floor. In Table 1 in the third, fourth and fifth columns the numbers of recorded building vibrations at the above mentioned three levels are collected, respectively. In Fig. 2, as an example, vibrations of the building of the BSK type in the longitudinal direction on the ground, on the basement and fourth floor level are shown, respectively. One of the explosions (long holes technology) in the nearby quarry was the source of these vibrations.

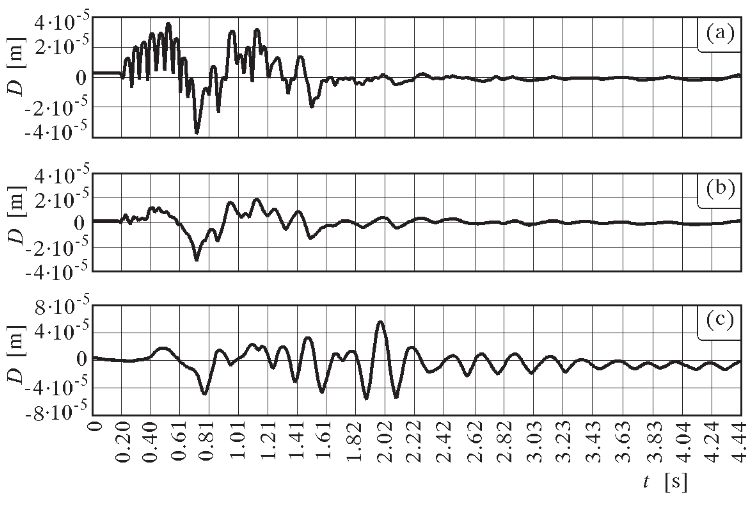


Fig. 2. Vibrations in the longitudinal direction of the BSK type building developed by one of explosions in the nearby quarry; (a) on the ground; (b) at the basement level; (c) on the fourth floor level

Table 1. Statement of experimental investigations of buildings

Building		Direction	Number of recorded vibrations			Number of patterns
			ground	basement	4th floor	
1		2	3	4	5	6
BSK (I)	seg. I	Transverse	14	9	15	23
		Longitudinal	7	13	14	20
	seg. II	Transverse	6	8	8	14
		Longitudinal	–	1	1	1
BSK (II)	seg. I	Transverse	4	–	4	4
		Longitudinal	–	–	–	–
WUF-GT 84	seg. I	Transverse	11	10	21	21
		Longitudinal	2	8	8	10
	seg. II	Transverse	6	5	8	11
		Longitudinal	–	2	2	2
C/MBY/V (III)		Transverse	–	1	1	1
		Longitudinal	–	1	1	1
DOMINO-68		Transverse	–	1	1	1
		Longitudinal	–	1	1	1
WUF-T-67-S.A./V		Transverse	–	1	1	1
		Longitudinal	–	1	1	1
			Total number of patterns:			112

4. Calculation of dynamic response of prefabricated medium-height buildings using neural networks

The paper concerns the following idea of estimation of the dynamic response of buildings by neural networks: the input vector includes the description of excitation vibrations and information about the dynamic properties of the building; on the output of the network the dynamic response of building is expected.

All the recorded experimental data in the form of vibrations in the time domain on the ground, the basement level and the fourth floor level were first preprocessed. The data preprocessing was carried out in order to obtain discrete values of variables. For all the excitation vibrations (the ground and the basement level), the displacement response spectra (S_d) were calculated.

The range of the vibration period (T) was from 0.025 s to 1.0 s with two steps: 0.01 s and 0.02 s. It can be stated that the forms of response spectra obtained for the larger step T (0.02 s) are very close to those estimated with greater precision (step 0.01 s). In Fig. 3 these two versions of the response displacement ground spectra are compared for the transverse direction of the building of the BSK type. These spectra were evaluated on the basis of vibrations caused by various technologies of explosions in the quarry.

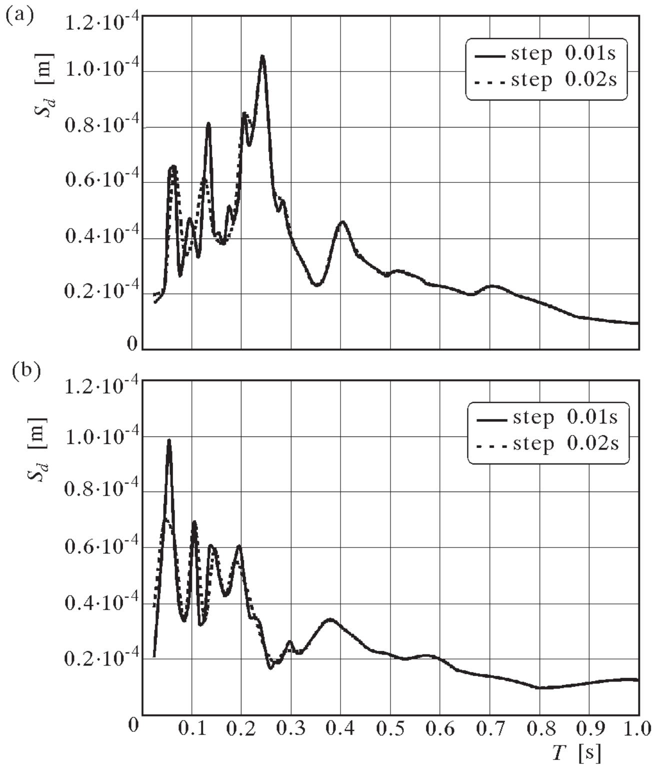


Fig. 3. Response displacement ground spectra for the transverse direction of the BSK type building; (a) vertical holes technology of explosions; (b) horizontal holes technology of explosions

Therefore, for the purpose of reduction of the neural network input vector dimension, it has been decided that the response spectra calculated with $\Delta T = 0.02$ s would be used for further analysis. Additionally, the description of excitations is confined to first twenty values of the displacement response spectrum, from $T = 0.025$ s to $T = 0.405$ s. The substantiation of this is the fact, that this range includes the fundamental natural periods of the analysed buildings with a considerable margin.

Some of the excitation vibrations were recorded on the ground in front of the buildings and some of them – at the basement level (cf. Table 1). But in the contact ground – building foundation there is observed the reduction of vibrations as a result of soil – structure interaction (cf. e.g. Ciesielski et al., 1990, 1994, 1998). Therefore, not only the excitation (by e.g. response spectrum), but also the place of its registration has to be described.

The dynamic properties of the analysed buildings (particularly values of fundamental natural periods) depend on the ground flexibility, the building dimension in the direction of vibrations, the equivalent bending stiffness and the shear stiffness (cf. Maciąg, 1986; Maciąg and Kuźniar, 1993; Kuźniar and Maciąg, 1999). The height of the building has also an effect on its fundamental natural period. But the discussed buildings are typical five-storey buildings and they are practically of the same height (every storey is 2.7 m or 2.8 m high). That is why the height of the building is not taken into consideration in the input vector.

Then the following input vector is proposed

$$\boldsymbol{X}_{(25\times 1)} = [d_1, d_2, ..., d_{20}, p, C_z, b, s, r] \tag{4.1}$$

where

d_i	–	digital values of the displacement spectrum, $i = 1, ..., 20$
p	–	parameter defining the place of recorded excitation; it was taken $p = 0.4$ for vibrations recorded on the ground and $p = 0.7$ for vibrations recorded at the basement level
C_z	–	coefficient of the elastic uniform vertical deflection of the soil basement
b	–	building dimension in the direction of vibrations
s	–	equivalent bending stiffness, $s = \sum_i EI_i/a$
r	–	equivalent shear stiffness, $r = \sum_i GA_i/a$
E, G	–	Young's and Kirchhoff's moduli, respectively
I_i, A_i	–	moment of inertia and area of the ith wall
a	–	length of the building.

The output of the network is the maximum displacement of the fourth building floor

$$Y = D_{max} \tag{4.2}$$

In Table 1 the total number of patterns and their division among the buildings and their vibration directions are put. The backpropagation neural network of architecture 25-4-1 with the Resilient backpropagation learning method was formulated. The sigmoid activation function was applied, so all the parameters were scaled to the range [0.1,0.9].

The calculations for the input vector in the form of (4.3) are also made

$$\boldsymbol{X}_{1(22\times1)} = [d_1, d_2, ..., d_{20}, p, T] \tag{4.3}$$

where

d_i, p – parameters as in (4.1)
T – fundamental natural period of building determined by neural analysis on the basis of parameters: C_z, b, s, r according to Kuźniar and Maciąg (1999).

The output of the network is just the same as the output of 25-4-1 network. The backpropagation neural network of structure 22-4-1 with the Resilient backpropagation learning method was applied. For the two versions of networks the SNNS package (Zell, 1995) was used.

For each of the maximum displacement of the fourth building floor (D_{max}), a relative error was calculated

$$e_{rel} = \Big(1 - \frac{D^{com}_{max}}{D^{exp}_{max}}\Big) \cdot 100\% \tag{4.4}$$

where

$D^{exp}_{max}, D^{com}_{max}$ – maximum displacement of the fourth building floor, experimental and computed by neural network, respectively.

In Fig. 4 the success rate (SR) for maximum displacements of the fourth building floor is shown as a function of the relative error (e_{rel}) computed for all the patterns (for networks: 25-4-1 and 22-4-1, respectively).

Using neural network analysis, D_{max} with the relative error not greater than 10% is predicted for 83% of patterns for network 25-4-1 and for 80% of patterns for network 22-4-1. Each of the two network versions also allowed determination of the maximum displacement of the fourth building floor with the relative error not greater than 15% for above 90% of the patterns. Similar results were obtained examining the transverse and longitudinal directions of the buildings separately.

Figure 5 presents the estimation of neural network analysis usability for the evaluation of the maximum displacement on the fourth building floor, separately in the case of kinematic excitation recorded on the ground and at the basement level.

It is stated that without regard for the place of recorded excitation (ground or basement level), the effects are similar. It results from the fact, that

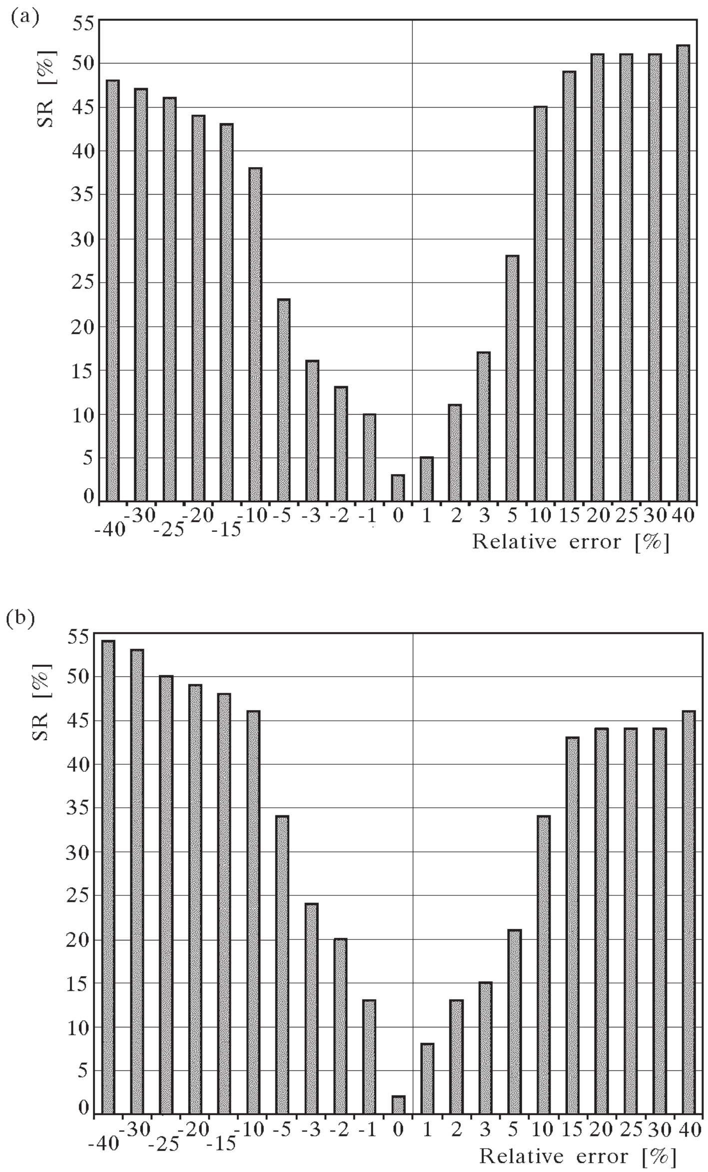
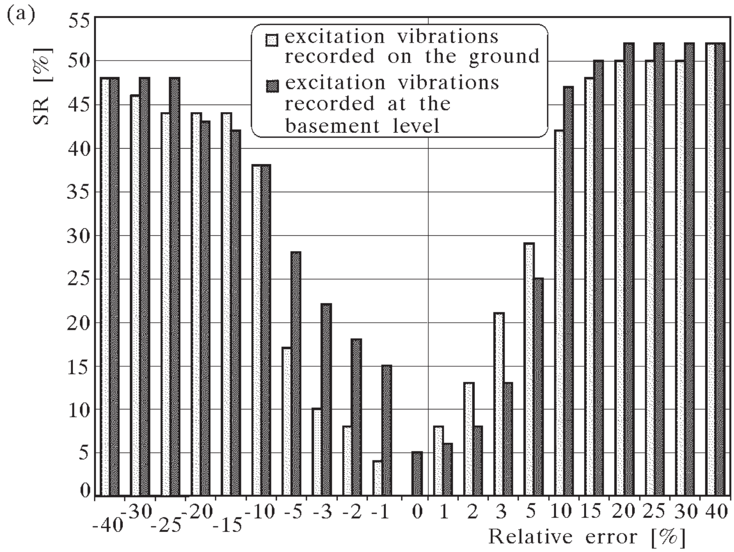


Fig. 4. Success rate (SR) for maximum displacements of the fourth building floor vs. relative error e_{rel} (all patterns); (a) network 25-4-1; (b) network 22-4-1



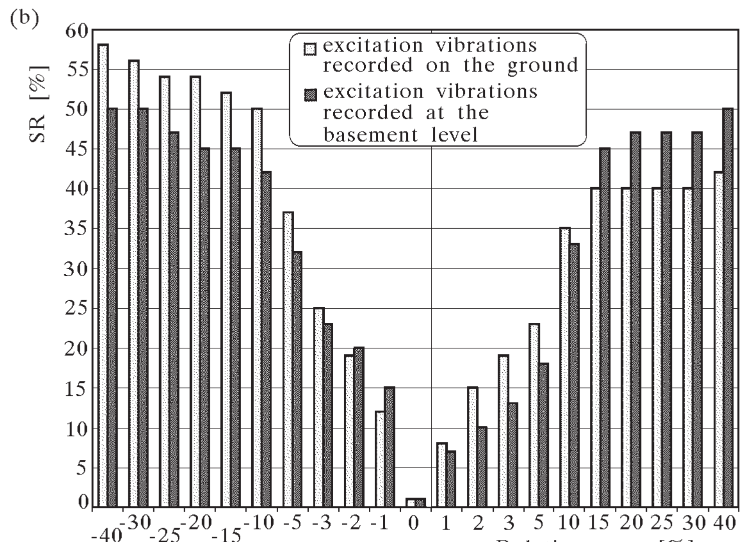


Fig. 5. Success rate (SR) for maximum displacements of the fourth building floor vs. relative error e_{rel}; (a) network 25-4-1; (b) network 22-4-1

the input vector includes information about the place of recorded excitation. The parameter p, cf. (4.1), is the parameter describing the soil-structure interaction. Thus, the relative errors not greater than 10% were obtained in the case of about 80% patterns using displacement response spectra based both on the vibrations on the ground and at the basement level. The relative errors for above 90% patterns are not greater than 15% for each of the places of excitation measurements. The above observations are very important from the practical point of view. Using the proposed neural networks allows one to take the soil-structure interaction into consideration in a very easy way. Even then, when the building is only in the phase of design (which excludes the excitations recording at the building basement level, of course), we can predict its dynamic response well, having measured ground vibrations on the place of its planned foundation.

5. Determination of the dynamic response by neural networks and averaged spectra

Because of economic reasons, in engineering practice, recording of real kinematic excitation is not possible for every building. Therefore, averaged response spectra are permitted to be applied (cf. e.g. Maciąg et al., 1999). The averaged response spectra are prepared on the basis of a huge number of recorded vibrations for each region of tremors.

In Fig. 6 the averaged displacement response spectra (S_d) for Chabry district in Opole, Poland are shown. Firings of explosives in the nearby quarry were the sources of vibrations. The spectra were determined separately for vibrations recorded on the ground in front of the BSK type building (cf. Fig. 1) and at its basement level. They are based on the vibrations recorded on the ground and at the basement level at the same time and also in the cases, when only the ground or basement vibrations were recorded. That explains the occurrence of greater ordinates of the averaged displacement response spectrum (S_d) based on vibrations recorded at the basement level. If in computations of S_d only the vibrations simultaneously recorded on the ground and at the basement level are taken into consideration, the obviously, in Fig. 5 the effect of vibrations reduction will be evident as a result of the soil-structure interaction.

The neural networks of architecture 25-4-1 and 22-4-1 were trained and tested using displacement response spectra determined on the basis of real experimental data of the vibrations. It was stated that the application of these

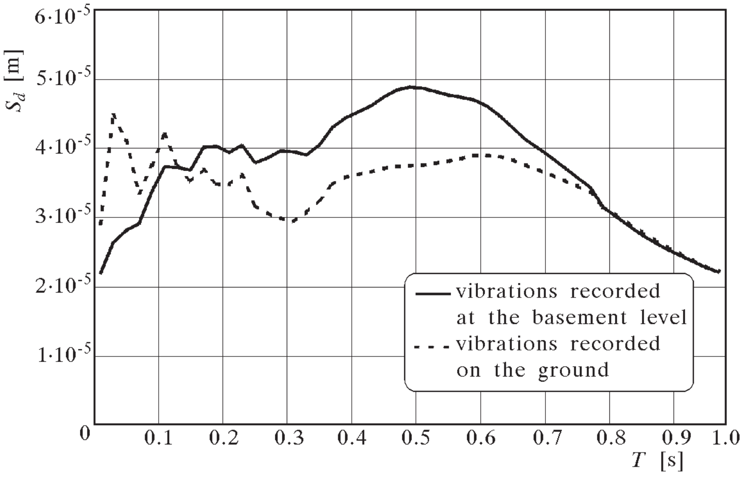


Fig. 6. Averaged displacement response spectra for Chabry district in Opole, Poland

neural networks enables us to predict the dynamic response of medium-height prefabricated buildings with satisfactory accuracy.

The thus trained networks were applied to the estimation usefulness of the averaged displacement response spectra in the determination of the dynamic response of the building of the BSK type. For this purpose, in the input vectors defined by (4.1) and (4.3) respectively, instead of actual values of the displacement spectrum: d_i, $i = 1, ..., 20$, the adequate values of averaged displacement response spectra for Chabry district in Opole, Poland were put in.

Using network 25-4-1 and the averaged displacement response spectra, D_{max} with the relative error not greater than 30% were predicted for 90% of patterns based on vibrations recorded on the ground and almost for 70% of the patterns with the response spectra based on vibrations recorded at the basement level.

When network 22-4-1 was used, the relative errors for D_{max} were a little greater. But the predicted values of maximum displacements of the fourth building floors were too great. Therefore, from the engineering point of view, the results were obtained in "safety side".

Thus, it is visible that in spite of application of the very approximate excitation description (in the form of averaged displacement response spectra), the discussed neural networks enable us to estimate the dynamic response of a five-storey building of the BSK type with good accuracy.

6. Conclusions

Application of displacement response spectra and using simple neural networks allows us to determine maximum displacements of the highest floors of prefabricated medium-height buildings in a simple way without analysing the equations of motion of the structures. Besides, the soil-structure interaction can be taken into consideration. The comparison of the results of the neural network analysis with the experimental ones on actual structures shows that the computational accuracy is sufficient in practice. The method of the estimation of a building dynamic response proposed in this paper can also be successfully used to prediction of responses of buildings in the design phase.

It seems that the analysed neural networks could also be applied to determination of the dynamic response of buildings with description of kinematic excitation in the form of averaged spectra only. Then, of course, with regard to the approximate character of excitations, the computed dynamic responses of the buildings will be evaluated with a little greater errors.

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Ocena drgań budynków ścianowych na podstawie spektrów odpowiedzi z wykorzystaniem SSN

Streszczenie

W pracy podjęto próbę zastosowania sztucznych sieci neuronowych oraz przemieszczeniowych spektrów odpowiedzi do wyznaczenia dynamicznej odpowiedzi ścianowych budynków prefabrykowanych o średniej wysokości. Wykorzystano również uśrednione spektra odpowiedzi. Wyniki obliczeń porównano z rezultatami badań doświadczalnych na obiektach rzeczywistych.

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