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Influence of Non-Structural Elements on Dynamic Response of Multi-Storey Rc Building to Mining Shock

Joanna M. Dulińska and Maria Fabijańska

Abstract**—**In the paper the results of calculations of the dynamic response of a multi-storey reinforced concrete building to a strong mining shock originated from the main region of mining activity in Poland (i.e. the Legnica-Glogow Copper District) are presented. The representative time histories of accelerations registered in three directions were used as ground motion data in calculations of the dynamic response of the structure. Two variants of a numerical model were applied: the model including only structural elements of the building and the model including both structural and non-structural elements (i.e. partition walls and ventilation ducts made of brick). It turned out that non-structural elements of multi-storey RC buildings have a small impact of about 10 % on natural frequencies of these structures. It was also proved that the dynamic response of building to mining shock obtained in case of inclusion of all non-structural elements in the numerical model is about 20 % smaller than in case of consideration of structural elements only. The principal stresses obtained in calculations of dynamic response of multi-storey building to strong mining shock are situated on the level of about 30% of values obtained from static analysis (dead load).

Keywords**—**Dynamic characteristics of buildings, mining shocks, dynamic response of buildings, non-structural elements

I. Introduction

NON-STRUCTURAL elements of multi-storey reinforced concrete buildings, like partition walls or ventilation ducts made of brick, are usually neglected in numerical models which are used for static calculations only. They are replaced by a linear load of intensity resulting from the their weight. In dynamic calculations, such simplifications can lead to improper determination of dynamic characteristics (natural frequencies and mode shapes) of these buildings. It is difficult to predict whether the consideration of non-structural elements leads to an increase or to a decrease in natural frequencies. On the one hand, these elements cause stiffening of the structure which results in the increase of natural frequencies, on the other hand an additional mass tends to the decrease in frequency values.

In low masonry residential buildings the influence of non-structural elements on the dynamic characteristics is noticeable [1], [2]. But non-structural elements introduced in multi-storey buildings have a smaller impact on the natural frequencies of these buildings. In such buildings the tendency to change the damping properties of the structure by introducing non-structural elements reveals much more.

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The confirmation of this fact can be found in many experimental works [3], [4].

Non-structural elements of buildings can also influence the dynamic response of structures to kinematic excitation, like earthquakes and mining shocks. Even though Poland is located in a zone of low natural seismicity there is an urgent need to protect engineering structures against mining shocks occurring in mining activity regions [5], [6]. The evaluation of dynamic response of buildings to mining shocks became a task of recent studies in Poland, but most papers concern mining related influences on low-rise typical residential buildings [2], [7]. The recognition of the influence of non-structural elements on dynamic response of multi-storey reinforced concrete buildings to kinematic excitation is still insufficient.

This paper presents complex evaluation of the influence of non-structural elements on dynamic characteristics of multi-storey RC building as well as the effect of these elements on the dynamic response of the structure to mining shock.

II. Data of Mining Shock from Legnica-Glogow Copper District

For the analysis of the dynamic response of multi-storey building a real mining shock was selected. This shock was registered in the Legnica-Glogow Copper District which is one of main mining activity regions in Poland [7], [8].

Time histories of ground accelerations in three directions are shown in Fig. 1.

In case of calculation of dynamic response of structures to earthquake a horizontal component of ground motion parallel to the direction of wave propagation plays central role. This component results from the Rayleigh wave propagation. Other components are usually found non-essential and they are rarely taken into account in seismic analyses. In case of mining shocks the situation is different. As the epicenter of the shock is located relatively close to the analyzed structure different types of waves, i.e. P, S and surface waves, reach the structure at the same time. In typical time history of a mining shock registered in a short distance from the epicenter values of amplitudes in three directions are comparable. Vertical amplitudes of ground motion can even be bigger than horizontal components.

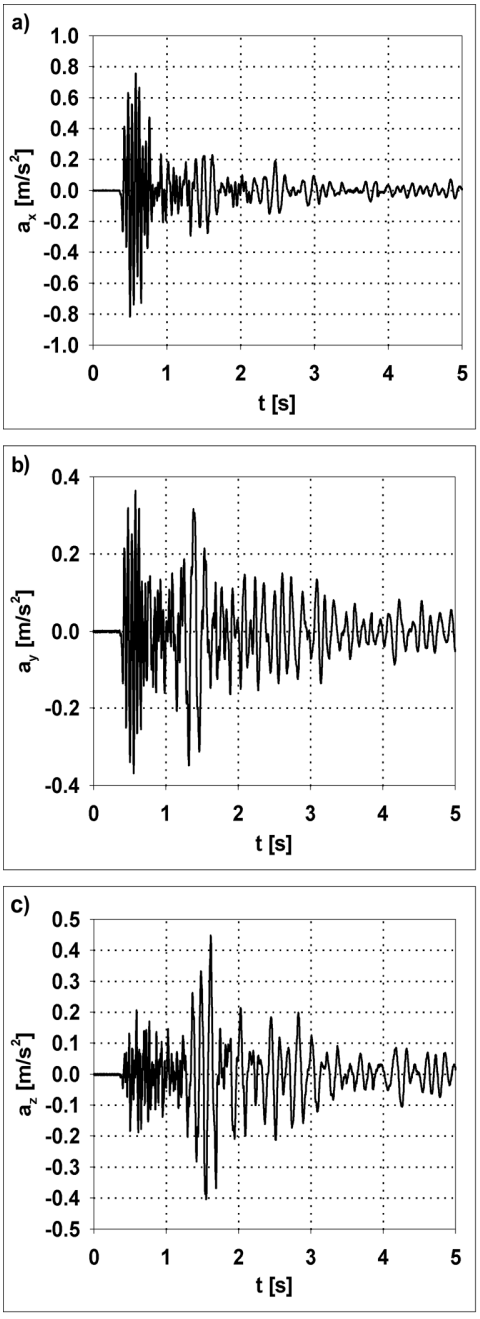

Fig. 1 Time histories of ground acceleration resulting from mining shock in the Legnica-Glogow Copper District: (a) horizontal direction X, (b) horizontal direction Y, (c) vertical direction Z

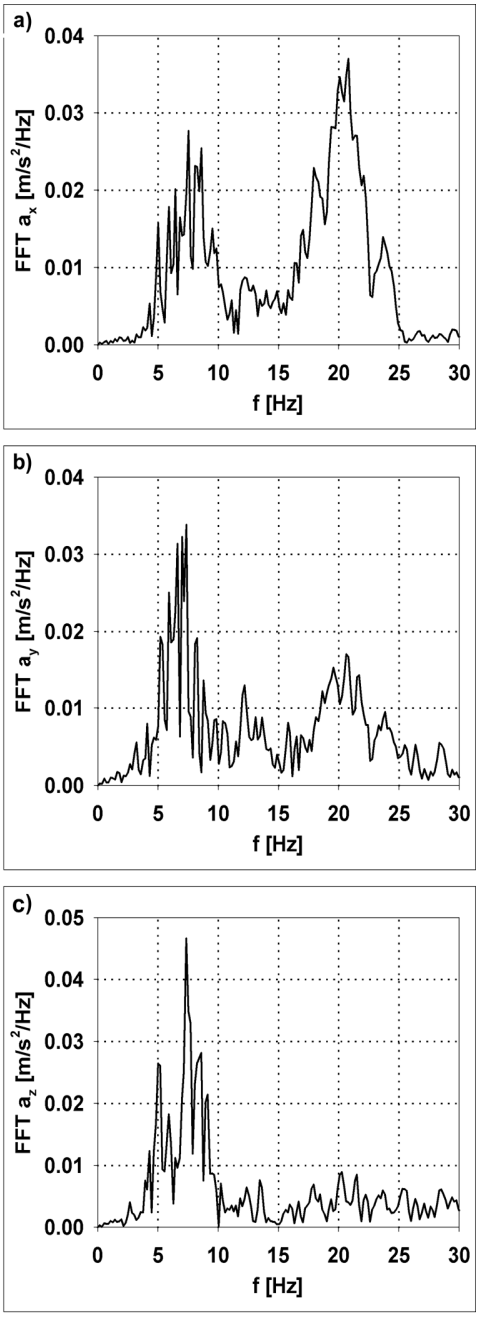

Fig. 2 Frequency spectra of acceleration of mining shock in the Legnica-Glogow Copper District: (a) horizontal direction X, (b) horizontal direction Y, (c) vertical direction Z

It could be observed in Fig. 1 that the maximal amplitudes of accelerations in horizontal and vertical directions are comparable. Hence, all three components of ground vibrations resulting from this mining tremor have to be considered in the dynamic analysis. The energy of the shock was about $5 \cdot 10^7$ J and it was one of the most intensive mining phenomenon registered in this region.

Fig. 2 shows the frequency spectrum of three component of the mining shock from the Legnica-Glogow Copper District. The amplitudes show maxima at the dominant frequencies of about 7 and 20 Hz.

III. Numerical Model of Multi-storey RC Building

A detailed analysis of the dynamic response to mining shock registered in the Legnica-Glogow Copper District was performed for a 7-storey reinforced concrete building of a skeleton structure. The essential dimensions of the investigated building are as follows: the length - 45.61 m, the width - 20.58 m, the height - 21.67 m. The main structural elements are columns with the dimensions of 30 cm x 30 cm and downstand beams with the dimensions of 30 cm x 45 cm. Load-bearing walls are made of concrete with a thickness of 30 cm. Reinforced concrete slabs separating each floor are 15 cm thick. The

reinforced concrete foundation slab 80 cm thick is spread beneath the whole building. The numerical model includes also footings of columns and slabs of balconies. All data of the geometry and material constants were taken from the documentation of the object. The material data of the structure are summarized in Table I.

TABLE I
MATERIAL DATA OF ANALYZED BUILDING

Part of the structure	Elasticity modulus [GN · m^{-2}]	Poisson's ratio [-]	Mass density [kg · m^{-3}]
Concrete columns	34	0.2	2500
Garage floor slab	32	0.2	2500
Upper floor slabs	31	0.2	2500
Concrete walls	30	0.2	2500
Foundation slab	32	0.2	2500
Non-structural brick walls and ventilation ducts	3	0.15	1800

A finite element model of the multi-storey reinforced concrete building is presented in Fig. 3. For modeling and calculations of the building the ABAQUS program was used – a general-purpose system for calculations of engineering structures based on FEM.

Fig. 3 Finite element model of the multi-storey RC building

Two variants of the numerical model of building were prepared: Variant A – the model of building that included only structural elements, i.e. the frame structure and the load-bearing walls, Variant B – the model of building that included all additional non-structural elements, such as: partition walls and ventilation ducts made of brick. The thickness of non-structural walls was 12 cm.

Fig. 4 shows the ground floor, whereas Fig. 5 - the top floor of the building in two analyzed variants. The location of the non-structural elements was assumed according to the documentation of the building. It could be observed from Figs 4 and 5 that there is a significant density of non-structural elements in the structure.

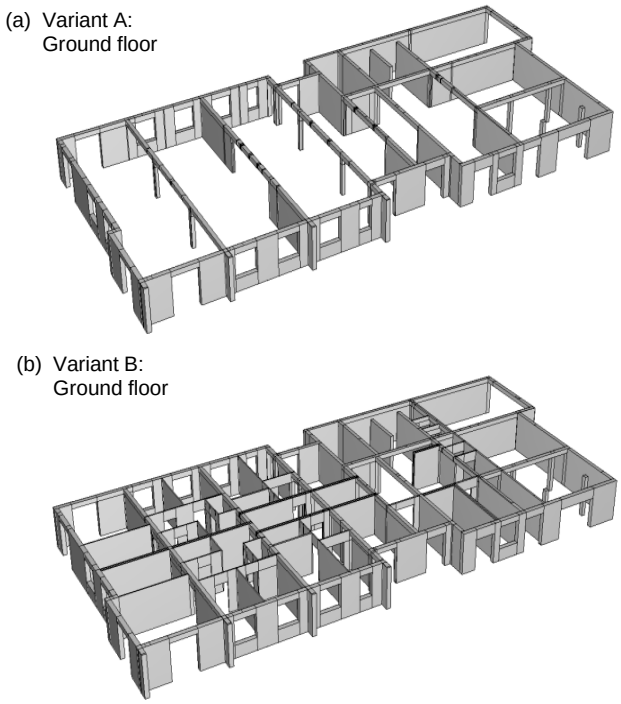

Fig. 4 Ground floor of the building: (a) Variant A - structural elements only, (b) Variant B - structural and non-structural elements

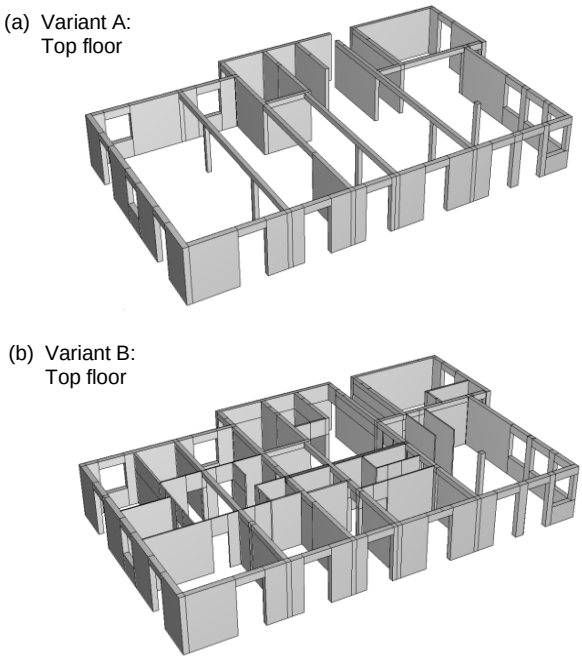

Fig. 5 Top floor of the building: (a) Variant A - structural elements only, (b) Variant B - structural and non-structural elements

IV. Dynamic Characteristics of Building

The evaluation of natural frequencies and modes of vibration was the first step of the dynamic analysis.

Fig. 6 shows first three modes of vibration. The first and the second mode of natural vibration are translational, the third mode is torsional. These mode shapes are similar for both Variants A and B of the numerical model.

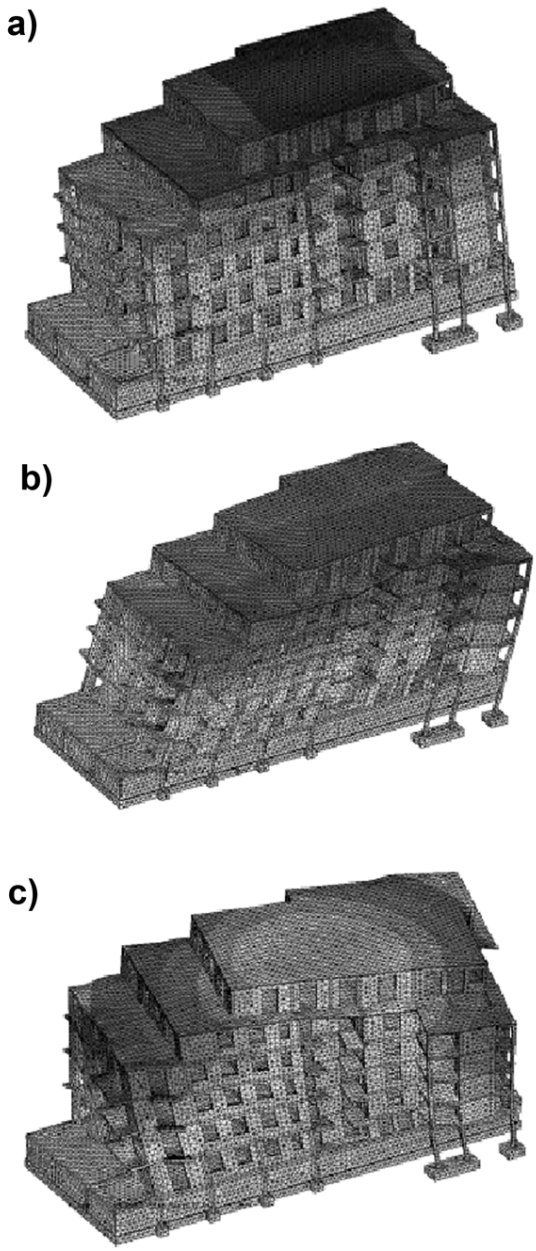

Fig. 6 Modes of natural vibration: (a) first mode – translational, (b) second mode – translational, (c) third mode – torsional

Table II summarizes the natural frequencies obtained for Variant A and Variant B. On the basis of the calculated differences it is easy to note that the inclusion of non-structural elements increases the natural frequencies. The differences reach 20 %. This means that the increase in the building stiffness caused by non-structural elements has greater impact on the dynamic characteristics than the increase in the weight of the building.

It should be pointed out that the first three natural frequencies are located within the range of the dominant frequencies of the mining shock registered in the Legnica-Glogow Copper District (see Fig. 2). Hence, the amplification of the building vibration may occur due to resonance effect.

TABLE II
COMPARISON OF NATURAL FREQUENCIES OF TWO VARIANTS OF BUILDING

Frequency no.	Frequency [Hz]		Difference [%]
	Variant A – structural elements only	Variant B – structural and non-structural elements	
1	7.125	7.849	10.16
2	8.184	8.931	9.14
3	10.028	11.254	12.21
4	17.393	20.644	18.69

For further dynamic analysis a model of Rayleigh damping was assumed:

$$[C] = \alpha \cdot [M] + \beta \cdot [K] \tag{1}$$

Rayleigh damping coefficients α and β were determined from the following relations:

$$2\xi_1 = \frac{\alpha}{2\pi \cdot f_1} + \beta \cdot 2\pi \cdot f_1 \tag{2}$$

$$2\xi_2 = \frac{\alpha}{2\pi \cdot f_2} + \beta \cdot 2\pi \cdot f_2 \tag{3}$$

where ξ_1, ξ_2 are critical damping fractions referring to frequencies f_1 and f_2 respectively. The critical damping fractions ξ_1, ξ_2 were assumed as 5 %. As f_1 in formula (2) the first natural frequency of the building equaled 7.125 Hz was assumed. As f_2 in formula (3) the natural frequency of the second mode of vibrations equaled 8.184 Hz was specified.

V. Influence of Non-Structural Elements on Dynamic Response of Building

In order to evaluate the influence of non-structural elements on the dynamic response of the building to the selected mining shock calculations of dynamic response were performed for both Variants A and B of the model. For further dynamic analysis maximal and minimal principal stresses at some representative points of the structure were calculated. In Table III the location of the selected points is described.

TABLE III
LOCATION OF REPRESENTATIVE POINTS SELECTED FOR ANALYSIS

Point no.	Location
P1	Central point of roof
P2 – P6	Central points of floor slabs
P7	Central point of ground floor
P8	Central point of basement floor
P9 – P16	Corners of floor slabs
P17 – P20	Corners of foundation slab

Figs 7, 8, 9 and 10 present of time histories of maximal as well as minimal principal stresses calculated at points P1, P3, P7 and P15, respectively. Continuous line refers to Variant A of the model (structural elements only), whereas dotted line pertains to Variant B (structural and non-structural elements).

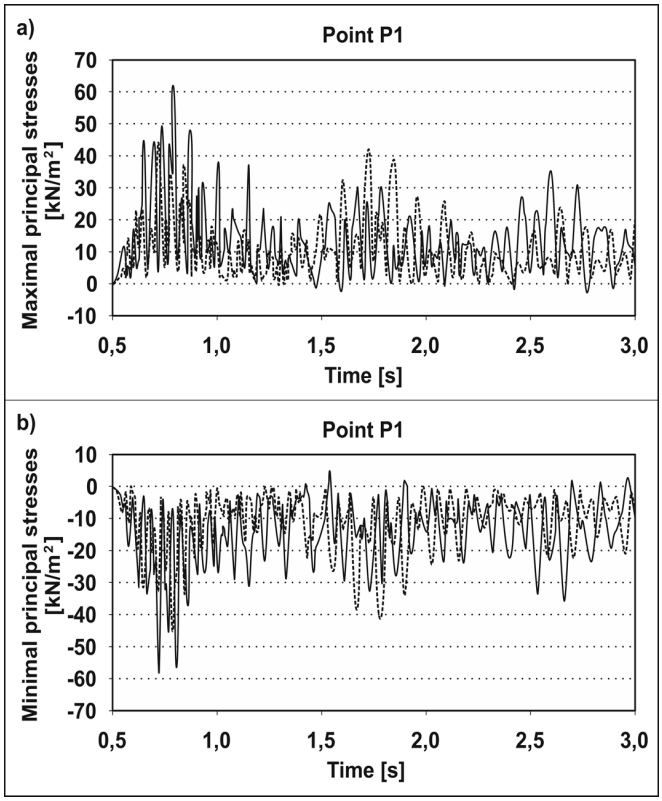

Fig. 7 Comparison of (a) maximal and (b) minimal principal stresses at point P1 for variant A (continuous line) and variant B (dotted line)

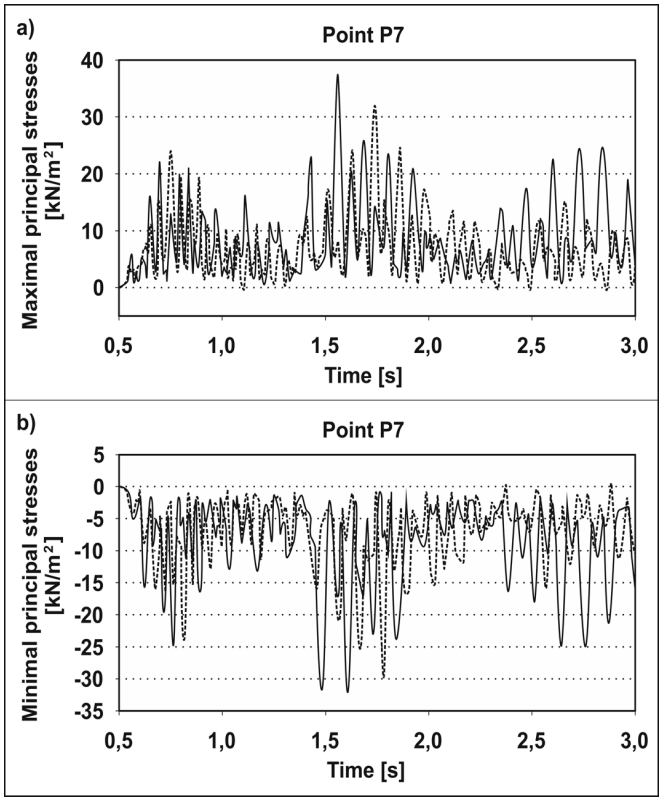

Fig. 9 Comparison of (a) maximal and (b) minimal principal stresses at point P7 for variant A (continuous line) and variant B (dotted line)

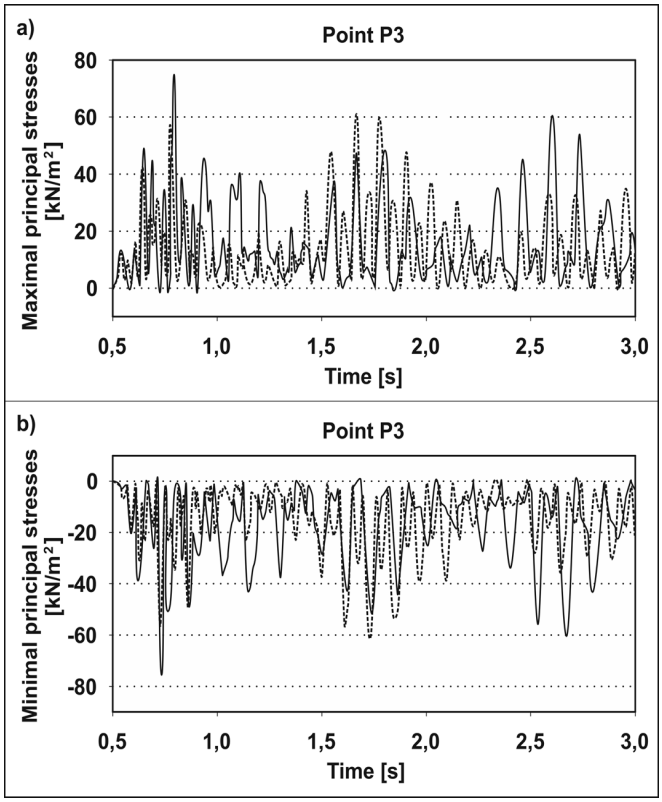

Fig. 8 Comparison of (a) maximal and (b) minimal principal stresses at point P3 for variant A (continuous line) and variant B (dotted line)

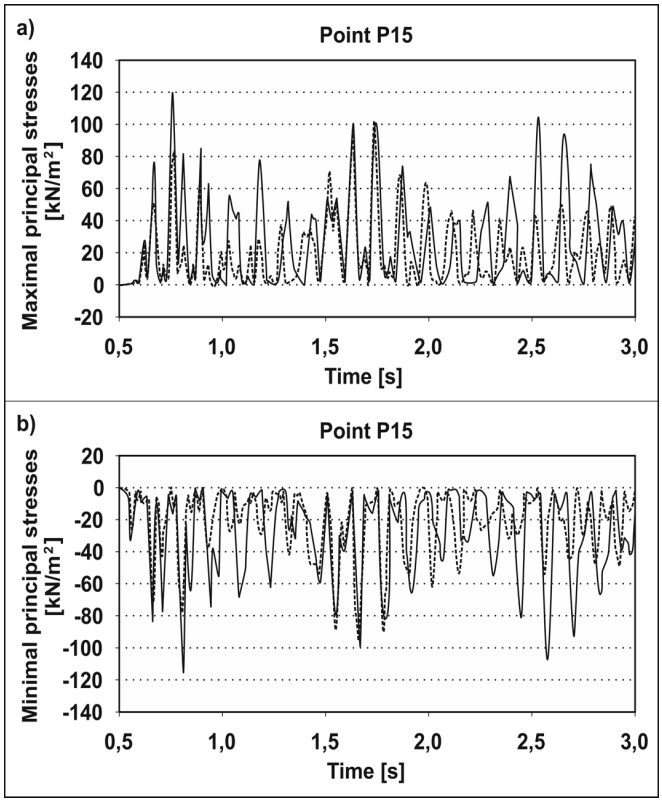

Fig. 10 Comparison of (a) maximal and (b) minimal principal stresses at point P15 for variant A (continuous line) and variant B (dotted line)

The decrease in both maximal and minimal principal stresses could be observed in Figs 7-10 due to the inclusion of non-structural elements into the numerical model of building. For comparison of the dynamic responses of both models: with and without non-structural elements the decrease in extreme values of principal stresses obtained for Variant B in comparison to Variant A were calculated for all analyzed points. Table IV summarizes the results of carried out comparisons for selected points located in different parts of the structure (see Table III).

TABLE IV
THE DECREASE IN MAXIMAL AND MINIMAL PRINCIPAL STRESSES OBTAINED FOR VARIANT B IN COMPARISON TO VARIANT A AT SELECTED POINTS

Point	Decrease in maximal principal stresses [%]	Decrease in minimal principal stresses [%]
P1	24.3	22.4
P3	18.3	18.7
P4	5.9	2.5
P7	16.4	7.4
P11	18.7	19.8
P15	15.9	17.4
P16	19.5	16.8
P17	4.1	11.4
P20	10.4	3.2

VI. CONCLUSIONS

In the paper the results of calculations of the dynamic response of multi-storey reinforced concrete building to strong mining shock originated from the main region of mining activity in Poland (i.e. the Legnica-Glogow Copper District) are presented. The numerical model including structural elements only as well as the model including both structural and non-structural elements of the building were studied.

The following conclusions and general remarks for engineering practice could be formulated:

1. Non-structural elements made of brick introduced in multi-storey RC buildings have a small impact on the natural frequencies of vibration of these structures. The increase in values of natural frequency of about 10 % could be noticed.
2. The presented comparisons of principal stresses show that the dynamic response obtained in case of inclusion of non-structural elements in the numerical model (Variant B) is smaller than the dynamic response obtained in case of consideration of structural elements only (Variant A). Additional stiffening of the model leads to the decrease of about 20% in the calculated principal stresses.
3. It should be pointed out that the analyzed mining shock belonged to the group of the strongest phenomena ever registered at the Legnica-Glogow Copper District. Moreover, the band of the dominant frequencies of the shock included first natural frequencies of the building so the dynamic response was increased by the resonance effect. Hence, the calculated principal stresses originated from the mining shock reach a relatively high level of about 30 % of stresses resulting from dead load. The extreme values of principal stresses in all analyzed points do not exceed 0.2 MPa.

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