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EVOLUTION OF THE BUILDING NATURAL FREQUENCY SPECTRUM DEFINED DURING PARASEISMICAL EXCITATION

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Abstract

The article contains the results of kinematics analysis of the quake force to the building structure. Attention was paid to changes in the natural frequency of the object due to degradation of the structure during the forced vibrations of the load. The spectral power density map of the applied force and the course of the natural frequency variation of small mortar building were compared. Time-frequency analysis was performed using the Gabor transform. A clear correlation was found between the course and force changes in the value of natural frequency of the structure.

1 INTRODUCTION

Intense human activity, as reflected in fields such as mining operation coal and copper ore is the source of static and dynamic influences of the ground on the buildings. These influences often cause failures to buildings, mostly masonry due to lack of appropriate safeguards and poor technical condition. Scratches and cracks in the structure may be associated with the transition under object convex and/or concave basin subsidence, discontinuous local deformation, or they result from the dynamic load. Some areas, for example in the Legnica - Głogów Copper are constantly exposed to quakes with peaks acceleration up to 2 m/s^2, so often there is a dynamic effect on the already damaged structure.

The problem of structural design and analysis of dynamic interaction is complex [2, 4] and is still ambiguous. It is worth noting that the biggest simplify concern usually the dynamic load. It is often treated as static without its characteristic time - spectrum. Purely dynamic analyses, for example Time History Analysis (*THA*), are still rare. The basic quantities characterizing the dynamic properties of the structure are frequencies (hereafter *NF*) and form of vibration. In the case of a dynamic analysis of the building, it is assumed that the values of these frequencies are constant during the dynamic loads action. Also material damping is assumed to be stable for the duration of the quake. This assumption is questionable.

This paper presents the results of numerical analysis of two models of low masonry building: initially undamaged (*MBN*) and pre-damaged (*MBU*) by the influence of deformation on the mining area. They are subjected to quake the paraseismic accelerations input generated by a strong mining quake that occurred in Polkowice in LGOM [5]. Structure material model, which took into account its degradation forming during the vibrations generated in the building by the quake and, consequently, change the *NF* value of model, was used. The aim of the analysis was to determine the final change of the models natural spectrum due to degradation of construction material caused by action the mining quake. They were complemented by the time – spectrum analysis assumed quake, which allowed to try to determine the correlation between changes in the value of the natural frequency of the model and that load.

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2 PRINCIPLES OF THE ANALYSIS OF BUILDING

Calculation procedure of *NF* values of a low building model during lasting dynamic load adapted to the algorithm of professional *FEM* package called ABAQUS, used to solve the task.

- At each time step $t_i = (i-1)\cdot\Delta t$, where Δt - discretization period, check the conditions of effort on the basis of which estimate the location and size of the material degradation area. In the degraded zone assumed new values of shear modulus. Calculations were performed for the full course kinematics excitation in time. Registered the number of time step N_{kryt} at which the degradation reaches extreme levels and stabilizes mainly due to the gradual disappearance of extortion.
- Calculations repeated for the same quake acting on the undegraded objects model and finished them for $t = (N_{kryt} - 1)\cdot\Delta t$. For the model of degraded natural frequencies were calculated.

Calculations carried out in different variants, which aim was to examine intermediate degradation steps prior to the final state and its quake on the natural frequency spectrum. This algorithm allows not only to the carrying out estimation of the degree and extent of degradation of the material objects model, but also to correlate the final changes the natural frequency with evolving spectrum of the kinematics excitations power density.

In calculations used non-linear elastic-plastic-degradation material model - Barcelona Model (*BM*), in which the material, after obtaining the certain level of effort, plastify itself and undergoes partial degradation. Mechanisms of strengthening/weakening and degradation during masonry tension and compression are described by relationships derived from the relevant laboratory tests [7]. This model takes also into account the partial restoration of degraded material properties during repetitive sequence tension - compression. Physically, this condition can be defined as "closing" cracks as a result of working the compressive stresses. To describe the level of degradation associated with tension, compression and closing cracks are three factors with values from a closed interval <0, 1>. Coefficients equal to zero mean lack of degradation, while the value equal to one - the total destruction of the material. The current values of the material elastic modulus are addicted from it.

Low building was analyzed in two versions. The first concerned to the model without any damage of the walls (*MBN*). In the latter case, the model characterized by the presence of initial failures of mining occurring i.e. primary in relation to the carried out analysis (*MBU*). Load-bearing walls (exterior and interior), ceilings and secondary elements were cracked and scratched [1]. Schematic scratches layout of the exterior walls in the real building and numerical model caused by the interaction of convex basin is shown in Figure 1. Cracks are focused typically on the bottom floor of the building and spread diagonally outside in higher parts of walls.

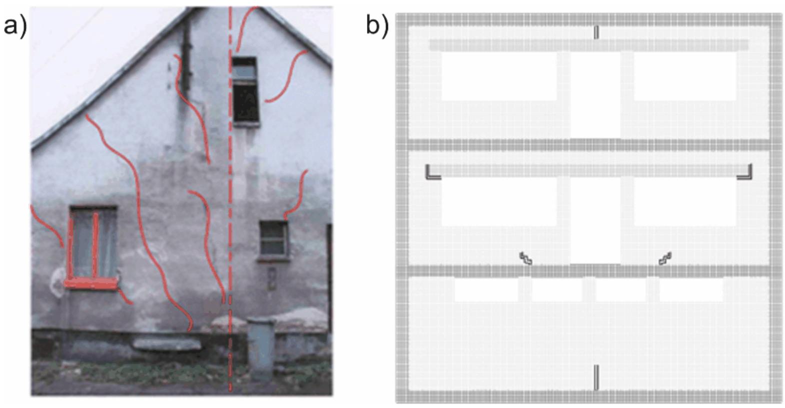

Fig. 1. Typical damage of the building caused by a convex basin (*NW*): a) real building, b) numerical model

3 ANALYZED BUILDING MODELS AND LOADS

An attempt was made to analyze the material degradation induced by mining quake using 3*D* model building. A dense mesh of finite elements, which was conditioned by the need to locate the degraded areas and to estimate their size and shape, was used. This model, however, in the course of the *THA* method proved to be unstable and results of the calculations were accidental, and therefore unreliable. Therefore, a simplified 2*D* plane model [5, 6], in which minimized the differences in response to static and dynamic both models, was used. For this purpose, properly chosen length of the lateral walls and ceilings, working with analyzed wall were inserted and substitute ground flexibility was assumed. In plane models linear - elastic characteristics of the construction material of ceilings and lateral walls and the square finite elements of side 5 *cm* were used. Damages were modeled by excision finite element in established areas, introducing the interaction within the modeled features. One-sided elastic contact between their edges with respect to compression was applied and it was assumed that the friction was characterized by coefficient with value of 0.7. This enabled the cracks opening during dynamic load action and interaction of the edge after its closure. It is assumed that in the initial stage (Fig. 1b), the maximum crack length was 60 *cm*, and their primary opening - 0.2 *mm*.

Dynamic analysis of both plane models was performed by *THA* method. It was preceded by the static calculations with a given deadweight and part of the long-term useful load in order to determine the initial state of stress and strain. In dynamic calculations assumed that load was in form of the kinematics excitation from Polkowice area. Selected that mining quake, which generated acceleration of a peak value 1 m/s^2 (Fig. 3), i.e. the average level as LGOM conditions, but its time - spectrum characteristic showed a high level of dynamic response of the building because of appearing a short-term resonance. Signal duration was 4.2 *s*, what with the discretization period $\Delta t=0{,}005\ s$ gives 841 points where *FEM* system of differential equations was resolved.

Analysis function is associated with the function of synthesis, because they are biorthogonal. This means that it is orthogonal both in time and frequency domain, which is represented by formula:

$$\sum_{m,n} g_{m,n}(t)\gamma^{*}_{m,n}(t') = \delta(t-t') \tag{1}$$

During analyzing of one signal is used one analysis window, which moves along the time domain signal. In this way, the coefficients values in different points in the plane specified time and frequency axes are obtained. The resulting time - frequency Gabor representations that are analogue of the spectral power density was calculated from the formula:

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

Equations (1) and (2) also have a discrete version. It completed with use a script written in Matlab. The solution of this task is a map in the frequency and time system, which is presented in Figure 2. Bright colors indicate the dominant frequency of the signal at the level of 3 to 6 *Hz* and 8 to 12 *Hz*.

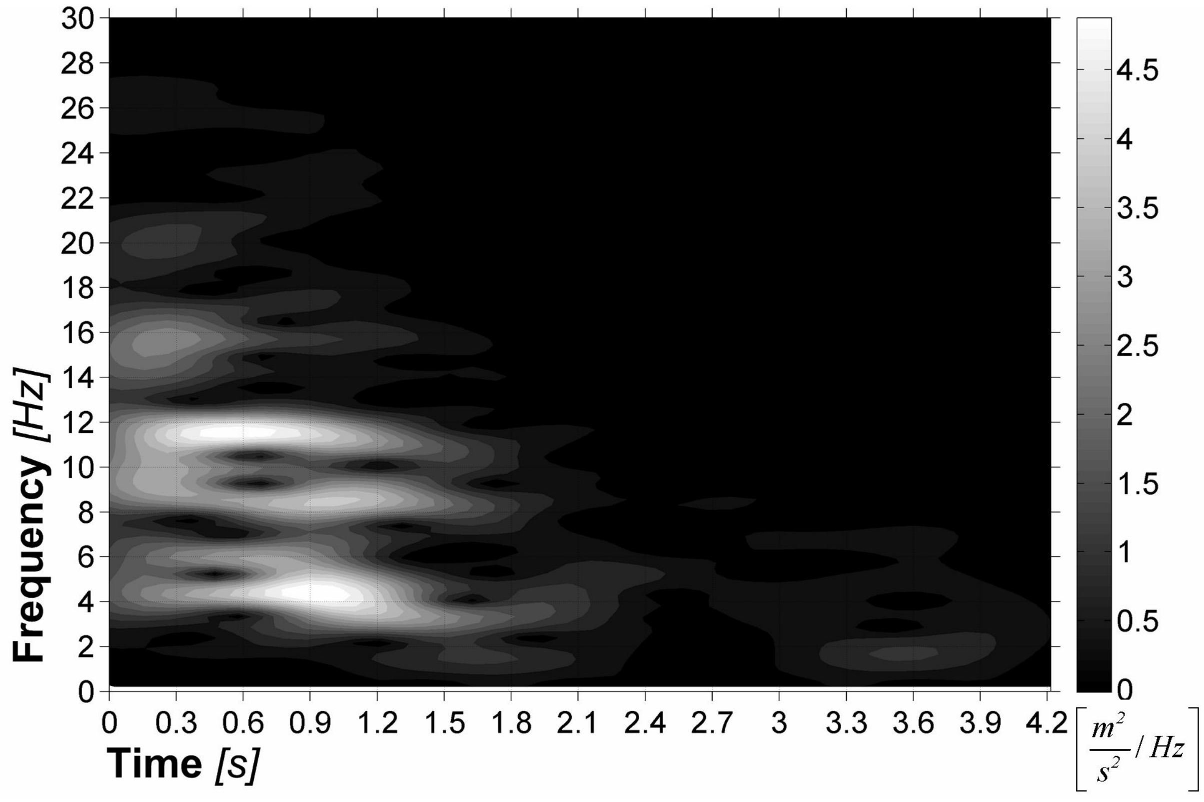

Fig. 2. Spectrum of Gabor transform modules of paraseismic quake

4 RESULTS OF CALCULATION

The dynamic calculations were preceded by a solution of eigenvalue problem. The values of the natural frequency of the two models in an initial state, i.e. before tremor acting from are summarized in Table 1.

Forms of natural frequency	**Values of natural frequency of models** *[Hz]*	
	MBN	**MBU**
1	5,60	5,07
2	16,39	15,99
3	18,08	17,87
4	22,26	21,89
5	28,94	26,51

Tab. 1 Values of natural frequency of models before the dynamic load acting

Modal forms of both walls are shown in sequence: first in Figure 3a and the third in Fig.3b. They are the result of flexural and non-dilatational deformation in the plane of the wall. The inclusion of ground flexibility caused that the second form of vibration is related to the vertical displacements of the wall, which acts as a rigid body. It was omitted in the following discussion. Regardless of whether the building model has the primary damage, or not the forms of vibration have the same character.
Due to calculations of both walls with acting on them kinematics excitation it was found the appearance of material degradations zones. Their principal effect was to reduce the value of the first (I *NF*) and third (III *NF*) natural frequencies. In each case, taking into account the dynamic load caused a decrease *NF* values compared to the initial solution (before loading). Characteristic results are summarized in Table 2 and shown in Figure 3.

Duration quake *[s]*	**Values of natural frequency of models** *[Hz]*			
	MBN- I ***NF***	**MBU- I** ***NF***	**MBN- III** ***NF***	**MBU- IIII** ***NF***
0,000	5,60	5,07	18,08	17,87
0,250	5,60	4,92	18,08	17,86
0,500	5,60	4,92	18,08	17,85
0,750	5,59	4,92	18,07	17,84
1,000	5,59	4,92	18,07	17,84
1,250	5,55	4,86	18,06	17,81
1,500	5,55	4,82	18,05	17,78
1,750	5,55	4,82	18,05	17,79
…	…	…	…	…
4,205	5,55	4,82	18,05	17,79

Tab. 2 Values of natural frequency of models during the dynamic load acting

The largest decrease occurred in the damaged model, in which the value of the first natural frequency decreased by 4.5%. In the model with no initial damage (*MBN*), a decrease of 0.9% has appeared. Differentiation of the effects of acting load in both models **-** *MBN* and *MBU* is clearly visible after taking into account the difference in value of *NF*, which was at the beginning of the analysis of 9.5% and increased to 13.2% at the end of the dynamic load acting.
Changes in the value of the fundamental frequency of vibration are clearly correlated with the duration of kinematics excitation because they occur primarily in the time interval 1.0 ÷ 1.3 *s*. In the same period in quake, local extremum appears in band 3.0 ÷ 5.5 *Hz*, what is seen in Figure 3. On the edge of this band are localized fundamental natural frequencies of both analyzed the walls. This suggests the occurrence of transient resonance of dynamical systems and rapid material degradation.
The third frequency almost has not changed, because the relative changes in its value amounted to less than 1%. This suggests that the degradation of the objects, which change explicitly values of the fundamental natural frequency, has not a greater influence on that third. This is probably due to the fact that its value is about 18 *Hz* (Fig.3b), while the next extremum of kinematics excitation is close to 12 *Hz*. There is not, therefore

instantaneous resonance associated with this frequency and corresponding state of walls, which would effect on her distinct change.

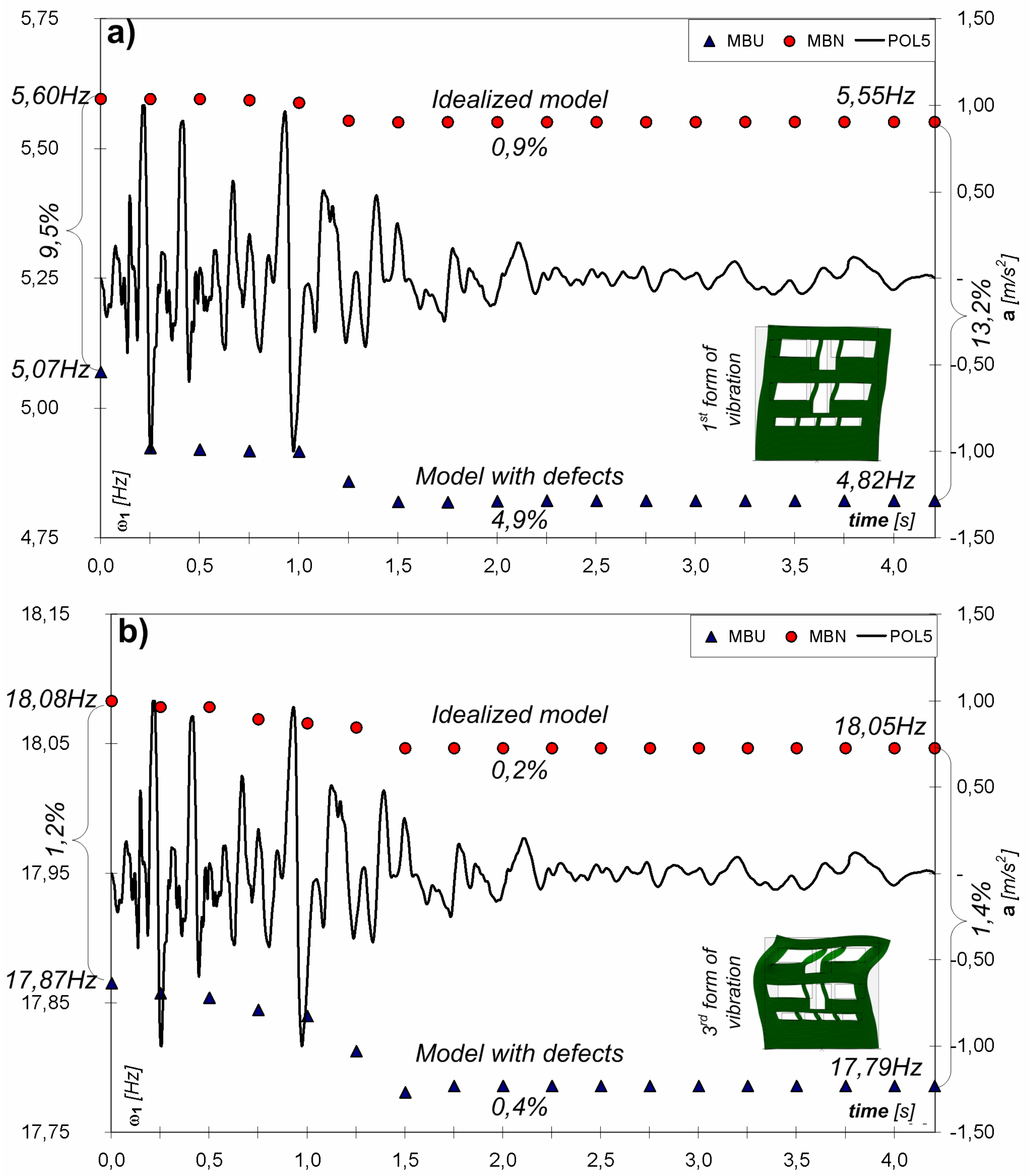

Fig. 3 The evolution of the natural frequencies of both two walls models - *MBN* and *MBU*, depending on the kinematics excitation: a) I frequency, b) III frequency

5 SUMMARY

Presented results authors treat as an attempt the numerical analysis of the relationship between the local material degradation, related with dynamic load of mining origin quake and the possible changes of natural spectrum of analyzed object. It is worth noting that the inclusion of geometric discontinuities i.e. initial cracks in object model results obtaining lower values of *NF* in comparison with the model of a continuous material. It was found that there is a clear change in the *NF* during dynamic load acting resulting from the material degradation. It is correlated with the instantaneous load extremes, especially if they cause short-lasting resonances of a dynamical system. It is planned in conjunction with the received results of previous studies renewed attempts of using three-dimensional models of buildings subjected to dynamic loads, as well as the study object model degradation caused by the quake of successive many different mining quakes. It seems that changes in the natural spectrum due to influencing on the object further various quakes could be used, for example, to assess the state of building degradation subjected to quake mining deformation and mining quakes in the case of conducting in it continuous or periodic dynamic monitoring.

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