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NONLINEAR ANALYSIS OF DEGRADED BUILDINGS APPLYING PLASTIC-DAMAGE MATERIAL MODEL

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Abstract

In mining regions a great hazard for masonry and concrete residential buildings are semi-seismic earth tremors, which potential energy could achieved 10^{10} *[J]. Only non-cracked buildings are numerically analysed and presented in literature. From practical engineering point of view more interesting problems are connected with behaviour of initially damaged objects. To analyse damaged and undamaged buildings a plastic-damage model called Barcelona Model (BM) of concrete and masonry is applied. Responses to different dynamical enforcements of both buildings models are presented.*

Key words

non-linear material model, dynamic of structures, tremors, mining influences, plastic-damaged model

1 INTRODUCTION

Intensive underground exploitation of useful minerals like coal or copper caused statical (drift of coal basin) and dynamical (tremors) ground deformations which are sources of buildings defects. Coal basin movement is accompanied by: a) spreading or shrinking and/or b) slope of the ground, and/or c) curving of the earth surface, d) and/or settlement. Often (statically) damaged buildings are additionally enforced by tremors (in Poland maximum horizontal acceleration can be greater than $2m/s^2$). Majority of research investigation and expertises (which deal with effort of building structures forced by tremors) focuses on models of initially undamaged buildings. It is assumed also that analysed constructions have no technological defects. From the second point of view – especially in expertise investigations – a problem is formulated in another way: how initial cracks influence on buildings safety if tremors (typical and characteristic ones for local area and a way of mining exploitation) enforce them additionally.

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In this paper it is assumed that materials of analysed masonry/concrete buildings can be modelled as elastic-plastic one but – additionally - different mechanisms of tensile and compressive degradations are taken into account. Two simulations of dynamical enforcements has been used: 1) real digitally recorded ground tremors (sometimes enlarged by multiplying of horizontal amplitudes of ground acceleration) or 2) harmonic enforcement which frequency is closed to a main free vibration of damaged (***DM***) or/and undamaged building models (***UDM***).

At this stage of the investigation the **3*D*** models of analysed objects are replaced by statically and dynamically "equivalent" **2*D*** models [5].

2 Types of the building failures

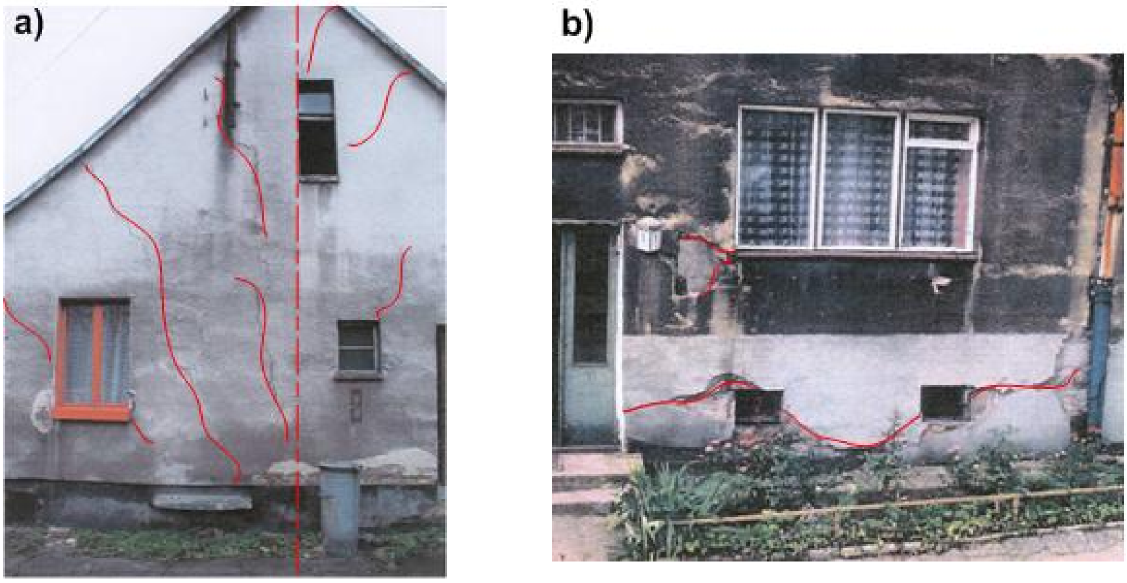
Sources, types and sizes of the building damages depend on many parameters. Their detailed analysis is out of the scope of this paper. Preparing physical and numerical models of buildings it was assumed four groups of typical, initial (from dynamical loading point of view) nets of cracks caused by typical statical influences.

It is assumed that analysed damages results from:

a) Forming of convex mining basin that caused cracks from symmetry axis to outside (up). Especially long faults are localised in upper stories.
b) Concave mining basin which influence manifests in heavy damages in lower parts of buildings.
c) Ground settlement (very often non-uniform one). Cracks are impossible to classification.
d) Non-continues ground surface deformations which generate vertical and/or skew fracturing. It can caused sometimes tear out some parts of building.

As an example, real damaged buildings corresponding to particular ground influences are shown in Fig. 1.

Obviously, different statical impacts could occur in buildings simultaneously (but not on the same step of useful mineral exploitation), with different intensity difficult to identification.



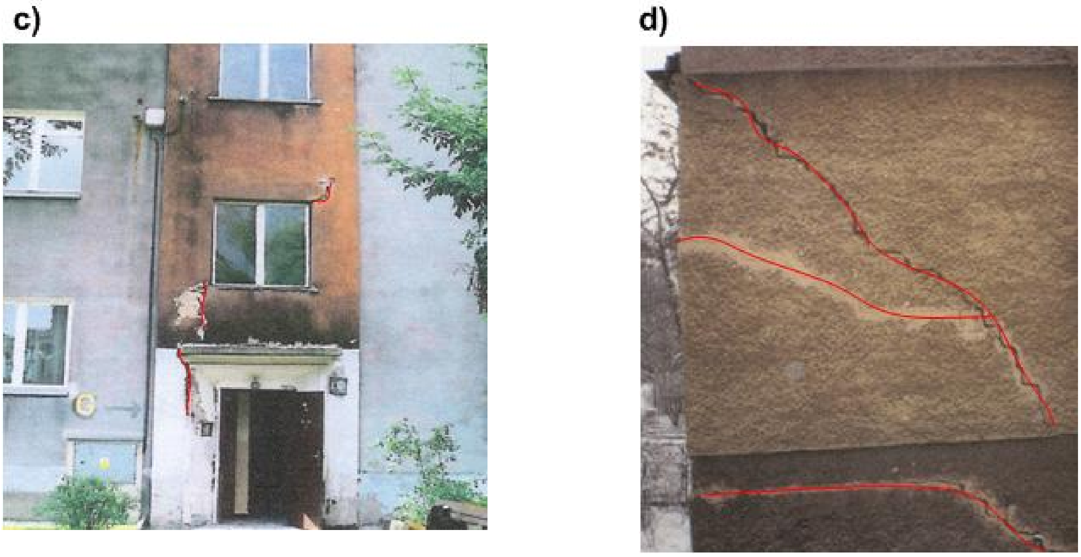


Fig. 1. Typical damages of building caused by: a) convex mining basin; b) concave mining basin; c) settlement; d) local non-continues ground deformations

3 NUMERICAL MODELS OF BUILDINGS

Because of high loads, both masonry and concrete (or reinforced concrete) could not be treated (like in simpler analyses) as linear elastic or also as elastic-plastic material. Both real materials are degraded locally during enlarging forces. It leads to material crashing (when high compressive stresses occur) or cracking (by tensile stresses). Additionally, cracks can close during compression and the material compressive properties are reconstructed (totally or partially). Among several material models which were implemented to professional finite element packages it was decided to apply plastic-damaged model called in literature as *BARCELONA MODEL* (***BM***).

Barcelona Model has been proposed by J. Lubliner [4], modified for cyclic problems by L. Fenves [3] and was implemented in the FEM software package ABAQUS. Some adaptations of the BM for a masonry structures have been proposed by Cińcio [1], [6].

The yield surface of the ***BM*** is an extension of the classical Drucker - Prager model with a non-circular deviatoric cross section (see Fig. 2). In order to apply the *Barcelona Model* in numerical simulations of heterogeneous material four material characteristics have to be described: nonlinear isotropic hardening/softening rules, different and independent, one for the tension and the other one for the compression. The ***BM*** takes also into account two different degradation mechanisms: separately for compression and tension. The level of degradation is described by the degradation parameters whose values depend on two characteristics obtained in cyclic laboratory respectively tests at compression and tension (more information about the ***BM*** [1, 3, 4, 6]).

All curves which characterise the *BM* are governed in Figures 2 – 4, respectively: Fig. 2. present the yield surface which is changed because of the hardening/softening of the material (described in Fig. 3). Degradation process depends on strain levels – Fig. 4.

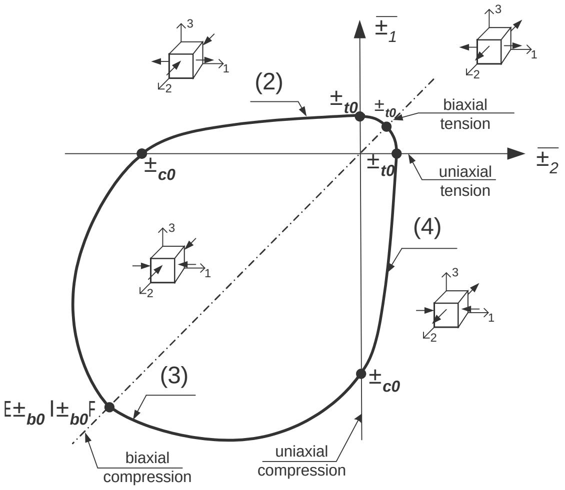


Fig. 2. Yield surface of the BM for the plane stress space

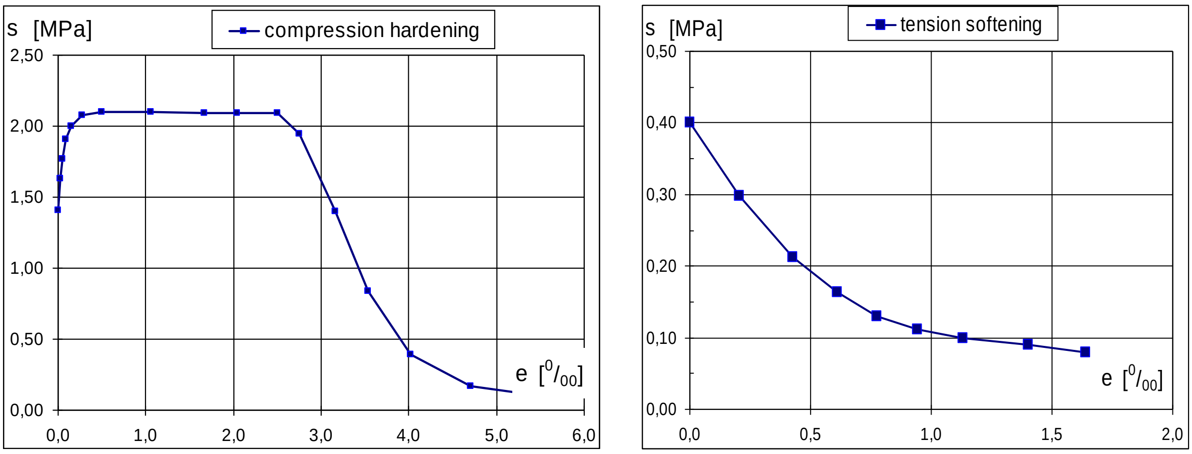


Fig. 3. a) & b) Hardening/softening curves for compression and tension, respectively

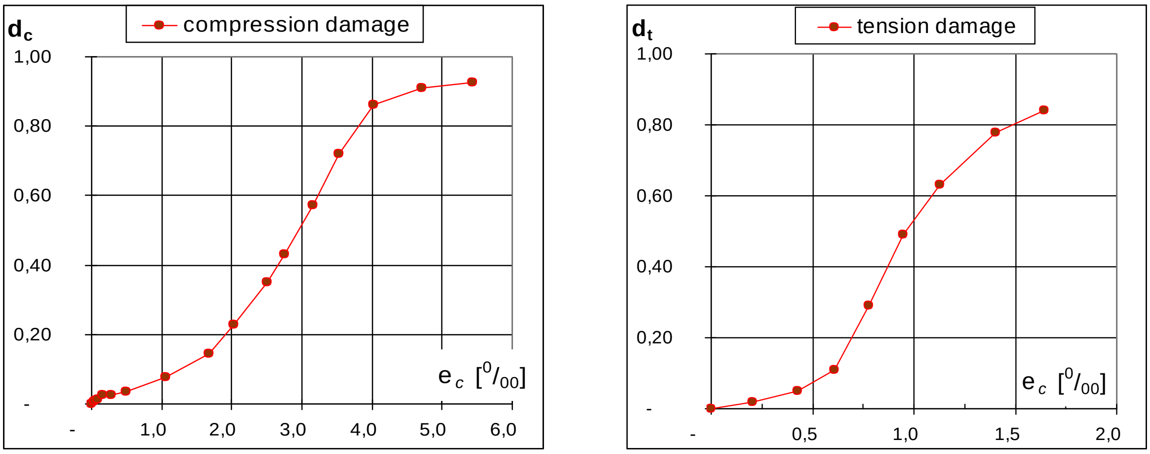


Fig. 4. a) & b) Degradation curves (compressive and tensile ones) for masonry

Preparing four plane numerical models of damaged walls it was assumed that in each model occur faults caused only by one characteristic type of mining influence. It is shown in Fig. 5.

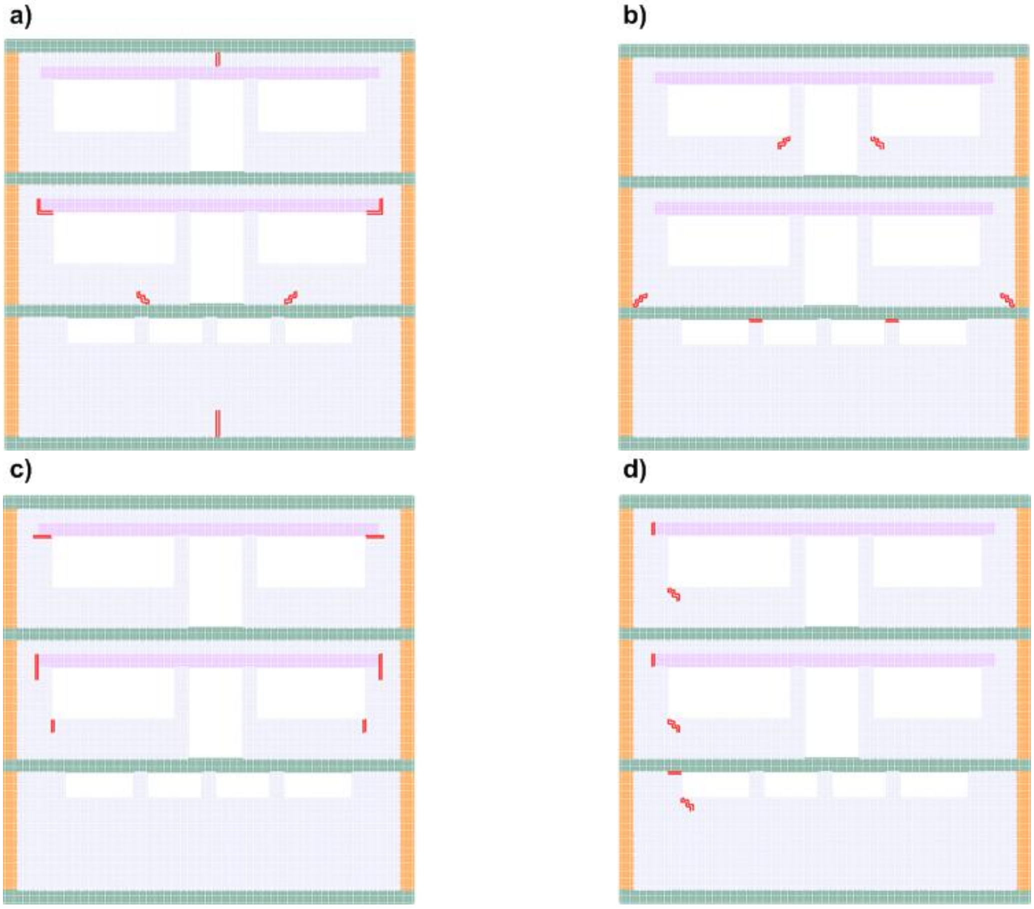


Fig. 5. Numerical models with damages caused by: a) convex mining basin; b) concave mining basin; c) settlement; d) local non-continues ground deformations

Numerical model of loads takes into account both weight and stiffness of suitable parts of the lateral walls. To find sizes of lateral parts following conditions are assumed: stress distribution obtained from statical analyses of the 3D and 2D models of analysed wall are almost the same. Also frequencies of the first free vibration for both models are closed.

4 RESULTS OF NUMERICAL ANALYSES

4.1. Free vibrations of damaged and undamaged models

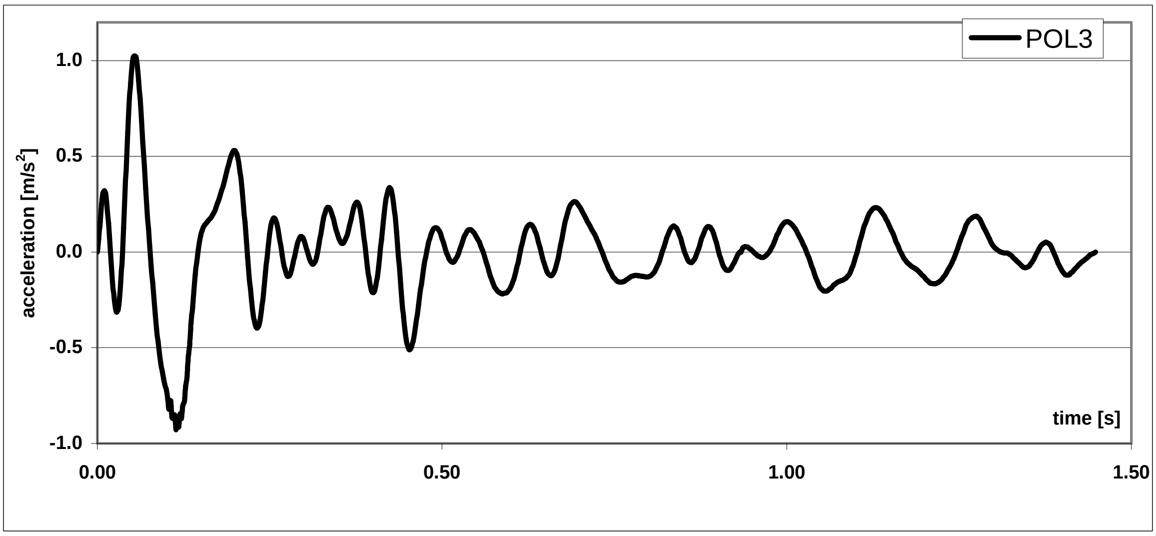
Till now influence of surface deformation – see Fig. 1 - on low masonry buildings (with two or three floors) has been investigated. Now we concentrate only on the first case of ground influences – convex mining basin. Arbitrary assumed sizes and shapes of the cracks on the modelled building are presented in Fig. 5a). This model is denoted in figures as RNW1. From modal analysis of buildings: without damages – ***UDM*** and with damages – ***DM*** results that value of the frequencies of the first free vibration are respectively equal to 35.159 and 30.943 [rad/s] (or 5.6 and 4.9 [Hz]). So difference between models refer to ***UDM*** is equal to 12.5%, it means is rather high. It can be expected that responses of both models strongly depends on value of dominated frequency of dynamic loading.

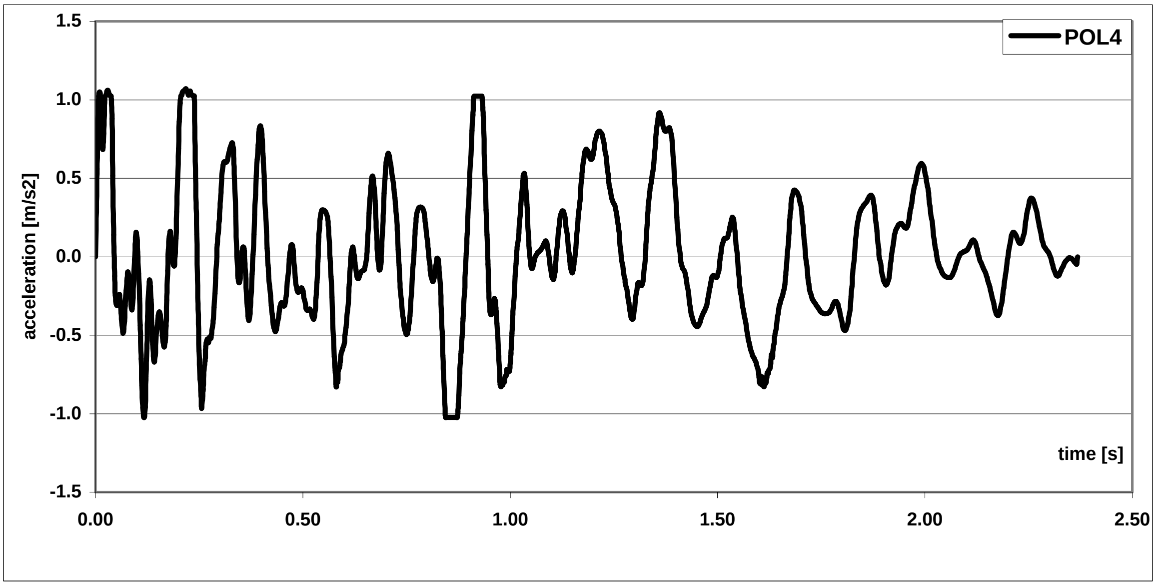
4.2 Characteristics of enforcement applied in numerical analyses

In numerical analyses four recorded enforcements (tremors) have been applied. They were observed in Copper Area in western part of Poland, in the vicinity of the small town Polkowice which is dominated by low masonry buildings and only a few concrete high (10-11 floors) block of flats are situated there.

The courses of ground tremors applying in the calculation (denoted as POL3, POL4, POL5 and POL6) differ in dominated frequency, namely:

- The enforcement POL3 has main frequency from the range 6.0 – 7.5 [Hz], so it is higher value than main frequencies of ***UDM*** and ***DM*** (RNW1).
- The enforcements POL4 & POL6 which main frequencies are from the range from 5.0 to 6.0 [Hz], belong to frequencies of ***UDM*** and ***DM***.
- Frequencies of both models are higher than main frequency of the last signal POL5.





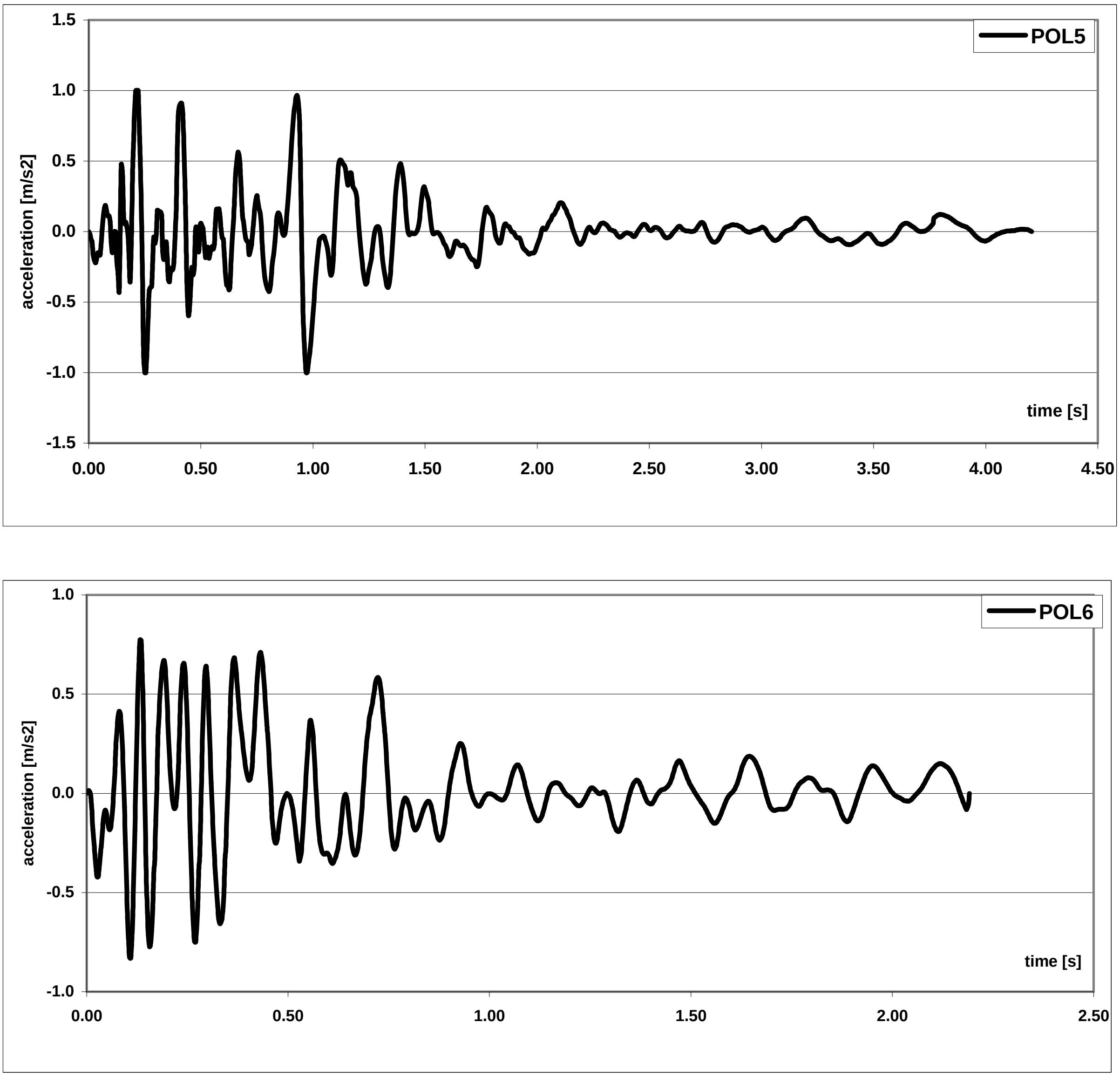


Fig. 6. Four recorded horizontal components of acceleration of the ground:

a) POL3; b) POL4; c) POL5; d) POL6

4.3 Analysis of the calculation results

It was assumed that a measure of masonry wall deformation is the global angle of the non-dilation strain defined as the angle *Θ* which is equal to a ratio of the difference between displacements of two extreme point (on vertical line) from selected, representative rectangular area (distinguished from analysed wall), to height of this area – Fig. 7. (see e.g. [2]). It means:

$$\Theta_{sd} = \left| \arctan\left(\frac{x_2 - x_1}{H + y_2 - y_1} \right) \right| \tag{1}$$

Polish design recommendations describe that allowance angle of non-dilatation strain for masonry structures is from the range $n_{adm} \in \langle 0.3; 0.5 \rangle$ [mm/m]. For figures below it is assumed that $n_{adm} = 0.5$.

Each version of ***UDM*** and ***DM*** models are analysed as the linear-elastic and the ***BM*** materials.

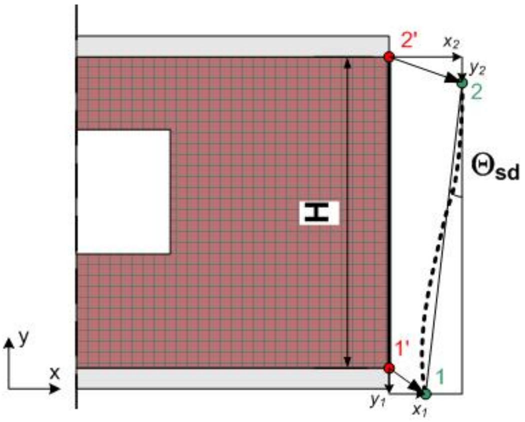


Fig. 7. Global angle of non-dilatation strain

The response (expressed by the angle *Θ*) of the model to enforcement POL3 (with the main frequency from the range 6.0 – 7.5 [Hz]) is obviously lower when the ***BM*** is applied. In Fig. 8 it is presented changes in time of the relative angle of non-dilatation strain (more exactly: absolute value $|n / n_{adm}|$). The solid line denotes linear elastic solution (R_NW1_el), the dashed line – non-linear one (R_NW1_BM).

From the comparison of two nonlinear solutions of ***UDM*** and ***DM*** (Fig. 9.) results that the second model can be damaged more than the first one – see also Fig. 10. It is easy to see that the main frequency of enforcement is closer to the resonant frequency of the model ***DM***.

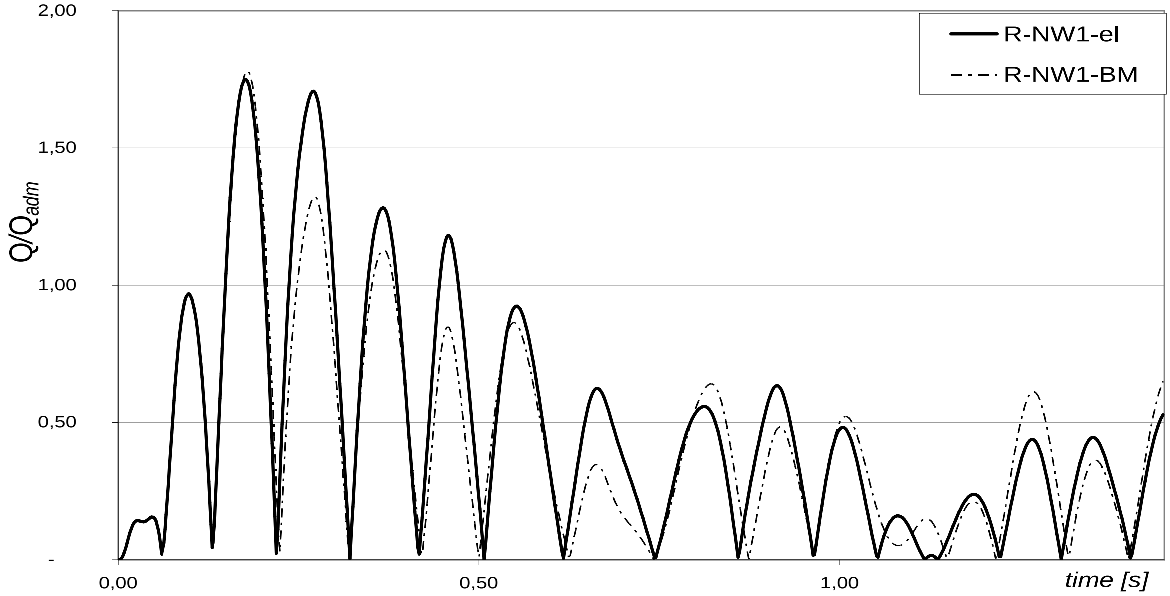


Fig. 8. (POL3) The RA changes in time - comparison between elastic and non-linear material models

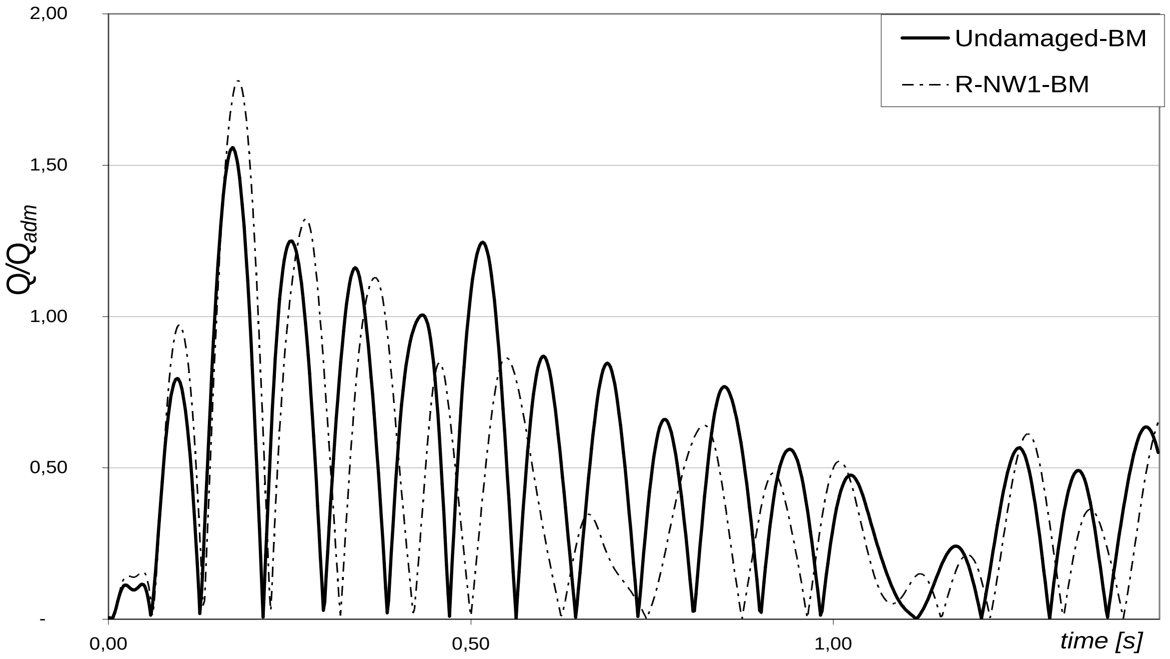


Fig. 9. (POL3) The RA changes in time - comparison between non-linear material models of damaged & undamaged buildings

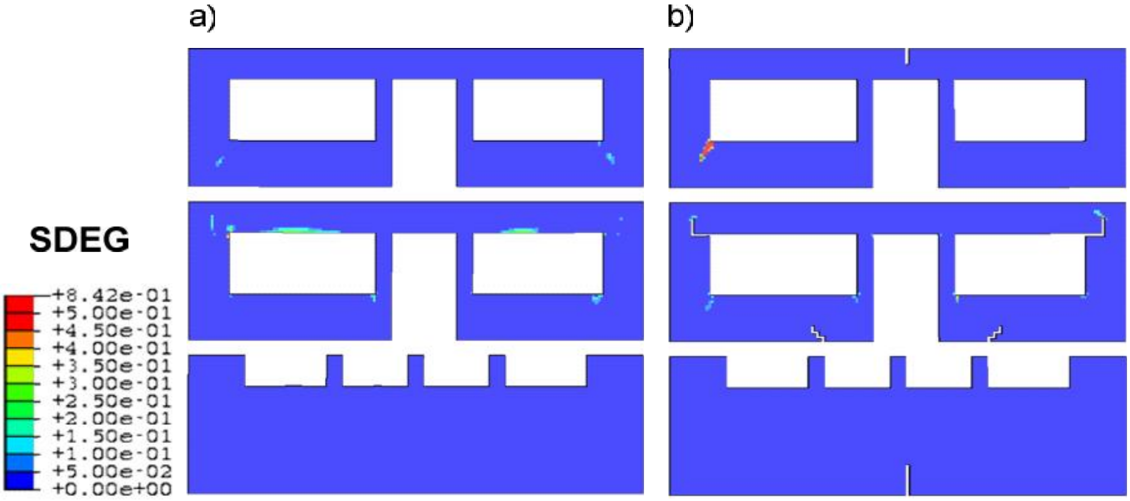


Fig. 10. (POL3) Total degradation parameters for two building models: a) undamaged, b) damaged

The enforcement POL4 (5.0 - 6.0 [Hz]) which the main frequency is closed to the first frequency of free vibration of ***UDM*** and ***DM***, generates huge differences between linear and non-linear solutions expressed by $\left| n / n_{adm} \right|$ – even more than 100% (Fig. 11). Also characteristics of angle answer are large. But the difference between degradations (the total and the tensile ones) of the undamaged and damage buildings are not large (Fig. 12.). The degradation level is higher for both models than in the previous loading case.

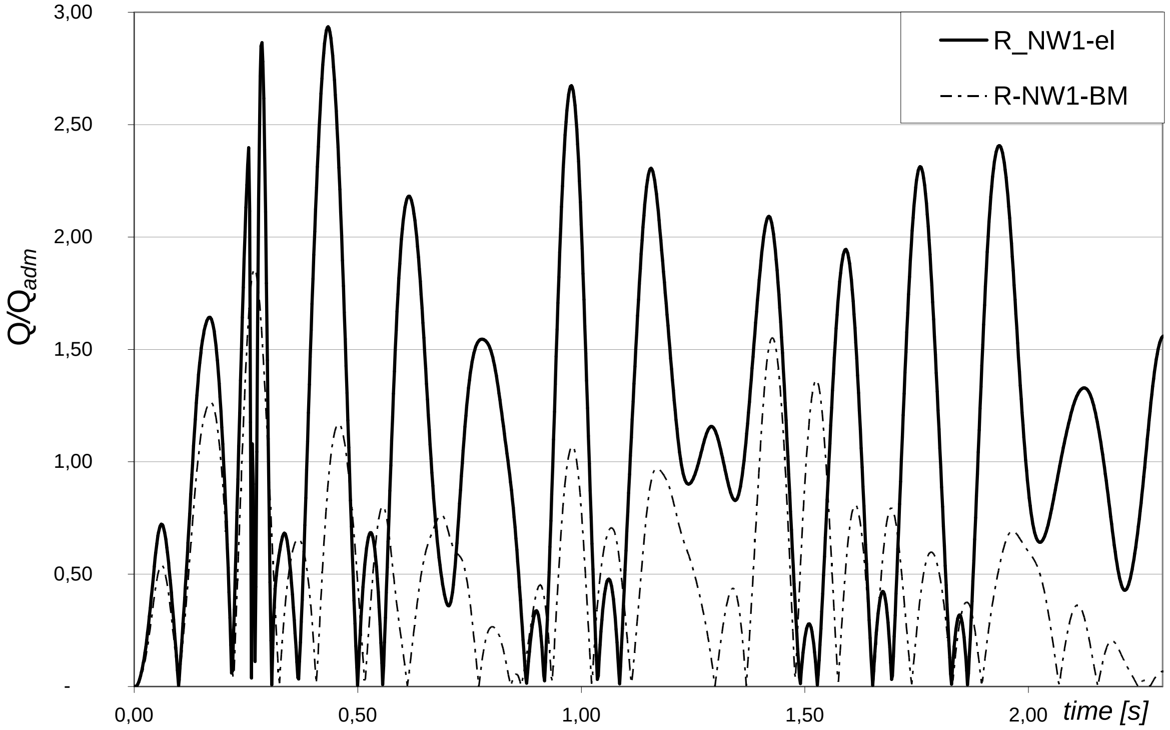


Fig. 11. (POL4) The RA changes in time - comparison between elastic and non-linear material models

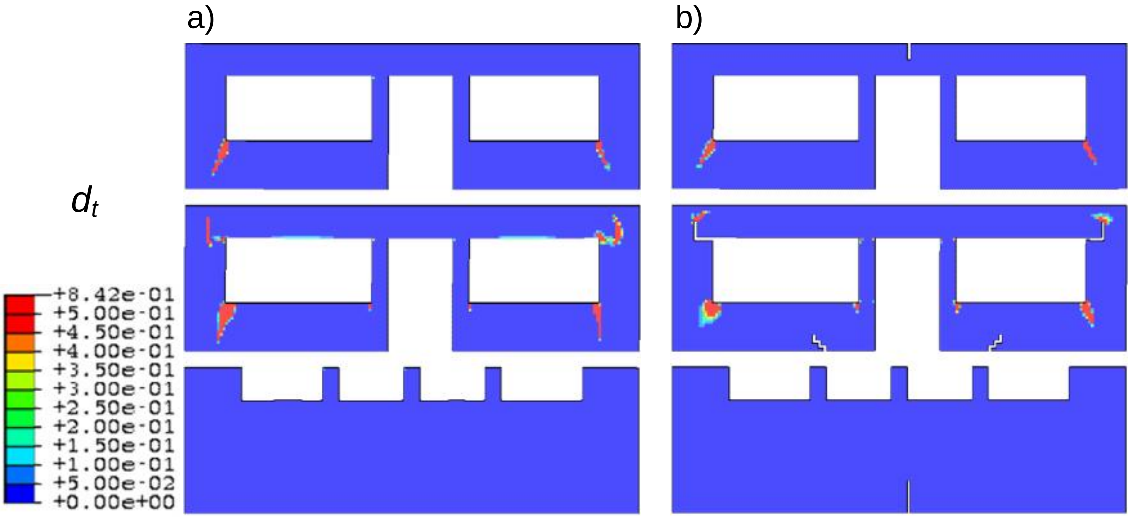


Fig. 12. (POL4) Tensile degradation parameters for two building models: a) undamaged, b) damaged

Another situation can be observed in the case of the enforcement POL5 with the dominated frequency below the frequencies of two buildings ***UDM*** and ***DM***. It does not generate large differences between these two models and between two types of analysis. It should be stressed that real recorded enforcement (which has been seemed as a dangerous one) was twice enlarged (the amplitudes x 2) to obtain some serious damages. As an example the tensile degradation parameters at the end of the dynamic loading POL5 are presented in Fig. 13.

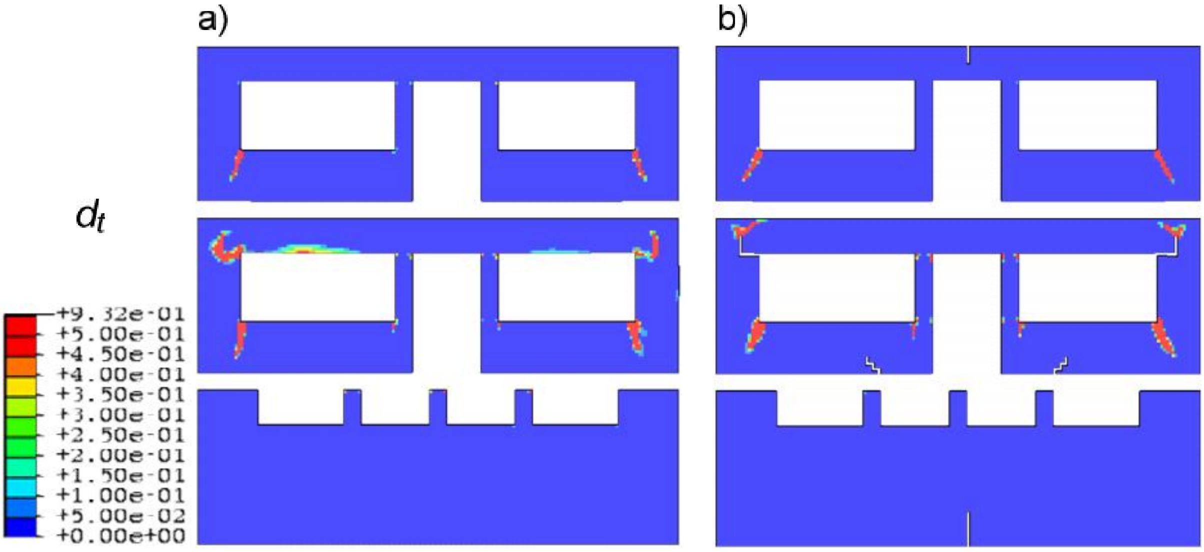


Fig. 13. (POL5) Tensile degradation parameters for two building models: a) undamaged, b) damaged

5 CONCLUSION

- Generally, for linear elastic material model response of model is higher than for plastic damaged material model. If the characteristic frequencies of applied horizontal accelerations are far from the main frequencies of the free vibrations of the analysed models the difference between linear and nonlinear solutions is not very high. This remark is right for semi-seismic tremors observe in Poland (also two or more times enlarged).
- At this stage of the investigation it has been resulted that level of safety of undamaged & damaged buildings strongly depends on the characteristic of dynamic enforcement (earth tremors). It is impossible to decide uniquely which model is more safety.
- Some cracks caused by convex (and concave – do not presented here) mining basin do not influence on the level of degradation (see Figs. 12b & 13b).

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