Dynamic analysis of initially damaged building

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Abstract
Dynamic response of initially damaged building using numerical simulations is presented in this paper. It is assumed that initial damages are caused by ground deformations which are consequence of mining activity or errors in technology. Material properties are described by the plastic-damage model for concrete (Barcelona Model) created by Lubliner[1] and adapted for masonry by Cińcio[3]. Comparisons of stress, degradation and angle of non-dilatational strain fields of damaged and undamaged buildings are presented.

1. Introduction

Every numerical analysis is only attempt of reflecting the reality. Usually buildings models are ideal in their form, it means they do not include realistic imperfections like cracks. These local degradations can be created in buildings on mining areas by the reason of ground deformation. It is possible that during this type of ground activity the seismic activity could occur. The problem is: how to describe different answers obtained from these two types of numerical models under dynamical loads? What kind of implementation it should be used to verify? It is necessary to give consideration to initially damaged in dynamical analysis. First of all we have to use material model which could reflected real behaviour under cyclic load. Barcelona Model (BM) using plastic-damage character can describe real behaviour of masonry. Very important part in this simulation is right modelling orientation and range of the crack. The investigation does not include initial model deformation and assume a position that construction is not reinforce. Put geometric degradation in the numerical model of building brings on need for minimalism size of finite element. This is a reason to increase time of analysis. Additionally including ground flexibility generates extra iterations for each time dynamical analysis.

2. Numerical models presentation

Dynamic analysis of initially damaged building was preceded by two types of simulations of building models without crack: the spatial one (3D) and the plane one (2D). It was necessarily because size of finite element must be as small as possible. The heading 2.4 includes comparison of 3D and 2D models response.

2.1 Characteristics of spatial and planar models

The numerical models represent one typical three storeys building in mining regions in Poland. It has got masonry walls with monolithic reinforced floors. Connections between walls and floors are modelled as hinge ones[6]. Overall dimensions of the spatial model are 8.7 x 8.7 x 9.4m. The analysed model has got a lot of openings in the walls. In this symmetrical model we could separate concrete elements like: continuous footing, lintel and circuital of storey. Ground flexibility is characterised by the elastic contact with friction coefficient. The value of this vertical elasticity is assumed equal to 15MPa/m^2 and 70% of this quantity corresponding to the horizontal elasticity. The friction coefficients have got two different values 0.7 and 0.5 in turn for horizontal and vertical activity. The size of finite elements (FE) used in the 3D model is set as 15cm quadrangle (see Figure 1a). Using 4 nodes for each shell FE (with 6 degrees of freedom- three displacements and three rotations) were producing more then 600 000 DOF. From the 3D model, the wall in axis 1 is chosen to analysis. Static and dynamic responses of 3D and 2D models are similar.

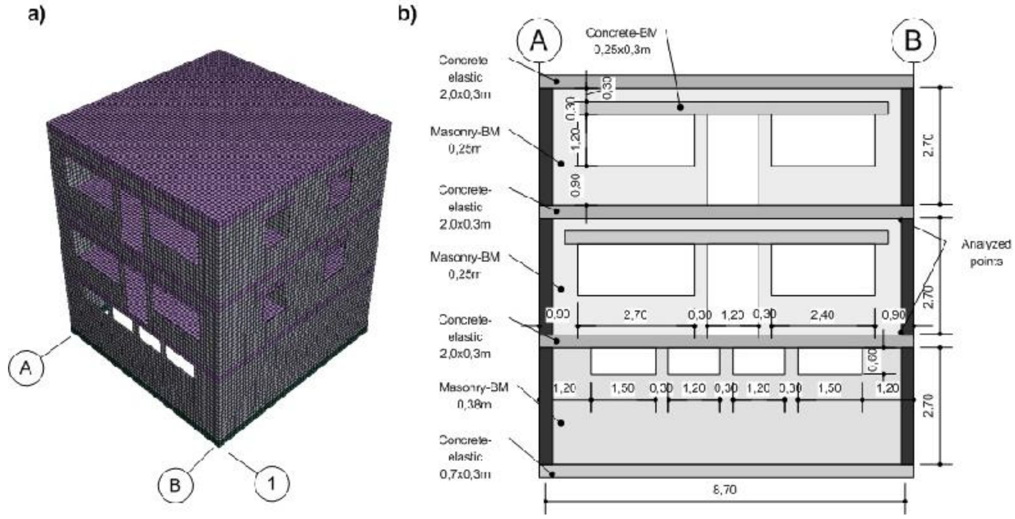

Figure 1: Geometry of: a) the spatial, b) the planar models

Additionally, the planar model includes some parts of ceiling and transverse walls[7]: one half of span ceiling and cooperate transverse wall as 1.0m. Characteristics of the ground flexibility of the 2D model are similar to the 3D one (see Figure 2). The value of elasticity is three times bigger than in spatial model. The finite element mesh of the planar model consists of 13 000 DOF and size of FE is the same as in 3D case.

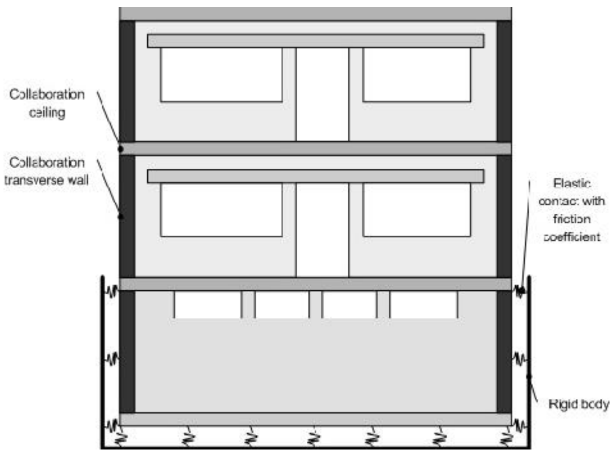

Figure 2: Details of support for the planar model

2.2 Material model

Cyclic changes of loads sign are typical for seismic activity. This kind of loading can generate cracks or local regions of degradation in plastic-brittle materials like concrete and masonry. All together form continuous process opening and closing of cracks.
The *Barcelona Model* (BM) proposed for concrete by Lubliner[1] in 1989 and modified for masonry by Cińcio[3,4,5] was applied to model the building materials. The BM was also implemented to the finite element package ABAQUS. This model takes into account two different degradation mechanisms separately for compression and tension. A level of degradation is described by degradation parameters, which values (scope <0,1>) depend on two characteristics obtained in the cyclic laboratory tests respectively for compression and tension[1,2].
If the experimental parameters and material characteristics are known then BM can be applied to numerical analyses. We must determine initial values of Young's modulus and Poisson's ratio. For the first cycle of loading is needful level of yield stresses separated to uniaxial compression band tension. Increasing or decreasing value of the yield stress during loading process is determine for two independent hardening or softening rules. Changes of the yield surfaces are described by hardening curves. The level of the local material degradation is described by the stiffness reducing. Degradation variables are definite as two monotonic functions separately for compression and tension.
Material model using in this article does not take into account bi-material character of masonry. Therefore masonry is recognized as homogenous.

2.3 Loads

All analyses include two kinds of load: static and dynamic ones. First of them includes deadweight and some part of live load added to the ceiling mass. The second one is defined as the kinematical enforcements provided on the rigid body as definite in Figure 2. As dynamical load it is used real recorded tremors (put as displacement) of the ground. This earth tremor was recorded in copper mining in Poland and has 2.122s length of time. This signal was multiply two times to better comparison.
Beside the real recorded activity, the horizontal harmonic ground enforcements with frequency approximately equal to the first natural frequency of the analyzed model are applied. In this case we have got two harmonics. First is connecting with natural frequency of undamaged model (sin35T) and second one with initially damaged (sin31T). See heading 3.2 to details. Both of them have got five periods. Time of the harmonic enforcement is equal about 1.0s and after that we can observe none of input to 1.5s. Digitized time was on the 0.005s and this equal 300 points which was multiplied by the DOF to get solution.

2.4 Initial damages in the planar model

Initial damages which are taken into account in analysed model are caused by convexity of the ground results from mining activity. Figure 3a presents real cracks set into the external wall. We can observe that these cracks run from centre of the bottom to the upper-outside. Those characteristics were included to the numerical model (see Figure 3b). The size of the finite element must be as small as possible to better crack geometric and solution. In this case side of the square FE was 0.05m. Cracks were modelled as breaks between FE. Value of this distance is approximately 1mm. Hard contact with friction coefficient is used in this case.

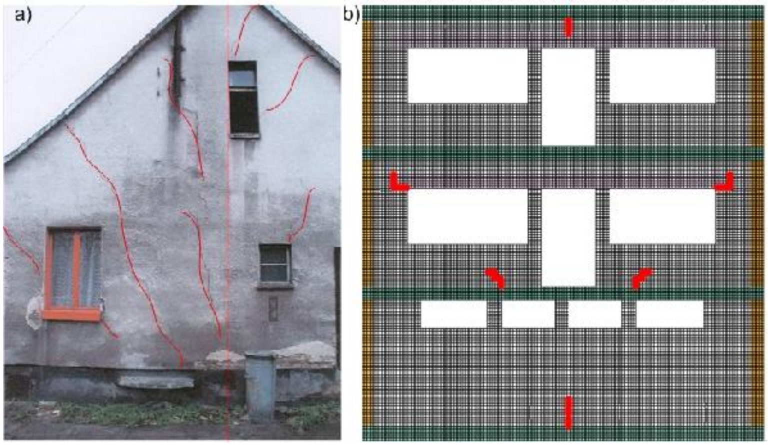

Figure 3: Cracks set into the wall: a) real photo, b) numerical model

Initially damage planar model presented in this paper does not take to account global deformation come from mining activity.

3. Modal analysis

The first step of the dynamic investigation is the modal analysis- basic natural forms of vibration and value of natural frequency of numerical model.

3.1 Spatial and planar model

The first form of vibration of the 3D model is presented in Figure 4a. This form is exactly the same for modified planar model (compare with Figure 4b).

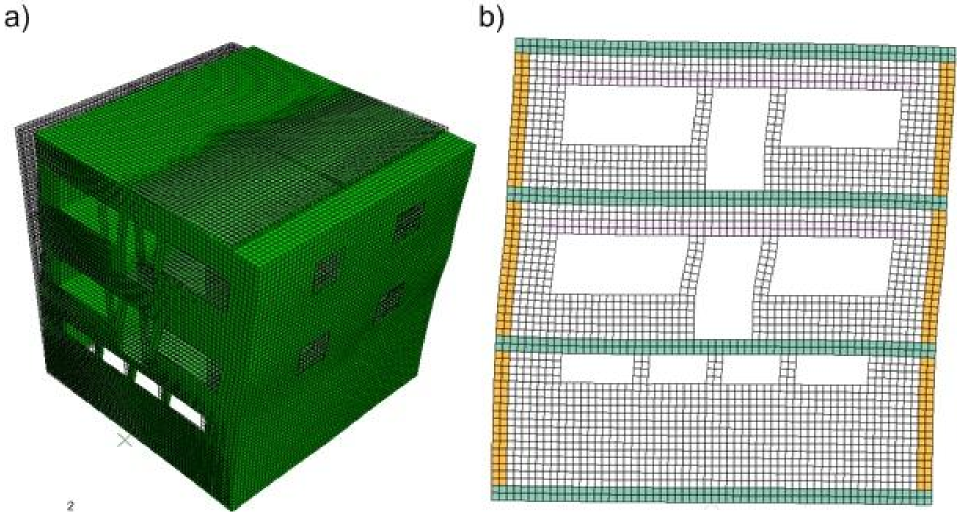

Figure 4: First form of vibration: a) 3D model, b) 2D model

Values of the first frequencies of vibration for spatial and planar models are respectively equals to 5.448Hz and 5.456Hz. It means that difference between 2D and 3D cases comes to 0.15% what is slightly.

3.2 Undamaged and initially damaged model

The first form of vibration initially damaged model is presented in Figure 5. This form is exactly the same as undamaged 3D and 2D models (comparison with Figure 4).

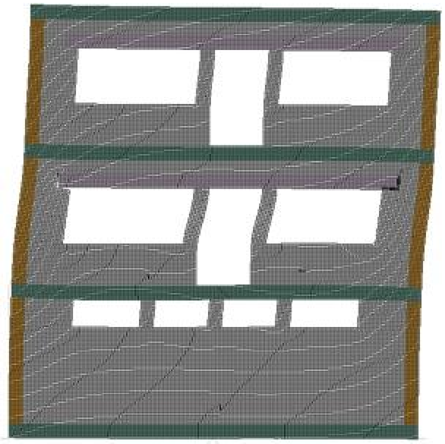

Figure 5: First form of vibration of the initially damaged model

Frequency of free vibration for undamaged model (for denser FE) equals 5.596Hz and for initially damaged reduced to 4.984Hz. Difference between those two types of model comes to 11% and it depends on cracks set.

4. Stress and degradations analyses

In this part of the paper maps of distribution of vertical normal stresses (σ_{22}) and total degradation parameter (SDEG) are presented. First of all we can compare the spatial model to the planar. Then influence initially damaged has been estimate in dynamical analyses.

4.1 Results comparison

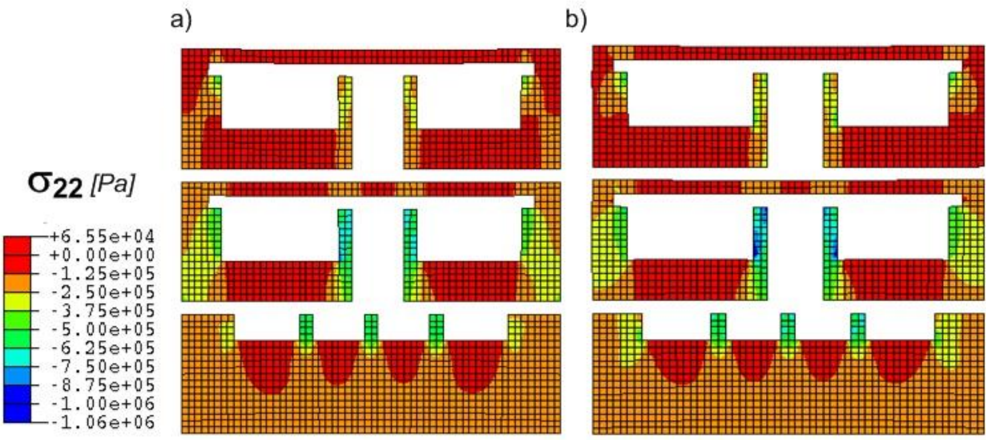

Figure 6: Vertical normal stresses distribution: a) 3D, b) 2D

Difference between distributions and level of the vertical normal component of the stress tensor σ_{22} are not significant (see Figure 6) in masonry part for static analyses.

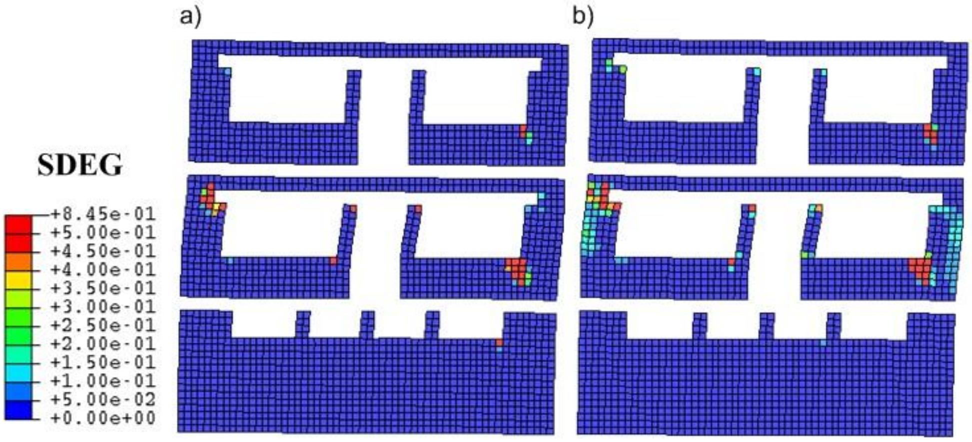

Figure 7: Distribution of the total degradation parameter: a) 3D, b) 2D

Distributions of the total degradation parameter for maximum displacement (for 0.29s) during horizontal harmonic (sin35T) ground enforcement are presented in Figure 7. As we can see, for masonry part difference between these two models could be neglected.

4.2 Comparison undamaged and initially damaged models

Initially damaged model with cracks set has shown in Figure 3b during dynamical load we can see that only cracks in the corners are important. For the rest propagation is not observed.

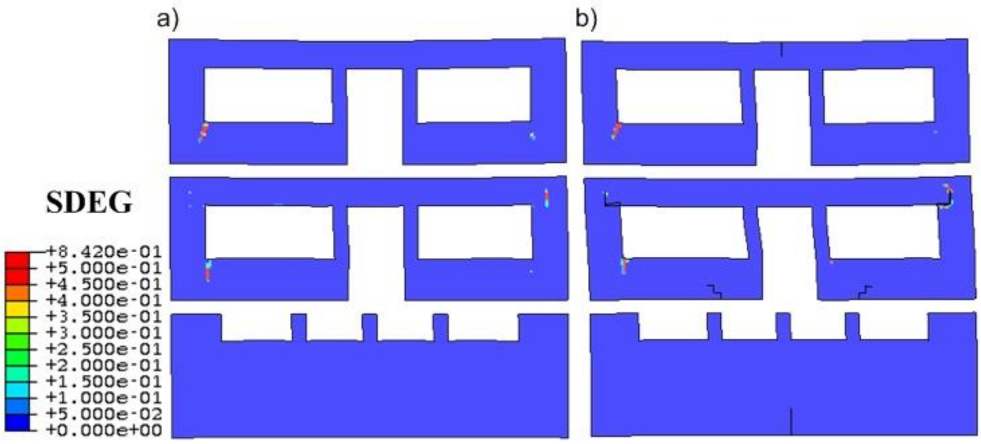

Figure 8: SDEG distribution during real enforcement: a) undamaged, b) initially damaged

Distributions of value of the total degradation parameter for different dynamic loads are compared in this heading. Figure 8 presents that cracks are not a menace to presented real enforcement. Region of degradation in initially damaged model is not much bigger than in undamaged.
Analysing models with horizontal harmonic ground enforcement (sin35T) it can be observed that values of the total degradation parameter are bigger for undamaged model (see Figure 9). Finally, for horizontal harmonic ground enforcement equals to the first natural frequency of initially damage model (sin31T) we can observe crack propagation and degradation regions are bigger than in undamaged model (see Figure 10).

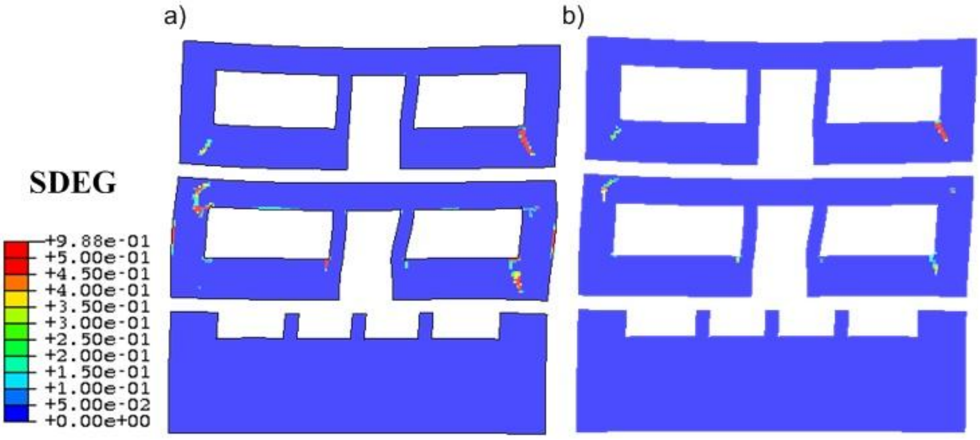

Figure 9: SDEG distribution during sin35T enforcement: a) undamaged, b) initially damaged

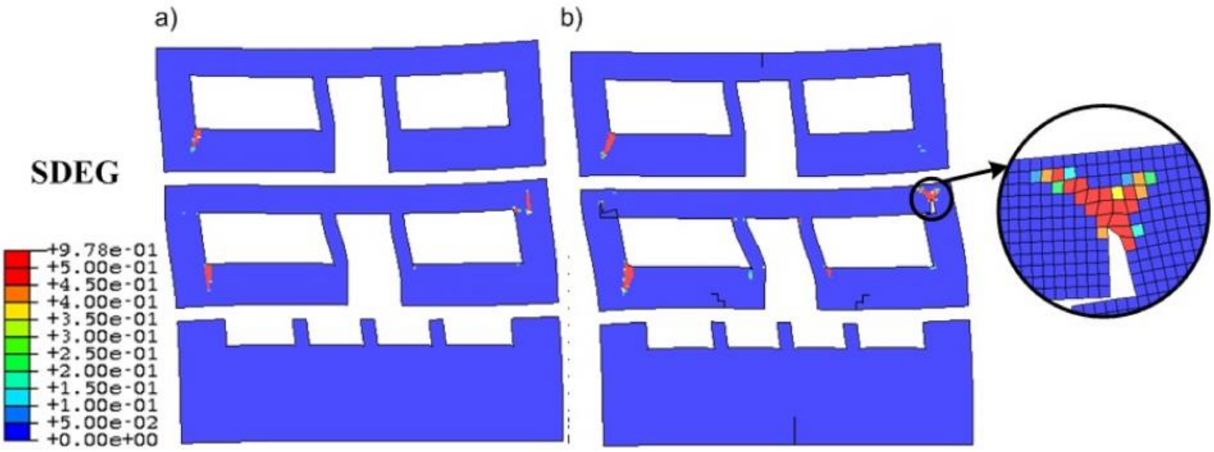

Figure 10: SDEG distribution during sin31T enforcement: a) undamaged, b) initially damaged

5. Angle of non-dilatation strain

Estimation of the total degradation parameter distribution does not provide precise solution therefore we need to compare two models- with and without the initially damages. The measurement the angle of non-dilatation strain was archived in the first of storey the masonry wall. Therefore we could say that value of this angle is global. Changeable value, which was received during the dynamic analyses, is compared to value taken from the Polish Code. The real value the angle of non-dilatation strain for masonry with cement-limo mortar has estimated by 0.3÷0.5mm/m. During these analyses value equals to 0.5mm/m from code PN-B-03002:2007 was assumption. This value indicates that in the deformation masonry wall the crack comes into being. In graph which is presented below value grater than 1.0 means that cracks could be creating in the masonry wall. During dynamical calculations value the angle of non-dilatation strain is changing the sign hence the absolute value is presented.

5.1 The real enforcement

Figure 11 presents changes of participation angle of non-dilatation strain for real enforcement. Differences between responses of these two models are not significant (compare with Figure 8). This low difference was estimated from the out of resonance signal character ground enforcement. If part of this signal equals to the natural frequency model then angle value of non-dilatation strain increases. Because of that reason, difference between undamaged and initially damaged model increases too.

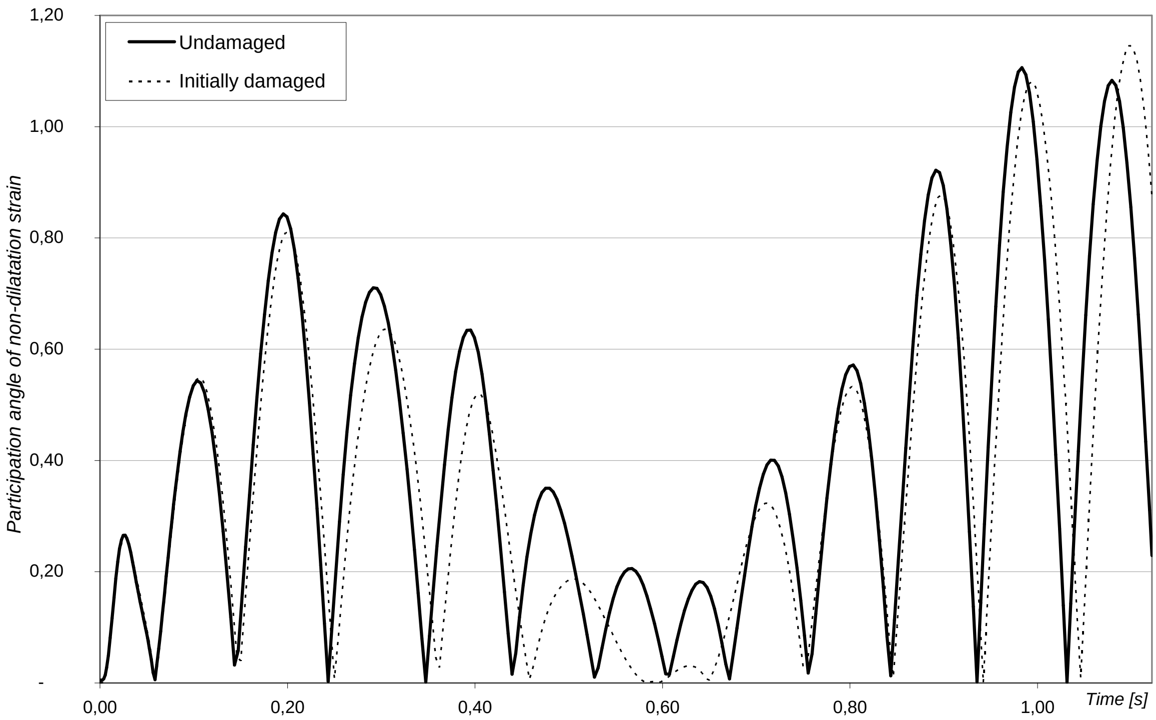

Figure 11: Changing participation angle of non-dilatation strain for real enforcement (description in text)

5.2 Horizontal harmonic enforcement

Change of participation angle of non-dilatation strain for horizontal harmonic ground enforcement presents differences between the responses of two models. First of them is presented in Figure 12 where it is shown the changes of strain values during the harmonic enforcement equals to the first natural frequency of undamaged model (sin35T). It is observed that initially damaged model is not as sensitive as undamaged one under the same dynamic load. The maximum difference comes up to the amount 50% between these two models. Then we can observe (in Figure 13) changing value of non-dilatation strain angle for ground enforcement equals to the first natural frequency of initially damaged model (sin31T). It is said that undamaged model is not as sensitive as initially damaged under this dynamic load and the maximum difference comes up to the amount 50% between these two models. Presented in this heading criterion is compared to the distribution of the total degradation parameter observed in Figure 9 and Figure 10. They confirm that any exceeding 0.5mm/m of angle of non-dilatation strain leads to cracks forming into masonry wall.

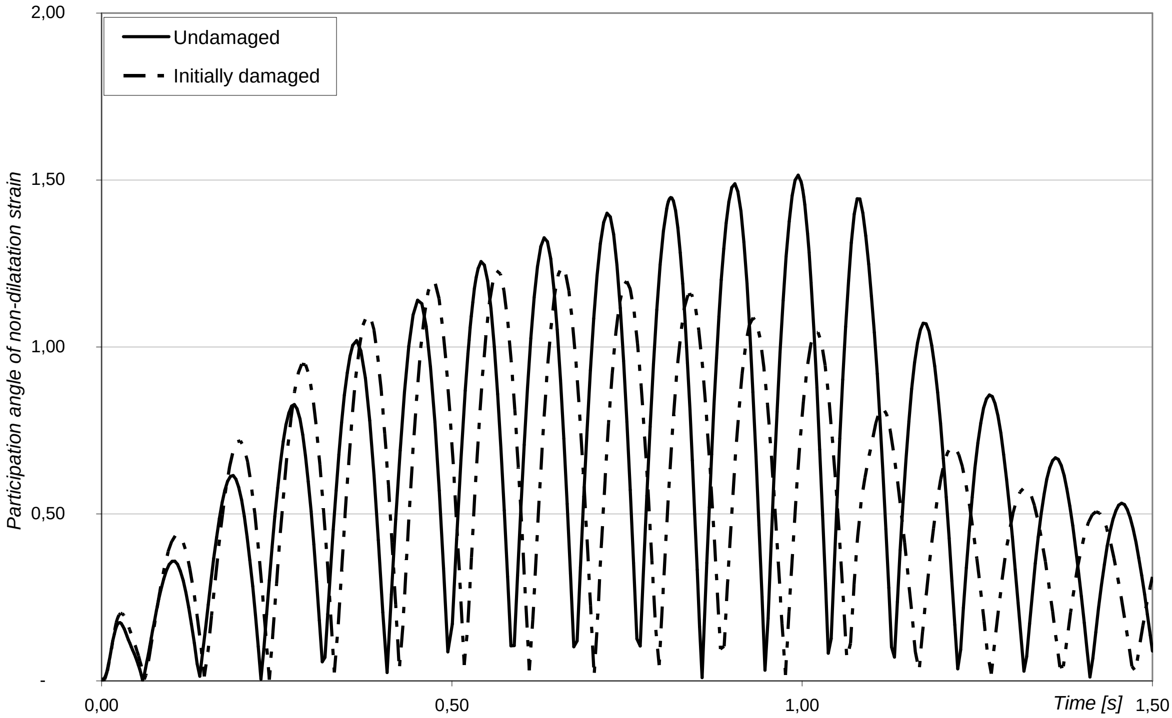

Figure 12: Changing participation angle of non-dilatation strain for sin35T enforcement (description in text)

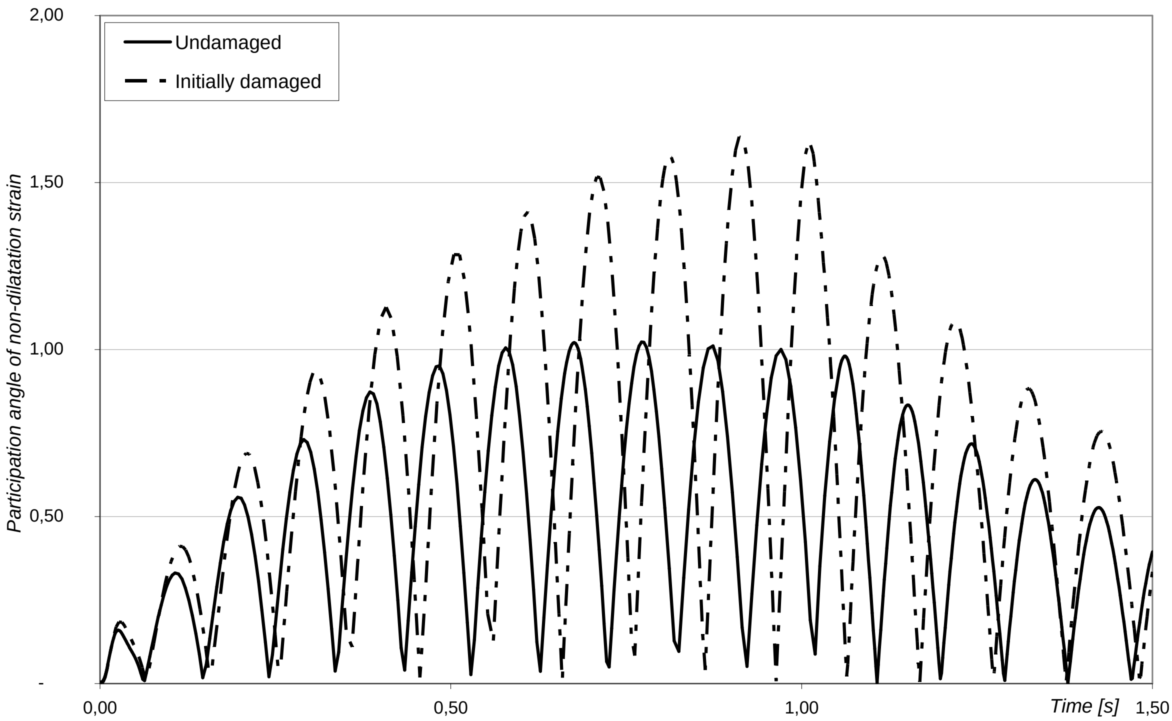

Figure 13: Changing participation of the angle of non-dilatation strain caused by sin31T enforcement (description in text)

6. Conclusions

All analyses lead to the following conclusions:

- Replacement the spatial model by the planar one is possible however it is required to study every new case.
- Including cracks set (see Figure 3) into the model provide depreciation of natural frequency. In this case 11% is decreased compared with undamaged model.
- The only initially damage in corners area is significant for dynamic load. Remaining localization of cracks is not so significant.
- If ground enforcement is near to the resonances range for analysed model then crack propagation is created.
- Criterion of angle of non-dilatation strain confirms distribution of total degradation parameter into masonry wall.

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