Parametric dynamic analysis of a masonry wall with lintels of reinforced concrete over the openings

CONFERENCE PAPER · JUNE 2007

DOI: 10.13140/RG.2.1.3354.1605

2 AUTHORS:

Maria E. Stavroulaki
Technical University of Crete

Evangelos (Vagelis) V. Liarakos
Technical University of Crete

ECCOMAS Thematic Conference on Computational Methods
in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, D.C. Charmpis, N.D. Lagaros, Y. Tsompanakis (eds.)
Rethymno, Crete, Greece, 13–16 June 2007

PARAMETRIC DYNAMIC ANALYSIS OF A MASONRY WALL WITH LINTELS OF REINFORCED CONCRETE OVER THE OPENINGS

Maria E. Stavroulaki[1]**, Vagelis B. Liarakos**[1]

[1] Applied Mechanics Laboratory, Department of Sciences, Technical University of Crete
73100 Kounoupidiana, Chania, Crete,
Greece
e-mail: mstavr@mred.tuc.gr, Vagelis_41@yahoo.gr

Keywords: Masonry, Finite element modeling; Unilateral contact; Dynamic analysis.

Abstract. *In order to study the unilateral contact effects (i.e. separation, sliding) between the lintels of reinforced concrete over the openings and the masonry wall, a parametric non-linear dynamic analysis was done. The nonlinear behaviour of the masonry is modelled by means of appropriately modified elastoplastic laws. Different values of the friction coefficient, various designs forthe roof and the horizontal plates at the first floor and various earthquakes are considered. From the analysis it is shown that the influence of this reinforcement on the dynamic response of masonry structures depends on many parameters like the magnitude of the ground motion and the friction coefficient of the interface between the lintels and the masonry. The positive effects of contact mechanisms can be reduced in case of a strong motion where topical relief in parallel with stress concentration to other places appear.*

1 INTRODUCTION

The application of various strengthening methods on existing masonry structures leads to changes of the existing structure and the need of cooperation between materials with different mechanical behaviour. This could be critical in some cases of dynamic loads like seismic excitations. The cooperation of the new materials and general the new structural elements with the old masonry depends on the way of construction and the degree of connection between them. If full connection does not exist partial contact phenomena are developed which are responsible for the beneficial aseismic behaviour.

The dynamic response of masonry structures depends on the non-linearity of both the masonry and the material used for the strengthening. By using an elastoplastic model for the masonry the computed plastic deformation indicates the degree of the developed damages. The comparison of the analytical results with the existing damages is used for modelling verification. Comparison of the results of the non-linear dynamic response analysis of the structure before and after the application of strengthening techniques, provide us with the evaluation of the strengthening method effectiveness.

The replacement of old wooden beams with lintels of reinforced concrete over the openings to a masonry wall is widely used technique. A lintel is a structural member placed over an opening in a wall. In the case of a brick masonry wall, lintels may consist of reinforced brick masonry, brick masonry arches, precast concrete or structural steel shapes. Regardless of the material chosen for the lintel, its prime function is to support the loads above the opening, and it must be designed properly. To eliminate the possibility of structural cracks in the wall above these openings, the structural design of the lintels should not involve the use of "rule-of-thumb" methods, or the arbitrary selection of structural sections without careful analysis of the loads to be carried and calculation of the stresses developed. Many of the cracks which appear over openings in masonry walls are due to excessive deflection of the lintels resulting from improper or inadequate design.

In this work the influence of the horizontal reinforced concrete lintels on the mechanical behavior of a typical masonry wall is studied, by taking into account contact effects (i.e. separation and sliding) between lintels and the masonry wall. The nonlinear behaviour of the masonry is modelled be means of appropriately modified elastoplastic laws and different values of the friction coefficient, various designs of the roof and the horizontal plates at the first floor and various earthquakes loads are considered. Some results of the parametric non-linear dynamic analysis are presented in this paper.

2 UNILATERAL FRICTIONAL CONTACT ANALYSIS

Several computational methods have been developed for modeling and analysis of historical masonry structures [1, 2]. The possibility that some separation appears between two parts of a structure coming into contact is known as the unilateral contact phenomenon. This is a typical variable-structure nonlinearity, which involves either-or decisions in the mechanical model. The frictional stick-slip nonlinearity is an analogous phenomenon. Both problems belong to the area known as nonsmooth mechanics [3, 4].

Unilateral contact along interfaces is a suitable model for nonlinear analysis of masonry structures [5, 6]. A number of potential interfaces at the boundaries of the lintels and the masonry wall, are defined and along these interfaces separation and frictional effects are considered. The actual state at each point of the interface will be found after the solution of the problem. In case of unilateral contact and friction, several empirical or semi-empirical algorithms have been proposed and modern general-purpose finite element software (like the MARC [7] which is used for this study) can be used for the solution of real-life problems.

Frictional contact interfaces also has been used to a finite element micromodel in order to study the dissipated friction energy at the frame-infill interface of the infilled frames, under varying lateral loading [8].

The numerical objective is to calculate the mechanical response of the bodies, to apply suitable constraints to avoid penetration and to apply appropriate boundary conditions for the friction behavior. The Coulomb friction model is used and the computation of Coulomb friction can be based on either nodal stresses or nodal forces. For the solution of the contact problem the direct constraint method is used in the following application. In this procedure, the motion of the bodies is tracked and when contact occurs, direct constraints are placed on the motion using boundary conditions, both kinematic constraints on transformed degrees of freedom and nodal forces. The constraint imposed ensure that penetration does not occur. In our model these constraints are modeled by the definition of tying relations for displacement components of the contacting nodes.

3 FINITE ELEMENT MODELING

3.1 Geometry of the models

A masonry wall including reinforcing elements from reinforced concrete material (lintels) over the door or window openings was considered. The finite element model with its dimensions is shown in Figure 1.

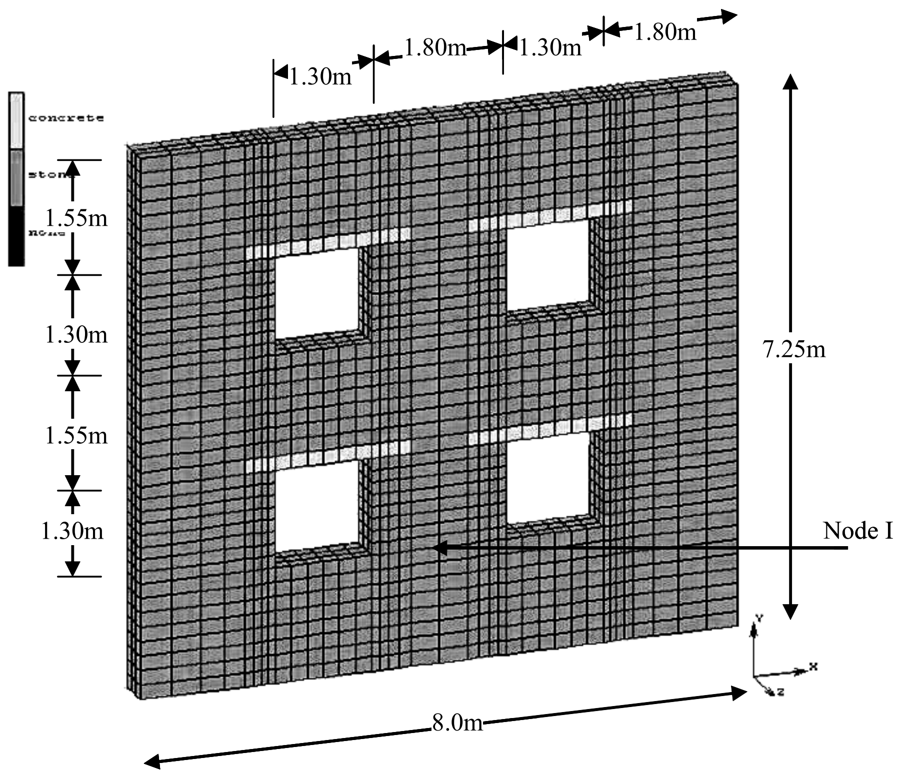


Figure 1: The finite element model of the masonry wall with the reinforced concrete lintels.

The following load cases were considered: the weight of the mass, a vertical pressure at the level of the first floor (simulating the loads which are transferred to the wall from the horizontal slab) and a vertical pressure at the top level (simulating the loads of the roof). A displacement history according to the earthquake of Kobe (1996) was considered at the applied base movement of the wall (fig. 2) in the out of plane direction (perpendicular to the wall). Since the earthquake excitation was strong enough, two load cases were considered:

First the real data of displacement was applied but the analysis was done for the first 10 sec, Second the whole history was applied but after multiplication of the displacement values with a factor 0.25, in order to see the influence of contact mechanism for a non strong excitation.

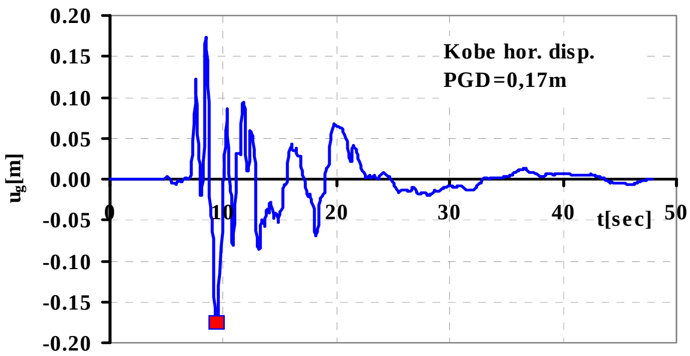


Figure 2: Displacement history of Kobe earthquake data.

3.2 Material Model

As it is well known the masonry or the stone wall is composed of materials with brittle mechanical behaviour, small to zero strength to tension, and is in a lot of cases non homogeneous. Although each component of a masonry wall has its own specific mechanical characteristics, they are all expected to act together as an homogeneous structural material. In the past a number of theories have been developed in order to represent the mechanical behavior of this composite material which consists of stones and mortar in between, with high compression and low tension strength.

In case of an earthquake, the structure will be subjected to a series of cyclic horizontal actions, which will often cause high additional bending and shear stresses in structural walls, exceeding the range of the elastic behaviour. The nonlinearity of the material appears for example if the stress-strain relationship or constitutive equation is nonlinear.
Thus, for the nonlinear analysis of the examined models, in addition to the elastic material constants (Young's modulus and Poisson's ratio), the yield stress and the hardening slopes were included. These last two constants deal with the inelastic (plastic) material behavior by the definition of a stress-strain curve which is described from two branches, the first one which corresponds to the elastic region of the material and the second one to the plastic region.

The magnitude of the yield stress is generally obtained from a uniaxial test but since the stresses in a structure are usually multiaxial, a yield condition must be used for measurement of yielding of the mutliaxial state of stress. The yield condition can be dependent on all stress components, on shear components only, or on hydrostatic stresses. In our application the Mohr-Coulomb material model was used which describe elastic-plastic behavior based on a yield surface that exhibits hydrostatic stress dependence. Such behavior is observed in a wide class of soil and rock-like materials.

The material data (elastic properties) of the masonry are as follows: Young's modulus E= 8820 MPa, Poisson's ration ν= 0.15 and Density 1700 Kg/m3 . The material has been considered as homogeneous and isotropic, the numerical values have been chosen on the basis of compression tests performed on specimens. Also a damping equal to 5% was considered. For masonry two cases were examined: first the Mohr-Coulomb model developed by Drucker and

Prager has been used with isotropic hardening and for the plasticity the initial yield stress is assumed to be equal to 228.523 kPa. As a second case failure criteria based on maximum stresses have been used. Particularly, the following considerations were done: maximum tensile stress = 880 kPa, maximum compressive stress=8.8 MPa and maximum shear stress=198 kPa.

The material data used for the description of the elastic properties of the shotcrete are as follows: Young's modulus E= 27406 MPa, Poisson's ration ν= 0.20 and Density 2400 Kg/m3.

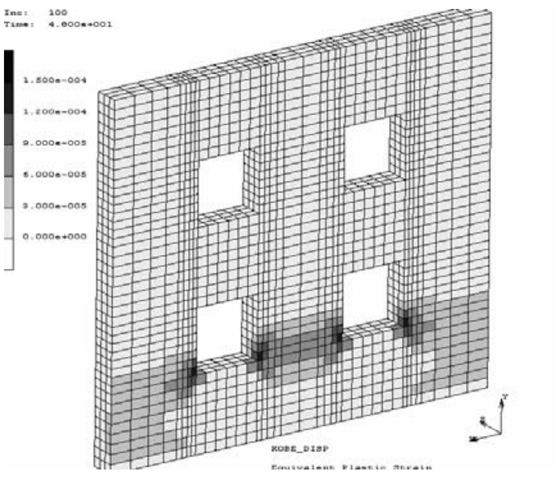
3.3 Finite element models

The finite element method was used on a three - dimensional, solid model of the wall. Solid finite elements have been used for the analysis In order to consider the unilateral contact effects in our analysis, the lintels were separated from the wall and were connected with unilateral frictional interfaces. The criterion about crack initiation - opening is based on the normal stresses which are developed at the outer nodes of the contact bodies. The yield limit was considered equal to 0.1Mpa.

The following three models, with different contact and friction conditions were examined:
Model 1: Fixed conditions were considered between the masonry wall and the lintels.
Model 2: Contact conditions with friction coefficient equal to 0.4, between the masonry wall and the lintels were considered.
Model 3: Contact conditions with friction coefficient equal to 0.6, between the masonry wall and the lintels were considered.

4 RESULTS

In the case with the elastoplastic material model, the estimation of the region with plastic strain is an indication of failure and crack development. The contours of the equivalent plastic strain, for the two load cases, are given in figure 3 and 4 respectively.



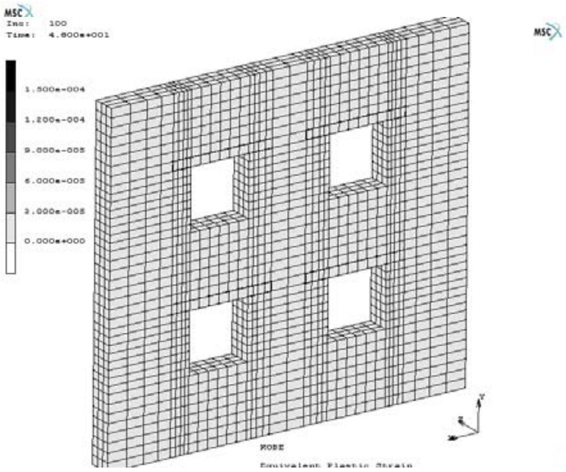


Figure 3: Equivalent plastic strain at time 48sec (First load case), for Model 1 (left) and Model 2 (right).

In a previous work [10], it was shown from a static analysis with a suitable earthquake equivalent loading, that the consideration of the unilateral effects reduces the plastic strains in the masonry wall. In the present investigation, which is based on dynamic analysis, it is shown that the horizontal reinforced concrete lintels, is able to eliminate the plastic strain in the case with the non strong earthquake (fig. 3), something which doesn’t happened in case with the strong excitation (fig. 4, the analysis of the first 10 sec and for the recorded values of the displacement).

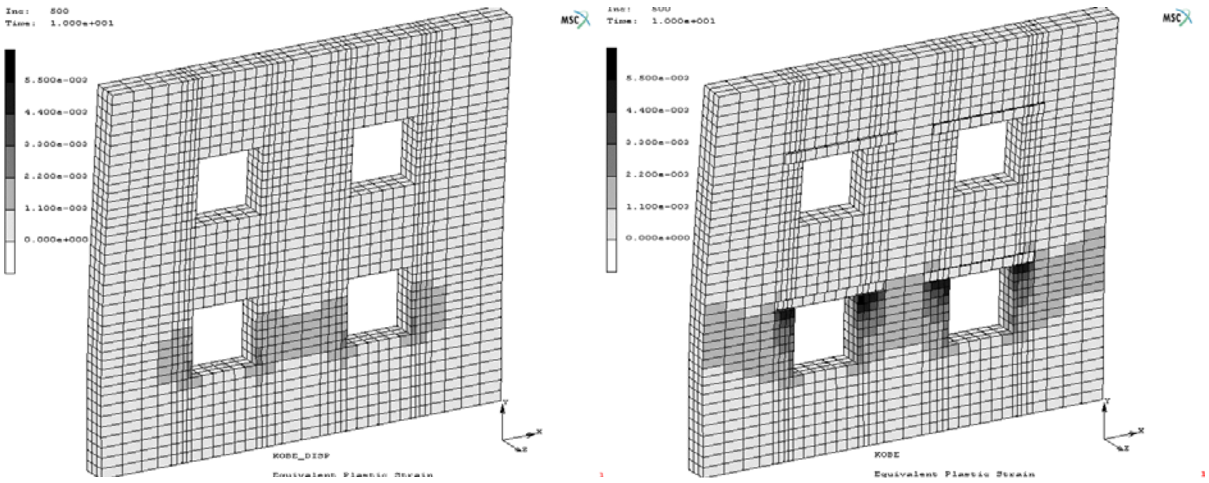


Figure 4: Equivalent plastic strain at time 48sec (First load case), for Model 1 (left) and Model 2 (right).

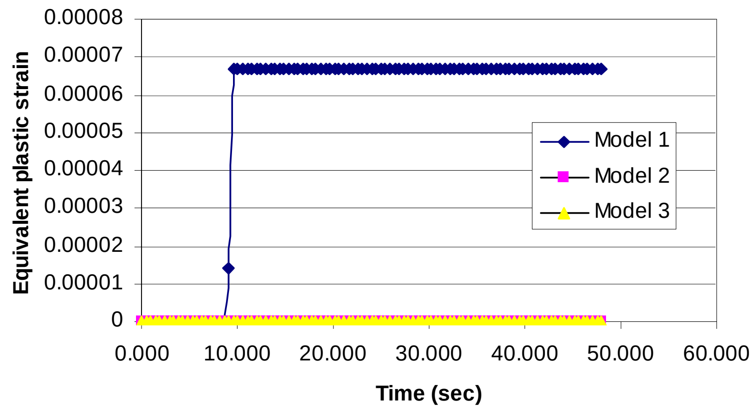


Figure 5: History of equivalent plastic strain of node I (first load case).

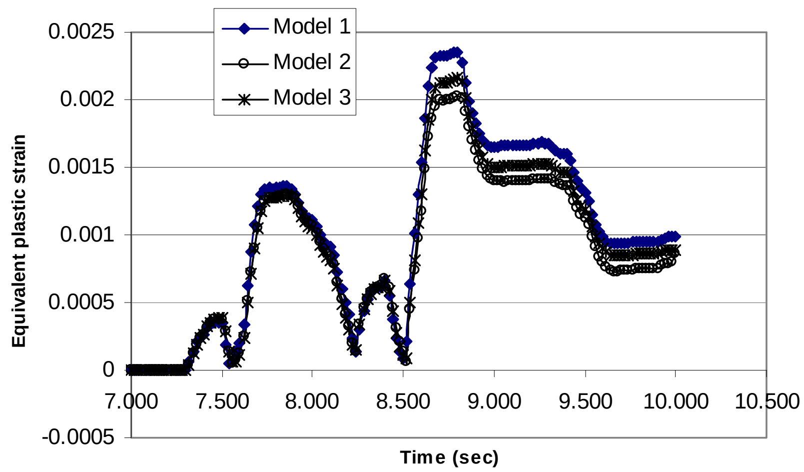


Figure 6: History of equivalent plastic strain of node I (second load case).

The same notice is shown in the figures 5 and 6 where the history of equivalent plastic strain and for a node at the level of the lower openings (node I, fig. 1), are given. The histories of total plastic strain energy for the two load cases are shown in figure 7 and 8. The same conclusion is given from the analysis considering failure criteria and calculating the corresponding failure index (fig. 9), which indicates the region where the stresses are over the maximum allowable level.

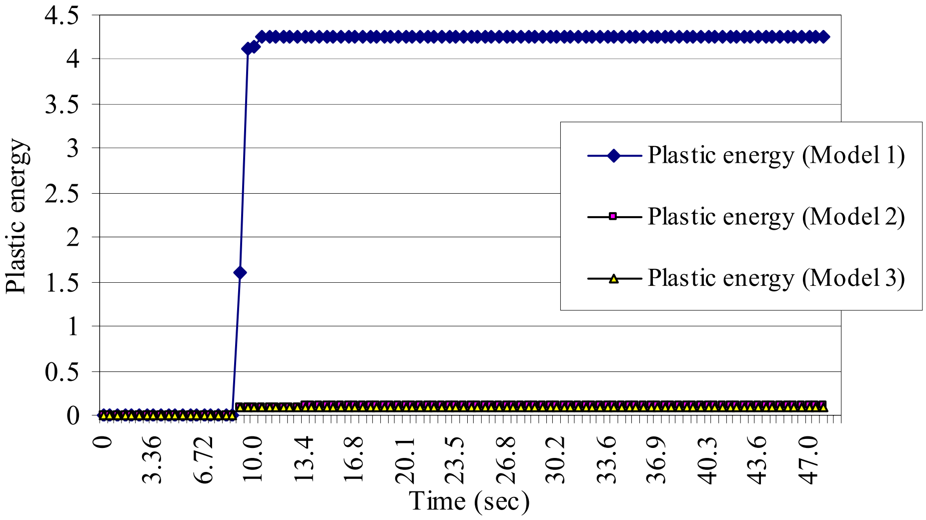


Figure 7: History of plastic strain energy (First load case).

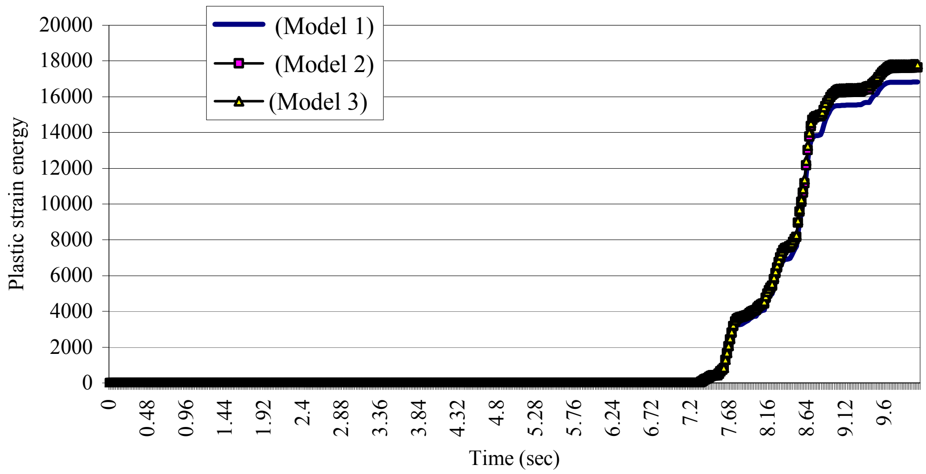


Figure 8: History of plastic strain energy (Second load case).

5 CONCLUSIONS

The horizontal reinforced concrete lintels, reduce the plastic strains when contact and friction effects exist between them and the masonry wall for not strong excitation. In opposite for strong excitations stress concentrations appear at different places. The energy dissipation mechanism which work in the case of small displacements would leads to negative results when the sliding movements between the lintels and the masonry goes beyond some limits.

Further investigation is needed about this mechanism and its behaviour under various seismic excitations.

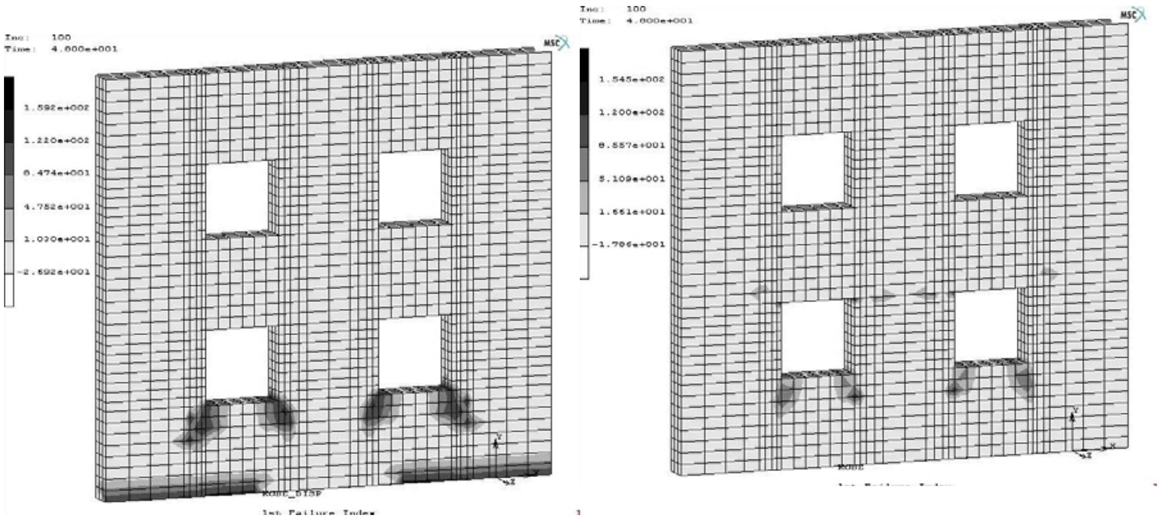


Figure 9: Failure index at time 48sec (First load case), for Model 1 (left) and Model 2 (right).

REFERENCES

[1] P.B. Lourenço, *Computations on historic masonry structures*, *Prog. Struct. Eng. Mater.*, **4**, 301-319, 2002.

[2] B. Leftheris, M.E. Stavroulaki, A.C. Sapounaki, G.E. Stavroulakis, *Computational methods for heritage structures*, WIT Press, Southampton, U.K., 2006.

[3] P.D. Panagiotopoulos, *Inequality problems in mechanics and applications. Convex and nonconvex energy functions*, Birkhauser Verlag, Basel, Boston, Stuttgart, 1985.

[4] E.S. Mistakidis, G.E. Stavroulakis, *Nonconvex optimization in mechanics, Smooth and nonsmooth algorithms, heuristics and engineering applications*, Kluwer Academic Publishers, Dordrecht, 1998.

[5] M. E. Stavroulaki, G.E. Stavroulakis, Unilateral contact applications using FEM software, Guest Editors: M. Sofonea, J.M. Viano, *International Journal of Applied Mathematics and Computer Sciences, Special Issue: Mathematical Modeling and Numerical analysis in Solid Mechanics*, **12**(1), 2002.

[6] M.E. Stavroulaki, G.E. Stavroulakis, Unilateral frictional contact nonlinearities in aseismic design and restoration of heritage structures, Editor: C.C. Baniotopoulos, *International Conference on Nonsmooth/Nonconvex Mechanics, with Applications in Engineering*, Thessalloniki, Greece, July 5-6, 209-216, 2002.

[7] *Theory and user information*, Volume A, MARC Analysis Research Corporation, 1997

[8] I.N. Doudoumis, Energy dissipation in infilled frames due to frictional interface conditions, Editor: C.C. Baniotopoulos, *International Conference on Nonsmooth/Nonconvex Mechanics, with Applications in Engineering*, Thessalloniki, Greece, July 5-6, 405-412, 2002.