VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D. R. J. Owen (Eds)


# ADAPTATION OF A PLASTIC-DAMAGE CONCRETE MODEL FOR MASONRY MATERIAL SUBJECTED TO CYCLIC LOAD

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**Key words:** Dynamics of Structures, Masonry Constitutive Macro-Model, Non-local Damage Mechanics.

**Summary.** *The paper contains a description of adaptation of an isotropic, plastic-damage concrete model (which was proposed by Lubliner [1] and modified by Fenves [2]) for masonry material subjected to cyclic or dynamic loading. The model is verified - with a good compatibility - by a numerical reconstruction of actual laboratory experiments carried out by Senthivel [3]. The verified isotropic model is applied to analyse the effort of two- and three stories buildings. Linear and nonlinear solutions are compared.*

## 1 MATERIAL MODEL

More than 15 years ago a new concrete *isotropic* model was proposed [2, 3] (the so-called *Barcelona Model – BM*). It is particularly useful in the case of numerical analyses of buildings which are subjected to cyclic or seismic loading [1, 2]. The *BM* is characterized by a bi-dissipative, isotropic degradation of material described by two separate damage variables $d_t$ and $d_c$ for tension and compression. These variables, determined on the basis of independent material damage functions, can be coupled, expressing the confirmed influence of the compression variable $d_c$ on the value of the tension degradation variable $d_t$, after changing the stress sign. The coupling of elastic-plastic material characteristics and description of its damage is realised by means of constitutive equations of the theory of plasticity by effective stresses.

Masonry is an *anisotropic* composite material. Laboratory experiments show that the shape and dimensions of the biaxial envelope of the load capacity of masonry is strongly dependent on the angle between the stress principal directions and bed joints. So it is not possible to adapt concrete parameters of *BM* for masonry only by simple rescaling of its yield stresses. In particular, it is a great problem to describe the biaxial envelope for anisotropic masonry by the isotropic envelope (the yield surface) of the *BARCELONA Model*. A new proposition has been presented by A. Cińcio [6]. Figure 1. presents an example of two envelopes: the first one is summarizes the experimental tests [5], the second one is based on guessing that in the biaxial area of compression the shape of the strength envelope is similar to a half of an elongated ellipse. In that proposition the following values of *BM* parameters have been assumed:

$$\alpha = \frac{\sigma_{b0} - \sigma_{c0}}{2\sigma_{b0} - \sigma_{c0}} = \frac{f_{mx} - 0.75 f_{mx}}{2 f_{mx} - 0.75 f_{mx}} = 0.20 \quad (1)$$

$$\beta(\boldsymbol{\kappa}) = \frac{\sigma_c(\kappa_c)}{\sigma_t(\kappa_t)}(1-\alpha) - (1+\alpha) = \frac{0.75 f_{mx}}{0.03 f_{mx}}(1-0.2) - (1+0.2) = 18.8 \quad (2)$$

The yield stresses for uni- and biaxial compressions ($\sigma_{c0}, \sigma_{b0}$) are respectively equal to 75% and 100% of uniaxial compressive strength $f_{mx}$ (see Figure 1a). In Eq. (2) $\boldsymbol{\kappa} = \{\kappa_c, \kappa_t\}^T$ denotes two hardening variables – see [1 – 3].

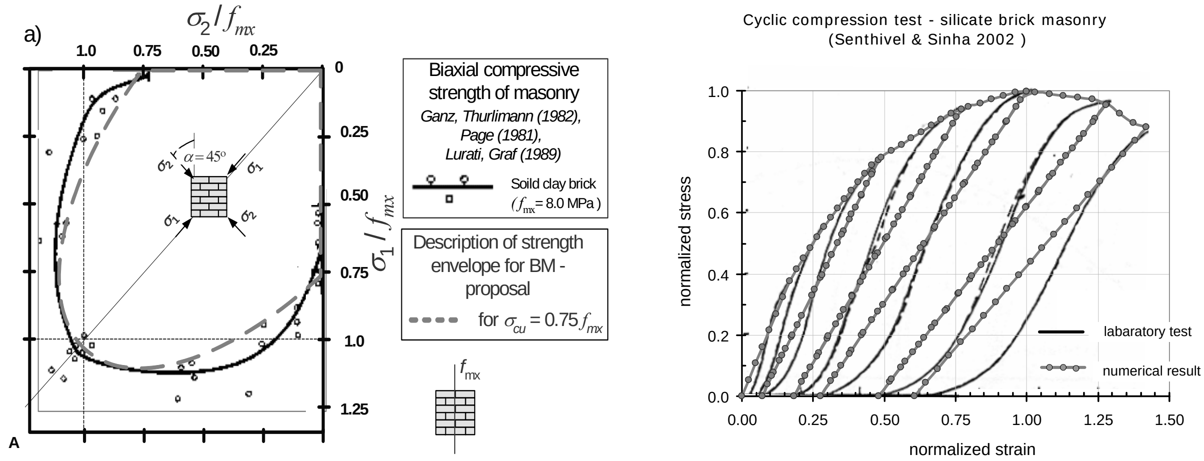


Figure 1: a) Proposition of the biaxial strength envelope for masonry (dashed line); b) Comparison between laboratory tests [3] and numerical results

## 3 MODEL VERIFICATION

The proposed modification of *BM* for a masonry wall was verified by a numerical reconstruction (simulation) of a real experiment which consists of cyclic uni-axial compression of calcium silicate brick masonry [5]. The model parameters were specified on the basis of [5], by: 1° determining the envelope of the stress/strain hysteresis curves under cyclic compressive loading – Figure 1b; 2° approximation of all particular hystereses by straight lines with different slopes - the straight lines with dots in Figure 1b. The changes of the slope are a measure of the material degradation ($d_c$ – the function of masonry degradation under compression). In numerical simulations cyclic compressions were realized by displacement forcing on the boundary of the model. Those displacements resulted from real strains in the successive loading/unloading cycles. The curves in Figure 1b prove a good agreement between the experiment and its numerical simulation, so that the model parameters can be applied for more complicated analyses, like responses of real buildings to earth tremors caused by mining operations.

## 4 NUMERICAL TEST OF REAL BULDINGS

The next step the verification of the model was a numerical assessment of the stress state in models of real two- and three-storey buildings (one example in Figure 2a) which were subjected to numerically recorded horizontal acceleration of the ground (in the Polish copper mining area – Figure 2b). It was assumed that all analysed buildings were masonry dwelling houses with concrete floors. In order to increase the stress effects (larger material degradation) the real acceleration course was tripled. The Figures 3a) & b) show – for instance – a comparison of elastic and plastic-damage (*BM*) solutions (horizontal stresses $\sigma_x$. It is easy to see the stress redistribution and meaningful decreasing of maximum stress value for a nonlinear task (Figure 3a & b). Also the time courses of the horizontal displacement of one point of the building (here it is the node No156 in finite element meshing of the numerical model) are considerably different (Figure 3c).

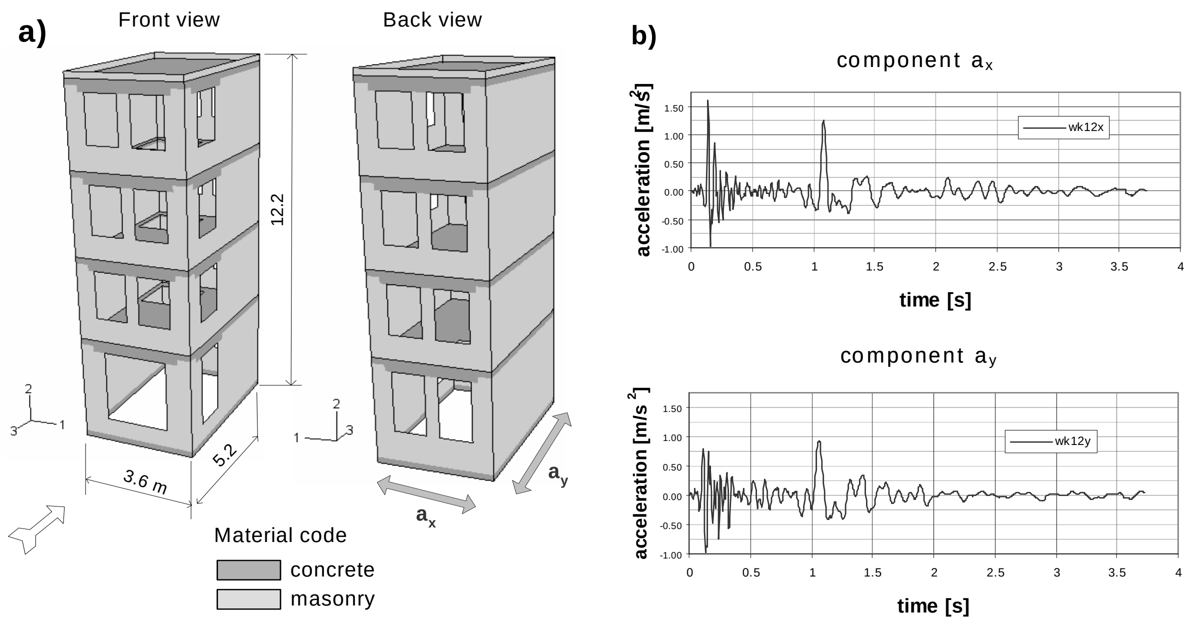


Figure *2*: a) Model of the analysed building b) Two recorded horizontal components of acceleration of the ground

## 5. CONCLUSIONS

- The *Barcelona Model* can be applied with success to analyse a masonry construction subjected to cyclic or dynamic loading.
- Non-linear solutions do not have any fictitious stress concentrations.
- Amplitudes of non-linear displacements are smaller in comparison with linear ones.
- The next step of analysis should concentrate on the modification of the masonry version of the *Barcelona Model* to materials which are characterised by orthotropic properties.

- The numerical results obtained within the framework of this paper (but not presented here) correspond well with observations of building failures in mining areas in Poland.

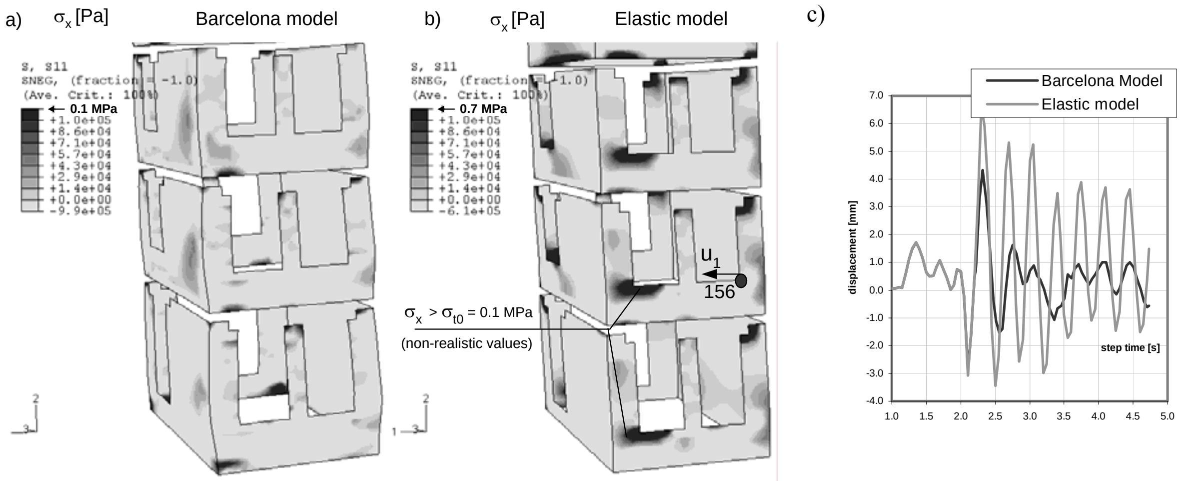


Figure 3: a) & b) Comparison between elastic and non-linear solutions; c) Elastic and non-linear horizontal displacement responds $u_1$ (for the node No. 156)

## 6. ACKNOWLEDGEMENTS

The financial assistance of the Ministry of Scientific Research and Information Technology within the grant number 7 T07E 021 28 is gratefully acknowledged herewith.

The numerical calculation were carried out in the Academic Computer Centre CYFRONET-AGH within the grant number KBN/SGI2800/PŚląska/023/2003.

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