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

VALIDATION OF A DAMAGE PLASTICITY MODEL FOR CONCRETE IN TENSION AND IN COMPRESSION

Ludovic Jason*, Marta Choinska†, Gilles Pijaudier-Cabot†, Shahrokh Ghavamian and Antonio Huerta*****

* CEA SACLAY, DM2S/SEMT/LM2S, Bat. 607 91191 Gif sur Yvette, France
e-mail: Ludovic.Jason@cea.fr, web page: http://www.cea.fr

† GeM, Ecole Centrale de Nantes, 1 rue de la Noé, 44300 Nantes, France

** EDF Recherche et Développement, 1 avenue du Général de Gaulle, 92141 Clamart cedex, France

*** LaCan, Universitat Politecnica de Catalunya, Jordi Girona 1-3 09034 Barcelona, Spain

Key words: Benchmarks, concrete, models, damage, plasticity

Summary. *A benchmark for the validation of an elastic plastic damage constitutive law in tension and in compression is presented. The aim is to propose, on a concrete example, an entire validation process including elementary (compression test), structural (reinforced bending beams) and pre-industrial tests that could be reused for further studies.*

1 INTRODUCTION

The simulation of a complex mechanical finite element problem follows different steps generally. Among those steps, one can find the definition and the representativity of the boundary conditions[1], the design of the meshes and obviously the choice of the constitutive relations which, coupled with the global mechanical behavior, enable to solve the problem. For situations where the experimental study is really difficult (sensitive environments like nuclear power plants for example), the validity of the constitutive law takes a special importance as experimental investigations are no longer possible. That is why a clear methodology has to be defined before launching heavy studies, to make sure that the model will be able to provide solutions for the industrial application. Elementary, structural and pre-industrial tests build the classical process for the validation of the constitutive relation. In this contribution, an elastic plastic damage model is considered. Damage is responsible for the softening evolution while plasticity accounts for the development of irreversible strains. It is first applied on a compression test for which the simulated results are compared with the experimental ones. A structural application is then considered with a three point bending beam of reinforced concrete. Finally, a pre industrial application is simulated to model the behavior of a Representative Structural Volume of a containment building for nuclear power plants.

2 MODEL

To represent the mechanical behavior of concrete structures and to determine the damage value especially, elastic damage models or elastic plastic constitutive laws are not totally sufficient. They indeed fail to reproduce the unloading slopes during cyclic loads which define experimentally the value of the damage in the material. A combined plastic – damage formulation is thus proposed[2] to circumvent the limitations of both approaches. The chosen plastic yield surface depends on four main functions $\overline{\rho}$ (second effective stress invariant), $\hat{k}$ (hardening function), $\overline{\rho}_c$ (deviatoric parameter) and r (deviatoric shape function) :

$$F = \overline{\rho}^2(\sigma') - \frac{\hat{k}(\sigma', k_h)\overline{\rho}_c(\sigma')}{r^2(\sigma')} \tag{1}$$

where σ' is the effective stress (stress of the undamaged material) and k_h the hardening parameter. It is then combined with an isotropic damage model[3]. The scalar variable D is computed from the elastic strain tensor ε^e

$$\varepsilon^e = E^{-1}\sigma' \tag{2}$$

E^{-1} is the inverse of the elastic stiffness. The damage loading surface g is defined by :

$$g(\varepsilon^e, D) = \tilde{d}(\varepsilon^e) - D \tag{3}$$

where D takes the maximum value reached by $\tilde{d}$ during the history of loading, $D = Max_{/t}(\tilde{d}, 0)$. $\tilde{d}$ is computed from an evolution law that distinguishes between tensile and compressive behaviors. Once the damage has been computed, the “real” total stress σ is determined using the equation :

$$\sigma = (1 - D)\sigma' \tag{4}$$

3 APPLICATIONS

3.1 Compression test

Cyclic compression is first used to validate the interest of the model. The numerical response provided by the elastic plastic damage law is given in figure 1a and compared with experiments[4]. Damage induces the global softening behavior while the plastic part reproduces quantitatively the evolution of the irreversible strains. Experimental and numerical unloading slopes are thus similar, contrary to a simple damage formulation response. If this difference could seem negligible, it is in fact essential if a correct value of the damage is to be captured. An elastic damage model overestimates D whereas the full constitutive law provides more acceptable results. Figure 1b illustrates the volumetric response. The introduction of plasticity simulates a change in the volumetric response from a contractant (negative volumetric strains) to a dilatant behaviour as it is observed experimentally. The elastic plastic damage model is thus able to reproduce the constitutive response of concrete in cyclic compression.

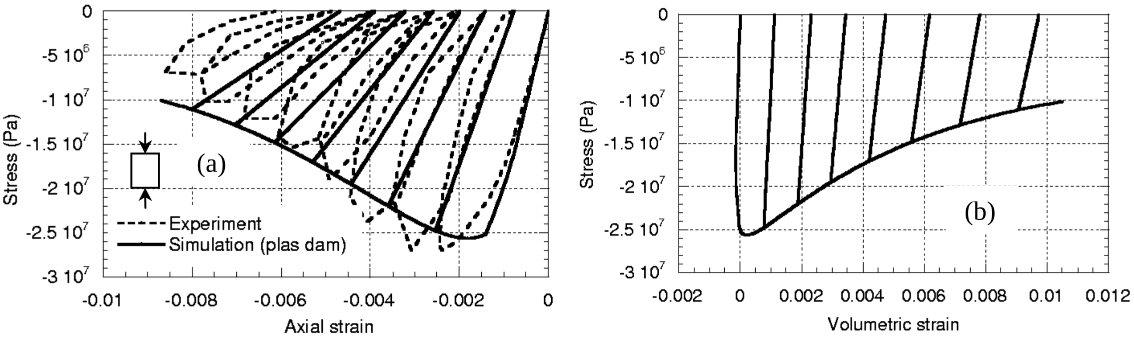

Figure 1 : Cyclic compression test. Axial and volumetric responses.

3.2 Three point bending beam

The structural application, extracted from a benchmark proposed by EDF[5], is a 3D computation of a reinforced concrete beam loaded in three point bending. Figure 2 illustrates the damage distributions for different loading steps. A major damage band appears in the middle of the beam, followed by some secondary bands that characterize the presence of steel in concrete. This “discrete” damage distribution illustrates well the formation of cracks in a reinforced concrete beam and is in qualitative agreement with experimental results. More quantitative comparisons would require a regularized approach[6] as the softening behavior triggers strain and damage localization which results in a mesh dependence and, in some extreme cases, in the simulation of physically unrealistic phenomena (failure without energy dissipation). Nevertheless, for three point bending beams, the elastic plastic damage approach is able to reproduce, at least qualitatively, the global behavior of the structure.

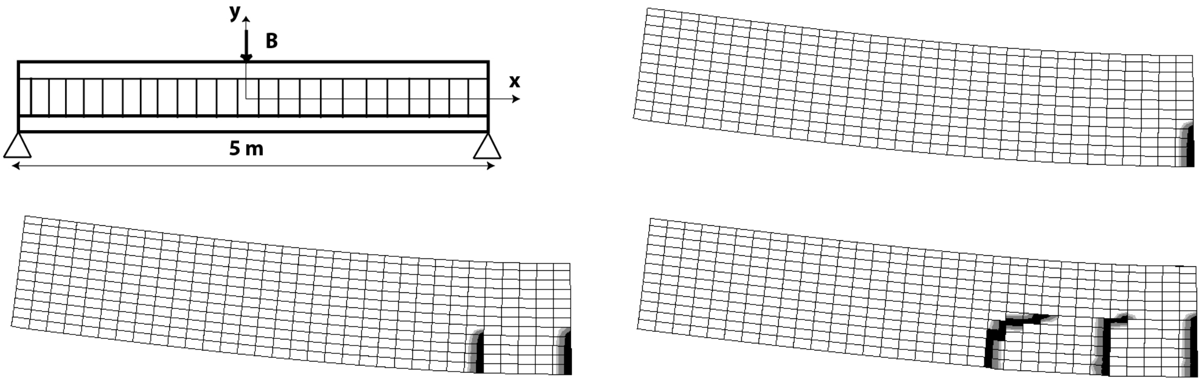

Figure 2 : Three point bending beam. Damage distributions. Black zones correspond to a damage equal to one. Only half of the beam is represented.

3.3 Representative Structural Volume of a containment building

The application presented in this part has been recently developed by Electricité de France. The test, called PACE 1300, is a Representative Structural Volume of a containment building of a French 1300 MWe nuclear power plant. It has almost all the features of the reinforced containment building : concrete, vertical and horizontal longitudinal passive bars, transverse passive bars and prestressed tendons in two directions (figure 3a). Integrity tests are simulated (internal pressure to evaluate a potential leakage rate). Figure 3b presents the damage distributions provided by the elastic plastic damage approach. Damage first develops in the middle of the volume, along the vertical tendon, then propagates in the depth and in the height of the structure to form a localized damage band. It emphasizes the importance of the tendons and the need to include a regularized technique if an objective response is to be captured.

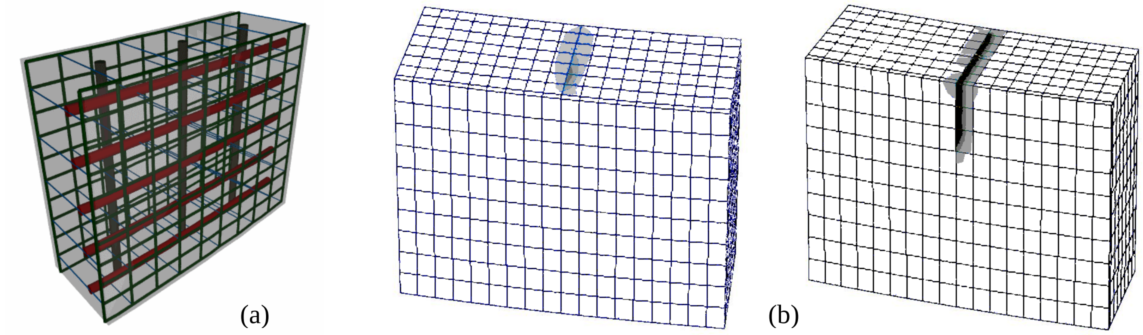

Figure 3. Representative Structural Volume. Principle and damage distributions. Black zones correspond to heavy damaged ones.

4. CONCLUSION

A benchmark has been proposed in this contribution for the validation of an elastic plastic damage formulation. Based on elementary (compression), structural (bending beam) or preindustrial applications (representative structural volume for containment vessel), it enables to appreciate the role of damage and plasticity in the constitutive behavior of concrete. But it also supposes an experimental background that is still missing, for heavy structural applications like containment vessels especially. This issue will be investigated in a near future.

REFERENCES

[1] M. Choinska, L. Jason, G. Pijaudier-Cabot, “Mechanical structural damage modelling and analysis of a containment building”, Proceedings of the fifth international conference on computation of shell and spatial structures, Salzburg, accepted (2005)

[2] L. Jason, A. Huerta, G. Pijaudier-Cabot, S. Ghavamian, “An elastic plastic damage formulation for concrete: application to elementary and structural tests”, *Computer Methods in Applied Mechanics and Engineering*, in press, (2005)

[3] J. Mazars, “Application de la mécanique de l’endommagement au comportement non linéaire et à la rupture du béton de structure”, PhD Thesis, Université Pierre et Marie Curie, France (1984)

[4] B.P. Sinha, K.H. Gerstle, L.G. Tulin, “Stress strain relations for concrete under cyclic loading”, *Journal of the American Concrete Institute*, 195-211 (1964)

[5] S. Ghavamian, “Evaluation tests on models of non linear behaviour of cracking concrete using three dimensional modelling” *Benchmark EDF R&D, CR-MMN 99/232* (1999)

[6] G. Pijaudier-Cabot, Z.P. Bazant, “Non local damage theory” *Journal of Engineering Mechanics ASCE*, 113, 1512-1533 (1987)