COMPUTATIONAL MODEL FOR LOCAL DAMAGE ASSESMENT OF STRUCTURES

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ABSTRACT

In the last years many studies have been developed to analyze the seismic behavior through the damage concept. In fact, the evaluation of the structural damage is important in order to quantify the safety of new and existing structures and, also, to establish a framework for seismic retrofitting decision making of structures.

Most proposed models are based on a post-earthquake evaluation in such a way they uncouple the computation of the structural response from that of damage. However, there are other models which include explicitly the existing coupling between the degradation and the structural mechanical behaviour. Those models are closer to the physical reality and its formulation is based on the principles of Continuum Damage Mechanics. In the present work, a coupled model is formulated using a simplified application of the Continuum Damage Mechanics to the analysis of frames and allows its representation in standard finite element programs.

This work is part of the activities developed by the Structural Mechanics Deparment (U.P.M.) within ICONS (European Research Project on Innovative Seismic Design Conceps for New and Existing Structures).

INTRODUCTION

The characterization of the structural damage is in a way a subjective matter so the main problem is its quantification. In fact, there are many proposed models in the literature which quantify the damage by means of the different parameters associated to the structural response variables.

Damage indices aim to quantify numerically the damage suffered by structures under earthquake loading. Its use is of particular importance in retrofit decision making. Damage indices have been developed to provide a way to quantify numerically the seismic damage in individual elements, storeys or complete structures. Indices may be defined locally, for individual members or at individual joints, or globally, for the whole structure. The first ones are important to locate where the damage is produced. The second ones, however, provide a global description of all or a large part of the structure.

The model used in the present study is based on a simplified application of the concepts and notions of the Continuum Damage Mechanics for the damage analysis of frames. So, it allows to use in its formulation the typical concepts of the continuous media thermodynamics. From the same point of view used in the lumped plasticity models, a generalized formulation to include the damage effects is employed. In this way, it is assumed that all the dissipative effects, such as plasticity and damage, are concentrated at the ends of the member (lumped dissipation models). According to the principles of Continuum Damage Mechanics a damage index is defined at each end of the member quantifying the degradation in these end sections. Those indices take values between zero and a critical value corresponding to the rupture and make possible account the effect of the damage on the structural mechanical behaviour.

The proposed model has been implemented in a computer code and some results have been obtained and compared with laboratory tests.

This work is part of an European Research Proyect in force, ICONS (Innovative Seismic Design Conceps for New and Existing Structures), in which participate Research Centers and Universities from Ispra, Milan, Bristol, Lisbon, Rome, Pavia, Patras, Cachan, Madrid and Liege.

LUMPED PLASTIC-DAMAGEABLE MODEL

Appling the principles of Continuum Damage Mechanics, Flórez-López (1995) proposed a simplified model for damage assesment in frames. For a frame member this model has two different parts; a elastic beam and two hinges where non-linear effects (plasticity and damage) are concentrated. The corresponding constitutive law, state and dissipative functions are introduced in Flórez-López (1995); while other aspects of this model are presented in Carnicero et al. (1997) or in the discussions of the ICONS meeting held in Corfu (1997).

The dissipative function which governing the damage evolution is written as

$$g = Y - \left[Y_{cr} + Z(D) \right]$$

where, Y is the Energy Relase Rate, Y_{cr} is a threshold under which there is not damage increment, and $Z(D) = q\frac{Ln(1-D)}{1-D}$ represents a hardening term. This function may be identified as a generalization of the Griffith criteria $(Y = Y_{cr})$ in fracture mechanics. The evolution of the plastic variables is controlled by the function

$$f = |M - X| - \left(M_y + R \right)$$

where M_y is the yield moment,

$$X = \frac{1-D}{4-D} c\alpha\theta_p$$

is the kinematic hardening and

$$R = c\frac{1-D}{4-D}(1-\alpha)max\left[\theta_p\right]$$

is the isotropic hardening. The main advantage of these dissipative functions is that althought the parameters of the model Y_{cr}, q, c and M_y do not have a physic meaning, they can be derived from the cracking moment, the yielding moment, the ultimate moment and the ultimate rotation, using well known reinforced concrete theory.

The shape of these functions and the parameters, in a Moment-Damage space, can be seen in figure 1.

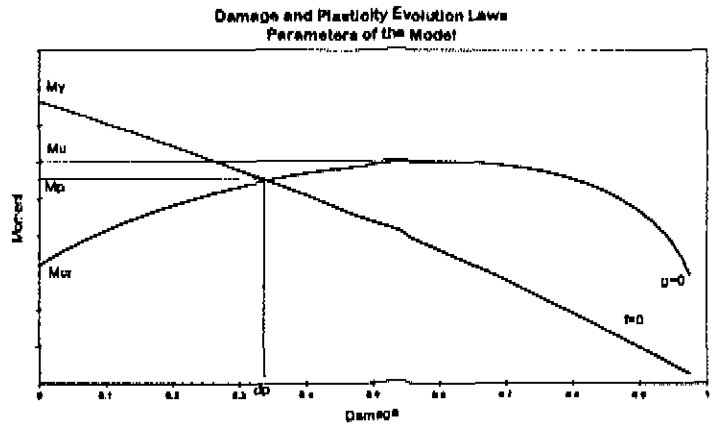

Fig 1. Damage and plasticity evolution laws

In case of reinforced concrete members, a unilateral behavior can be considered. This concept implies that the damage produced by positive actions has no influence on the behavior in compression (due to the closure of the cracks which is supposed instantaneous). In this case two equal dissipative functions are assumed, but the damage variable is associated only with the part of beam which has possitive actions, so two damage indices are required.

Considering those funcions some examples have been computed. The results of a pier of reinforced concrete of circular cross section (Chai et al., 1991) under cyclic loading is presented in figure 2.

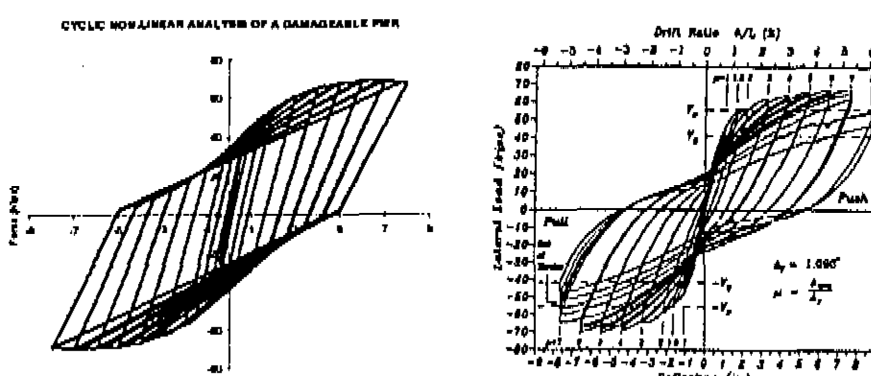

Fig 2. Comparation of results. Chai et al.

As the results show, this model is not be able to represent the strenght degradation that appears due to fatigue effects. The main reason is that the dissipative function proposed depends only on the elastic energy. That effect would be modelled including in the function a new term dependent of a parameter that allows including cumulative effects, v.g. the number of cycles or the cumulative plastic deformation. Another possibility is the definition of a new free energy function and a new energy relase rate parameter, as proposed by Ju (1989).
The new dissipative function is written as

$$g = Y - \left[Y_{cr} + Z(D)\right]\xi(\omega)$$

where $\xi(\omega)$ is a function of a cumulative parameter ω, to represent the fatigue. The classic plasticity function must also be corrected

$$f = \left|M - X\xi(\omega)\right| - \left(M_y + R\right)$$

Some examples have been computed with the new model. Experimental results performed by Kunnath (1997) on a concrete circular pier of 1.375 m height and a 0.375 m diameter are shown in Fig. 3. In Fig. 4 the results obtained with the proposed model for the same pier are presented.

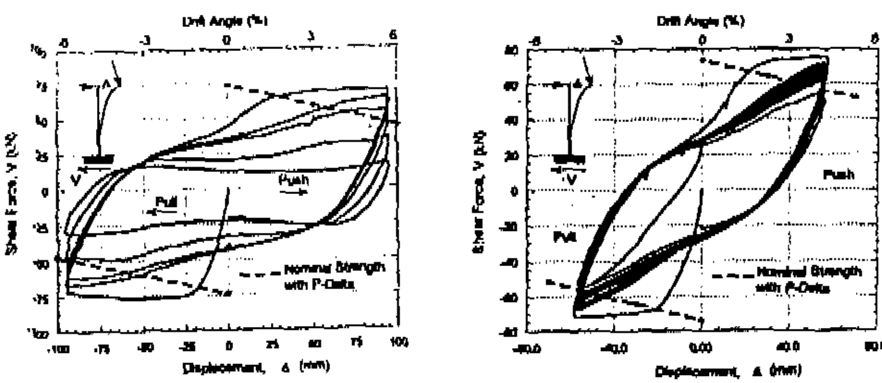

Fig 3 . Experimental results of cyclic loading at a constant displacement amplitude of ± 57 mm (4% Lateral drift) and ± 95 mm (7% Lateral drift)

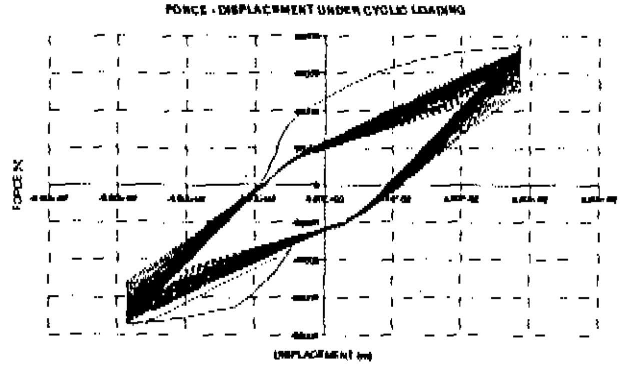

Fig 4a. Cyclic loading at a constant displacement amplitude of ± 57 mm (4% Lateral drift)

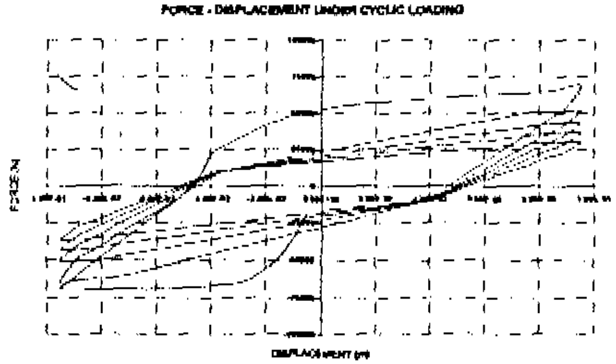

Fig 4b. Cyclic loading at a constant displacement amplitude of ± 95 mm (7% Lateral drift)

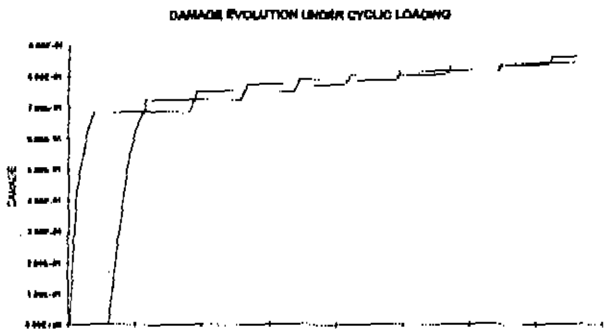

Fig 4c. Damage evolution at the previous load case (7% Lateral drift)

CONCLUSIONS

The results obtained are very promising. The model performs very well *under monotonic and incresed cyclic loading*. The decrease of the strength due to fatigue needs a further study in order to introduce cummulative effects under different amplitudes. The pinching effect which currently the model is not able to represent is another challenge that will probably be treated taking into account different degrees of crack closure.

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ACKNOWLEDGEMENTS

This project is supported by the European Commision, DG XII for Science, Research and Development, Climate and Natural Risks.