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COUPLED PLASTIC DAMAGE MODEL FOR LOW AND ULTRA-LOW CYCLE SEISMIC FATIGUE

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The fatigue phenomenon produces a loss of material strength as a function of the number of cycles, load amplitude, reversion index, etc. This loss of strength induces the material to inelastic behavior, micro-cracking followed by crack coalescence, leading to the final collapse of structural parts. When dealing with low and ultra-low cycle fatigue (LCF and ULCF), characterized by levels of stress superior to the elastic limit, this collapse occurs for material failing below 10^5 cycles and is due to both damage and plasticity effects.

The most common procedures used to simulate LCF and ULCF are those based on counting the number of cycles that can be applied to the material for a given plastic strain. Examples of those approaches are the Coffin-Manson rule, or the enhanced rule proposed by L. Xue in [1]. However, one of the main drawbacks of these formulations is that they require regular cycles to predict the material failure, and, often, this regularity does not exist.

This work proposes the coupling of a plastic model with a damage model to simulate Low and Ultra Low Cycle Fatigue. The proposed model is based on the work of Luccioni et al [2] for monotonic loads. The cyclic load is taken into account as proposed by Oller et al. [3] and incorporates the plastic model proposed by Martinez et al. in [4], which accounts for isotropic and kinematic hardening. Furthermore, it can make use of the load-advancing strategy proposed by Barbu et al. in [5] ensuring a reasonable computational time for materials that fail in a range of 10^4-10^5 cycles.

The plastic model proposed in [4] allows a correct monitoring of the energy required in each hysteresis cycle, enabling the extension of the model from regular cycles to highly irregular cyclic strain amplitudes like those characteristic for seismic loads.

Evolution of plastic and damage strains is obtained from the consistency condition of the problem, taking into account that yield and damage equations need to be integrated simultaneously. This is achieved with en Euler-backward algorithm. Furthermore, in each increment the rate of the plastic and damage multipliers is obtained by means of the Newton-Raphson method. Both plastic and damage internal variables are obtained by normalizing the energy each process dissipates to unity.

The consistent tangent matrix is obtained by means of numerical perturbations as described in [6]. Despite the computational cost, this procedure provides an accurate approximation that improves the global convergence of the problem.

The validation examples included in this work show the capability of the formulation to simulate all fatigue ranges, from ultra-low cycle fatigue to high cycle fatigue. Furthermore, each fatigue failure is triggered by the corresponding model naturally, without requiring the definition of the model that has to be considered. Consequently, when dealing with ultra-low cycle fatigue, the failure will be predicted by the plastic model, with the damage law having no influence in the final result. On the other hand, when dealing with high-cycle fatigue, failure will be characterized by the damage law and plasticity will never develop. In the case of low cycle fatigue, both models will interact. The simulation will know if the structure is subjected to high, low or ultra-low fatigue by the type of load applied and the material properties provided: elastic threshold, ultimate tensile strength and fracture energy.

Therefore, the proposed formulation provides a comprehensible procedure to conduct fatigue analysis without requiring the pre-definition of the fatigue model that has to be used. Thus it is the model, by its own, the one that defines the number of cycles that can be applied to the structure.

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