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QUALITY ASSURANCE OF UNCERTAIN MECHANICAL SYSTEMS CONSIDERING THE EFFECTS OF FATIGUE AND FRACTURE

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ABSTRACT

Mechanical systems operating under cyclic loading conditions may be prone to Multi Site Damage (MSD), i.e. the development and growth of cracks in the rivet holes and/or weldments, which can lead to partial failure or collapse. The damage accumulation during the lifetime of such systems plays a key role in defining the optimal mechanical configuration, i.e the initial design, and the best conditions for its operation (maintenance and/or repair schedule). On the other hand, the parameters that affect the MSD development can not be characterized deterministically, e.g. the precise values of the loadings and mechanical properties (toughness, Young's modulus) are generally unknown. Hence, the decision-making process when dealing with this type of mechanical systems is rather complicated due to the uncertainties present in the problem. In this context, Reliability-based Optimization (RBO) offers a rational framework for the decision-making by providing an optimal solution (regarding the design and operation) which takes into account the construction costs, the maintenance and repair costs and the consequences of a partial failure (or a collapse). The optimal solution is an appropriate trade-off between an acceptable reliability level and economy of the structure, which are conflicting design objectives.

The solution of an RBO problem considering fatigue and fracture requires the quantitative assessment of the structural reliability, which is a challenging task. Even though Advanced Simulation Techniques (e.g., Line Sampling and Subset Simulation) have proved to be most instrumental and efficient in assessing the reliability of real engineering structures, the numerical costs involved in the solution of an RBO problem can be still prohibitive, e.g. the reliability assessment problem nested in a optimization cycle may require the repeated computation of large FE models to simulate the crack development phenomenon. In this context, the aim of this contribution is to discuss and analyze an efficient strategy for solving RBO problems involving fatigue and fracture. Such strategy considers the use of efficient techniques at different levels of the solution of the problem, namely:

- The solution the of mechanical model by means of the Finite Element Alternating Method (FEAM). Such an approach allows to compute the crack growth in a mechanical component by combining iteratively a single FE analysis with an analytical model (see, e.g. [6]).
- The use of advanced simulation techniques for assessing the structural reliability, such as Line Sampling (LS) (see, e.g. [5]) or Subset Simulation (SS) (see, e.g. [1]).

- The construction of approximate representations of the reliability of a structural system as an explicit function of the design parameters, i.e. the decoupling of the reliability analysis from the optimization step (see, e.g. [2,3]).
- The solution of the optimization problem by means of a series of simplified reduced problems, i.e. the original RBO problem is broken into a series of simpler problems with the same optimal solution (the so-called Sequential Approximate Optimization Method) (see, e.g. [4]).

The application of these specific techniques allow to solve a given RBO problem with an enhanced efficiency. The advantages of the proposed approach are addressed by means of application examples concerning optimal maintenance scheduling of mechanical components. The applicability of the approach in more general design cases is also discussed.

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