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A model reduction approach in space and time for fatigue damage simulation

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Summary

The motivation of the research project is to predict the life time of mechanical components that are subjected to cyclic fatigue phenomena. The idea herein is to develop an innovative numerical scheme to predict failure of structures under such loading. The model is based on classical continuum damage mechanics introducing internal variables which describe the damage evolution. The challenge lies in the treatment of large number of load cycles for the life time prediction, particularly the residual life time for existing structures.

Traditional approaches for fatigue analysis are based on phenomenological methods and deal with the usage of empirical relations. Such methods consider simplistic approximations and are unable to take into account complex geometries, and complicated loadings which occur in real-life engineering problems. A thermodynamically consistent continuum-based approach is therefore used for modelling the fatigue behaviour. This allows to consider complicated geometries and loads quite efficiently and the deterioration of the material properties due to fatigue can be quantified using internal variables. However, this approach can be computationally expensive and hence sophisticated numerical frameworks should be used.

The numerical strategy used in this project is different when compared to regular time incremental schemes used for solving elasto-(visco)plastic-damage problems in continuum framework. This numerical strategy is called Large Time Increment (LATIN) method, which is a non-incremental method and builds the solution iteratively for the complete space-time domain. An important feature of the LATIN method is to incorporate an on-the-fly model reduction strategy to reduce drastically the numerical cost. Proper generalised decomposition (PGD), being a priori a model reduction strategy, separates the quantities of interest with respect to space and time, and computes iteratively the spatial and temporal approximations. LATIN-PGD framework has been effectively used over the years to solve elasto-(visco)plastic problems. Herein, the first effort is to solve continuum damage problems using LATIN-PGD techniques.

Although, usage of PGD reduces the numerical cost, the benefit is not enough to solve problems involving large number of load cycles and computational time can be severely high, making simulations of fatigue problems infeasible. This can be overcome by using a multi-time scale approach, that takes into account the rapid evolution of the quantities of interest within a load cycle and their slow evolution along the load cycles. A finite element like description with respect to time is proposed, where the whole time domain is discretised into time elements, and only the nodal cycles, which form the boundary of the time elements, are calculated using LATIN-PGD technique. Thereby, classical shape functions are used to interpolate within the time element.

This two-scale LATIN-PGD strategy enables the reduction of the computational cost remarkably, and can be used to simulate damage evolution in a structure under fatigue loading for a very large number of cycles.

Keywords: LATIN method, damage mechanics, (visco)plasticity, metal fatigue, model order reduction, PGD, multi-temporal scale