Accepted Manuscript

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PII: S0142-1123(17)30102-0
DOI: http://dx.doi.org/10.1016/j.ijfatigue.2017.03.015
Reference: JIJF 4278

To appear in: *International Journal of Fatigue*

Received Date: 9 January 2017
Revised Date: 10 March 2017
Accepted Date: 13 March 2017

Please cite this article as: Kindrachuk, V.M., Unger, J.F., A Fourier transformation-based temporal integration scheme for viscoplastic solids subjected to fatigue deterioration, *International Journal of Fatigue* (2017), doi: http://dx.doi.org/10.1016/j.ijfatigue.2017.03.015

A Fourier transformation-based temporal integration scheme for viscoplastic solids subjected to fatigue deterioration

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Abstract

Using continuum damage mechanics (CDM) for lifetime prediction requires numerical integration of evolving damage until the onset of failure. The primary challenge for the simulation of structural fatigue failure is caused by the enormous computational costs due to cycle-by-cycle temporal integration throughout the whole loading history, which is in the order of $10^3 - 10^7$ cycles. As a consequence, most approaches circumvent this problem and use empirical methods such as Wöhler curves etc. They are well suited for approximating the lifetime, but they are not capable to capture a realistic degradation of the material including redistribution of stresses. The main objective of the paper is to provide a technique for finite element (FE) simulations of structures under fatigue loading while reducing computational costs.

A Fourier transformation-based temporal integration (FTTI) scheme is proposed, which adapts the conventional FE method for modeling the viscoplastic deterioration in a structure subjected to cyclic loading. The response fields are represented by a Fourier series which assumes a temporal scale separation: a microchronological (short time) scale arises from the oscillatory loading and a macrochronological (long time) scale is due to the slow material relaxation resulting from yielding and damage evolution. The original dynamic boundary value problem (BVP) is approximated by the stationary BVP on the microchronological scale. Alternation of the displacement field on the macrochronological scale is correlated with evolution of the history variables by means of a high order adaptive cycle jump method. Performance and significant acceleration of the FE simulations is demonstrated at different loading scenarios for a constitutive damage model where the progressive damage accumulation is driven by viscoplastic yielding.

Keywords: fatigue, accelerated time integration, continuum damage mechanics, Fourier series

1. Introduction

The enormous increase in computational power and algorithmic performance within the last decades is an important factor that enables complex simulations such as realistic modeling of failures in critical con-

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