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MODELING OF LARGE RATCHETING STRAINS WITH LARGE TIME INCREMENTS

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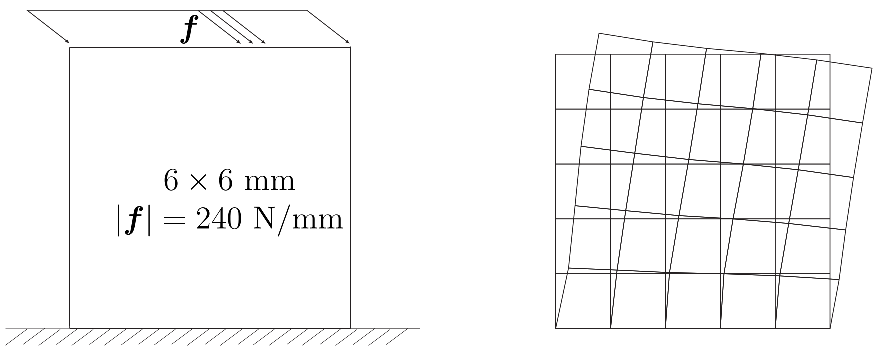
1 INTRODUCTION

Important railway turnout-components are loaded in a cyclic fashion with high induced mid stresses. These conditions may give rise to severe ratcheting in the material whereby the geometry of specific components changes. Such geometry changes have been recorded by measurements. With the purpose to model these geometrical changes, a material model for multi-axial ratcheting and large strains in rail steel has been proposed in Johansson et al. 2005 [3]. The model calibration is carried out against uni-axial stress tests with different stress magnitudes and a bi-axial stress test [4]. Boundary value problems that represent the application of interest can then be solved via a finite element discretization whereby the internal variables and the updated coordinates $\boldsymbol{x}$ are calculated from the deformation gradient $\boldsymbol{F}$. In particular, the internal variables are the plastic part of the deformation gradient $\boldsymbol{F}_{\mathrm{p}}$ and tensor-valued measures $\boldsymbol{F}_{\mathrm{k1}}$, $\boldsymbol{F}_{\mathrm{k2}}$, ... that represent kinematic hardening.

Simulating the cyclic response by adopting the conventional step-by-step time-increments of the cyclic loading history combined with a finite element scheme requires prohibitively large computational time. One remedy is to adopt the method of large time increments introduced by Ladevéze (cf., Cognard and Ladevéze 1993 [1]), where the problem is solved in a iterative fashion via a parameterization and decomposition of the iterative updates into sub-problems which are purely time-dependent and purely space-dependent, respectively. Another approach is to take large increments that span several cycles via Taylor expansions of the response set $\mathcal{S} \doteq \{\boldsymbol{x}, \boldsymbol{F}_{\mathrm{p}}, \boldsymbol{F}_{\mathrm{k1}}, \boldsymbol{F}_{\mathrm{k2}}, \ldots\}$. Both of the mentioned methods need to be accompanied with error control. For the later approach we also need to choose the length of the large increment in an adaptive fashion (e.g., Fish and Yu 2002 [2]).

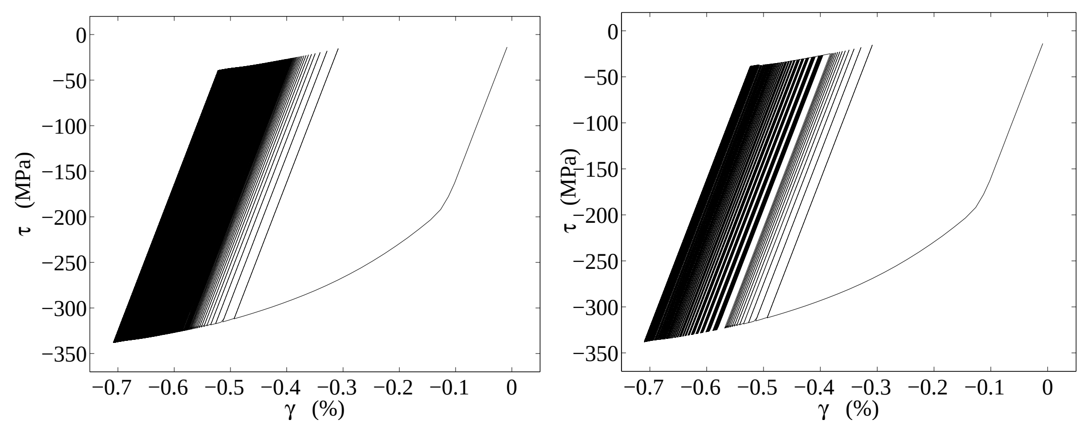
2 DISCUSSION

The potential of large time increment strategies is now illustrated with a simple numerical example. Consider a boundary value problem defined by a planar square-shaped geometry with fixed lower side. The upper side is exposed to a pulsating shearing and compressive force, cf., Figure 1. A material model that accounts for large strains and multi-axial ratcheting is adopted [3, 4]. Furthermore, the geometry is discretized by 25 four-node elements with linear interpolation. The shear stress τ (Cauchy) versus the shear strain γ (Almansi) in the center of the geometry is shown in Figure 2a for the first 5000 load cycles. In Figure 2b we show the corresponding response where we adopt a truncated



a) b)

Figure 1: a) Geometry with boundary and loading conditions; b) Initial and deformed finite element discretization.



a) b)

Figure 2: a) Response with standard step-by-step time increments; b) Response with extrapolation under adaptive step length.

Taylor expansion of $\mathcal{S}$. The length of the increment ΔN is determined in an adaptive fashion by studying the derivative $\mathrm{D}_N\mathcal{S}$ of $\mathcal{S}$ with respect to the cycle number

$$\Delta N = \min\{\Delta N_{\min} + c_1|\mathrm{D}_N\mathcal{S}|^{-c_2},\ \Delta N_{\max}\}, \tag{1}$$

where $\Delta N_{\min}$, $\Delta N_{\max}$, c_1 and c_2 are parameters. Furthermore, each large increment ΔN is controlled by an error estimation. Due to the decaying rate of ratcheting, the incremental length ΔN determined from Eq. (1) will increase.

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