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NUMERICAL MODELING OF TRANSIENT IMPACT PROCESSES WITH LARGE DEFORMATIONS AND NONLINEAR MATERIAL BEHAVIOR

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Summary. *A robust computational approach for transient dynamic impact processes will be presented. Main focus will be on an adaptive remeshing strategy and constitutive models for metals and geomaterials under impact loading.*

1 INTRODUCTION

The present study is concerned with a special case of solid mechanics, where structures are exposed to short-time, highly concentrated loading. Such transient impact processes appear in civil and military security technology, dynamic soil compaction, vehicle crash or fastening and demolition technology. They are characterized by varying non-linearities, as e.g. large deformations and strains, highly non-linear material behavior, frictional contact between multiple bodies and stress wave propagation. Development and combination of different methods in the fields of adaptivity, constitutive modeling, element technology, efficient time discretization and contact are essential for reliable computations and predictions in engineering practice. Accuracy, robustness and efficiency are mandatory requirements for the solution of those complex problems.

In this contribution, we will mainly focus on two issues, namely adaptive remeshing and constitutive modeling of metals and geomaterials especially elaborated for impact loading.

The proposed methods are tested for model problems and their performance in relevant industrial applications is verified.

2 CLASS OF PROBLEMS

The specific class of problems focussed in this study excel themselves through a large complexity. Essentially these are fast transient plane strain or axisymmetric problems that are treated in an explicit way. Adopted material models range from simple elastic up to large strain thermo-elastic-viscoplastic models. The problems exhibit large deformations and may even include severe mesh distortion. Frictional contact is an essential feature of the related physical processes.

3 ADAPTIVE REMESHING

Since large deformations occur in impact simulations and a Lagrangean description is used, repeated remeshing of individual domains is necessary [1,2]. To achieve a quality controlled solution and an optimal distribution of used computational resources at the same time, an adaptive strategy is applied. The essential ingredients of an adaptive remeshing strategy in this highly nonlinear regime are (i) a mesh quality check for triggering automatic remeshing, (ii) a reasonable assessment of discretization errors and derivation of a corresponding mesh density distribution, (iii) an automatic mesh generation tool for graded meshes and (iv) methods for the transfer of state variables from old to new discretization. The core of this strategy is the assessment of discretization errors by adequate indicators. Different indicators are presented and new methods are developed, which are especially suited for the simulation of transient impact processes. Theoretical definitions and numerical treatment of these aspects are dealt with.

In our approach, two categories of error indicators, gradient-based as well as local quantity-based, are used for adaptive remeshing. For the first category, we compute local gradients of the solution at finite element nodes using the superconvergent patch recovery technique. Then, these gradients are directly transformed to desired element sizes for a new spatial discretization. This results in a refinement or coarsening in regions of high or low gradients (h-adaptivity). For the second category, i.e. local quantity indicators, no gradients of the solution have to be determined. Instead, absolute values of relevant physical quantities are used to control the mesh density. The adaptive remeshing then aims at allocating elements so that every element experiences roughly the same amount of 'physical action'. Both types of indicators as well as the question of the 'relevant quantities' are tightly connected to the specific physical process or even to the specific example at hand. The different indicators will be used separately or in combination. At the boundary the resulting mesh density will be enhanced via a geometric indicator. To this end the geometric parameter 'curvature' is used as a geometric refinement indicator for strongly curved boundaries. It is only activated for refinement and not for coarsening of the 'mechanical mesh density'.

To demonstrate the effectiveness of our adaptive strategy and especially to examine the suitability of different error indicators for large deformation transient problems, the benchmark of a metal bar impact, often called Taylor bar impact, is used.

4 CONSTITUTIVE MODELING

Based on the theory of finite plasticity [3], constitutive models for thermoviscoplastic metals and cohesive as well as non-cohesive frictional materials are presented and developed. One focus will be on a formulation for loose, granular media under high pressure loadings [4]. For this a Drucker-Prager-Cap model [5] is modified and enhanced. The properties and effects of the developing powder will be examined.

4.1 Metals

The mechanical behavior of metals under transient impact loadings is mainly affected through strain rate and temperature. Therefore, a Johnson-Cook plasticity model [6] is used, where the yield limit is a function of effective plastic strain, effective plastic strain rate and absolute temperature. In this empirical formula, the yield limit is multiplicatively composed of a static, a dynamic and a thermal part. In the static part, the strain hardening behavior is described. The increase of strength due to high strain rates, i.e. the viscosity, is considered through the second term. With the last part, the effect of decreasing strength for high temperatures is reproduced. In combination with the adaptive remeshing strategy, problems with strain softening (e.g. adiabatic shear bands) can be treated very well.

4.2 Geomaterials

A constitutive model for cohesive and non-cohesive frictional materials will be presented, which is especially suited for dynamic impact processes. During a high velocity impact acting on cohesive frictional material (e.g. sandstone), a comminuted zone appears directly under the impactor nose. In this region of high multiaxial loading, the intact material disintegrates and loose, powder-like media develops. Realistic description of this powderization and the material modeling of powder itself are important topics of our study.

Since powder-like materials are distinctly compressible, depending on the initial density, they can have severe damping and energy absorbing effects in dynamic impact processes that are of interest in a number of different applications. Herein, the kinetic energy of a system is transformed into internal energy by a relativ volume change of the powder. A better understanding of this phenomenon is needed to extenuate or to intensify the damping and energy absorbing influence of powder in a quantitative and predictable way. In our investigations, the powder material of interest is of dry fine sand type.

In this study, a continuum cap model for the axisymmetrical simulation of dry powder under quasi-static as well as dynamic loading is presented. It is implemented in the context of multiplicative hyperelasticity-based finite strain elasto-plasticity. A nonsmooth multisurface plasticity model with tension cutoff, Drucker-Prager failure envelope and strain hardening cap provides the reproduction of the relevant phenomena: tensile failure, material flow under shearing and compaction under pressure. For the comminution process, i.e. the transition from intact, cohesive frictional material to loose, granular media, this model had to be enhanced. It includes a criterion for the powder development and different evolution laws for material parameters like tensile strength, cohesion and compressibility.

5 NUMERICAL EXAMPLES

Practical relevant applications will demonstrate the performance of our overall approach (see the two examples in Figure 1).

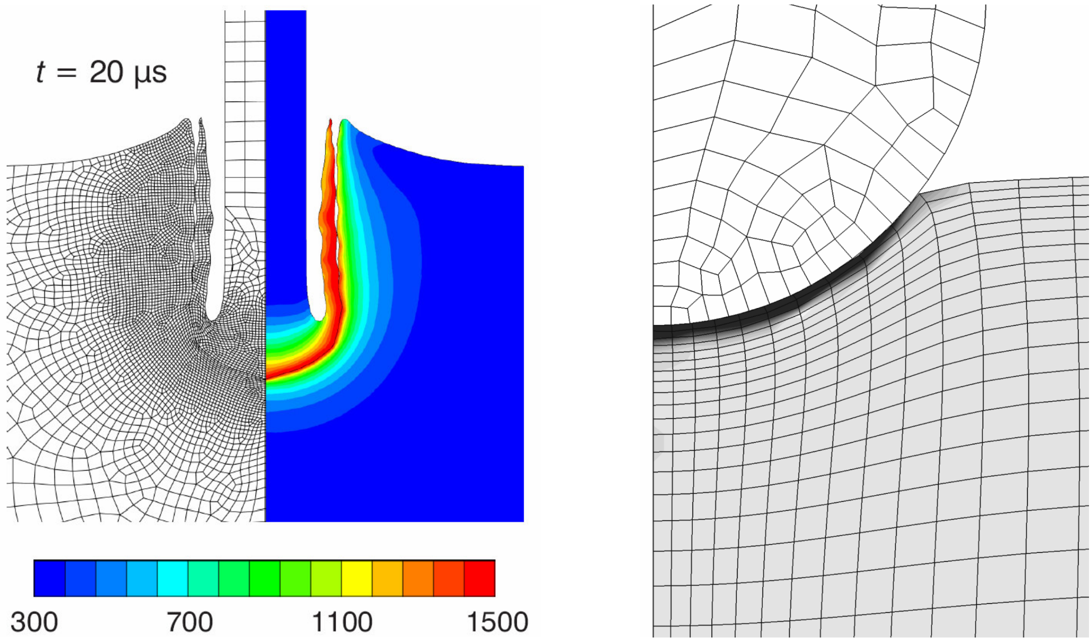

Figure 1: WHA rod penetration - temperature in Kelvin (left)
Powder development under impactor (right)

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