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H-adaptive mesh refinement for shear band localization in elasto-plasticity Cosserat continuum

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Abstract

In this paper, an h-adaptive mesh refinement is presented based on the gradient of deformation in the modeling of localization due to material instability. As the classical continuum models suffer from pathological mesh dependence in the strain-softening models, the governing equations are regularized by adding rotational degrees-of-freedom to the conventional degrees-of-freedom. Adaptive strategy using element elongation is applied to compute the distribution of required element size using the estimated error distribution. Once the new element size and its alignment have been indicated, an automated procedure is used to construct the mesh according to a predetermined size and elongation distribution. Finally, the efficiency of the proposed model and computational algorithms is demonstrated by several numerical examples. Clearly, a finite shear bandwidth is achieved and the load–displacement curves is uniformly converged upon mesh refinement. It is shown that the h-adaptive remeshing using Cosserat continuum can be effectively used in the modeling of localization phenomena.

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1. Introduction

Analysis of strain localization has been an important subject in the attempt to improve the numerical simulation of structure failures. The presence of strain-softening in the constitutive laws brings great difficulties to classical (local) continuum theories [1–4]. The problem is no longer

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mathematically well posed after the onset of localization in strain-softening materials, because local continuum allows for an infinitely small band width in shear or in front of a crack tip [5]. At the numerical level, these difficulties translate in mesh dependence of solutions [6]. In problems exhibiting strain localization, objectivity with respect to the mesh size and orientation can be ensured if the constitutive model is generalized to a non-local formulation.

Various techniques have been implemented to provide a physically acceptable solution. Some impose restrictions on the constitutive moduli in the post-localization regime, while others artificially restrict the size of finite element by comparison to the localization zone. The former is based on enriching the continuum with non-conventional constitutive relations in such way that an internal or characteristic length scale is introduced. Bifurcation analysis techniques based on the early work of Thomas [7] and Rice [8] were adopted by many researchers to determine the shear band localization [9–12]. Non-local theories are the Cosserat continuum [13,14], the higher gradient theories [15], and the integral theory or the gradient theory [16,17]. The later is based on a suitable mesh refinement using normal, continuous, approximations to all the variables [18–22].

The present study is concerned mainly with a combination of both methods based on the Cosserat continuum using adaptive finite element analysis to better simulate strain localization in elasto-plastic solids. The Cosserat continuum theory, first proposed by Cosserat brothers in 1909 [23], has attracted many attentions in the last decade. The first implementation of the theory into a finite element code was made by de Borest [24]. It was then extended to associated and non-associated materials by Peric et al. [25], Iordache and Willam [26] and Carmer et al. [27]. This theory has two main characteristics. Firstly, the rotational degree-of-freedom is taken into account in addition to translation degrees-of-freedom. In fact, the introduction of rotational degree-of-freedom leads to the existence of moment stresses (moment per area) in addition to the stresses of classic continuum. Secondly, an internal length scale is introduced in the field of constitutive equation. This parameter, which plays the most important role in controlling shear bandwidth, relates couple stresses to micro-curvature.

Adaptive mesh refinement in strain-softening problems has received important attention in the last decade. Peraire et al. [28] developed an adaptive remeshing algorithm for compressible flow computations in the capturing of discontinuous shocks. Ortiz and Quigley [29] employed an *r*-adaptive method with an error criterion based on interpolation for strain localization problems. Pastor et al. [18] applied an adaptive remeshing algorithm to solve the inception and development of shear bands on both homogeneous and non-homogeneous stress fields. An *h*-adaptive finite element method was used by Belytschko and Tabbara [19] for dynamic problems, to capture the details of the shear band by refining the mesh at appropriate locations. An automatic adaptive remeshing using element elongation was proposed by Zienkiewicz et al. [20] in the capturing of discontinuous solutions. Deb et al. [30] developed a mesh enrichment procedure which can be adaptively refined in the shear band of localized zone for elasto-visco-plastic solids. Recently, Diez and Huerta [31] proposed a unified approach to remeshing strategies for finite element *h*-adaptivity, based on a priori error estimates and the standard principles of finite precision computation. More recently, Khoei and Lewis [22] presented an adaptive remeshing method for capturing the localization phenomenon in powder forming processes.

The purpose of the present paper is to develop a numerical solution based on the gradient of deformation in the modeling of shear band localization. The fundamental relations in Cosserat continuum are briefly reviewed and the strategy of adaptive mesh refinement is presented. This