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An algorithm based on incompatible modes for the global tracking of strong discontinuities in shear localization analyses

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Highlights

- A method for FE analysis of localized shear failure in frictional solids is proposed.
- Using the EAS approach, a global tracking algorithm for discontinuities is developed.
- EAS-based tracking and Embedded Strong Discontinuity kinematics are combined.
- Neither mesh size nor orientation has an influence on predicted strong discontinuity topology.
- The method predicts strong discontinuities even before the localization condition is fulfilled.

Abstract

Numerical methods for predicting localized shear failure in elasto-plastic solids have experienced considerable advancements in the last decades. Among these approaches, the so-called "Embedded Strong Discontinuity (ESD)" method is often successfully used to accurately simulate the post-localization response with negligible dependence on the finite element discretization. However, it was observed that the employed discontinuity tracking strategy plays a crucial role in the successful localization analysis. In this contribution, we propose a novel strategy for the global tracking of discontinuity surfaces. It is based on exploiting information obtained from the enhanced parameters employed in Enhanced Assumed Strain (EAS) formulations. It is well known, that enhanced strain element formulations are able to better capture localized shear deformations as compared to standard finite elements. This can be explained as a consequence of the improved performance in bending. We observed, that the approximation of the strain jumps delimiting the shear band is connected with a deformation field characterized by opposite bending curvatures across these two discontinuities. Hence, in view of the relations existing between the kinematics of strong and weak discontinuities, we formulate a proper scalar function of the enhanced parameters to identify potential strong discontinuity surfaces, which are evaluated in each step of the analysis with negligible computational cost. This proposed approach has a global character, as it is based upon evaluating discontinuity surfaces defined in the complete analysis domain that are, by construction, continuous across elements. We demonstrate that the tracking algorithm correctly identifies the potential strong discontinuity surface already in early loading stages, even before a localization condition is fulfilled. In those elements which are crossed by the potential failure surface and which also satisfy the localization condition, the kinematics of embedded strong discontinuities is activated to capture the shear failure surface. The performance of the new tracking algorithm is demonstrated by means of several numerical shear localization

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analyses using associative and non-associative Drucker–Prager elastoplastic models to simulate 2-D and 3-D benchmark analyses.

Keywords: Strain localization; Tracking algorithm; Strong discontinuities; Enhanced assumed strain; Finite element method; Shear band

Nomenclature

$N_i(\boldsymbol{\xi})$	Nodal shape functions
u_i, v_i, w_i	Nodal displacement components
u_i^*, v_i^*, w_i^*	Incompatible displacement components
$\breve{\boldsymbol{\varepsilon}}$	Enhanced strain field
$\mathbf{G}(\boldsymbol{\xi}), \bar{\mathbf{G}}(\boldsymbol{\xi})$	Interpolation functions for enhanced strain in physical and iso-parametric space, resp.
$\boldsymbol{\alpha}^e$	Vector of internal strain parameters (enhanced variables)
$J(\boldsymbol{\xi}), J_0$	Jacobian determinant of the isoparametric mapping and its value at the centroid, resp.
$\chi, \bar{\chi}$	Scalar function obtained from lumped nodal projection of ω^e and test function, resp.
$\boldsymbol{\chi}^e, \bar{\boldsymbol{\chi}}^e$	Elemental vectors of nodal values of χ and $\bar{\chi}$, resp.
ω^e	Elemental scalar function (projection of α^e onto $\mathbf{m}$)
Γ	Potential discontinuity path, defined as the zero locus of χ.
$\mathbf{u}_\mu$	Displacement field in a local neighborhood Ω_x of a point $\mathbf{x}$ on Γ
H_Γ	Heaviside step function across Γ.
$\mathscr{F}_\Gamma$	"Indicatrix function"
$\boldsymbol{\zeta}$	Displacement jump field
δ_Γ	Dirac delta distribution across Γ
$g(\boldsymbol{\sigma}, q)$	Plastic potential function
$f(\boldsymbol{\sigma}, q)$	Yield function
$\mathcal{H}$	Isotropic (continuum) hardening modulus
α_μ, q	Strain- and stress-like conjugated hardening variables
λ	Plastic consistency parameter
Ψ	Localized dilatancy
ζ_n, ζ_t	Normal and tangent components of the displacement jump, resp.
$\tilde{\mathcal{H}}$	Localized hardening modulus
$\tau_\Gamma, \sigma_\Gamma$	Tangent and normal components of $\mathbf{t}_\Gamma$ on Γ
$\mathbf{t}_\Gamma$	Traction vector on Γ
$\beta, \bar{\beta}$	Drucker–Prager pressure and dilatancy coefficients, resp.
φ, ψ	Mohr–Coulomb friction and dilatancy angles, resp.
$\Omega_{e,loc}$	Localized finite element
s_Γ	Projected constitutive traction

1. Introduction

The prediction of the load carrying capacity and of the failure mechanisms in cohesive-frictional solids plays a crucial role in the assessment of structural and geotechnical safety, e.g. against failure of foundations, instability of slopes, collapse of tunnels and caverns during excavation. These failure processes are often accompanied by the propagation shear strain localization zones in the form of narrow bands or slip surfaces. At the band boundaries, shear localization phenomena exhibit discontinuities in the strain field, which are often denoted as "weak discontinuities", in order to contrast them with localization phenomena denoted as "strong discontinuities", which exhibit jumps in the displacement field (e.g. the slip surfaces) (see, e.g. [1–3] and references therein).