Regularized Explicit Finite Element Formulation of Shear Localization with Global Tracking of Embedded Weak Discontinuities

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ABSTRACT

Shear localization is a damage mechanism characterized by the concentration of plastic deformation within thin bands of materials, often observed as a precursor to failure in metals. In this talk, we present a three-dimensional explicit finite element formulation with embedded weak discontinuities for the treatment of shear localization under highly dynamic loading conditions. The proposed computational framework can be classified as a sub-grid method, in which the element characteristic length should be larger than the width of the embedded shear band. The finite shear band width, which is obtained from experiments, is treated as a material parameter severing as a length scale to regularize the material post-localization behavior. The onset of localization is detected via a material stability analysis suitable for rate-sensitive materials, and the continuity of propagating shear bands is ensured using a global tracking strategy involving a heat-conduction type boundary value problem, solved for a scalar level set function over the global domain of the problem. In addition, we propose a modified quadrature rule that is used to compute the contribution of an individual element to the global finite element arrays, taking into account the position of the embedded shear band within that element. The mechanical threshold stress (MTS) model, modified to account for dynamic recrystallization, is adopted as the constitutive model for rate- and temperature-sensitive metallic materials, and the constitutive equations are formulated in a corotational framework. The algorithmic setup of the integrated finite element framework, including the global tracking strategy, is described in detail. Thorough mesh-sensitivity analyses are conducted in all the numerical examples provided in this talk to examine the influences of mesh size on various numerical results, including global quantities such as the force-displacement relationship and the volume of the propagating shear band, and local quantities such as the evolution of state variables at Gauss points. By comparing with the conventional finite element method, we demonstrate that the proposed numerical approach consistently alleviates the mesh-dependence typically exhibited in localization problems. Moreover, we show that the total volume and the geometry of the fully developed shear band are mesh-independent.

REFERENCES

[1] Oliver, J., Huespe, A.E., Samaniego, E., Chaves, E.W.V. On strategies for tracking strong discontinuities in computational failure mechanics. *Proceedings of the Fifth World Congress on Computational Mechanics, Vienna, Austrilia Mang HA, Rammerstorfer FG, Eberhardsteiner J (eds),* (2002).

[2] Jin, T., Mourad, H.M., Bronkhorst, C.A. A comparative study of shear band tracking strategies in three-dimensional finite elements with embedded weak discontinuities. *Finite Elements in Analysis and Design,* Vol. 155, pp. 11-31, (2019).