

## STRAIN LOCALIZATION AND ADVANCED CONSTITUTIVE MODELING IN GEOMATERIALS

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Strain localization, the process by which deformation of a body becomes concentrated over a narrow region, occurs in nearly all solid materials under proper loading conditions. Geomaterials, including soils, rocks, and concrete, are no exception. In fact, geotechnical engineers have developed analysis methods based on the idea of strain localization and have been using them for centuries. Analytical techniques based on these so-called failure surfaces or slip surfaces usually include simplifying assumptions, including the geometry of the surface. While these methods have proved valuable for many simple geometries, they are limited in cases of complex geometry and loading conditions, as well as in their ability to predict post-localization deformation patterns, which may be important to assess the safety of nearby structures or earthquake response.

To perform a more detailed and accurate analysis of strain localization, we turn to numerical methods such as finite element techniques. These methods enable the analysis of complex geometries while allowing the theory to focus on what is occurring at a material point. Localization is viewed as a bifurcation in the response, when the tangent modulus becomes singular, allowing an arbitrary deformation in a given direction. This not only signals the onset of strain localization, but also reports the orientation of the failure surface and the direction of flow. Unfortunately, this condition also marks the loss of strong ellipticity in the governing differential equations, which can lead to mesh-dependent and inaccurate solutions in standard finite element methods.

To alleviate this mesh dependence, we introduce a failure plane across the element, and post-bifurcation constitutive model. This latter model is based on the frictional response of granular materials. This technique is general, save for the specific post-bifurcation behavior of the material, and can be applied to metals, polymers, glasses and other materials as well as granular materials.

In order to accurately capture this bifurcation, however, we must develop constitutive models that accurately capture the overall response of the material. Such characteristics as difference in triaxial extension vs. triaxial compression strength, Baushinger (or Masing) effect, shear dilatancy, shear hardening/softening response, and compaction hardening could all have significant effects on the material behavior, and hence the formation of shear bands, as well as other bifurcations such as compaction or dilation bands. Many of the behaviors cannot be captured by simple Mohr-Coulomb or Drucker-Prager models. In addition, we investigate the implementation of these advanced constitutive models with numerical methods such as principal stress decomposition that allow for greater efficiency in computation.