Enhanced Finite Element Modeling of Earthen Structural Materials with Weak Interfaces

C. D. Foster*, D. A. Weed

Department of Civil and Materials Engineering, University of Illinois at Chicago
MC 246, 842 W. Taylor St., Chicago, IL 60607, USA, fosterc@uic.edu

Many materials can fracture either along existing weak interfaces or through the bulk solid material, along with more diffuse failure modes. Layered composites, reinforced concrete, and welded joints are examples. Often such materials fail through some combination of mechanisms.

Masonry materials are a classical example of this type of material. In our research, we are particularly interested in studying earthen structural materials such as rammed earth and stabilized mud block [1]. While the former only has weak interfaces between compacted layers, the latter is an earthen brick that is often joined with standard or soil-cement mortar. Unlike standard masonry construction, the blocks may be weaker and more ductile than the mortar, admitting a wide range of failure modes [2].

To analyze these materials, we have developed an enhanced finite element that allows for failure both on predefined interfaces and through the bulk element at a critical orientation defined during the simulation.

The continuum deformation is defined by a 3-invariant cap plasticity model with isotropic and kinematic hardening. Initially developed for geomaterials, the model is currently under modification with a smooth tensile cap to better capture the behavior in that regime.

Bulk localization is determined by the now classical loss of ellipticity conditions, both for continuous and discontinuous bifurcation for this model [3]. Motion on existing weak interfaces is governed by a traction yield surface. This surface uses an elliptical relationship to account for the coupled shear and normal traction in tension, and a cohesive-frictional model in compression along the surface. A slip-weakening traction-displacement [4] relationship describes the loss of cohesive force with motion along the interface.

Bulk softening is governed by a similar constitutive model, though with different parameters, as it is typically more ductile for these materials. In the case that both bulk and existing interfaces localize at once, the more critical interface governs. Propagating fractures are allowed to follow the bulk material or the interface, depending on which is most critical.

The models are used to examine the behavior of earthen structures under shear loading, both in-plane shearing and out-of-plane bending of walls. Critical importance is placed in examining the effects of openings, and the design of the brick laying to improve the performance of these structures.

References

[1] A. G. Tennant, B. V. Venkatarama Reddy, C. D. Foster, Verification Of Masonry Building Code To Flexural Behavior Of Cement Stabilized Soil Block, J Mater Civil Eng (*in press*).

[2] U. Andreaus, Failure criteria for masonry panels under in-plane loading, J Struct Eng-ASCE (1996) 37–46.

[3] R. A. Regueiro, C. D. Foster, Bifurcation analysis for a rate-sensitive, non-associative, three-invariant, isotropic/kinematic hardening cap plasticity model for geomaterials: Part I. Small strain, Int J Numer Anal Met 35 (2011) 201–225

[4] R. I. Borja, C. D. Foster, Continuum mathematical modeling of slip weakening in geological systems, J Geophys Res 112 (2007).