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INFLUENCE OF IMPERFECTIONS ON SHEAR BAND FORMATION AND EVOLUTION FOR GRADIENT-ENHANCED CAM-CLAY MODEL

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ABSTRACT

Introduction: In the paper the problem of instability and localization phenomena in granular materials is approached. In the analysis the modified Cam-clay plasticity model is used in its gradient version for a two-phase medium (including the limiting cases of drained and undrained conditions). The gradient-enhancement of the model is proposed in order to avoid the spurious discretization dependence of finite element solutions. The obtained numerical results are mesh-independent, however, the width of the shear band is not constant. As the critical state is approached, the localization zone starts to widen.
The reasons for this response are analyzed in the paper and imperfection sensitivity is examined. Calculations are performed using the development version of the FEAP finite element package.
Material model: Attention is focused on fully saturated soil. The problem variables are the solid displacement vector $\boldsymbol{u}$ and the excess pore fluid pressure p_f. Such a two-phase medium, with the assumption of incompressibility of solid grains, is governed by the following two equations [3, 4]:

$$\boldsymbol{L}^{\mathrm{T}}\boldsymbol{\sigma}_t + \hat{\rho}\boldsymbol{g} = \boldsymbol{0}, \quad \boldsymbol{\nabla}^{\mathrm{T}}\dot{\boldsymbol{u}} + \boldsymbol{\nabla}^{\mathrm{T}}\boldsymbol{v}_d + n\frac{\dot{p}_f}{K_f} = 0, \tag{1}$$

with: $\boldsymbol{\sigma}_t = \boldsymbol{\sigma} - \boldsymbol{\Pi}\, p_f,\ \hat{\rho} = (1-n)\rho_s + n\rho_f$, and Darcy's fluid flow velocity given by $\boldsymbol{v}_d = -\boldsymbol{k}\boldsymbol{\nabla}\frac{p_f}{\rho_f g}$. In the above equations $\boldsymbol{L}$ is the differential operator matrix (Voigt's notation is used), $\boldsymbol{\sigma}_t$ is the total stress tensor, $\hat{\rho}$ - saturated density of the solid-fluid mixture, $\boldsymbol{g}$ - gravitation vector, n - porosity, K_f - fluid bulk modulus, $\boldsymbol{\sigma}$ - effective stress tensor, $\boldsymbol{\Pi} = [1,1,1,0,0,0]^T$, ρ_s - density of the solid phase, ρ_f - density of the fluid phase, $\boldsymbol{k}$ - permeability matrix, and n - porosity.
The yield function for the gradient-dependent modified Cam-clay model is written as [2]:

$$f(\boldsymbol{\sigma}, \Lambda, \nabla^2\Lambda) = q^2 + M^2 p\,(p - p_c + g\nabla^2\Lambda), \tag{2}$$

where the equivalent deviatoric stress q is defined as $q = \sqrt{3J_2}$, M is a function of internal friction angle ϕ: $M = \frac{6\sin\phi}{3-\sin\phi}$, p is the effective pressure acting on the soil skeleton, p_c is the current preconsolidation pressure. Finally, g is a positive gradient influence factor. The details of the formulation can be

found in [2], including a discussion of other possible variants of gradient-enhancement of the model.

Numerical results: Unlike in dynamics (cf. [1]), in static simulations of localization phenomena the imperfections merely trigger the process and set the initial position of deformation bands. Here, the analysis is limited to the influence of imperfection location on the results.

The biaxial compression test is considered. The size of the specimen is 1m $\times$ 2m. The model is discretized with 20 $\times$ 40 finite elements. The following material data are adopted: Poisson's ratio $\nu = 0.2$, swelling index $\kappa = 0.013$, initial void ratio $e_0 = 1.0$, initial overconsolidation measure $p_{c0} = 1.0$ MPa, compression index $\lambda = 0.032$, material constant $M = 1.1$ and gradient influence coefficient $g = 0.05$ kN^2/m^2. In the selected test, eight elements in the middle of the left edge of the sample are assigned a 10% smaller value of the initial overconsolidation measure. Some results for this test are presented in Fig. 1. The contour plots with the distributions of invariant J_2 of the strain tensor show the shear band evolution. First a crossed pattern of bands is formed, then one of them remains active, since this is energetically preferable. Finally, as the critical state is approached, the band width increases. This seems to be an unphysical outcome of the adopted form of regularization. A uniaxial approximation of the relation between the gradient scaling coefficient g and the internal length scale l is $g = -hl^2$, where h is the softening modulus, and in this case its role is played by the derivative of p_c with respect to $\Delta\Lambda$. The width of the shear band is governed by l and for dilatant flow the derivative decreases, hence l apparently grows. To accommodate this the gradient factor g must be made a (decreasing) function of a plastic strain measure (which physically means a reduction of nonlocality as the critical state is approached).

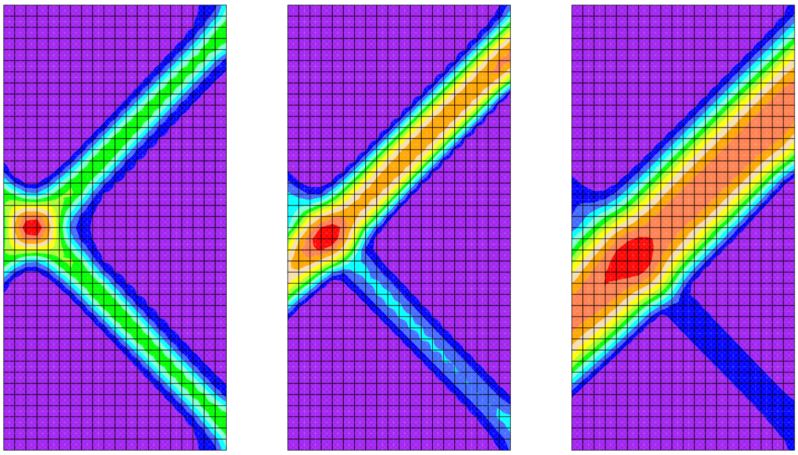

Figure 1: Shear band evolution for eight-element imperfection located next to the middle of the left edge of the sample

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