PARAMETRIC STUDY OF GRADIENT-ENHANCED CAM-CLAY MODEL

A. Stankiewicz*, *J. Pamin
Cracow University of Technology, Cracow, Poland

1. General

In the paper the problem of instability and localization phenomena in two-phase granular medium (including the limiting cases of drained and undrained conditions) is considered. In the analysis the modified Cam-clay plasticity model in a gradient-enhanced version is used in order to avoid the spurious discretization sensitivity of finite element solutions. The main goal of the research is a parameter study of numerical solutions for selected problems. The sensitivity of the numerical results to the gradient influence parameter, to various drainage conditions, preconsolidation pressure and initial void ratio is focused on. The calculations are performed using the development version of the FEAP finite element package.

2. Material model

The yield function for the gradient-dependent modified Cam-clay model is written as [2]:

$$f(\boldsymbol{\sigma}, \Lambda, \nabla^2\Lambda) = q^2 + M^2 p\,[p - p_c + g\nabla^2\Lambda], \tag{1}$$

where $\boldsymbol{\sigma}$ is the effective stress tensor, Λ is the plastic multiplier, q is the equivalent deviatoric stress defined as $q = \sqrt{3J_2}$, M is a function of the 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 and the Laplacian $\nabla^2\Lambda$ represents the nonlocal character of the model.

The attention is focused on fully saturated soil. The problem variables are the solid displacement vector $\boldsymbol{u}$ and the water pore 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]:

$$\boldsymbol{L}^{\mathrm{T}}\boldsymbol{\sigma}_t + \hat{\rho}\boldsymbol{g} = \boldsymbol{0}, \tag{2}$$

$$\boldsymbol{\nabla}^{\mathrm{T}}\dot{\boldsymbol{u}} + \boldsymbol{\nabla}^{\mathrm{T}}\boldsymbol{v}_d + n\frac{\dot{p}_f}{K_f} = 0. \tag{3}$$

In eq. (2) $\boldsymbol{L}$ is the differential operator matrix, $\boldsymbol{\sigma}_t = \boldsymbol{\sigma} - \boldsymbol{\Pi} p_f$ is the total stress, $\boldsymbol{\Pi} = [1, 1, 1, 0, 0, 0]^T$, $\hat{\rho} = (1-n)\rho_s + n\rho_f$ is the saturated density of the solid-fluid mixture, n is the porosity, ρ_s - density of the solid phase, ρ_f - density of the fluid phase, $\boldsymbol{g}$ - gravitation vector. In eq. (3) $\boldsymbol{v}_d$ is the Darcy's fluid flow velocity given by $\boldsymbol{v}_d = -\boldsymbol{k}\boldsymbol{\nabla}\frac{p_f}{\gamma_f}$, where $\boldsymbol{k}$ is the permeability matrix, γ_f is the specific weight and K_f is the fluid bulk modulus. Porosity n and void ratio e are related by: $n = e/(1+e)$.
The details of the formulation of the gradient model can be found in [2], including a discussion of other possible variants of the gradient-enhancement of the model. The finite element formulation for the gradient-enhanced two-phase material can be found in [1].

3. Numerical results

The aim of the paper is to analyse the sensitivity of the results to some material model parameters. In particular, different values of preconsolidation pressure p_c, gradient scaling factor g, initial void ratio e_0 or permeability coefficient k are taken into account.
The following example allows us to investigate the influence of the gradient scaling factor on the

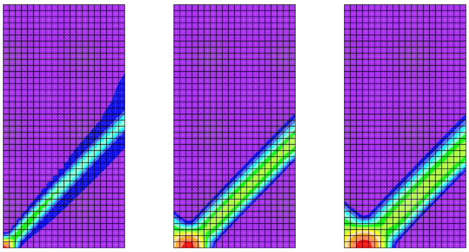

Figure 1. Equivalent plastic strain distribution for gradient scaling factor $g = 0.025$ kN^2/m^2

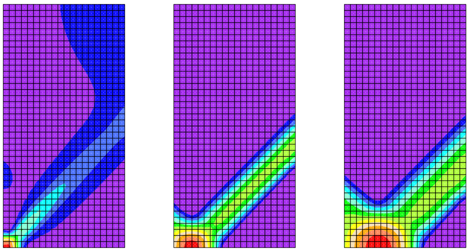

Figure 2. Equivalent plastic strain distribution for gradient scaling factor $g = 0.05$ kN^2/m^2

results obtained in a biaxial compression test. 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 $\lambda = 0.032$, inclination of the critical state line $M = 1.1$. Two values of gradient constant g are considered: $g = 0.025$ kN^2/m^2 and $g = 0.05$ kN^2/m^2. Drained state is here assumed.
The diagram of the load-deformation relation (not included) shows that the solution for a larger value of g is a bit more ductile. In Figs 1- 2 the distribution of the equivalent plastic strain at various stages of numerical calculations is presented for the two values of g. We can observe that the shear bands evolve during the loading process. The width of the localization zone is different for the two considered cases and determined by the value of g. Finally, as the critical state is approached, the band width increases in both cases. This seems to be an unphysical outcome of the adopted form of regularization. To overcome this problem, the gradient factor g would must be made a (decreasing) function of a plastic strain measure (which physically means a reduction of non-locality as the critical state is approached). This option is now verified and the results will be presented at the conference together with the influence of the other mentioned material model parameters.

[1] A. Stankiewicz and J. Pamin. Finite element analysis of fluid influence on instabilities in two-phase cam-clay plasticity model. *Computer Assisted Mechanics and Engineering Sciences*, 13(4):669–682, 2006.

[2] A. Stankiewicz and J. Pamin. Gradient-enhanced Cam-clay model for strain localization in soil. *Foundations of Civil and Environmental Engineering*, 7:293–318, 2006.

[3] A. Truty. On certain class of mixed and stabilized mixed finite element formulations for single and two-phase geomaterials. Technical Report Monograph 48, Cracow University of Technology, Cracow, 2002.

[4] O.C. Zienkiewicz, A.H.C. Chan, M. Pastor, B.A. Schrefler, and T. Shiomi. *Computational Geomechanics*. John Wiley & Sons, Chichester, 2000.