19- Swelling Rock Model – PLAXIS

This model is the Swelling Rock model that is presented and offered by PLAXIS and as a user-defined material model. The model is developed using the user-defined material model option in RS^2 and RS^3.

The model is based on the work by Wittke-Gattermann and Wittke (2004) and Anagnostou(1993) for swelling behavior of . The features that are considered in this model are calculation of swelling strain based on Wittke model or Anagnostou model, a transversely isotropic elastic behavior and shear strength following the Mohr-Coulomb (MC) failure criterion.

All the formulations presented here are in the material coordinate and appropriate transformations/ (rotations) are applied to transfer the stress and strain states to the general system of coordinates that models are defined in.

The total strain $(\dot{\varepsilon}_{ij})$ consists of three parts, elastic strain $(\dot{\varepsilon}_{ij}^{e})$, plastic strain $(\dot{\varepsilon}_{ij}^{p})$ and swelling strain $(\dot{\varepsilon}_{ij}^{q})$ as presented below. The first two parts are discussed in previous sections on Elastic models and Mohr Coulomb model. The swelling strain is the concern of this section.

$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}_{ij}^{e} + \dot{\varepsilon}_{ij}^{p} + \dot{\varepsilon}_{ij}^{q} \tag{19.1}$$

Equation 19.2 presents the final swelling strain, $\varepsilon_i^{q(t=\infty)}$, in terms of axial stress in the direction of swelling based on Grob's decadic logarithmic swelling law

$$\varepsilon_i^{q(t=\infty)} = -k_{qi} \log_{10}\left(\frac{\sigma_i}{\left(\sigma_{q0}\right)_i}\right) \tag{19.2}$$

where k_{qi} is the swelling parameter, σ_i is the stress, and $\left(\sigma_{q0}\right)_i$ is the maximum swelling stress all in i direction. The swelling parameter could be different in and out of the plane of isotropy. The material axes are the same for the swelling and transversely isotropic elasticity.

The evolution of swelling strains with time from the current state towards the final, follows an exponential function.

$$\varepsilon_i^{q(t)} = \varepsilon_i^{q(t=\infty)}\left(1-e^{-t/\eta}\right) \tag{19.2}$$

The η could be constant or can be dependent on the elastic volumetric strain (ε_v^e) and plastic volumetric strain (ε_v^p) .

$$\eta = \frac{1}{A_0 + A_e \varepsilon_v^e + A_p \varepsilon_v^p} \tag{19.3}$$

In above A's are material parameters.

The incremental form for calculation of increments of swelling strains is presented in Equation 19.4. all the variable required for this calculation are based on the state of material at the beginning of step.

$$\varepsilon_i^{q(t+\Delta t)} = \varepsilon_i^{q(t)} + \left(\frac{\varepsilon_i^{q(t=\infty)} - \varepsilon_i^{q(t)}}{\eta} \right) \Delta t \tag{19.4}$$

Calculations of swelling strains in 3D for the general constitutive model requires some assumptions regarding the influence of swelling in different directions, tangential and perpendicular to the planes of isotropy. This will be the difference between the two formulations presented below that are also considered as options for the Swelling Rock model.

19.1- Wittke formulation

In this formulation there is no coupling between the swelling strains. The swelling strains are calculated in the material coordinate, and different swelling parameters aredefined for normal (subscript *n*) and tangential (subscript *t*) to planes of isotropy.

$$\Delta \varepsilon_n^q = \frac{\Delta t}{\eta} \left(-\left(k_q\right)_n \log_{10} \left(\frac{-\sigma_n}{\left(\sigma_{q0}\right)_n} \right) \right) \tag{19.5}$$

$$\Delta \varepsilon_t^q = \frac{\Delta t}{\eta} \left(-\left(k_q\right)_t \log_{10} \left(\frac{-\sigma_t}{\left(\sigma_{q0}\right)_t} \right) \right)$$

where $\left(k_q\right)_t$ and $\left(k_q\right)_n$ are the swelling parameters tangential and normal to the plane of isotropy, respectively. Similarly, $\left(\sigma_{q0}\right)_t$ and $\left(\sigma_{q0}\right)_n$ are the maximum swelling stresses tangential and normal to the plane of isotropy, respectively.

19.2- Anagnostou formulation

In this formulation the swelling parameters are different in directions normal and tangential to the plane of isotropy. The influence and coupling effects of swelling strains on each other is formulated through parameters β that is defined in Equation (19.6)

$$\beta = \frac{\left(k_q\right)_n - \left(k_q\right)_t}{\left(k_q\right)_n + 2\left(k_q\right)_t} \tag{19.6}$$

$$\beta_n = \frac{1+2\beta}{3} \quad , \quad \beta_t = \frac{1-\beta}{3}$$

$$\beta_\sigma = -\sigma_{t1}\beta_t - \sigma_{t2}\beta_t - \sigma_n\beta_n$$

$$\beta_{\sigma_{q0}} = \left(\sigma_{q0}\right)_t \beta_t + \left(\sigma_{q0}\right)_t \beta_t + \left(\sigma_{q0}\right)_n \beta_n$$

In case that swelling parameters are the same the predicted swelling strain will be isotropic as well.

The swelling strains are calculated as:

$$\Delta\varepsilon_n^q = \frac{\Delta t}{\eta}\left(-\left(k_q\right)_n \log_{10}\left(\frac{\beta_\sigma}{\beta_{\sigma_{q0}}}\right) - \varepsilon_n^q\right) \tag{19.7}$$

$$\Delta\varepsilon_t^q = \frac{\Delta t}{\eta}\left(-\left(k_q\right)_t \log_{10}\left(\frac{\beta_\sigma}{\beta_{\sigma_{q0}}}\right) - \varepsilon_t^q\right)$$

References

Anagnostou, G. (1993). A model for swelling rock in tunnelling. Rock Mechanics and Rock Engineering 26 (4), 307-331.

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Wittke-Gattermann, P. & Wittke, M. (2004) Computation of Strains and Pressures for Tunnels in Swelling Rocks. Proc. ITA 2004 E14, 1-9.