Numerical integration of the incrementally non-linear, zero elastic range, bounding surface plasticity model for sands

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ABSTRACT

SANISAND-Z is a recently developed plasticity model for sands with zero purely elastic range in stress space within the framework of Bounding Surface (BS) plasticity. The model can predict realistically the highly non-linear soil behavior under conventional and non-conventional, monotonic, circular and cyclic stress paths for various densities and effective pressures by a unique set of model constants. However, as a consequence of zero elastic range the plastic strain increment direction, and consequently the elastic-plastic moduli fourth order tensor depend on the direction of the stress increment, rendering the model incrementally non-linear. Therefore the numerical implementation becomes very difficult and constitutes the objective of the present work.

The fact that in the constitutive stress-strain relationship, the stress increment on the left hand side depends on its own direction that enters the fourth order elastic-plastic tangent moduli tensor on the right hand side, renders the model intrinsically implicit. In the present work the incrementally nonlinear and intrinsically implicit nature of the SANISAND-Z is thoroughly discussed. An iterative algorithm is presented to solve the non-linear system of ordinary differential equations. A non-traditional consistency condition based on the plastic multiplier is introduced as a core element of the system. The algorithm is based on a Backward Euler numerical integration scheme. The Newton-Raphson method with damping is applied, and modifications like the adaptive trial stress predictor function are introduced to ensure stability. A thorough analysis of the stability and accuracy of the algorithm is presented based on error estimation and visualization with the use of iso-error maps.

The proposed integration scheme allow the use of SANISAND-Z framework in Finite Element Analysis. This BS framework together with the proposed integration scheme can be applied to any material exhibiting zero elastic range mechanical behavior such as artificial graphite, boulders and rocks, or other granular materials.