Abstract

Undrained deformation of dilative sand generates negative excess pore pressure. It enhances the strength which is called dilative hardening. This increased suction is not permanent. The heterogeneity at the grain scale triggers localisations causing local volume changes and associated drainage. The negative hydraulic gradient drives fluid into dilating shear zones. It loosens the soil and diminishes the shear strength. Continuum-based finite element method cannot apprehend pore-fluid movements at grain scale without extreme mesh refinement. This thesis aims to evaluate the capabilities of the finite element method and existing material models to identify the onset and propagation of localisation in dilatant hardening materials. Then constitutive relations are upgraded to provide mesh-independent results for different drainage conditions. First, the ability of critical state Nor-Sand model to simulate drained and undrained deformation of dense sand is evaluated. Then non-coaxial and non-associative flow theories are integrated. Different flow rules are examined for proportional and non-proportional loading paths. Both theories inhibit the tendency to dilate. Non-coaxial Nor-Sand model reduces the overly stiff response predicted by the original Nor-Sand model during undrained dilative shearing. Secondly, a bifurcation analysis is conducted to evaluate the potential of constitutive models to detect the onset of localisation. Under strict isochoric constraint, the Rice criterion is never met by the Nor-Sand model. Both non-coaxial and non-associative flow rules do not bring destabilising effects in dilative sand. The local drainage is the triggering mechanism of shear bands in globally undrained dense sand. Third, the nonlocal regularisation is applied to Nor-Sand model and its capability to produce mesh objective results is elucidated for drained sand. Along with scaling, nonlocal Nor-Sand model can reduce the mesh sensitivity without extreme mesh refinement. Fourth, a comprehensive parametric study is conducted to examine the rate and mesh dependence of saturated dense sand with closed and open drainage boundaries. In both cases, the hydro-mechanical coupling decides both the onset and propagation of localisation. Depending on the local degree of drainage shear zones can be fully or partially drained. The normalised velocity at the boundary between localised and uniform deformation is mesh dependent. For saturated sand, the nonlocal method is successful only when either all material points or shear band material points are fully drained depending on global boundary conditions. The regularisation of drained soil skeleton is not effective when the hydro-mechanical coupling is active. A mesh-independent, rate-dependent constitutive model is developed to capture the pore fluid diffusion at the grain scale. It describes the macroscopic constitutive behaviour of undrained dense sand in the presence of a locally drained or partially drained shear band.