Abstract

There is a long standing belief that density and partial saturation play an important role in the failure mechanism of landslides. This PhD dissertation explores their influences on the mechanical behaviour of saturated/dry and unsaturated sand in element tests, its constitutive modelling and its application to granular flow simulations using the material point method (MPM).

The mechanical behaviour was explored by means of element testing. It was found that partial saturation enhances the dilatancy characteristics and that the enhancement by partial saturation of the peak strength is more significant than the enhancement of the critical state strength. Moreover, it was found that the stress-dilatancy theories of saturated sand are still valid for unsaturated sands when stresses are expressed as effective. This offers simplicity when extending existing constitutive models to partially saturated conditions. The use of state indices to predict the peak state dilatancy rates is also explored and is extended to unsaturated sand.

A constitutive model is developed for unsaturated sand from the stress-dilatancy theories and takes the degree of saturation and the void ratio as model variables. Therefore, a unique set of model parameters is only required to model the behaviour of a wide range of different initial states. This is of importance for large deformation simulations. The extension from saturated to partially saturated sand only requires four new model parameters, which have physical meanings and are quantifiable from laboratory tests. This model is able to predict both wetting-induced swellings and collapses by considering the changes in the dilatancy characteristics.

The newly developed model is implemented in an MPM code, called Anura 3D, which is used to explore the influence of density and partial saturation on the failure mechanism, post-failure flow behaviour and run-out distance of a well-established laboratory experiment called the *granular column collapse*. The role of the constitutive model was explored by comparing their performance with the granular column collapse simulations. It was found that simple models dissipate insufficient energy during the flow behaviour and, hence, over-predict the run-out distance whereas a more advanced constitutive model called *Nor-Sand* was able to predict the correct run-out distance. The MPM simulations showed that the influences of

density and partial saturation, which affect the dilatancy behaviour, on the run-out distance were more significant for small aspect ratio columns than for large aspect ratios. This was confirmed by the analyses of the energy balance of the mobilised mass. It also provided an explanation on the two different collapse regimes.