Abstract

Soil/water interaction is a central challenge for studying hydraulic problems such as seepage flows through embankments, overtopping induced dam failures and the erosion of riverbanks and coastal areas. Since numerical simulations are significantly less costly tools than physical experiments even on a small scale, the past decades have witnessed the dramatic development of computer-aided simulation methods which generally fall into mesh-based methods and meshfree methods. The material point method (MPM), one of the latest developments of meshfree methods, was first utilised in the analysis of large deformation problems in solid mechanics. Since, in MPM the background mesh is used only for solving balance equations while the material properties are stored on the material points, mesh distortions exhibited in the classical finite element method (FEM) are easily avoided when coping with large deformations. With dual sets of material points representing the solid phase and liquid phase separately, the two-point MPM is capable of capturing the relative movement between water and solid skeletons. However, despite having gained great popularity in the geotechnical community, this novel numerical technique has rare applications in the field of hydraulic engineering which usually involves rapid soil/water movements. In this research, a single-phase single-point MPM is exploited to study dam-break floods which are usually studied by solving shallow water equations (SWEs) in the hydraulic community for convenience. The MPM simulation results indicate that with the increase in the initial aspect ratio, the basic assumptions behind SWEs are violated, leading to the over-prediction of the flood propagation speed. The critical aspect ratio for the applicability of SWEs is identified as one below which the SWEs can be used by engineers with confidence. In/outflow boundary conditions (BCs) are also implemented during this research to enable the MPM to solve flow-type problems. The two-point MPM is used to investigate the initiation of scour around a pipeline under conditions of various embedment ratios and hydraulic gradients. To achieve this, free-slip BCs for circular shapes are proposed to eliminate the un-physical blockage of MPs in elements near the pipe. Lastly, the coupled MPM is further employed to analyse the dike stability under the action of seepage flows and post-failure behaviours due to overtopping flows. Predictions of seepage through porous media show good agreement with experiments and analytical solutions. Through the simulations of dike failures due to overtopping, the effect of the bottom drainage (BD) location, protection methods by applying surface/core protection, the effects of BD maximum drainage capacities and the material parameters on dike failure behaviours are studied in detail.