Applicability of the Fracture Flow Interface to the Analysis of Piping in Granular Material

S. Bersan[1], C. Jommi[2], A. Koelewijn[3], P. Simonini[1]

[1]University of Padua, Padua, Italy
[2]Delft University of Technology, Delft, The Netherlands
[3]Deltares, Delft, The Netherlands

Abstract

The structural integrity of water retaining structures such as dikes and dams is threatened by internal erosion. Piping is a kind of backward progressing internal erosion that occurs under impervious hydraulic structures lying on a sandy soil (Fig. 1). Despite not many cases of piping-induced collapse have been documented, piping is nowadays considered a big threat due to the difficulty in recognizing clearly the traces of this mechanism before and even after collapse occurs [1,2]. For this reason, small-scale physical models are being set up in the laboratory, in an attempt to reproduce the conditions leading to the growth of erosion channels (pipes) in sand [3]. COMSOL Multiphysics® was chosen to investigate issues related to the design of such a facility, and to analyse the coupled thermo-hydraulic behavior of groundwater flow in the soil-pipe system to the aim of early-stage detection by means of temperature sensors. In this contribution, the attention is focused on alternative strategies for modelling fluid flow in a soil sample including a pipe.

The numerical model reproduces a sand sample 0.32 m long, prepared in a box and subject to a hydraulic head difference applied between inlet and outlet of the sand box. Steady state analyses were run to model the situation when the pipe, growing backwards, reaches half the seepage length. For simplicity a straight pipe of constant section is considered to develop at the centre of the sample. Coupling of the flow in the sand with the flow in the pipe can be achieved in COMSOL Multiphysics® by using the Free and Porous Media interface (FPM). Applicability of the Darcy's Law interface (DL) and Fracture Flow interface (FF) to describe laminar flow in the pipe was also evaluated, in order to reduce the computational effort. Details of modelling strategies are given in the paper.

The numerical model was firstly used to study the influence of the pipe on the pore water pressure field, in order to optimise the size and some other features of the small-scale set-up. Both 2D and 3D analyses were performed, exploiting the symmetry of the problem. The results allow analysing how the pipe acts as a drain, with water entering both at the head and at the bottom of the slot. The thicker the sand layer the more water is entering at the bottom compared to the amount of water entering at the head. However a value Dlim can be defined, above which the flow to the pipe and the pore pressure field are not influenced anymore by further increase in the depth of the sand layer (Fig. 3). By comparing the different approaches, it was found that FF underestimated the flux in the pipe of an amount that increased with the depth of the sand layer up

to Dlim and therefore increased with increasing flux at the exit of the pipe (Fig. 4). In a 2D analysis the maximum error remains lower that 4%, hence suggesting the Fracture Flow interface as a valuable alternative to other approaches having higher computational cost.

Reference

1. J.K. Vrijling, Piping - Realiteit of Rekenfout?, Rijkswaterstaat, Waterdienst (2010).
2. M. Foster, R. Fell and M. Spannangle, The statistics of embankment dam failures and accidents, Canadian Geotechnical Journal, vol. 37, pp. 1000-1024 (2000).
3. V.M. van Beek, J.G. Knoeff and J.B. Sellmeijer, Observations on the process of piping by underseepage in cohesionless soils in small-, medium- and full-scale experiments, European Journal of Environmental and Civil Engineering, vol. 15 (8), pp. 1115-1138 (2011).

Figures used in the abstract

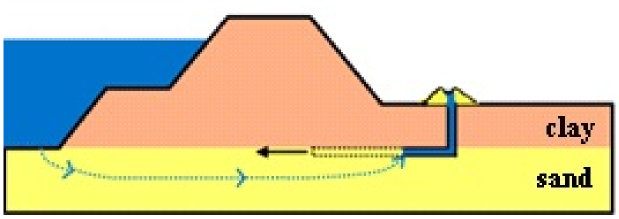


Figure 1: Pipe development under an impervious water retaining structure.

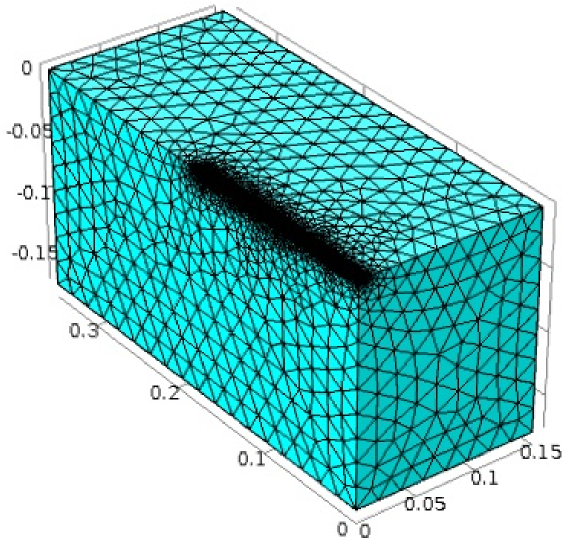
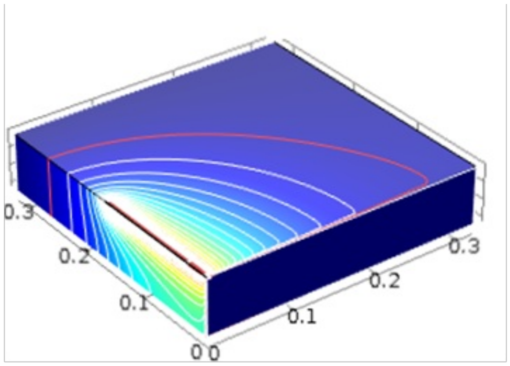
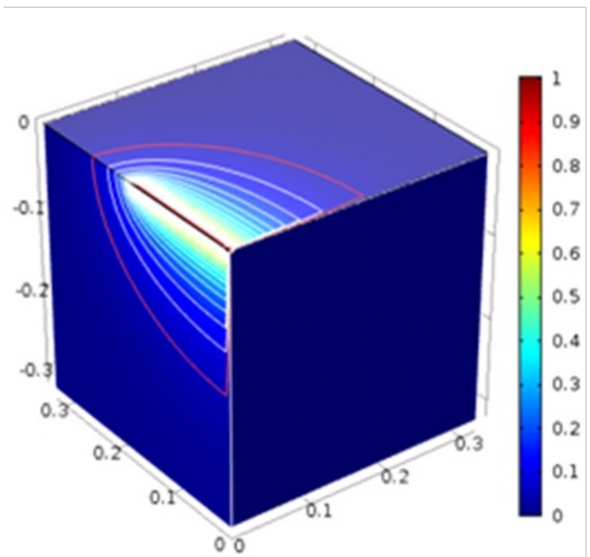


Figure 2: 3D numerical model of the small-scale set-up reproducing a dike foundation with pipe. The finely meshed region corresponds to the pipe and its surrounding area.



(a)



(b)

Figure 3: Relative variations of the pressure induced by the presence of the pipe for different aspect ratios of the sand layer: (a) D=0.2L and (b) D=L. The red curve indicates a 5% variation.

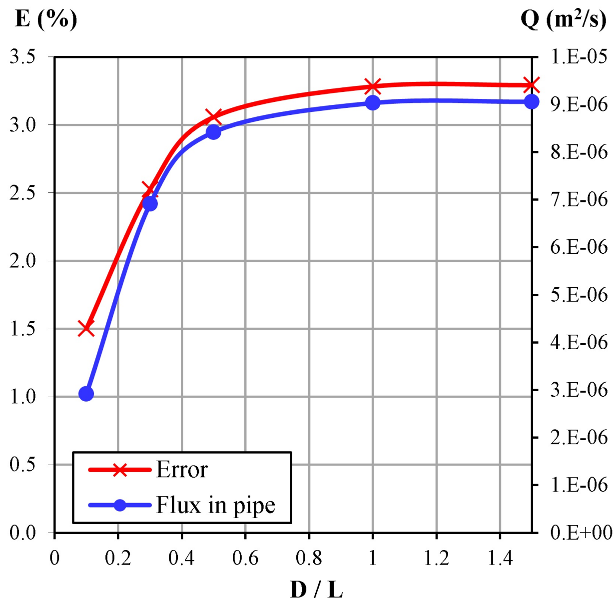


Figure 4: Error committed by using the Fracture Flow interface and flux at the exit of the pipe for increasing depth of the sand layer.