EWG-11 3D Numerical Simulation of Backward Erosion Piping Tube Experiments

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Backward erosion piping (BEP) is an internal erosion mechanism, driven by the detachment of particles at the pipe tip and erosion of the particles along the pipe walls and bottom. This erosion mechanism was extensively studied in (Robbins et al., 2018), who describe horizontal tube experiments in which the head loss along the erosion pipe was measured during pipe formation. This study investigates the ability of numerical models to predict the head loss in the erosion pipe in a 3D situation by simulating the tube experiments using DgFlow (Van Esch et al., 2013), a finite element (FE) program in which the groundwater flow is coupled to the pipe flow using line elements, and using the 3D finite element program described in Robbins and Griffiths (2018), in which backward erosion is simulated by changing soil elements to pipe elements.

Experiments

Horizontal tube experiments, described in Robbins et al. (2018) and Van Beek et al. (2019) were conducted to investigate the local critical gradient at the pipe tip, causing pipe progression, and the critical shear stress in the pipe, which controls the dimensions of the pipe. During the experiments, the head was measured along the top of the tube using pore pressure transducers spaced 10 cm apart. Van Beek et al. (2019) describe the critical shear stress in the pipe, obtained from measurements in a selection of experiments for which the pipe had progressed partially through the sample. The critical shear stresses from the tube experiments were found to be in adequate agreement with the Shields curve. For simulation of the experiments, a selection of 4 experiments was used. The selection contains experiments on two different sand types (3C, 4B and 4C on 40/70 sand, with d50 of 300 µm, and 8B on 20/40 sand with d50 of 600 µm), conducted with two tube sizes (B – 76.2 mm and C – 152.4 mm in diameter). For more information about the selected experiments, the interested reader is referred to Robbins et al. (2018) and Van Beek et al. (2019).

Numerical simulations

Since the critical shear stress of the sand dictates the dimensions of the erosion pipe, and therefore its resistance to flow, it is an important parameter in backward erosion piping modelling. Although the critical shear stress can be derived from the Shields curve, it has not yet been verified that numerical models using laminar flow equations for the erosion pipe yield reasonable hydraulic solutions when using typical critical shear stresses for sands. In this study, the tube experiments have been modelled in two different FE programs to investigate whether use of the measured critical shear stress in the model results in the correct representation of the hydraulic losses in the erosion pipe. The used programs are DgFlow (Van Esch et al, 2013), a finite element program in which the groundwater flow is coupled to the pipe flow using line elements, and the 3D finite element program described in Robbins and Griffiths (2018), in which backward erosion is simulated by changing hexahedral soil elements to pipe elements. Both of the programs represent the erosion pipe as viscous, laminar flow in wide and shallow pipes (2D flow). The difference in approach for representing the pipe has consequences for the way the flow through the pipe is translated to the exerted shear stress: since line elements have no width, a width-to-depth ratio needs to be specified for DgFlow, whereas for the program by Robbins and Griffiths (2018) the width of the elements is controlled by the mesh size. The number of elements to be opened simultaneously is an input value to this program, and influences the width to depth ratio.

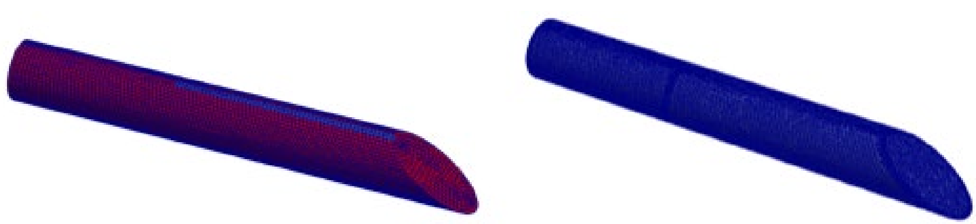
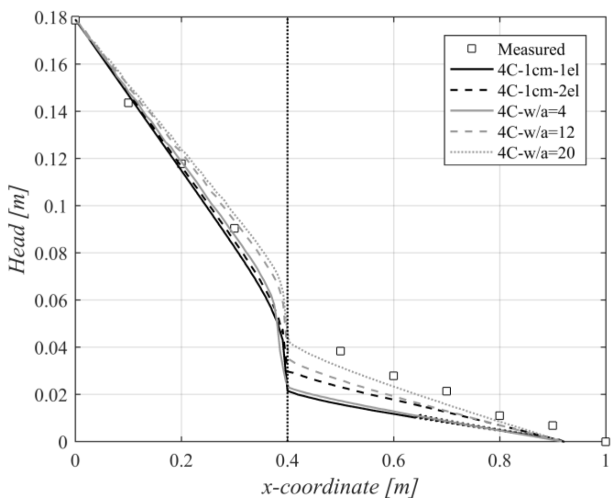


Figure 1. Tube as simulated for the FEM model by Robbins and Griffiths (2018), with pipe elements in blue (left) and tube simulated for DgFlow (right).

In the simulations with DgFlow the width to depth ratio of the pipe was varied (4, 8, 12 and 20), while the mesh size was kept constant at 0.01 m. In the simulations with the model by Robbins and Griffiths (2018), the element size and number of elements used to represent the erosion pipe were varied (0.01 and 0.005 m, and 1, 2, 4 respectively). The width-to-depth ratio was calculated afterwards as the ratio of the combined width of the parallel elements representing the erosion pipe and the average pipe depth along the entire pipe profile. Figure 1 shows examples of the simulated tubes in the two programs.

Analysis of head profiles

The head profiles along the top of the tube were retrieved from the numerical calculations and compared to the measurements from the experiments. Figure 2 (left) shows the head profile for experiment 3C. For all experiments both the measured and computed head along the length of the pipe was fairly linear. Therefore, for comparison of the head profiles, the average measured and calculated pipe gradients were compared by plotting the ratio of the two gradients to the width-to-depth ratio (Figure 2 - right). The figure illustrates that the calculated pipe gradients are lower when the model by Robbins and Griffiths is used. This can be due to the larger inflow area in general and the (relative) increase of surface area with increase of width-to-depth ratio. The larger inflow area allows for more flow through the pipe, resulting in larger pipe depths and therefore lower pipe gradients. For both models, the ratio of pipe gradients is relatively higher for the 20/40 sand than for the 40/70 sand, implying that for the 20/40 sand a lower width-to-depth ratio would be more appropriate than for the 40/70 sand. Since the 20/40 sand is coarser than the 40/70 sand, the pipe could be restrained by the size of the tube resulting in lower *w/a* ratios.



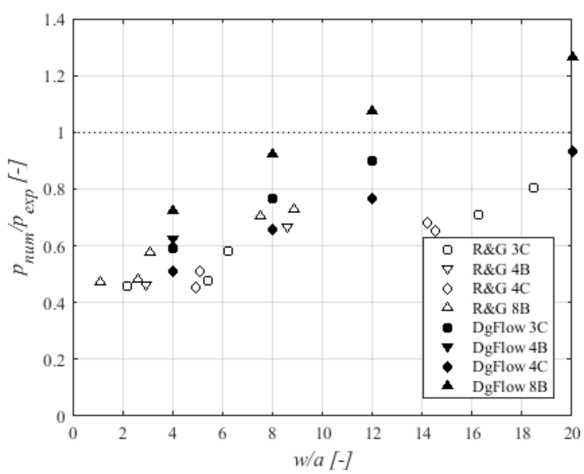


Figure 2: Left: Examples of measured and calculated head profiles, using the Robbins and Griffiths (2018) model (black lines) and DgFlow (grey lines). The dotted black vertical line indicates the position of the pipe tip. Right: ratio of average numerical and measured pipe gradients plotted to the (average) width-depth-ratios. The dotted horizontal line indicates the line of perfect match.

Conclusions

When applying a critical shear stress in 3D backward erosion piping modelling for the estimation of head loss in the erosion pipe, it must be realized that the width-to-depth ratio has a significant effect on the result. The simulation of tube experiments illustrates that this ratio may both depend on the model assumptions and possibly the soil type. More research is required to quantify this effect more precisely such that guidelines for modeling BEP in practice can be developed.

References

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