Numerical modeling of small-scale experiments for a coarse sand barrier as a measure against backward erosion piping

E. Rosenbrand

Deltares

V.M. van Beek¹, J.M. van Esch¹, A. Noordam¹, F. Pederzani³, K. Vandenboer² & A. Bezuijen¹,²

¹Deltares
²Universiteit Gent,
³Politecnico di Milano

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Backward erosion piping can occur when an unfiltered exit is present on the downstream side of a levee and seepage forces are sufficient to transport sand grains. A pipe forms that progresses upstream, backwards, below the levee. When the pipe makes contact with the water on the upstream side of the levee, the flow rate in the pipe increases and progressive erosion of the cavity below the levee can cause failure of the embankment. Backward erosion piping has been studied extensively both numerically and by means of laboratory experiments (e.g. Sellmeijer (1988), Weijers and Sellmeijer (1993), van Beek et al (2014), Vandenboer et al. (2013), Robbins and van Beek (2015), Robbins et al. (2016), van Beek (2015).

One method to prevent the pipe from growing upstream is to place a barrier of coarse sand below the levee in the course of the path. The larger grains have a higher resistance to erosion, and furthermore the hydraulic gradient within the coarse barrier will be lower due to its higher permeability. Both factors contribute to the resistance against backward erosion piping. Van Beek (2016) observed that even in a relatively homogeneous sand, the presence of a slightly coarser layer band can already cause the pipe to deflect and develop parallel to the coarser layer. This was further studied in small-scale laboratory experiments by Negrinelli et al. (2016) who added a coarse sand layer to a uniform sand body. They found that a significant increase in the head drop is required for the pipe to progress across the barrier.

Small-scale laboratory experiments were conducted to determine the overall head drop beyond which the pipe progresses through the barrier, and measure the head distribution at 15 points in the model during the experiments. In order to relate the head drop across the setup to the local head gradient in the barrier, or conversely to relate the critical gradient in the barrier to the maximum head drop in a field situation, numerical modelling of groundwater flow distribution is used. This contribution concerns the analysis of the small scale experiments, and the modelling of these experiments by using a finite element groundwater simulation programme.

In the tests it was observed that for a given barrier sand, the local horizontal gradient in the barrier at the point that the pipe progresses into the barrier is similar, regardless of the downstream sand, or the depth of the barrier in the model. However with a lower relative density of the barrier, the pipe progresses into the barrier at a lower local gradient. This suggests that a strength criterion of the barrier may indeed be derived based on this local gradient, and that this criterion can be used to predict the
overall critical gradient for different geometries and background sands by using numerical groundwater modeling.

To model the results, it was necessary to introduce a low permeability layer on the upstream interface of the barrier with the fine sand. This suggests that possibly some fine material formed a filter cake during the experiments, as a high flow rate was applied. The upstream fine sand did not appear to be transported through the barrier however. The effect on the permeability was strongest for the experiment with a low relative density, possibly because there was more space for the background sand grains to penetrate. Although this provides an extra strength in the laboratory tests, the question is whether this may be counted on in field situations.