EWG-8 Large-Scale Test of a Coarse Sand Barrier as a Measure Against Backward Erosion Piping

E. Rosenbrand; V. van Beek; U. Förster; B. van der Kolk; A. Wiersma; J. Terwindt; D. Peters; S. Akrami; A. Koelewijn; K. van Gerven; L. Voogt; Adam Bezuijen

A novel remediation technique against backward erosion piping is being investigated in a multi-scale experimental program. The coarse sand barrier (CSB) is a trench containing densified coarse sand that is placed below an embankment dam or levee in order to prevent the upstream progression of a pipe. The effectiveness of the measure is based on the larger resistance of the densified coarse sand in the barrier against piping erosion, and on the low hydraulic load in the barrier resulting from the conductivity contrast between barrier and background material. This method was investigated in laboratory experiments on a small-scale (aquifer depth 0.10 m) and a medium-scale (aquifer depth 0.40 m) and was found promising. In order to increase the confidence in the potential of the measure for application in the field, two experiments at a larger scale (aquifer depth 3 m) were conducted. This contribution presents the analysis of the piping process of the first large-scale experiment based on measurements during the test and excavation of the sample after the test.

Experiment

The samples were prepared in an experimental facility at Deltares, the Delta Flume. The sand body is trapezoidal, 5 m wide, 34.1 m long at the top, 18 m long at the bottom, and 3 m thick. The sand body was densified and covered by a blanket of compacted clay, except for the inflow area and outflow area (a transverse ditch of 0.5 m wide). The barrier is 0.5 m deep in the sand body, penetrates ca. 0.2 m into the blanket layer and is 0.3 m thick. A plan view of the sample is shown in Figure 1.

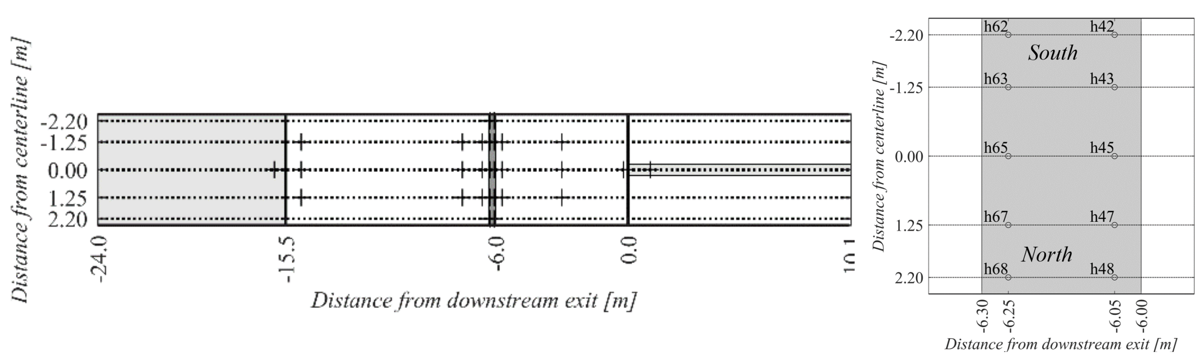

Figure 1. l.h.s: plan view of the top of the sample, the dark grey area indicates the location of the barrier, the light grey areas indicate the inflow area (from -24 m to -15.5 m) and the outflow area at the ditch (from 0 m to 10.1 m), the white area is covered by the blanket. Crosses indicate locations of PPT's; r.h.s.: close-up of the barrier, transducer row h6# is at the upstream side of the barrier, h4# is on the downstream side of the barrier.

The sand body was instrumented with pore pressure transducers (PPTs) and buoyant tracers. Visual observations and discharge measurements were recorded periodically. During the test leakage occurred and the upstream water level was lowered for repairs during the test and also prior to achieving a clear breakthrough of the pipe through the barrier. Excavations were performed after the test.

Analysis of piping progress

During laboratory experiments, the piping process occurred below a transparent cover (Akrami et al. 2019). Those tests show that the head measured inside the barrier, and the gradient over the barrier, as computed from measurements on the upstream and downstream side inside the barrier, provide a good indication of the pipe reaching the barrier, and of progression of the pipe inside the barrier. For the large-scale test, the measured heads in row h6# on the upstream side inside the barrier, the applied upstream head, and the computed gradients during the test are shown in Figure 2. These are combined with observations during the test and observations from excavation to infer how the piping process took place.

Sand boils were observed on both the north and south side inside the ditch indicating the formation of pipes. The first pipe appears to arrive at the barrier close to side #2 (the south side): all heads in the barrier fall, and the gradient at side #2 rises. The rise at side #3 shortly afterwards suggests progression of the pipe parallel to the barrier in the background sand over a limited distance. The gradient in side #2 continues to increase sharply indicating erosion continues downstream. There is a gap in the data, during which the upstream head is maintained at 4 m, and subsequently lowered for repairs. At the reduced head drop, the head indicated by h62 is ca. 5 cm higher than the head indicated by the other transducers in row 6#. This suggests that this transducer has settled by ca. 5 cm during the data gap. This suggests that erosion of the barrier created a void into which the transducer sank during the repair activities. From then the measurements of h62, and the computed gradient at side #2 are not representative.

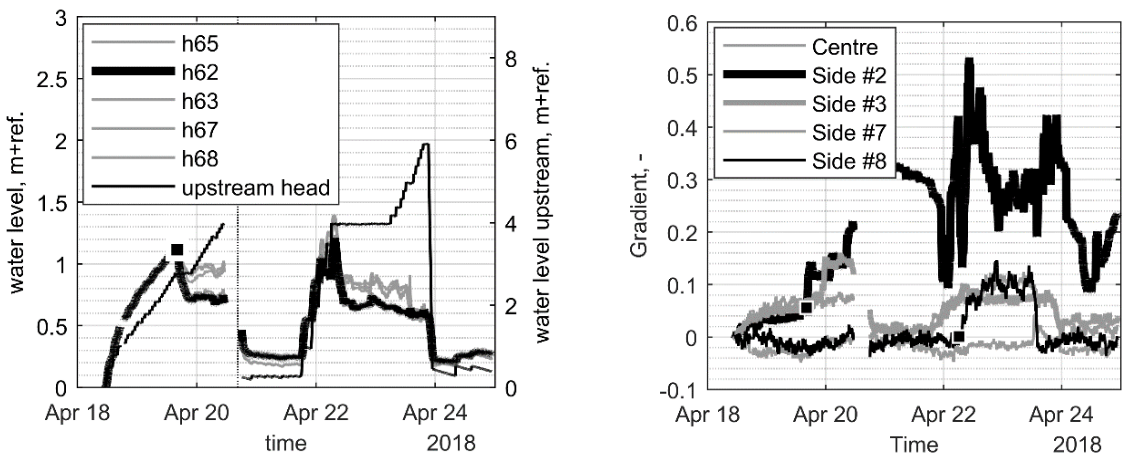

Figure 2. l.h.s.: head measured relative to the surface of the sand body in the row of transducers on the upstream side of the barrier (left hand axis) and upstream water level (right hand axis). Data is missing from 20-04, 11:10 to 18:00, but the upstream water level was maintained at 4 m until 16:30 (vertical line), then the upstream water level was reduced for repairs against leakage; r.h.s.: computed gradient over transducer pairs inside the barrier. Squares indicate times at which a pipe appears to have reached the barrier in the vicinity of h#2 and h#8.

Excavations support this interpretation, these show that a large pipe formed on the south side of the ditch and progressed to the south side of the barrier. This pipe cut into the cover layer, and was filled with barrier material. In front of the barrier, a ca. 0.4 m wide area was eroded on the south side of the model. Above the barrier itself, the cover layer had subsided over a width of ca. 0.5 m. At this location, a thin layer of fine sand was found on top of the barrier. The origin of this sand was not adequately explained. If the pipe had progressed through the barrier, a larger amount of sand would be expected. However, it cannot be ruled out that the pipe did breach the barrier, as the upstream water level was being lowered in the period that the erosion occurred. The subsidence of the blanket into the barrier may then have prevented further erosion at this location.

When the upstream water level was raised again, sand boils on both sides of the ditch were activated, but the erosion activity on the north side of the model appeared dominant. A pipe appears to reach the barrier around side #8 on 22-04 causing the gradient to increase. Gradients at side #7 and #8 start to fall on 23-04 at 12:30. This might indicate progression of the pipe in the barrier, but excavations indicate that the barrier was intact on the north side. Leakage was observed in the north side of the model at that time. Excavations revealed several pipes on the north side of the model at the ditch, these spread out into a delta towards the barrier. These pipes were much smaller than on the south side. That would be expected, as flow initially concentrated to the south pipe in the barrier, and later was distributed over several pipes. A larger pipe in the south side would also provide more space for eroded barrier material, which would account for the greater extent of damage that occurred on the south side of the model. This test indicates that the pipe did not progress parallel to the entire barrier prior to damage of the barrier, which is different from the laboratory tests. In the laboratory tests, the barrier was level with the sand body, and pipe progression into the barrier is considered to be governed by the local horizontal gradient in the barrier. In the current test, the barrier penetrates into the cover layer, therefore the barrier can crumble into the pipe downstream to a much greater extent. It appears that in this case the progression of the erosion front in the barrier is also limited by the space and transport capacity of the pipe downstream of the barrier. Settlement of the clay layer may also have hindered the continuation of the process in this experiment.

The second large-scale test was conducted with a barrier that was level with the sand body, where the resistance of the barrier would be controlled by the same mechanism as in the laboratory tests. However, results from this first test are important with regards to practical application, as the installation of a barrier that is level with the background sand is more challenging than the installation of a barrier that penetrates into the cover layer.

References

Förster, U. et al (2019), A coarse sand barrier as an alternative preventive measure against backward erosion piping. Proceedings of the XVII ECSMGE, Reykjavik.

Akrami et al. (2019), Analysis of pipe progression during backward erosion piping in the presence of a coarse sand barrier. Proceedings of EWG-IE 27th Annual Meeting, Vancouver.