EWG-10 Analysis of Pipe Progression during Backward Erosion Piping in the Presence of a Coarse Sand Barrier

S. Akrami; A. Bezuijen; V. van Beek; E. Rosenbrand; U. Förster; A. Koelewijn

Introduction

The coarse sand barrier (CSB) is considered as a promising measure to prevent failure of embankments due to backward erosion piping. In this method, a trench consisting of coarse sand is placed below the blanket layer at the downstream side of the embankment, across the possible path of the pipe to prevent development of a pipe. A pipe can progress upstream until it encounters the CSB, which prevents further progression of the pipe unless a significantly higher head drop (compared to the case without CSB) is applied. This results in a much higher safety level for the levee. The increased strength is due to the barrier's higher resistance against erosion, and the relatively high hydraulic conductivity contrast between the barrier and the background material leading to a reduction of the hydraulic load in the barrier. The feasibility of this method has been investigated in a three-phase experimental programme at Deltares consisting of small-, medium- and large-scale experiments, confirming this method as a highly effective piping inhibiting measure. This contribution presents the results of one phase of this research, the medium-scale experiments, during which several laboratory experiments were conducted. In this paper, the piping process and observations on the pipe progression in presence of a CSB are presented and analyzed to get a better insight in the principle of pipe progression with respect to different barrier materials.

Experimental study

The medium-scale experiments have been conducted in a box with inner dimensions of 1.753 m length, 0.881 m width, 0.403 m depth, seepage length of 1.385 m, exit hole diameter of 0.082 m and barrier thickness of 0.300 m. Dimensions of sand body and exit hole of the medium-scale set-up are approximately four times larger than the small-scale set-up. A detailed description of the small-scale apparatus is given in Bezuijen et al. (2018). The test procedure during small- and medium-scale experiments is the same as is described by Bezuijen et al. (2018), and Van Beek et al. (2015). During the medium-scale tests, a constant head drop is applied for 5 minutes or longer. In case of sand transport, the head is kept constant until the transport stops for several minutes, after which the head is increased again. Flow rate is measured for each head increment and head measurements are recorded, using pore pressure transducers. During these experiments, different combinations of fine sand and barrier materials are tested to investigate the effect of hydraulic conductivity contrast, amongst other factors. Due to the transparent cover layer of the set-up, the piping process can be observed. In this paper results of four medium-scale experiments are presented with combinations of Baskarp fine (B15) or Baskarp coarse (B25) sand (with d_{50} of 0.151 and 0.228 mm respectively and C_u of 1.6) as a background sand and compound materials GZB1 or GZB 2 (with d_{50} of 1.402 and 0.886 mm, and C_u of 3.7 and 2.2 respectively) as a CSB with high relative density.

Results

The observations of the experiments were similar for the four experiments. When a head difference is created, flow is concentrated towards the exit hole, resulting in local fluidization and formation of an erosion lens. Subsequently several pipes formed at the exit hole. However, for the pipe progression from the exit hole to the barrier, further head increments are required. The common procedure of backward erosion piping will continue by progression of the pipe towards upstream leading to failure. Once the pipe reaches the CSB, the flow towards the pipe is insufficient to cause the pipe to grow into the barrier due to the more stable situation. The high flow rates and lower erosion resistance in the background sand next to the pipe, compared to that of the barrier, result in pipe formation parallel to the CSB, along the entire width of the CSB. This formed a T-shape pipe as also observed in small-scale experiments with a CSB, described by Bezuijen et al. (2018). This transverse development of the pipe causes the flow to be redistributed, reducing the load on the barrier. Therefore, flow is conveyed through the barrier towards the T-shape pipe to exit through the central pipe which causes converge of flow to the centre of the model. This results in the largest depth, just downstream of the CSB in the centre of the model. Due to the collection of water to exit through the central pipe, major crumbling of the barrier at that location and some crumbling along the entire width is observed.

As the head is increased in time, the pipe enters the barrier and lengthens through the barrier in several noteworthy steps, which will be defined here, see Figure 1. After the pipe reaches the barrier and progresses along the barrier, it enters the barrier at the damage step, which is defined as the point at which one or more pipes are observed to grow few cm into the barrier. However, formation of largest depth downstream of the CSB and extensive crumbling of the barrier affected a large area inside the barrier, making the damage point difficult to register. At the next step (short growth), one or more pipes grow several cm but do not progress beyond halfway through the barrier. In some tests, after the short growth, there is another significant growth step (medium growth), which still does not cause the pipe to lengthen past halfway through the barrier. There is also lengthening of pipes in smaller amounts that is not considered as a step. At the next step (long growth), one of the pipes progressed beyond halfway through the barrier but stops before the upstream barrier interface. After this step, the pipe progressed nearby the upstream interface of the barrier and typically grew parallel to the upstream interface, inside the barrier (lateral growth/pre-failure in barrier). Subsequently, further head increase can cause the pipe to progress through the upstream interface leading to breaching of the barrier interface (failure). It should be noticed that these steps are only recognizable in the observations, and the results of pore-water pressure transducers only demonstrate when the pipe reaches the barrier, long growth and failure steps, which are therefore defined as the most significant progression steps.

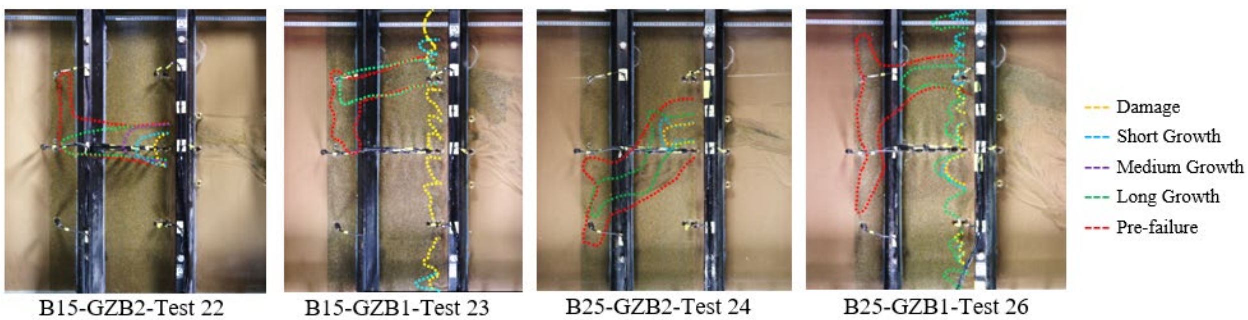

Figure 1. Pipe progression in different experiments for the various defined steps

Discussion and Conclusions

The observed process of pipe formation and progression in the barrier is sketched in different tests as shown in Figure 1. Transverse development of the pipe at the barrier interface in the background sand downstream was observed in all the experiments prior to damage. In the experiments with a stronger barrier, GZB 1, several pipes tend to form and progress inside the barrier, whereas, with a weaker barrier, GZB 2, typically one dominant pipe enters the barrier and progresses. For the experiments with B15, in all the progression steps after short growth, the pipe width is observed to be constant during lengthening of the pipe. While, in the tests with B25, widening and lengthening of the pipe occurred at the same time. Moreover, the occurrence of a long growth and subsequent pipe progression parallel to the upstream interface of the barrier inside the barrier occurred in all the experiments. As a consequence, the steps in the observations illustrate that the largest resistance to erosion can be found when the pipe has progressed into the barrier. In addition, the observations assist the numerical modelling of the experiments for the development of a prediction model.

References

Bezuijen A, Rosenbrand E, Van Beek VM, Vandenboer K (2018) Experiments for a coarse sand barrier as a measure against backward erosion piping. International conference on physical modelling in geotechnics. 17-20 July 2018. University of London, London.

Van Beek, V.M. (2015). Backward Erosion Piping Initiation and Progression. Ph.D. thesis. TU Delft, Delft.