EWG-9 Hydraulic Losses through Sand Boils: Measurements and Theory

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Extended Abstract:

Levees and dykes are often built on alluvial and deltaic foundations that consist of granular soils covered by more cohesive, fine grained deposits. This common foundation condition is highly susceptible to backward erosion piping (BEP), an internal erosion mechanism by which shallow erosion channels progress through the sand foundation under the cohesive cover layer. The probability of failure due to BEP is commonly assessed by comparing the head loss across a structure to critical values obtained from predictive methods. The total head loss at the critical pipe length can be divided into head loss occurring across the intact soil upstream of the pipe, head loss occurring in the erosion pipe, and head loss occurring over the sand boil and cover layer. While much focus has been given to the first two sources of head loss, very little attention has been given to the head loss over the sand boil and cover layer.

In 2016, high water levels were observed along the Mississippi River in the United States and the Waal River in the Netherlands. The high water levels caused sand boils to activate at both locations such that the head losses occurring over the sand boil and cover layer could be measured. Measurements of the pressure profile along the sand boil throat were made by inserting small standpipes down the sand boil throat as shown in Figure 1. The standpipe was lowered down the sand boil throat in intervals, with a measurement of the excess head (relative to the water surface above the boil) taken at each depth once the water level in the standpipe had stabilized. The measured pressure profiles, shown as excess head relative to the water surface, for each location are shown in Figure 2. In addition to measurements of the pressure profile, the flow rate, sand boil dimensions, and flow velocities in the sand boil throat were also measured. Samples of the sand in the sand boils were obtained for determining particle size distributions of the eroded material. For complete details on the measurements made, the interested reader is referred to Robbins et al. (2019).

a.  b. 

Figure 1. Photographs of head loss measurements in sand boils located along (a) the Mississippi River in the United States and (b) the Waal River in the Netherlands.

Interestingly, the head loss profiles observed in the two boils (Figure 2) were completely different. The Mississippi River sand boil had a well-defined cone in which a heavy suspension of sand was actively "boiling". As seen in Figure 2, this upper boiling sand zone caused approximately 8-9 cm of head loss, below which no additional losses were observed in the sand boil. To the contrary, the Waal River sand boil appeared to have a near constant pressure gradient from the ground surface to a depth of roughly 0.8 m. While quite different trends were observed, it was found that a physical explanation for the observed pressure profiles was provided by considering the relationship between flow velocity and suspension porosity. Baldock et al. (2004) presents a relation between the porosity of a fluid suspension under steady state conditions and the flow velocity, particle diameter, and particle density. Using these concepts, a simple hydraulic theory was developed to predict the head loss profile in the sand boils. As shown in Figure 2, the developed theory closely predicted the measured trends observed in the field. For complete details on the theoretical formulation, refer to Robbins et al. (2019).

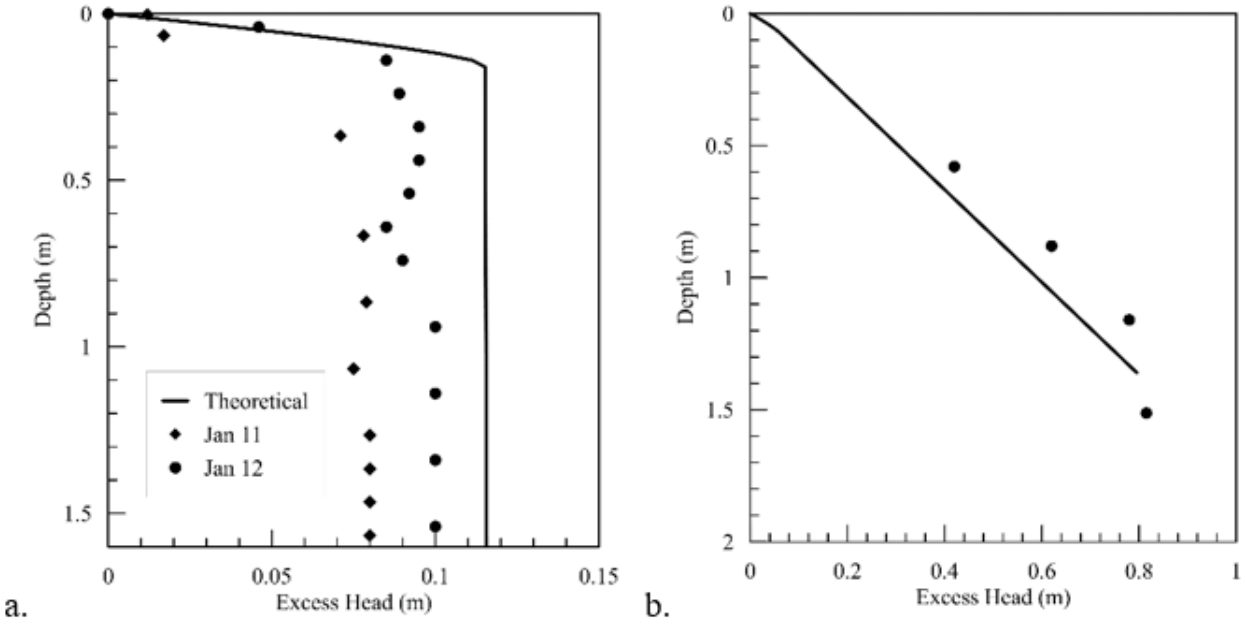

Figure 2. Measured and predicted head profiles for (a) Mississippi River and (b) Waal River sand boils.

The results of this study illustrate that the head loss across a sand boil (and associated cover layer) is a function of the flow velocity through the boil and the properties (diameter and density) of the sand grains being transported. A simple hydraulic theory was found to favourably predict the trends in the head loss profiles observed in the field. By coupling the hydraulic theory for sand boil head losses to numerical models for predicting BEP, the risk of embankment failure due to BEP can be more accurately assessed.

References

Baldock, T.E., Tomkins, M.R., Nielsen, P. & Hughes, M.G. (2004). Settling velocity of sediments at high concentrations. Coastal Engineering 51, No. 1, 91–100.

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