Understanding Piping using Pore Pressure Observations

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This presentation will focus on the use of densely spaced pore pressure observations to better understand the spatial and temporal progression of backwards erosion piping (piping). Pore pressure observations were collected during the IJkdijk 2009 experiments, conducted in the Netherlands to better understand piping as a failure mechanism and the monitoring of piping progression (Flood Control IJkdijk 2015). Patterns in pore pressure response during piping progression will first be presented by comparing the observed pore pressures to the upstream water level and to expected pore pressures. The changes in pore pressure distribution caused by spatial changes in hydraulic conductivity will then be presented followed by the introduction of inversion to back calculate changes in hydraulic conductivity from spatial pore pressure distributions. The inversion will be used on the IJkdijk 2009 spatial pore pressure observations at continuous snapshots in time. This will estimate the spatial and temporal progression of piping.

During the IJkdijk 2009 experiments, full scale embankments were designed and built to better understand backwards erosion piping progression. In the experiment, a sandy aquifer was built under a clay embankment. While the downstream water level was maintained constant, the upstream water level was incrementally increased. Please refer to the following sources for more information on the IJkdijk 2009 experiments (van Beek et al. 2010, Sellmeijer et al. 2011, van Beek 2015, Flood Control IJkdijk 2015, Parekh et al. 2016). Parekh et al. 2016 describes the temporal changes in pore pressure as piping progresses, noting that there is a point at which the pore pressure rapidly decreases followed by point at which the pore pressure stabilizes or starts to increase. Temporal changes in pore pressure are compared to expected pore pressures along a cross section in Figure 1 below. These changes in pore pressure are also observed spatially during snapshots in time. It is noted that a large decrease in pore pressure is surrounded by smaller decreases, implying that the pore pressure is affected locally and remotely of the pipe. Finite element modeling is used to confirm that pore pressure changes occur both local and remote of the pipe (Bocovich et al., 2017).

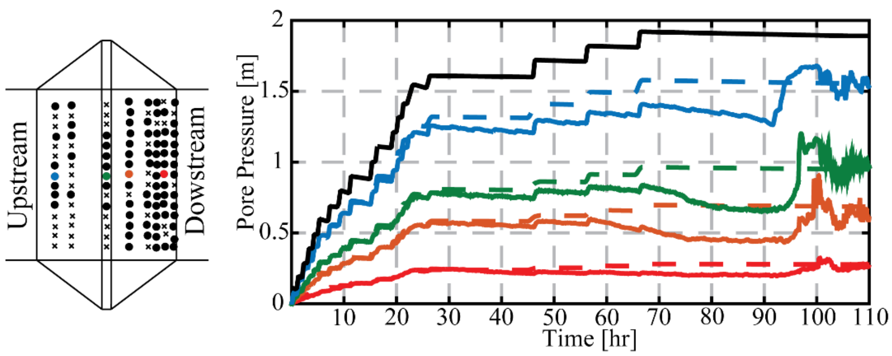

Figure 1. Observed and expected temporal changes in pore pressure from IJkdijk 2009 experiment

Finite element modeling is further used to verify the use of changes in hydraulic conductivity to simulate pore pressure changes due to piping (Bocovich et al. 2017). All modeled pore pressures are calculated using COMSOL Multiphysics, a finite element software, assuming a transient Darcy equation to model fluid flow. It is shown that modeling a high hydraulically conductive anomaly simulates similar changes as pore pressures observed in the IJkdijk 2009 experiment, however it is not a perfect simulation. This indicates that spatial changes in hydraulic conductivity should be sufficient to model the pipe, but further analysis is required to estimate spatial location of the pipe. This is done through inversion of pore pressure measurements to estimate the spatial changes in hydraulic conductivity.

Inversion is a process that minimizes an objective function dependent on the difference between the observed and estimated pore pressure and information about the changes in hydraulic conductivity. It is assumed that there is no mechanism, such as clogging or densification, to cause a decrease in hydraulic conductivity, only increases in hydraulic conductivity relative to the initial aquifer hydraulic conductivity of $1.4*10^{-4}$ m/s are assumed to occur. It is also assumed that piping only occurs at the top layer of the aquifer, and the hydraulic conductivity below this top layer remains constant, as suggested through observations of small and medium scale experiments (van Beek 2015). First synthetic models created in COMSOL are used to better understand the capabilities and limitations of inversion using pore pressure to estimate hydraulic conductivity. It should be noted that this is a highly nonlinear and non-unique inversion problem. The recreation of one of these anomalies is shown in Figure 2, below.

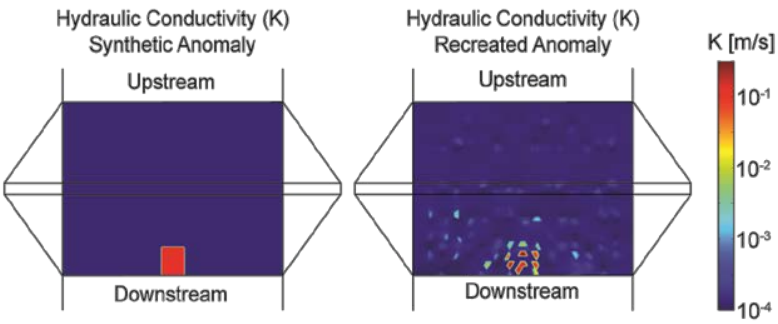

Figure 2. Example of a modeled anomaly to determine inversion capabilities with recreated, or estimated,anomaly.

The inversion optimization equation and algorithm are then used to estimate spatial changes in hydraulic conductivity using observed pore pressures during the IJkdijk 2009 experiment. The inversion is performed to estimate 2D spatial changes in hydraulic conductivity during consecutive snapshots in time to develop both a temporal and spatial change in hydraulic conductivity and to gain a better understand of spatial and temporal progression of piping.

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