Modeling Internal Erosion Processes in Soil Pipes

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Introduction: Subsurface erosion through soil pipes on the land can lead to significant changes in landscape morphology and slope stability. The erosion produces gullies and can also lead to landslides. Subsurface erosion in man-made structure features such as dams and flood levees can be devastating, resulting in significant property damage and loss of life. Examples of internally eroded features include a collapsed parking lot surface in Mississippi caused by erosion beneath the pavement (Figure 1a), and gully formation in a watershed (Figure 1b).

(a) (b)

Figure 1. Examples of soil structural changes caused by internal erosion. a. Collapsed pavement surface, Meridian, MS. Photo by Jason Hartwig, CNN; b. Gullies caused by erosion of soil pipes in Goodwin Creek watershed, MS.

Methods: The analysis is based on the solution to the governing equations for turbulent flow in a pipe to derive the distribution of water pressure and velocity, and the convection-dispersion equation to derive the erosion of the pipe wall and the transport of detached soil particles. The k-w model for turbulence was selected. The pipe wall erosion rate (kg/m^2-s) is given by the 'excess shear stress equation' (Wilson, 2011) expressed as $q = k(\tau_w - \tau_c)$, where k is the empirical erodibility coefficient (s/m), τ_w is the wall shear stress calculated from the turbulent velocity profile, and τ_c is the critical shear stress required to initiate erosion. This expression is applied along the wall of the soil pipe to produce the source of sediment transported in the soil pipe.

Results: Wilson (2011) conducted a number of experiments in a laboratory setting in which a soil pipe was constructed into a soil tank 100 cm wide, 20 cm deep, and 140 cm long. The soil pipe was constructed along the long dimension of the tank. A reservoir of water was applied at the upstream open end of the pipe so that full pipe flow would occur. A schematic of the tank is shown in Figure 2. One of the soils tested belongs to the soil series Providence, which is a silt loam. For that soil estimates of the critical shear stress and the erodibility coefficient varied.

For the case considered here the soil pipe was set to be 1 m long and 0.05 m in diameter. The erosion parameters were set to k = 0.009 s/m, and τ_c = 0.005 Pa, values reported by Wilson (2011) for one of the experiments. The mean velocity of flow entering the soil pipe was set to 0.8 m/s. The mechanical dispersion for transported sediment caused by the turbulence of the flow (R_e=40,000) was set to 5×10^{-4} m^2/s.

The velocity distribution is illustrated in Figure 3, and the resulting erosion of the pipe wall leads to the transported sediment concentration distribution shown in Figure 4.

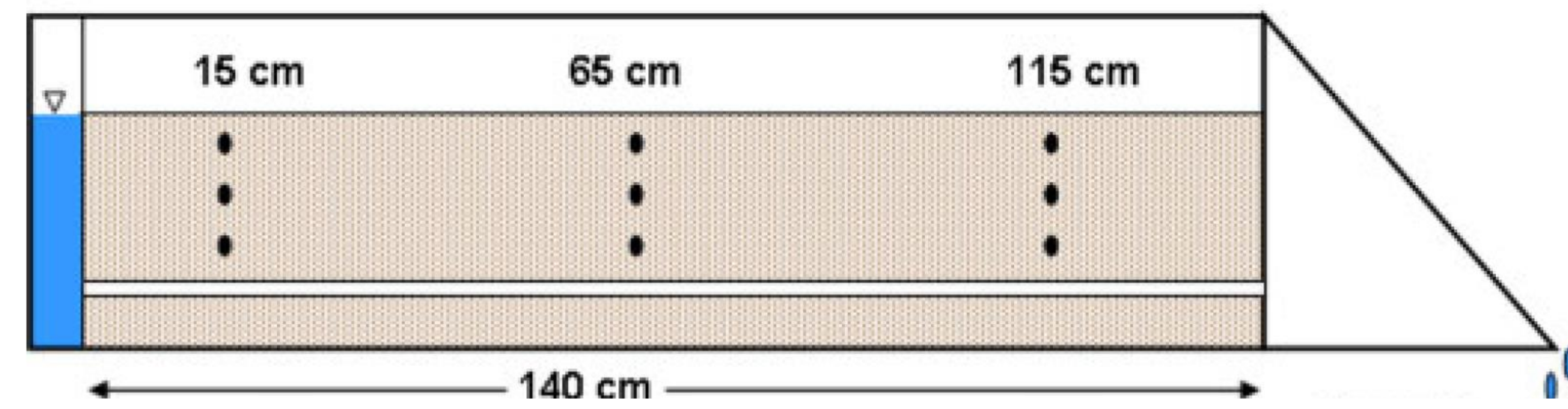

Figure 2. Illustration of the experimental setup used by Wilson (2011) for studying the erosion of soil pipes. The black ovals are locations of tensiometers used to measure soil water pressure.

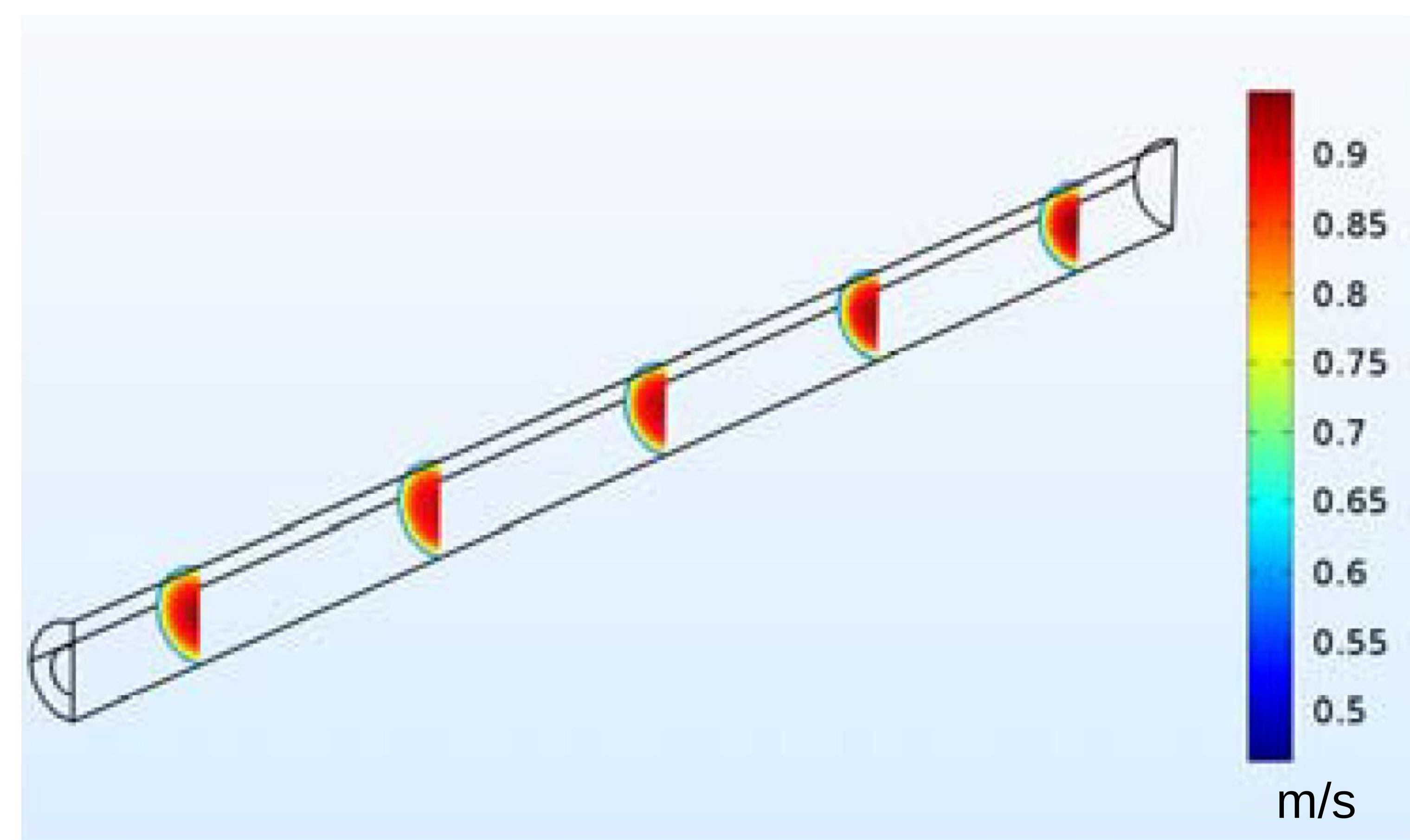

Figure 3. Illustration of the velocity distribution in the soil pipe. The velocity is given in m/s. Note that only the half-plane of the soil pipe is shown due to imposed symmetry.

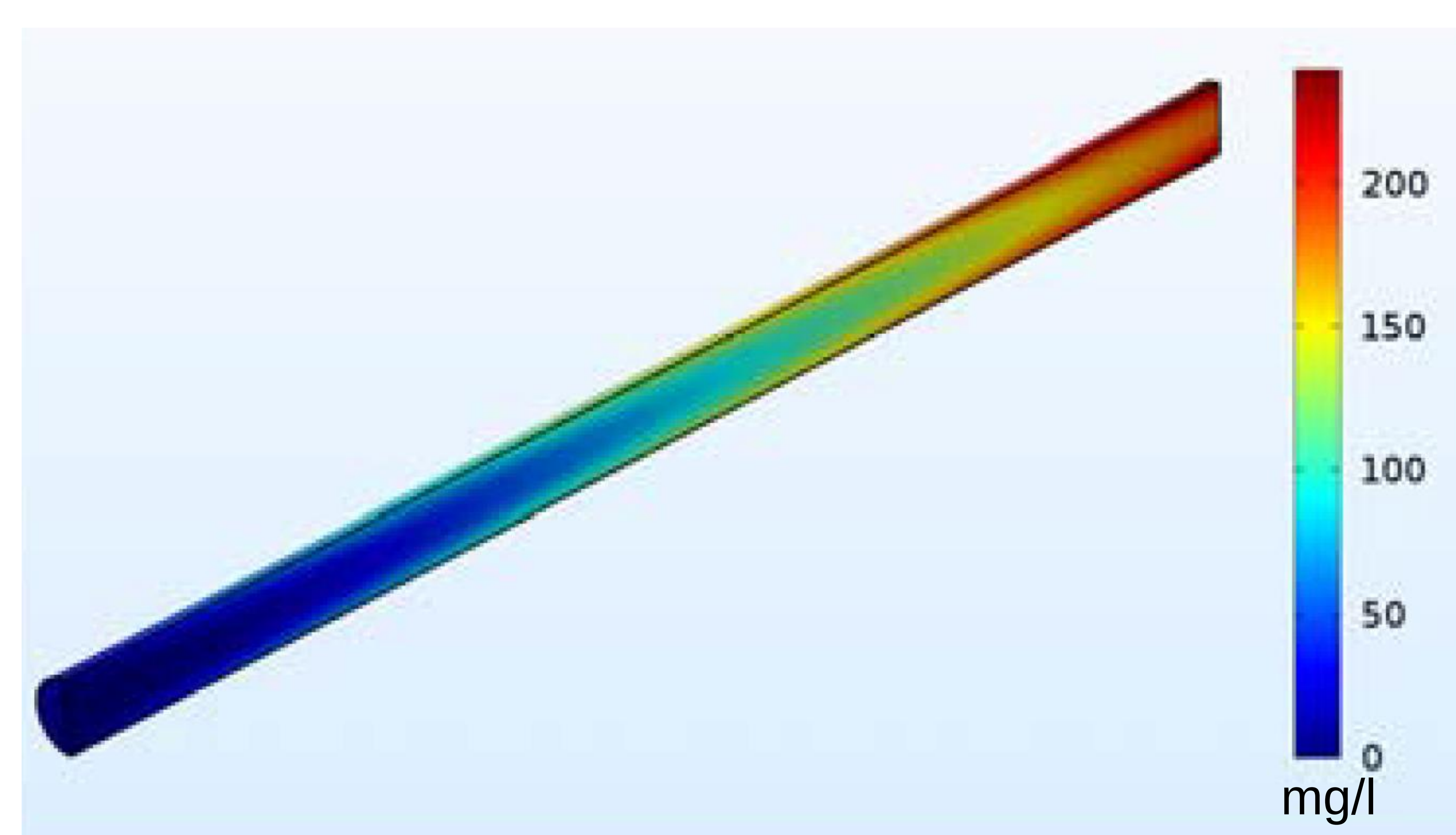

Figure 4. Illustration of the distribution of sediment concentration in the soil pipe. The concentration is given in mg/l. Note that only the half-plane of the soil pipe is shown due to imposed symmetry.

The shearing on the soil pipe wall erodes the wall surface, and the transported eroded particles are mechanically dispersed by turbulence transversely to the flow. For the case shown here the flux of sediment from the soil pipe is 0.084 kg/s-m^2, a value of the same order as that measured by Wilson (2011).

Conclusion and Future Work: The high velocity of water flow in the soil pipe leads to erosion of the pipe wall. This study did not account for the change in pipe geometry resulting from the erosion. In the Wilson (2011) experiment the soil pipe increased in diameter seven-fold due to the erosion. To model this will require a dynamic geometry model. We intend to extend our work to this in future efforts.

Reference:

Wilson, G.V., 2011. Understanding soil-pipe flow and its role in ephemeral gully erosion, Hydrological Processes, 25: 2354–2364