Fall 2010

Stability of streambanks subjected to highly variable streamflows: the Osage River Downstream of Bagnell Dam

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along a planar slip surface, and the failed block slides toward the toe of the bank before toppling into the channel [6]. It is common for deep tension cracks to appear before a planar failure occurs [12]. An example of a planar or slab-type failure is provided in Figure 2.1.

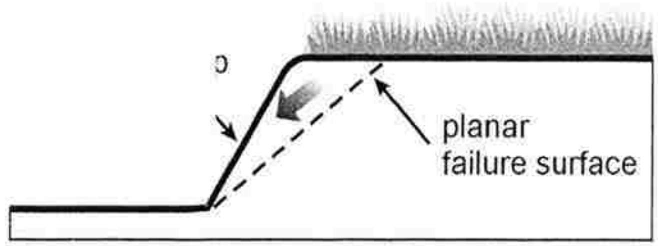

Figure 2.1 Example of Planar Bank Failure [3]

Rotational failures occur along a slightly curved slip surface, and are prevalent in streambanks with large bank heights and mild slopes. Generally a bank with a bank angle of less than 60 degrees is classified as mildly-sloped. The appearance of vertical tension cracks prior to a rotational failure is common. The failure block typically rotates toward the bank while it slides downward [6,12]. An example of a rotational failure is provided in Figure 2.2.

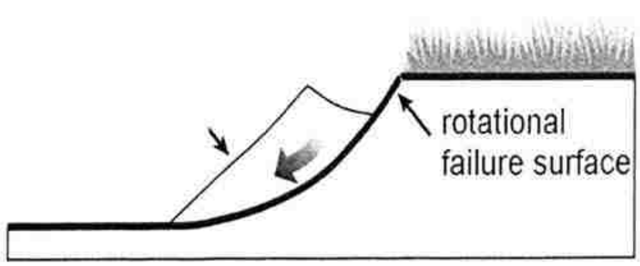

Figure 2.2 Example of Rotational Bank Failure [3]

Cantilever failures are typically seen in streambanks that are composed of a layer of noncohesive material underlying an upper layer of cohesive material. Cantilever, or overhanging, banks form when the bank toe material is noncohesive and is significantly eroded, resulting in a loss of the material that had been supporting the cohesive layer. This loss of material is also referred to as undercutting. When the magnitude of the downward force of gravity on the overhanging bank exceeds its strength, a portion of the bank will break off and fall downward into the eroded area [7]. An example of a cantilever failure is provided in Figure 2.3.

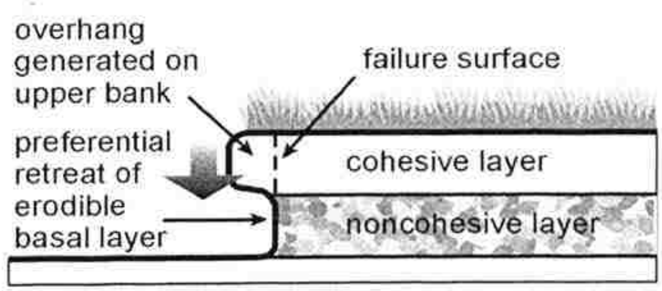

Figure 2.3 Example of Cantilever Bank Failure [3]

A piping failure may occur when the streambank is saturated, and water exfiltrates from the bank into the channel. A piping condition exists when the water carries with it soil particles as it flows toward the river. If the exfiltrating flow is significant enough and removes a sufficient amount of soil, the bank may fail [7].

Ultimately, failure of a streambank occurs when the driving forces downward are greater than resisting forces within the bank. The various forces acting on the failure block include its weight, the weight of the water in the channel acting downward on the block, the hydrostatic force applied by the water in the channel, the hydrostatic force of water in the tension cracks, if they exist, the force of water exfiltrating from the bank, the shear force resisting all downward forces, and the normal force along the failure surface [6].

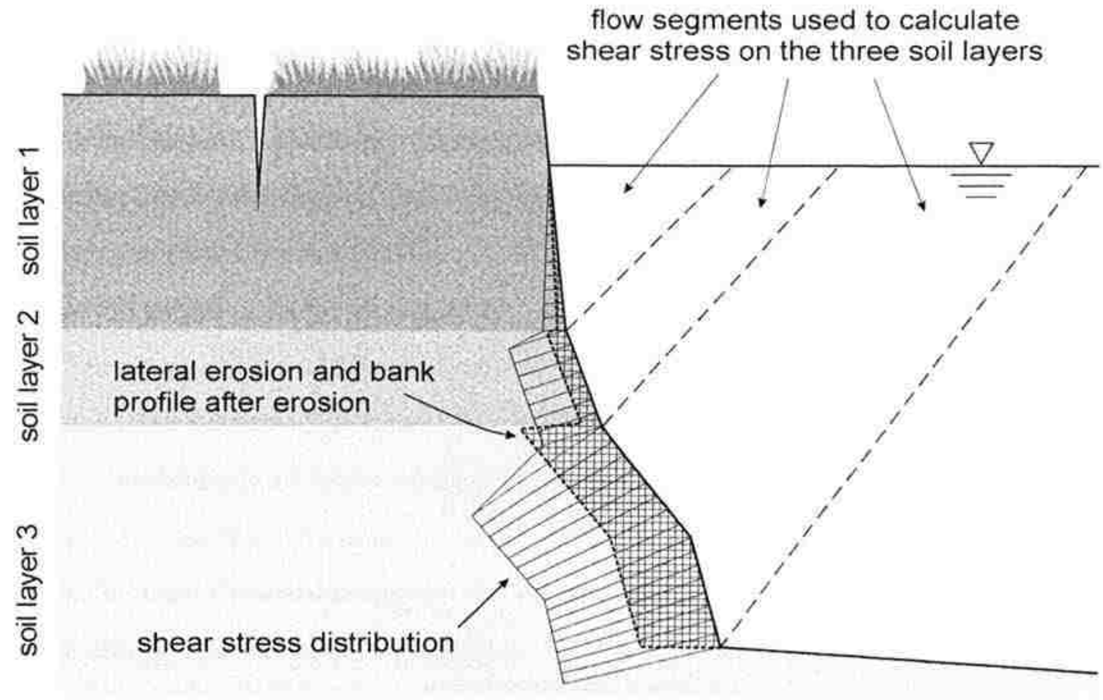

Figure 3.1 Example of Shear Stress Distribution in BSTEM [3]

In this equation, τ is the shear strength of the soil, c' is the effective cohesion of the soil, σ is the normal stress on the failure block, u_a is the pore air pressure, φ' is the friction angle in terms of effective stress, u_w is the pore water pressure, and φ^b is the angle that represents the increase in apparent cohesion due to negative pore pressures. The angles are measured in degrees in this equation, and all other variables are measured in kPa [8,13].

The longer the given flow elevation is sustained within a cross-section, the greater the amount of material that will be eroded. An area of eroded material is determined for each cross-section; this can be converted to a volume of eroded material by multiplying by the reach length. Once the eroded profile for the given flow elevation and duration has been determined, the FS for a planar failure of the bank is computed using the limit equilibrium method.

The pore pressures within a bank are a crucial factor in the determination of the FS. As discussed previously, positive and negative pore pressures play a large role in the overall stability of a streambank. In BSTEM, if pore pressures are not defined for each soil layer and the user simply provides a depth to the phreatic surface, pore pressures are calculated for each layer. The pore pressures below the phreatic surface are calculated assuming hydrostatic conditions, thus the pore pressure is equal to the unit weight of water multiplied by the head of the water table above the centerline of each soil layer. Pore pressures above the water table are calculated the same way; however the pore pressures are negative rather than positive, and represent matric suction.

The program has a built-in algorithm that iterates over multiple failure scenarios to determine the scenario that results in the lowest FS. The iterations cover many different combinations of shear emergence elevations and shear angles. The shear emergence elevation is the elevation on the bank where the failure plane will intersect the cross-section face. The shear angle is the angle of the failure plane. Figure 3.2 illustrates the shear emergence elevation and angle.

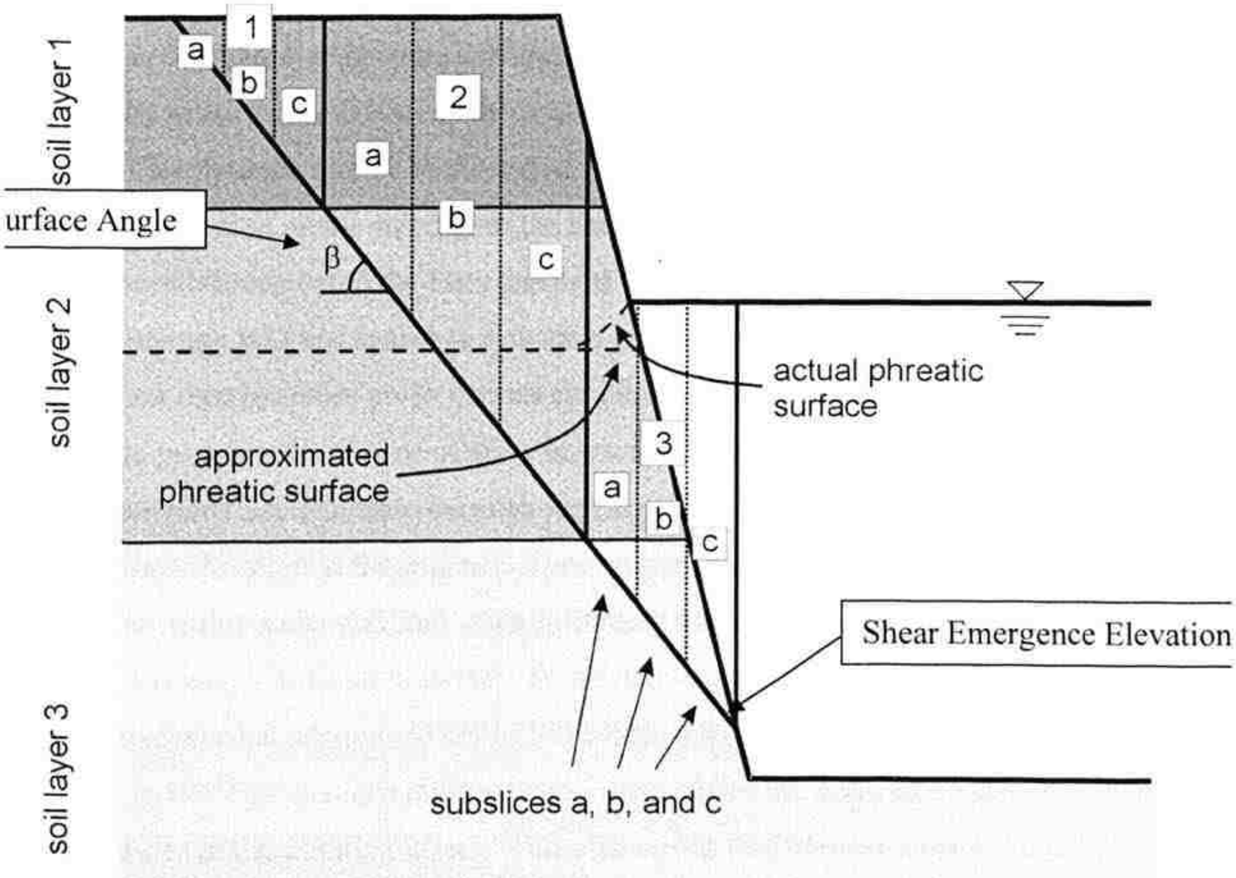

Figure 3.2 Figure Showing Shear Emergence Elevation and Shear Surface Angle [3]

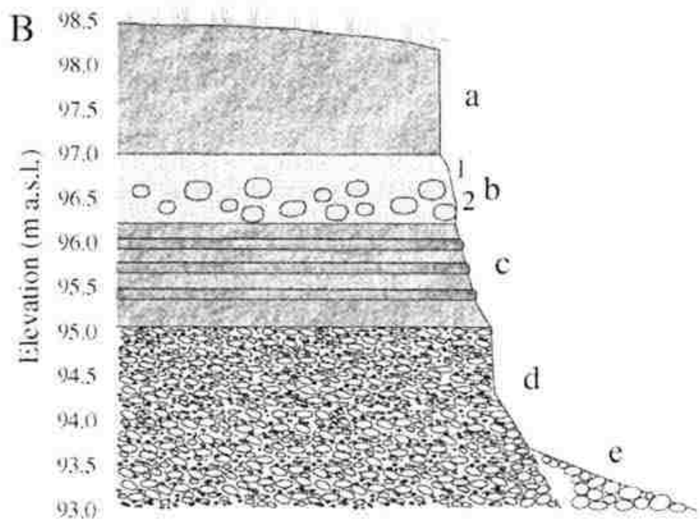

Figure 5.1 Bank Stratigraphy [13]

thick, and is comprised of silty sand, with silt sublayers throughout the upper and central portions of the layer. Layer *d* is a 2.0 m thick layer of packed and imbricated sand, gravel and cobbles. Layer *e* is the bank toe, and the soil type in this layer is described as loosely packed gravel and cobbles.

The geotechnical properties for layers *a* through *c* were determined through a series of triaxial tests and borehole shear tests. The values reported for these layers are provided in Table 5.1, and were used unchanged in the BSTEM model. In cases where the triaxial tests and borehole shear tests resulted in slightly different parameter values, the values were averaged before being used as input.

Table 5.1 Geotechnical Properties

Layer	φ' (degrees)	c' (kPa)	γ (kN/m3)	φ_b (degrees)
a	34	2	17.7	28
b	37.5	1	18.3	32
c	34.5	2	17.8	26

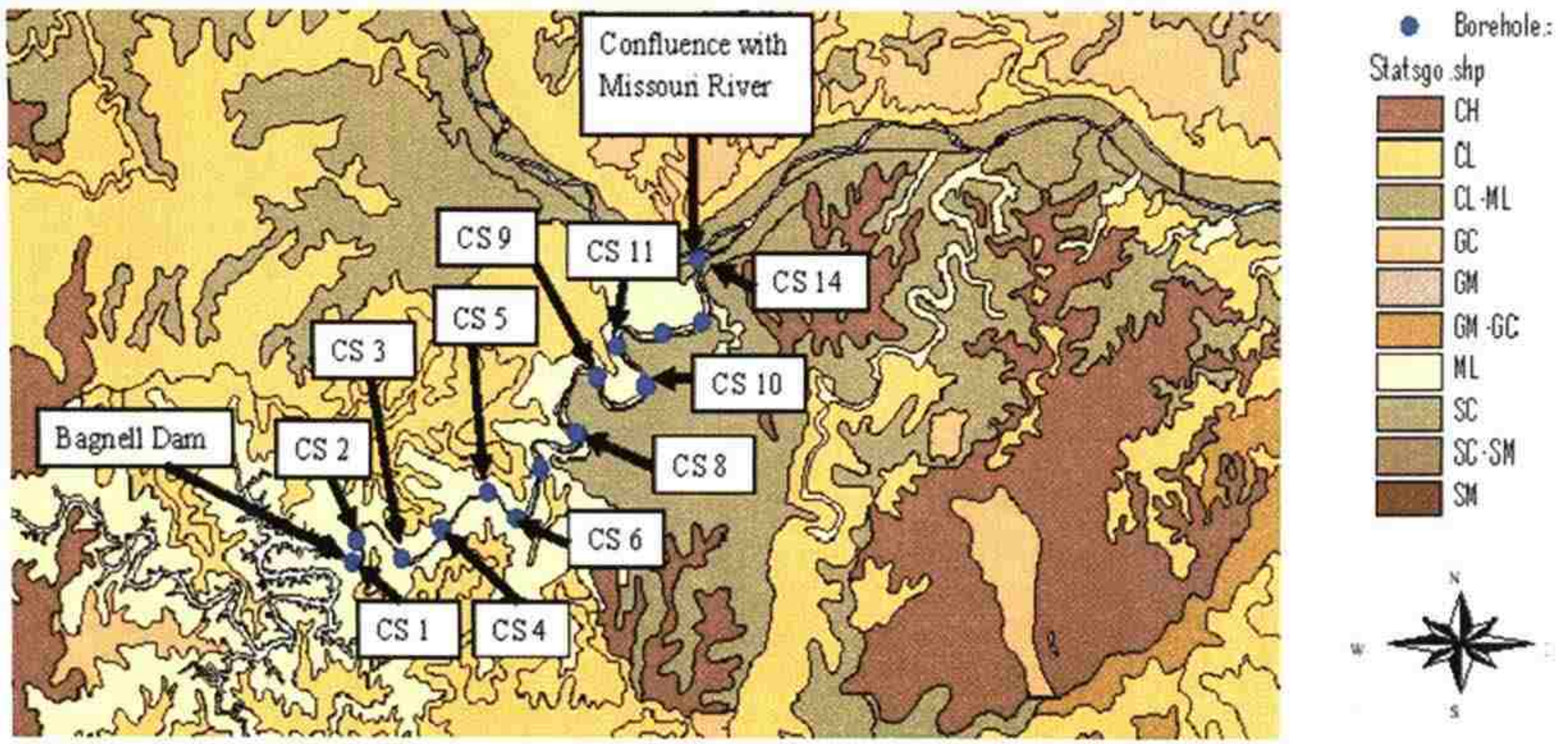

Figure A.1 Map Showing Cross-Section Locations [2]