Bank-Stability and Toe-Erosion Model

Andrew Simon, Robert Thomas, Andrea Curini and Natasha Bankhead
USDA-ARS National Sedimentation Laboratory, Oxford, MS
andrew.simon@ars.usda.gov

Model Structure

Web Address
http://www.ars.usda.gov/Research/docs.htm?docid=5044

Model Structure (cont’d)
- **Input Geometry page**: Enter coordinates for bank profile, soil layer thickness, and flow parameters.
- **Bank Material page**: Enter bank-material properties (geotechnical and hydraulic)
- **Bank Vegetation and Protection page**: Run root reinforcement (RipRoot) model and to input default values of bank and toe protection.
- **Bank Model Output page**: Enter water-table depth and obtain results.

Model Structure (cont’d)
- **Toe Model Output page**: Run shear stress macro and obtain toe-erosion results.
- **Unit Converter page**: Imperial (English) to metric units

2-D wedge- and cantilever-failures
- **Tension cracks**
- Search routine for failures
- Hydraulic toe erosion
- Increased shear in meanders
- Accounts for grain roughness
- Complex bank geometries
- Positive and negative pore-water pressures
- Confining pressure from flow
- Layers of different strength
- Vegetation effects: RipRoot

Inputs: \( \gamma_s \), \( c' \), \( \phi' \), \( h \), \( u_w \), \( k \), \( \tau_c \)

Bank-Stability Model Version 5.4
Modeling Steps

- Model the current bank profile by first evaluating the effect of hydraulic erosion at the bank toe.
- Take the resulting new profile and run this in the bank-stability model to see if the eroded bank is stable.
- Investigate the effects of water-table elevation, stage, tension cracks, vegetation, and toe protection.

Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B for bank geometry and input geometry data. For this first example select Option B.
Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”...to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness

Enter Bank Layer Thickness: Detail

Layer 5 should (but does not have to) end at or below the base of the bank toe. Therefore, the basal elevation of layer 5 should be equal to or less than the elevation of point V (base of bank toe) if Option A is selected or 0 (zero) if Option B is selected.

For this example, enter 1m thicknesses for all five layers

Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”...to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter bank-layer thickness
6. Enter channel and flow thickness, and check cross section inputs:
   a. View Geometry
   b. Bank Geometry Macro
Check Cross Section Inputs: I (View Geometry)

Check Cross Section Inputs: II (Geometry Macro)

Check Geometry and Flow Level

1. Model will direct you to the Bank Material Level
2. Click on Bank Model Output sheet

Channel and Flow Parameters

Channel and Flow Parameters: Detail

Channel and flow parameters

100  Input reach length (m)
0.0035  Input reach slope (m/m)
2.00  Input elevation of flow (m)
12  Input duration of flow (hrs)

Input the above values for this example
Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet

Select Bank Materials by Layer

Select material types (or select “own data” and add values below)

<table>
<thead>
<tr>
<th>Bank Material</th>
<th>Bank Toe Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own data</td>
<td>Own data</td>
</tr>
</tbody>
</table>

Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”... to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)

Bank Model Output: No Tension Crack

Set water-table depth to 3.0 m

Bank is Unstable

Click “Run Bank-Stability Model”

Profile Exported into Option A

(Model Directs you to “Input Geometry” sheet)

Check profile (View Geometry) and select top of bank toe

For this case select Point Q

Either: (1) Select shear emergence elevation and shear angle or (2) leave blank for search routine

Data for Pore-Water Pressure

In “Bank Model Output” worksheet

In this case select option to use water table depth, and enter a value of 3.0m below the bank top

Bank Model Output: Specific Results

Failure plane from search routine

Failure dimensions (loading)

Save your file under a different name
Operational Steps

1. Open Excel file “BSTEM-5.4”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”
11. Save file under different name

How can you make this bank more stable or more unstable?

Try experimenting with the following parameters to get a feel for the model:

- Water surface elevation (Input Geometry Sheet)
- Shear angle (Input Geometry Sheet)
- Water table height (Bank Model Output sheet)
- Bank material types (Bank Model Output sheet)

We’ll work with the effects of vegetation later…

Distinguish Between Hydraulic and Geotechnical Bank Protection

- Hydraulic protection reduces the available boundary hydraulic shear stress and increases the shear resistance to particle detachment
- Geotechnical protection increases soil shear strength and decreases driving forces

Operational Steps

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4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”
11. Save file under different name
12. Open file and Click on “Bank Vegetation and Protection” sheet

Incorporating Vegetation Effects and other Protection

Root Reinforcement: RipRoot (from measured data)

Bank and Toe Protection (from literature values)
**Operational Steps**

1. Open Excel file “BSTEM-5.4”
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4. Select EITHER Option A or Option B to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”
11. Save file under different name
12. Open file and Click on “Bank Vegetation and Protection” sheet
13. Click “Run Root-Reinforcement Model”

**Root Reinforcement using RipRoot**

**Simple Case: 1 species**

1. Select “Meadow, Wet”
2. Enter age and percent contribution to stand
3. Click when finished

**Root Reinforcement using RipRoot**

**Root Reinforcement using RipRoot**

**Root Reinforcement using RipRoot**

Still Unstable with Vegetation
### Channel and Flow Parameters

1. **Input Reach Slope (m/m)**
   - 0.0035
2. **Input Elevation of Flow (m)**
   - 2.50
3. **Input Reach Length (m)**
   - 100
4. **Input Duration of Flow (hrs)**
   - 24

### Bank-Toe Protection

1. Re-open BSTEM-5.4.xls
2. Select “Input Geometry sheet”
3. Select Option B
4. Input these values:
   - Bank height (m)
   - Bank angle (°)
   - Bank toe length (m)
   - Bank toe angle (°)
5. Input channel and flow parameters
6. Click “Run Bank Geometry Macro”
7. Open “Bank Material” sheet
8. Select “Moderate silt” for all layers
9. Select “Toe Model Output” sheet
10. Click “Run Toe-Erosion Model”
11. Select “Bank Material” sheet and select “Boulders” for layer 5 and toe material
12. Select “Toe Model Output” sheet and click “Run Toe-Erosion Model”

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### Further Simulations... Tension Cracks

1. Click “Run Bank Stability Model”
2. Click “Yes” for tension crack
3. Enter depth of tension crack
![Image](https://via.placeholder.com/150)

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### Toe Erosion without Protection

1. Re-open BSTEM-5.4.xls
2. Select “Input Geometry sheet”
3. Select Option B
4. Input these values:
   - Input bank height (m)
   - Input bank angle (°)
   - Input bank toe length (m)
   - Input bank toe angle (°)
5. Input channel and flow parameters
6. Click “Run Bank Geometry Macro”
7. Open “Bank Material” sheet
8. Select “Moderate silt” for all layers
9. Select “Toe Model Output” sheet
10. Click “Run Toe-Erosion Model”
11. Select “Bank Material” sheet and select “Boulders” for layer 5 and toe material
12. Select “Toe Model Output” sheet and click “Run Toe-Erosion Model”

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### Bank-Toe Protection

- Enter a bank height and angle, and shear will generate a bank profile.

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### Results with Tension Crack

![Image](https://via.placeholder.com/150)

- $F_s = 0.84$
- Bank is unstable again due to loss of strength along upper part of failure plane.

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### Conditionally Stable with Lower Water Table

![Image](https://via.placeholder.com/150)

- Change water-table depth to 3.75 m
- Revised pore-water pressures and $F_s$ calculated automatically

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### Toe Erosion = 0.66 m²

![Image](https://via.placeholder.com/150)

- We often use ½ the value or observed vertical-face heights

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### Further Simulations... Tension Cracks

- Change water-table depth to 3.75 m
- Maximum based on cohesion and unit weight
- We often use ½ the value or observed vertical-face heights

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### Bank-Toe Protection

- Enter a bank height and angle, and shear will generate a bank profile.

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### Conditionally Stable with Lower Water Table

- Change water-table depth to 3.75 m
- Revised pore-water pressures and $F_s$ calculated automatically

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### Toe Erosion = 0.66 m²

- We often use ½ the value or observed vertical-face heights
**Enhanced Shear Stress in Bend**

1. Return to “Bank-Material Sheet”
2. Change Layer 5 and Toe Material back to “Moderate Silt”
3. Go to “Toe-Model Output Sheet”
4. Click “Account for Stream Curvature” and then click “Run Toe-Erosion Model”
5. Select material types (or select “own data” and add values below)

```
Layer 1                   Layer 2      Layer 3  Layer 4      Layer 5
Type                  Description Mean grain size, D50  (m)  Friction angle, \(\phi\) (degrees) Cohesion, \(c'\) (kPa) Saturated unit weight, \(\gamma_s\) (kN/m³) Chemical concentration, \(C\) (kg/kg)
1                      Boulders                  0.512                        42.0                0.0 18.0 15.0               -
2                      Cobbles                  0.128                        42.0                0.0 20.0 15.0               -
3                      Gravel                   0.0113                       36.0                0.0 18.0 15.0               -
4                      Angular sand        0.00035                       36.0                0.0 18.0 15.0               -
5                      Rounded sand         0.00035                       27.0                0.0 18.0 15.0               -
6                      Silt                      0.0001                      18.0                0.0 18.0 15.0               -
```

6. Click “Run Toe-Erosion Model” (straight channel)

**Enhanced Shear Stress in Bend**

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3                      Gravel                   0.0113                       36.0                0.0 18.0 15.0               -
4                      Angular sand        0.00035                       36.0                0.0 18.0 15.0               -
5                      Rounded sand         0.00035                       27.0                0.0 18.0 15.0               -
6                      Silt                      0.0001                      18.0                0.0 18.0 15.0               -
```

6. Click “Run Toe-Erosion Model” (straight channel)
Enhanced Shear Stress in Bend

In bend: $\tau_{o} = 75.3$ Pa; Eroded area = 0.964 m$^2$
In straight reach: $\tau_{o} = 51.1$ Pa; Eroded area = 0.655 m$^2$

Enhanced Shear Stress in Bend Coupled with Reduced Stress from Grain Roughness

1. Return to “Bank-Material Sheet”
2. Change Layer 5 and Toe Material back to “Moderate Silt”
3. Go to “Toe-Model Output Sheet”
4. Click “Run Toe-Erosion Model” (straight channel)
5. Click “Account for Stream Curvature” and then click “Run Toe-Erosion Model”
6. Enter “Channel Width at Entered Flow Depth”, “Radius of Curvature” and “Manning’s ‘n’ at Entered Flow Depth”
7. Click “Effective Stress Acting on Each Grain” and the click “Run Toe-Erosion Model”

Enhanced Shear Stress in Bend Coupled with Reduced Stress from Grain Roughness

Average applied boundary shear stress 75.270 Pa
Maximum Lateral Retreat 36.525 cm
Eroded Area - Bank 0.369 m$^2$
Eroded Area - Bank Toe 0.595 m$^2$
Eroded Area - Bed 0.000 m$^2$
Eroded Area - Total 0.964 m$^2$

Export New (Eroded) Profile into Model

Enhanced Shear Stress in Bend Coupled with Reduced Stress from Grain Roughness

In bend: $\tau_{o} = 15.0$ Pa; Eroded area = 0.158 m$^2$

Good Job!!!