Chapter 16

Table of Contents

BANK FAILURE CALCULATIONS IN HEC-6T

by

William A. Thomas [1]

Introduction

Several mechanisms are known to cause channel banks to fail: 1) bed degradation, 2) an increase in the channel forming discharge, 3) the down-valley movement of the meander pattern, 4) an increase in the amplitude of the meander pattern due to the growth of the point bar deposit, 5) poor, or lack of, alignment of the current pattern resulting from a natural or constructed change in planform, 6) local bank failures due to local runoff, and 7) piping or sapping through the soil column. Some of these mechanisms cause the channel to become wider. Others simply cause the banks to migrate down the valley or across the floodplain while keeping the channel width unchanged.

The first of these calculations to be added to HEC-6T was bank failure due to bed degradation. The purpose is to predict the width and bed elevation of channel erosion in a reservoir deposit following the removal of a dam. This bank failure calculation was made possible by

-utilizing the capability in HEC-6T to make the width of erosion smaller than the width deposition at a cross section,

-establishing the channel bottom width by applying river morphology principles, and

-coding a sufficient number of coordinate points (Station, Elevation) into the initial cross section to allow the channel width to increase by increments as bed degradation causes the banks to fail.

---

[1] This document was prepared by William A Thomas for MBH Software, Inc. It is part of the documentation for computer program, "Sedimentation in Stream Networks" (HEC-6T), and is the property of MBH Software, Inc. P.O. Box 264, Clinton, Mississippi, 39060. Copyright (C) 2002. All rights are reserved.

{Note: HEC-6T permits modeling the cross section in two zones: Cross Section Zone 1 is the portion shaped by both erosion and deposition whereas Cross Section Zone 2 is deposition only. Cross Section Zone 2 is coded on the H, HD, HI, or HL-Record. Zone 1 is coded on the HE-Record. The width of Zone 1 should be calculated using river morphology principles. The key to modeling channel widening is to determine and code the bottom width, not the top width, of Cross Section Zone 1. The sedimentation process of erosion will be limited to the HE-Record width. Soil mechanics processes are calculated in Cross Section Zones 1 and 2}

The modeling techniques are discussed in the document, "Dam Removal Studies with HEC-6T" by William A. Thomas. [2]

The bank failure calculation due to degradation was added to Version V5.13.19 in March 2002. The default angle of internal friction was set to 30 degrees. The default critical safety factor was set to 1.75. This combination produces a stable slope of 1::3. These values cannot be modified in Version V5.13.19. Starting with Version V5.13.20 dated February 2003, the friction angle and safety factor values can be input using the new CW-Record.

Approach

There are two fundamental approaches to calculating the failure of channel banks. One is the soil mechanics approach which utilizes the physics of slope stability to calculate stable bank slopes. The other is a quasi-physical approach which calculates stable bank slopes from the measured cross sections. There are advantages and disadvantages to each. The advantage of the soil mechanics approach is that the physical properties of the soils are used to calculate the stable slope. The disadvantage is the large amount of field data that is required to make the calculation. The advantage of the quasi-physical approach is that the cross sections provide all of the data that is needed to make the calculations. The disadvantage is that it will not adjust the critical bank slopes if the bank line migrates into materials whose properties are different from those of the surveyed cross sections. If bank materials change, the stable bank height-bank angle values which were calculated from the surveyed cross sections may not accurately reflect the stability of the new bank materials.

---

[2] Thomas, William A. January 15, 2003. "Dam Removal Studies with HEC-6T." MBH Software, Inc.

HEC-6T uses the quasi-physical approach. This decision was made because of the difficulty of obtaining adequate field data for the soils mechanics based approach.

Conceptual Model

This mathematical model for bank failure was formulated from the following concepts.

1) The default critical slope for stability is 1::3. The slope angle, β, is 18.26 degrees.

2) A cross section is composed of panels where a panel is the element between two consecutive (Station, Elevation) points, Figure 1.

3) The surveyed slope of each panel is calculated from the station-elevation points. If the panel-slope is steeper than the default critical slope for stability, the surveyed value is adopted as the critical slope for stability. If the surveyed panel-slope is flatter than the default critical slope for stability, the surveyed panel-slope is replaced with the default critical slope.

4) These critical, panel-slopes are not changed during the simulation.

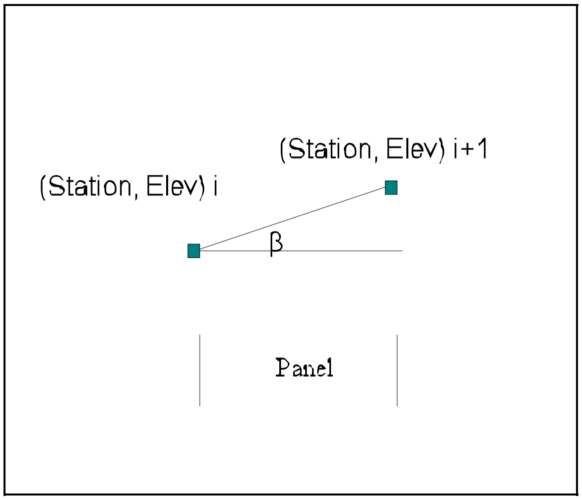


Figure 1. **A Cross Section Panel**

5) During a simulation, HEC6T calculates new cross section elevations at the end of each computational time step. When the cross section is degrading, new panel-slopes are calculated.

6) If a new panel-slope exceeds the critical value for that panel, HEC6T will fail that panel of the cross section. The failure of one panel may cause adjacent panel-slopes to become

unstable. Therefore, testing and adjustments continue until all panels in the new cross section are stable.

{Note: HEC-6T does not insert cross section (station, elevation) points when a panel fails. Stability calculations are based on the points coded in the input data file. Therefore, place cross section stations sufficiently close together so the shape of the calculated cross section can mimic the prototype when the banks fail. For example, the spacing across the zone where the banks are expected to fail could be approximately the width of observed failure blocks. Another idea is to space points at three to five feet apart. In narrow channels, a distance of ten percent of the bottom width may be reasonable for coding the cross section (station, elevation) points. Precision is not the issue. The objective is to allow the model to capture the trend and pattern of bank failure observed in the prototype.}

7) The failed volume of sediment is calculated and added to the Bed Sediment Reservoir. It is assigned the same gradation as the bed and is mixed with the active layer. It will be available for erosion during the next water discharge event.

8) A vertical slope is flagged as a non-eroding bank.

Theoretical Development

The following relationships are based on the application of analytical geometry and engineering logic. The slope of the banks are calculated from the original cross section coordinates when the cross section is read from the input data file. The equation is:

$$dydxl(i,j) = \left| \frac{y(i+1) - y(i)}{x(i+1) - x(i)} \right| \qquad \textbf{(16-1)}$$

Where:

dydxl(i, j) = the absolute value of the panel-slope between points i and i+1 at cross section j
x = surveyed cross section station at Time Zero (i.e. Time zero refers to the beginning of the simulation.)
y = surveyed cross section elevation at Time Zero
i = sequence number of the (station, elevation) coordinate point
j = sequence number of the cross section in the geometric model

HEC-6T will test each calculated slope, and if it is less than the default critical slope for stability, dydxl(i.j) is set equal to the default critical slope for stability for that panel. When these tests are finished, the values in dydxl(i.j) are the critical slopes for stability.

In their book, Introductory Soil Mechanics and Foundations[3], Sowers and Sowers give the values of internal friction shown in columns 1 and 2 of table 1. The default critical slope for stability in HEC-6T is 1::3 which converts to a slope angle of 18.26 degrees. The difference between the default critical slope for stability and the tangent of the angle of internal friction is expressed as a safety factor.

---

[3] Sowers, George B., and George F. Sowers. 1958. Introductory Soil Mechanics and Foundations. The MacMillan Company, New York, NY. p 47

$$dydx = \frac{(y(i+1) - y(i))}{(x(i+1) - x(i))} \qquad \textbf{(16-2)}$$

$$y(i+1)_{t+1} = y(i)_t + dydxl(i,j),$$

The movable portion of the cross section is specified on the [H, HD, HI, or HL-Record.] The cross section station where the movable bed starts on the left side is at ISM, and the cross section station where it stops on the right side is at IFM.

Two Foot Test Even though the smoothing option is turned on, the program will not erode the banks until the difference in elevation across a panel becomes more than 2-feet. This constraint comes from field observations in which near vertical cuts exist when the bank height is small. Small is a relative term, and two feet is arbitrary limit. However, the constraint allows the model to mimic observed conditions for vertical cuts when the difference in panel elevations is less than two feet. Note, the two foot test makes the selection of cross section (station, elevation) points important. When coding the initial cross sections, use only two points for small streams. Put one station at the top of bank and the other at the toe.

Mass Conservation. If any elevation is changed, all elevations within the movable bed are adjusted as necessary to conserve mass. The adjustment is based on cross sectional area.

$$\Delta A = A_2 - A_1$$

The calculated cross sectional area prior to failure is A_1. After cross section elevations have been adjusted for bank failure, the new cross section area, A_2, is calculated. The difference between the two areas is ΔA. If ΔA is not zero, the cross section elevations in the smoothed portion of the cross section are corrected to make it zero. The cross section will then contain the same flow area as it did before smoothing was performed. Therefore, mass is conserved.

Command to Calculate Bank Failure

The option to calculate bank failure is requested with the $SMOOTH-Record. Smoothing is turned off by default. To turn it on, place the $SMOOTH-Record, with the selected options, at the beginning of the Hydrological Data Set.

The smoothing calculation can make a noticeable difference in execution time. Therefore, it can be turned OFF when bank caving is no longer active in the simulation. Actually, smoothing can be turned on or off at any location in the Hydrological Data Set where a command record can be placed.

The originally purpose of the $SMOOTH calculation was to smooth out numerical irregularities between coordinate points which sometimes develop during long term simulations. It's application to bank failure is just an extension of that purpose. The above is a suggested procedure for studies where bank failure is the process of interest.

Example of $Smooth-Command

The command in the following example turns smoothing ON and sets the interval at 1.

```
Example:           FIELDS
    1       2       3       4       5       6       7       8       9      10
1234567 1234567 1234567 1234567 1234567 1234567 1234567 1234567 1234567 1234567
$HYD
$SMOOTH       ON       1       1
$RATING        1
RC             6     200     100            1.37    1.84    2.01    2.16    2.28
RC          2.39
*   AB     RUN 1
Q   1000
T     55
W      1
.
.
.
$$END
```

The $SMOOTH-Command is not described in the user's manual. Briefly, set up the values in 8-column fields as shown above. The [ON, OFF] option is self explanatory. The 1 in Field 3 sets the interval for the smoothing calculation. A 1 instructs the program to smooth after each computation time step. If the Hydrological Data Set is coded with the W-Record, a computation time step is DD, the duration of the event in days. If the X-Record is used in the Hydrological Data Set, the computation time step is DT.

The 1 in Filed 4 is an option to prevent HEC-6T from eroding the bed below the Elevation of Model Bottom. The value can be either 1 or 0. A zero value allows HEC-6T to run like HEC-6, and it will erode sediment based on volume of the deposit in the bed sediment reservoir. A value of 1 instructs HEC-6T to test the thalweg elevation versus the model bottom elevation. Erosion will cease if the two become equal even though a volume of sediment is still present in the bed sediment reservoir. The input description for the $SMOOTH-Record contains more information about these options. It is available on our web site.

An example of the calculation is shown in Figure 16-1. The initial geometry was the flat surface of a sand deposit shown in the Figure. An artificial notch was cut into the deposit to establish a pilot channel. The bottom width of the notch, which defined the limits of erosion on the HE-Record, was made equal to the bottom width of the inflowing stream channel. The depth of the notch, which is somewhat arbitrary, was made two-feet. Station and Elevation coordinate points were coded at 10-foot intervals across the cross section even though the bed was flat. These extra (Station, Elevation) points will allow the channel banks to form when the model is run. Bed degradation will cause the cross section panel-slopes to exceed the critical value, and the slopes will fail. The base level at the downstream end of the model was lowered by 10 feet, and after 5 minutes (aprx 0.003 days) of flow the cross section invert had degraded 1.6 feet. The resulting bank angle of the notch increased from its original value of 11.3 degrees to 19.8 degrees. Since that is greater than the critical value of 18.26 degrees, the bank failed. The top bank moved to the next point in the cross section which is a distance of 10 feet.

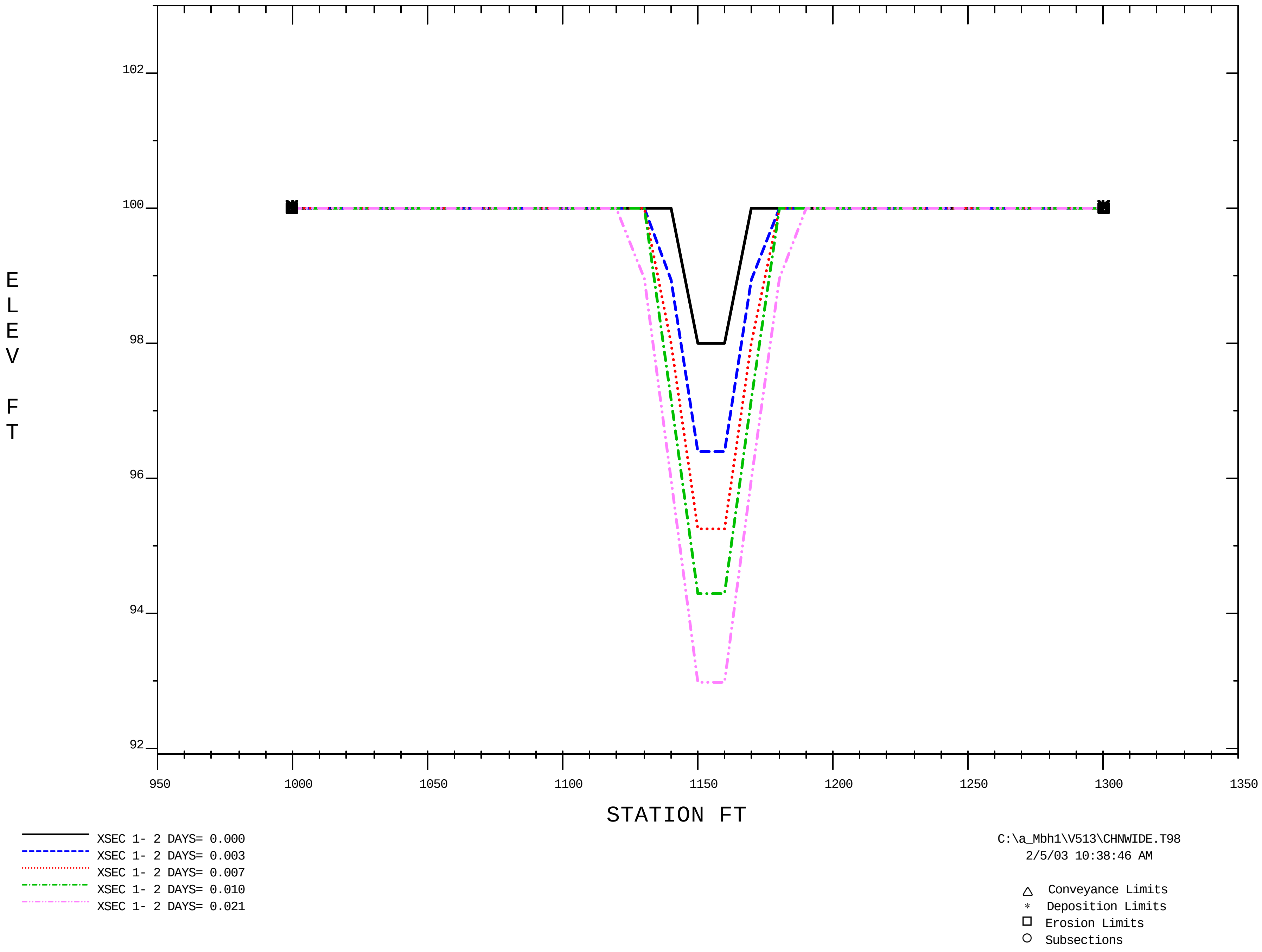
During the next 5 minutes of flow, the bed degraded another 1.1 feet. {Note: The legend on Figure 16-1 shows time in days to 3 decimal places which rounds to 0.007 Days. The actual value in the computations is 0.00694 DAYS.} The slope of the lower bank panel is stable at the critical angle, and the top panel is degrading to remain stable. Bank height is 4.75 feet.

Computations are being made in five minute time steps, and by the end of 30 minutes another high panel has failed. The top bank has moved back one more increment. If the computations were to continue, the panels would continue to over-steepen and fail until the bed reached the equilibrium slope for the inflowing water-sediment mixture and bed degradation ceased.

Printout.

Normal print out does not provide the level of detail needed to view bank failure calculations. Code a C in column 7 of the *-Record in the Hydrological Data Set, and HEC-6T will write the smoothing calculations to the Printout File, *.T6. Search for the string, SMOOTH. The calculation of critical panel-slopes will be shown first followed by the calculations which use those values for smoothing and bank failure. The cross section stations and elevations will be printed before and after smoothing. These outputs are made as the calculations proceed. This level of printout produces large output files. Tables are intended for debugging rather than for displaying model results.

1 test run


102
100
98
96
94
92
E L E V F T
950
1000
1050
1100
1150
1200
1250
1300
1350
STATION FT
XSEC 1- 2 DAYS= 0.000
XSEC 1- 2 DAYS= 0.003
XSEC 1- 2 DAYS= 0.007
XSEC 1- 2 DAYS= 0.010
XSEC 1- 2 DAYS= 0.021
C:\a_Mbh1\V513\CHNWIDE.T98
2/5/03 10:38:46 AM
△ Conveyance Limits
* Deposition Limits
☐ Erosion Limits
○ Subsections