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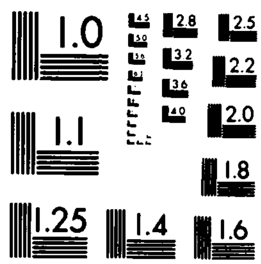

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ANALYSIS OF BANK STABILITY IN THE DEC WATERSHEDS, MISSISSIPPI

By

Colin R. Thorne

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Contract Number DAJA45-87-C-0021

First Periodic Report

May - June 1987

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July - Oct 1987

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report, is the first periodic report on the project named in box 4. It lists the scientific work to date and tasks planned for the remainder of the project. An annex contain the user's manual for a calculator program to analyse streambank stability. This is the main product of the project to date.

Colin Thorne, July 10th, 1987.

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1. SCIENTIFIC WORK DONE

1.1 Logistics

I left England on April 23, 1987 and traveled to Vicksburg, Miss. and I used the last week of April to locate accommodations and obtain a vehicle. Although the contract did not start officially until May 1, I did visit the Hydraulics Lab. at Waterways Experiment Station (WES) prior to that date, in order to start the processes of gaining security clearance and finding desk space in the Hydraulic Analysis Branch.

1.2 Professional Contacts

When I began work on May 1 my first task was to make contact with the other scientists and engineers working on the DEC project, and on other projects involving the study of bank stability. This was essential in order that I quickly learn the current status of DEC related research, and that I should be in a position to maximize the benefits of work already completed, by applying the results in my own study.

At WES I met with and talked at length to: Mr Bob Brown, Mr John Ingram and Mr Terry Waller in the Hydraulic Design Branch. Each of these individuals is involved in DEC or DEC related work. Mr Brown is a member of the DEC Task Committee. The DEC related work at WES is concerned with sediment transport prediction and stream modeling and so bank stability considerations are of immediate relevance and my findings will be of interest to the WES staff.

At the Vicksburg District I have worked closely with Mr Phil Combes and Mr David Biedenharn in the Hydraulics Section. Both are directly involved in the DEC Project, and Mr Biedenharn isa Corps technical advisor to the DEC Task Committee. They have provided vital guidance on the selection of specific locations for the analysis of bank stability, the types and quality of historical data available, and the schedule for undertaking the work in this project. I have also worked with Mr Chuck Mendrop in the Geotechnical Section at the District. He is supplying data on the engineering properties of bank materials in the DEC watersheds from borehole records at specific locations.

I have also talked with other individuals who are working as AE's on the DEC Project. Dr Chester Watson of Water Engineering Technology, Fort Collins, Co. has been using bank analyses which I developed in 1981, to undertake a geomorphic analysis of Hotophia Creek. He has found bank stability to be the single most important factor in controlling stream channel changes, and has found my analysis to be successful in predicting and explaining bank response to changing hydraulic and sedimentary conditions. Dr Watson has made available to me all of the results of his studies to date.

Simons, Li and Associates have recently completed their study of Hickahala/Senotobia Creek. Their report has been made available to me. They too used my bank stability approach, but only qualitatively. They found it useful in the area just downstream of a headcut but generally give the impression in their report that further development of the analysis is needed - especially to include additional modes of failure such as rotational slips. This will be incorporated into my current research.

Northwest Hydraulic Consultants, Seattle, Wa. are just beginning studies of Black Creek and of Long Creek. I have spoken to Mr Charie Neill, the PI, and told him of my work on bank stability - an area where Northwest have comparatively little experience. We plan to liaise closely in the coming months to incorporate my analyses into their approach.

In the first months of this project I have developed good working relationships with the individuals working on related research and implementation of the DEC scheme. This is a vital prerequisite for the success of my project.

1.3 Development of Bank Stability Theory

Most of the theoretical analysis was already completed prior to my being awarded this contract, and was presented in the original proposal in appendices B and C. Since starting on the project, I have further developed the theoretical analysis and practical applications, specifically to account for conditions found in the Mississippi Bluff Line streams. The theory and applications are set out in detail in papers accepted for publication in the Journal of Hydraulic Engineering of the ASCE (Osman & Thorne, 1988; Thorne & Osman, 1988). These papers have been taken from draft submission to final form during the first two months of this project and the support of the U.S. Government is duly acknowledged.

The computations involved in the analysis are relatively straight forward, but still present numerous opportunities for arithmetic errors. Also, correct interpretation of the output of the stability model demands some prior knowledge of stability theory. Therefore, I have written a program for the Hewlett-Packard HP-41C calculator which prompts for the required data, performs the analysis, presents and interprets the results, and directs the user to the next computational step. This program reouires no prior knowledge of the HP-41C and can be used on site as the calculator is battery powered. The user manual gives complete instructions for the analysis of steep streambanks subject to erosion and bed degradation. A copy of the user manual is attached in Annex 1.

1.4 Testing the Bank Stability Analysis

Testing and calibration of the theoretical analysis requires field data from unstable banks. These data have been supplied by Mr Biedenharn for sites on Long Creek, and its tributaries Caney Creek and Goodwin Creek. Resurvey cross-sections, long profiles, and channel planforms for 1978,1979, and 1985 have already been supplied and data for 1986 will be supplied soon.

2 RESEARCH PLANS

The data from Long Creek will be used to test predictions of bank stability and channel change based on the theoretical analysis. Based on these results the model will be modified and developed as necessary to produce reliable predictions of bank stability on Long Creek. The results will be communicated to the relevant people at Northwest Hydraulic Consultants, for incorporation into their analysis of the Long Creek watershed.

Next it is planned to generalize the model to make it applicable to other watersheds in the DEC scheme and throughout Mississippi. This will require further data for testing and development.

A concurrent aim is to incorporate the bank stability analysis into existing Corps models for aggradation and degradation in streams. This major undertaking would require considerable effort from scientists at WES in cooperation with myself, but could greatly improve the power and utility of the Corps models. I have put this proposal to the District and had a favorable response - they feel this to be a worthwhile undertaking. The next step is to talk to the WES personnel, get their reaction and decide how best to proceed. This is an immediate priority.

3 ADMINISTRATIVE ACTIONS

There have been no personnel changes or important changes of an administrative nature during this period. The project has proceeded as set out in the original proposal.

4 REFERENCES

Osman, A.M. and Thorne, C.R. (1988) 'River Bank Stability Analysis : I. Theory' Journal of Hydraulic Engineering, ASCE, accepted for publication.

Thorne, C.R. and Osman, A.M. (1988) ' River Bank Stability Analysis : II. Applications' Journal of Hydraulic Engineering, ASCE, accepted for publication.

ANNEX 1

CALCULATOR PROGRAM FOR ANALYSIS OF STREAMBANK STABILITY

Colin R. Thorne Visiting Scientist, Vicksburg District, US Army Corps of Engineers (on leave from Queen Mary College, Univ. London, LONDON E1 4NS, England)

1 INTRODUCTION

Streambank retreat usually occurs by a combination of flow erosion and mass failure. Bank failures occur when erosion of the bank and the bed adjacent to the bank increase the height and angle of the bank so that it reaches a condition of limiting stability. The mechanism of failure depends on the geometry of the bank and engineering properties of the bank material (Thorne,1982).

Eroding banks are usually steep and commonly fail by a slab-type mechanism, where a block of soil topples forward into the channel (Fig.1). The weakening effects of tension cracks between the block and the bank can be important in triggering failure and should be accounted for when analysing the stability of this type of bank.

Figure 1. Slab failure of a streambank in Northwest Mississippi.

Failures usually occur during "worst case" conditions, when the strength of the bank materials is minimised and the weight is maximised due to high moisture levels. Such conditions are associated with periods of prolonged rainfall, snowmelt, and drawdown following high flow stages in the channel. Banks which are stable under "average" values for soil properties, but which are unstable for "worst case" conditions are at risk of failure. That means that their stability cannot be relied upon and they may be expected to fail sometime in the near future.

The analysis of the stability of streambanks with respect to slab failure was undertaken by Thorne, Murphey and Little (1981). Recntly Osman and Thorne (1988)have developed an improved approach to this problem. The method uses the resolution of driving and resisting forces in static equilibrium on the most critical potential failure plane to derive a factor of safety (FS) for a bank with respect to slab failure. A value of FS greater than one indicates stability, and equal to one indicates the critical condition with the bank on the point of failure. Values less than one suggest that the bank is unstable and should have failed already.

This manual provides a calculator program for the Hewlett-Packard HP-41CV or CX calculator, which may be used on-site for application of the Osman-Thorne analysis. The HP-41C may be used provided that it has a quad memory module fitted.

This Users Guide explains how the program is used to calculate the factor of safety for an existing bank, and how to find the amounts of flow erosion and bed degradation which would cause the bank to fail. The bank height, tension crack depth, failure plane angle, block width, and block volume for slab failure are computed. These parameters define the amount of top bank retreat, the volume of slumped material input to the channel, and the new bank geometry after failure.

No prior experience with the HP-41 is necessary.

2 DATA REQUIREMENTS

The folowing data are needed to perform the analysis:

Variable	Symbol	Units
Total Bank Height	H	ft
Upper Bank Height	H1	ft
Bank Slope Angle	I	Degrees
Specific Weight	Sp.Wt.	lb/ft^3
Effective Friction Angle	phi	Degrees
Effective Cohesion	c	lb/ft^2
Tension Crack Index	K	-

The tension crack index is defined by:

$$K = Y/H$$

where Y = tension crack depth (ft) and H = total bank height. Experience shows that crack depth is usually limited to less than half the bank height. If there are no data on the depth of cracking at the site being investigated, K = 0.5 may be used. The variables are shown in Figure 2.

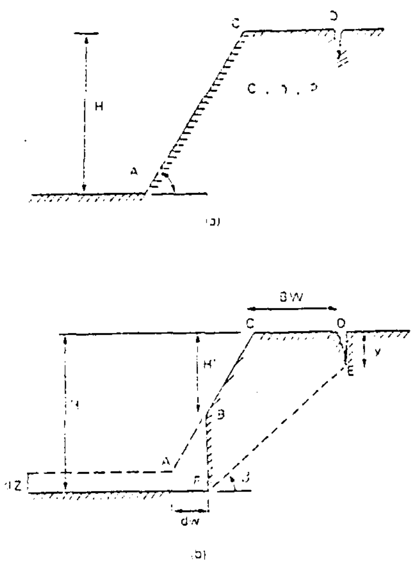

Figure 2. Definition diagram for variables in slab failure analysis: a) Initial geometry; b) After erosion and bed degradation to the critical case.

3 INSTRUCTIONS

First check if the program is already in the calculator. To do this key in:

XEQ ALPHA USFS ALPHA

if the calculator responds with:

NONEXISTENT

then you must load the program as described in section 3.1. If the program is initiated and displays:

then you may go straight to section 3.2.

3.1 Loading the Program

3.1.1 Manual Loading

1. Turn on the calculator
2. Key in SHIFT GTO . .
3. Put the calculator in Program mode
4. Key in the program exactly as listed in appendix 4.

Note,

i) All statements followed by either ARCL or PROMPT are entered in ALPHA mode. To select this press the ALPHA key. To complete entry press ALPHA again.

ii) Commands not found on the keyboard (for example PROMPT, PSE) are entered by keying;

XEQ ALPHA command ALPHA

for example to key in the command "PROMPT" the sequence is;

XEQ ALPHA PROMPT ALPHA

iii) The symbol, - , means APPEND and is keyed in by;

ALPHA SHIFT K ----- ALPHA

for example to key in the units that follow an output variable the sequence is;

ALPHA SHIFT K FT ALPHA

iv) The SHIFT key is yellow.

3.1.2 Magnetic card loading

If you have the program on magnetic cards and have a card reader, load the program as follows:

1. Turn on the calculator
2. Key in GTO . .
3. Ensure the calculator is <u>NOT</u> in Program mode
4. Insert the cards into the card reader
5. When all cards have been accepted, key in GTO ..

The program is now ready to run.

3.2 Running the Program

After loading the program (and checking for keying errors if it was keyed in manually) the program is initiated by keying:

XEQ ALPHA USFS ALPHA

After that it is only necessary to press the RUN/STOP (R/S) key to proceed, entering data as prompted by the calculator and noting output data on the record sheet, Table 1. Figure 3 shows the program flow chart. The complete user instructions are listed in section 3.2.1.

3.2.1 User Instructions

STEP	INSTRUCTION	INPUT	FUNCTION	DISPLAY
1	Initialize program		XEQ USFS	COLIN THORNE- BANK ANALYSIS STEP NO. 1. H ? FT
2	Input total height	H	R/S	H1 ? FT
3	Input upper height	H1	R/S	I ? DEG
4	Input bank angle	I	R/S	SP.WT ? LB/FT3
5	Input specific wt.	Sp.Wt	R/S	PHI ? DEG
6	Input friction angle	phi	R/S	c ? LB/FT2
7	Input cohesion	c	R/S	K ?
8	Input crack index	K	R/S	FS=_____
9	Displays Factor of Safety for initial bank geometry		R/S	A: BANK STABLE B: H = CRITICAL
10	Displays A or B If A, continue If B, go to step 19			
11	Indicates bank is below critical height.No failure will occur without erosion and/or degradation		R/S	STEP NO.__

12	Displays number of current step		R/S	DW ? FT
13	Input lateral erosion distance	DW	R/S	DZ ? FT
14	Input degradation distance	DZ	R/S	H=____FT
15	Displays new H		R/S	H1=___FT
16	Displays new H1		R/S	FS=____
17	Displays new FS		R/S	A: BANK STABLE B: H = CRITICAL C: BANK TOO HIGH
18	Displays A,B,or C If A, go to step 11 If B, go to step 19 If C, go to step 27			
19	Indicates bank is on point of failure		R/S	H CRIT=___FT
20	Displays critical H		R/S	H1CRIT=___FT
21	Displays critical H1		R/S	Y CRIT=___FT
22	Displays critical Y		R/S	I CRIT=__DEG
23	Displays critical I		R/S	BETA =___DEG
24	Displays failure plane angle, BETA		R/S	BW =___FT
25	Displays failure block width, BW		R/S	VB =___FT3/FT
26	Displays failure block volume per per unit channel length, VB		R/S	RUN COMPLETE
	Program returns to step 1			
27	Indicates DW &/or DZ were too large so bank geometry is unstable and could not exist		R/S	REDUCE DW + DZ

28 Indicates reduced DW &/or DZ values must be used and step repeated — R/S — STEP NO.__

Returns to step 12

Table 1 Results Table

Stream Name					Site Name		
Date					Bank		
Initial Data							
H = ft		I = degrees			phi = degrees		
H1 = ft		Sp.Wt = lb/ft³			c = lb/ft²		
K =							
Step	DW (ft)	DZ (ft)	H (ft)	H (ft)	I (deg)	FS	COMMENTS
Critical Bank Geometry Parameters							
H CRIT = ft		I CRIT = deg			BW = ft		
H1CRIT = ft		BETA = deg			VB = ft³/ft		
Y CRIT = ft							

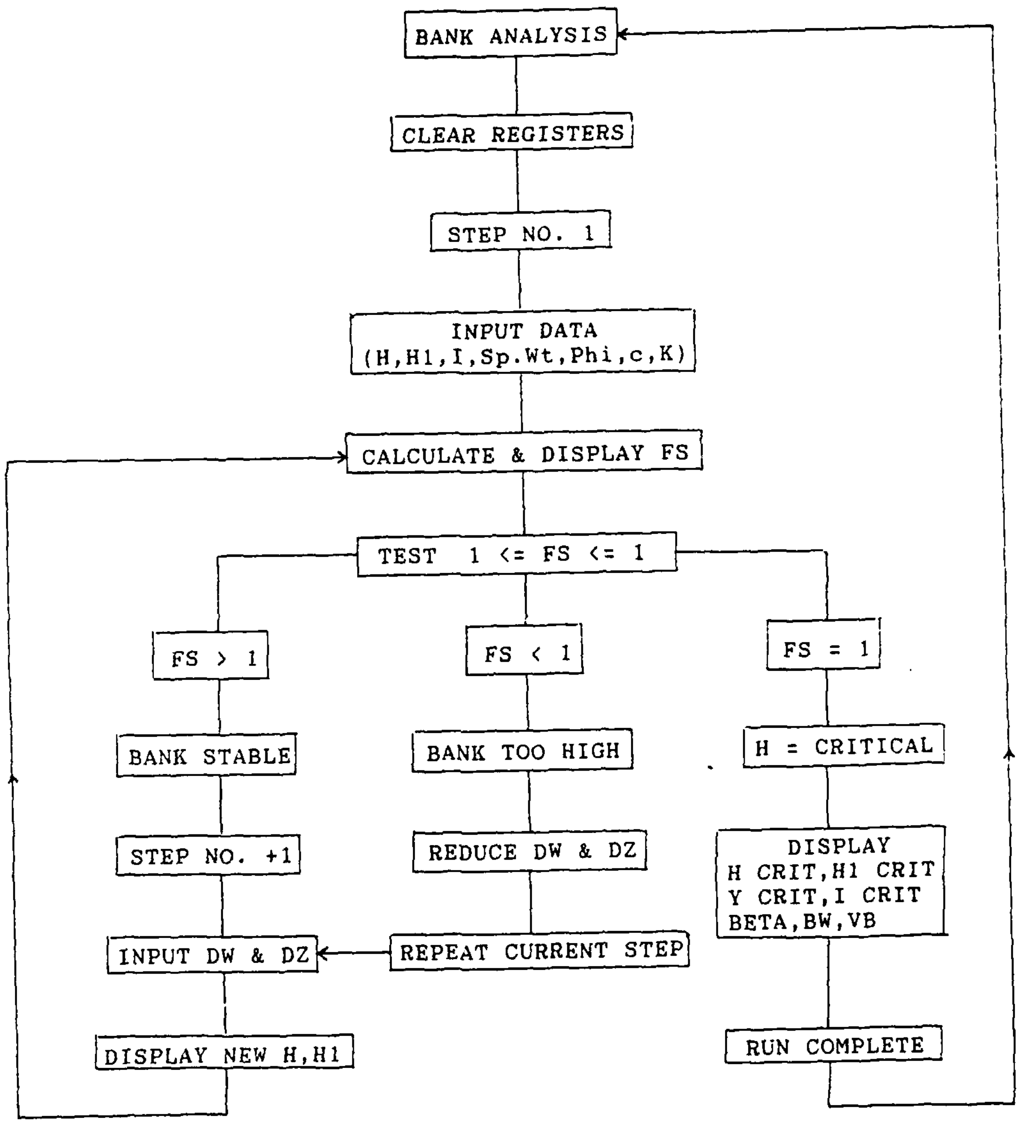

Figure 3. Flow Chart for Bank Stability Analysis

4 EXAMPLE

4.1 Program Steps

****

KEYSTROKE	DISPLAY
XEQ ALPHA USFS ALPHA	COLIN THORNE- BANK ANALYSIS STEP NO. 1. H? FT
15 R/S	H1? FT
15 R/S	I? DEG
70 R/S	SP.WT? LB/FT3
100 R/S	PHI? DEG
12 R/S	C? LB/FT2
400 R/S	K?
0.5 R/S	FS = 1.30
R/S	BANK STABLE
R/S	STEP NO. 2.
R/S	DW? FT
0.6 R/S	DZ? FT
1.5 R/S	H = 16.50 FT
R/S	H1= 13.35 FT
R/S	FS = 1.11
R/S	BANK STABLE
R/S	STEP NO. 3.
R/S	DW? FT
0.6 R/S	DZ? FT
1.2 R/S	H = 17.70 FT
R/S	H1= 11.70 FT
R/S	FS = 0.98
R/S	BANK TOO HIGH
R/S	REDUCE DW + DZ
R/S	STEP NO. 3.
R/S	DW? FT
0.5 R/S	DZ? FT
1.1 R/S	H = 17.60 FT
R/S	H1= 11.98 FT
R/S	FS = 1.00
R/S	H = CRITICAL
R/S	H CRIT = 17.6FT
R/S	H1CRIT = 12.0FT
R/S	Y CRIT = 8.8 FT
R/S	I CRIT = 70 DEG
R/S	BETA = 44.7 DEG
R/S	BW = 4.54 FT
R/S	VB = 91.4FT3/FT
R/S	RUN COMPLETE COLIN THORNE- BANK STABILITY STEP NO. 1. H ? FT

****

4.2 Example Results Table

Stream Name	No Name Creek	Site Name	No Place
Date	6/18/87	Bank	Left

Initial Data

H = 15.0 ft	I = 70 degrees	Phi = 12 degrees
H1 = 15.0 ft	Sp.Wt = 100 lb/ft^3	c = 400 lb/ft^2
K = 0.5		

STEP	DW (ft)	DZ (ft)	H (ft)	H1 (ft)	I (deg)	FS	COMMENTS
1	0	0	15.00	15.00	70	1.30	Stable
2	0.6	1.5	16.50	13.35	70	1.11	Stable
3	0.6	1.2	17.70	11.70	70	0.98	Too High
3	0.5	1.1	17.60	11.98	70	1.00	Critical

Critical Geometry Parameters

H CRIT = 17.6ft	I CRIT = 70 deg	BW = 4.54 ft
H1CRIT = 12.0ft	BETA = 44.7 deg	VB = 91.4 ft^3/ft
Y CRIT = 8.8ft		

APPENDIX 1 - SYMBOLS

BETA	Angle between the failure plane and the horizontal. Becomes the new bank angle after slab failure.
c	Effective cohesion of bank material.
DW	Increment of lateral bank erosion by the flow.
DZ	Increment of bed degradation by the flow.
FS	Factor of safety with respect to slab failure.
H	Total bank height above the bed.
H1	Upper bank height. Equals total bank height if DW and DZ are zero. Equals total bank height if bank is vertical.
I	Angle between the bank surface and the horizontal.
K	Tension crack index. K = Y/H.
phi	Effective angle of internal friction of bank material.
Sp.Wt	Specific weight of bank material.
VB	Volume of failure block per unit channel length.
Y	Depth of tension cracking.

APPENDIX 2 - MESSAGES AND ERRORS

<u>DISPLAY</u>	<u>MEANING</u>
BANK UNSTABLE : CHECK DATA	The initial bank geometry has a factor of safety less than 1. If "worst case" values are being used then this means that the bank is at risk of failure. If "average" values are being used then the input data are suspect and should be checked. Keying R/S returns the program to Step 1.
BANK VERTICAL DUE TO EROSION	Lateral erosion reduces the height of the upper bank, H1. If H1 goes to zero before failure, the sloping portion of the bank is eliminated and the bank is made vertical. In this case the program makes I = 90 and H1 = H. Further lateral erosion produces retreat of the whole bank and does not affect mass stability. Therefore, no further DW values are requested. Vertical banks may fail due to bed degradation represented by further DZ increments.
H1>H BAD DATA	The upper bank height input is greater than the total bank height. This is impossible and the program will not accept H1>H. Initially, if DW and DZ are zero, then H1 = H. Keying R/S returns the program to Step 1.
H1<0, REDUCE DW	The input value of DW would reduce H1 below zero which is impossible. H<=H1>0 by definition. If H1 goes to zero then the whole bank is vertical and H = H1. This is taken into account in the program. Keying R/S returns the program to Step 12 and prompts for a reduced DW value.
I>90, BAD DATA	Input value of the bank angle I is greater than 90, inferring either data error or an cantilevered bank. Cantilever stability can simply

	be assessed using the Thorne-Tovey (1981) analysis. The slab analysis used here would be inapplicable. Keying R/S returns the program to Step 6 and prompts for another value of I.
K>1 BAD DATA	Input value of tension crack index K is greater than 1, which is impossible. Check the value of K. Keying R/S returns the program to Step 8 and prompts for another value of K.
WARNING : I<60	Input value of bank angle I is less 60 degrees.Such banks often fail by rotational slip, not slab failure and this analysis may overestimate the factor of safety. Program continues, but results should be used with caution for I<60 degrees.

APPENDIX 3 - REFERENCES

Osman, A.M. & Thorne, C.R. (1988) " River bank stability analysis: I Theory" ASCE, Journal of Hydraulic Engineering, Accepted for publication-In Press.

Thorne, C.R. (1982) " Processes and mechanisms of river bank erosion " in, Gravel-Bed Rivers, Hey,R.D., Bathurst, J.C. & Thorne,C.R.(Eds.), J. Wiley & Sons, Chichester, UK, pp 227-272.

Thorne, C.R., Murphey, J.B. & Little, W.C. (1981) "Bank stability and bank material properties in the Bluff line streams of northwest Mississippi" Report to the Vicksburg District Corps of Engineers, USDA Sedimentation Lab., 258p.

Thorne, C.R. & Tovey, N.K. (1981) "Stability of composite river banks" Earth Surface Processes and Landforms, Vol. 6, pp 469-484.

APPENDIX 4 - PROGRAM LISTING

```
01♦LBL "[illegible]"
02 CL[illegible]
03 "[illegible]"
04 AVIEW
05 PSE
06 "[illegible]"
07 AVIEW
08 PSE
09 DEG
10♦LBL "[illegible]"
11 [illegible]
12 STO 24
13 FIX [illegible]
14 "[illegible]"
15 RCL 24
16 AVIEW
17 PSE
18 "[illegible]"
19 PROMPT
20 STO 0[illegible]
21 "[illegible]"
22 PROMPT
23 STO 02
24 RCL 01
25 [illegible]
26 [illegible]
27 [illegible]
28 [illegible]=Y?
29 GTO [illegible]
30 "[illegible] BAD DATA"
31 PROMPT
32 ST- 24
33 GTO "DATA"
34♦LBL 09
35 "[illegible] DEG"
36 PROMPT
37 STO 03
38 60
39 X<=Y?
40 GTO 01
41 "WARNING [illegible] 60"
42 AVIEW
43 PSE
44♦LBL 01
45 90
46 RCL 03
47 X<=Y?
48 GTO 07
49 "[illegible] BAD DATA"
50 PROMPT
51 GTO 09
52♦LBL 07
53 "SP.WT? LB/FT3"
54 PROMPT
55 STO 04
56 "PHI? DEG"
57 PROMPT
58 STO 05
59 "C? LB/FT2"
60 PROMPT
61 STO 06
62♦LBL 12
63 "K?"
64 PROMPT
65 STO 07
66 1
67 X<Y?
68 GTO "CALC"
69 "K>1, BAD DATA"
70 PROMPT
71 GTO 12
72♦LBL "CALC"
73 RCL 01
74 RCL 02
75 /
76 STO 20
77 0
78 X<Y?
79 GTO "US"
80 RCL 03
81 TAN
82 1
83 RCL 07
84 X↑2
85 -
86 *
87 RCL 01
88 RCL 02
89 /
90 X↑2
91 *
92 ATAN
93 RCL 05
94 +
95 2
96 /
97 STO 08
98 1
99 RCL 07
100 X↑2
101 -
102 RCL 08
103 SIN
104 RCL 08
105 COS
106 *
107 RCL 03
108 COS
109 X↑2
110 RCL 05
111 TAN
112 *
113 -
114 *
115 STO 09
116 2
117 ENTER↑
118 1
119 RCL 07
120 -
121 *
122 RCL 06
123 *
124 RCL 04
125 [illegible]
126 RCL 02
127 /
128 STO 10
129 RCL 09
130 SIN
131 RCL 09
132 COS
133 *
134 RCL 03
135 TAN
136 *
137 RCL 08
138 SIN
139 X↑2
140 -
141 RCL 03
142 TAN
143 /
144 STO 11
145 RCL 10
146 RCL 09
147 /
148 STO 12
149 X↑2
150 4
151 RCL 11
152 *
153 RCL 09
154 [illegible]
155 -
156 SQRT
157 RCL 12
158 +
159 2
160 [illegible]
161 STO 13
162 CL[illegible]
163 CL[illegible]
164♦LBL "CHECK"
165 RCL 13
166 RCL 20
167 /
168 STO 25
169 FIX 2
170 "FS="
171 ARCL 25
172 PROMPT
173 1.005
174 [illegible]=Y?
175 GTO "ST"
176 RCL 25
177 .995
178 [illegible]
179 GTO "US"
180 BEEP
181 "H=CRITICAL"
182 PROMPT
183 FIX 1
184 "H CRIT="
185 ARCL 01
186 "FT"
187 PROMPT
188 "HICRIT="
189 ARCL 02
190 "FT"
191 PROMPT
192 RCL 01
193 RCL 07
194 *
195 STO 29
196 "V CRIT="
197 ARCL 29
198 "FT"
199 PROMPT
200 FIX 1
```

```
201 "ICRIT="
202 ARCL 07
203 "+DEG"
204 PROMPT
205 "BETA="
206 ARCL 05
207 "+ DEG"
208 PROMPT
209 RCL 01
210 RCL 01
211 RCL 07
212 *
213 -
214 RCL 03
215 TAN
216 /
217 RCL 02
218 RCL 03
219 TAN
220 /
221 -
222 STO 26
223 FIX 2
224 "BW="
225 ARCL 26
226 "+ FT"
227 PROMPT
228 RCL 01
229 X↑2
230 RCL 01
231 RCL 07
232 *
233 X↑2
234 -
235 RCL 08
236 TAN
237 [illegible]
238 RCL 02
239 X↑2
240 RCL 03
241 TAN
242 [illegible]
243 -
244 [illegible]
245 [illegible]
246 STO 27
247 FIX 1
248 "VS="
249 ARCL 27
250 "+FT3 FT"
251 PROMPT
252 CLX
253 "RUN COMPLETE"
254 AVIEW
255 PSE
256 PSE
257 GTO "USFS"
258•LBL "ST"
259 "BANK STABLE"
260 PROMPT
261•LBL "HI"
262 1
263 ST+ 24
264 FIX 0
265 "STEP NO. "
266 ARCL 24
267 PROMPT
268 RCL 03
269 90
270 X=Y?
271 GTO 03
272 RCL 20
273 10
274 X<=Y?
275 GTO 13
276 FIX 3
277 "DH? FT"
278 PROMPT
279 STO 21
280 RCL 02
281 RCL 21
282 RCL 03
283 TAN
284 *
285 STO 16
286 X=0?
287 GTO 09
288 /
289 STO 23
290 1.005
291 X<=Y?
292 GTO 09
293 RCL 23
294 .995
295 X<=Y?
296 GTO 13
297 "H1(0.[illegible]"
298 PROMPT
299 1
300 ST- 24
301 GTO "HI"
302•LBL 09
303 RCL 16
304 CHS
305 RCL 02
306 +
307 STO 02
308 GTO 03
309•LBL 13
310 CLX
311 STO 21
312 90
313 STO 03
314 "BANKVERTICAL"
315 AVIEW
316 PSE
317 "DUETOEROSION"
318 AVIEW
319 PSE
320•LBL 03
321 CLX
322 "DD? FT"
323 PROMPT
324 STO 22
325 RCL 01
326 +
327 STO 01
328 FIX 2
329 "H="
330 ARCL 01
331 "+ FT"
332 PROMPT
333 90
334 RCL 07
335 X=Y?
336 GTO 04
337•LBL 05
338 "H1="
339 ARCL 02
340 "+ FT"
341 PROMPT
342 GTO "CALC"
343•LBL 04
344 RCL 01
345 STO 02
346 GTO 05
347•LBL "US"
348 1
349 ST- 24
350 RCL 24
351 X=0?
352 GTO 02
353 "BANKTOO HIGH"
354 PROMPT
355 "REDUCE DW-[illegible]"
356 PROMPT
357•LBL 10
358 RCL 01
359 RCL 22
360 -
361 STO 01
362 90
363 RCL 03
364 X=Y?
365 GTO 06
366 TAN
367 RCL 21
368 *
369 RCL 02
370 +
371 STO 02
372 GTO "HI"
373•LBL 06
374 RCL 01
375 STO 02
376 GTO "HI"
377•LBL 02
378 0.0010
379 STO 29
380 BEEP
381•LBL 11
382 "BANK UNSTA[illegible]"
383 AVIEW
384 PSE
385 "CHECK DAT[illegible]"
386 AVIEW
387 PSE
388 ISG 29
389 GTO 11
390 1
391 ST- 24
392 GTO "DA[illegible]"
393 END
```

5781-EN.

ANALYSIS OF BANK STABILITY IN THE DEC WATERSHEDS, MISSISSIPPI

By

Colin R. Thorne

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Contract Number UA45-87-C-0021

Second Periodic Report

July - October 1987

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is the second periodic report on the project named in box 4. It lists the scientific work to date, and tasks planned for the remainder of the project. An annex contains an updated program for bank stability analysis on the HP41CV calculator, dealing with the initial failure due to bed degradation and subsequent failures due to basal clean-out.

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1. SCIENTIFIC WORK DONE

1.1 Logistics

Throughout the second period of study I have been based at the Waterways Experiment Station (WES) at Vicksburg, working on the development and testing of the bank stability analysis for the DEC watersheds. I have continued to liaise with scientists and engineers at WES and at the Lower Mississippi Vicksburg District (LMVD). Preliminary trips to the field have been made for reconnaissance and site selection for application and detailed testing of the method.

In July I traveled to Oxford, Mississippi to visit the USDA Sedimentation Laboratory and make contact with the staff there who are involved in the DEC scheme. Accompanied by David Biedenharn, Charlie Montague, and John Smith of the LMVD, I inspected sites of severe bank erosion on Long, Marcum and Caney Creeks, and looked at recently constructed grade-control structures on Long and Caney Creeks. Detailed data collection was impossible because of the dense growth of vegetation in the channel and on the bank tops, especially of the climbing vine "Kudzu". Although this vine does little to enhance bank stability, it does limit access to the banks and hides areas of potential instability from view.

In early October, I traveled to the Red River in Arkansas and Louisiana with David Biedenharn, Charlie Little and Freddie Pinkard of the LMVD. The purpose of this trip was to examine the banks of the Red River and determine the processes and mechanisms of failure. It is possible that the Red might be used to regionalize the results of the bank stability studies in the DEC watersheds.

1.2 Professional Contacts

The results to date of this study have been communicated to interested parties at WES and the LMVD. Also, liaison with the AE's has continued. Specifically, copies of the first period report have been sent to Simons, Li and Associates (SLA) and to Water Engineering Technology (WET) at Fort Collins. The project has also been discussed at length with Dr Mike Harvey of WET. No feedback has been forth coming from SLA. Northwest Hydraulics have withdrawn from consideration to be the AE for Long Creek, and no AE has been named to date.

Data on channel changes and geotechnical properties of the bank materials has been supplied by the LMVD for the years 1976, 1978, 1985 and 1986 for various reaches of Long

Creek and its tributaries, Caney, Goodwin, Johnson and Marcum Creeks.

1.3 Development of Bank Stability Theory

The theoretical and applications papers describing the analysis of bank stability used in this project have been scheduled for publication in the February 1988 edition of the Journal of Hydraulic Engineering of the American Society of Civil Engineers (Osman and Thorne, 1988; Thorne and Osman, 1988a).

The program for the HP-41CV calculator has been debugged and extensively tried and tested for accuracy. Minor changes have been made to the program to eliminate bugs and to improve its computational efficiency. A new program has been written, to analyse subsequent failures due to basal clean-out of the initial failure, and further lateral erosion or bed degradation. The revised and expanded program is listed in Annex 1. A revised users' manual is in preparation.

Consideration has been given to the role of bank stability in channel evolution towards a stable hydraulic geometry. The results are reported in a paper to be presented at the International Conference on River Regime to be held at Wallingford, UK next May (Thorne and Osman, 1988b). Also, some thought has been given to the influence of bank vegetation on channel geometry and particularly width. The results are reported in a companion paper for the same conference (Thorne, et al. 1988)

1.4 Testing the Bank Stability Analysis

On the basis of the field trip to Long Creek in July, a reach around structure #1, at range 300+00 upstream of the confluence with Johnson Creek, was selected for initial application and testing of the bank stability analysis.

Table 1. Soil parameters for Long Creek around Structure #1

Soil Unit	Percent of Bank Height (%)	Friction Angle (°)	Cohesion (lb/ft²)	Unit Weight (lb/ft³)	Tensile Strength (lb/ft²)
PSA	50	12	430	123	46
MBI(YP)	20	16	317	122	106
L (OP)	10	14	720	132	221
Sands	20	20	0	111	0
Bank Averages		16	270	130	46*

* Only upper bank tensile strength is relevant to calculation of tension crack depth as crack depth rarely exceeds half the bank height.

The data on soil properties supplied by the LMVD were used together with measurements made in 1980 on the banks of Goodwin and Johnson Creeks, to derive representative soil properties for the four soil units observed in the banks of Long Creek in that area. The mean soil properties and weighted averages for typical banks are listed in Table 2. Only "worst case" values are listed as previous experience shows these to be relevant to bank stability calculations (Thorne et al., 1981).

The data presented in Table 2 were used to estimate the depth of tension cracking behind the banks using a procedure developed by Thorne et al. in 1981. This predicted a maximum crack depth of 5.16ft.

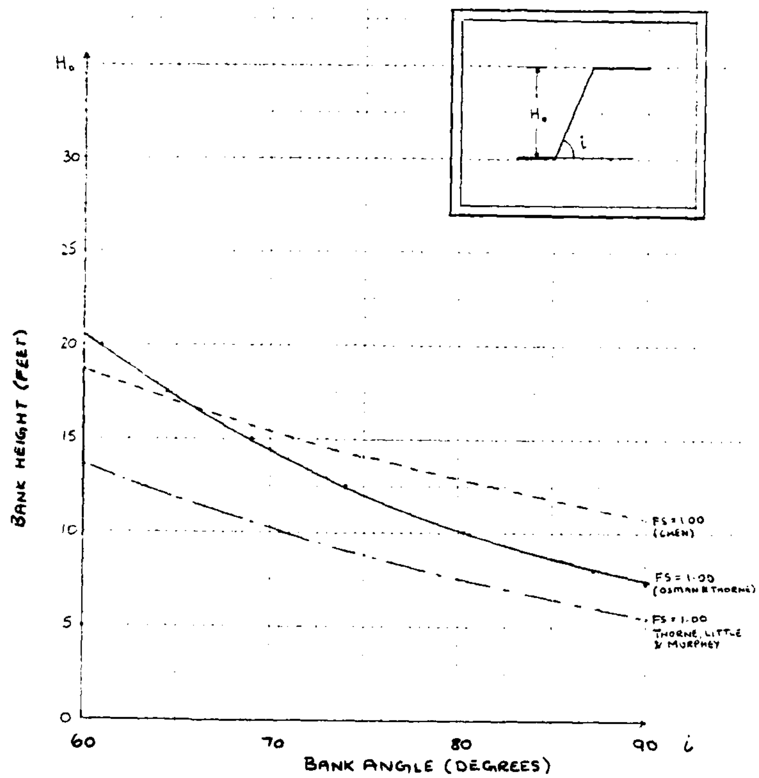


Fig.1 Critical Height for Slab-Type Failure of Streambanks

The soils data and crack depth were used in the HP-41CV program, to develop curves of critical bank height, critical degradation depth and critical lateral erosion distance for the study reach. Fig. 1 shows the critical bank height as a function of bank angle. Curves based on the earlier analyses of Chen (1979) and of Thorne et al. (1981) are plotted for comparison.

Curves to predict the critical degradation depth to instigate mass failures under gravity for banks of various initial heights and angles are shown in Fig. 2.

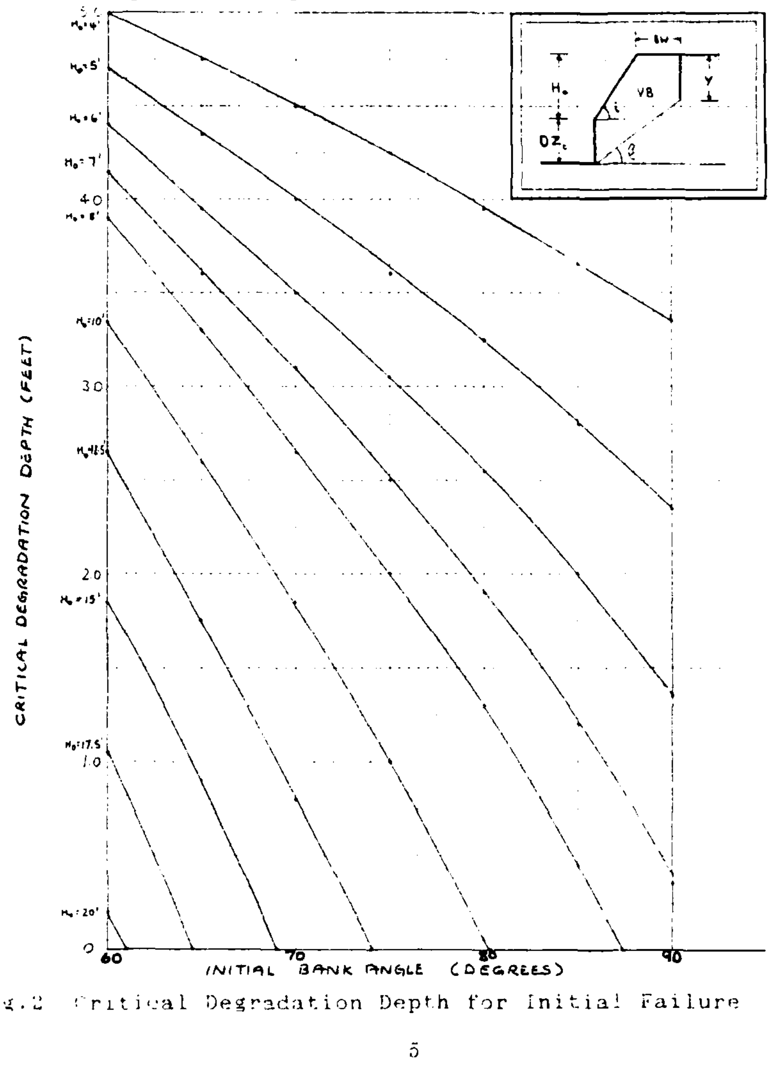
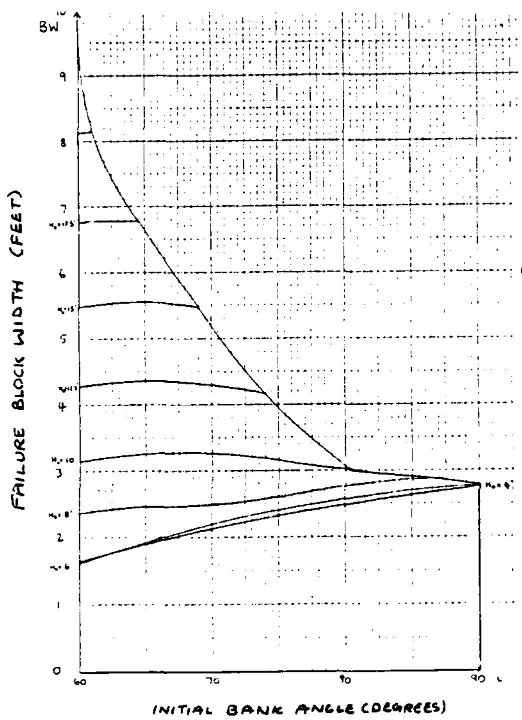


Fig.2 Critical Degradation Depth for Initial Failure

Figs.3 and 4 show the failure block width and block volume per unit length of channel respectively. These curves could be used to predict the channel's width response to degradation of the bed and estimate the volume of disturbed bank debris input to the channel as a result of bank instability.



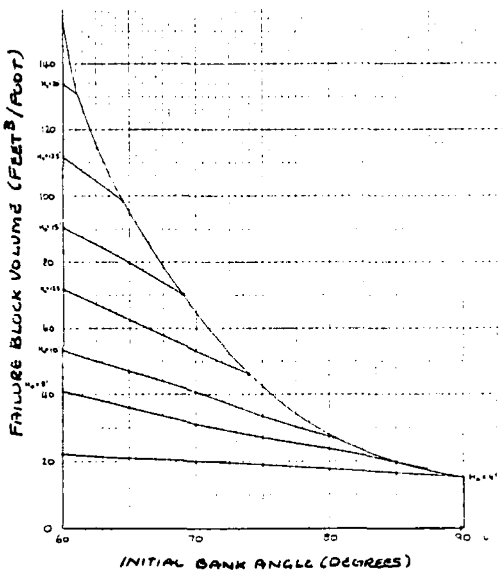


Fig.3 Block Width for Initial Failure

Fig.4 Block Volume for Initial Failure

Following the initial failure due to degradation, further failures occur when the flow cleans-out the slump debris and erodes the bank. Curves of critical lateral erosion distance versus initial bank angle for different initial bank heights are plotted in Fig. 5. The block width is in this case equal to the critical erosion distance. The block volume is obtained from Fig 6. These curves could be used to predict the extent of widening due to lateral erosion and basal clean-out, and the volume of sediment derived from bank failures.

Evaluation of these curves is currently under way, using the data supplied by the LMVD. However two problems have arisen in this regard. Firstly, when surveying the channel cross-sections, the field crews tended to avoid the steepest banks because of the difficulty of surveying them (M. Harvey, personal communication, 1987). Hence, the data sets are biased towards flatter bank angles. Secondly, the surveys are spaced several years apart, so that there is no

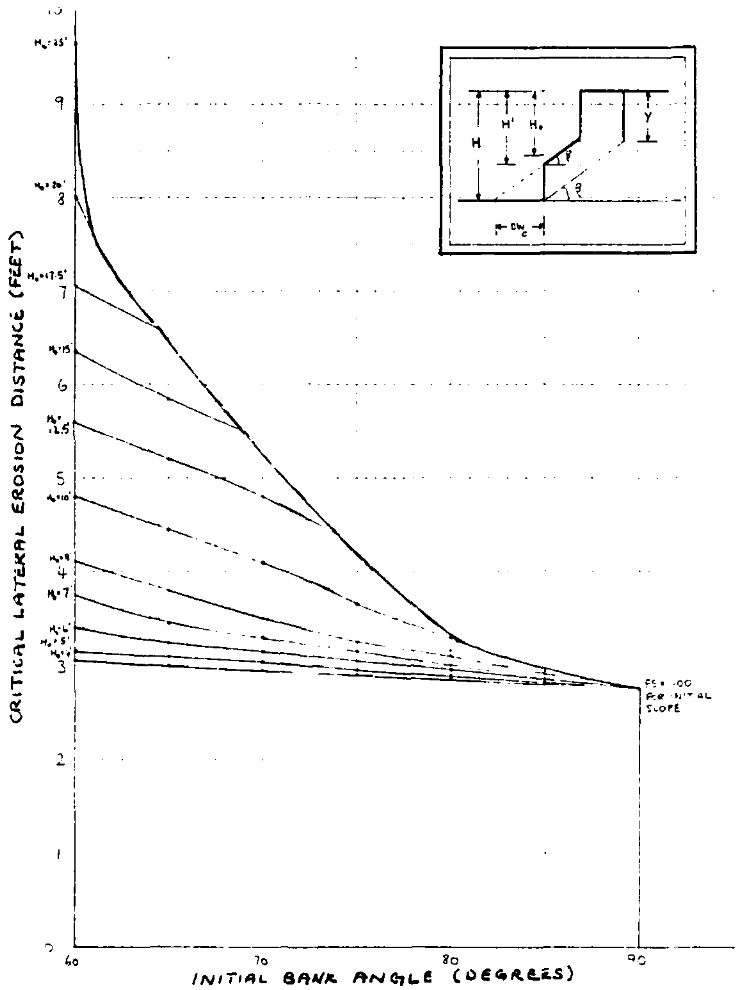


Fig.5 Critical Lateral Erosion Distance for Subsequent Failures of Long Creek Streambanks

way to determine the sequence of events responsible for bringing the bank to an unstable condition, or of knowing the geometry at the time of failure. Thus, while the data are of use for general testing of Fig. 1, they are not sufficient to test the other figures.

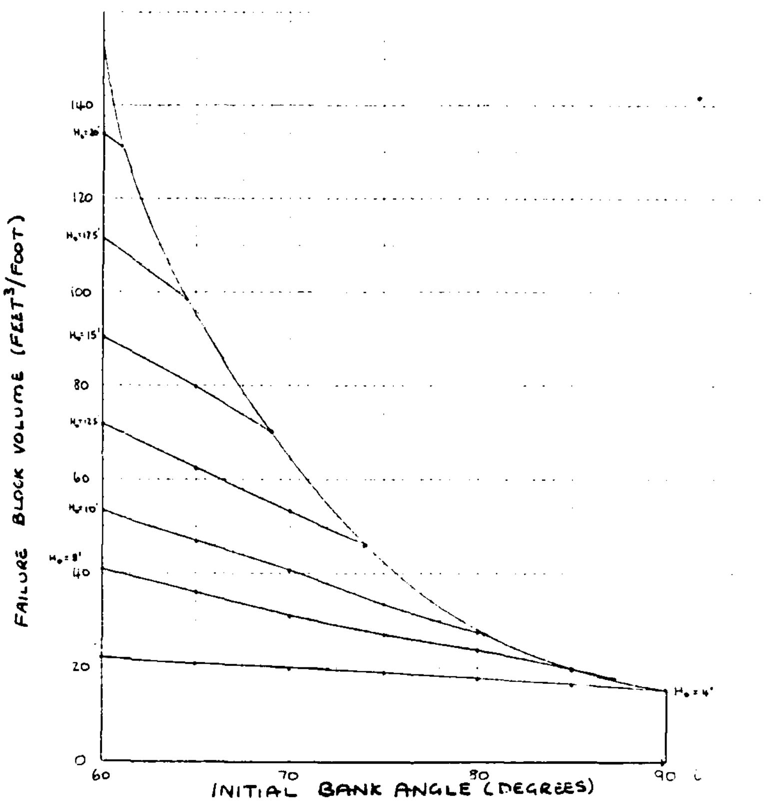


Fig.6 Block Volume for Subsequent Failures of Long Creek Streambanks

2 RESEARCH PLANS

To overcome the limitations of the data supplied by LMVD, field trips will be made to Long Creek in the coming months, to make detailed observations of bank geometry just prior to and just following failure. A number of banks profiles will be surveyed in areas known to be actively retreating, and the staff at the Sedimentation Laboratory will keep me informed of high flow events and associated bank erosion leading to bank failures, so that banks can be re-surveyed soon after failure.

Regionalization of the bank analysis using data from the Red River is distinctly possible, on the evidence of this month's visit there. This possibility will be pursued with the LMVD.

Investigation of development of the Corps of Engineers' aggradation/degradation model, HEC-6, to include a bank stability criterion will continue.

3 ADMINISTRATIVE ACTIONS

The requirement for field work and data collection has necessitated that a field assistant be available to me to act as note taker and surveying rod-man. Also, the large volume of historical channel data supplied by LMVD requires many hours of work on data reduction. At no cost to the project, my graduate student at Queen Mary College, Lisa Cheadle, will help me with these tasks. She will gain valuable experience and exposure to channels of a type unfamiliar to her, which will benefit her in her studies toward a higher degree from the University of London. Therefore, I have requested of the European Research Office that Ms Cheadle be added to the project as a temporary, unpaid, field assistant. She will return to her regular studies in January, 1988.

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ANNEX 1 : BANK STABILITY PROGRAM FOR HP 41-CV

INITIAL FAILURE

```
01♦LBL "USE:"
02 CLX
03 "COLINTHORNE-"
04 AVIEW
05 PSE
06 "BANKANALYSIS"
07 AVIEW
08 PSE
09 CLRG
10♦LBL 01
11 1
12 STO 24
13 FIX 0
14 "STEP NO."
15 ARCL 24
16 AVIEW
17 PSE
18 "H? FT"
19 PROMPT
20 STO 01
21 "H1? FT"
22 PROMPT
23 STO 02
24 RCL 01
25 /
26 1/X
27 1
28 X<=Y?
29 GTO 02
30 TONE 1
31 "H1>H,BAD DATA"
32 PROMPT
33 ST- 24
34 GTO 01
35♦LBL 02
36 "I? DEG"
37 PROMPT
38 STO 03
39 60
40 X<=Y?
41 GTO 03
42 TONE 9
43 "WARNING: I>60"
44 AVIEW
45 PSE
46♦LBL 03
47 90
48 RCL 03
49 X<=Y?
50 GTO 04
51 TONE 1
52 "I>90,BAD DATA"
53 PROMPT
54 GTO 02
55♦LBL 04
56 "SP.WT? LB/FT3"
57 PROMPT
58 STO 04
59 "PHI? DEG"
60 PROMPT
61 STO 05
62 "C? LB/FT2"
63 PROMPT
64 STO 06
65♦LBL 05
66 "K?"
67 PROMPT
68 STO 07
69 1
70 X>Y?
71 GTO 06
72 TONE 1
73 "K>1, BAD DATA"
74 PROMPT
75 GTO 05
76♦LBL 06
77 RCL 01
78 RCL 02
79 /
80 STO 20
81 0
82 X>Y?
83 GTO 07
84 RCL 03
85 TAN
86 1
87 RCL 07
88 X↑2
89 -
90 *
91 RCL 01
92 RCL 02
93 /
94 X↑2
95 *
96 ATAN
97 RCL 05
98 +
99 2
100 /
101 STO 08
102 1
103 RCL 07
104 X↑2
105 -
106 RCL 08
107 SIN
108 RCL 08
109 COS
110 *
111 RCL 03
112 COS
113 X↑2
114 RCL 05
115 TAN
116 *
117 -
118 *
119 STO 09
120 2
121 ENTER↑
122 1
123 RCL 07
124 -
125 *
126 RCL 06
127 *
128 RCL 04
129 /
130 RCL 02
131 /
132 STO 10
133 RCL 08
134 SIN
135 RCL 08
136 COS
137 *
138 RCL 05
139 TAN
140 *
141 RCL 08
142 SIN
143 X↑2
144 -
```

```
RCL 03
TAN
/
STO 11
RCL 10
RCL 09
/
STO 12
X↑2
4
RCL 11
*
RCL 09
/
-
SQRT
RCL 12
+
2
/
STO 13
RCL 13
RCL 20
/
STO 25
FIX 2
"FS="
ARCL 25
PROMPT
1.005
X<=Y?
GTO 08
RCL 25
.995
X>Y?
GTO 07
BEEP
"H=CRITICAL"
PROMPT
FIX 2
"H CRIT="
ARCL 01
"├FT"
PROMPT
"H1CRIT="
ARCL 02
"├FT"
PROMPT
RCL 01
RCL 07
*
STO 28
"Y CRIT="
ARCL 28
"├FT"
PROMPT
"ICRIT="
ARCL 03
"├DEG"
PROMPT
"BETA="
ARCL 08
"├ DEG"
PROMPT
RCL 01
RCL 01
RCL 07
*
-
RCL 08
TAN
/
RCL 02
RCL 03
TAN
/
-
STO 26
FIX 2
"BW="
ARCL 26
"├ FT"
PROMPT
RCL 01
X↑2
RCL 01
RCL 07
*
X↑2
-
RCL 08
TAN
/
RCL 02
X↑2
RCL 03
TAN
/
-
2
/
STO 27
FIX 1
"VB="
ARCL 27
"├FT3/FT"
PROMPT
1
"RUN COMPLETE"
AVIEW
PSE
"FOR NEW BANK"
AVIEW
PSE
"PRESS  0 R/S"
AVIEW
PSE
"FOR"
AVIEW
PSE
"SUBSEQUENT"
AVIEW
PSE
"FAILURES"
AVIEW
PSE
"PRESS  1 R/S"
PROMPT
X=Y?
"I"
GTO "FSS"
GTO "USFS"
♦LBL 08
"BANK STABLE"
PROMPT
♦LBL 09
1
ST+ 24
FIX 0
"STEP NO. "
ARCL 24
PROMPT
RCL 03
90
X=Y?
GTO 10
RCL 20
10
X<=Y?
GTO 11
"BW? FT"
PROMPT
STO 21
RCL 02
RCL 21
RCL 03
TAN
*
STO 16
X=0?
GTO 12
/
STO 23
1.005
X<=Y?
GTO 12
RCL 23
.995
X<=Y?
GTO 11
TONE 9
"H1<0,REDUCEBW"
PROMPT
1
ST- 24
GTO 09
♦LBL 12
RCL 16
CHS
RCL 02
+
STO 02
GTO 10
♦LBL 11
CLX
STO 21
90
STO 03
TONE 5
"BANKVERTICAL"
AVIEW
PSE
"DUETOEROSION"
AVIEW
PSE
♦LBL 10
CLX
"DZ? FT"
PROMPT
STO 22
RCL 01
+
STO 01
FIX 2
"H="
ARCL 01
"├ FT"
PROMPT
90
RCL 03
X=Y?
GTO 13
♦LBL 14
"H1="
ARCL 02
"├ FT"
```

```
361 PROMPT
362 GTO 06
363+LBL 13
364 RCL 01
365 STO 02
366 GTO 14
367+LBL 07
368 1
369 ST- 24
370 RCL 24
371 X=0?
372 GTO 15
373 TONE 5
374 "BANKTOO HIGH"
375 AVIEW
376 PSE
377 "REDUCE DW+DZ"
378 PROMPT
379 RCL 01
380 RCL 22
381 -
382 STO 01
383 90
384 RCL 03
385 X=Y?
386 GTO 16
387 TAN
388 RCL 21
389 *
390 RCL 02
391 +
392 STO 02
393 GTO 09
394+LBL 16
395 RCL 01
396 STO 02
397 GTO 09
398+LBL 15
399 TONE 3
400 TONE 1
401 "BANK:UNSTABLE"
402 AVIEW
403 PSE
404 "CHECK DATA"
405 AVIEW
406 PSE
407 1
408 ST- 24
409 GTO 01
410 .END.
```

SUBSEQUENT FAILURES

```
01+LBL "FSS"
02 "ANALYSIS OF"
03 AVIEW
04 PSE
05 "SUBSEQUENT"
06 AVIEW
07 PSE
08 "FAILURES"
09 AVIEW
10 PSE
11 1
12 STO 24
13 FIX 0
14 "STEP NO. "
15 ARCL 24
16 PROMPT
17 RCL 01
18 STO 02
19 RCL 08
20 STO 03
21 RCL 02
22 RCL 01
23 RCL 07
24 *
25 STO 32
26 -
27 RCL 08
28 TAN
29 /
30 STO 33
31+LBL 17
32 RCL 01
33 RCL 02
34 /
35 STO 20
36 RCL 08
37 COS
38 RCL 08
39 SIN
40 *
41 RCL 08
42 COS
43 X↑2
44 RCL 05
45 TAN
46 *
47 -
48 STO 14
49 2
50 ENTER↑
51 1
52 RCL 07
53 -
54 *
55 RCL 06
56 *
57 RCL 04
58 /
59 RCL 02
60 /
61 STO 15
62 RCL 14
63 /
64 X↑2
65 4
66 +
67 SQRT
68 RCL 15
69 RCL 14
70 /
71 +
72 2
73 /
74 STO 13
75 RCL 20
76 /
77 STO 25
78 FIX 2
79 "FSS="
80 ARCL 25
81 PROMPT
82 1.005
83 X<=Y?
84 GTO 18
85 RCL 25
86 .995
87 X>Y?
88 GTO 19
89 BEEP
90 "H1=CRITICAL"
91 PROMPT
92 FIX 2
93 "HCRIT="
94 ARCL 01
95 "├FT"
96 PROMPT
97 "H1CRIT="
98 ARCL 02
99 "├FT"
100 PROMPT
101 RCL 01
102 RCL 07
103 *
104 STO 28
105 "Y CRIT="
106 ARCL 28
107 "├FT"
108 PROMPT
109 "BETA="
110 ARCL 08
111 "├DEG"
112 PROMPT
113 RCL 01
114 RCL 02
115 -
116 RCL 08
117 TAN
118 /
119 STO 30
120 FIX 2
121 "BW="
122 ARCL 30
123 "├FT"
124 PROMPT
125 RCL 01
126 X↑2
127 RCL 02
128 X↑2
129 -
130 2
131 /
132 RCL 08
133 TAN
134 /
135 STO 31
136 FIX 1
137 "VB="
138 ARCL 31
139 "├FT3/FT"
140 PROMPT
141 "RUN COMPLETE"
142 AVIEW
143 PSE
144 STOP
145 GTO "USFS"
146+LBL 18
147 "BANK STABLE"
148 PROMPT
149+LBL 20
150 1
```

```
151 ST+ 24
152 FIX 0
153 "STEP NO. "
154 ARCL 24
155 PROMPT
156 0
157 RCL 33
158 "DW? FT"
159 PROMPT
160 STO 21
161 -
162 STO 33
163 X>Y?
164 GTO 21
165 RCL 02
166 RCL 32
167 -
168 RCL 21
169 RCL 08
170 TAN
171 *
172 X=0?
173 GTO 09
174 CLX
175 GTO 21
176 TONE 5
177 "H1<0,REDUCEDW"
178 PROMPT
179 RCL 21
180 RCL 33
181 +
182 STO 33
183 1
184 ST- 24
185 GTO 20
186♦LBL 21
187 RCL 21
188 RCL 08
189 TAN
190 *
191 STO 16
192 CHS
193 RCL 02
194 +
195 STO 02
196♦LBL 22
197 CLX
198 "DZ? FT"
199 PROMPT
200 STO 22
201 RCL 01
202 +
203 STO 01
204 FIX 2
205 "H="
206 ARCL 01
207 "├FT"
208 PROMPT
209♦LBL 24
210 "H1="
211 ARCL 02
212 "├FT"
213 PROMPT
214 GTO 17
215♦LBL 19
216 1
217 ST- 24
218 TONE 5
219 "BANKTOOSTEEP"
220 AVIEW
221 PSE
222 "REDUCE DW+DZ"
223 PROMPT
224♦LBL 25
225 RCL 01
226 RCL 22
227 -
228 STO 01
229 RCL 16
230 RCL 02
231 +
232 STO 02
233 RCL 21
234 RCL 33
235 +
236 STO 33
237 GTO 20
238 END
```

END

DATE
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