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ANALYSIS OF BANK STABILITY IN THE DEC WATERSHEDS
MISSISSIPPI (U) QUEEN MARY COLL LONDON (ENGLAND)
C R THORNE OCT 87 DAJA45-87-C-0021

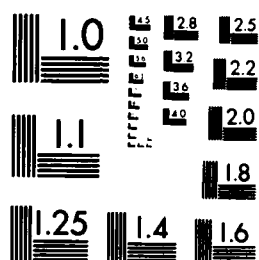
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ANALYSIS OF BANK STABILITY
IN THE DEC WATERSHEDS, MISSISSIPPI

By

Colin R. Thorne

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Contract Number DAJ45-87-C-0021

First Periodic Report

May - June 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 contains 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 10 th , 1987.		

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A

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 is a 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 requires 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

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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). Recently 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 following data are needed to perform the analysis:

<u>Variable</u>	<u>Symbol</u>	<u>Units</u>
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.

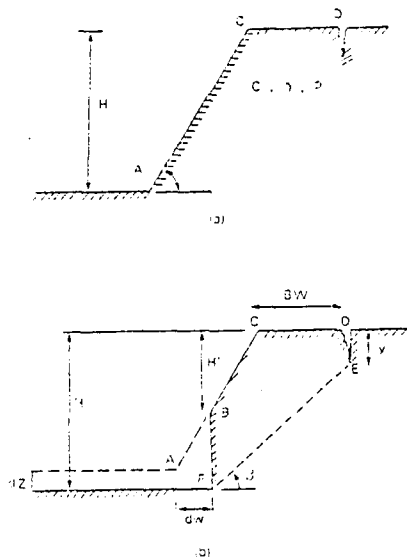


Figure 2. Definition diagram for variables in slab failure analysis: a) Initial geometry; b) After erosion and bed degradation to the critical case.

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:

COLIN THORNE-BANK ANALYSIS

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 NOT 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

<u>STEP</u>	<u>INSTRUCTION</u>	<u>INPUT</u>	<u>FUNCTION</u>	<u>DISPLAY</u>
1	Initialize program		XEQ USFS	COLIN THORNE- BANK ANALYSIS STEP NO. 1. H ? FT H1 ? FT
2	Input total height	H	R/S	
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 =____FT ³ /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

STEP NO. _____

Table 1 Results Table

[illegible]

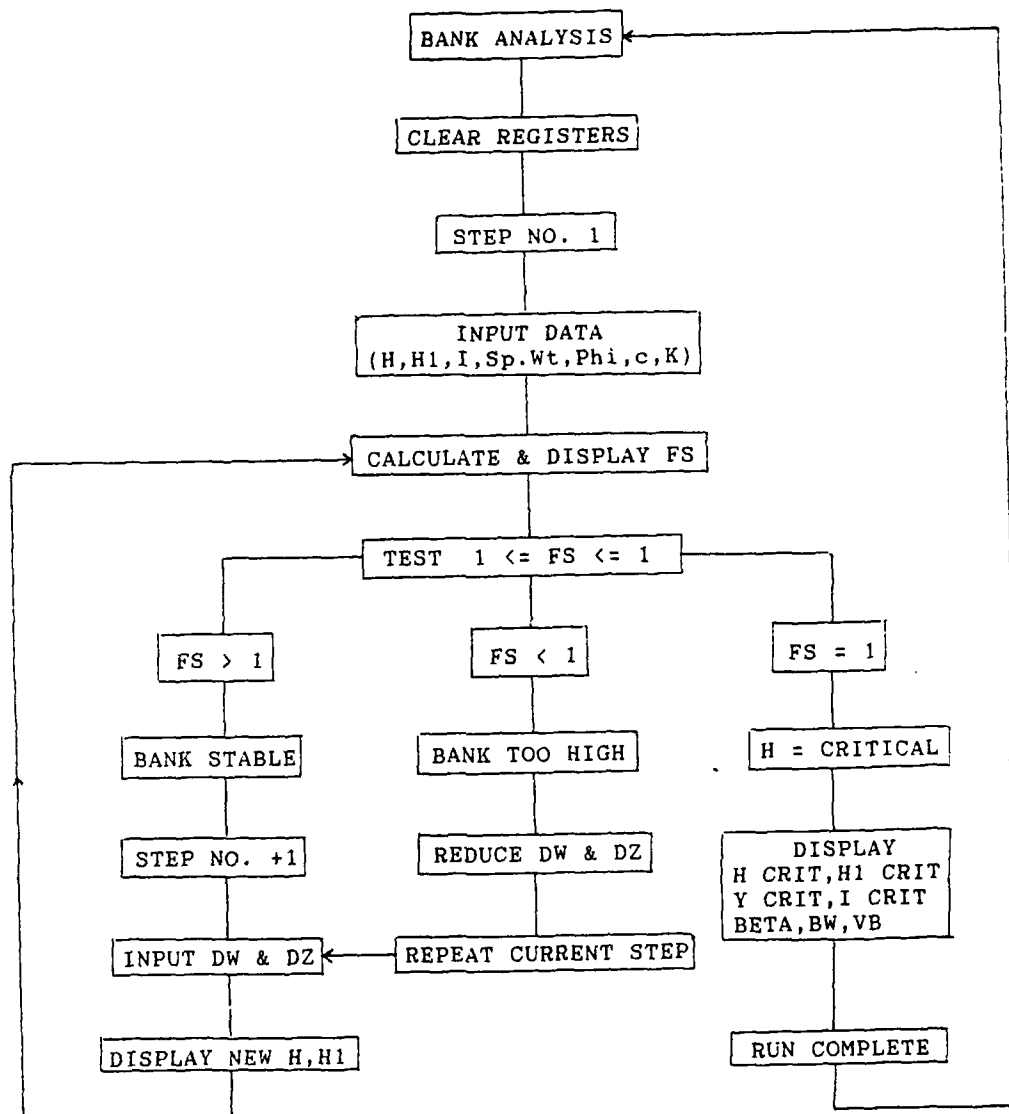


Figure 3. Flow Chart for Bank Stability Analysis

4 EXAMPLE

4.1 Program Steps

KEYSTROKE

DISPLAY

XEQ ALPHA USFS ALPHA

15 R/S

15 R/S

70 R/S

100 R/S

12 R/S

400 R/S

0.5 R/S

R/S

R/S

R/S

0.6 R/S

1.5 R/S

R/S

R/S

R/S

R/S

R/S

0.6 R/S

1.2 R/S

R/S

R/S

R/S

R/S

R/S

R/S

0.5 R/S

1.1 R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

R/S

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BANK ANALYSIS

STEP NO. 1.

H? FT

H1? FT

I? DEG

SP.WT? LB/FT3

PHI? DEG

C? LB/FT2

K?

FS = 1.30

BANK STABLE

STEP NO. 2.

DW? FT

DZ? FT

H = 16.50 FT

H1= 13.35 FT

FS = 1.11

BANK STABLE

STEP NO. 3.

DW? FT

DZ? FT

H = 17.70 FT

H1= 11.70 FT

FS = 0.98

BANK TOO HIGH

REDUCE DW + DZ

STEP NO. 3.

DW? FT

DZ? FT

H = 17.60 FT

H1= 11.98 FT

FS = 1.00

H = CRITICAL

H CRIT = 17.6FT

H1CRIT = 12.0FT

Y CRIT = 8.8 FT

I CRIT = 70 DEG

BETA = 44.7 DEG

BW = 4.54 FT

VB = 91.4FT3/FT

RUN COMPLETE

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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

DISPLAY

BANK UNSTABLE :
CHECK DATA

BANK VERTICAL
DUE TO EROSION

H1>H BAD DATA

H1<0, REDUCE DW

I>90, BAD DATA

MEANING

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.

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.

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.

The input value of DW would reduce H1 below zero which is impossible. $H \leq H1 > 0$ 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.

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 "MENU"	51 GTO 03	101 -	151 RCL 11
02 LBL	52*LBL 07	102 RCL 09	152 *
03 "COLLIMATOR E-"	53 *SP.WTO LB/FTZ*	103 SIN	153 RCL 09
04 AVIEW	54 PROMPT	104 RCL 08	154 *
05 PSE	55 STO 04	105 COS	155 -
06 "SEA WAVE 10"	56 *PHI2 DEG*	106 *	156 STPT
07 AVIEW	57 PROMPT	107 RCL 01	157 RCL 12
08 PSE	58 STO 05	108 COS	158 *
09 LBL	59 *ST LB/FTZ*	109 X12	159 *
10*LBL "24"	60 PROMPT	110 RCL 05	160
11 *	61 STO 06	111 TAN	161 STO 13
12 STO 14	62*LBL 12	112 *	162 CL
13 RCL 2	63 *K*	113 -	163 CL
14 *STPT	64 PROMPT	114 *	164*LBL "CHELY"
15 RCL 14	65 STO 07	115 STO 04	165 RCL 13
16 PSE	66 *	116 *	166 RCL 20
17 PSE	67 X/Y	117 ENTER	167 *
18 *STPT	68 GTO "CALC"	118 *	168 STO 25
19 PROMPT	69 *K1, END DATA*	119 RCL 07	169 SIN 2
20 STO 01	70 PROMPT	120 -	170 *PSE*
21 *STPT*	71 GTO 13	121 *	171 RCL 25
22 PROMPT	72*LBL "CALC"	122 RCL 06	172 PROMPT
23 STO 02	73 RCL 01	123 *	173 L/RAS
24 RCL 01	74 RCL 03	124 RCL 04	174 *STPT*
25	75 /	125	175 STO *ST*
26 LBL	76 STO 20	126 RCL 01	176 RCL 25
27 *	77 0	127 *	177 *PSE*
28 LBL	78 X/Y	128 STO 10	178 *STPT*
29 STO 11	79 GTO "US"	129 RCL 08	179 *STPT*
30 "PHYS END DATA"	80 RCL 03	130 SIN	180 PSE
31 PROMPT	81 TAN	131 RCL 02	181 "ACRITICAL"
32 STO 24	82 *	132 COS	182 PROMPT
33 STO "DATA"	83 RCL 07	133 *	183 RCL 1
34*LBL 08	84 X12	134 RCL 05	184 *ACRITICAL*
35 *STPT DEG*	85 -	135 TAN	185 RCL 01
36 PROMPT	86 *	136 *	186 *STPT*
37 STO 03	87 RCL 01	137 RCL 06	187 PROMPT
38 60	88 RCL 02	138 SIN	188 "ACRITICAL"
39 X/Y	89 /	139 X12	189 RCL 02
40 GTO 01	90 X12	140 -	190 *STPT*
41 *WARNING 1 60*	91 *	141 RCL 03	191 PROMPT
42 AVIEW	92 ATAN	142 TAN	192 RCL 01
43 PSE	93 RCL 05	143 *	193 RCL 07
44*LBL 21	94 *	144 STO 11	194 *
45 30	95 *	145 RCL 10	195 STO 20
46 RCL 07	96 /	146 RCL 09	196 *Y OPT*
47 X/Y	97 STO 08	147 *	197 RCL 28
48 GTO 07	98 *	148 STO 12	198 *STPT*
49 "I 90 200 DATA"	99 RCL 07	149 X12	199 PROMPT
50 PROMPT	100 X12	150 *	200 RCL 1

```

201 "ICRIT="
202 APCL 01
203 "4500"
204 PROMPT
205 "BETA="
206 APCL 01
207 "4 500"
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 06
223 FIX 2
224 "BN="
225 APCL 06
226 "4 FT"
227 PROMPT
228 RCL 01
229 X12
230 RCL 01
231 RCL 07
232 *
233 X12
234 -
235 RCL 00
236 TAN
237 /
238 RCL 02
239 X12
240 RCL 03
241 TAN
242 /
243 -
244 1
245 /
246 STO 27
247 FIX 1
248 "VS="
249 APCL 27
250 "4500 FT"

```

```

251 PROMPT
252 CLX
253 "RUN COMPLETE"
254 AVIEW
255 PSE
256 PSE
257 GTO "USF3"
258 LBL "ST"
259 "BANK STABLE"
260 PROMPT
261 LBL "N1"
262 1
263 ST+ 24
264 FIX 0
265 "STEP NO. "
266 APCL 24
267 PROMPT
268 RCL 03
269 00
270 X=Y?
271 GTO 03
272 RCL 20
273 10
274 X=Y?
275 GTO 13
276 FIX 3
277 "BN2 FT"
278 PROMPT
279 STO 21
280 RCL 02
281 RCL 01
282 RCL 03
283 TAN
284 *
285 STO 16
286 X=0?
287 GTO 04
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 "H10.0.0.0.0.0.0"
298 PROMPT
299 1
300 ST+ 24

```

```

301 GTO "N1"
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 00
313 STO 03
314 "BANK VERTICAL"
315 AVIEW
316 PSE
317 "QUOTED POSITION"
318 AVIEW
319 PSE
320 LBL 03
321 CLX
322 "222 FT"
323 PROMPT
324 STO 22
325 RCL 01
326 +
327 STO 01
328 FIX 2
329 "H="
330 APCL 01
331 "4 FT"
332 PROMPT
333 00
334 RCL 03
335 X=Y?
336 GTO 04
337 LBL 05
338 "41="
339 APCL 01
340 "4 FT"
341 PROMPT
342 GTO "CALC"
343 LBL 04
344 RCL 01
345 STO 01
346 GTO 05
347 LBL "US"
348 1
349 ST+ 24
350 RCL 24

```

```

351 "07"
352 GTO 02
353 "BANK TOO HIGH"
354 PROMPT
355 "REDUCE BN=10"
356 PROMPT
357 LBL 10
358 RCL 01
359 RCL 22
360 -
361 STO 01
362 00
363 RCL 03
364 X=Y?
365 GTO 06
366 TAN
367 RCL 21
368 *
369 RCL 02
370 +
371 STO 02
372 GTO "N1"
373 LBL 06
374 RCL 01
375 STO 02
376 GTO "N1"
377 LBL 02
378 0.0010
379 STO 29
380 BEEP
381 LBL 11
382 "BANK UNSTABLE"
383 AVIEW
384 PSE
385 "CHECK DATA"
386 AVIEW
387 PSE
388 100 29
389 GTO 11
390 1
391 ST+ 24
392 GTO "DATA"
393 END

```

5781-EN.

ANALYSIS OF BANK STABILITY
IN THE DEC WATERSHEDS, MISSISSIPPI

By

Colin R. Thorne

Queen Mary College, University of London, UK

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 HP41C calculator, dealing with the initial failure due to bed degradation and subsequent failures due to bank 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 forthcoming 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	Unit Weight	Tensile Strength
	(%)	(°)	(lb/ft ²)	(lb/ft ³)	(lb/ft ²)
PSA	50	12	430	123	46
MBI (YP)	20	16	317	122	106
L (OP)	10	14	720	132	221
Sands	20	20	0	141	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.

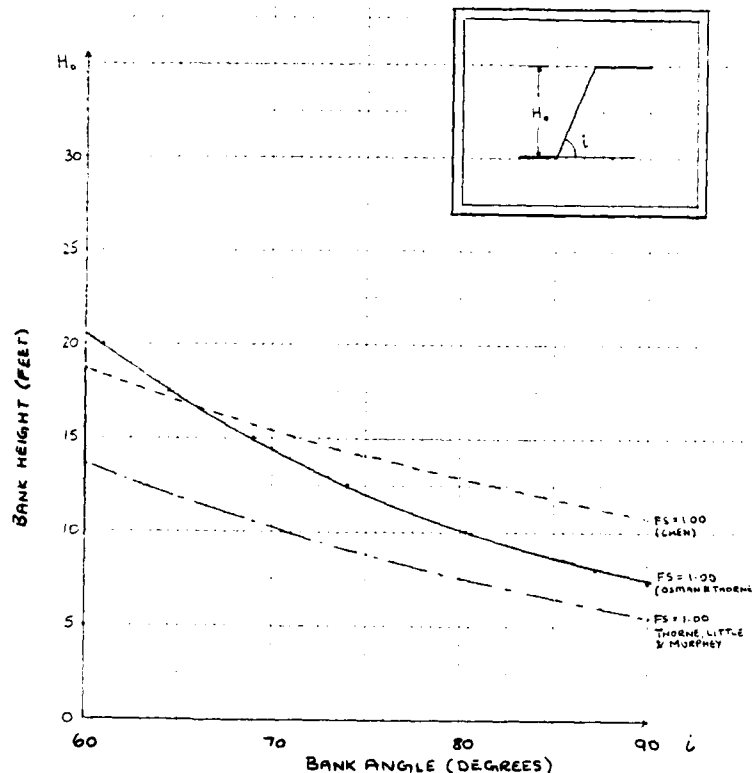


Fig.1 Critical Height for Slab-Type Failure of Streambanks

The soils data and crack depth were used in the HP-11CV 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.

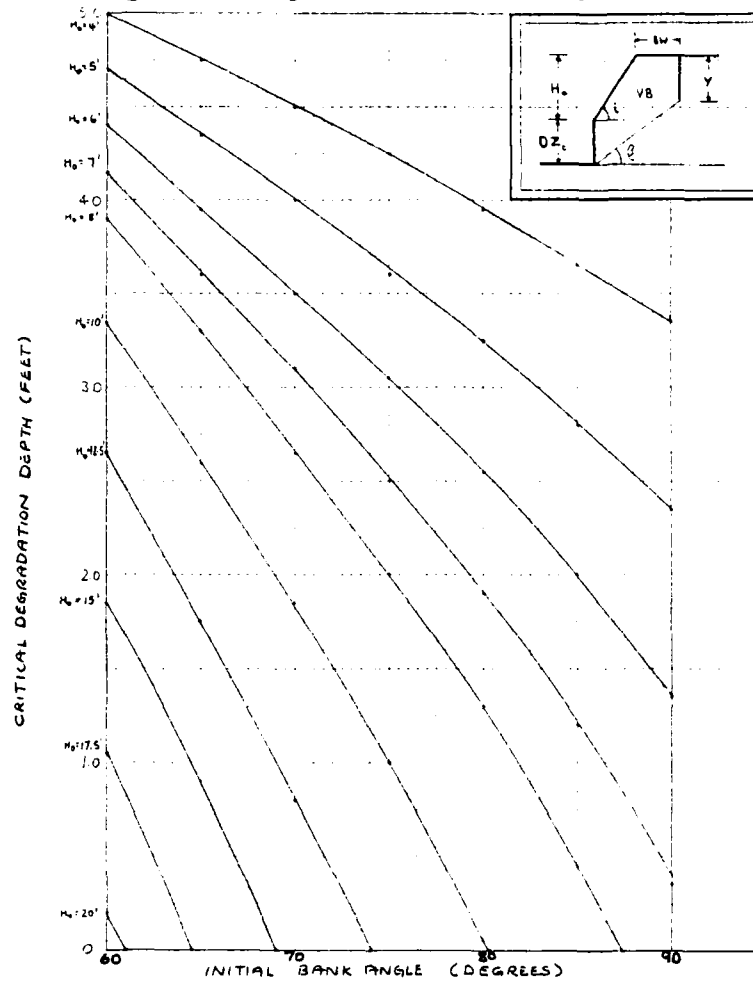


Fig. 2 Critical Degradation Depth for Initial Failure

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.

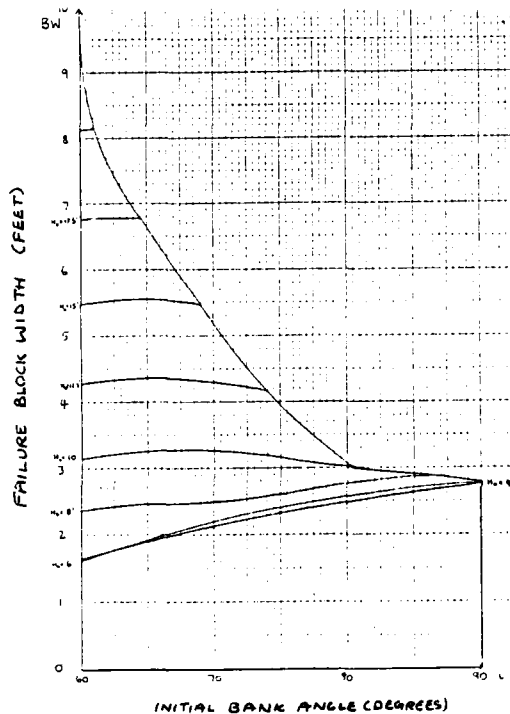


Fig.3 Block Width for Initial Failure

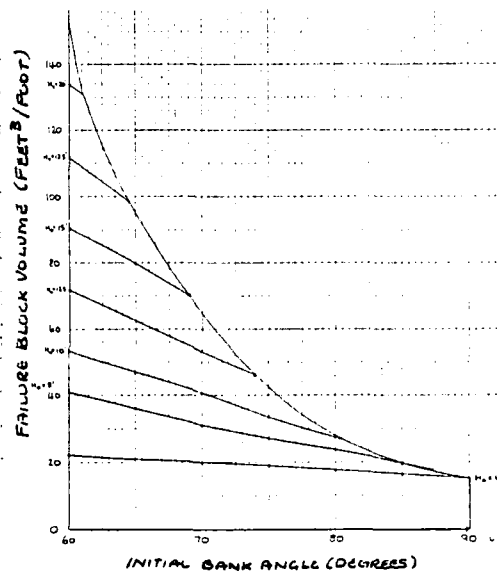


Fig.4 Block Volume for Initial Failure

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

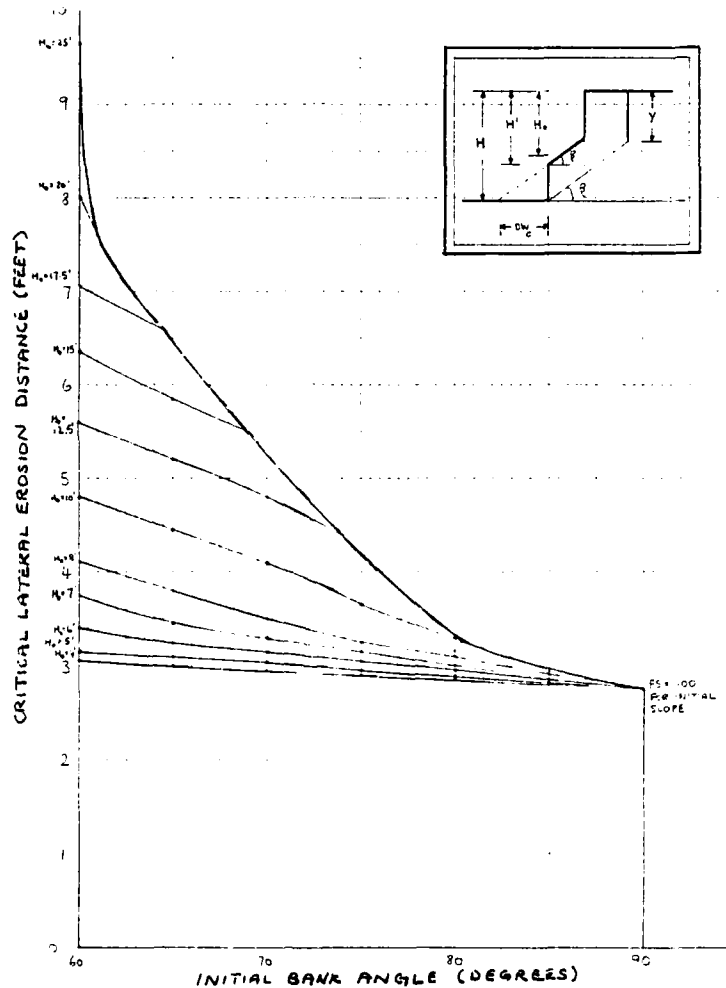


Fig.5 Critical Lateral Erosion Distance for Subsequent Failures of Long Creek Streambanks

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.

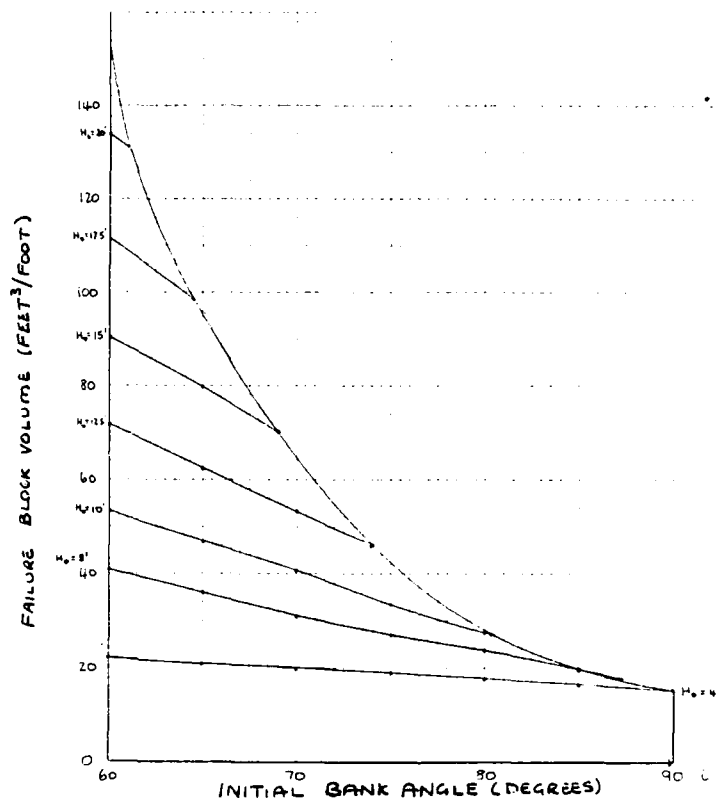


Fig. 6 Block Volume for Subsequent Failures of Long Creek Streambanks

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 bank 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, 1983.

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ANNEX 1 : BANK STABILITY PROGRAM FOR HP 41-CV

INITIAL FAILURE

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

145 RCL 03	199 "FT"	253 "RUN COMPLETE"	307 STO 23
146 TAN	200 PROMPT	254 AVIEW	308 1.005
147 /	201 "ICRIT="	255 PSE	309 X<=Y?
148 STO 11	202 ARCL 03	256 "FOR NEW BANK"	310 GTO 12
149 RCL 10	203 "DEG"	257 AVIEW	311 RCL 23
150 RCL 09	204 PROMPT	258 PSE	312 .995
151 /	205 "BETA="	259 "PRESS 0 R/S"	313 X<=Y?
152 STO 12	206 ARCL 08	260 AVIEW	314 GTO 11
153 X*2	207 "DEG"	261 PSE	315 TONE 9
154 4	208 PROMPT	262 "FOR"	316 "HI<0,REDUCEJW"
155 RCL 11	209 RCL 01	263 AVIEW	317 PROMPT
156 *	210 RCL 01	264 PSE	318 1
157 RCL 09	211 RCL 07	265 "SUBSEQUENT"	319 ST- 24
158 /	212 *	266 AVIEW	320 GTO 09
159 -	213 -	267 PSE	321*LBL 12
160 SQRT	214 RCL 08	268 "FAILURES"	322 RCL 16
161 RCL 12	215 TAN	269 AVIEW	323 CWS
162 +	216 /	270 PSE	324 RCL 02
163 2	217 RCL 02	271 "PRESS 1 R/S"	325 +
164 /	218 RCL 03	272 PROMPT	326 STO 02
165 STO 13	219 TAN	273 X=Y?	327 GTO 10
166 RCL 13	220 /	274 "I"	328*LBL 11
167 RCL 20	221 -	275 GTO "FSS"	329 CLX
168 /	222 STO 26	276 GTO "USFS"	330 STO 21
169 STO 25	223 FIX 2	277*LBL 08	331 90
170 FIX 2	224 "BW="	278 "BANK STABLE"	332 STO 03
171 "FS="	225 ARCL 26	279 PROMPT	333 TONE 5
172 ARCL 25	226 "+ FT"	280*LBL 09	334 "BANKVERTICAL"
173 PROMPT	227 PROMPT	281 1	335 AVIEW
174 1.005	228 RCL 01	282 ST+ 24	336 PSE
175 X<=Y?	229 X*2	283 FIX 0	337 "DUETOEROSION"
176 GTO 08	230 RCL 01	284 "STEP NO. "	338 AVIEW
177 RCL 25	231 RCL 07	285 ARCL 24	339 PSE
178 .995	232 *	286 PROMPT	340*LBL 10
179 X>Y?	233 X*2	287 RCL 03	341 CLX
180 GTO 07	234 -	288 90	342 "DZ? FT"
181 BEEP	235 RCL 08	289 X=Y?	343 PROMPT
182 "H=CRITICAL"	236 TAN	290 GTO 10	344 STO 22
183 PROMPT	237 /	291 RCL 20	345 RCL 01
184 FIX 2	238 RCL 02	292 10	346 +
185 "H CRIT="	239 X*2	293 X<=Y?	347 STO 01
186 ARCL 01	240 RCL 03	294 GTO 11	348 FIX 2
187 "FT"	241 TAN	295 "BW? FT"	349 "H="
188 PROMPT	242 /	296 PROMPT	350 ARCL 01
189 "MICRIT="	243 -	297 STO 21	351 "+ FT"
190 ARCL 02	244 2	298 RCL 02	352 PROMPT
191 "FT"	245 /	299 RCL 21	353 90
192 PROMPT	246 STO 27	300 RCL 03	354 RCL 03
193 RCL 01	247 FIX 1	301 TAN	355 X=Y?
194 RCL 07	248 "VB="	302 *	356 GTO 13
195 *	249 ARCL 27	303 STO 16	357*LBL 14
196 STO 28	250 "FT3/FT"	304 X=0?	358 "HI="
197 "Y CRIT="	251 PROMPT	305 GTO 12	359 ARCL 02
198 ARCL 28	252 1	306 /	360 "+ 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 "BANK TOO HIGH"
 375 AVIEW
 376 PSE
 377 "REDUCE DW+DL"
 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 X12
 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 X12
 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 X1Y?
 88 GTO 19
 89 BEEP
 90 "H1=CRITICAL"
 91 PROMPT
 92 FIX 2
 93 "HCRT"
 94 ARCL 01
 95 "HFT"
 96 PROMPT
 97 "HICRT"
 98 ARCL 02
 99 "HFT"
 100 PROMPT

101 RCL 01
 102 RCL 07
 103 *
 104 STO 28
 105 "Y CRIT"
 106 ARCL 28
 107 "HFT"
 108 PROMPT
 109 "BETA"
 110 ARCL 08
 111 "HDEC"
 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 "HFT"
 124 PROMPT
 125 RCL 01
 126 X12
 127 RCL 02
 128 X12
 129 -
 130 2
 131 /
 132 RCL 08
 133 TAN
 134 /
 135 STO 31
 136 FIX 1
 137 "VB"
 138 ARCL 31
 139 "HFT3/HFT"
 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 *BW? 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 *M1'0,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 *BZ? 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 RVIEW
 221 PSE
 222 *REDUCE DW+DC*
 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
FILMED

3 88