BERM FAILURE TECHNICAL ANALYSES

SOUTH PLATTE GRAVEL PIT EVALUATION CRITERIA

Prepared for
Urban Drainage and
Flood Control District

WWE

Wright Water Engineers, Inc.

January 2013
121-030.000

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INTRODUCTION

The 1987 *Technical Review Guidelines for Gravel Mining Activities Within or Adjacent to 100-Year Floodplains* (Guidelines) is based upon the 1985 criteria developed for Adams County. The 1985 and 1987 parameters as published represent the combined knowledge and experience of the many dozens of individuals who conferred on original and early Wright Water Engineers, Inc. (WWE) draft documents and criteria.

The criteria of the guidelines were based upon engineering principles and practical objectives related to rock product mining of the 1980s. Original and initial guideline drafts in early 1985 were modified via significant industry and regulatory agency input during the spring of 1985. The technical criteria given in the 1987 guidelines are based upon principles, policy and criteria from the 1969 Urban Drainage and Flood Control District (UDFCD) Urban Storm Drainage Criteria Manual (USDCM), the 1984-1985 Master Plan, industry practices and economics, regulatory agency needs and the civil and geotechnical engineering professions. The parameters are supportable.

In 2012, WWE prepared updates to the guidelines, including evaluation of the original setback requirements using research performed and calculation methods developed over the 25-years since the guidelines were first published. The calculation methods are discussed in greater detail in the attachments to this memorandum. The calculation attachments are as follows:

Attachment A–Embankment Overtopping Analysis per Federal Highway Administration (FHWA) Method

Attachment B–Dam Breach Analysis per Colorado State Engineer’s Office (SEO) Guidance

Attachment C–Steep Slope Riprap Sizing per the Gravel Guidelines

Attachment D–Steep Slope Riprap Sizing per Hydrologic Engineering Circular (HEC) 23

ASSUMPTIONS

For Attachments A through D, the following assumptions were used for each set of stability test calculations:

- The embankment overtopping depth varies between 2-feet and 6-feet.
- Overtopping flows were bracketed between 1,000 cfs and 20,000 cfs.
- For unprotected or natural vegetation berms, an assumed top width of 300-feet was analyzed.
- The downstream gravel pit is essentially empty. A similar hydraulic drop is assumed for overflow to the River.
- The flooding event will last 24 to 48 hours.

BERM FAILURE

The Attachment A and B calculations were performed for comparison with each other. The attachment A calculation method was developed through a series of large-scale hydraulic model experiments to simulate floods overtopping highway embankments. The hydraulic model experiments varied several parameters, including crest cover with pavement, grass, or bare soil, and embankment slopes either covered with grass of bare soil. These conditions are similar to the gravel pit berms in that the roadway embankment soil compaction and soil type may vary, as is the possible case with gravel pit berms which consist of natural undisturbed soil or overburden placed at along the edge of the pit excavation during reclamation efforts. The study referenced in attachment A was issued in March of 1987. The Attachment B dam breach analysis was used for comparison with the attachment A results. The dam breach guidelines were assembled by the Colorado SEO Dam Safety branch to provide guidance for dam failure inundation mapping and assigning dam hazard classifications. This guidance documents was released in February of 2010 and summarized numerous methods of dam breach modeling based on regression equations developed from data bases of actual dam failures. The dam breach guidance is not a direct comparison because dams tend to be constructed with a greater amount of soil compaction and compaction testing than roadway embankments and the dam breach analysis focuses on peak flow rate and breach size once the dam failure begins, rather than a prolonged overtopping scenario. The dam breach analysis does provide a reasonableness check for the roadway embankment failure analysis as well as better representing the gravel berm heights of nearly 30-feet when compared with the typical roadway embankment height of up to 15-feet. Figure 1 shows the dimensions and variables of the example berm analyzed.

The results of the calculations presented in attachments A and B are summarized below for comparison purposes.

Table 1
Volume of Eroded Embankment
Lateral Berms without Protection

Condition		Erosion Volume per Foot of Embankment Length		Percent of Embankment Eroded
		CY/FT	CF/FT	
30-Foot Tall Berm	Bare Soil, 6 Feet Overtopping for 24 Hours	323	8,709	78 %
	Bare Soil, 6 Feet Overtopping for 48 Hours	605	16,330	100%
	Paved Crest, 6 Feet Overtopping for 24 Hours	271	7,309	65%
15-Foot Tall Berm	Bare Soil, 6 Feet Overtopping for 24 Hours	155	4,180	82%
	Bare Soil, 6 Feet Overtopping for 48 Hours	290	7,838	100%
	Paved Crest, 6 Feet Overtopping for 24 Hours	130	3,509	69%
30-Foot Tall Berm	Bare Soil, 2 Feet Overtopping for 24 Hours	169	4,572	40%
	Bare Soil, 2 Feet Overtopping for 48 Hours	318	8,573	76%
	Paved Crest, 2 Feet Overtopping for 24 Hours	161	4,355	39%

Note: The 30-foot tall berm has a volume of 417 cy/ft and the 15-foot tall berm has a volume of 188 cy/ft.

Table 2
Dam Breach Analysis—Volume of Eroded Soil, Peak Flow Rate from Breach and Time for Breach Formation

Calculation Method		Peak Breach Discharge	Breach Formation Time	Volume of Material Eroded	Avg. Breach Width	Erosion Volume per Foot of Embankment Length		Percent of Embankment Eroded[4]
		(cfs)	(hours)	(cy)	(ft)	(cy/ft)	(cf/ft)	(%)
30-Foot Tall Berm	MLM Method [1] 6 feet Overtopping	10,087	0.55	10,126	40	254	6,860	61
30-Foot Tall Berm	Froehlich Method[2] 6 feet Overtopping, Overtopping Failure	13,981	0.71	48,000	116	414	11,170	99
30-Foot Tall Berm	Froehlich Method[2] 6 feet Overtopping, Piping Failure	14,764	0.71	37, 000	89	417	11,250	100
15-Foot Tall Berm	MLM Method 6 feet Overtopping	8,530	0.52	8,590	46	186	5,040	100
15-Foot Tall Berm	Froehlich Method[3] 6 feet Overtopping, Overtopping Failure	3,411	1.43	21,150	112	189	5,100	100
15-Foot Tall Berm	Froehlich Method[3] 6 feet Overtopping, Piping Failure	3,890	1.43	16,250	86	189	5,100	100
30-Foot Tall Berm	MLM Method [1] 2 feet Overtopping	6,952	051	8,274	36	230	6,205	55
30-Foot Tall Berm	Froehlich Method[2] 2 feet Overtopping, Overtopping Failure	12,635	071	48,000	116	414	11,170	100
30-Foot Tall Berm	Froehlich Method[2] 2 feet Overtopping, Piping Failure	13,196	0.71	37,000	89	417	11,250	100

[1] Berm height less than listed height used due to calculation method limits.
[2] Eroded volume based on an average berm width of 375 feet.
[3] Eroded volume based on an average berm width of 340 feet.
[4] Percent of embankment eroded assumes consistent erosion along entire breach width, while the calculation method assumes a full breach through the dam occurs.

The results above indicate a significant portion of the berm could be eroded during a flood event. The calculations above only account for one failure method at a time; however, animal burrow holes in the embankment can lead to a piping type failure after partial failure has occurred due to overtopping.

Comparing the results of Attachment A and B shows an order of magnitude similarity in the estimated volume of soil eroded. The difference between the results can be attributed to the fact that the calculations are based on different assumptions. The dam breach calculations are intended to predict the breach size and time to failure under the assumption that a breach will occur; while the embankment overtopping calculations are intended to show the volume of earth moved during an overtopping event which might not cause complete failure of the embankment. It is worth noting that the dam breach calculations indicate the full breach will form within 30 minutes to 1.5 hours from the time the breach begins. This shows that if a breach begins to form in the gravel pit berm, it will quickly open and allow water to flow downstream, which can result in more failures downstream due to the in rush of water. The flow rate associated with a breach is a result of the potential energy in the stored water; the flow is above the flow rate occurring in the river. In addition, the sudden draining of a gravel pit can cause instability in the upstream banks which could cause the next upstream gravel pit to breach its bank.

RIPRAP SIZING

The Attachments C and D present calculations for flow down riprap on steep slopes, in particular for protecting the pitside banks during overtopping from the river. These calculations are also applicable for overtopping flow from one pit to the next down river pit or return flow from the pit to the river. For both attachments, flow over the embankment crest and down the steep slope was modeled as a wide modified trapezoidal channel with a 100-foot bottom width and sideslopes of 0.1 percent (1,000 H: 1V). Calculations were based on embankment overflows of 1,000 cfs and 20,000 cfs to bracket the range of potential overtopping flow along the South Platte River.

Attachment C uses the pitside bank steep riprap slope sizing method presented in the 1987 guidelines (Section 2.4.1). The method and equations are similar to the method presented in HEC 11, which was issued in 1989 and revised in 2000 with metric units.

Attachment D calculations are based on a steep slope method presented in HEC 23, Design Guidance 5. HEC 23 is a large, two volume publication covering bridge scour and stream instability by the FHWA. HEC 23, which was released in 2009, addresses roadway overtopping and relies on the FHA document referenced in Attachment A. The method in Attachment D was developed in the 1990's at Colorado State University Hydraulics Laboratory Flume.

In Attachments C and D, each of the methods reviewed indicate a very thick layer of large riprap (larger than the UDFCD maximum size VH/D_{50} = 24") is necessary on steep (2½: 1) slopes for high flows. The results of the two methods are summarized for comparison in Table 3 below. These results, which are not practical given local material availability and the cost impact of lining long berms, support alternate methods of bank stabilization. For example, the use of spillways will concentrate flow in specific areas, allowing heavy armoring to be placed selectively for high overtopping flow rates. This allows the design flow rate for the remainder of the pitside bank to be reduced, which would allow smaller riprap or boulders. Other methods to avoid large riprap or boulders are grouted boulders, soil cement or flatter side slopes.

Table 3
Riprap Sizing Comparison

Bank Slope	**UDFCD Gravel Guidelines Method**		**HEC Steepslope Method**[1]	
	1,000 cfs	**20,000 cfs**	**1,000 cfs**	**20,000 cfs**
2.5H:1V	D_{50}=3.5 ft	D_{50}=8.9 ft	D_{50}=1.0 ft t=2.0 ft	D_{50}=6 ft t=12 ft
3H:1V	D_{50}=2.2 ft	D_{50}=6.8 ft	D_{50}=1.0 ft t=2.0 ft	D_{50}=6 ft t=12 ft
4H:1V	D_{50}=1.4 ft	D_{50}=4.3 ft	D_{50}=1.0 ft t=2.0 ft	D_{50}=6.5 ft t=13 ft
5H:1V	D_{50}=1.1 ft	D_{50}=3.2 ft	N/A	N/A

[1] HEC Steepslope method does not include a safety factor.

The calculations do indicate that in lower flow conditions (1,000 cfs) a smaller size riprap could be used on steep slopes under the Attachment D calculation method than the Attachment C method, but it is worth noting that the method used in the calculation is based on a riprap gradation that is locally non-standard (in the Denver metro area). In addition, the Attachment D method was developed based on flow tests using a 3-meter wide test flume in the 1990's and has not been subject to years of experience like the UDFCD method and gradations have been. Based on these factors, the riprap sizing method contained in the Guidelines still is reasonable to protect a resource as important at the South Platte River.

The existing 1987 guidelines did not offer specific direction for selecting the design flow for the overtopping protection due to the variable geometries available along the river; the intent was and remains to allow the design engineer to determine a reasonably conservative flow rate as appropriate for the local river reach. We would suggest the minimum flow should be the overbank flow during the 100-year event, based on the modeling results presented in the Master Plan or Flood Hazard Area Delineation report.

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Figure

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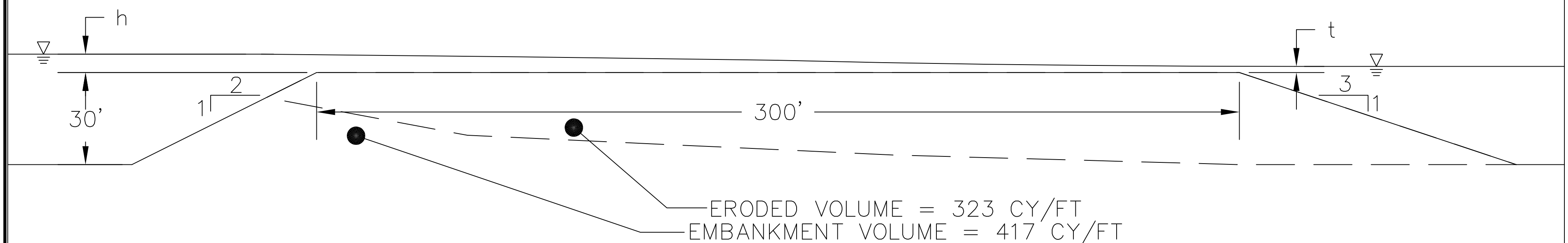

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DESIGN	-
DETAIL	JMN
CHECK	KRW
DATE	11/20/12
SCALE	1"=50'

FIGURE 1

EMBANKMENT CROSS SECTION EXAMPLE LATERAL BERM

Attachment A
Embankment Overtopping Analysis per Federal Highway Administration (FHWA) Method

Wright Water Engineers, Inc.

CALCULATION SHEET

WRIGHT WATER ENGINEERS, INC.

Project: UDFCD Gravel Mining Criteria
Job. No.: 121-030.000
Date: 9/11/2012
Subject: Lateral Berm Erosion Analysis

Design: JMN
Check: TAE

I. Purpose

Estimate volume of material eroded from embankments during overtopping

II. References

1. Development of a Methodology for Estimating Embankment Damage Due to Flood Overtopping, FHA Report No FHWA/RD-86/126, March 1987
2. FHAD South Platte River, Adams County, CO., UDFCD/CDM April 2005
3. Technical Review Guidelines for Gravel Mining Activities Within or Adjacent to 100-Year Floodplains, UDFCD/WWE Dec. 1987 (April, 2004)

III. Assumptions

1. Embankment overtopping occurs for 24 fours to 48 hours.
2. Noncohessive soils
3. Average Erosion Rate: $E = K_1K_2E_a$ Ref # 1, Eqn 33

   where:

   K_1 = time adjustment factor for flood duration

   K_2 = adjustment factor for embankment height

   E_a = erosion rate for a 5-foot embankment

   E_a is based on the ratio of tailwater to headwater (t/h)
4. Erosion Volume V_s =E * time (hours)
5. For purposes of these calculations the supply of sediment from embankments is not a limiting factor.

IV. Calculations

1. Case 1, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; 24 hrs

t =	-3					
h =	6		also equals overtopping depth			
t/h =	-0.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			ok
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			ok
Bare Soil Embankment						
E_a =	2.8		Ref #1, Fig 47 (projected)			ok
E =	13.4	cy/hr/ft				ok
duration =	24	hours				
V_s =	**323**	**cy/ft**	**=**	**8709**	**cf/ft**	ok

2. Case 2, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; **48 hrs**

t =	-3	
h =	6	also equals overtopping depth
t/h =	-0.5	if t/h <= 0, use free fall curves

duration =	48	hours				
K_1 =	0.6		Ref #1, Fig 57			ok
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			ok
Bare Soil Embankment						
E_a =	2.8		Ref #1, Fig 47 (projected)			ok
E =	12.6	cy/hr/ft				
duration =	48	hours				
V_s =	**605**	**cy/ft**	**=**	**16330**	**cf/ft**	ok

3. Case 3, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and **paved top** and bare slopes; **24 hrs**

t =	-3					
h =	6		also equals overtopping depth			
t/h =	-0.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			ok
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			ok
Paved Top, Bare Slopes Embankment						
E_a =	2.35		Ref #1, Fig 51			ok
E =	11.3	cy/hr/ft				
duration =	24	hours				
V_s =	**271**	**cy/ft**	**=**	**7309**	**cf/ft**	ok

Test cases 1-3 with embankment height equal to the maximum height publised in reference 1 (15-feet).

1a. Case 1a, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; 24 hrs

t =	-3					
h =	6		also equals overtopping depth			
t/h =	-0.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			ok
15-foot tall embankment						
K_2 =	3.6		Ref #1, Fig 58			ok
Bare Soil Embankment						
E_a =	2.8		Ref #1, Fig 47 (projected)			ok
E =	6.5	cy/hr/ft				
duration =	24	hours				
V_s =	**155**	**cy/ft**	**=**	**4180**	**cf/ft**	ok

2a. Case 2a, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; 48 hrs

t =	-3					
h =	6		also equals overtopping depth			
t/h =	-0.5		if t/h <= 0, use free fall curves			
duration =	48	hours				
K_1 =	0.6		Ref #1, Fig 57			ok
15-foot tall embankment						
K_2 =	3.6		Ref #1, Fig 58			ok
Bare Soil Embankment						
E_a =	2.8		Ref #1, Fig 47 (projected)			ok
E =	6.0	cy/hr/ft				ok
duration =	48	hours				
V_s =	**290**	**cy/ft**	**=**	**7838**	**cf/ft**	ok

3a. Case 3a, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and paved top and bare slopes; 24 hrs

t =	-3		
h =	6		also equals overtopping depth

t/h =	-0.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			ok
15-foot tall embankment						
K_2 =	3.6		Ref #1, Fig 58			ok
Paved Top, Bare Slopes Embankment						
E_a =	2.35		Ref #1, Fig 51			ok
E =	5.4	cy/hr/ft				ok
duration =	24	hours				
V_s =	**130**	**cy/ft**	**=**	**3509**	**cf/ft**	ok

Rerun cases 1-3 with overtopping height equal to 2-feet to establish a range of erosion volumes.

4. Case 4, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; 24 hrs

t =	-3					
h =	**2**		also equals overtopping depth			
t/h =	-1.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			
Bare Soil Embankment						
E_a =	**1.47**		Ref #1, Fig 47			
E =	7.1	cy/hr/ft				
duration =	24	hours				
V_s =	**169**	**cy/ft**	**=**	**4572**	**cf/ft**	ok

5. Case 5, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and bare soil; **48 hrs**

t =	-3					
h =	**2**		also equals overtopping depth			
t/h =	-1.5		if t/h <= 0, use free fall curves			
duration =	48	hours				
K_1 =	0.6		Ref #1, Fig 57			
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			
Bare Soil Embankment						
E_a =	**1.47**		Ref #1, Fig 47			
E =	6.6	cy/hr/ft				
duration =	48	hours				
V_s =	**318**	**cy/ft**	**=**	**8573**	**cf/ft**	ok

6. Case 6, 300 foot wide berm, 3:1 slope downstream, 2:1 slope upstream and **paved top** and bare slopes; **24 hrs**

t =	-3					
h =	**2**		also equals overtopping depth			
t/h =	-1.5		if t/h <= 0, use free fall curves			
duration =	24	hours				
K_1 =	0.64		Ref #1, Fig 57			
30-foot tall embankment						
K_2 =	7.5		Ref #1, Fig 58 (projected)			
Paved Top, Bare Slopes Embankment						
E_a =	**1.4**		Ref #1, Fig 51			
E =	6.7	cy/hr/ft				
duration =	24	hours				
V_s =	**161**	**cy/ft**	**=**	**4355**	**cf/ft**	ok

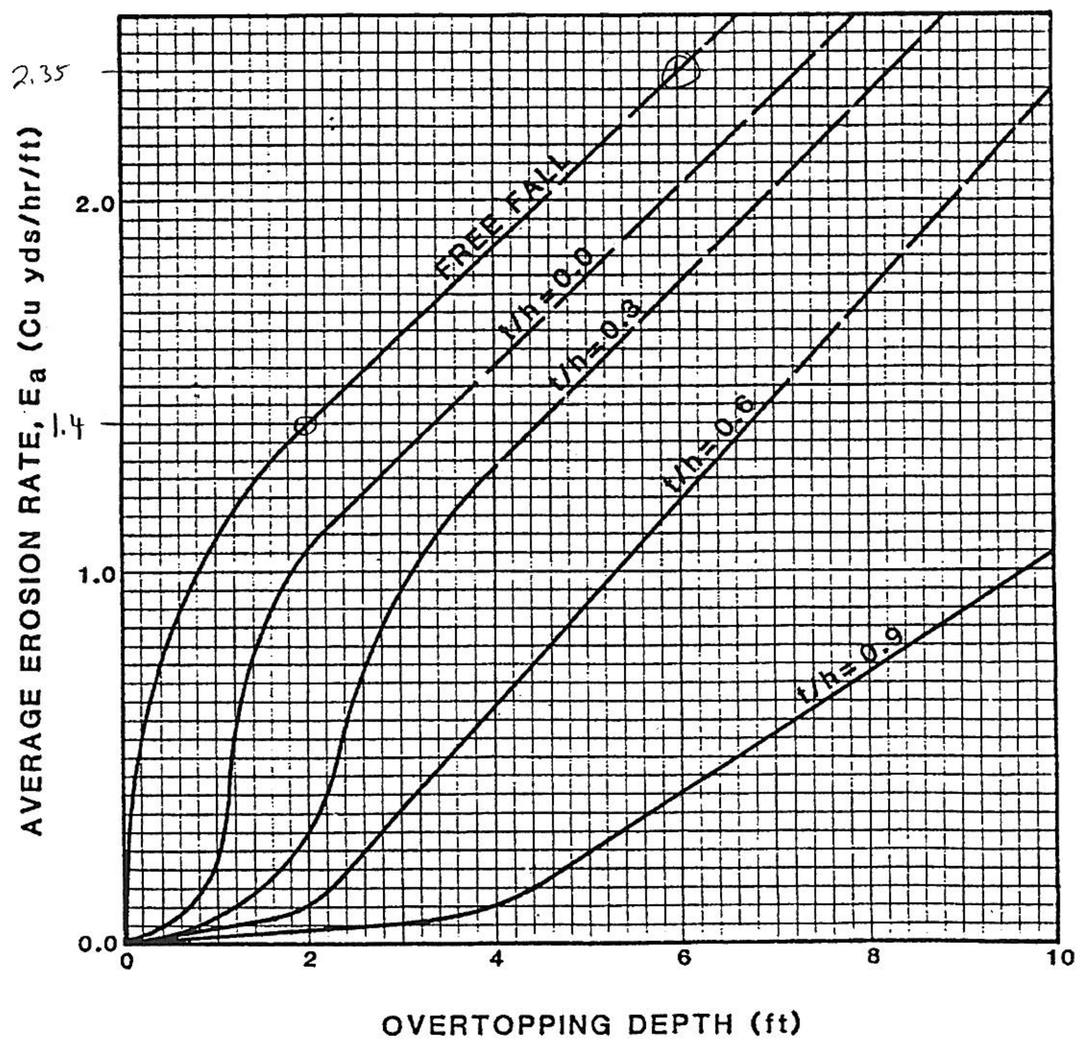

Figure 51. Average erosion rate during 4-hour flow overtopping of 5-foot paved noncohesive soil embankment without vegetal cover.

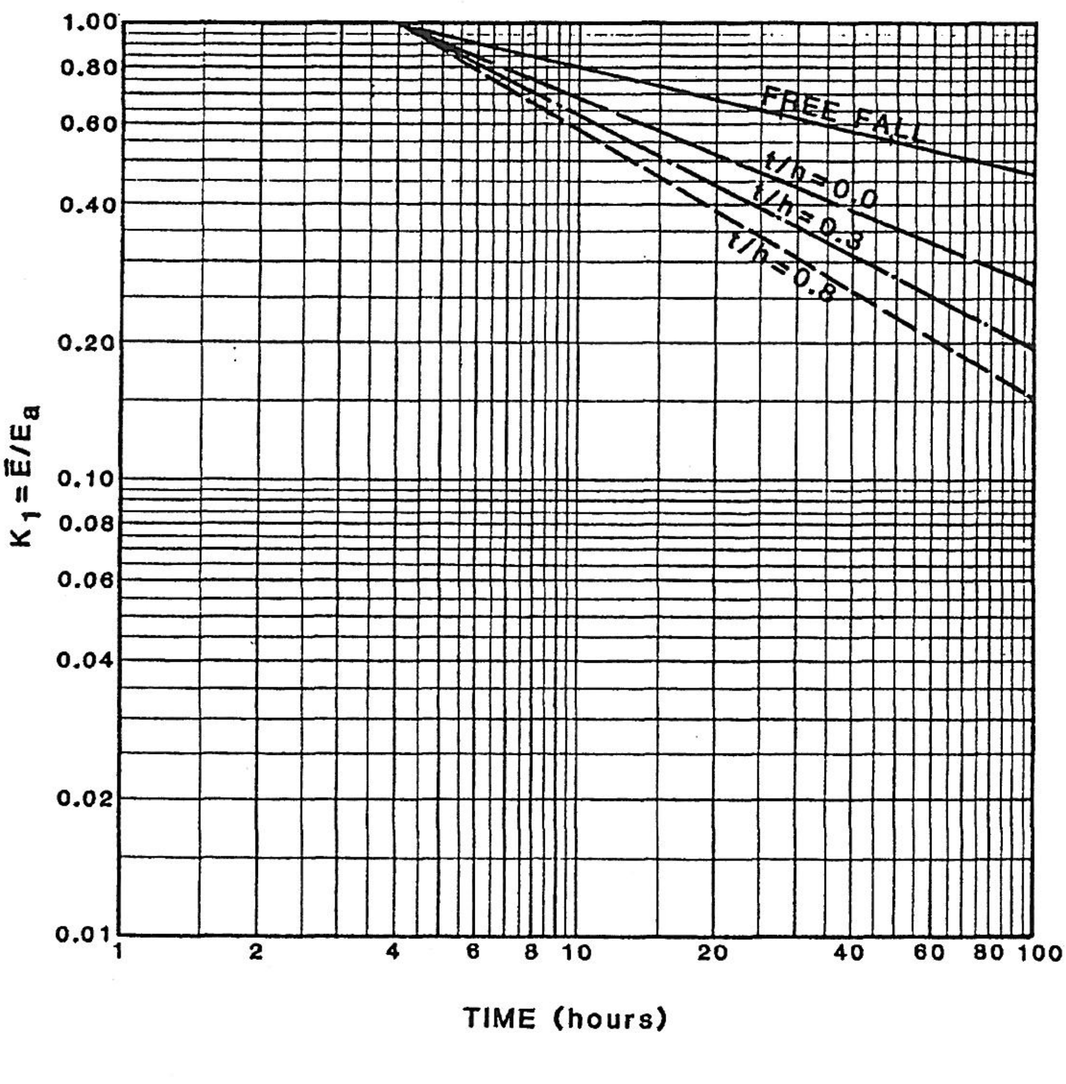

Figure 57. Average erosion rate change with time duration.

EXTRAPOLATE TO 30'
ALSO, USE 15

30ft embankment

$K_2 = ([(30ft - 5ft) \div 5] * 1.3) + 1 = 7.5$

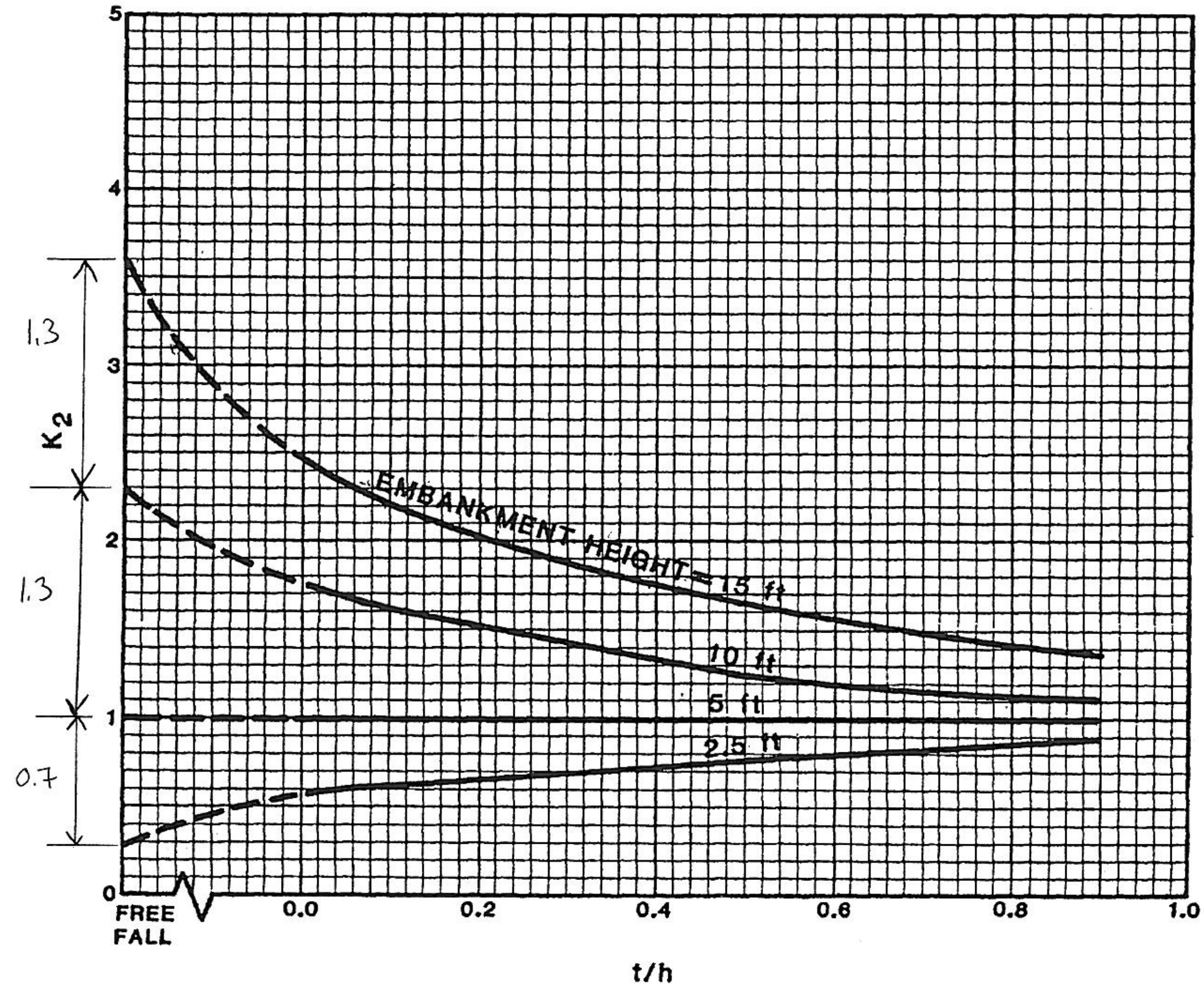

Figure 58. Adjustment factor considering embankment height.

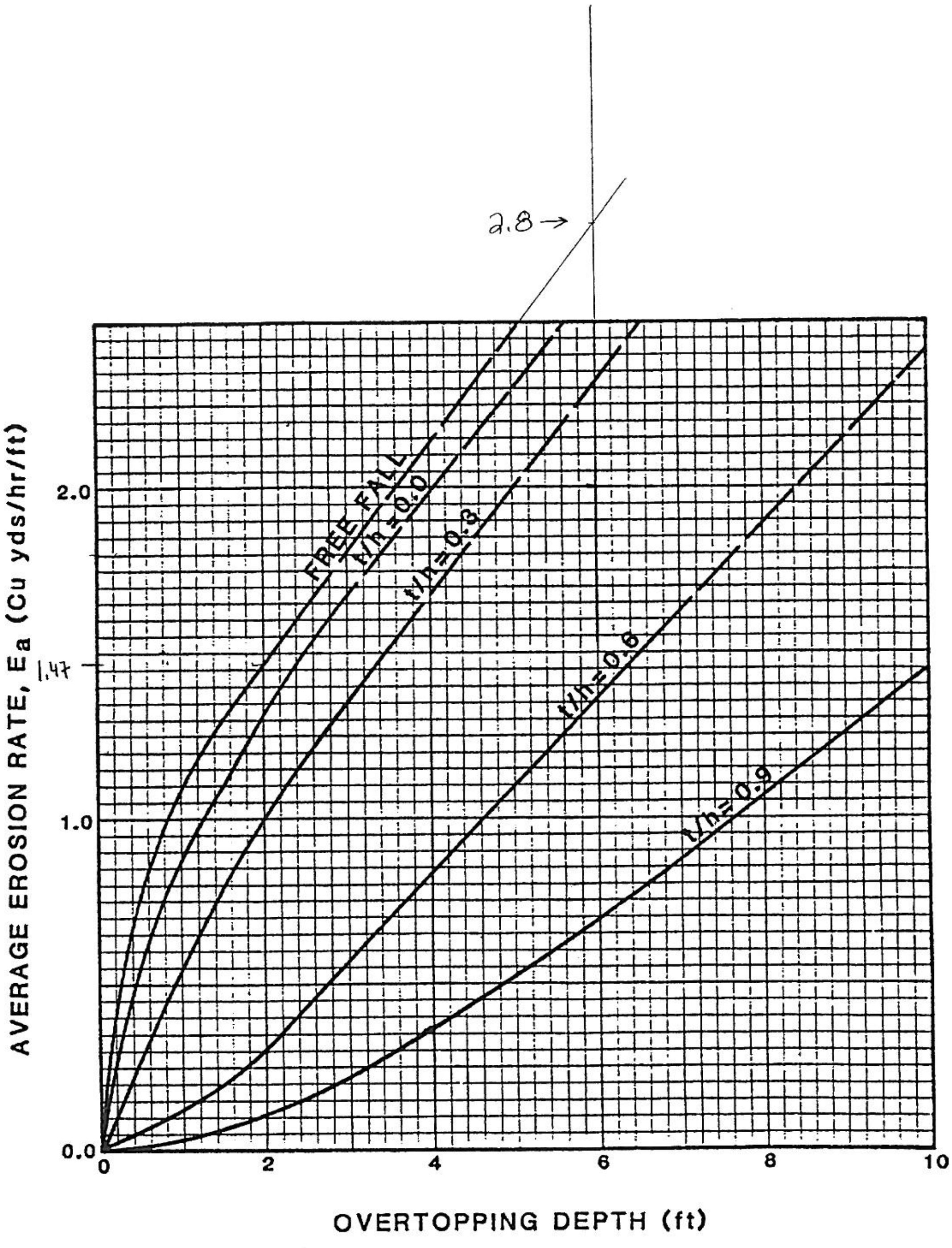

Figure 47. Average erosion rate during 4-hour overtopping of 5-foot noncohesive bare soil embankment (d_{50} less than 8 mm).

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Development of a Methodology for Estimating Embankment Damage Due to Flood Overtopping

$24.95

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

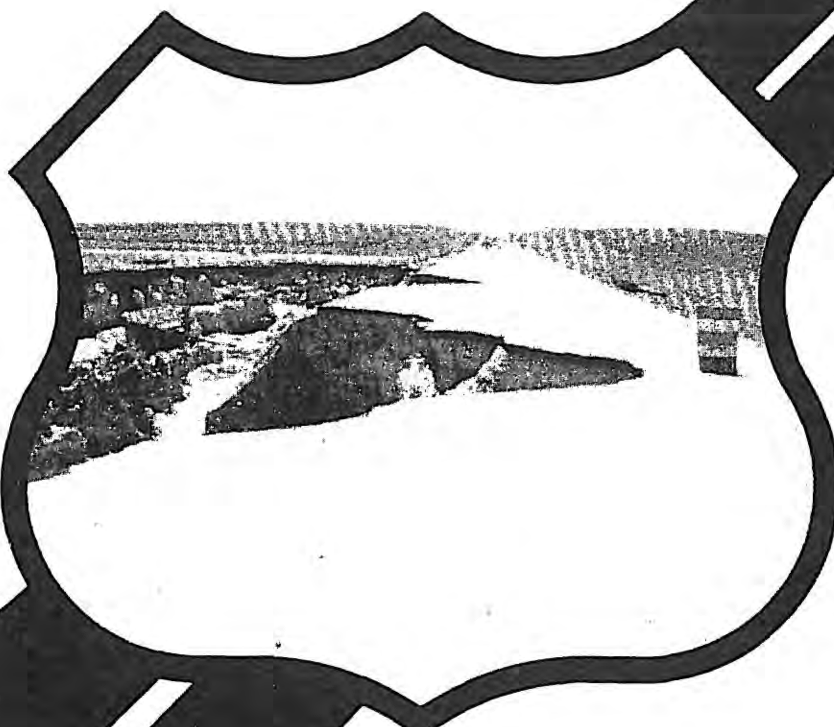
Report No.
FHWA/RD-86/126

U.S. Department of Transportation
Federal Highway Administration

Co-sponsored by:

**U.S. Department of Agriculture
Forest Service
Washington, D.C. 20590**

Final Report
March 1987



FOREWORD

This report describes a series of large-scale hydraulic model experiments to simulate floods overtopping highway embankments. Test conditions included embankments with and without pavement, with and without grass cover, with a range of headwater and tailwater elevations, and with a limited number of protective measures. The report will be of interest to hydraulic engineers for State highway agencies, consultants and other Government agencies who deal with flood damage evaluations of highway embankments or who deal with evaluations of dam safety in general.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA regional office, one copy to each FHWA division office and one copy to each State highway office. Direct distribution is being made to the division offices.

Charles F. Galambos /for
Richard E. Hay, Director
Office of Engineering and
Highway Operations
Research and Development
Federal Highway Administration

NOTICE

Technical Report Documentation Page

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	6. Performing Organization Code
7. Author(s): Y. H. Chen and Bradley A. Anderson	8. Performing Organization Report No.
9. Performing Organization Name and Address: Simons, Li & Associates, Inc., 3555 Stanford Road, P.O. Box 1816, Fort Collins, Colorado 80522	10. Work Unit No. (TRAIS): FCP 35H4-042
	11. Contract or Grant No.: DTFH61-82-C-00104
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	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager (COTR): J. Sterling Jones (HNR-10)

Co-sponsored by: U.S. Dept. of Agriculture, Forest Service, Washington, D.C. 20013

16. Abstract

The objectives of this study are to conduct laboratory tests and develop a methodology to quantitatively determine embankment damage and assess protective measures. During the study, available literature and field data were collected. The embankments used in this study are 6 ft (1.8 m) high, 10 to 22 ft (3.0 to 6.7 m) in crest width, and 3 ft (0.9 m) in length, with slope varying from 2:1 to 3:1. The embankment surfaces include both with and without protective measures (pavement, grass, mattresses, Geoweb, soil cement, Enkamat, and others). The flood overtopping depths ranging from 0.5 to 4 ft (0.15 to 1.22 m), discharges ranging from 1 to 25 cfs/ft (0.1 to 2.32 cms/m) and tailwater conditions ranging from 10 percent water-surface drop to free fall. A computer model was developed to determine hydraulics of overtopping flow and associated erosion damage. This model was verified using field data and laboratory test results, and was utilized to generate charts for estimating embankment damage.

17. Key Words	18. Distribution Statement
Embankment, Erosion, Protection, Soil, Velocity, Shear Stress, Flood Over-topping, Headwater, Tailwater, Free Fall, Mathematical Model	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
		215	

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. Highway Design and Operation for Safety

Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. Traffic Control and Management

Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. Highway Operations

This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. Pavement Design, Construction, and Management

Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. Structural Design and Hydraulics

Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. RD&T Management and Coordination

Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.

Attachment B
Dam Breach Analysis per Colorado State Engineer’s Office (SEO) Guidance

Attachment C
Steep Slope Riprap Sizing per the Gravel Guidelines

Attachment D
Steep Slope Riprap Sizing per Hydrologic Engineering Circular (HEC) 23

Attachment E
CD of Attachments and References

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