Documentation of Initial Hazard Potential Classification Assessment

East Fly Ash Pond System
Havana Power Station
Mason County, Illinois

Prepared for:
Dynegy

October 12, 2016

Stantec Consulting Services Inc.
Design with community in mind
www.stantec.com

Table of Contents

Section **Page No.**

List of Appendixes

Executive Summary

This report documents the hazard potential classification assessment for the East Fly Ash Pond System at the Havana Power Station as required per the CCR Rule in 40 C.F.R. § 257.73- (a)(2). The applicable hazard potential classifications are defined in 40 C.F.R. § 257.53 as follows:

> (1) <u>High hazard potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.
>
> (2) <u>Significant hazard potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.
>
> (3) <u>Low hazard potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Based on these definitions and the analysis herein, the East Fly Ash Pond System is classified as a <u>High hazard potential</u> CCR surface impoundment.

This report contains supporting documentation for the hazard potential classification assessment. The hazard potential classification for this CCR unit was determined by a breach analysis conducted by Stantec in August, 2016.

1. Introduction

1.1. Background

The CCR Rule was published in the Federal Register on April 17, 2015. The Rule requires that a hazard potential classification assessment be performed for existing CCR surface impoundments that are not incised. A previously completed assessment may be used in lieu of the initial assessment provided the previous hazard assessment was completed no earlier than April 17, 2013. The applicable hazard potential classifications are defined in the CCR Rule 40 C.F.R. § 257.53 as follows:

High Hazard Potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.

Significant Hazard Potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.

Low Hazard Potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Dynegy has contracted Stantec Consulting Services Inc. (Stantec) to prepare hazard potential classification assessments for selected impoundments[1].

It was determined that there was no existing available hazard potential classification assessment documentation for the East Fly Ash Pond System.

1.2. Location

Havana Power Station is located along the Illinois River, directly south of Havana, Illinois in Mason County. The station is located on the west side of State Route 78. The East Fly Ash Pond System is located directly south of Havana, Illinois on the east side of State Route 78. A site overview figure is included in Appendix A.

2. Source Data

The following information was used to perform the hazard assessment of the East Fly Ash Pond System:

- Aerial Imagery (USDA National Aerial Imagery Program 2015)

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[1] Dynegy Administrative Services Company (Dynegy) contracted Stantec on behalf of the Havana Power Station owner, Dynegy Midwest Generation, LLC. Thus, Dynegy is referenced in this report.

- Topographic survey information, existing conditions (Weaver Consultants Group for Dynegy, December 2015 – 1 foot contour data and planimetrics)
- IDNR Dam Safety Program, DRAFT Emergency Action Plan, Havana Power Station, Havana, Illinois, IDNR Permit No. DS2011079, Dam ID No. IL50483
- Topographic information, pre-existing conditions (Illinois Power Company, 1980, Topographic Plan, Proposed East Ash Pond
- Topographic information, surrounding area (USGS National Elevation Dataset 10-meter Digital Elevation Model)

3. Potential Failure Scenarios

3.1. Facility Description

The East Fly Ash Pond System is approximately 120 acres in footprint, at the crest. It was formed by constructing an earthen embankment from approximately 10 to 35 feet in height above the adjacent grade. Four operational cells are part of the impoundment. Pertinent geometric details for each cell per the East Fly Ash Pond System Draft Emergency Action Plan revised February 2015 (All elevations are provided in the North American Vertical Datum 1988 (NAVD 88)) follow:

- Cell 1:
  - Normal Pool Elevation – 485.7 Feet
  - Emergency Spillway Elevation – 487.7 Feet
  - Dam Crest Elevation – 489.7 Feet
  - Normal Pool Surface Area – 2.1 Acres
  - Storage, Top of Dam – 488 Acre-Feet
  - Principal Spillway – 2.5 foot standpipe, Corrugated Metal Pipe
  - Emergency Spillway – Two Steel Pipes
- Cell 2:
  - Normal Pool Elevation – 485.7 Feet
  - Emergency Spillway Elevation – 487.7 Feet
  - Dam Crest Elevation – 489.7 Feet
  - Normal Pool Surface Area – 11.5 Acres
  - Storage, Top of Dam – 615 Acre-Feet
  - Principal Spillway – 3.0 foot standpipe, Ductile Iron Pipe
  - Emergency Spillway – Concrete Lined Spillway

- Cell 3:
  - Normal Pool Elevation – 490.2 Feet
  - Emergency Spillway Elevation – 493.7 Feet
  - Dam Crest Elevation – 495.7 Feet
  - Normal Pool Surface Area – 31.1 Acres
  - Storage, Top of Dam – 1,410 Acre-Feet
  - Principal Spillway – 3.0 foot standpipe, Ductile Iron Pipe
  - Emergency Spillway – Concrete Lined Spillway
- Cell 4:
  - Normal Pool Elevation – 484.2 Feet
  - Emergency Spillway Elevation – 487.7 Feet
  - Dam Crest Elevation – 489.7 Feet
  - Normal Pool Surface Area – 4.6 Acres
  - Storage, Top of Dam – 89.9 Acre-Feet
  - Principal Spillway – Concrete Stop-Log Structure
  - Emergency Spillway – Concrete Lined Spillway

3.2. Failure Scenarios

For the purposes of this evaluation all cells were conservatively assumed to be storing water to the elevation of their crest. Free water volume is defined as the storage volume available between the crest elevation and the existing surface as defined in the 2015 survey. Solids volumes used in the analysis included volume of the cells' earthen embankments and in-place waste based on an estimate developed by comparing the 2015 survey of the impoundment to original 1980 drawings of the area before the facility was constructed.

Six breach scenarios, Scenarios A-F, were developed and analyzed. Breach hydrographs were developed utilizing the US Army Corps of Engineers (USACE) Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) version 4.0 (Reference 2). The hydrographs were routed downstream using the two dimensional capabilities of USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) version 5.0.1 (Reference 12).

Unless otherwise noted, all elevations herein are referenced to NAVD 88.

The assumptions below that include 1/3 of the solids volume were based in part on Stantec's experience with other CCR surface impoundment failure analyses and is supported by industry literature. For breach purposes, solid outflow was conservatively assumed to behave the same as liquids, slurry flow was not modeled.

3.2.1. Scenario A – Cell 3

Overtopping breach initiated along the north or eastern face of Cell 3. Bottom of breach assumed at 470.0 feet. Volume of breach assumed as 1/3 the volume of Cell 3 solids, above bottom of breach elevation, plus the free water volume of cells 1, 2, 3, and 4. Discharge would primarily flow to the north and west as it exists to the Illinois River. A portion of the discharge would flow south, around the system, and eventually exit to the Illinois River near County Road 1370 N.

3.2.2. Scenario B – Cell 3

Overtopping breach initiated along the south or southeastern face of Cell 3. Bottom of breach assumed at 470.0. Volume of breach assumed as 1/3 the volume of solids within cells 2 and 3, above bottom of breach elevation, plus the free water volume of cells 1, 2, 3, and 4. Discharge would flow into a natural depression directly to the southeast of Cell 3. After filling in the depression, discharge would flow north and west as well as south and west at it exits to the Illinois River.

3.2.3. Scenario C – Cell 1

Overtopping breach initiated along the south or east face of Cell 1. Bottom of breach assumed at 472.0 feet. Volume of breach assumed as 1/3 the volume of solids within Cell 1, above bottom of breach elevation. Due to existing geometry and location of available free water storage within Cell 1 it was assumed that free water does not contribute to this breach. Discharge would flow to the west or south and west as it exits to the Illinois River.

3.2.4. Scenario D – Cell 4

Overtopping breach initiated along the west face of Cell 4. Bottom of breach assumed at 465.0 feet. Volume of breach assumed as 1/3 the volume of solids within cells 1, 2, and 4, above bottom of breach elevation, plus the free water volume of cells 1, 2, 3, and 4. Discharge would flow to the west as it exits to the Illinois River.

3.2.5. Scenario E – Cell 3

Overtopping breach initiated along the west face of Cell 3. Bottom of breach assumed at 465.0 feet NAVD 88. Volume of breach assumed as 1/3 the volume of solids within Cell 3, above bottom of breach elevation, plus the free water volume of cells 1, 2, 3, and 4. Discharge would flow to the west as it exits to the Illinois River. This scenario was not modeled because Scenario F occurs within the same downstream area and has a larger breach volume.

3.2.6. Scenario F – Cell 2

Overtopping breach initiated along the north or west face of Cell 2. Bottom of breach assumed at 455.0 feet. Volume of breach assumed as 1/3 the volume of solids within cells 2 and 3, above bottom of breach elevation, plus the free water volume of cells 1, 2, 3, and 4. Discharge would flow to the west as it exits to the Illinois River.

3.3. Breach Hydrograph Development

Breach hydrographs were developed using HEC-HMS version 4.0. The breach function of HEC-HMS requires input of estimated breach parameters and impounded volumes. Breach parameters were determined using empirical equations. Since there is uncertainty in predicting dam breach parameters, Stantec used several empirical equations and based final breach parameters on engineering judgment (References 3 - 11).

Table 1 summarizes the breach parameters used for this analysis. These values are based on the assumed failure conditions, height of breach, impoundment volume above breach, and width of the embankment. B_{avg} is the average width of a breach failure and t_f is the time for the breach to fully develop.

Table 1 Summary of Estimated Dam Breach Parameters

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario F
Range of Breach Width Estimates (feet)	45.5 – 125.0	45.5 - 126.8	16.2 – 65.0	54.3 – 137.5	71.8 – 162.5
Range of Failure Time Estimates (hours)	0.1 – 0.8	0.1 – 0.9	0.1 – 0.6	0.1 – 0.7	0.2 – 0.6
B_{avg} (feet)	91.8	93.7	48.7	106.1	122.8
t_f (hours)	0.5	0.5	0.3	0.5	0.5

There is no contributing watershed upstream of the East Fly Ash Pond System, therefore runoff calculations were not performed. Each of the cells were conservatively assumed to have ponded water to the crest during a breach, as could occur during an extreme storm event with a clogged or blocked principal spillway.

Stage-storage curves for the East Fly Ash Pond System were developed based on historic topographic data and 2015 existing condition survey data. The stage-storage curves were unique for each of the scenarios modeled due to the volume assumptions of each.

3.4. Hydraulic Model Development

The breach hydrographs developed from HEC-HMS were routed downstream using the two dimensional capabilities of HEC-RAS version 5.0.1.

3.4.1. Hydraulic Parameters

Pertinent hydraulic parameters used during the hydraulic analysis are summarized below.

- The two-dimensional grid used to route the hydrographs was split into 40 foot x 40 foot cells. This grid cell size returned acceptable results for this analysis so a finer grid was not utilized. The terrain source data was a 10-meter x 10-meter grid.
- The minimum allowable breach flow was fixed at either 50 or 100 cubic feet per second (cfs) depending on the breach scenario. The fixed values increased model stability while have a negligible impact on the peak inundation results.
- The Manning's 'n' was fixed at 0.060 for all 2D grid cells because it was the average 'n' across the whole downstream inundation area. After reviewing model results it was determined spatial variation of Manning's 'n' would not result in a different peak inundation area.
- The Full Momentum equation set was utilized to model the breach scenarios because the Diffusion Wave equations resulted in a truncated rising limb of the breach outflow.

3.5. Breach Modeling Results

Inundation limits for each of the breach scenarios were evaluated to determine the potential impacts on property and structures and the potential risk to human life.

Model results have been summarized below for selected areas of impact. One metric included in the description is the time to a flooding depth of 2-feet. Faster moving water creates greater risk for damage to infrastructure and a greater chance of loss of life; according to the National Flood Insurance Program (NFIP), water moving at more than 5 feet per second is considered to be moving with high velocity (Reference 13). The time for flooding to reach 2-feet in depth is a surrogate for velocity.

All of the modeled breach scenarios indicate potential impacts to infrastructure believed to be off of the Havana Power Station property, while only two of the scenarios predict impacts to plant infrastructure. All of the modeled scenarios result in a risk of loss of life based on the inundation evaluations. Discharge to the Illinois River is predicted in all of the scenarios.

3.5.1. Breach Pathways

1. A breach in the north/northeast direction would progress overland simultaneously to the north and to the west with a breach wave averaging

approximately 3 feet per second and to the south and to the west with a breach wave averaging approximately 2 feet per second. This breach would affect multiple buildings, roads, and the railroad.

a. In the vicinity of Wagner Avenue, the maximum approximate flood depth is 6.0-feet which occurs within 30 minutes. A depth of 2 feet occurs within 10 minutes.

b. In the vicinity of State Route 78, north of W Tinkham Street, the maximum approximate flood depth is 3.5 feet which occurs within 40 minutes. A depth of 2.0 feet occurs within 25 minutes.

c. In the vicinity of W Illinois Street, the maximum approximate flood depth is 3.5 feet which occurs within 50 minutes. A depth of 2.0 feet occurs within 35 minutes.

d. In the vicinity of W South Street, the maximum approximate flood depth is < 2 feet which occurs within 25 minutes.

e. In the vicinity of E County Road 1500 N, the maximum approximate flood depth is < 2 feet which occurs within 100 minutes.

2. A breach in the south direction would progress overland simultaneously to the south and to the west with a breach wave averaging approximately 2 feet per second and to the north and to the west with a breach wave averaging approximately 2 feet per second. This breach would affect multiple buildings, roads, and the railroad.

   a. In the vicinity of E County Road 1500, the maximum approximate flood depth is 4.0 feet which occurs within 45 minutes. A depth of 2.0 feet occurs within 20 minutes.

   b. In the vicinity of State Route 78 and N County Road 1450, the maximum approximate flood depth is 3.5 feet which occurs within 85 minutes. A depth of 2.0 feet occurs within 55 minutes.

   c. In the vicinity of County Road 1400, the maximum approximate flood depth is 3.5 feet which occurs within 105 minutes. A depth of 2.0 feet occurs within 90 minutes.

   d. In the vicinity of the State Route 78 Bridge, south of County Road 1400 N, the maximum approximate flood depth is 2.0 feet which occurs within 135 minutes.

   e. In the vicinity of Wagner, the maximum approximate flood depth is 4.0 feet which occurs within 73 minutes. A depth of 2.0 feet occurs within 55 minutes.

f. In the vicinity of State Route 78, north of W Tinkham Street, the maximum approximate flood depth is 2.0 feet which occurs within 90 minutes.

3. A breach in the west/northwest direction would progress overland generally due west to the Illinois River with a breach wave averaging approximately 2 feet per second. This breach would affect multiple buildings, roads, the railroad, and the Havana plant.

   a. In the vicinity of the Havana Power Station facility, the maximum approximate flood depth is 3.5 feet which occurs within 30 minutes. A depth of 2.0 feet occurs within 15 minutes.

   b. In the vicinity of State Route 78, north of the Havana Power Station, the maximum approximate flood depth is 5.5 feet which occurs within 30 minutes. A depth of 2.0 feet occurs within 15 minutes.

4. Hazard Classification

Areas of potential impact were identified with results discussed in Section 3.5 of this report. All of the modeled breach scenarios predict impacts to multiple structures and/or roadways that would put people at risk. Based on the results of the modeling of a breach of the East Fly Ash Pond System, it is Stantec's opinion that such an event could cause loss of human life.

Therefore, the impoundment fits the definition for a High hazard potential CCR surface impoundment (as defined in the CCR Rule §257.53) (Reference 1).

5. References

1. US Environmental Protection Agency. (2015). *Disposal of Coal Combustion Residuals from Electric Utilities, 40 CFR § 257 and § 261* (effective April 17, 2015).

2. US Army Corps of Engineers, Hydrologic Engineering Center, "Hydrologic Modeling System", HEC-HMS, Version 4.0 computer program, revised December 2013

3. Johnson, F.A and Illes, P. (1976). "A Classification of Dam Failures." *Water Power Dam Construction,* 28, 43-45.

4. Singh, Krishan P. and Snorrason, A. (1982*). SWS Contract Report 288: Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models*. Illinois Department of Energy and Natural Resources, State Water Survey Division.

5. Singh, Krishan P. and Snorrason, A. (1984*).* "Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models." *Journal of Hydrology*, 68, 295-310.

6. MacDonald, T. C., and Langridge-Monopolis, J. (1984). "Breaching Characteristics of Dam Failures." *Journal of Hydraulic Engineering*, 110 (5), 567-586.

7. Federal Energy Regulatory Commission (FERC). (1987). *FERC 0119-1: Engineering Guidelines for the Evaluation of Hydropower Projects*. Office of Hydropower Licensing.

8. Froehlich, D. C. (1987). "Embankment Dam Breach Parameters." *Proceedings of the 1987 National Conference on Hydraulic Engineering*, ASCE, Williamsburg Virginia, 570-575.

9. US Bureau of Reclamation (USBR). (1988). *ACER Technical Memorandum No. 11: Downstream Hazard Classification Guidelines*. Assistant Commissioner-Engineering and Research, Denver, Colorado, 57.

10. Von Thun, Lawrence J. and D. R. Gillette. (1990). *Guidance on Breach Parameters*, unpublished internal document, USBR, Denver, Colorado, 17. (Referenced in Wahl 1998).

11. Froehlich, D. C. (1995). "Embankment Dam Breach Parameters Revisited." *Proceedings of the 1995 ASCE Conference on Water Resources Engineering*, ASCE, San Antonio, Texas, 887-891.

12. US Army Corps of Engineers, Hydrologic Engineering Center, "River Analysis System", HEC-RAS, Version 5.0.1 computer program, revised April 2016

13. Federal Emergency Management Association (FEMA). (2012). *Assessing the Consequences of Dam Failure*. A How-to-Guide.

Appendix A

Site Overview Figure

0 1,500 Feet

1:18,000 (At original document size of 11x17)

Project Location 175605019
Latitude: 40.280785
Longitude: -90.078625
Mason County, Illinois

Prepared by WSW on 2016-10-05
Technical Review by NS on 2016-10-05
Independent Review by MH on 2016-10-05

Client/Project
Dynegy Inc
Hazard Potential Classification Assessment
Havana Power Station

Figure No.
Appendix A

Title
Site Overview Figure
East Fly Ash Pond
Havana Power Station

Notes
1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Aerial Source: 2015 NAIP Imagery
3. Impoundment Boundaries Provided by Client (Dated 9/9/2015)

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Appendix B

Breach Parameters

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario A Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1085.0	ac-feet	1338327.8	m^3
Volume of water at breach	V_w	1085.0	ac-feet	1338327.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

		English Units		SI Units	
Breach width	B_{AVG}	91.8	feet	28.0	meters
Breach bottom width	B_W	62.3	feet	19.0	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	47,149	ft^3/s	1335.2	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	262642.1	ft^3	7437.5	m^3
Volume of water discharged	V_o,V_{out}	1085.00	ac-feet	1338327.8	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	13.9	45.5						
2 - Singh and Snorrason 1982, 1984	27.7	91.0						
3 - MacDonald and Langridge-Monopolis 1984	24.8	81.4		6597.4				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	23.8	78.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	37.6	123.2			1.4			
8 - Froehlich 1987			2.150			33.5	1.0	
9 - USBR 1988	23.8	78.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	38.1	125.0						18.3
12 - Froehlich 1995	34.2	112.0			1.4			
13 - Froehlich 1995			1.400					

Dam Breach Parameter Estimation

Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)

Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station

Location: Havana, Mason County, Illinois

Notes: Scenario A Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1085.0	ac-feet	1338327.8	m^3
Volume of water at breach	V_w	1085.0	ac-feet	1338327.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	91.8	feet	28.0	meters
Breach bottom width	B_W	62.3	feet	19.0	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	47,149	ft^3/s	1335.2	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	262642.1	ft^3	7437.5	m^3
Volume of water discharged	V_o,V_{out}	1085.00	ac-feet	1338327.8	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	**t_f** (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.459
16 - FERC 1987	0.550
17 - Froehlich 1987	0.807
18 - USBR 1988	0.308
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.119
22 - Von Thun and Gillette 1990	0.302
23 - Froehlich 1995	0.696

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario A Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1085.0	ac-feet	1338327.8	m^3
Volume of water at breach	V_w	1085.0	ac-feet	1338327.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	91.8	feet	28.0	meters
Breach bottom width	B_W	62.3	feet	19.0	meters
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Peak discharge	Q_p	47,149	ft^3/s	1335.2	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	262642.1	ft^3	7437.5	m^3
Volume of water discharged	V_o,V_{out}	1085.00	ac-feet	1338327.8	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	Q_p (m^3/s)	Q_p (ft^3/s)	η	k	d
24 - Kirkpatrick 1977	246.2	8,686			
25 - SCS 1981	764.6	26,981			
26 - Hagen 1982	1758.8	62,065			
27 - USBR 1982	879.8	31,045			
28 - Singh and Snorrason 1984	670.5	23,661			
29 - Singh and Snorrason 1984	1345.6	47,484			
30 - MacDonald and Langridge-Monopolis 1984	905.3	31,945			
31 - MacDonald and Langridge-Monopolis 1984	2971.7	104,865			
32 - Costa 1985	3484.4	122,957			
33 - Costa 1985	875.9	30,908			
34 - Costa 1985	3250.2	114,691			
35 - Evans 1986	1271.8	44,878			
36 - Froehlich 1995	507.5	17,907			
37 - Webby 1996	445.9	15,734			
38 - Walder and O'Connor 1997	649.4	22,916	764.9	55	5.95

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario B Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1218.0	ac-feet	1502380.9	m^3
Volume of water at breach	V_w	1218.0	ac-feet	1502380.9	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	93.7	feet	28.6	meters
Breach bottom width	B_W	64.2	feet	19.6	meters
Breach formation time	t_f	0.5	hours	0.50	hours
Peak discharge	Q_p	49,354	ft^3/s	1397.6	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	268153.5	ft^3	7593.5	m^3
Volume of water discharged	V_o,V_{out}	1218.00	ac-feet	1502380.9	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	13.9	45.5						
2 - Singh and Snorrason 1982, 1984	27.7	91.0						
3 - MacDonald and Langridge-Monopolis 1984	27.1	89.0		7210.9				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	23.8	78.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	38.7	126.8			1.4			
8 - Froehlich 1987			2.150			33.5	1.0	
9 - USBR 1988	23.8	78.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	38.1	125.0						18.3
12 - Froehlich 1995	35.4	116.3			1.4			
13 - Froehlich 1995			1.400					

Dam Breach Parameter Estimation

Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)

Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station

Location: Havana, Mason County, Illinois

Notes: Scenario B Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1218.0	ac-feet	1502380.9	m^3
Volume of water at breach	V_w	1218.0	ac-feet	1502380.9	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

		English Units		SI Units	
Breach width	B_{AVG}	93.7	feet	28.6	meters
Breach bottom width	B_W	64.2	feet	19.6	meters
Breach formation time	t_f	0.5	hours	0.50	hours
Peak discharge	Q_p	49,354	ft^3/s	1397.6	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	268153.5	ft^3	7593.5	m^3
Volume of water discharged	V_o,V_{out}	1218.00	ac-feet	1502380.9	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	**t_f** (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.463
16 - FERC 1987	0.550
17 - Froehlich 1987	0.852
18 - USBR 1988	0.314
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.119
22 - Von Thun and Gillette 1990	0.308
23 - Froehlich 1995	0.740

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario B Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	26.0	feet	7.9	meters
Height of breach	h_b	26.0	feet	7.9	meters
Height/depth of water at breach	h_w	26.0	feet	7.9	meters
Storage	S	1218.0	ac-feet	1502380.9	m^3
Volume of water at breach	V_w	1218.0	ac-feet	1502380.9	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	93.7	feet	28.6	meters
Breach bottom width	B_W	64.2	feet	19.6	meters
Breach formation time	t_f	0.5	hours	0.50	hours
Peak discharge	Q_p	49,354	ft^3/s	1397.6	m^3/s
Breach side slope	Z	1.13		1.13	
Volume of embankment eroded	V_{er}	268153.5	ft^3	7593.5	m^3
Volume of water discharged	V_o,V_{out}	1218.00	ac-feet	1502380.9	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	246.2	8,686			
25 - SCS 1981	764.6	26,981			
26 - Hagen 1982	1863.5	65,759			
27 - USBR 1982	879.8	31,045			
28 - Singh and Snorrason 1984	670.5	23,661			
29 - Singh and Snorrason 1984	1420.8	50,136			
30 - MacDonald and Langridge-Monopolis 1984	949.4	33,503			
31 - MacDonald and Langridge-Monopolis 1984	3116.4	109,969			
32 - Costa 1985	3721.8	131,335			
33 - Costa 1985	919.5	32,446			
34 - Costa 1985	3419.8	120,677			
35 - Evans 1986	1352.2	47,714			
36 - Froehlich 1995	525.1	18,529			
37 - Webby 1996	465.2	16,416			
38 - Walder and O'Connor 1997	649.4	22,916	858.6	55	5.95

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario C Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water at breach	h_w	18.0	feet	5.5	meters
Storage	S	85.0	ac-feet	104846.0	m^3
Volume of water at breach	V_w	85.0	ac-feet	104846.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:					
Breach width	B_{AVG}	48.7	feet	14.8	meters
Breach bottom width	B_W	27.6	feet	8.4	meters
Breach formation time	t_f	0.3	hours	0.31	hours
Peak discharge	Q_p	14,303	ft^3/s	405.0	m^3/s
Breach side slope	Z	1.17		1.17	
Volume of embankment eroded	V_{er}	74522.2	ft^3	2110.3	m^3
Volume of water discharged	V_o,V_{out}	85.00	ac-feet	104846.0	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	B (m)	B (ft)	Z	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	9.6	31.5						
2 - Singh and Snorrason 1982, 1984	19.2	63.0						
3 - MacDonald and Langridge-Monopolis 1984	4.9	16.2		701.5				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	16.5	54.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	18.1	59.4			1.4			
8 - Froehlich 1987			2.329			25.9	1.0	
9 - USBR 1988	16.5	54.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	19.8	65.0						6.1
12 - Froehlich 1995	14.1	46.2			1.4			
13 - Froehlich 1995			1.400					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario C Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water at breach	h_w	18.0	feet	5.5	meters
Storage	S	85.0	ac-feet	104846.0	m^3
Volume of water at breach	V_w	85.0	ac-feet	104846.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

		English Units		SI Units	
Breach width	B_{AVG}	48.7	feet	14.8	meters
Breach bottom width	B_W	27.6	feet	8.4	meters
Breach formation time	t_f	0.3	hours	0.31	hours
Peak discharge	Q_p	14,303	ft^3/s	405.0	m^3/s
Breach side slope	Z	1.17		1.17	
Volume of embankment eroded	V_{er}	74522.2	ft^3	2110.3	m^3
Volume of water discharged	V_o,V_{out}	85.00	ac-feet	104846.0	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.290
16 - FERC 1987	0.550
17 - Froehlich 1987	0.341
18 - USBR 1988	0.163
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.082
22 - Von Thun and Gillette 1990	0.179
23 - Froehlich 1995	0.251

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario C Breach Parameter Estimation

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water at breach	h_w	18.0	feet	5.5	meters
Storage	S	85.0	ac-feet	104846.0	m^3
Volume of water at breach	V_w	85.0	ac-feet	104846.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	48.7	feet	14.8	meters
Breach bottom width	B_W	27.6	feet	8.4	meters
Breach formation time	t_f	0.3	hours	0.31	hours
Peak discharge	Q_p	14,303	ft^3/s	405.0	m^3/s
Breach side slope	Z	1.17		1.17	
Volume of embankment eroded	V_{er}	74522.2	ft^3	2110.3	m^3
Volume of water discharged	V_o,V_{out}	85.00	ac-feet	104846.0	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	102.2	3,606			
25 - SCS 1981	387.3	13,665			
26 - Hagen 1982	409.6	14,454			
27 - USBR 1982	445.6	15,723			
28 - Singh and Snorrason 1984	334.6	11,808			
29 - Singh and Snorrason 1984	406.5	14,346			
30 - MacDonald and Langridge-Monopolis 1984	272.5	9,615			
31 - MacDonald and Langridge-Monopolis 1984	897.0	31,654			
32 - Costa 1985	816.0	28,796			
33 - Costa 1985	257.5	9,088			
34 - Costa 1985	901.6	31,814			
35 - Evans 1986	329.8	11,637			
36 - Froehlich 1995	151.7	5,355			
37 - Webby 1996	104.6	3,693			
38 - Walder and O'Connor 1997	259.0	9,139	217.0	55	4.12

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Stantec

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario D Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	31.0	feet	9.5	meters
Height of breach	h_b	31.0	feet	9.5	meters
Height/depth of water at breach	h_w	31.0	feet	9.5	meters
Storage	S	1210.0	ac-feet	1492513.0	m^3
Volume of water at breach	V_w	1210.0	ac-feet	1492513.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
User Input Data
Default calculation, user can change.
Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	106.1	feet	32.3	meters
Breach bottom width	B_W	74.5	feet	22.7	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	55,023	ft^3/s	1558.1	m^3/s
Breach side slope	Z	1.02		1.02	
Volume of embankment eroded	V_{er}	279674.2	ft^3	7919.8	m^3
Volume of water discharged	V_o,V_{out}	1210.00	ac-feet	1492513.0	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	16.5	54.3						
2 - Singh and Snorrason 1982, 1984	33.1	108.5						
3 - MacDonald and Langridge-Monopolis 1984	33.5	110.0		8213.6				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	28.4	93.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	40.3	132.3			1.4			
8 - Froehlich 1987			1.566			25.9	1.0	
9 - USBR 1988	28.4	93.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	41.9	137.5						18.3
12 - Froehlich 1995	36.6	119.9			1.4			
13 - Froehlich 1995			1.400					

Dam Breach Parameter Estimation

Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)

Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station

Location: Havana, Mason County, Illinois

Notes: Scenario D Breach Parameter Estimation

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	31.0	feet	9.5	meters
Height of breach	h_b	31.0	feet	9.5	meters
Height/depth of water at breach	h_w	31.0	feet	9.5	meters
Storage	S	1210.0	ac-feet	1492513.0	m^3
Volume of water at breach	V_w	1210.0	ac-feet	1492513.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	106.1	feet	32.3	meters
Breach bottom width	B_W	74.5	feet	22.7	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	55,023	ft^3/s	1558.1	m^3/s
Breach side slope	Z	1.02		1.02	
Volume of embankment eroded	V_{er}	279674.2	ft^3	7919.8	m^3
Volume of water discharged	V_o,V_{out}	1210.00	ac-feet	1492513.0	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.470
16 - FERC 1987	0.550
17 - Froehlich 1987	0.724
18 - USBR 1988	0.356
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.142
22 - Von Thun and Gillette 1990	0.327
23 - Froehlich 1995	0.630

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario D Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	31.0	feet	9.5	meters
Height of breach	h_b	31.0	feet	9.5	meters
Height/depth of water at breach	h_w	31.0	feet	9.5	meters
Storage	S	1210.0	ac-feet	1492513.0	m^3
Volume of water at breach	V_w	1210.0	ac-feet	1492513.0	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:

- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	106.1	feet	32.3	meters
Breach bottom width	B_W	74.5	feet	22.7	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	55,023	ft^3/s	1558.1	m^3/s
Breach side slope	Z	1.02		1.02	
Volume of embankment eroded	V_{er}	279674.2	ft^3	7919.8	m^3
Volume of water discharged	V_o,V_{out}	1210.00	ac-feet	1492513.0	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	Q_p (m^3/s)	Q_p (ft^3/s)	η	k	d
24 - Kirkpatrick 1977	376.5	13,286			
25 - SCS 1981	1058.7	37,358			
26 - Hagen 1982	2028.1	71,568			
27 - USBR 1982	1218.1	42,984			
28 - Singh and Snorrason 1984	934.9	32,991			
29 - Singh and Snorrason 1984	1416.4	49,981			
30 - MacDonald and Langridge-Monopolis 1984	1018.0	35,924			
31 - MacDonald and Langridge-Monopolis 1984	3340.9	117,893			
32 - Costa 1985	3707.9	130,842			
33 - Costa 1985	987.2	34,837			
34 - Costa 1985	3684.3	130,010			
35 - Evans 1986	1347.4	47,548			
36 - Froehlich 1995	651.8	23,000			
37 - Webby 1996	593.6	20,948			
38 - Walder and O'Connor 1997	1008.1	35,572	460.9	55	7.09

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario F Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	41.0	feet	12.5	meters
Height of breach	h_b	41.0	feet	12.5	meters
Height/depth of water at breach	h_w	41.0	feet	12.5	meters
Storage	S	1305.0	ac-feet	1609693.8	m^3
Volume of water at breach	V_w	1305.0	ac-feet	1609693.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

		English Units		SI Units	
Breach width	B_{AVG}	122.8	feet	37.4	meters
Breach bottom width	B_W	81.2	feet	24.8	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	69,880	ft^3/s	1978.9	m^3/s
Breach side slope	Z	1.01		1.01	
Volume of embankment eroded	V_{er}	554211.0	ft^3	15694.1	m^3
Volume of water discharged	V_o,V_{out}	1305.00	ac-feet	1609693.8	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	**V_{er}** (m^3)	**K_o**	$\overline{W}$ (m)	K_c	**C_b**
1 - Johnson and Illes 1976	21.9	71.8						
2 - Singh and Snorrason 1982, 1984	43.8	143.5						
3 - MacDonald and Langridge-Monopolis 1984	25.7	84.4		10793.2				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	37.5	123.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	44.1	144.5			1.4			
8 - Froehlich 1987			1.542			33.5	1.0	
9 - USBR 1988	37.5	123.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	49.6	162.5						18.3
12 - Froehlich 1995	39.5	129.6			1.4			
13 - Froehlich 1995			1.400					

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

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Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario F Breach Parameter Estimation

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	41.0	feet	12.5	meters
Height of breach	h_b	41.0	feet	12.5	meters
Height/depth of water at breach	h_w	41.0	feet	12.5	meters
Storage	S	1305.0	ac-feet	1609693.8	m^3
Volume of water at breach	V_w	1305.0	ac-feet	1609693.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	122.8	feet	37.4	meters
Breach bottom width	B_W	81.2	feet	24.8	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	69,880	ft^3/s	1978.9	m^3/s
Breach side slope	Z	1.01		1.01	
Volume of embankment eroded	V_{er}	554211.0	ft^3	15694.1	m^3
Volume of water discharged	V_o,V_{out}	1305.00	ac-feet	1609693.8	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	**t_f** (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.603
16 - FERC 1987	0.550
17 - Froehlich 1987	0.582
18 - USBR 1988	0.412
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.188
22 - Von Thun and Gillette 1990	0.337
23 - Froehlich 1995	0.510

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet
Last Updated/By: 8-24-12 - Erman Caudill (Stantec)
Refer to accompanying Equation Reference document.

Stantec

Project Data (Optional):

Dam: East Ash Pond System, Havana Power Station
Location: Havana, Mason County, Illinois
Notes: Scenario F Breach Parameter Estimation

Inputs:

		English Units		SI Units	
Height of dam	h_d	41.0	feet	12.5	meters
Height of breach	h_b	41.0	feet	12.5	meters
Height/depth of water at breach	h_w	41.0	feet	12.5	meters
Storage	S	1305.0	ac-feet	1609693.8	m^3
Volume of water at breach	V_w	1305.0	ac-feet	1609693.8	m^3
Width of dam at base	W_{base}	200.0	feet	61.0	meters
Width of dam at crest	W_{crest}	20.0	feet	6.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	122.8	feet	37.4	meters
Breach bottom width	B_W	81.2	feet	24.8	meters
Breach formation time	t_f	0.5	hours	0.48	hours
Peak discharge	Q_p	69,880	ft^3/s	1978.9	m^3/s
Breach side slope	Z	1.01		1.01	
Volume of embankment eroded	V_{er}	554211.0	ft^3	15694.1	m^3
Volume of water discharged	V_o,V_{out}	1305.00	ac-feet	1609693.8	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	743.3	26,228			
25 - SCS 1981	1775.8	62,663			
26 - Hagen 1982	2422.3	85,476			
27 - USBR 1982	2043.2	72,101			
28 - Singh and Snorrason 1984	1585.9	55,961			
29 - Singh and Snorrason 1984	1467.6	51,789			
30 - MacDonald and Langridge-Monopolis 1984	1178.4	41,585			
31 - MacDonald and Langridge-Monopolis 1984	3866.0	136,422			
32 - Costa 1985	3871.1	136,602			
33 - Costa 1985	1146.0	40,441			
34 - Costa 1985	4307.5	152,000			
35 - Evans 1986	1402.5	49,491			
36 - Froehlich 1995	942.6	33,263			
37 - Webby 1996	902.7	31,856			
38 - Walder and O'Connor 1997	2027.9	71,560	186.8	55	9.38

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

Assumptions:

- Equations here were extracted from the USBR Report "Prediction of Embankment Dam Breach Parameters" and the Journal of Hydraulic Engineering article "Uncertainty of Predictions of Embankment Dam Breach Parameters" by the same author (Tony L. Wahl, USBR). Citation for that reference is included below, but recursive references have been omitted.
- All earthen embankments.
- Measurements are in SI units (meters, m^3/s, hours) unless otherwise noted. Spreadsheet is set up to do the English-SI input conversions, then convert answers back to English units.

Input Parameters, Constants, and Variables:

h_d = height of dam: input
h_b = height of breach: input, generally = h_d
h_w = height (depth) of water at failure above breach bottom: input
S = storage: input parameter
V_w = volume of water above breach invert at time of breach: input, generally = S
W = Embankment width: input
Z = breach opening side slope: input or calculated

g = acceleration of gravity = 9.8 m/s^2 =127,008,000 m/hr^2

B = average breach width: calculated (see below)
B_W = breach bottom width: calculated using B, h_b, and Z (see equation 39)
t_f = breach formation time, hours: calculated (see below)
Q_p = peak breach outflow: calculated (see below)
Z = breach opening side slope: input or calculated (see below)
V_{er} = volume of embankment material eroded: generally calculated (see Equation 40)
V_o,V_{out} = volume of water discharged: calculated = S + inflow during breach

Breach Width & Dimension Equations:

Johnson and Illes 1976

(1) $0.5h_d \le B \le 3h_d$

Singh and Snorrason 1982, 1984

(2) $2h_d \le B \le 5h_d$

MacDonald and Langridge-Monopolis 1984

(3) $V_{er} = 0.0261(V_{out}h_w)^{0.769}$

(4) $Z = 1H{:}2V$

FERC 1987

(5) $2h_d \le B \le 4h_d$

(6) $0.25 \le Z \le 1.0$

Froehlich 1987

$$\overline{B^*} = \frac{\overline{B}}{h} = 0.47K_o(S^*)^{0.25}$$

$$S^* = \frac{S}{{h_b}^3}$$

(7) $\overline{B} = 0.47h_b K_o \left(\frac{S}{h_b{}^3}\right)^{0.25}$ Ko = 1.4 overtopping; 1.0 otherwise

$$Z = 0.75K_c(h_w{}^*)^{1.57}\left(\overline{W^*}\right)^{0.73}$$

$$h_w{}^* = \frac{h_w}{h_b}$$

$$\left(\overline{W^*}\right) = \frac{\overline{W}}{h} = \frac{W_{crest} + W_{bottom}}{2h}$$

(8) $Z = 0.75K_c\left(\frac{h_w}{h_b}\right)^{1.57}\left(\frac{\overline{W}}{h_b}\right)^{0.73}$ Kc = 0.6 with corewall; 1.0 without a corewall

USBR 1988

(9) $B = 3h_w$

Von Thun and Gillette 1990

(10) $Z = 1H{:}1V$

(11) $\overline{B} = 2.5h_w + C$

$$C_b = f(\text{reservoir size}, m^3) = \left\{\begin{array}{cc} \textit{Size} & C_b \\ < 1.23x10^6 & 6.1 \\ 1.23x10^6 - 6.17x10^6 & 18.3 \\ 6.17x10^6 - 1.23x10^7 & 42.7 \\ > 1.23x10^7 & 54.9 \end{array}\right\}$$

Froehlich 1995

(12) $\overline{B} = 0.1803K_o V_w{}^{0.32} h_b{}^{0.19}$ Ko = 1.4 overtopping; 1.0 otherwise

(13) $Z = 1.4$ for overtopping, 0.9 otherwise

Failure Time Equations:

Singh and Snorrason 1982, 1984

(14) $0.25\ \text{hr} \le t_f \le 1.0\ \text{hr}$

MacDonald and Langridge-Monopolis 1984

(15) $t_f = 0.0179(V_{er})^{0.364}$

FERC 1987

(16) $0.10\ \text{hr} \le t_f \le 1.0\ \text{hr}$

Froehlich 1987 (t_f* equation was corrected from the report)

$$S^* = \frac{S}{h_b{}^3}$$

$$t_f{}^* = 79(S^*)^{0.47} = 79\left(\frac{S}{h_b{}^3}\right)^{0.47}$$

$$t_f{}^* = t_f\sqrt{\frac{g}{h}}$$

(17) $t_f = \dfrac{79\left(\frac{S}{h_b{}^3}\right)^{0.47}}{\sqrt{\frac{g}{h_b}}}$

USBR 1988

(18) $t_f = 0.011B$

Von Thun and Gillette 1990

Erosion Resistant

(19) $t_f = 0.020h_w + 0.25$

(20) $t_f = \frac{\overline{B}}{4h_w}$

Highly Erodible

(21) $t_f = 0.015h_w$

(22) $t_f = \frac{\overline{B}}{4h_w + 61.0}$

Froehlich 1995

(23) $t_f = 0.00254{V_w}^{0.53}{h_b}^{(-0.90)}$

Peak Flow Equations:

Kirkpatrick 1977

(24) $Q_p = 1.268(h_w + 0.3)^{2.5}$

SCS 1981

(25) $Q_p = 16.6(h_w)^{1.85}$

Hagen 1982

(26) $Q_p = 0.54(S \times h_d)^{0.5}$

USBR 1982

(27) $Q_p = 19.1(h_w)^{1.85}$

Singh and Snorrason 1984

(28) $Q_p = 13.4(h_d)^{1.89}$

(29) $Q_p = 1.776(S)^{0.47}$

MacDonald and Langridge-Monopolis 1984

(30) $Q_p = 1.154(V_w h_w)^{0.412}$

(31) $Q_p = 3.85(V_w h_w)^{0.411}$

Costa 1985

(32) $Q_p = 1.122(S)^{0.57}$

(33) $Q_p = 0.981(S \times h_d)^{0.42}$

(34) $Q_p = 2.634(S \times h_d)^{0.44}$

Evans 1986

(35) $Q_p = 0.72(V_W)^{0.53}$

Froehlich 1995

(36) $Q_p = 0.607{V_w}^{0.295}{h_w}^{1.24}$

Webby 1996

(37) $Q_p = 0.0443g^{0.5}{V_w}^{0.367}{h_w}^{1.40}$

Walder and O'Connor 1997

$$\eta = \frac{kV_o}{g^{0.5}d^{3.5}}$$

k = vertical erosion rate = 10 m/hr – 100 m/hr
d = 50-100% of dam height

(38) $$Q_p = \begin{Bmatrix} 1.51(g^{0.5}d^{2.5})^{0.06}\left(\frac{kV_o}{d}\right)^{0.94} & \eta < \sim 0.6 \\ 1.94g^{0.5}d^{2.5}\left(\frac{h_d}{d}\right)^{0.75} & \eta \gg 1 \end{Bmatrix}$$

Other Equations:

Breach Bottom Width

(39) $$B_W = B - h_b Z$$

Embankment Volume

(40) $$V_{er} = \left(B_w h_b + Z{h_b}^2\right)\left(\frac{W_{crest} + W_{base}}{2}\right) = (Bh_b)\left(\frac{W_{crest} + W_{base}}{2}\right)$$

$$B = \frac{V_{er}}{h_b\left(\frac{W_{crest} + W_{base}}{2}\right)}$$

References:

U.S. Department of the Interior, Bureau of Reclamation, Dam Safety Office. July 1998. "Prediction of Embankment Dam Breach Parameters, A Literature Review and Needs Assessment, DSO-98-004, Dam Safety Research Report", Tony L. Wahl, Water Resources Research Laboratory. 67 pp.

"Uncertainty of Predictions of Embankment Dam Breach Parameters", Tony L. Wahl. Journal of Hydraulic Engineering, Vol. 130, No. 5, May 1, 2004. 9 pp.

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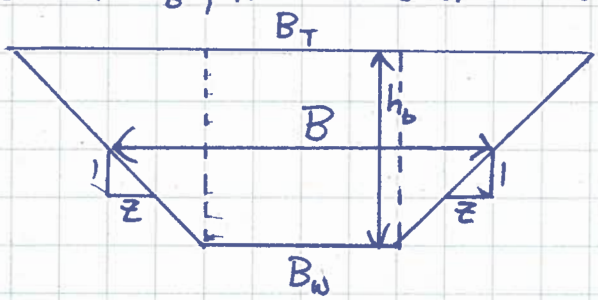
DAM BREACH EQUATIONS

DERIVATIONS NOT SHOWN

1. BREACH BOTTOM WIDTH GIVEN AVG. BREACH WIDTH B, BREACH HEIGHT H_b, AND BREACH SIDE SLOPES Z



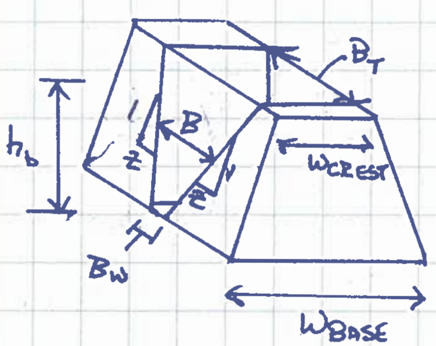
$$B = \frac{B_T + B_W}{2}$$

$$B_T = B_W + 2 h_b Z$$

$$B = \frac{(B_W + 2h_b Z) + B_W}{2} = \frac{2B_W + 2h_b Z}{2} = B_W + h_b Z$$

$$B_W = B - h_b Z$$

2. VOLUME OF EMBANKMENT ERODED



AREA AT CENTER

$$A_c = B_w h_b + Z h_b^2$$

$$\forall = A_c W_{CREST} + 2 \frac{A_c}{2} \frac{(W_{BASE} - W_{CREST})}{2} \quad \cancel{(W_{CREST} - W_{BASE})}$$

$$= A_c W_c + \frac{A_c W_B}{2} - \frac{A_c W_c}{2}$$

$$= \frac{A_c W_c}{2} + \frac{A_c W_B}{2}$$

$$= A_c \left(\frac{W_c + W_B}{2} \right)$$

$$\forall = (B_w h_b + Z h_b^2)\left(\frac{W_c + W_B}{2} \right)$$

$$\forall = B h_b \left(\frac{W_c + W_B}{2} \right) \rightarrow B = \frac{\forall}{h_b \left(\frac{W_c + W_B}{2} \right)}$$