Hazard Classifications & Dam Break Analysis

Types of Dam Failures

- Overtopping 34%
- Piping 30%
- Foundation 20%
- Other 16%

Other Causes of Dam Failures

- Structural Failures
- Earthquake
- Trees
- Animal Burrows
- Poor Design
- Poor Construction
- Neglect / Lack of Maintenance
- Lightning

Source: ASDSO, 2009

Map Courtesy of James S. Halgren, National Weather Service, 2006

Overtopping Failure

Overtopping Begins
Piping Failure for Earth Dam

Foundation Failure

Slope Failure

Embankment Dam Schematic

Dam Overtopping Photo

Overtopping Breach of Earth Dam
Overtopping Breach Stages for Earth Dam

Overtopping Begins

Early Erosion Stage

Horizontal Erosion Continues

Overtopping Breach Stages for Earth Dam

Vertical Erosion Begins

Overtopping Breach Stages for Earth Dam

Vertical Erosion Ends

Piping Failure at Loveton Dam (1989)
Loveton Dam Failure (1989)

Loveton Failure Viewed from Downstream

Medford Quarry Wash Pond Piping Failure

Piping Failure

Anti-seep collars do not prevent seepage failures!

Annap. Mall Piping Failure

Sinkhole in Dam Crest
Structural Failure

Dam Hazard Classifications

- **Low Hazard** = Class “a”
- **Significant Hazard** = Class “b”
- **High Hazard** = Class “c”

MDE Dam Hazard Classifications

- **Low Hazard** - Potential loss of life is very unlikely due to low danger flood depths.
- **Significant Hazard** - Potential loss of life is possible with no more than 6 lives in jeopardy and flooding to no more than two isolated houses and downstream roads.
- **High Hazard** - Potential loss of life is very likely with more than 6 lives in jeopardy, and serious damage to residential, commercial, or industrial buildings, and downstream roads.

Loss of Life from Dam Failure Varies with Warning Time

- **Warning time < 15”,** Loss of Life = 0.5(PAR)
- **Warning time 15” to 90”,** Loss of Life = PAR.6
- **Warning time > 90”,** Loss of Life = 0.0002(PAR)


Incremental Flood Analysis

Flood Conditions without & with Dam Failure

**Storms to Evaluate**

- Sunny Day (Normal Pool)
- 100-Year Storm
- Brim-up Storm (fill reservoir to top of dam)
- 1/2 of Probable Maximum Flood
- Full Probable Maximum Flood
Probable Maximum Flood (PMF)

PMF - the largest flood considered possible based on the most severe combination of meteorological and hydrologic conditions that are reasonably possible.

Failure Storms to Analyze

PMF
Brim-UP
100-Year
Sunny Day

Small Dam or Pond
Use NWS Dam Break Equation

- 15 ft or less in height,
- Storage volume less than 20 acre-feet
- Drainage area less than 640 acres (1 square mile)

Increased Flood Risks

Before Downstream Development

After Downstream Development

Increased Flooding

WORLD RECORD RAINFALL AMOUNTS


Increased Flooding

100-YR 1/2 PMF PMF
Sunny Day
Hydrology for Dams

- GISHydro2000 Model > 400 acres
- TR-20 Models
- HEC-1 Model
- HydroCad Model (new dam break added)

Web Sites:
www.gishydro.umd.edu
www.hydrocad.net

Dam Break Models

- HEC-1 Computer Model
- HECRAS Computer
- NWS DAMBRK or FLDWAV
- NWS Simple DAMBRK Equation
- HEC-HMS (New HEC-1 but not recommended)

Learn HEC1 Model

- ALL DATA IS ENTERED IN FIELDS OF 8 WITH TEN COLUMNS MAXIMUM UNLESS YOU USE FREE FORMAT
- THE NEXT CARD TELLS THE COMPUTER TO PRINT OUT A TREE DIAGRAM OF THE WATERSHED
- THE NEXT THREE CARDS ARE PROJECT DESCRIPTION CARDS, USE ONE OR MORE OF THESE CARDS
- ID Your Dam Name, File Name (*.dat)
- ID 100 YEAR ROUTING WITH & WITHOUT DAM FAILURE (DESCRIPTION)
- ID HYDROLOGIC DATA OBTAINED FROM 11/79 SCS (USE AS MANY OR ONLY ONE ID CARD)
- Next card is the time computing ordinates 6 minutes interval and 300 ordinates
- The next card says that there are 2 jobs (without failure & with failure)

Breach Parameters for HEC-1 Model

- Breach Bottom Elevation
- Breach Top Elevation (Trigger Elevation)
- Bottom Breach Width
- Breach Side Slope
- Time of Failure
Breach Parameters

Bottom Width, \( b \)

Trigger Elevation for Failure

\( Z = 0 \) to \( 1 \)

\( H \), Breach Height

Breach Bottom Elevation

Bottom Width, \( b \)

\( Z = 0 \) to \( 1 \)

Suggested Breach Parameters for Earth Dams

<table>
<thead>
<tr>
<th>Source</th>
<th>Average Breach Width (ft)</th>
<th>Breach Side Slope (1V:ZH)</th>
<th>Breach Failure Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWS (1988)</td>
<td>1H to 5H</td>
<td>( Z = 0 ) to ( 1 )</td>
<td>0.1 to 2.0</td>
</tr>
<tr>
<td>COE (1980)</td>
<td>0.5H to 4H</td>
<td>( Z = 0 ) to ( 1 )</td>
<td>0.5 to 4</td>
</tr>
<tr>
<td>FERC (1991)</td>
<td>1H to 5H</td>
<td>( Z = 0 ) to ( 1 )</td>
<td>0.1 to 1.0</td>
</tr>
<tr>
<td>USBR (1982)</td>
<td>3H</td>
<td>N/A</td>
<td>0.00333b</td>
</tr>
<tr>
<td>Ross Dambrk (1988)</td>
<td>0.5 to 4H</td>
<td>( Z = 0 ) to ( 1 )</td>
<td>0.5 to 4</td>
</tr>
<tr>
<td>Harrington (1999)</td>
<td>1H to 8H</td>
<td>( Z = 0 ) to ( 1 )</td>
<td>H/120 to H/180</td>
</tr>
</tbody>
</table>

Froelich Breach Predictor Equations

\[
b = 9.5 K_0 \left( V_s H \right)^{1.25}
\]

\[
T_f = 0.59 \left( V_s^{0.47} \right) / H^{0.91}
\]

\( b \) = Average Breach Width (ft),

\( T_f \) = Time of Failure (hrs)

\( K_0 \) = 0.7 for Piping & 1.0 for Overtopping Failure

\( V_s \) = Storage Volume (ac-ft)

\( H \) = Selected Failure Depth (ft) above Breach Bottom

\( T_f \) = Time of Failure (hrs, \( \sim H/120 \) or Minimum of 10 Min)

Dam Break Models

NWS Simple Dam Break Equation

\[
Q_b = Q_0 + 3.1B_f \left( C/T_f + C/\sqrt{H} \right)^3
\]

\( Q_b \) = Breach + Non-Breach Flow (cfs)

\( Q_0 \) = Non-Breach Flow (cfs)

\( B_f \) = Final Average Breach Width (ft, \( \sim 1H \) to \( 5H \))

\( C \) = 23.4 \( A_s/Br \)

\( A_s \) = Reservoir Surface Area (ac) at Failure Elevation

\( H \) = Selected Failure Depth (ft) above Final Breach Elevation

\( T_f \) = Time of Failure (hrs, \( \sim H/120 \) or Minimum of 10 Min)

SCS (NRCS) Breach Formula

\[
Q_b = 3.2H^{5/2}
\]

- Usually Conservative Estimate of Breach Flow but not Always
- Storage Volume not included in Formula
- Similar to a V-Notch Weir Formula
**Recommended Dam Failure Methods**

**for Small Dams 15 feet or less in height**

- Use NWS SMPDBK Equation to determine Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths
- Stop Danger Reach when roads flood < 1.5 feet, and Flooding to Houses & Buildings < 6 inches

**for Dams > 15 & < 75 feet high**

- Use Hec-1 Model for Breach Flows
- Use HECRAS Model to determine Downstream Flood Depths & USBR Hazard Charts to determine Flood Dangers
- Stop Danger Reach when increased Flooding < 1 foot or no structures flooded

**for Dams > or = 75 feet high**

- Use HMR-52 & HEC-1 Model for Hydrology
- Use HECRAS Model for Breach Flow
- Use the Unsteady HECRAS Model if feasible
- May also use DAMBRK, or FLDWAV Models for Breach Flow
HMR52 Model – Elliptical Rainfall Distribution

10 to 20,000 square mile rainfall cells

Rainfall Bands

Watershed Boundary

Flood Danger for Cars

Source: USBR Hazard Charts, 1988

Flood Danger for Houses

Source: USBR Hazard Charts, 1988

Flood Danger for Adults

Source: USBR Hazard Charts, 1988

Hurricane Floyd
September 15-16, 1999

Rainfall from Hurricane Floyd, Sept 99
Hurricane Floyd Rainfall on Eastern Shore

Nagel Mill Dam before Floyd

Nagel Mill Dam after Floyd

Nagel Mill Dam after Floyd

Nagel Mill Dam after Repair

Nagel's Breach Statistics

- Piping Failure
- Breach Width = 60 ft = 4H
- Side Slope Z = 0.4
- Time of Failure < 20 min
Foreman Dam Breach Statistics

Overtopping Failure
Breach Width = 85 ft = 8H
Side Slope Z = 0.5
Time of Failure <30 min
Frazer Dam Breach Statistics

Overtopping Failure
Breach Width = 120 ft = 6H
Side Slope Z = 0.6
Time of Failure Unknown
Jones Lake Dam Breach Statistics

Piping Failure
Breach Width = 103 ft = 6H
Side Slope Z = 0.6
Failure Time Unknown

Sassafras Dam before Floyd

Sassafras Dam after Floyd

Sassafras Dam During Floyd

Sassafras Dam after Repair

Sassafras Dam During Repair
**Sassafras Dam Breach Statistics**

Overtopping Failure  
Breach Width = 47 ft = 4H  
Side Slope Z = 0.2  
Failure Time = 15 Min

**Stubbs Dam after Floyd**

**Stubbs Dam Breach Statistics**

Piping Failure  
Breach Width = 30 ft = 2.5H  
Side Slope Z = 0.2  
Failure Time Unknown
Boundary Dam Near Seattle Washington

MDE Dam Break Web Site
Go to www.mde.state.md.us & Search for technical references

- Hazard Guidelines
- Model Emergency Action Plans
- NWS Dam Break Equation
- USBR Hazard Graphs
- Hydrology Spreadsheets
- Hydraulic Spreadsheets
- HEC-1 Program
- NWS Simple Dam Break Program
- Sample Data for HEC-1 & NWS Simple Dam Break

Any Questions?
Bruce Harrington, MD Dam Safety, 410-713-3687