Geosyntec Consultants

Cascading Dam Breach Analysis



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- Need for Dam Breach Analysis
 - Edenville (MI)
- Case Study of 3 Dams in Series
- Lessons Learnt



NEED FOR ANALYSIS

Need for Analysis



General Need

- Dam failure may cause catastrophic damage to human life and property
- With Dam Breach Analysis, the damage can be predicted, and Emergency Action Plan can be put in place.
- Recent dam breaches such as Edenville (MI) have highlighted the need to understanding the impacts of cascading dam breaches on downstream areas.

Edenville Dam Failure

Edenville Dam Breach

- 5:35 p.m. on May 19, 2020
- Static Liquefaction
 - failure of loose, saturated sands in the downstream section of the dam which led to embankment instability
 - Rare type of failure

Sanford Dam Breach

- 7:46 p.m. on May 19, 2020
- Embankment overtopping
- Breach outflows from Edenville Dam Breach

Damages

- More than \$200 million in estimated damages
- Temporary evacuation of about 10,000 people in two counties

















CASE STUDY

Need for Analysis



• Specific Need

- Evaluate the impacts of a potential embankment failure for Dam
 1
 - Identify impacted structures and roadways within the inundation extent
- State Requirement
 - To ensure the emergency planning and response meets the most recent State requirements
 - Previous inundation mapping completed using DAMBRK software in 2000.
 - New state require inundation mapping to be completed using HEC-RAS software.



Stream



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Dams, Bridges and	Distance (Miles)		
Culverts	from Dam 1		
Dam 1	0		
Structure 1	0.2		
Dam 2	1.0		
Structure 2	1.2		
Structure 3	2.4		
Structure 4	3.1		
Dam 3	3.8		
Structure 5	4.0		
Structure 6	5.0		
Structure 7	5.4		
Structure 8	6.5		
Structure 9	6.8		
Structure 10	7.6		
Structure 11	9.3		
Structure 12	10.8		

	Dam 1	Dam 2	Dam 3				
Approximate Storage Volume at Failure (acre-feet)	5,000	300	4,500	Dam 1 Structure 1			
Approximate Dam Height (feet)	120	40	100	Dam 2			
(feet) 120 40 100 Structure 10 Structure 10 Structure 10 Structure 9 Structure 6 Structure 6 Structure 7 Structure 5 Structure 12							
 Structure 				Miles			







- Embankment Breach Development
- Typical Dam Breach Failure Modes, FEMA (2013)

Failure Mode	Example	Percentage of Failures	
Hydrologic	Overtopping	71%	
Geologic	Piping/Seepage	14%	
Structural	Failure of upstream/downstream face	2%	
Seismic	Earthquake	Unlisted	
Human Related	Misoperation/Terrorism	1%	

HEC-RAS 2D Model Development

- Digital Terrain Model (DEM) from NOAA
 - 2012 LIDAR data
 - Resolution: 4'x4'
 - Vertical Datum: NAVD88 ft
- Manning's Roughness Values
 - National Land Cover Database (NLCD, 2016)
 - Manning's n Values for Various Land Covers (USDA, 2016)
- Boundary Condition
 - Assumed to flow off the grid



Stage-storage for the Dams

• Dam 1

- As-built reservoir area map
 - 10-foot contours
- Previous dam breach analysis
- Dam 2 and Dam 3
 - Historic USGS Contour
 - 20 feet Contour for Dam 2 and Dam 3





HEC-RAS 2D Model Assumptions

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- Sunny day mode of failure was assumed;
- No infiltration losses are assumed;
- No losses due to evapotranspiration were considered;

Breach Characteristics



- Froehlich (2008) equations
- Assumptions made based on engineering judgement and regulator guidance:
 - The model assumes obstruction on the bottom half of all downstream bridges and culverts.
 - One (1) acre-foot of pool volume at failure has been assumed for all bridges for calculation of breach parameters.
 - All downstream structures breach when overtopped with two feet of flow, or more.
 - The entire bridge structure collapses due to the breach.





- 20 bridges and culverts downstream
 - Cost of surveying
 - First pass of the model
 - Aerial
 - Engineering judgement
- Selected 12 out of 20 bridges to input in HEC-RAS model









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1+10 1+20 1+30 1+40 1+50 1+60 1+70 1+801+85

0+00 0+10 0+20 0+30 0+40 0+50 0+60 0+70 0+80 0+90

1+00









FROM NORTH





16



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Inundation Map





More than 70 buildings were Inundated as a result!

The structures were identified by the regulator.







Hazard Potential

- Loss of life is considered probable when destruction factor is greater than 15
 - (maximum velocity in feet per second x maximum depth in feet)
- High potential for loss of human life
- Destruction factor less than 15 at Dam 3, Structure 11 and 12







- Breach of Dam 1 would result in breach of Dam 2
- 10 of the 12 modeled bridges would breach
- More than 70 structures would be inundated
- Destruction factor greater than 15 for most modeled bridges. Dam failure could result in loss of life and significant damage to the properties.

Lessons Learned



- Consideration to downstream bridges and dams
- Engineering judgement
 - Number of structures to survey
 - Bathymetry
 - Modeling domain
- Field visits
 - Aerial / photos for guidance
- Publicly available data
 - Historical data
- Unsteady 2D HEC-RAS Model are very unstable





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Dam Characteristics



Estimated Permitted Area Characteristics (units)	Dam 1	Dam 2	Dam 3
Storage Volume at Failure (acre-feet)	5000	280	4500
Embankment Top Elevation (feet)	1600	1500	1300
Bottom Elevation (feet)	1500	1400	1200
Maximum Depth (feet)	120	40	100
Embankment Length (feet)	1500	400	2100
Embankment Crest Width (feet)	35	20	20