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Examples, Statistics and Failure modes of tailings dams and consequence of failure

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REMTECH– OCT 15, 2015

Outline

1. **Recent tailings dam failures and ‘statistical’ review**
2. **Introduction to Failure Modes**
3. **Consequence of failure classification and Risk Assessment (quick mention)**

42 slides in 25 mins = Let’s go!!

“For any engineer to judge a dam stable for the long-term simply because it has been apparently stable for a long period of time is, without any other substantiation, a potentially catastrophic error in judgment"

(Szymanski and Davies(2004): "Tailings Dams - Design Criteria and Safety Evaluations at Closure" - BC Reclamation symposium)

Definitions

- **Tailings, also called mine dumps, culm dumps, slimes, tails, refuse, leach residue or slickens:**

  are the materials left over after the process of separating the valuable fraction from the uneconomic fraction (gangue) of an ore.

*schematic not representative of all facilities

Recent tailings dam failures

Can anyone name the most recent major tailings dam failure?

Recent tailings dam failures

Nope…not Mt. Polley

Brazil Tailings Dam Failure: Herculano, Itabirite – Sept 11, 2014

3 deaths confirmed (very limited public information)

What about before that?

Nope…still not Mt. Polley

August 18, 2014 – "Just last week, a massive tailings dam failed at the Buenavista del Cobre mine in Canenea, Sonora, and dumped 40 million liters of copper sulfate into the Rio Sonora. Mexican authorities are blaming the mine's owners, Southern Copper Corp., a subsidiary of Grupo México."

Source: http://www.rosemontminetruth.com/?p=3749 http://www.mineweb.com/mineweb/content/ | Saskatoon city council ... | Chronology of major ta... | Mexican governmen... | Google Transl

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Editors Picks

Mexican government files criminal charges in copper mine acid spill

Mexico's Environmental Secretary has estimated that the fine for the Buenavista copper mine spill could reach $3 million.

Author: Dorothy Kosich
Posted: Wednesday , 20 Aug 2014

13 days later

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RENO (MINEWEB) -

Mexico's federal environmental protection regulator, Profepa, has filed criminal charges with the Federal Attorney General's Office against Grupo Mexico's Buenavista del Cobre and Minera Mexico over a leakage caused by defects in newly constructed leaching ponds, which contaminated two rivers and left thousands of

Recent tailings dam failures

Imperial Metals – Mount Polley – Likely, BC – August 4, 2014

July 24, 2014 to August 5, 2014

Source: http://en.wikipedia.org/wiki/Mount_Polley_mine_disaster

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Mount Polley mine disaster

From Wikipedia, the free encyclopedia

Coordinates: 52.513437°N 121.5963

The **Mount Polley mine disaster** is an environmental disaster in the Cariboo region of British Columbia, Canada, that began in the early morning of 4 August 2014[2] when the Mount Polley tailings pond partially breached, releasing 10 million cubic metres of water and 4.5 million cubic metres[2] of slurry into Polley Lake.[3] The tailings pond covers four square kilometres and by 8 August according to Brian Kynoch, president of Imperial Metals, [3] the owner of the Mount Polley copper and gold mine,[4] the tailings pond was "virtually empty."[4][2] The contaminated slurry carrying felled trees, mud and debris "scoured away the banks" of Hazeltine Creek which flows out of Polley Lake and continued into the nearby Quesnel Lake. The spill caused Polley Lake to rise by 1.5 metres (4.9 ft).[4] Hazeltine Creek was transformed from a 2-metre-wide (6.6 ft) stream to a 50-metre-across (160 ft) "wasteland."[5] Cariboo Creek was also affected.[2] The spill has been called one of the biggest environmental disasters in modern Canadian history.[6][7][8]

Contents [hide]

Mount Polley mine disaster

July 24, 2014

Last major mine spills in Canada?

Picture of a 100 km long leak of coal mine sludge, making its way down the Athabasca River. This photo taken on Nov. 11 or 12, near the confluence of the Lesser Slave River. One billion litres of sludge leaked from the closed Obed Mountain Mine near Hinton on Oct. 31, 2013

Last major mine spills in Canada?

- There were 46 “dangerous or unusual occurrences” at tailings ponds at mines across B.C. between 2000 and 2012, according to annual reports of B.C’s chief inspector of mines http://www.vancouversun.com/news/Liberals+keeping+dangerous+occurrences+tailings+ponds+secret/10131898/story.html#ixzz3YcCrZRng

- Cliff’s Resources:
  - Fined $7.5M for release from Bloom Lake tailings ponds in Quebec
  - Breach of the Triangle Tailings Pond dam and a separate release of 14,500 litres of ferric sulfate into water frequented by fish

  - http://www.netnewsledger.com/2014/12/26/7-5-million-dollar-fine-for-cliffs-natural-resources-general-partner/#sthash.hWF2mgaK.dpuf https://www.google.ca/?gws_rd=ssl#q=tailings-

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Chronology of major tailings dam failures
www.wise-uranium.org/mdaf.html
Sep 4, 2014 - copper, gold, **tailings dam failure**, 7.3 million m^3 of tailings, 10.6 million m^3 of water, and 6.5 million m^3 of interstitial water, tailings flowing into ...

Images for tailings dam failure Report images

More images for tailings dam failure

Tailings.info Stava tailings dam failure
www.**tailings**.info/casestudies/stava.htm
Stava **tailings dam failure**, Trento, Italy. One of the worst tailings disasters in history.

Tailings dam failure kills three workers | MINING.com
www.mining.com/**tailings-dam-failure**-in-brazil-kills-workers-67230/
Sep 12, 2014 - The military were called to the accident around 7:50 a.m. and worked for four hours to rescue buried miners. The Municipal Secretary of ...

Category:Tailings dam failures - Wikipedia, the free ...
en.wikipedia.org/wiki/Category:**Tailings_dam_failures**
Pages in category "**Tailings dam failures**". The following 8 pages are in this category, out of 8 total. This list may not reflect recent changes (learn more).

Production boost preceded tailings dam breach at Mount ...
www.vancouversun.com/Production...**tailings+breach**.../story.html

http://www.wise-uranium.org/mdaf.html | Chronology of major tailing... | cbc.ca

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Chronology of major tailings dam failures

(from 1960)

(last updated 18 May 2015)

Note: Due to limited availability of data, this compilation is in no way complete

Four in 2014

Date	Location	Parent company	Ore type	Type of Incident	Release
2014, Sep. 10	Herculano mine, Itabirito, Região Central, Minas Gerais, Brazil	Herculano Mineração Ltda	iron	tailings dam failure	?
2014, Aug. 7	Buenavista del Cobre mine, Cananea, Sonora, Mexico	Southern Copper Corp. (Grupo México)	copper	tailings dam failure	40,000 m^3 of copper sulphate
2014, Aug. 4	Mount Polley mine, near Likely, British Columbia, Canada	Imperial Metals Corp.	copper, gold	tailings dam failure due to foundation failure (view details)	7.3 million m^3 of tailings, 10.6 [cut off] water, and 6.5 million m^3 of int[cut off]
2014, Feb. 2	Dan River Steam Station, Eden, North Carolina, USA	Duke Energy	coal ash	collapse of an old drainage pipe under a 27-acre ash waste pond	about 82,000 short tons [74,40[cut off] coal ash and 27 million gallons [[cut off] of contaminated water
2013, Nov. 15-19	Zangezur Copper Molybdenum Combine, Kajaran, Syunik province, Armenia	Cronimet Mining AG	copper, molybdenum	damage of tailings pipeline	?
2013, Oct. 31	Obed Mountain Coal Mine, northeast of Hinton, Alberta, Canada	Sherritt International	coal	breach of wall in containment pond	spill of 670,000 m^3 of coal was[cut off] 90,000 tonnes of muddy sedim[cut off]
2012, Dec. 17	former Gullbridge mine site, Newfoundland, Canada		copper	embankment dam failure, width 50 m	
2012,	Sotkamo, Kainuu,	Talvivaara Mining Company Plc	nickel, (uranium by-		hundreds of thousands of cubic

Worst of all time?

Stava, Italy

At 12h:22':55" on 19th July 1985 the bank of the upper basin gave way and collapsed onto the lower basin, which, too, collapsed. The muddy mass composed of sand, slime and water moved downhill at a velocity approaching 90 km/h, killing people and destroying trees, buildings and everything in its path, until it reached the river Avisio. Few of those hit by this wave of destruction survived.

Along its path, the mud killed 268 people and completely destroyed 3 hotels, 53 homes, and six industrial buildings; 8 bridges were demolished and 9 buildings were seriously damaged. A thick layer of mud measuring between 20 and 40 centimetres in thickness covered an overall 435,000 square metres over 4.2 kilometres.

Approximately 180,000 cubic metres of material poured out of the dams. A further 40,000 - 50,000 cubic metres came from erosion, buildings demolished by the flow and hundreds of uprooted trees.

The July 19th 1985 disaster in the Stava valley was the most tragic of its kind. With its toll of 268 lives lost and 155 million Euros in damage, it was one of the worst industrial catastrophes in the world.

Stava Monument

http://www.tailings.info/casestudies/stava.htm

Statistics?

Source: ICOLD, 2001

Some quick statistics regarding tailings dam failures (~221):

- **Approximately 3,500 tailings dam worldwide**
- **1970-2001 – annually 2 to 5 major tailings dam failures (we don't often hear about the minor failures)**

Key Point – Annual rate of failure: 1:700 to 1:750

Knowing these statistics, a couple interesting questions:

- **What is the life span of your facility?**
- **(number of facilities) x (age) ?**

Source: **Azam, Li** – “Tailings Dam Failures – A review of the last 100 years” Geotechnical News – December 2010

Statistics?

“For a world inventory of 18401 mine sites, the failure rate over the last one hundred years is estimated to be 1.2%”

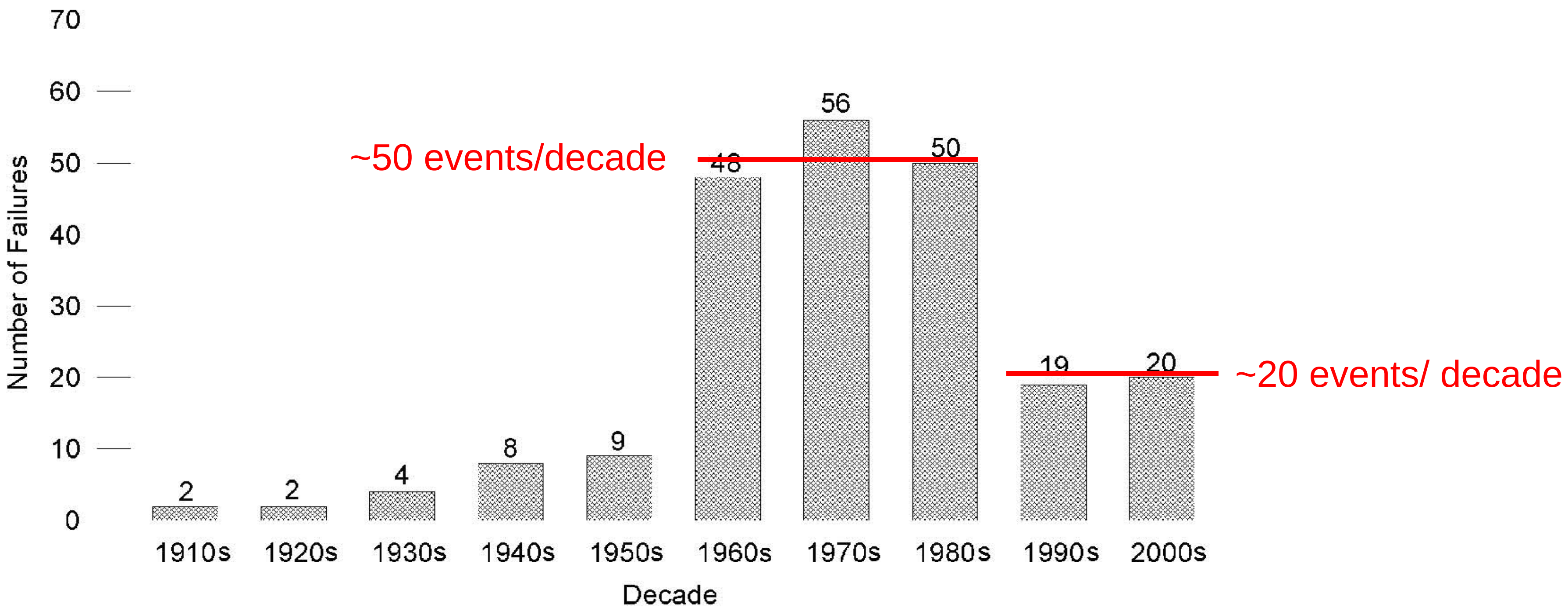

Figure 1. Failure events over time.

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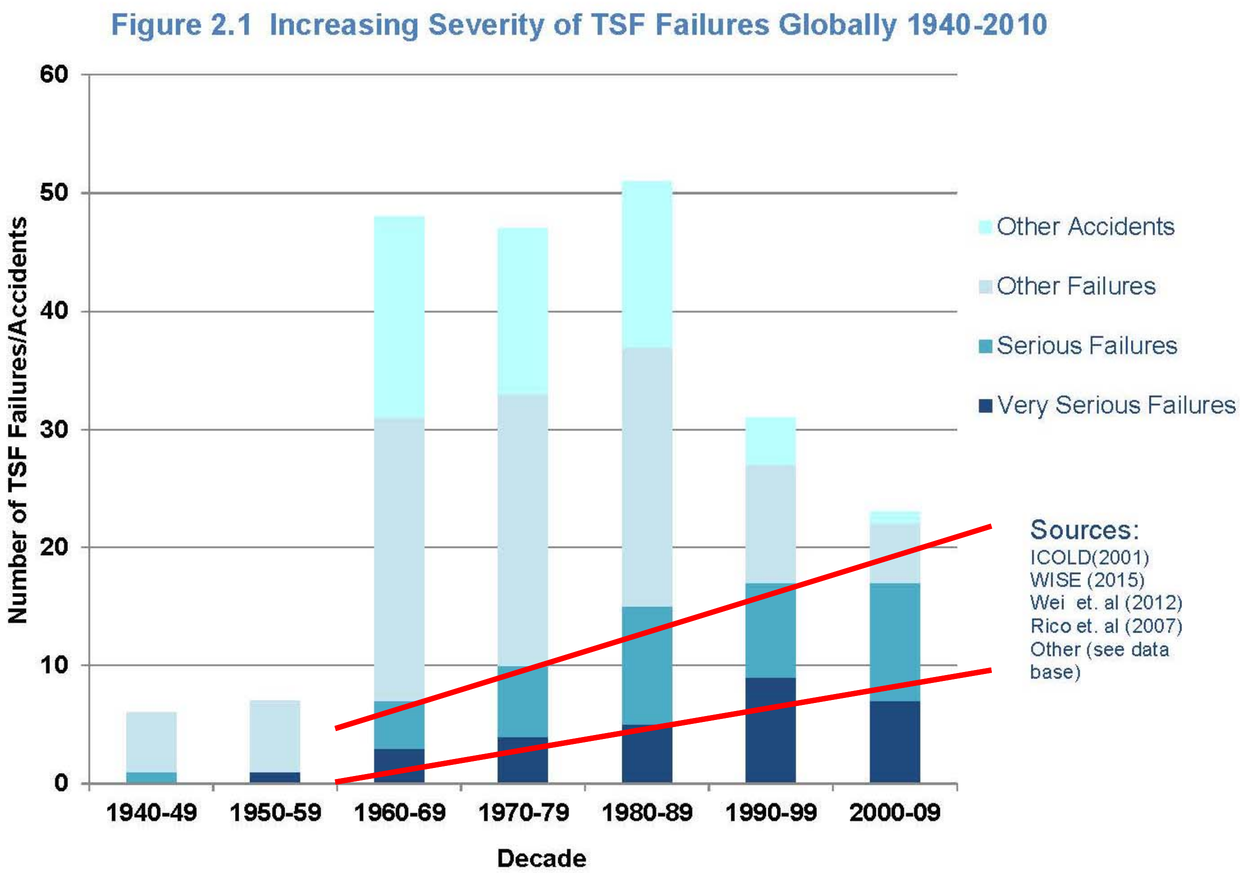
Statistics?

"Risk potential has increased by a factor of 20 every 1/3 century." (Robertson 2011 – Tailings and Mine Waste Conference, Keynote Address)



Source: **Bowker & Chambers** – "The Risk, Public Liability & Ecomonmics of Tailings Storage Facility Failures" July 2015

Statistics?

Failure rate of different dam types from 1831 to 1965*				
Dam Type	**Number of Dams Built**	**Number of Dams that Failed**	**Failure Rate (%)**	**odds**
Embankment				
Soil	4551	121	2.66%	2/75
Rock	285	13	4.56%	1/22
Total	4836	134	2.77%	1/36
Concrete				
Arch	566	7	1.24%	1/81
Buttress	373	7	1.88%	1/53
Gravity	2271	40	1.76%	1/57
Total	3210	54	1.68%	1/59
Combined Total	8046	188	2.34%	1/43

* Reproduced from Cenderelli, 2000

Cenderelli, D.A. (2000). Floods from natural and artificial dam failures. In: Wohl, *Inland Flood Hazards: human, riparian, and aquatic communities* (pp 73-103). New York: Cambridge University Press

Failure Modes

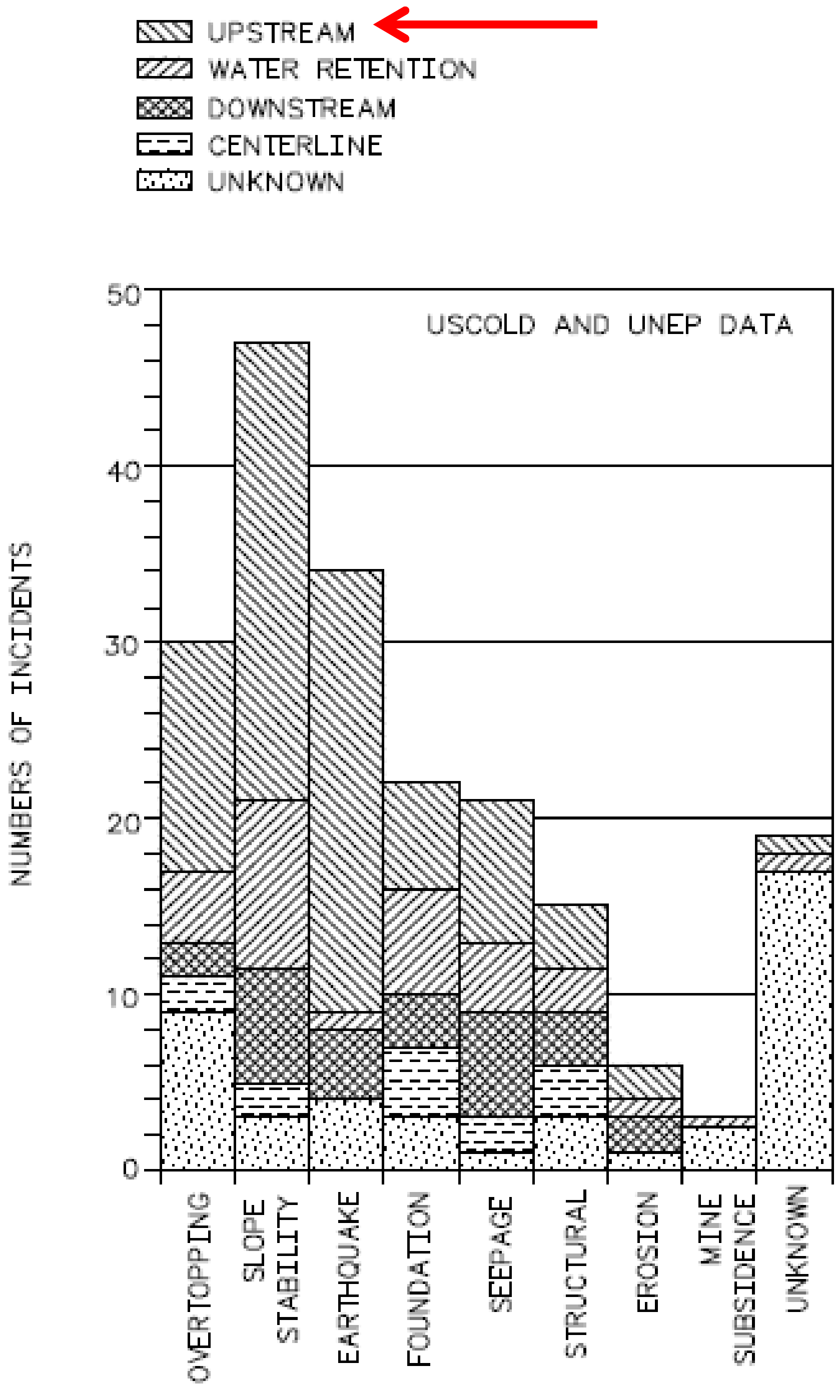
#1 – Slope Stability
#2 – Seismic
#3 – Overtopping

Source: ICOLD, 2001

Analysis of failures between 1970-2001

COMMISSION INTERNATIONALE DES GRANDS BARRAGES
INTERNATIONAL COMMISSION ON LARGE DAMS

http://www.icold-cigb.org/



So what’s the message??

‘Empirical’ Statistics are interesting, but how do we change them?

Mining Association of Canada Guidelines

Canadian Dam Association Guidelines

Qualified Persons?

Engineer of Record?

Failure Modes Analysis and

Consequence of Failure (Risk)

Failure Modes

Physical / Structural

- Slope failure
- Foundation failure
- Surface Erosion
- Internal Erosion
-

Functional

- Adequate size / Volume
- Resultant density
- Beaching angles
- Dewatering
- Reclaim quality

Environmental

- Groundwater
- Surface water
- Dust
- Noise
- Visual Impact
- …

Contributing Factors

Failure Modes

During Inspections:
- Seepage
- Cracking
- Deformation
- Erosion

Physical / Structural

Slope Failure
- Raising of Dyke
- Placement of tailings
- Undercutting
- Poor construction materials
- Over-steepening
- Direct loading
- Seismic

Foundation Failure
- Undrained loading
- Sensitivity clays
- Seepage forces
- Strength loss
- Weak layers

Surface Erosion
- Overtopping
- Runoff
- Excessive inflow
- Insufficient outflow conveyance
- Inadequate rip-rap
- Landslide into impoundment

Internal Erosion
- Piping
- Lack of adequate filter
- Zoned dams
- Sinkholes
- Unprotected conduits
- Joints/seepage in foundation/ abutments

Contributing Factors for Mode of Failure

Design / Construction

- Dam type
- Materials
- Hydrology/hydrogeology
- Construction
- Outlet Structures
- Freeboard
- Foundation/ Abutments
- Chemical processes
- Biological Processes

Operation / Maintenance

- Rate of deposition
- Water Management
- Inspection / Monitoring
- Maintenance
- Chemical processes
- Biological processes

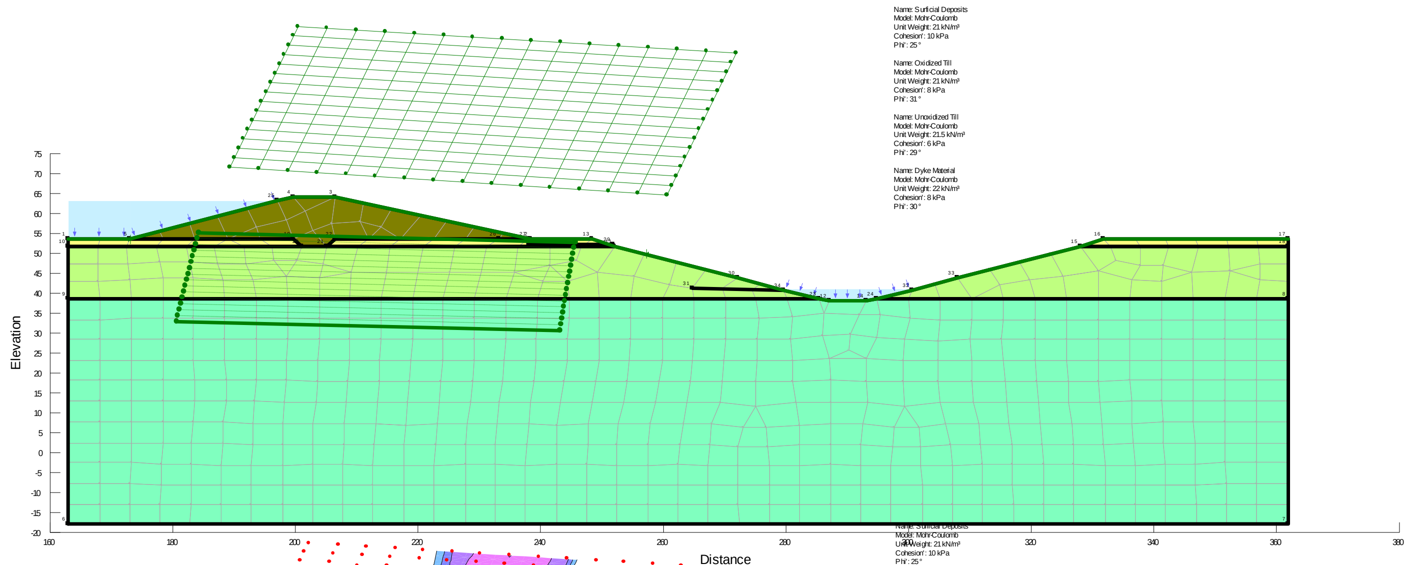
External Factors

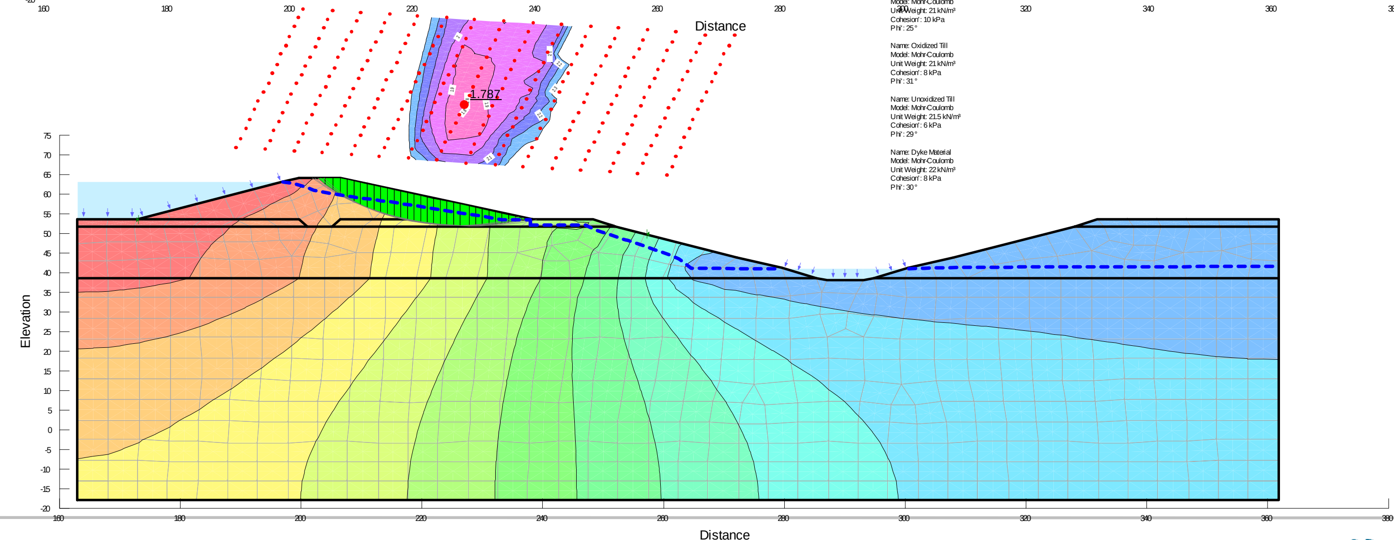
- Human Activity
- Climate/weather
- Seismic activity
- Earth movement
- Onforeseen

…a partial list

Failure Modes

Slope Failure





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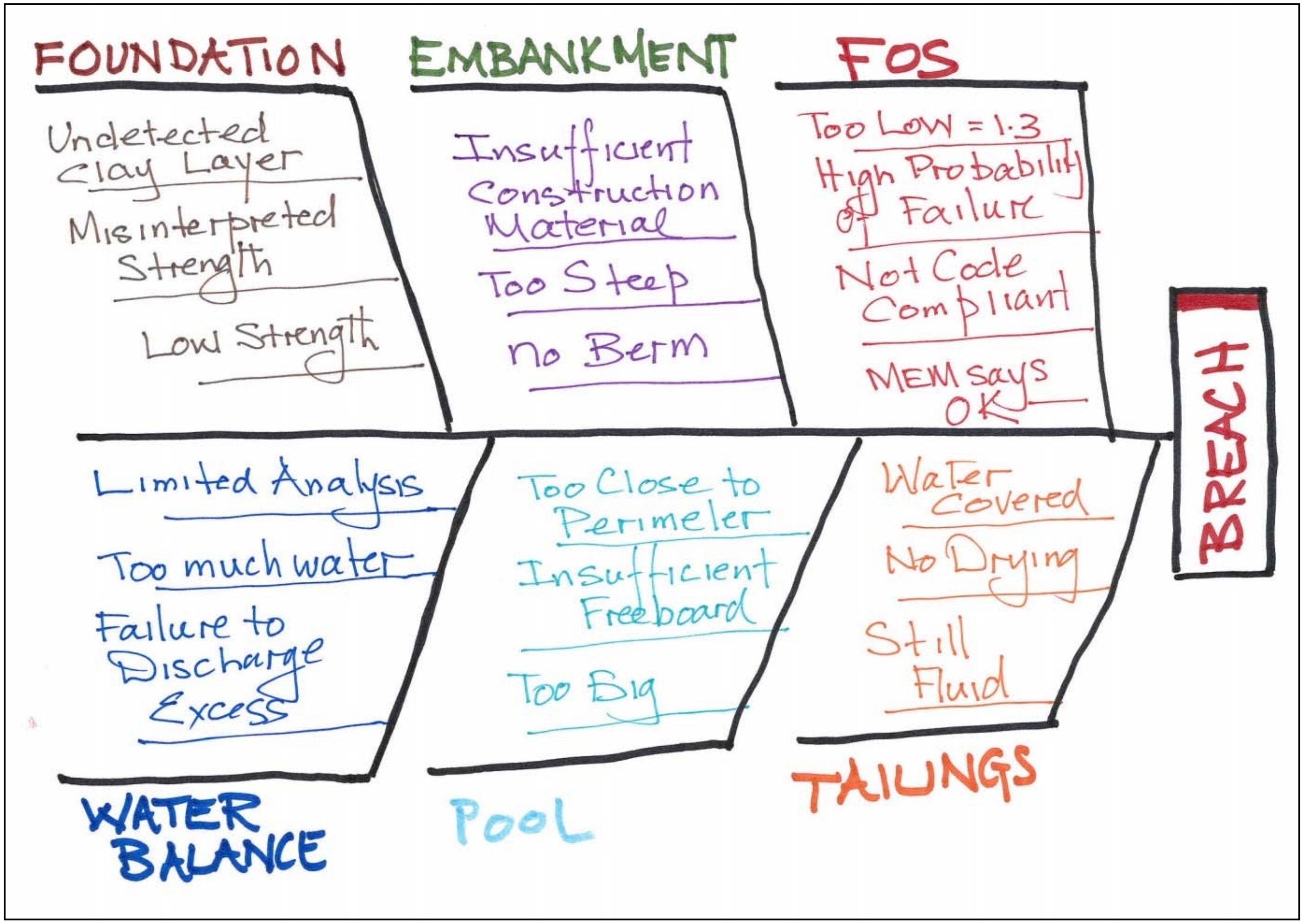
Failure Modes

Slope Failure

-Highest point in dyke?
-Centreline construction
-Recent raise
-Aligned of natural channel
-Repose angle slopes
-overtopping initiated by foundation slope instability

Failure Modes

Slope Failure

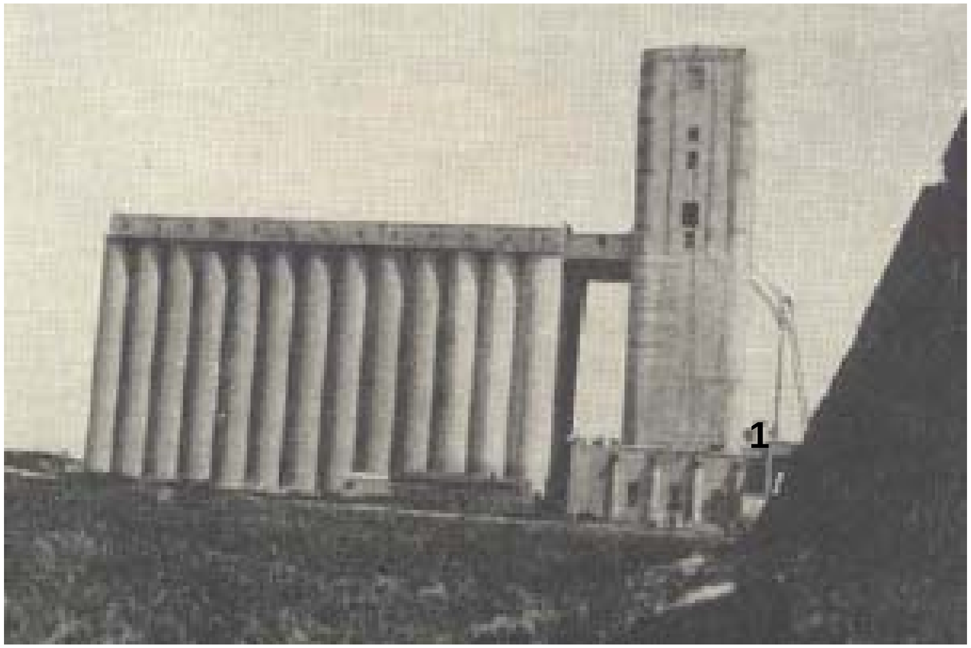


CREDIT : Jack Caldwell – Infomine

Failure Modes

Foundation Failure

Transcona Grain Elevator, near Winnipeg, Manitoba (analogous)



Built in 1913
Started filling with grain September 1913

October 19, 1913
27° tilt toward the west

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Failure Modes

Surface Erosion

Merriespruit Tailings Dam Overtopping Failure, Virginia, South Africa, February 22, 1994
50 mm of rain fell in 30 minutes; 17 people killed, 80 houses destroyed

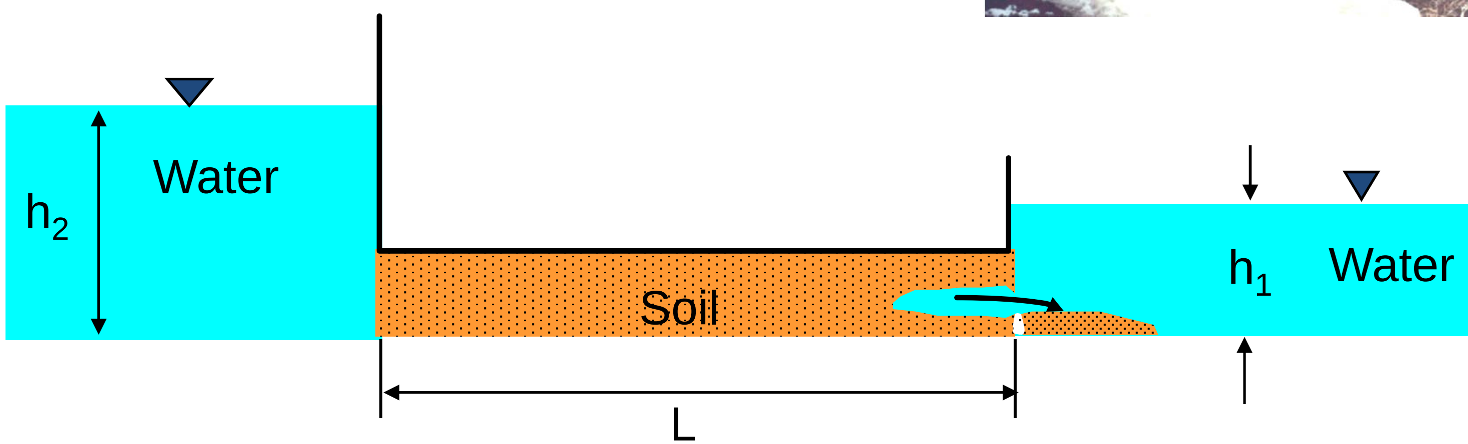
Source: http://en.wikipedia.org/wiki/Merriespruit_tailings_dam_disaster

Failure Modes

Internal Erosion

$$\text{Gradient} = i = \frac{h_2 - h_1}{L} = \frac{\Delta\,\text{Energy}}{\text{Length}}$$

Critical gradient (fresh water) ~ 0.9-1.0
Critical gradient (brine) ~ 0.5-0.6
(i.e. hazard of piping at potash mines is high)



Failure Modes

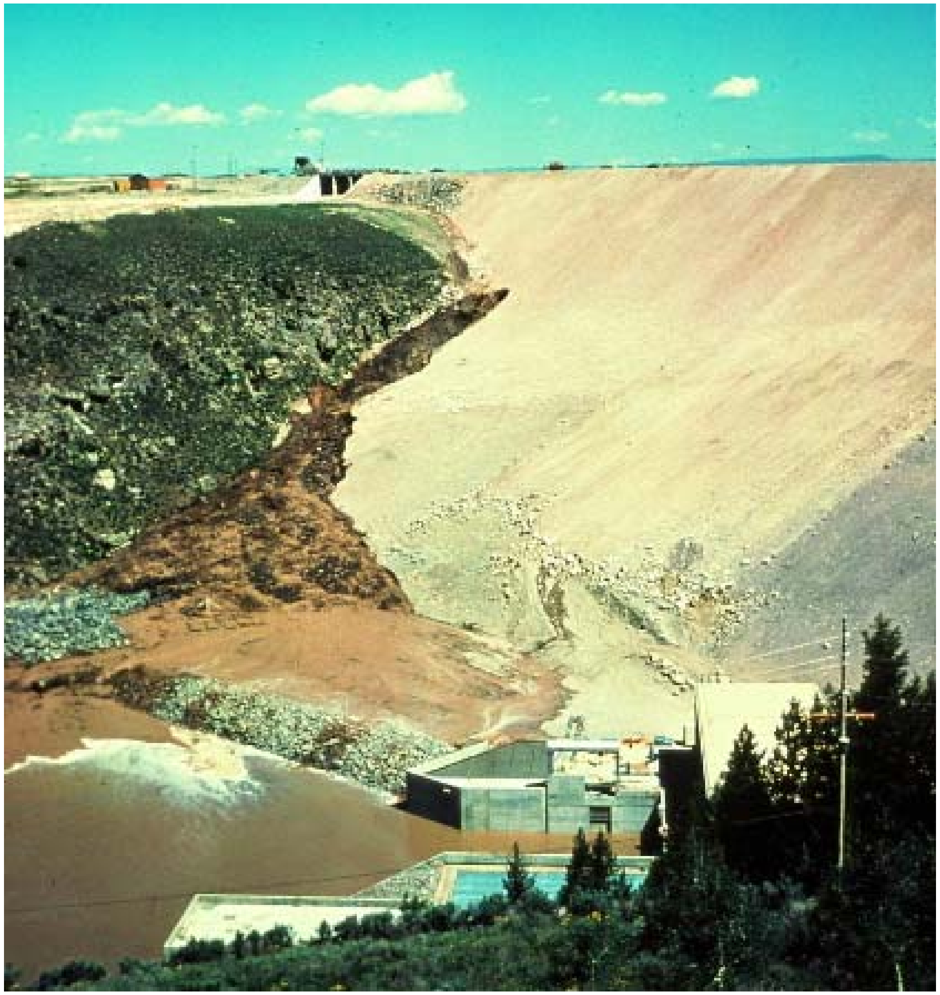
Internal Erosion

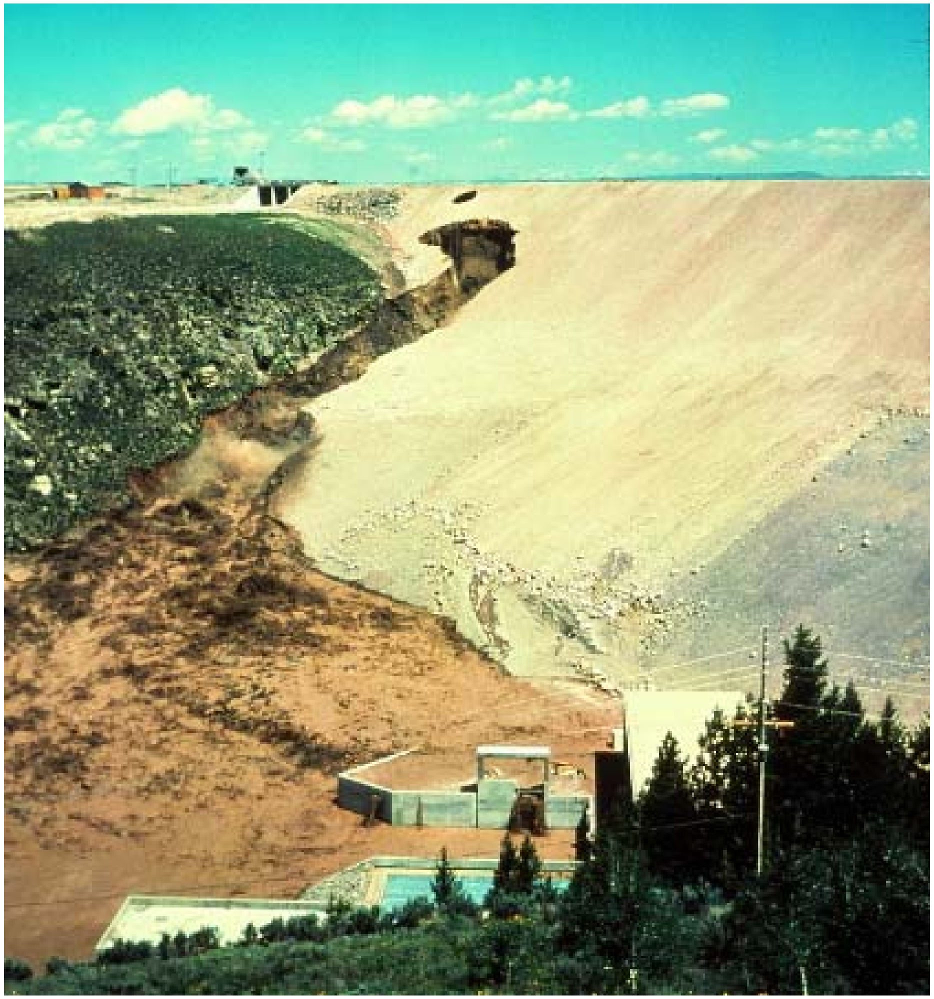
1976 FAILURE OF TETON DAM – IDAHO

-Failed during filling of dam
-80 billion gallons – 300 million cubic meters
-200 residences destroyed
-14 deaths
-1 billion dollars in damage

Failure Modes

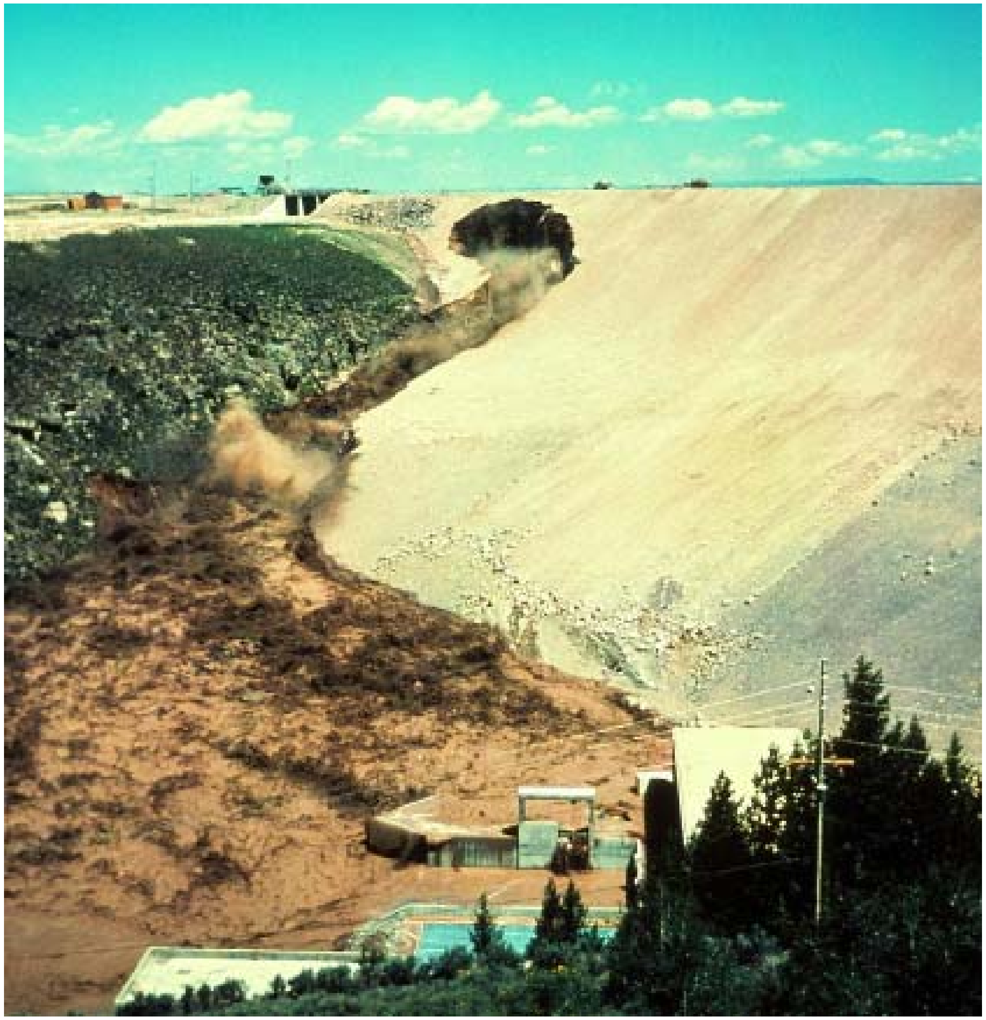
Internal Erosion

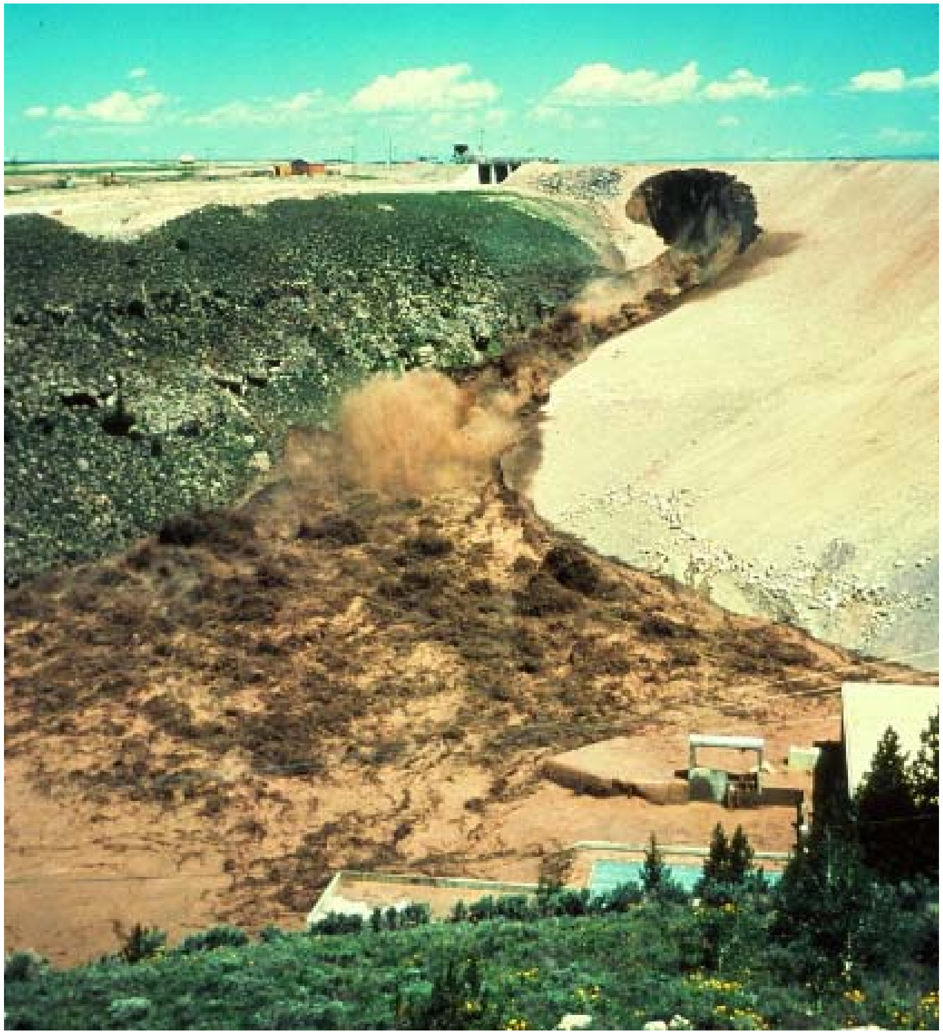




Failure Modes

Internal Erosion





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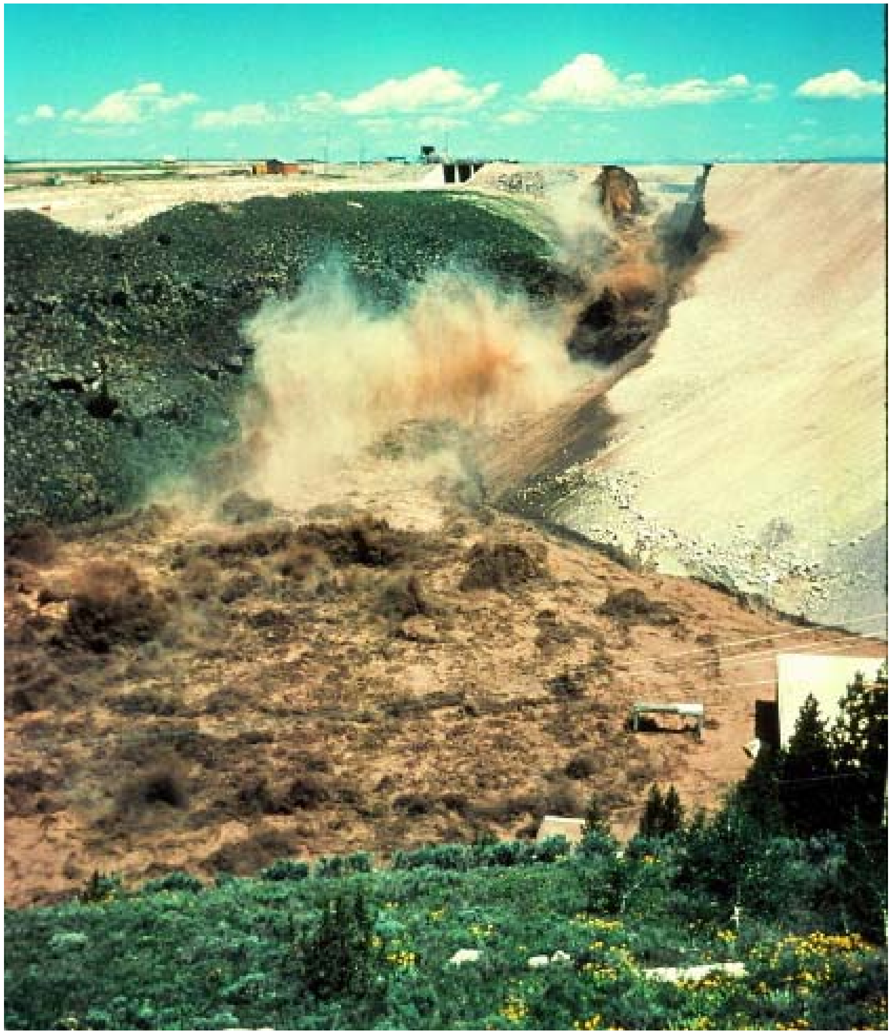
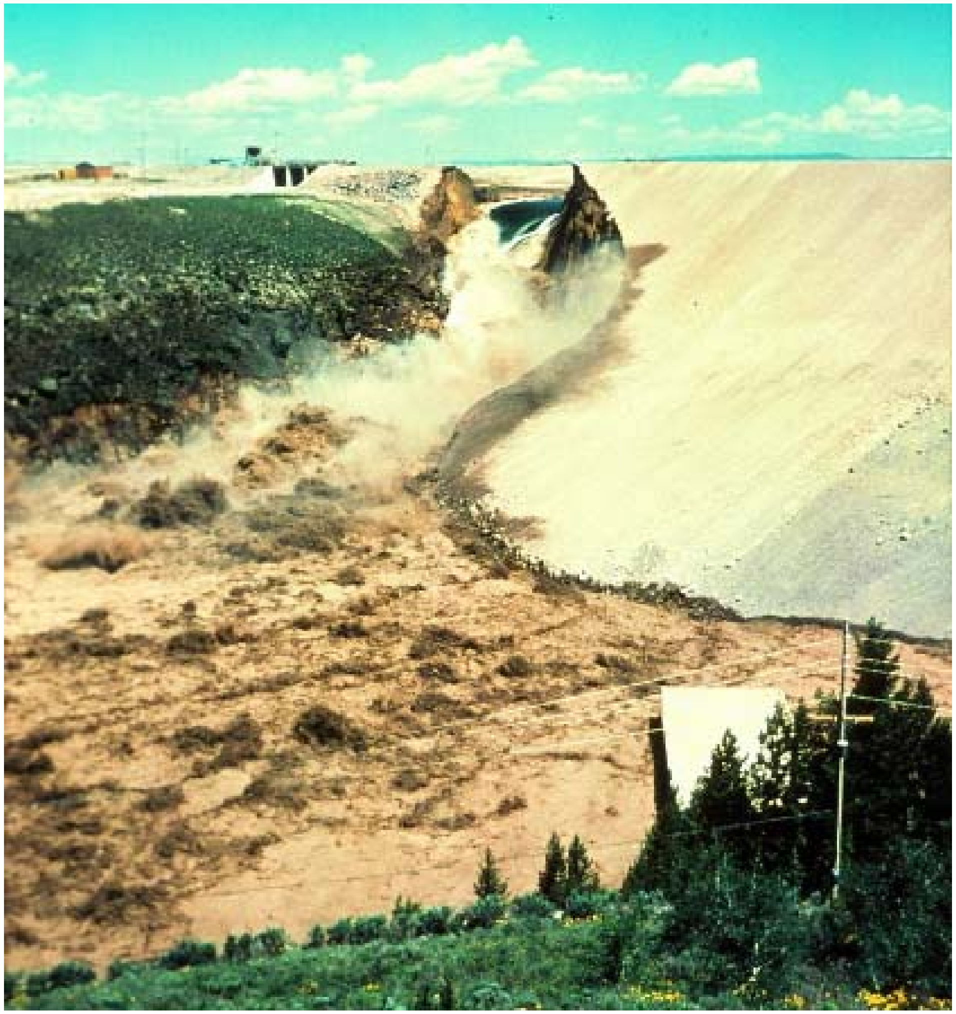
Failure Modes

Internal Erosion

Failure Modes

Internal Erosion





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Failure Modes

Internal
Erosion

Failure Modes

Internal Erosion

Failure Modes

Internal
Erosion

CDA ACB

Consequence of Failure

Table 2-1 (CDA Dam Safety Guidelines)

My recommendation:

Incorporate ‘Likelihood’ to develop Risk Assessment

Consider:

Direct vs. Indirect Consequences

Source: Table 2-1 of CDA 2013

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	Environmental and cultural values	Infrastructure and economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

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Summary

- Tailings dams continue to fail around the world
  - Mother nature is working to make the world flat
  - Dykes conditions are constantly changing (think of watching your kids growing)
- Many failure modes exist
  - Physical, Environmental, Functional
- Consequence of Failure
  - Can be separated from likelihood
  - Risk based (including probability/likelihood) allows for increased ability to manage failure modes
  - Recommended: Use FMEA with Risk assessment to drive priority identification for facility management
  - Recommended: Follow the MAC and CDA guidelines, statistics will be reduced

References

- International Committee on Large Dams (ICOLD), 2001, Tailings Dams Risk of Dangerous Occurrences, Bulletin 121.
- Canadian Dam Association (CDA), 2007, Dam Safety
- Canadian Dam Association (CDA), 2014, Application of Dam Safety Guidelines to Mining Dams

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