Knight Piésold CONSULTING

MINE TAILINGS – PAST AND PRESENT

MARCH 12th, 2013

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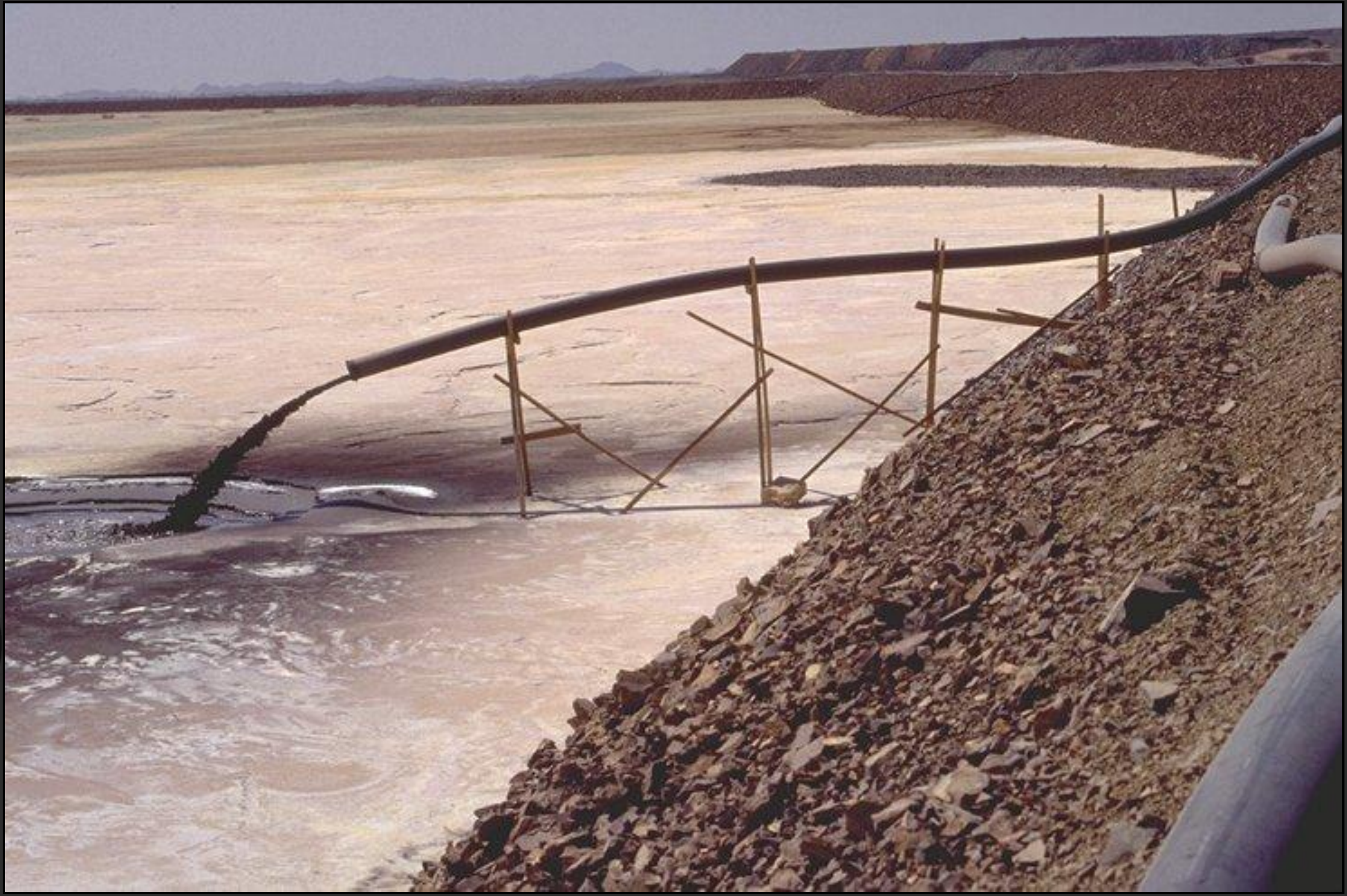
Outline

- What are tailings?
- Tailings Management – Brief History
- Tailings Management Technologies
- What is a Tailings Storage Facility?
- Tailings Dam Construction Methods
- Alaska Dam Safety Program
- TSF Design Considerations
- Closure
- Overview of dam failures

What Are Tailings?



What are Tailings?

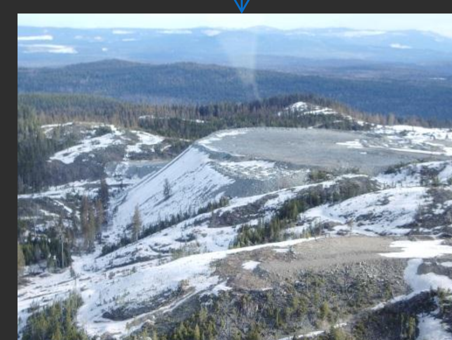
- Tailings are the ground-up solids left over after the mineral concentrate has been extracted from the processed ore.

Mining produces waste and ore materials

Ore

Waste

Mill



Waste Pile

What are Tailings?

- Ore grade rock is typically ground to the sand/silt size (less than 1mm) range prior to the milling process.

What are Tailings?

- The milling process produces mineral concentrate and tailings

Mineral Concentrate

Tailings

Mostly solids, typically contains 80% to 90% of the economic minerals in the ore.

Tailings Storage Facility

What are Tailings?

- Tailings material typically contain:
  - Residual quantities of economic minerals – milling process does not extract 100% of the economic minerals
  - Chemical reagents used in ore processing

- Tailings may also be Potentially Acid Generating (PAG)

Tailings Management – Brief History

- Historically, tailings were routinely discharged directly into the nearest surface water course. Examples include:
  - Kitsault Mine, Canada
  - Britannia Mine, Canada
  - Alaska Juneau Mining Company

Tailings

Tailings Management – Brief History

- Tailings disposal also included uncontrolled discharged on surface

Historic Mine in Nevada

Tailings Management – Brief History

- Managing tailings behind containment dams not a new concept.
- However, very early dams had very little, if any, engineering or regulatory input
    - Buffalo Creek Dam failure (West Virginia)
- Programs developed to ensure a high level of tailings disposal security include:
    - Guidelines for Cooperation with the Alaska Dam Safety Program
    - International Commission of Large Dams (ICOLD)
    - Canadian Dam Safety Association guidelines
    - Mining Association of Canada

Tailings Management – Brief History

- Tailings management often the most critical mine component for regulators (and public)
- Mining companies now use specialist geotechnical consultants to provide independent review, advice and design for tailings facilities
- Many companies incorporate third party reviews/risk assessments for tailings dams
- Larger mining companies also have internal tailings management specialists

Tailings Management Technologies

- Tailings management technologies include conventional tailings, thickened tailings, paste tailings, and filtered tailings

Conventional tailings

Thickened tailings

Slurry "wet" tailings

Ultra thickened "paste" tailings

Filtered "dry" tailings

Increasing Solids Concentration (less water) →

Increasing Complexity, cost, power requirements →

- Conventional, thickened, and paste tailings pumped to tailings storage facility. Filtered tailings trucked or conveyed.

Tailings Consolidation

Tailings Management Technologies
Slurry Tailings

Kensington Mine, Alaska

Fort Knox Mine, Alaska

Tailings Management Technologies
Paste and Filtered or “Dry Stacked” Tailings

Paste-Bulyanhulu Project, Tanzania

Filtered-Pogo Mine, Alaska

Filtered - Greens Creek, Alaska

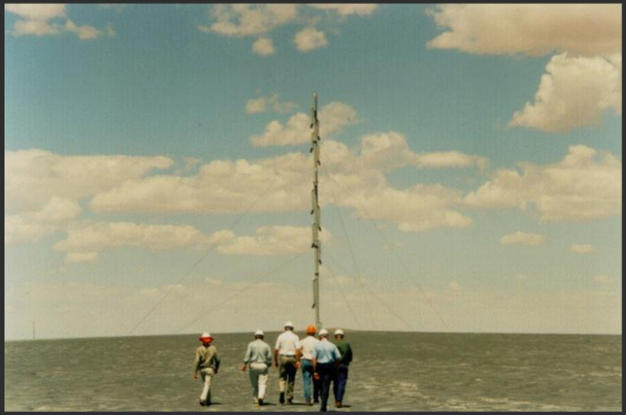
Greens Creek and Pogo Mine relatively small mines

Mill throughputs in the order of 2,000 to 3,000 tpd

When to Consider Paste Tailings

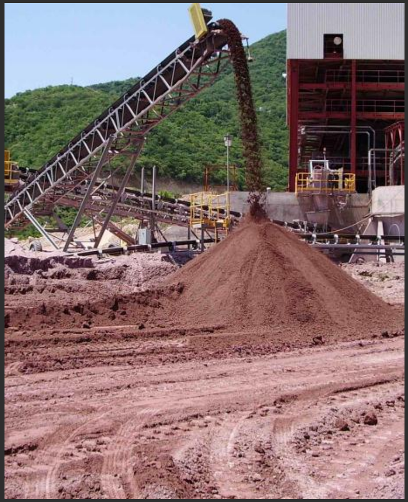
- When seasonal/climatic variations can be accommodated
- When water is scarce
- When operational controls can be assured
  - back-up plan may be required
- Often, when real estate is ample

  (Central Thickened Discharge)



When to Consider Filtered Tailings

- When seasonal/climatic variations can be accommodated
- When maximum water recovery is needed
- When operational controls can be assured
  - back-up plan may be required
- When adequate compaction can be achieved in “dry” stack
- More suitable for low tonnage operations



Tailings Management

- Tailings management is different for all mines. There is no generic tailings management plan, tailings technology that is suitable for all mines.

Greens Creek, Alaska

Filtered tailings

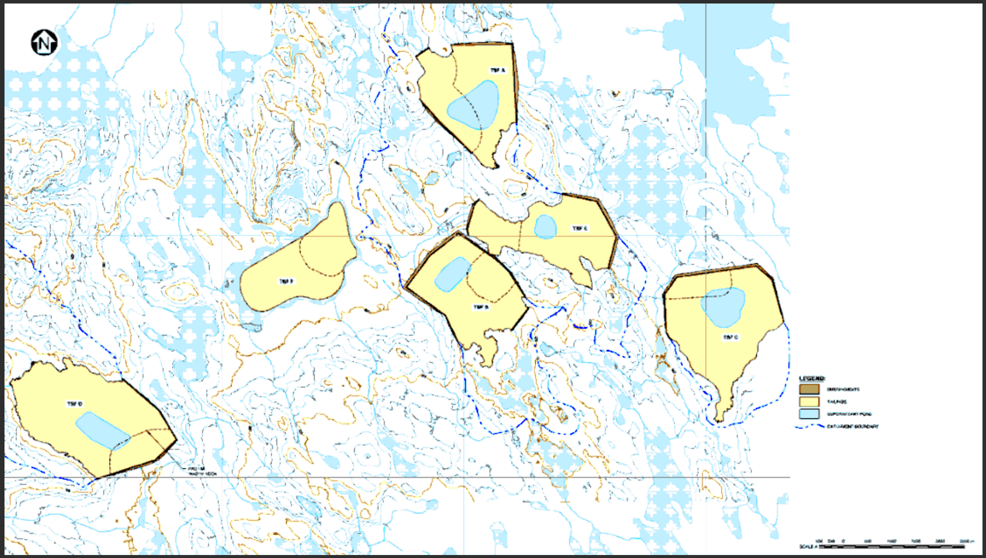
Fort Knox, Alaska

Slurry tailings

Tailings Management

Tailings management considerations include:

- ✓ Site characteristics (topography, climate, seismicity, precipitation, groundwater)
- ✓ Mine/Mill production schedule
- ✓ Total storage requirements
- ✓ Seepage management
- ✓ Precedent
- ✓ Physical and geochemical tailings characteristics
- ✓ Environmental and social considerations
- ✓ Foundation conditions
- ✓ Water management
- ✓ Closure
- ✓ Costs - $/ton



What is a Tailings Storage Facility?

- Tailings Storage Facilities (TSF) are engineered structures designed to provide permanent storage for all tailings produced during life of mine
- May also act as a reservoir for mill process water and site runoff

Mount Polley Mine, Canada

Fort Knox Mine, Alaska

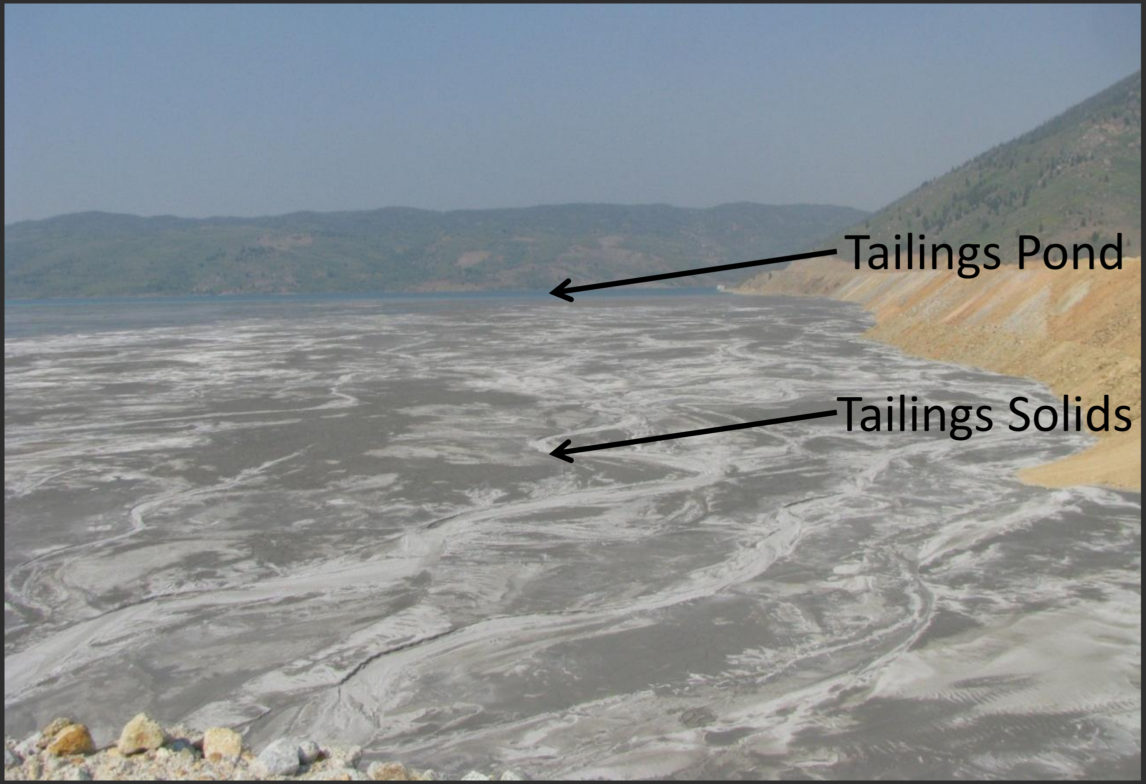
What is a Tailings Storage Facility?

- Paste and filtered “dry stack” tailings require additional water ponds for process water and stormwater management
- Ponds may be very large in wet or northern climates

Raglan Mine, Canada

What is a Tailings Storage Facility?

- Tailings Storage Facilities are solids retention facilities – surface pond is very small



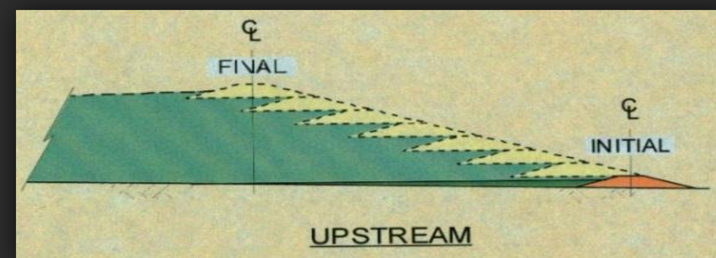
Montana Resources, Montana

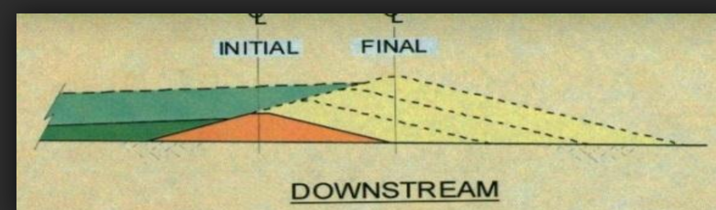
Tailings Dam Construction Methods

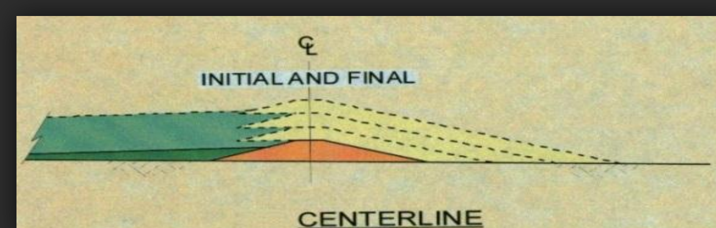
- TSF Embankments typically constructed using earthfill and rockfill materials

- Embankments constructed using upstream, downsteam, or centerline construction methods

- Embankment constructed in staged lifts throughout mine life



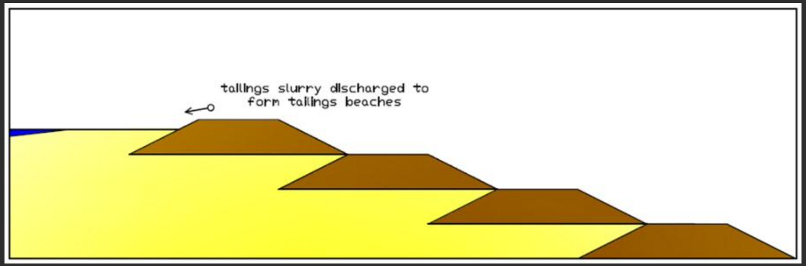




Tailings Dam Construction Methods

UPSTREAM CONSTRUCTION

- Least cost construction method
- Sensitive to water management, operational factors, earthquakes
- Highest number of tailings dam failures



Tailings Dam Construction Methods

DOWNSTREAM

- Highest cost construction method
- Large fill requirements
- Seismically stable

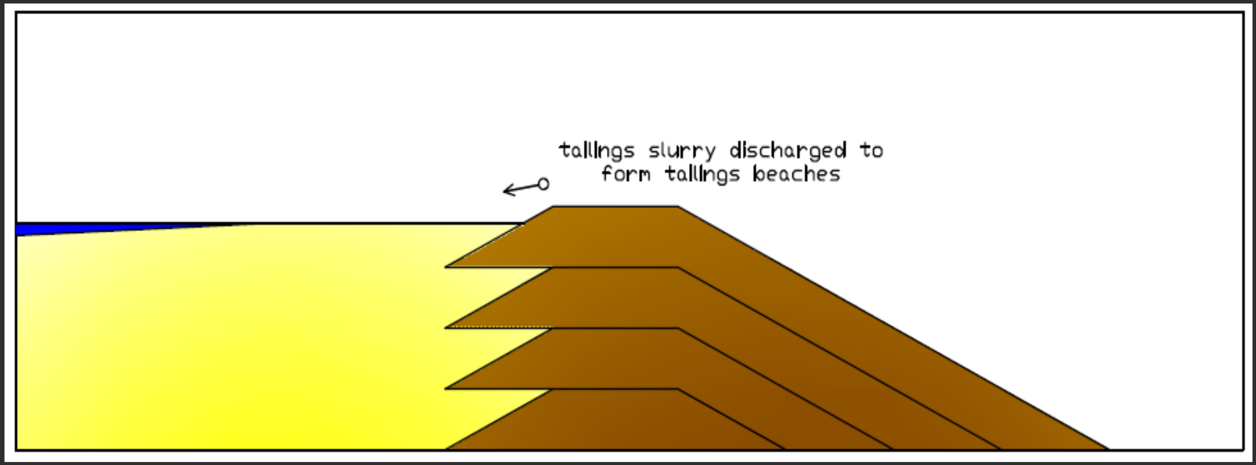
Palmarejo Mine, Mexico

- Geomembrane on dam face for seepage control necessitates downstream raises
- Low permeability clay or till for core zone not locally available

Tailings Dam Construction Methods

CENTERLINE

- Intermediate cost construction method
- Moderate fill required
- Seismically stable



Alaska Dam Safety Program

- All dams in Alaska (water and tailings dams) are regulated by the Alaska Dam Safety Program (ADSP).
- Regulations mandate sound, safe design, construction and operations
- “A person may not construct, enlarge, repair, alter, remove, maintain, operate, or abandon an dam or reservoir without approval from the ADSP”

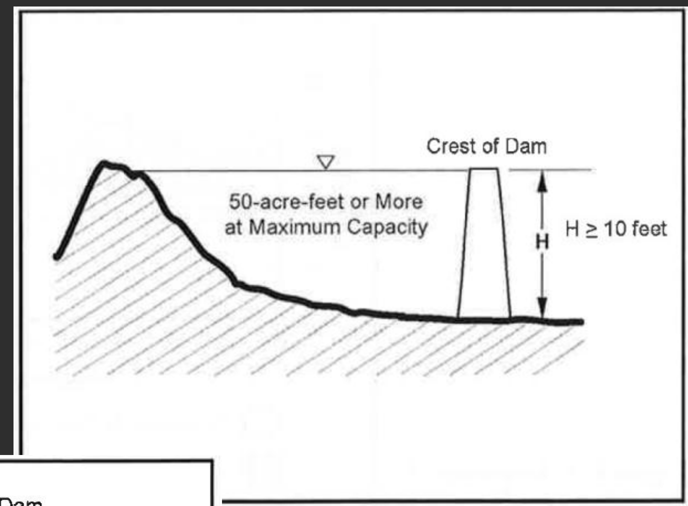
Alaska Regulatory Process

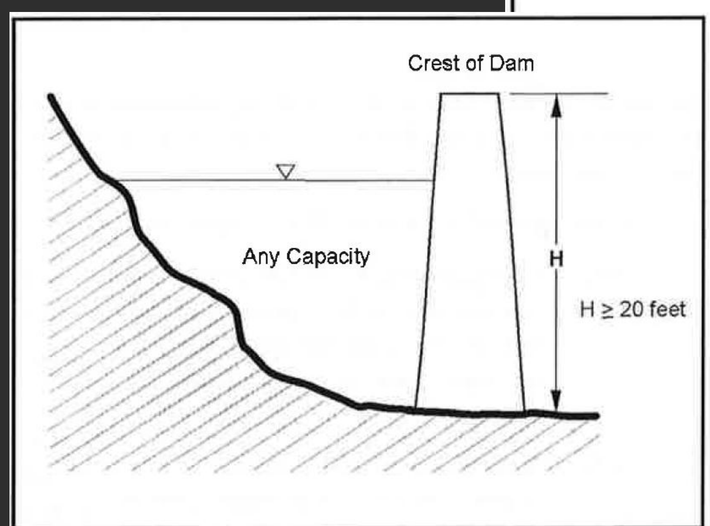
All dams in Alaska come under ADSP jurisdiction if they fall into any of the following categories:

Capacity and dam height:

50 acre feet

~ 80,000 cubic yards





Dam Height only

Alaska Regulatory Process

The Alaska Dam Safety Requirements Include:

- Rigorous Technical Reviews
- Regulatory Agency Reviews
- Regularly Scheduled Audits by Third Party Specialists
- Annual Inspections by the Design Engineers

- Inspections continue post closure

Hazard Classification

- All dams are classified on the basis of their Hazard Potential Classification, which includes:
  - Definition of the potential impacts if the structure were to hypothetically fail. This may include a hypothetical dam breach analysis..
  - All of the potential adverse impacts, in terms of loss of life, environmental and economic impacts

- The Dam Classification is then used to define the Design Earthquake, Inflow Design Flood, and monitoring and inspection frequency

Hazard Classification

- The Hazard Classification for Alaska dams is based on the following criteria:

Hazard Class	Effect on Human Life	Effect on Property
I (High)	Probable loss of one or more lives	Irrelevant for classification, but may include the same losses indicated in Class II or III
II (Significant)	No loss of life expected, although a significant danger to public health may exist	Probable loss of or significant damage to homes, occupied structures, commercial or high-value property, major highways, primary roads, railroads, or public utilities, or other significant property losses or damage not limited to the owner of the barrier Probable loss of or significant damage to waters identified under 11 AAC 195.010(a) as important for spawning, rearing, or migration of anadromous fish
III (Low)	Insignificant danger to public health	Limited impact to rural or undeveloped land, rural or secondary roads, and structures Loss or damage of property limited to the owner of the barrier

- The selected hazard classification requires approval by ADSP

Design Earthquake and Flood Events

- Design earthquake and Inflow Design Flood (IDF) based on dam classification. Operations and closure considered when defining hazard classification.
- Design earthquake

	Return Period, Years	Return Period, Years
Dam Hazard Classification	**Operating Basis Earthquake**	**Maximum Design Earthquake**
I	**150 to >250**	**2,500 to MCE**
II	**70 to 200**	**1,000 to 2,500**
III	**50 to 150**	**500 to 1,000**

- IDF

Dam Hazard Classification	IDF
Minimum Standard for Class III Dams	**100 year flood event**
Maximum Standard for all Class Dams	**PMF**
Calculated Standard for all Class Dams	**incremental hazard evaluation**

Permitting Schedule for New Dams (ADSP)

- The suggested schedule for permitting a new dam involves several stages of submissions and review

Dam Safety Review

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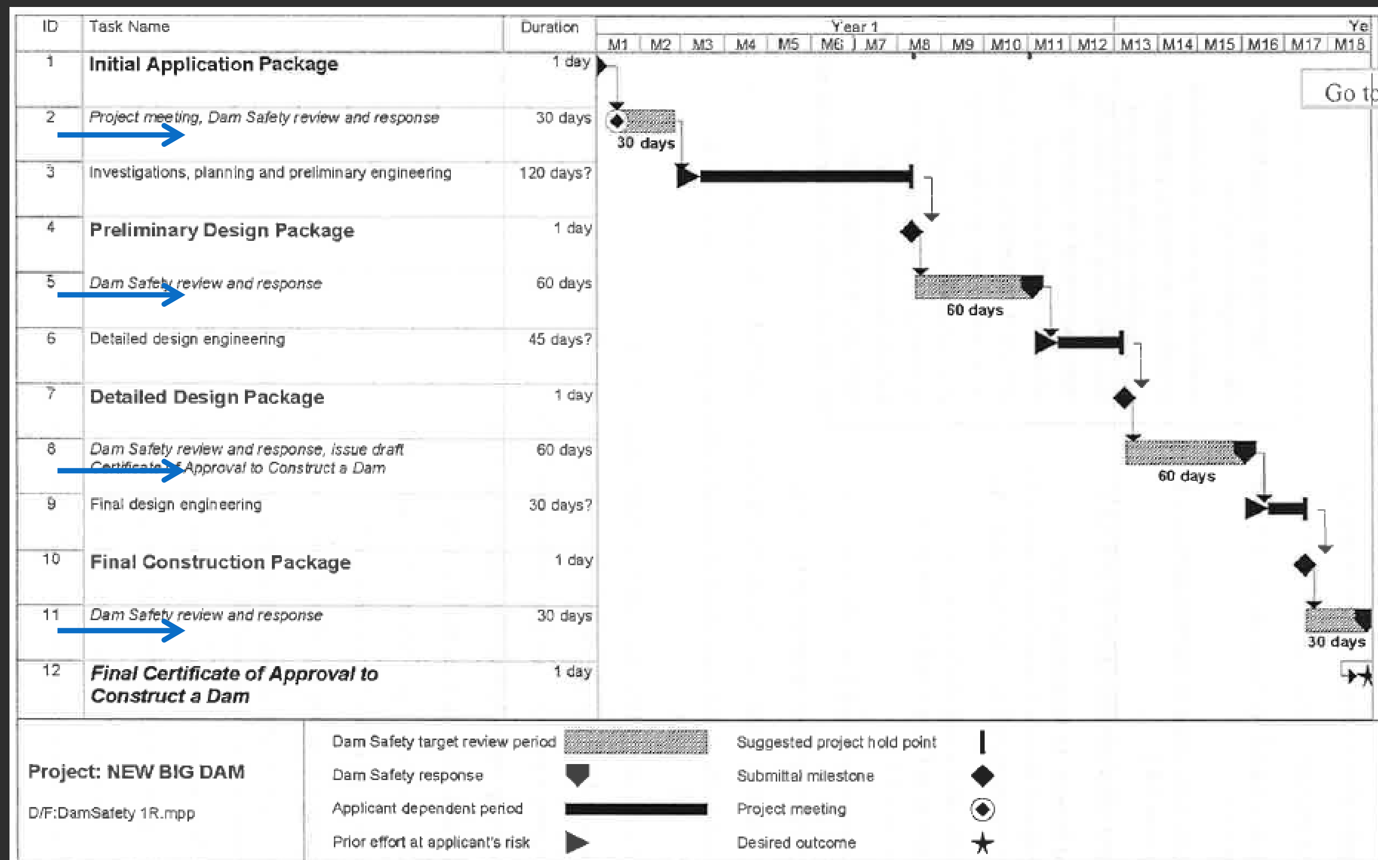

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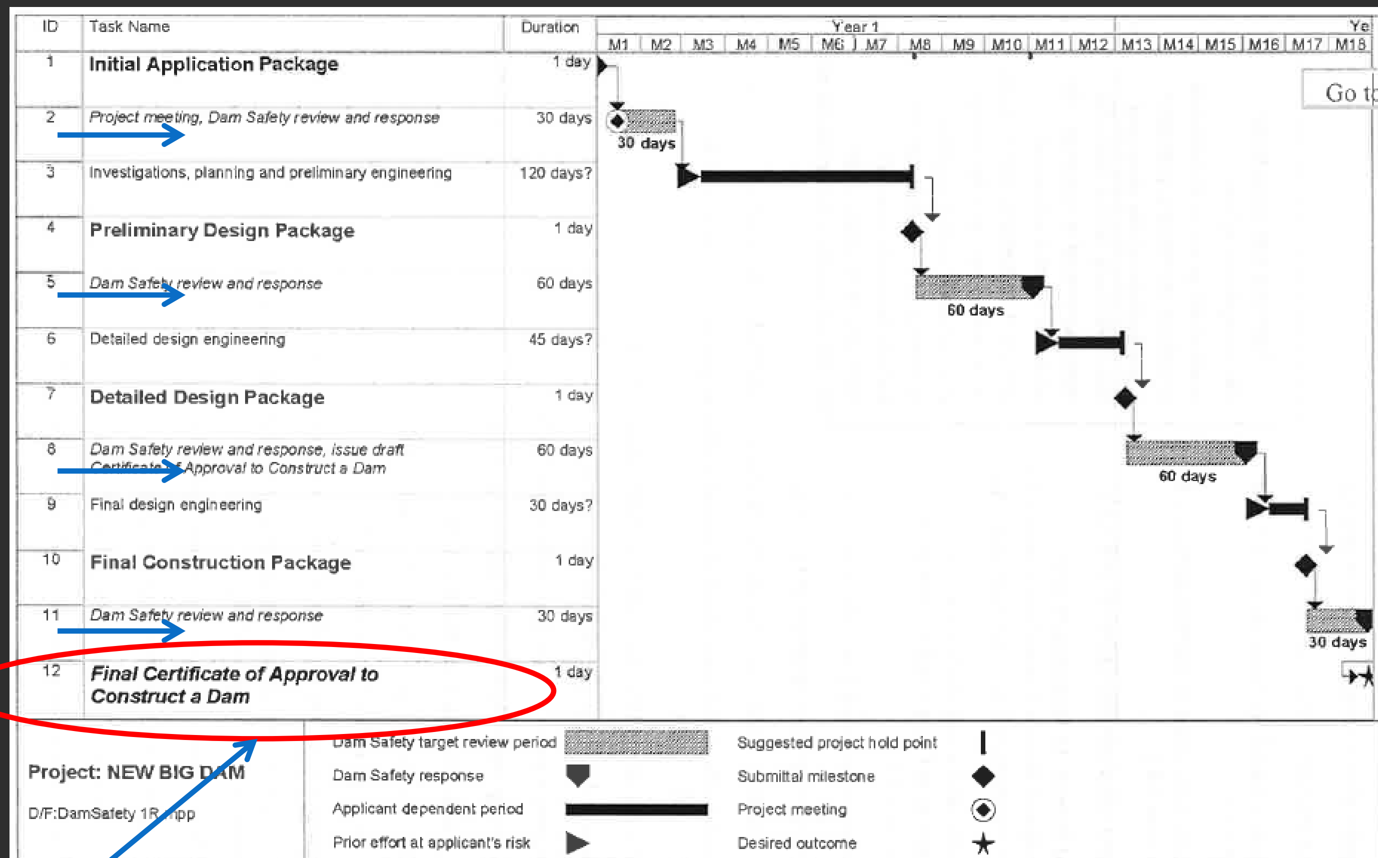
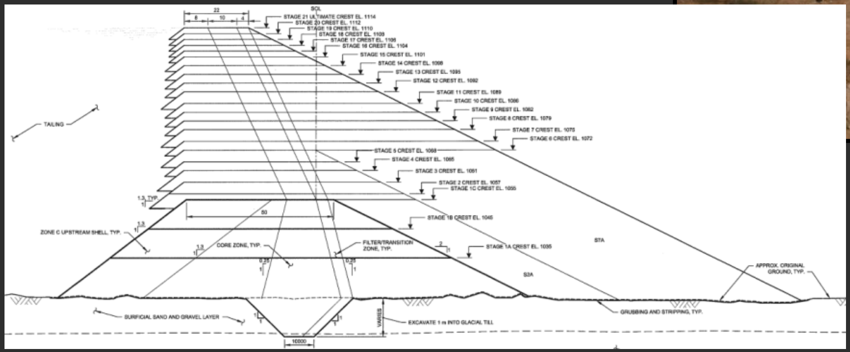


Certificate of Approval to Construct a Dam

TSF Design Considerations

- Tailings embankments are designed and constructed of specific earth materials placed in a specific arrangement, according to a detailed engineering design

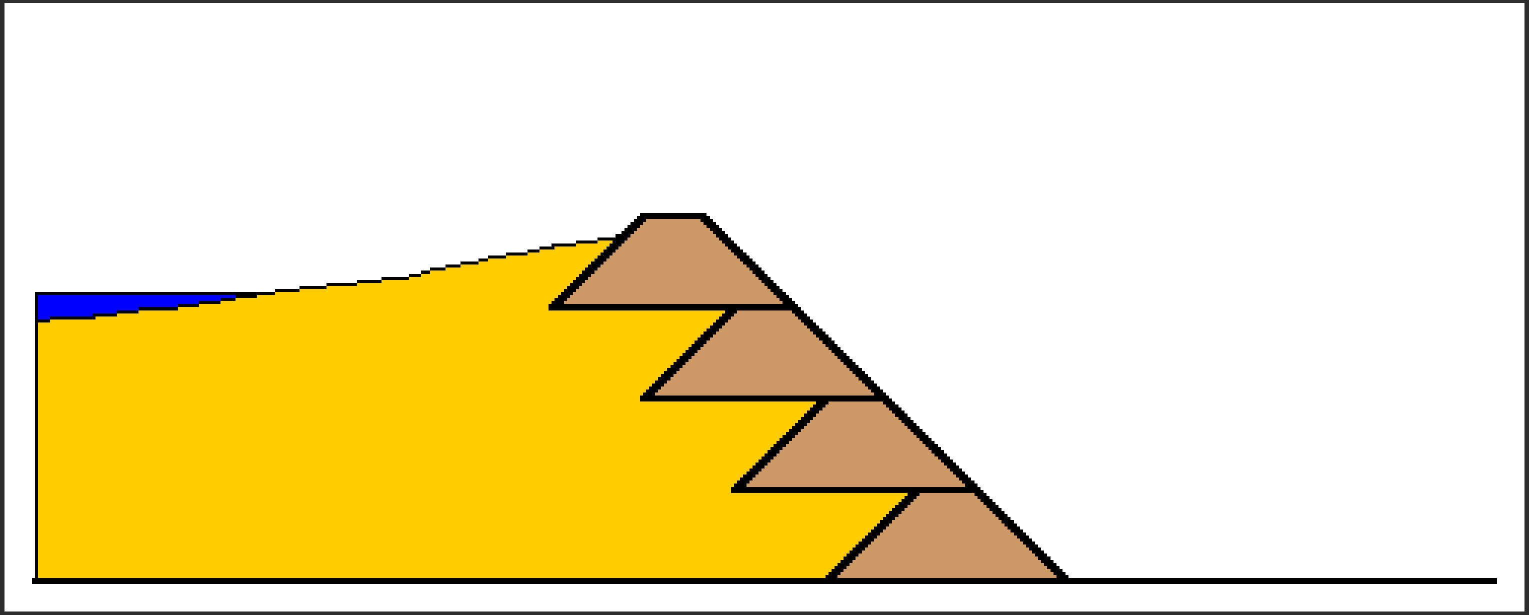


Designing for Storm Events

- Designing for very large storm events is a normal (and required) part of the design, review, and permitting process.

Designing for Storm Events

- Dam overtopping from large storm event



- This would not be permittable in Alaska

Designing for Storm Events

- Dam designs required to provide storage or routing (through spillway) of the Inflow Design Flood at all times

Dam Hazard Classification	IDF
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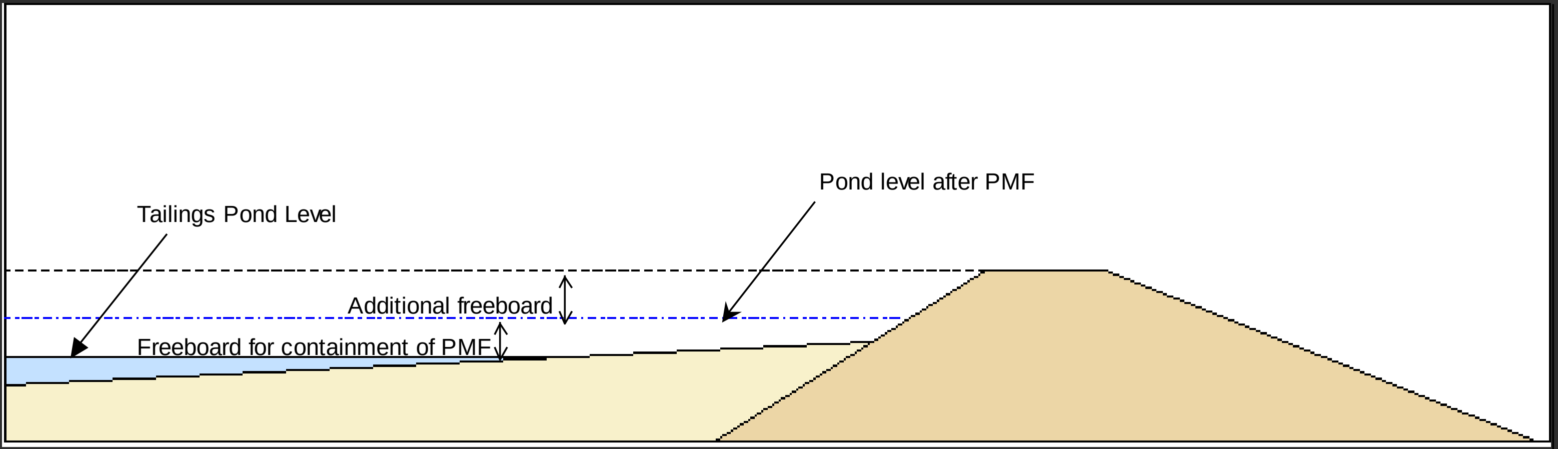

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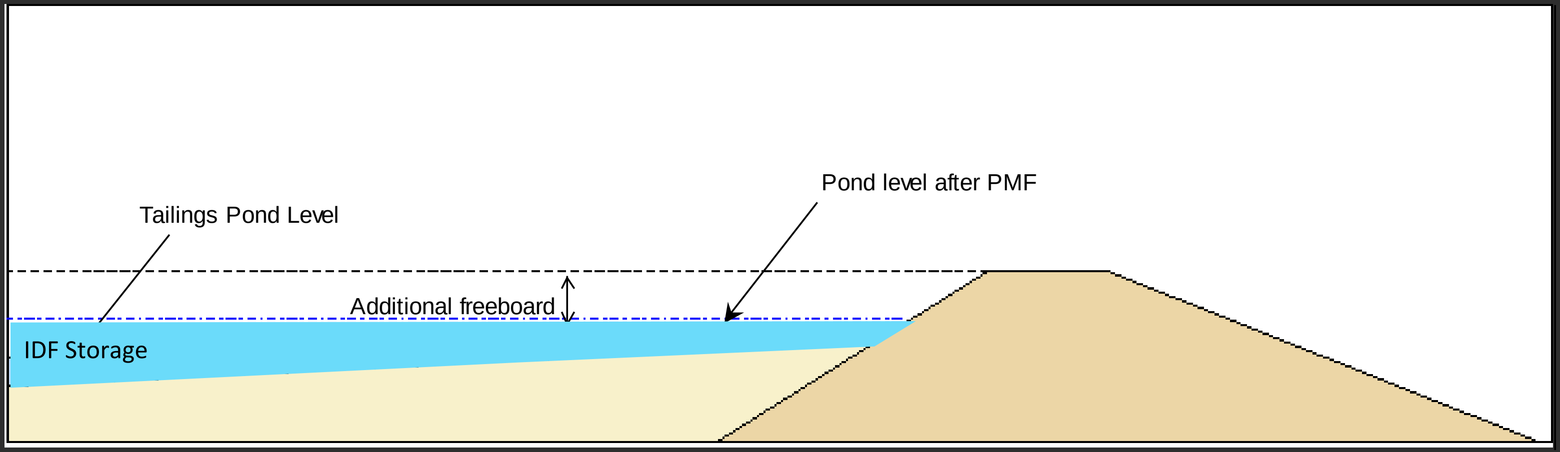
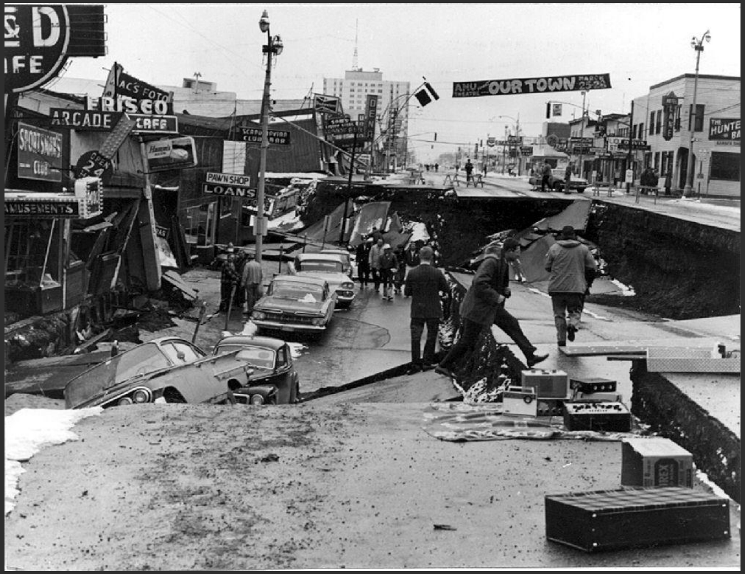
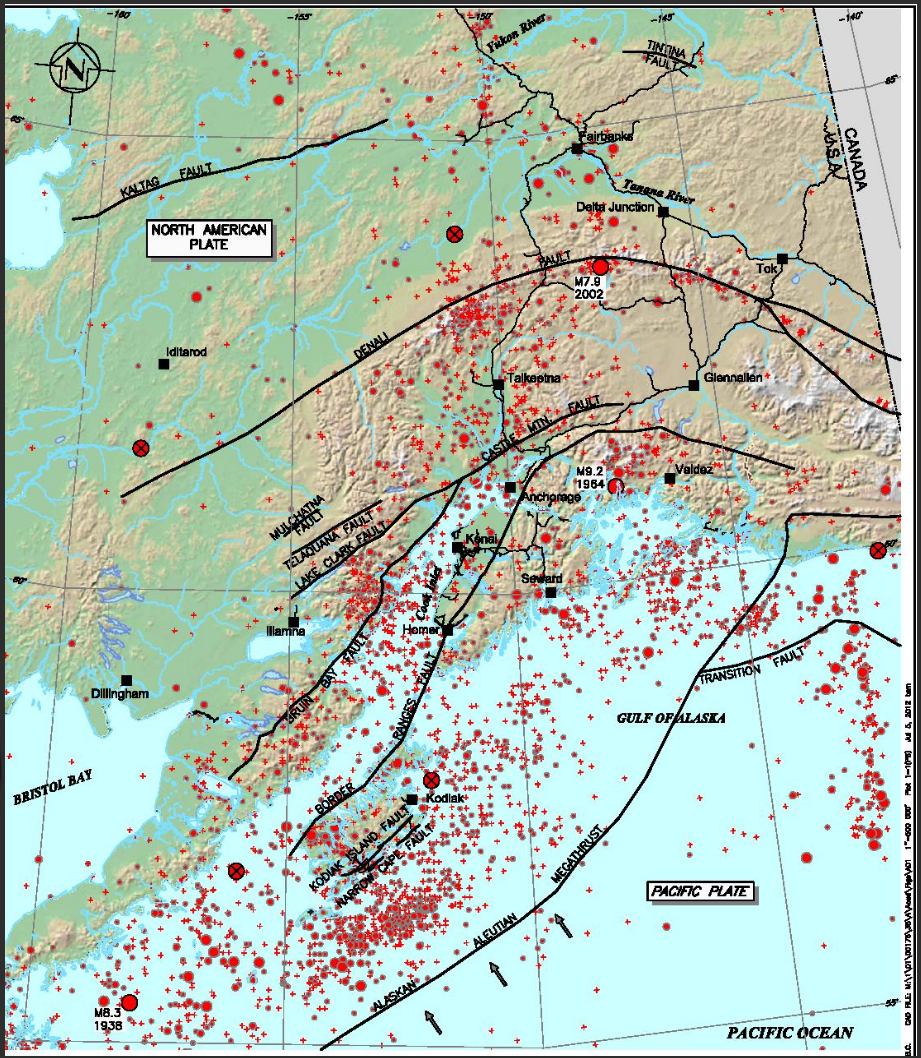


Designing for Earthquakes

- Designing for very large earthquakes is a normal (and required) part of the design, review, and permitting process.
- Magnitude 9.2 earthquake in Alaska, March 27, 1964



Designing for Earthquakes

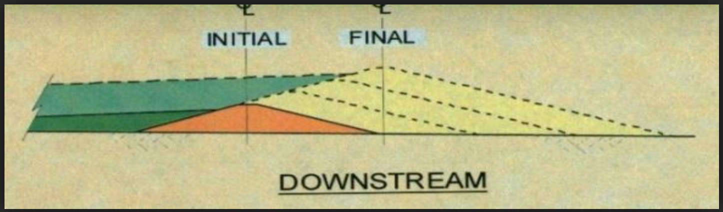


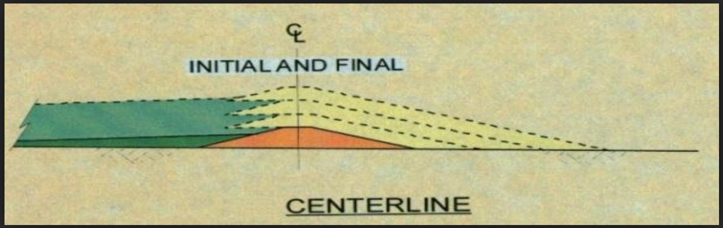
Seismicity of Southern Alaska

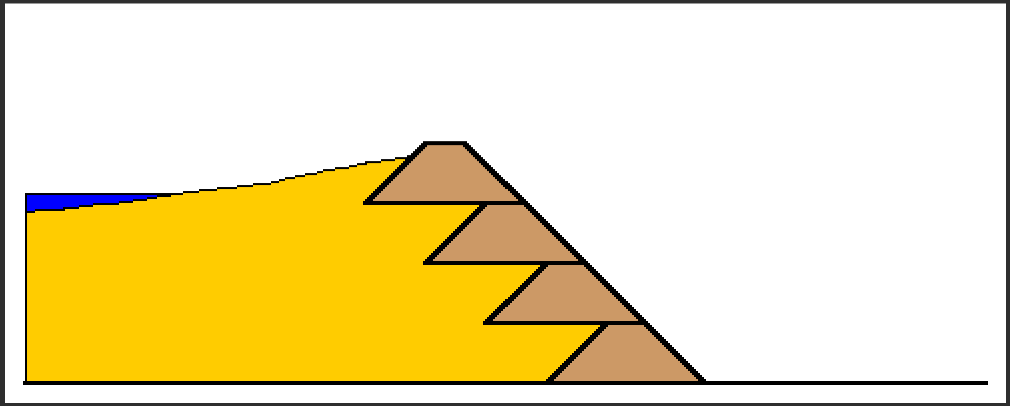
- Understand regional seismicity
- Design earthquake defined by selected and approved hazard classification

Designing for Earthquakes

- Select appropriate construction method and construction materials for dam (centerline or downstream construction method for high seismic areas)







- Upstream construction method not suitable in high seismic areas

Designing for Earthquakes

- Magnitude 8.8 earthquake in Chile on February 27th, 2010

Designing for Earthquakes

- No damage to operating tailings dams from Magnitude 8.8 earthquake.

Figure 11.8. March 10, 2010 View of Ovejeria Tailings Dam from Helicopter (S33.054182°, W70.768953°)

Designing for Earthquakes

- Sand boils in tailings

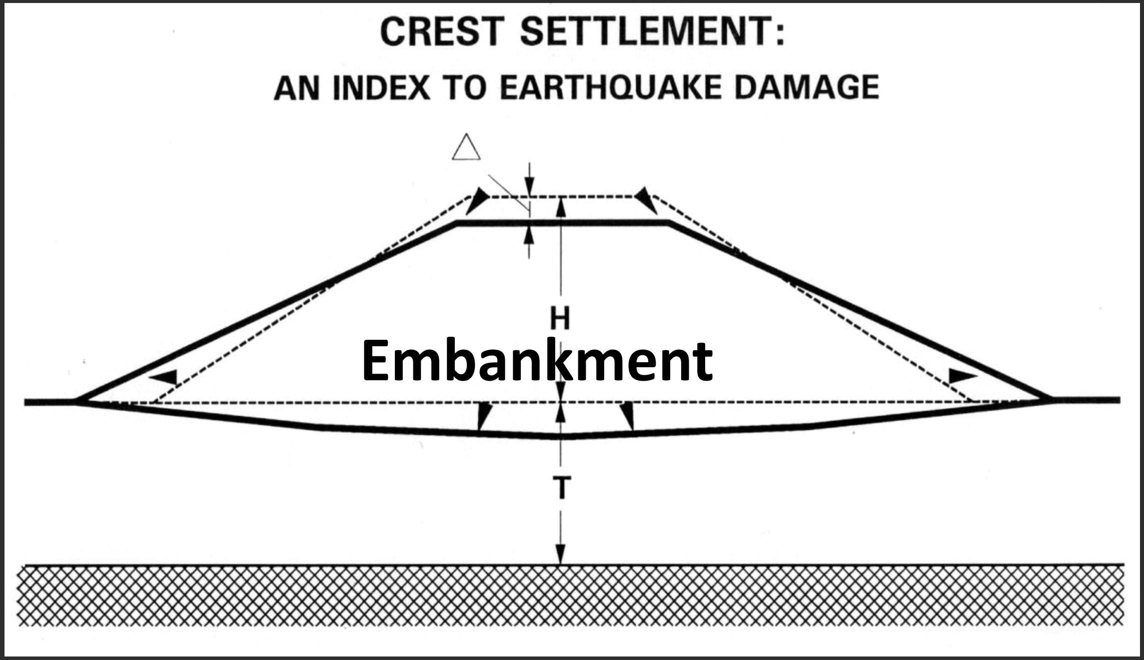
Figure 11.11. March 9, 2010 Sand Boils in Tailings about 10 m Upstream of Ovejeri
(S33.052016°, W70.798687°)

- Tailings mass settled approximately 4-5 feet
- No damage to liner
- No damage to dam

Figure 11.12. March 10, 2010. Upstream face of the Ovejeria Tailings Dam showing approximately 0.5 m of the tailings adjacent to the dam. (S33.052081, W70.792067)

Designing for Earthquakes

- Embankment settlement from earthquake (Swaisgood)



- Post earthquake embankment settlement considered in design of freeboard requirements
- Standard practice to perform sophisticated seismic modeling for dams in areas of high seismicity

Construction Quality Assurance and Quality Control

Nuclear densometers

Winter Construction

Operation & Maintenance, Emergency Action planning

Next to proper design and construction, O&M and Emergency Action planning are the most important aspects of an owner’s commitment to the safety of the dam

Dam Safety will only issue a *Certificate of Approval to Operate a dam* after an O&M Manual and an Emergency Action Plan (EAP) are submitted by the dam operator

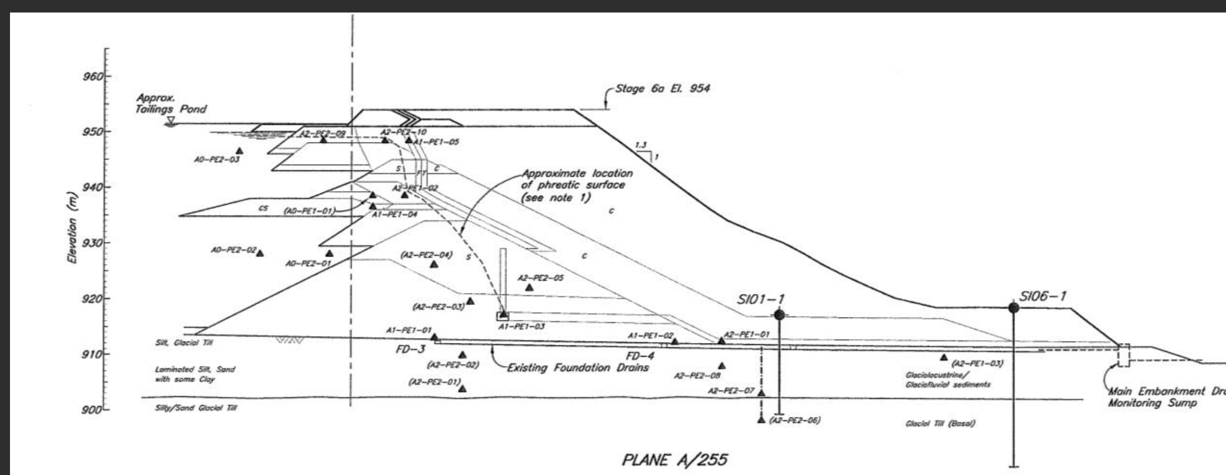
The O&M Manual will include, amongst other things:

- Critical design criteria
- Schedules for safety inspections, monitoring and maintenance
- Instructions for monitoring equipment
- Site specific visual check-lists

The EAP will detail all actions and measures that will be taken in response to an emergency

TSF Instrumentation

- TSF Instrumentation monitoring (piezometers, inclinometers, settlement monuments) critical in monitoring dam performance to ensure it is safe and operating as designed.



Closure

- Develop a vision for the end use of the mine at early stages of project life

- Designing for Closure - Each stage of the mine development (not just the TSF) considers the reclamation and closure objective

- Construct spillway at TSF. Conservative design flows to account for changing climatic conditions.

Closure

- Reclamation and closure bond required at mine start-up
- Bond reviewed at five year increments
- Bond value to cover reclamation costs and long term water management/treatment, if required
- Financial Assurance must ensure State can do reclamation even if company cannot.

Overview of Dam Failures

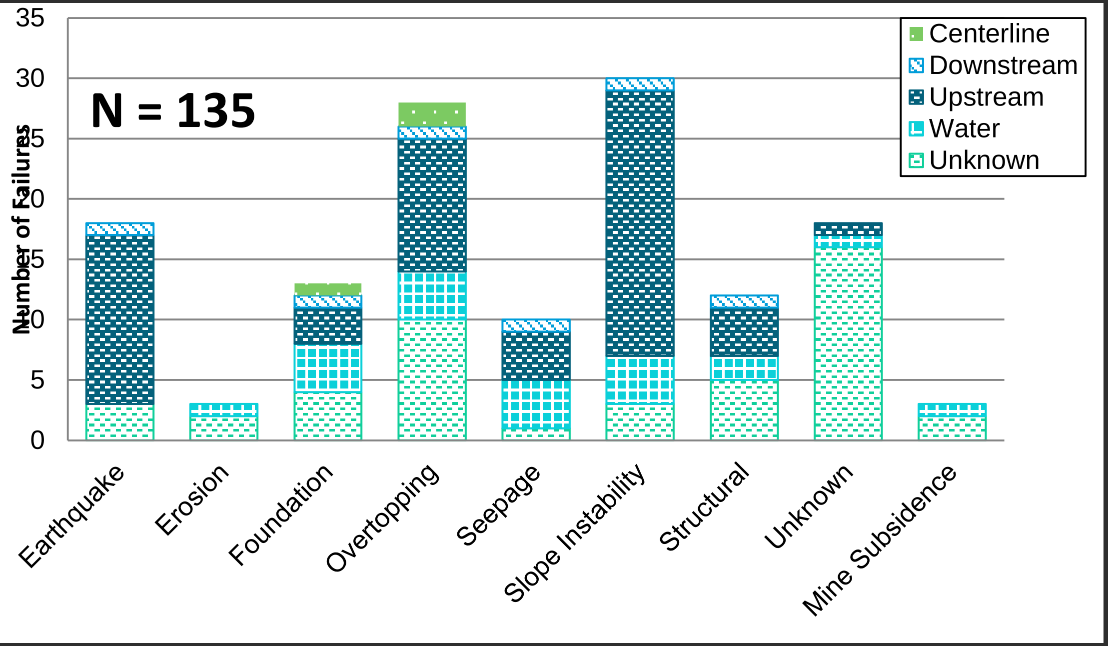
- International Commission of Larger Dams (ICOLD Bulletin 121) Tailings Dams – Risks of Dangerous Occurrences – Lessons learnt from past Experiences

- ICOLD definition of dam failure:

"a collapse or movement of a part of the dam or its foundation so that the dam cannot retain the stored water (and tailings)"

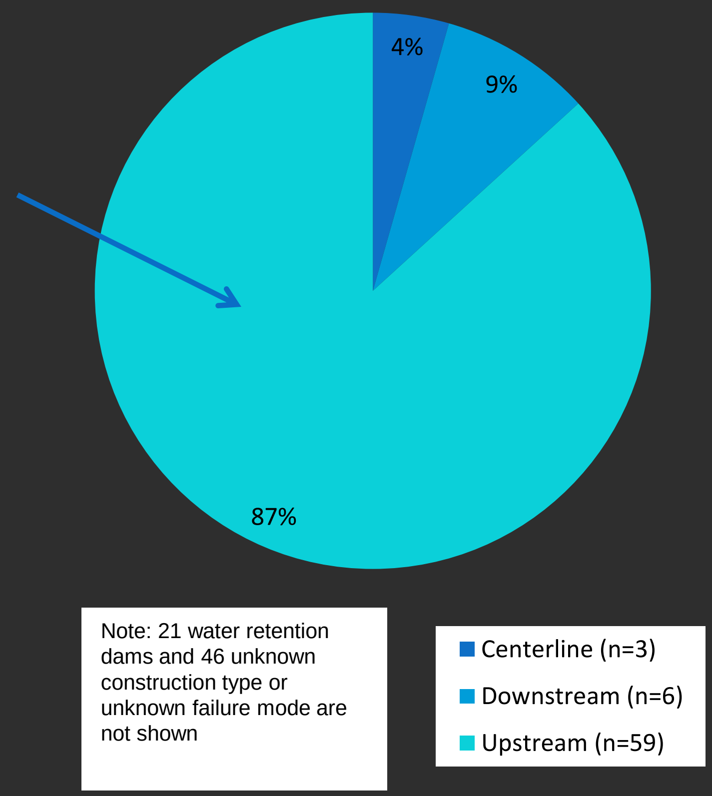
Original ICOLD Failure Numbers/Modes for all Dams

- Over 48,000 large dams worldwide (large dam defined as over 50 feet high - ICOLD)
- ICOLD (Bulletin 121) identified 135 dam failures (water dams, tailings dams, and “unknown” dams)

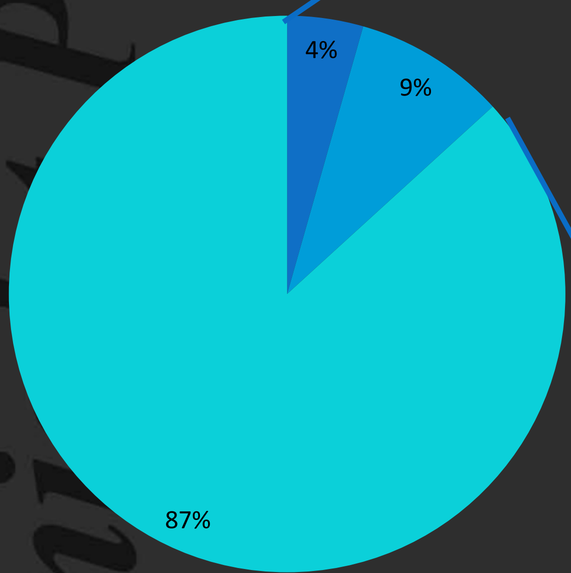


Failures Number/Modes for Upstream, Downstream and Centerline Construction Tailings Dams

- Removing water and ``unknown`` dams reduces the total of 135 total dams to 68 tailings dams
- Approximately 87% of tailings dam failures are for upstream construction dams

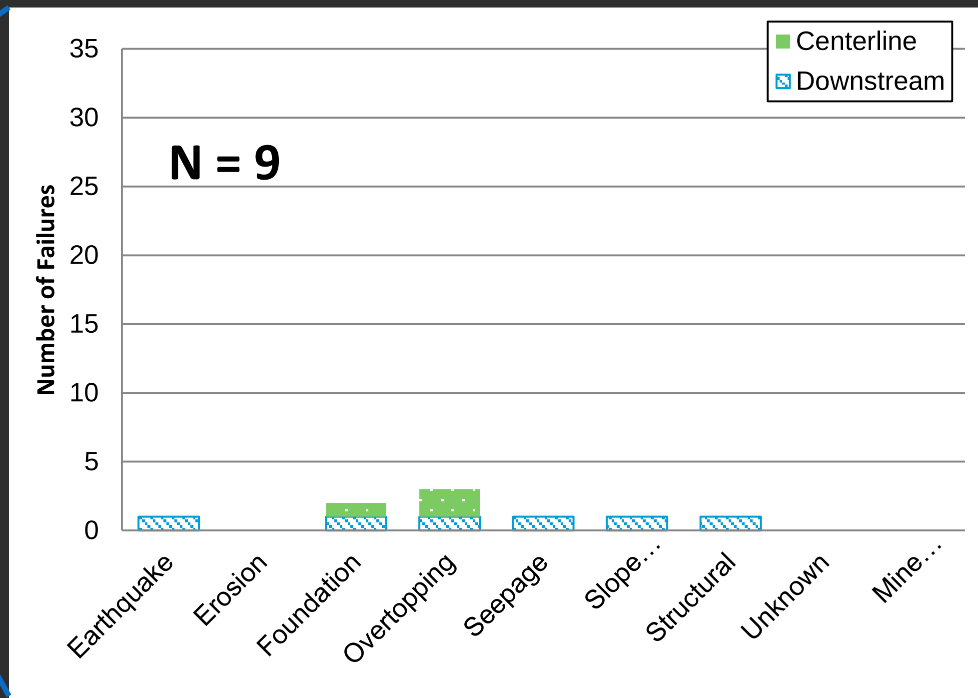


Failures Number/Modes for Downstream and Centerline Construction Tailings Dams



Note: 21 water retention dams and 46 unknown construction type or unknown failure mode are not shown

Centerline (n=3)
Downstream (n=6)
Upstream (n=59)



- Dam failures a result of well understood failure mechanisms. Tailings dam failures not due to unknown/mysterious circumstances.

Summary of ICOLD Dam Failure Statistics

- Most historical tailings dam failures have occurred in dams constructed using the upstream method

- Few dam failures in tailings dams with centerline or downstream methods

- The engineering principles required to avoid tailings disasters are well known and understood

- White paper by Haile and Brouwer (2012), Design and Construction of Tailings Dams In Alaska

Summary

- Regulations governing dam design and environmental protection relatively new. All dams in Alaska governed by ADSP.
- Mining companies using specialist geotechnical consultants to provide independent review, advice and design for tailings facilities
- Selection of preferred tailings technology is project specific
  - Geochemical characterization of tailings is key.
- Designing for earthquakes and flood events is standard practice

Summary

- Managing water as important as managing tailings solids
- Closure, closure, closure
- Previous tailings dam failures not unpredictable events. The engineering principles required to avoid tailings disasters are well known and understood

- All mine locations and tailings management plans are different

End

Modern TSFs are designed to provide safe, long term storage for mine tailings through operations and post closure

Questions?