Inspection of Concrete Dams and Appurtenant Structures

National Dam Safety Program Technical Seminar | 2024

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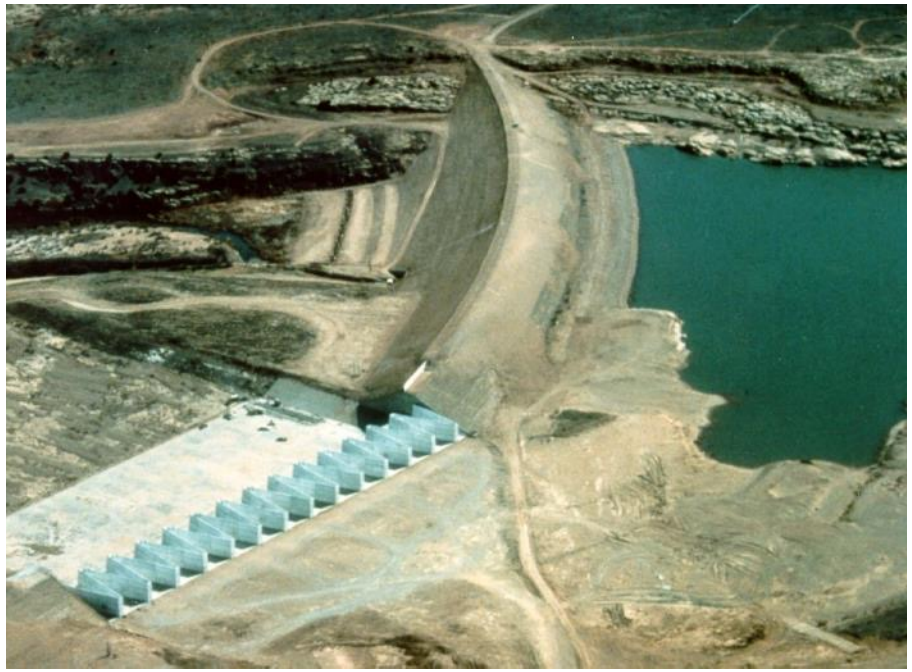
Examination of Concrete Dams and Appurtenant Structures



Labyrinth service spillway,
Ute Dam, New Mexico

Morrow Point Dam, Colorado

Outline

- Introduction
- Definition of Appurtenant Structures
- Types of concrete Dams
- Concrete strength/durability
- Examination of Appurtenant Structures
- Examination of Concrete Dams

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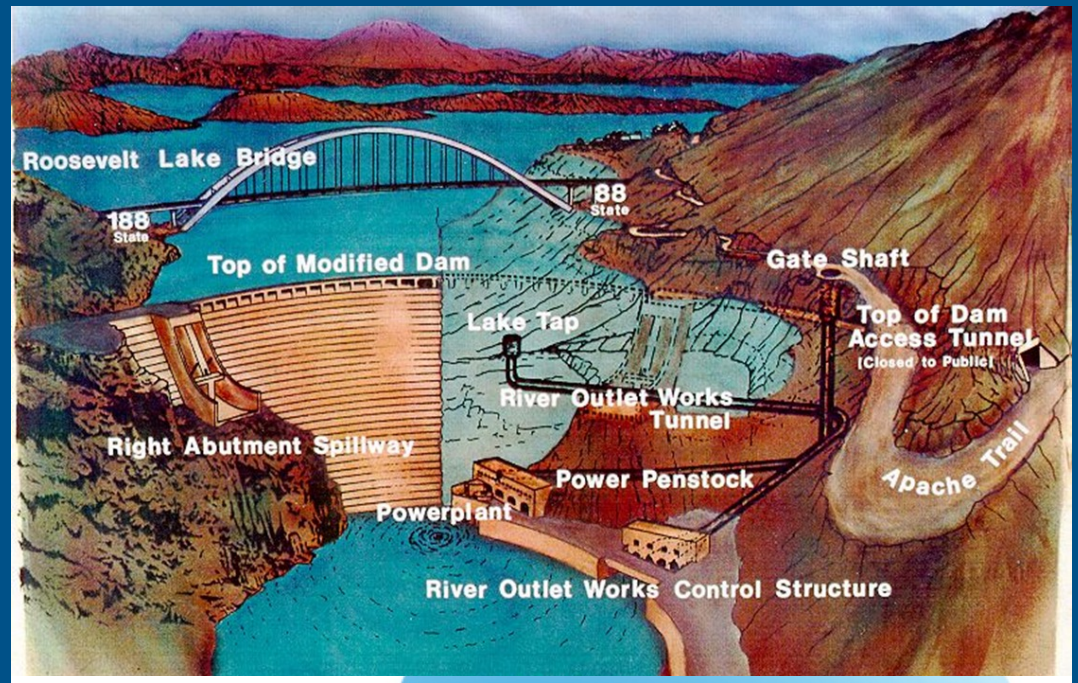
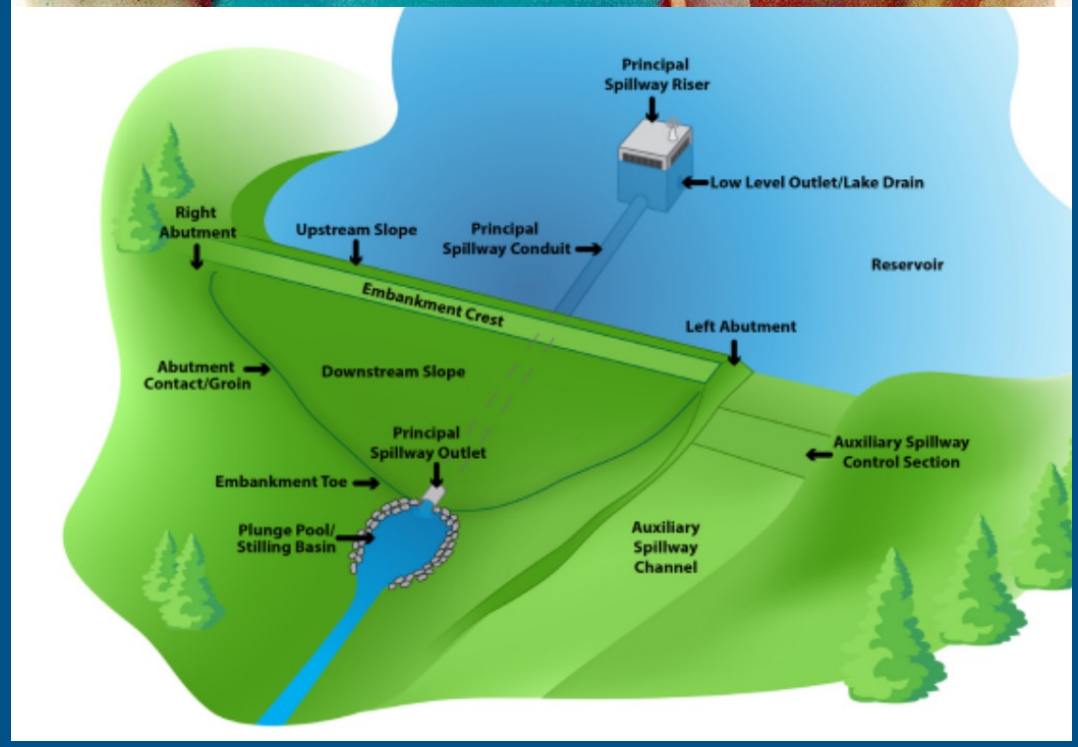
Definition & Examples of Appurtenant Structures

- Hydraulic structures that safely regulate/release water impounded by dams and dikes
- Examples:
  - Spillways – service, auxiliary, and emergency
  - Outlet works
  - Other Features – penstocks, pipelines and canals





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Definition & Examples of Appurtenant Structures (2)

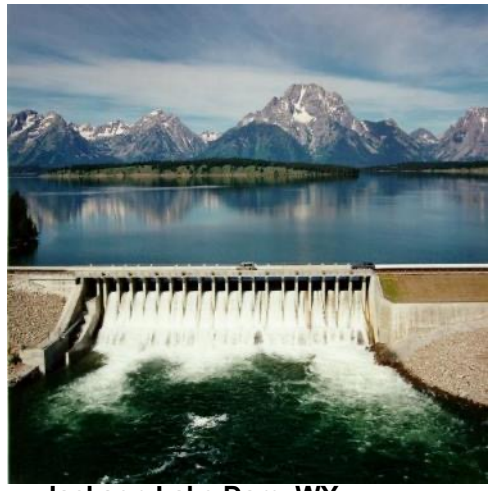
Free-flow (morning glory) service spillway

Monticello Dam, CA

Gated service spillway

McPhee Dam, CO

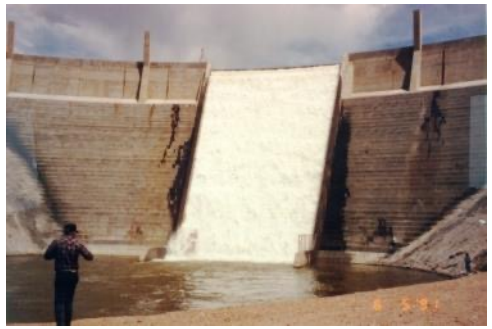
Gated service spillway



Jackson Lake Dam, WY

Free-flow, auxiliary & fuseplug emergency spillways along reservoir rim.

New Waddell Dam, AZ



Santa Cruz Dam, NM

Free-flow, stepped service spillway & free-flow auxiliary spillway (dam crest)

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Definition & Examples of Appurtenant Structures (3)

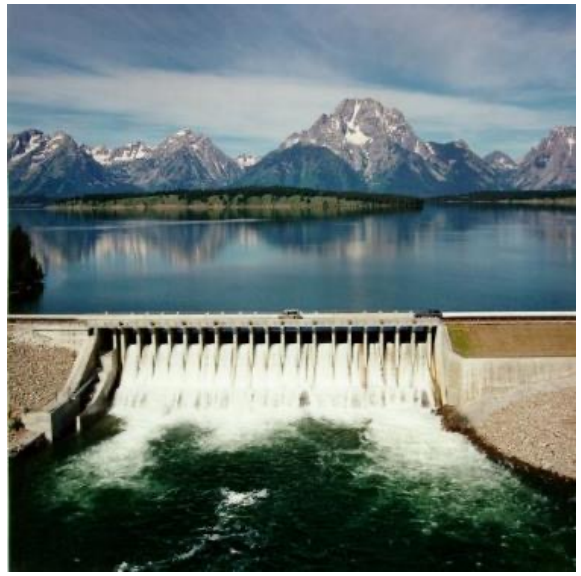
Free-flow (morning glory) service spillway

Monticello Dam, CA

Gated service spillway

McPhee Dam, CO

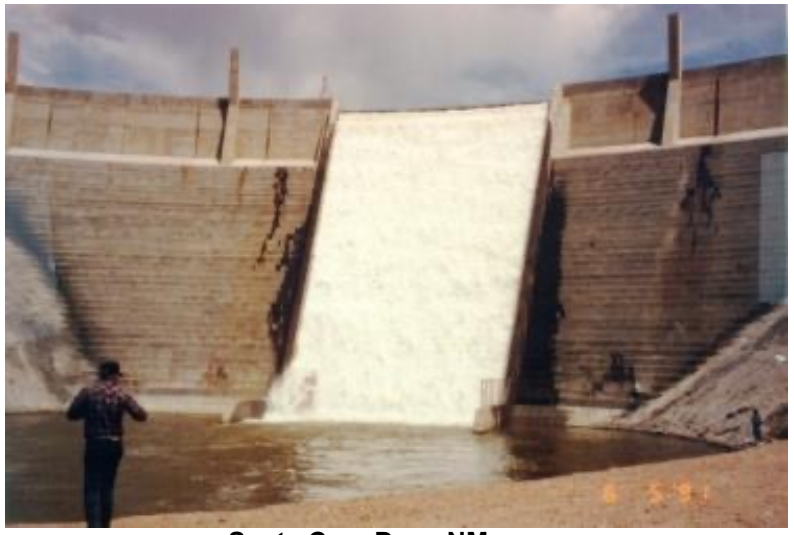
Gated service spillway



Jackson Lake Dam, WY

Free-flow, auxiliary & fuseplug emergency spillways

New Waddell Dam, AZ



Santa Cruz Dam, NM

Free-flow, stepped service spillway

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Concrete Dams

- Four types of concrete dams:
  - Gravity
  - Arch
  - Buttress
  - Composite

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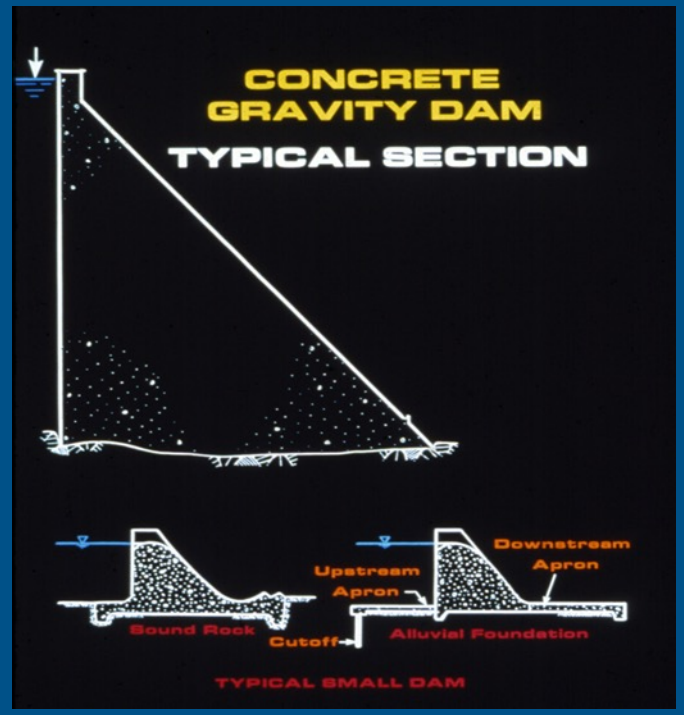
Concrete Dams (2)

- Four types of concrete dams:
  - Gravity
  - Arch
  - Buttress
  - Composite



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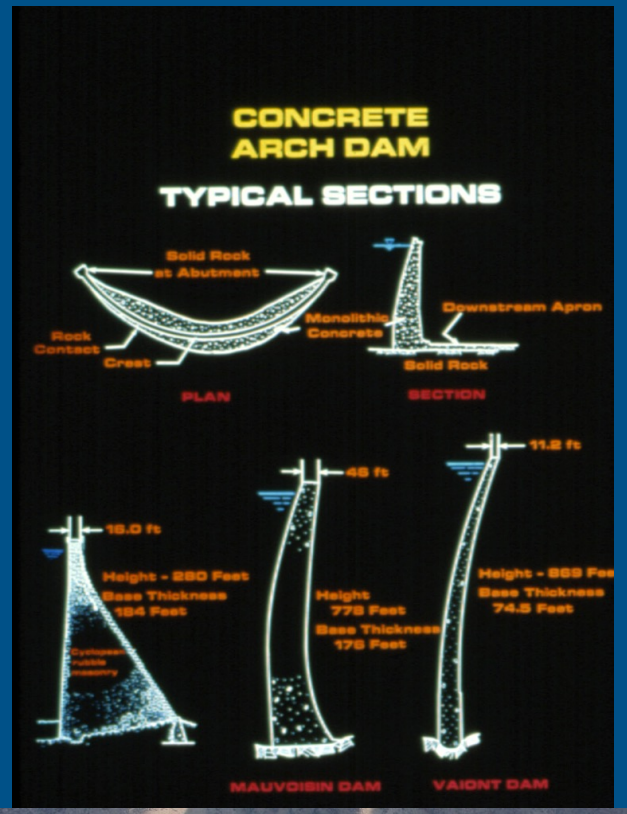
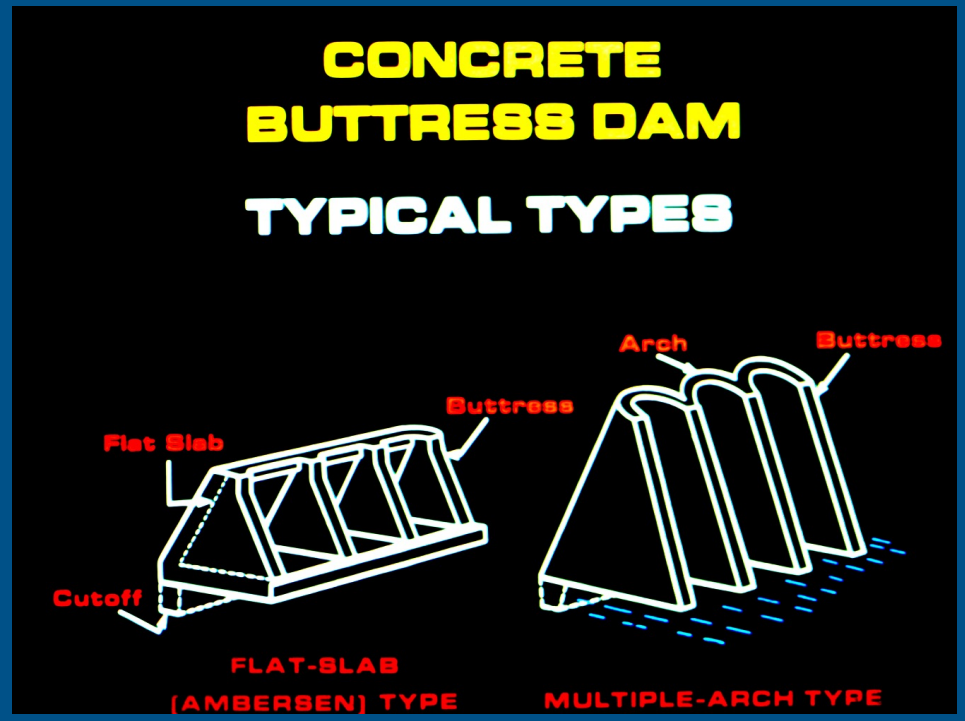
Concrete Dams (3)

- Four types of concrete dams:
  - Gravity
  - Arch
  - Buttress
  - Composite



Concrete Dams (4)

- Four types of concrete dams:
  - Gravity
  - Arch
  - Buttress
  - Composite



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Concrete Dams (5)

- Four types of concrete dams:
  - Gravity
  - Arch
  - Buttress
  - Composite

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Purpose of Examination

- Provide process to inspect/identify safety of dams (SOD) deficiencies and operation & maintenance (O&M) issues.
- Collect visual data to help assess:
  - Capability to safely pass floods.
  - Capability to evacuate the reservoir.
  - Capability to safely withstand seismic events.
  - Capability to withstand static (normal operating) loads.

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Background Information

Concrete Durability

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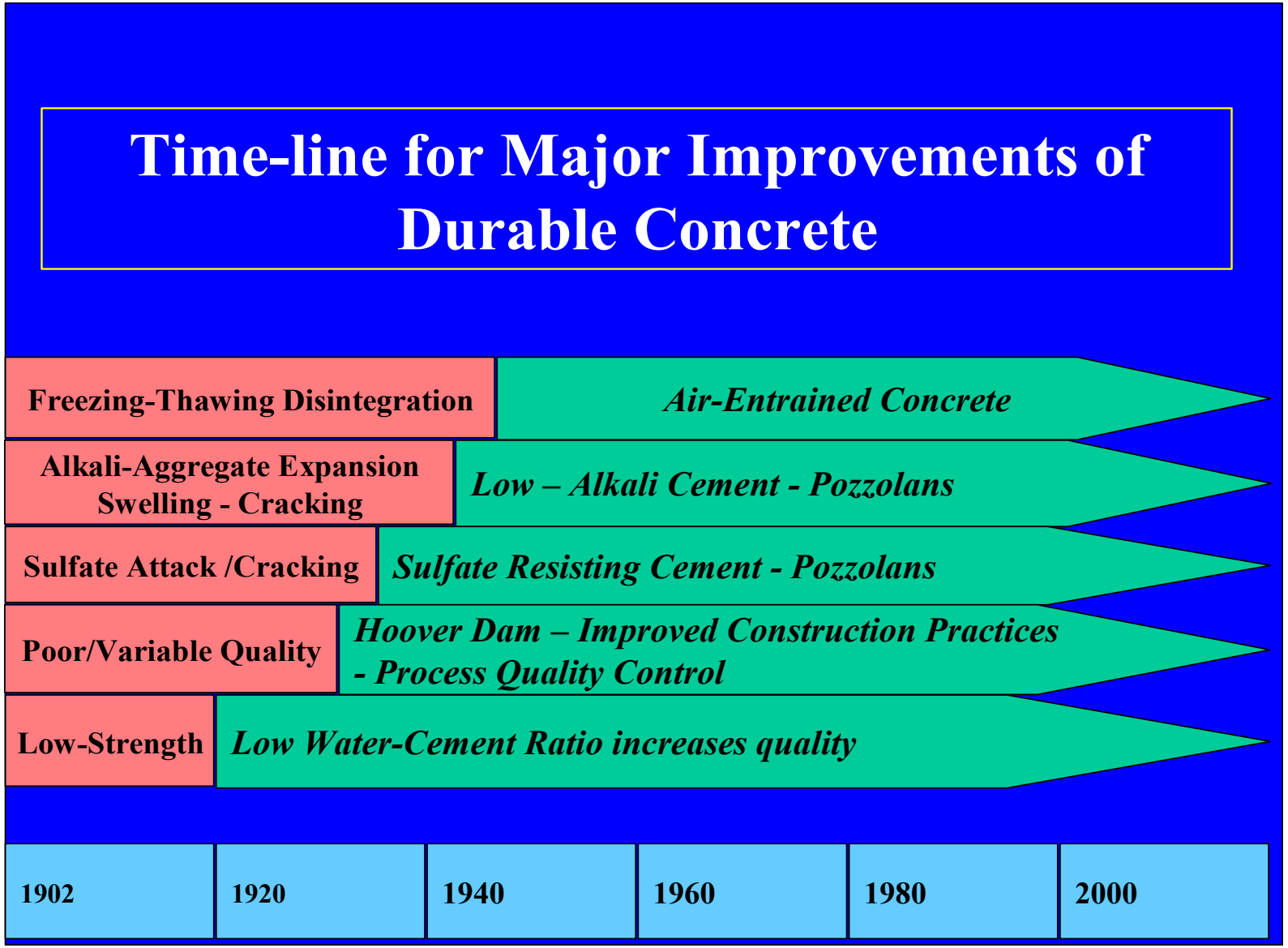
Factors Influencing Concrete Strength/Durability

- Freeze-thaw action
- Alkali-aggregate reaction
- Sulphate attack
- Poor mix design/construction
- Low aggregate strength

Age of Concrete Structure

- Concrete durability has advanced significantly over the last century
- Many concrete dams were constructed before certain durability issues were recognized and addressed
- Helps in identifying structures that are most vulnerable to accelerated deterioration and to prioritize repair

Time-line


Time-line for Major Improvements of Durable Concrete
Freezing-Thawing Disintegration
Air-Entrained Concrete
Alkali-Aggregate Expansion Swelling - Cracking
Low – Alkali Cement - Pozzolans
Sulfate Attack /Cracking
Sulfate Resisting Cement - Pozzolans
Poor/Variable Quality
Hoover Dam – Improved Construction Practices - Process Quality Control
Low-Strength
Low Water-Cement Ratio increases quality
1902
1920
1940
1960
1980
2000

Freeze - Thaw Action

- Causes

  - Absorptive aggregate

  - Repeated freezing and thawing

  - Lack of entrained air

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Freeze - Thaw Action (2)

- Effects

  - Surface cracking

  - Spalling

- Visible evidence

  - Pattern cracking

  - Progressive surface deterioration

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Examples

Examples (2)

Alkali-Aggregate Reaction (Alkali-Silica Reaction)

- Cause

  - Two-stage chemical reaction between alkali in cement and silica in aggregate

Alkali + Silica → Reaction Gel

Reaction Gel + Moisture → Expansion

Alkali-Aggregate Reaction (Alkali-Silica Reaction) (2)

- Effects

  - Swelling of unconfined concrete

  - Cracking

  - Loss of structural integrity

  - Swelling can cause binding of gates

Alkali-Aggregate Reaction (Alkali-Silica Reaction) (3)

- Visible evidence

  - White precipitate on concrete surface

  - Pattern cracking, often severe

  - Sometimes severe distortion of structure

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Sulphate Attack

- Causes:
  - Sulphates in adjacent soil or water
  - Low sulphate-resistant cement
- Effects:
  - Swelling of concrete
  - Cracking
  - Degradation of concrete surface
- Visible evidence:
  - Pattern cracking
  - Spalling

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Poor Mix Design/Construction

- Causes

  - Outdated design or construction methodology

  - Ignorance

  - Negligence or poor workmanship

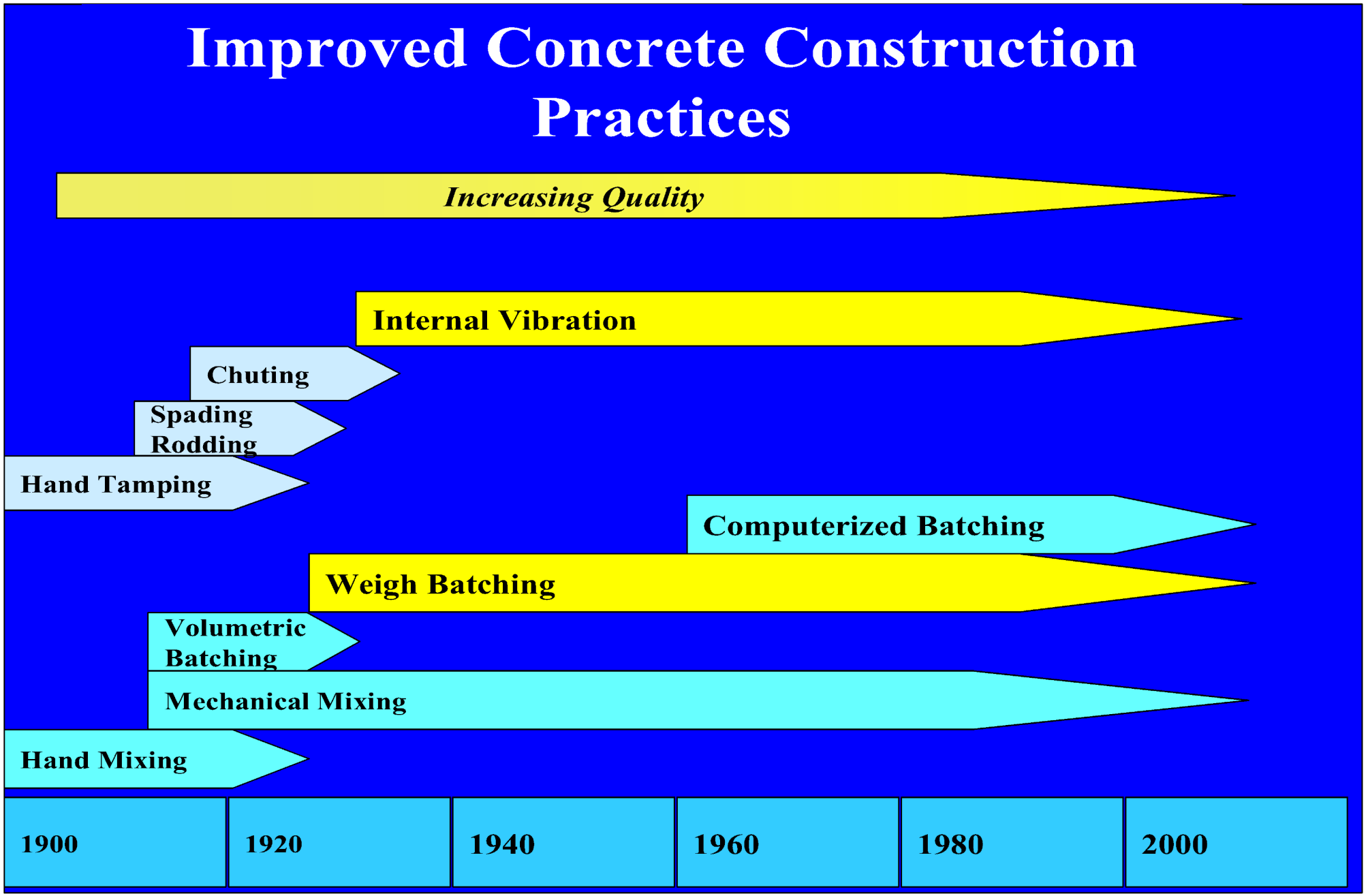
Examples (3)

Examples (4)

Examples (5)

Examples (6)

Improved Concrete Construction Practices



Poor Mix Design/Construction (2)

- Effects
  - Low concrete strength
  - Poor concrete durability
  - Disbonding between lifts

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Poor Mix Design/Construction (3)

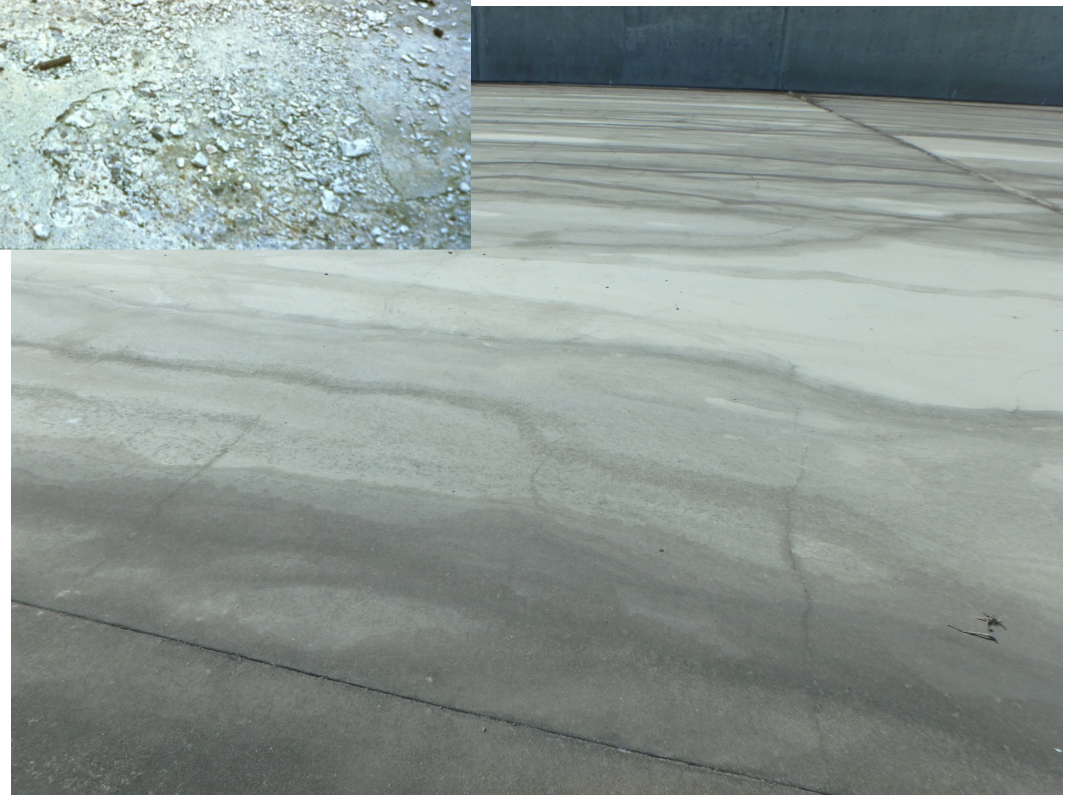
- Visible evidence

  - Cracking

  - Spalling

  - Crushing of concrete in compression

  - Surficial and internal concrete degradation



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Low Aggregate Strength

- Causes:
  - Low compressive strength aggregate
  - Absorptive aggregate
  - Contamination (dirty aggregate)
  - Poor aggregate thermal properties
- Effects:
  - Poor bond between aggregate and cement
  - Low strength/durability concrete
  - Swelling
- Visible evidence
  - Cracking
  - Crushing of concrete in compression
  - Surficial and/or internal concrete degradation

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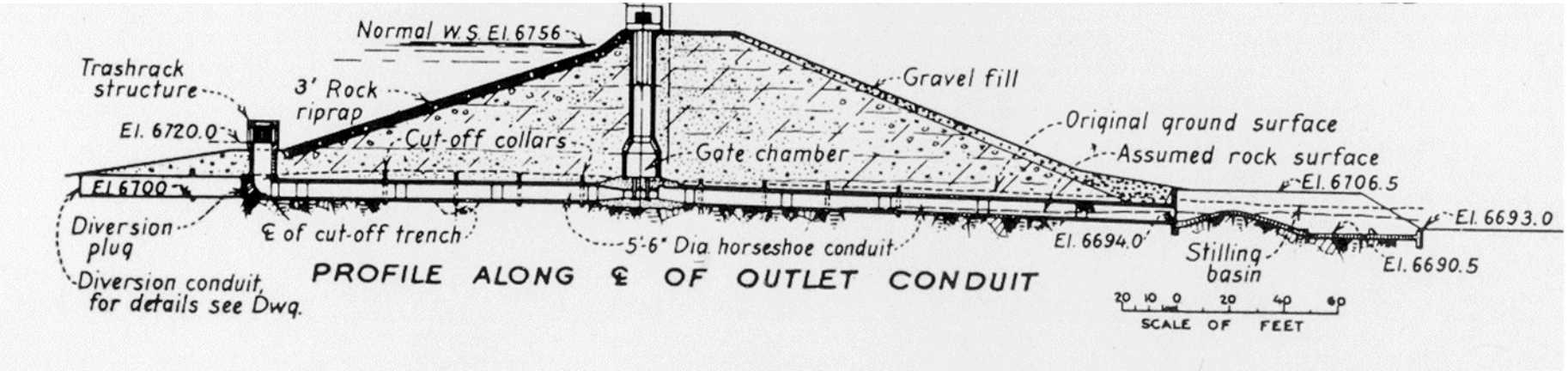
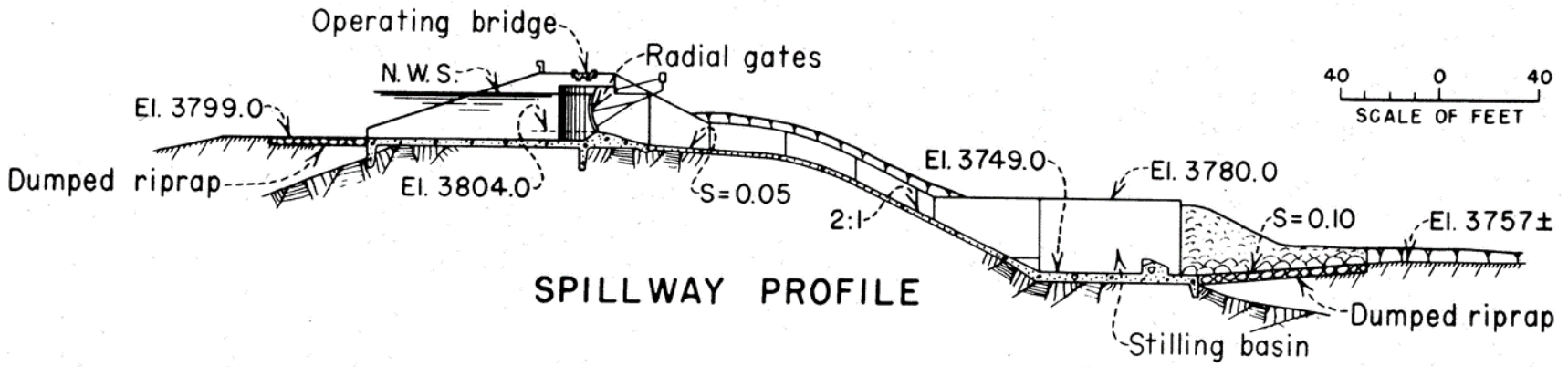
Examination of Appurtenant Structures

Examination of Outlet Works



- Intake structure
  - including trashracks, gates/valves, bulkhead and slots, if applicable
- Conveyance features
  - such as U/S and D/S conduit/tunnel
- Control structure
  - such as gate chamber, gates/valves, access shaft/adit/conduit, operating equipment
- Terminal structure and exit channel

Examination of Spillways



- Approach channel and safety/debris/log boom
- Control structure
  - Such as crest structure or grade sill, gates, bulkhead, stoplogs, and operating equipment, if applicable
- Conveyance features
  - Such as chute, and/or conduit/tunnel
- Terminal structure and exit channel

Examination of Spillways (2)

Ochoco Dam, OR

Examples - Appurtenant Structures Issues/Deficiencies

- Only illustrate (not all inclusive)
- Hydraulic issue examples include:
  - Inadequate discharge capability
  - Flow obstructions
  - Flow damage
- Structural/materials issues examples include:
  - Movement
  - Concrete, metal, earth/rock degradation

Hydraulic Issues

- Flow obstructions
- Flow damage

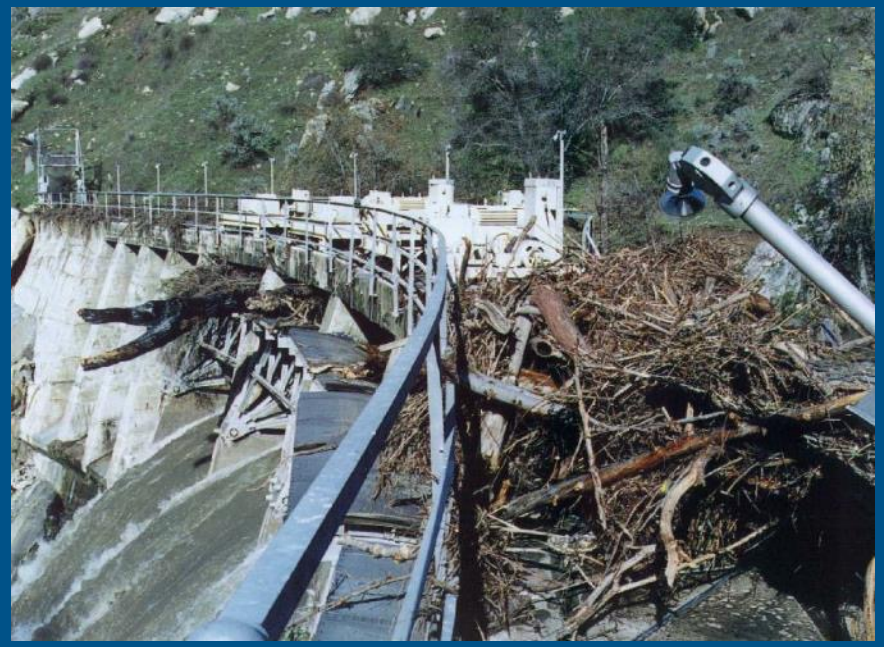
Flow Obstructions

Cold Springs Dam, OR

Flow Obstructions (2)

Cold Springs Dam, OR

Debris Plugging



Kerckoff Dam, CA

Palagnedra Dam, Switzerland

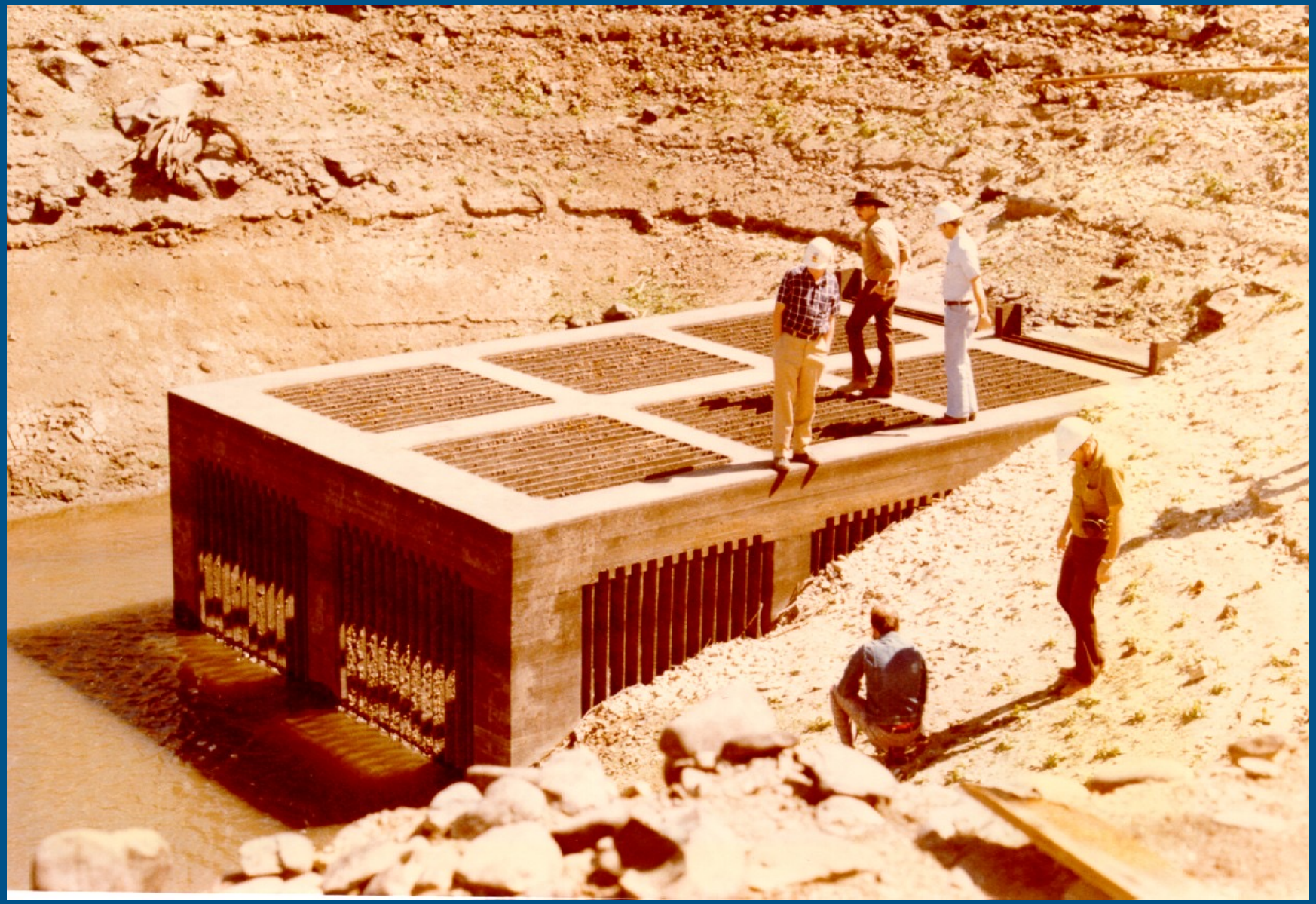
Moon Lake Dam, UT

Rockfall

Rain-induced rockfall damages and temporarily eliminates operation of left abutment spillway.

Horse Mesa Dam, AZ

Sediment Plugging



Agency Valley Dam OR

Sediment Plugging (2)

Greatwestern Dam, CO

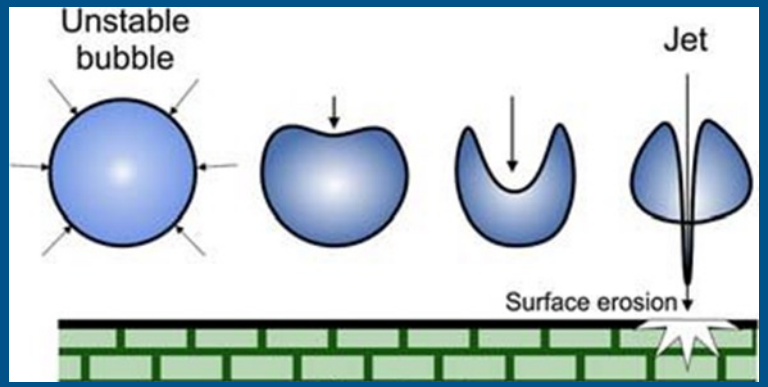
Flow Obstructions (3)

Unknown Dam

Hydraulic Issues (2)

- Flow obstructions
- Flow damage

Cavitation



Cavitation (2)

"Christmas Tree" appearance – Tell-tale sign of cavitation damage

Glen Canyon Dam, AZ

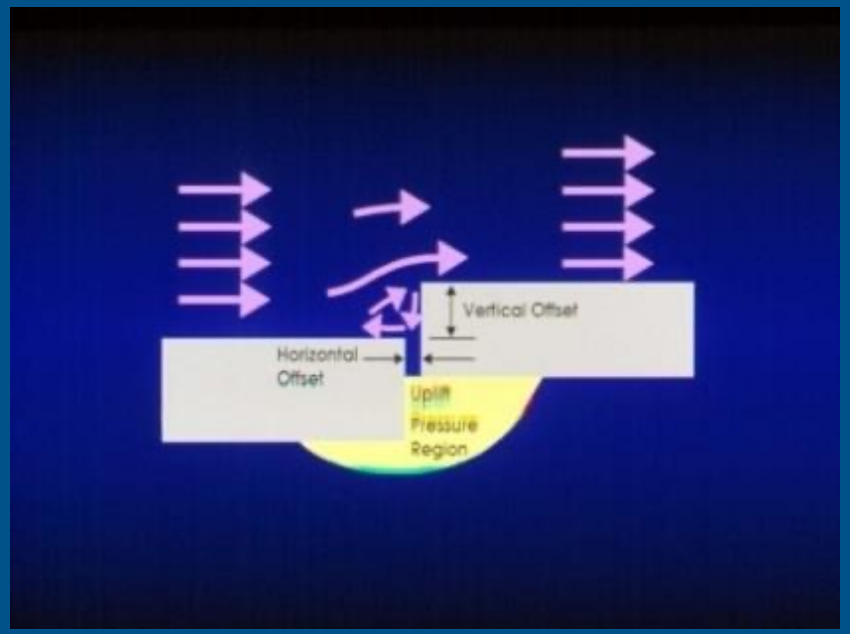
Cavitation (3)

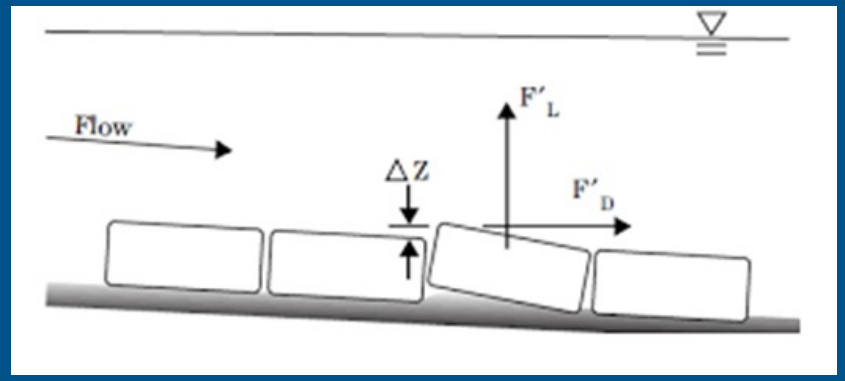
Folsom Dam, CA

Reclamation employee becoming one with the damaged outlet (i.e., appreciating the size of the cavitation induced erosion of the concrete)

Palisades Dam, ID

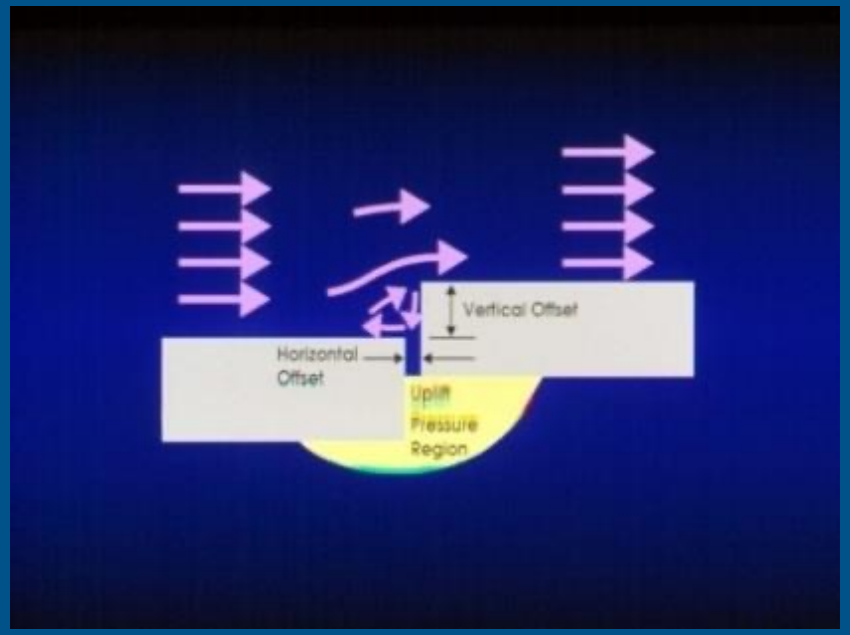
Hydraulic Jacking

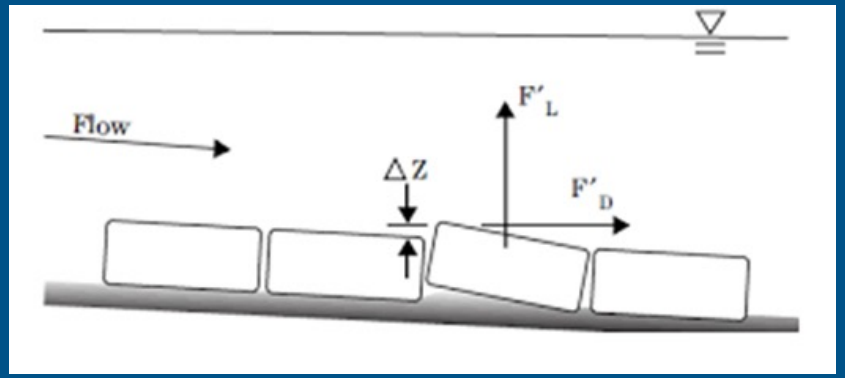


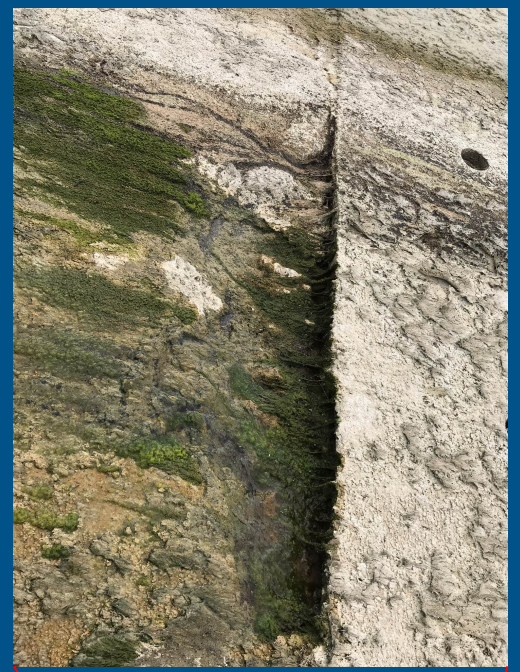


Big Sandy Dam, WY

Hydraulic Jacking (2)







Ball Milling

Navajo Dam, NM

Adverse Hydraulics Evidence

Unknown Dam

Erosion

Unknown Dam, CO

Structural/Material Issues

- Movement
- Concrete, metal, earth/rock degradation

Unknown Dam, wall failed due to improper backfill (not free draining)

Movement

Jamestown Dam, ND
Outlet works stilling basin

Grassy Lake Dam, WY
Spillway chute

Movement (2)

Vallecito Dam, Co
Excessive pore pressure and frost heave failed wall

Movement (3)

Settlement of backfill adjacent to spillway wall

Tension crack in backfill behind spillway wall

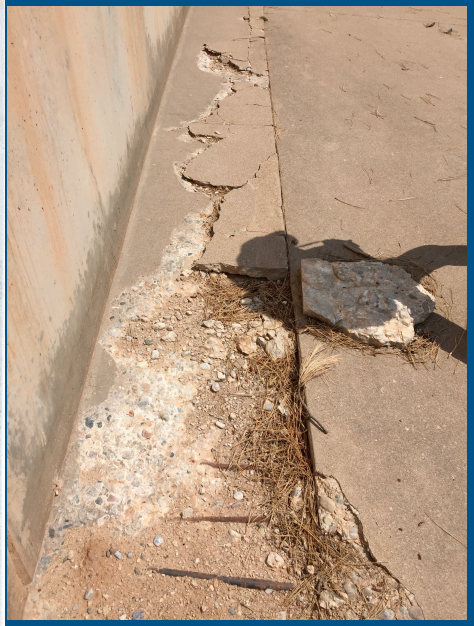
Separation of spillway walls

Tilting spillway wall

Belcourt Dam, ND

Movement and Spalling

Vallecito Dam, CO



Movement and Spalling (2)

Vallecito Dam, CO

Inadequate Foundation

Unknown Dam

Voids

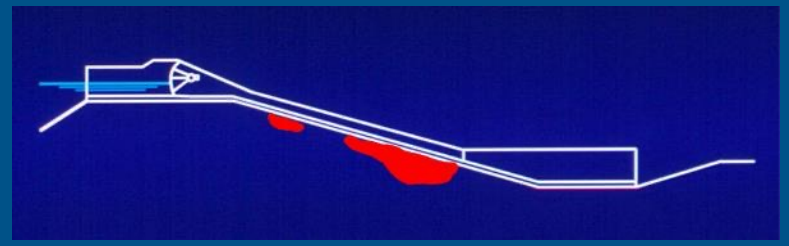


Illustration of voids (loss of foundation) below a spillway

Dickinson Dam, ND

Unknown Dam

Voids (2)

Spalling/cracking of flow surfaces

Underdrain discharge transporting sediment (foundation material)

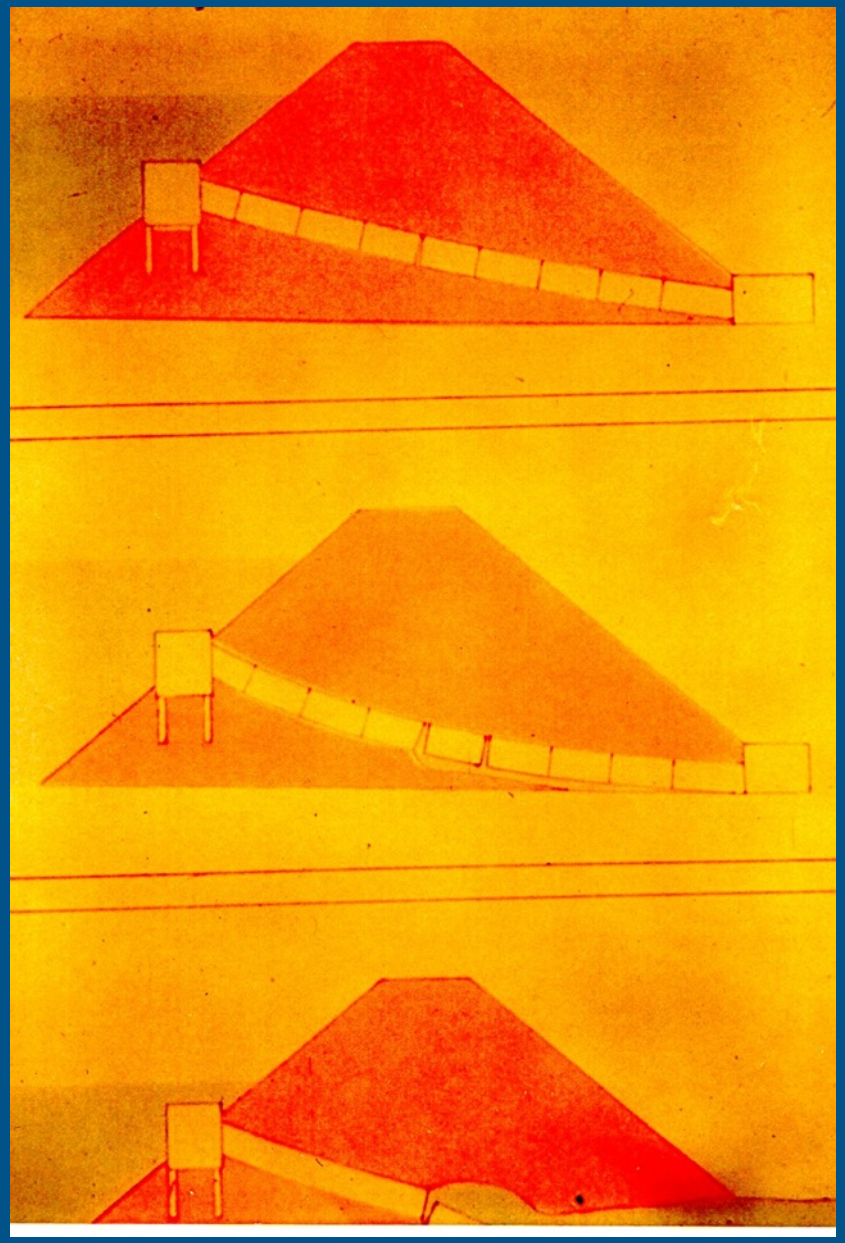
Exploration/investigation: Ground Penetrating Radar, coring, and video inspection of foundation

Hyrum Dam Spillway, UT

Settlement

Sheep Creek Dam

Settlement (2)



Sheep Creek Dam

Visual Cues

Whiskeytown Dam, CA

Structural/Material Issues (2)

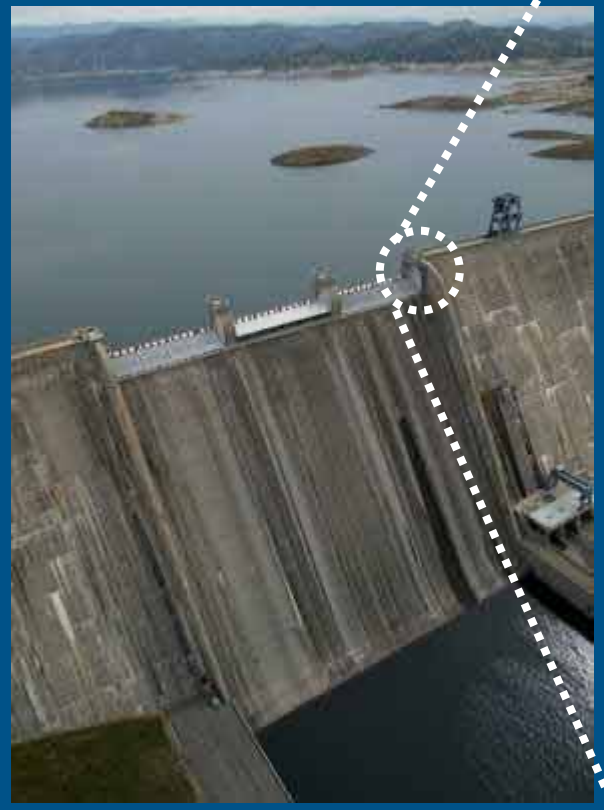
- Movement
- Concrete, metal, earth/rock degradation

Alkali-Silica Reaction (ASR)

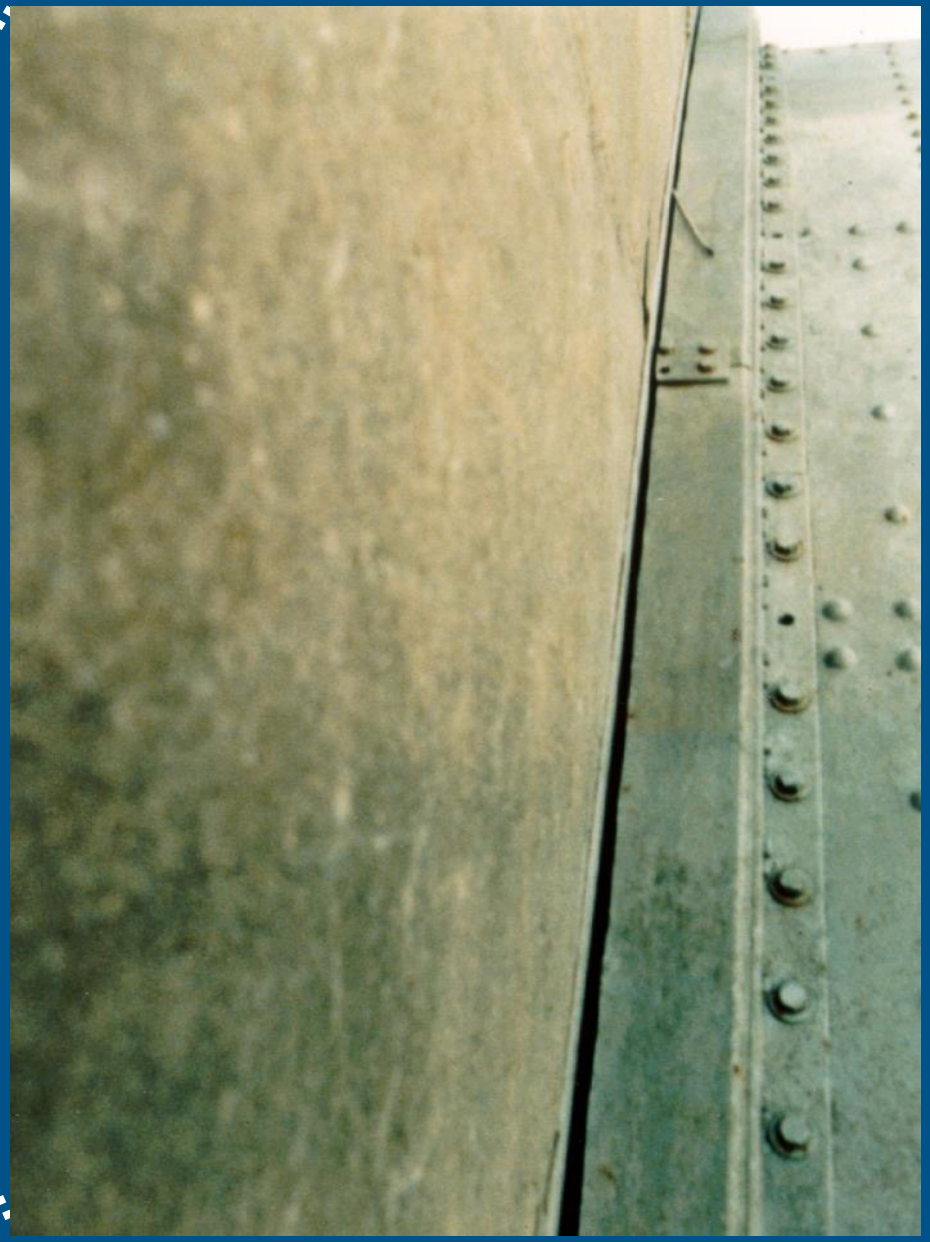
ASR affected concrete/aggregate observed during a pertrographic examination.

ASR

Friant Dam Spillway



Friant Dam, CA



Unbonded Lift Lines or Joints

Island Park Dam, ID

Unbonded Lift Lines or Joints (2)

Unknown Dam

Internal Erosion

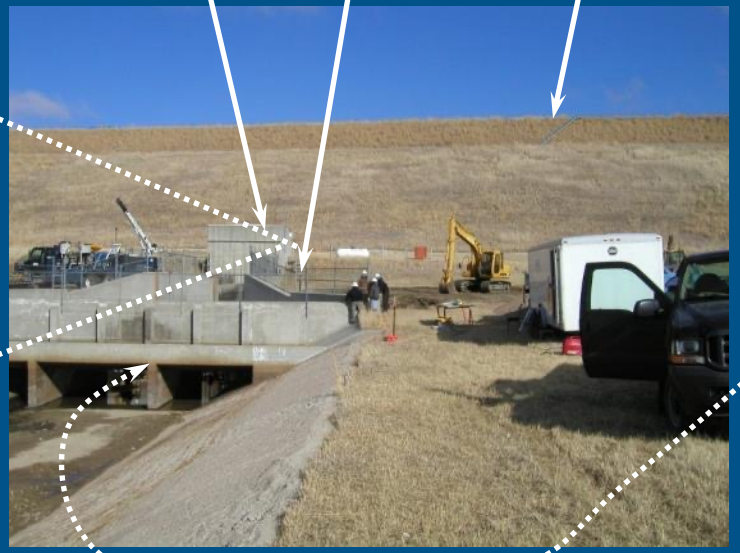
Unknown Dam

Internal Erosion (2)

Outlet works control house

Dam

Sinkhole



Underdrain outfall in chute block & drain filter deposit.

Sinkhole adjacent to outlet works control house.

Internal Erosion (3)

Corrugated metal pipe (CMP) outlet

Pre-cast bell-and-spigot pipe outlet

Unknown Dams

Examination of Concrete Dams

Areas to be Examined

- Foundation and abutments
- Upstream and downstream faces
- Galleries
- Crest

What to look for (foundation and abutments)

- Signs of movement (cracking, settlement, joint offsets)
- Crushing of concrete
- Movement of fines with seepage
- Increased seepage for similar reservoir levels, indicating potential solutioning of foundation (sampling of seepage for chemical analysis recommended)

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Some Findings from an Examination

Areas to be Examined (2)

- Foundation and abutments
- Upstream and downstream faces
- Galleries
- Crest

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What to look for (upstream and downstream faces)

- Cracking
- Spalling, or other deterioration caused by weathering, freeze-thaw activity, AAR
- Horizontal cracks or unbonded lift lines, resulting in leakage and potential instability from pressure

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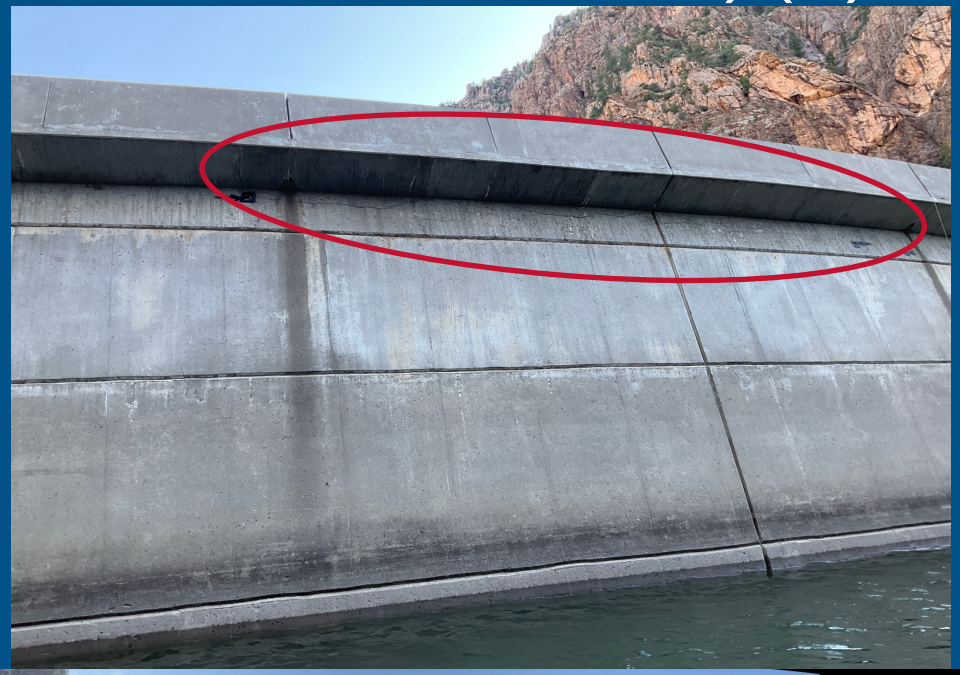
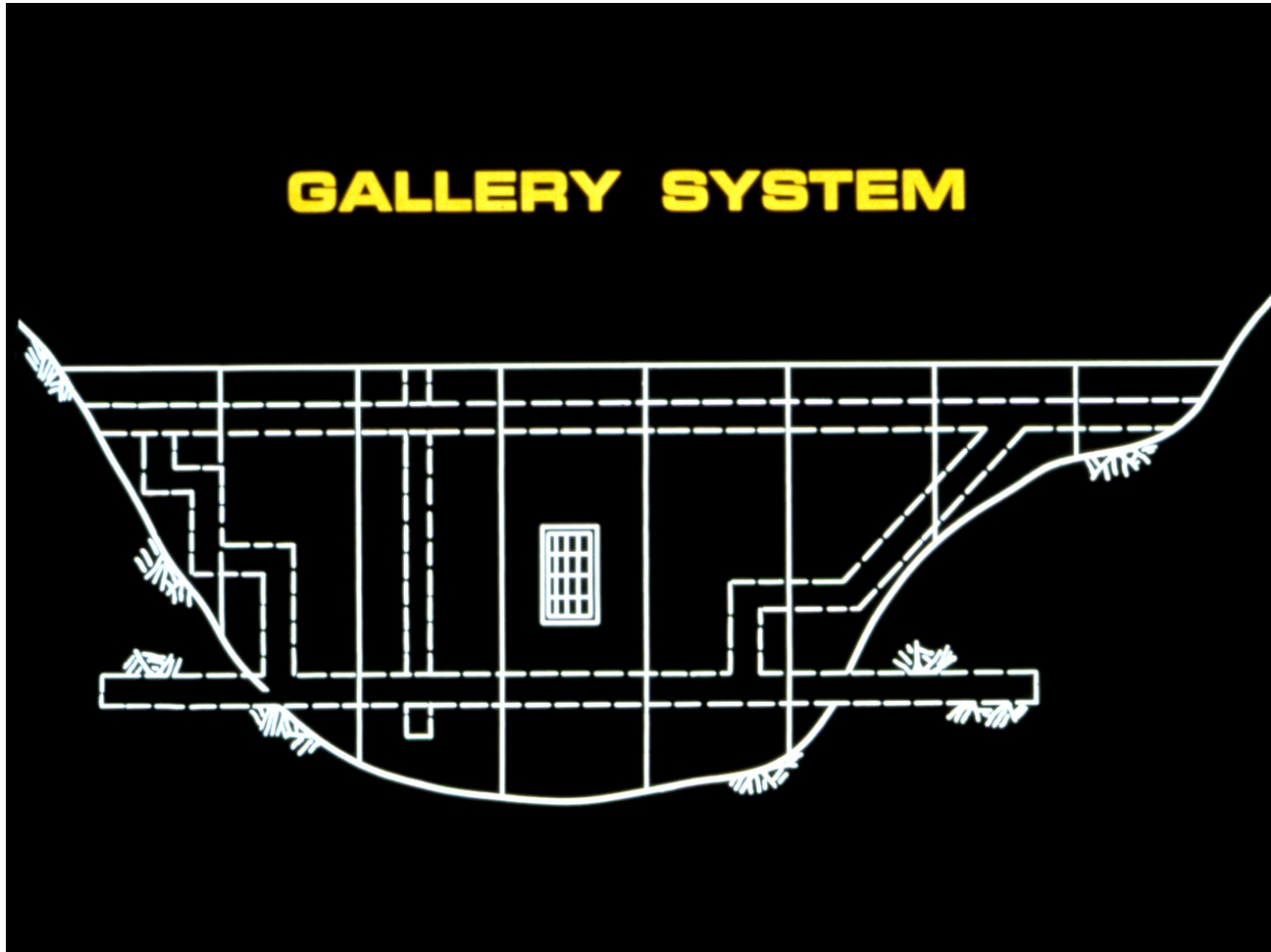
What to look for (upstream and downstream faces) (2)



What to look for (upstream and downstream faces) (3)

Areas to be Examined (3)

- Foundation and abutments
- Upstream and downstream faces
- Galleries
- Crest



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What to look for…

- Cracks
- Offsets at joints
- Blocked drains
- Spraying leakage at cracks or joints
- Increased/decreased seepage, indicating opening of joints/cracks, or sedimentation of reservoir

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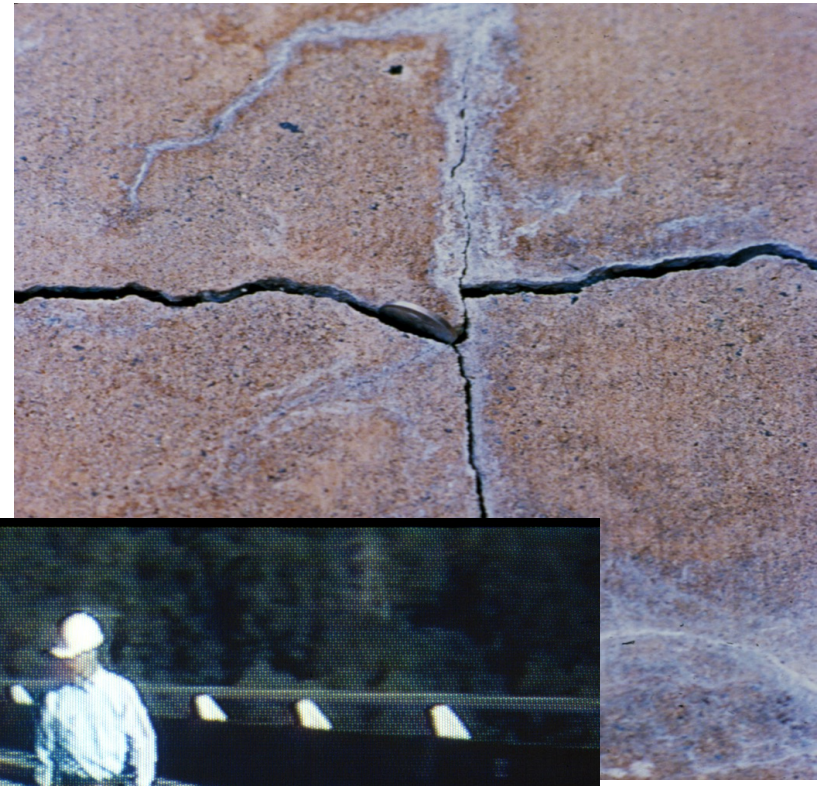
Examples (7)

Areas to be Examined (4)

- Foundation and abutments
- Upstream and downstream faces
- Galleries
- Crest

What to look for... (2)

- Cracks – Are they random and shallow? Do they appear deep, and do they extend to upstream and downstream dam faces?
- Differential vertical movement at joints
- Differential transverse movement at joints, best observed by sighting along parapets, curbs, handrails, and crane rails
- Spalling, weathering, or other deterioration



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What to look for... (3)

What to look for... (4)

Thank you!

Jaron Hasenbalg, P.E.
Civil Engineer
Jhasenbalg@USBR.gov

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