The 2017 Oroville Dam Spillway Incident – Incident Management and Recovery Program

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Maryland Dam Safety Training
14 November 2018

Presentation Topics

- Incident management / emergency response
- Recovery design and construction

Issues During Emergency Response

- Who's in charge?
- Inundation mapping
- Conflicting opinions on the balance of risks

Who's in Charge?

- Initially not clear who was in charge for California DWR – eventually this role was assumed by the Acting Director
- County sheriff was in charge for local emergency responders – but he had little understanding of dams
- Ultimately the Sheriff and the Acting Director served as top decision makers and led emergency response

Inundation Maps

- Only maps available were for inundation from failure of the 770 foot high main dam
- No time to generate accurate maps for a failure of the emergency spillway crest structure
- Decisions on extent of evacuation were made based on some approximate mapping and judgment

Balancing Risks

Additional SS Damage

Emergency Spillway Operation

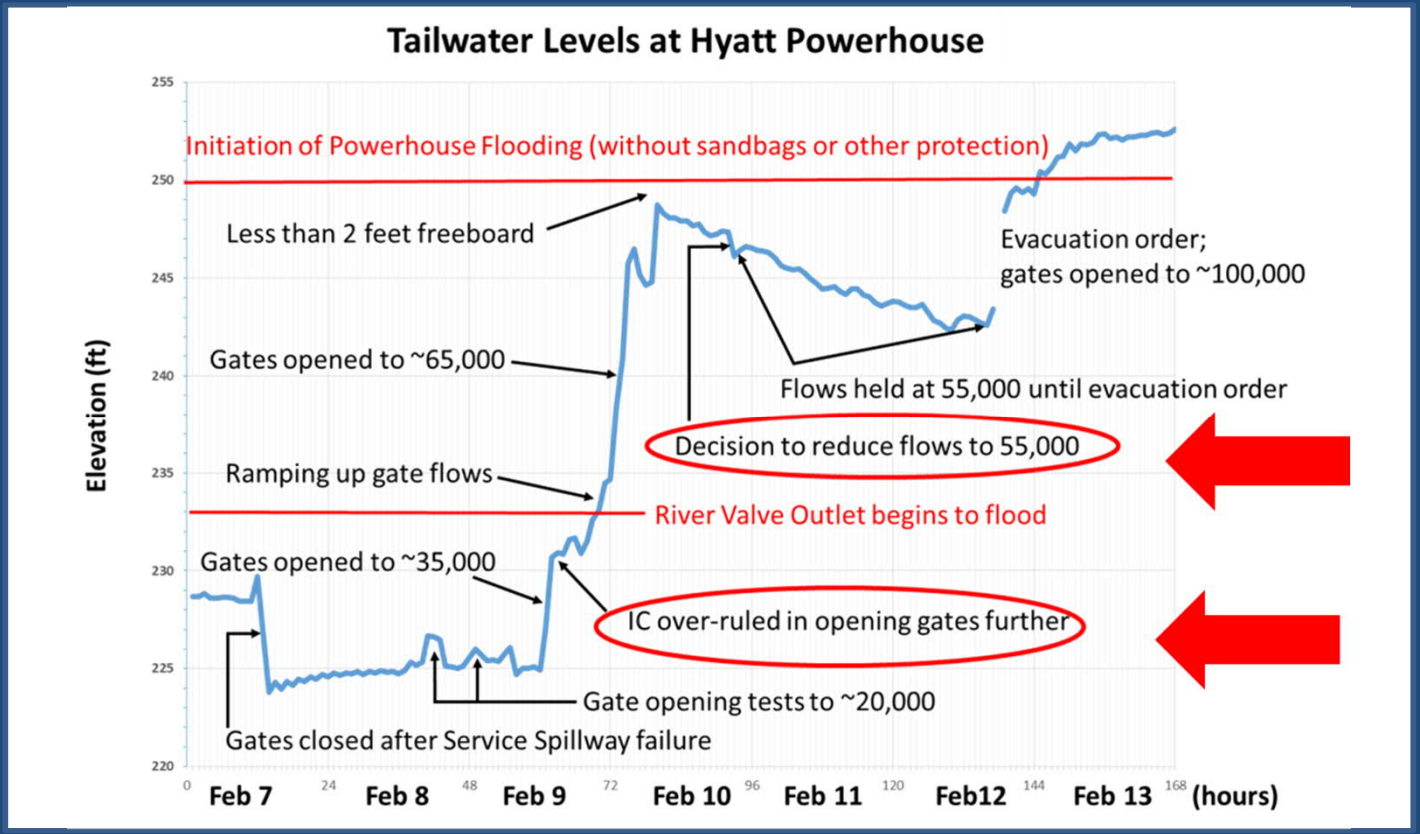
Powerplant Flooding

Power Transmission Towers

Conflicting Opinions on Risks

- Generally divided into two camps:
  - Operations personnel and mechanic/electrical engineers – protection of powerplant and transmission lines was most important
  - Civil/geotechnical/geological engineers – prevention of operation of emergency spillway was most important
  - Not necessarily unanimous in either camp
  - Protection of powerplant and transmission lines generally prevailed

Tailwater Levels and Decisions



Lack of Durability of Repairs

- Following information based on presentation slides provided by Ted Craddock, CA DWR, and a technical paper from ICOLD 2018, Vienna Austria, Oroville Dam Spillway Incident – Fast-Track Recovery Design and Construction to Address Critical Dam Safety, by Craddock et al.

Project Objective and Constraints

"Restore the Spillway Capacity to Ensure Public Safety in Advance of the Flood Season"

- Restore Capacity of Spillway Chute
- Armor Emergency Spillway
- Constraint – Time, Time, Time…
  - Design - March to June - 4 months!!!
  - Mobilization - April
  - Construction - June to November - 5 months!!!

Project Team

- Over 100 Team Members
  - Ramped-up within a few weeks
- DWR, Agency, and Industry Partners
  - Worked from same location
- Dedicated and Committed to Project Success
  - 12+ hour days, 6 to 7 days a week
- Regulatory Agencies
  - Regular and frequent coordination

Key Design Considerations

Scour Holes

Overhanging Rock Faces

Key Design Considerations

Condition of Remaining Chute

Hydraulics

2017 Geological Investigations

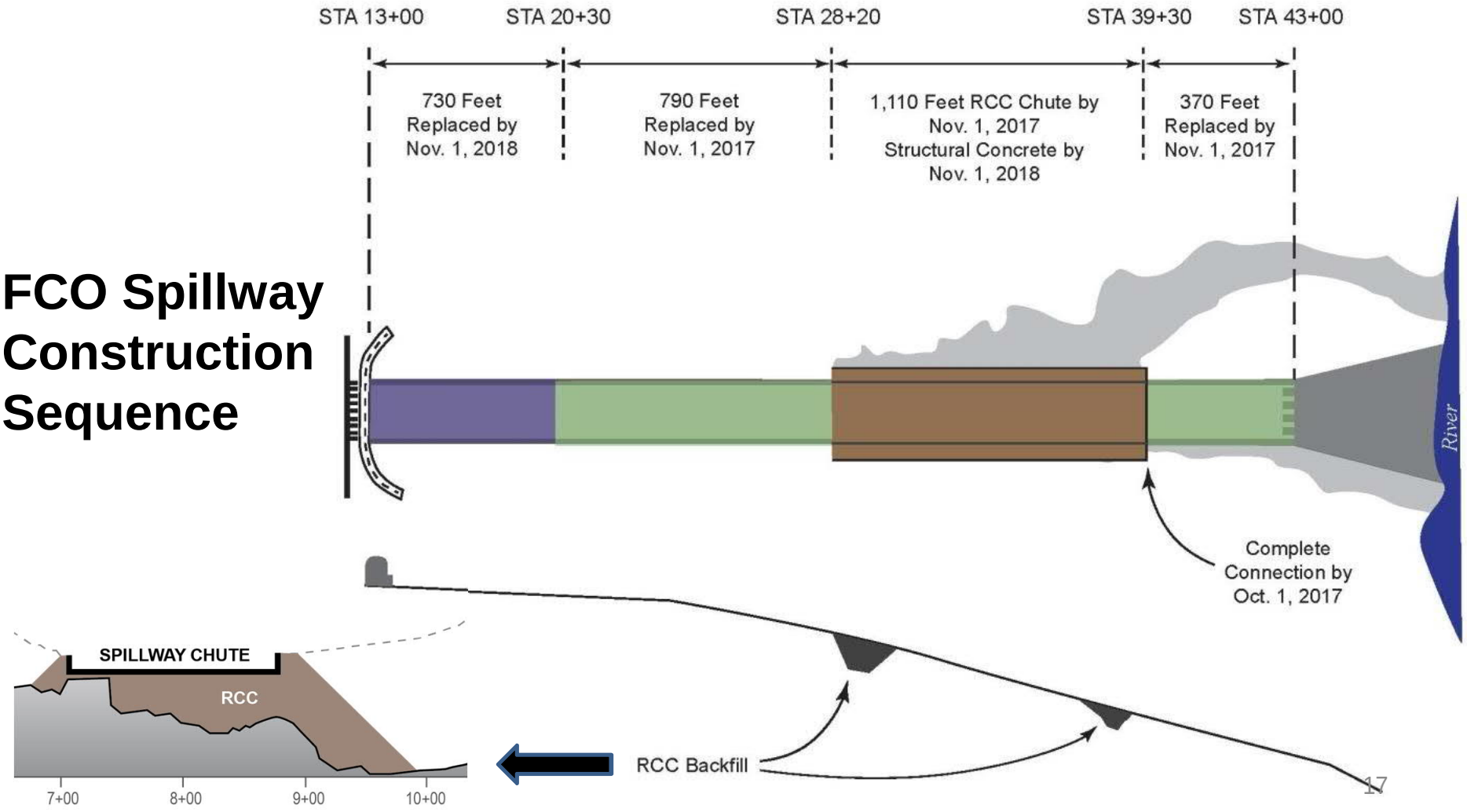
- 10 drill rigs – 104 borings, 26 piezometers, 15 inclinometers
- 22 seismic refraction lines
- Extensive geologic mapping

2017 Target Flows for Design

Summary of Key Design Milestones

- Spillways Management Organized 2/14/17
- Recovery Framework Adopted 2/23/17
- BOC Meeting No. 1 3/1 and 2/17
- Spillways Team Leads Organized 3/6/17
- Alternatives Analysis 3/17/17
  - Evaluated options for chute and emergency spillway
  - Incorporated contingencies

FCO Spillway Construction Sequence

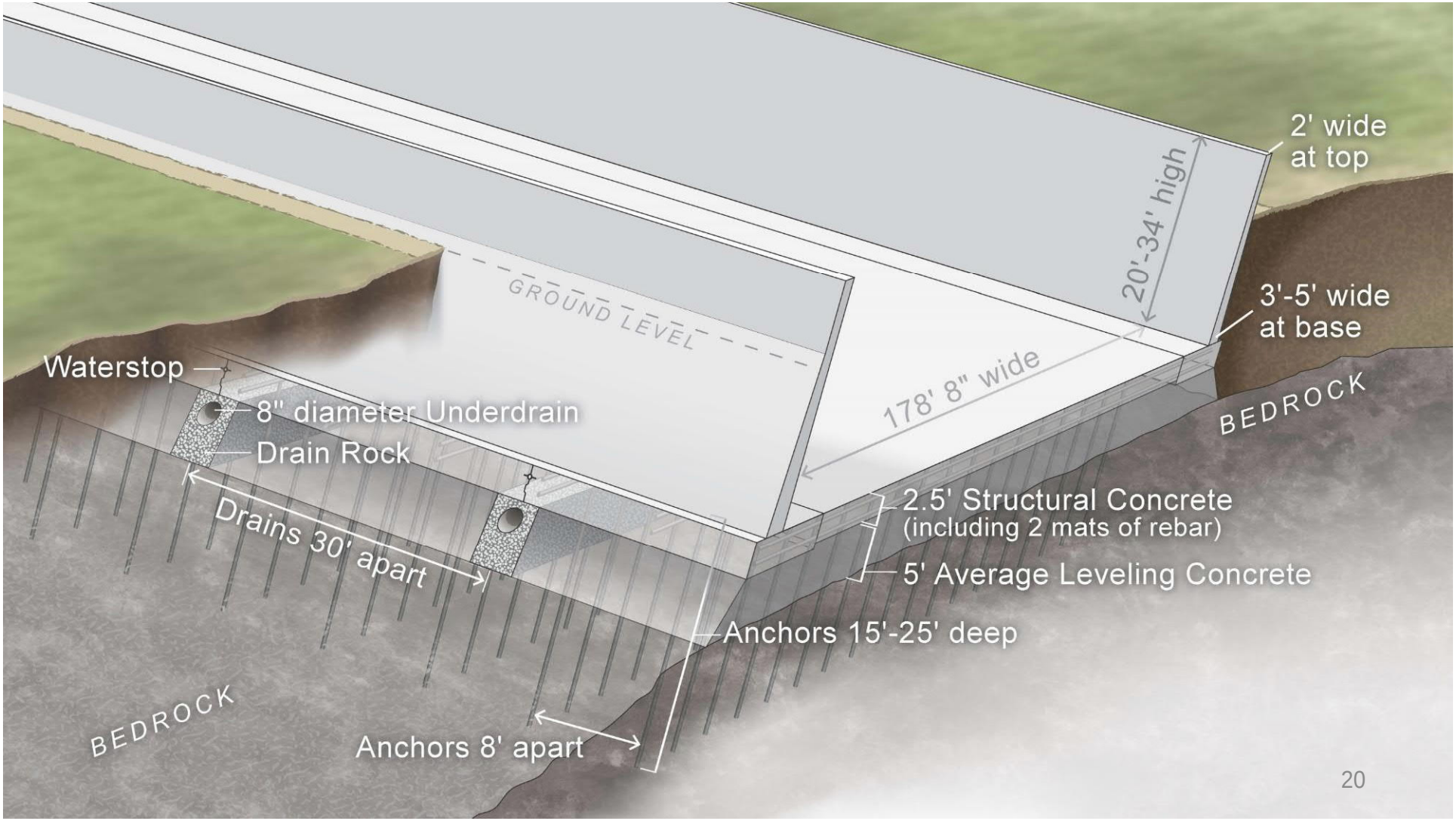


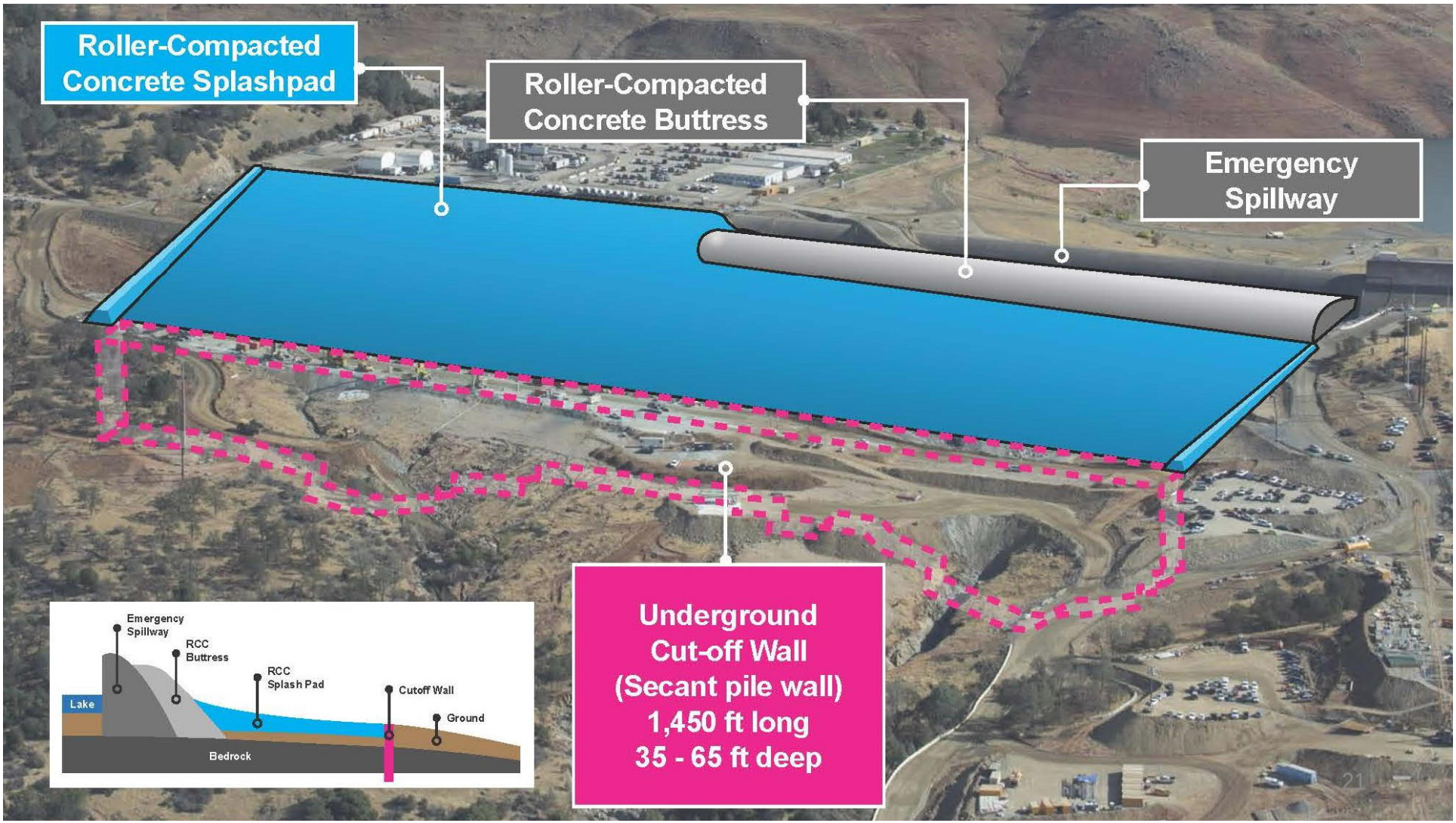
Service Spillway Design Features

Original Service Spillway	New Service Spillway
Relatively thin slab – 15-inches	30-inch minimum slab thickness
Only one layer of light reinforcement	Two layers of robust reinforcement
No joint waterstops	Waterstops in all joints
Large variations in slab thickness	Leveling concrete to control slab thickness
Corrosion of reinforcing bars	Epoxy coated bars in upper layer
Protruding underdrains	Underdrains entirely beneath slab
Underdrain and backfill drainage combined	Separation of underdrain flow and backfill drainage
Brittle clay underdrain pipes	PVC underdrain pipes
Perforated underdrain pipes too small – 6-in.	8-inch slotted PVC underdrain pipes

Service Spillway Design Features

Original Service Spillway	New Service Spillway
No undedrain cleanouts	Cleanouts for each underdrain pipe
Non-filter compatible gravel around drains	Filter compatible material around drains
Untreated erodible rock foundations in places	Erodible rock over-excavated
Untreated shears in foundation	Shear zones over-excavated and treated
Less than rigorous foundation clean-up	Very rigorous foundation clean-up
Insufficient rock anchorage – 5 feet	Deeper anchors – 15 to 25 feet
Partial corrosion of rock anchors	Rock anchors epoxy coated
Potential cavitation	Aeration added in Phase 1 spillway section


2' wide
at top
20'-34' high
3'-5' wide
at base
GROUND LEVEL
178' 8" wide
Waterstop
8" diameter Underdrain
Drain Rock
BEDROCK
Drains 30' apart
2.5' Structural Concrete
(including 2 mats of rebar)
5' Average Leveling Concrete
Anchors 15'-25' deep
BEDROCK
Anchors 8' apart


Roller-Compacted Concrete Splashpad
Roller-Compacted Concrete Buttress
Emergency Spillway
Underground Cut-off Wall (Secant pile wall) 1,450 ft long 35 - 65 ft deep
Emergency Spillway
RCC Buttress
RCC Splash Pad
Cutoff Wall
Ground
Lake
Bedrock

Summary of Key Design Milestones

- Advertised Spillways Contract – 3/31/17
  - 30% Plans and Specifications
  - Mobilize RCC, PCC, Rock Plants & Procure Materials
- Awarded Spillways Contract – 4/20/17
- M.D. 6, Scour Hole Slope Stabilization – 5/9/17
- M.D. 11, 75% Plans & Specs. – 5/18/17
- M.D. 20, Final Plans & Specs. – 6/21/17
- M.D. 27, Revised Final Plans and Specs. – 7/20/17

Construction - Early Start

- Site Access
- Concrete, RCC, & Rock Plants
- Slope Stabilization
- Material Procurement

Concrete Plant

RCC Plant

2017 Construction Overview

- Quantities (November 1, 2017)
  - 234 Structural Slabs
  - 30,000 CY Structural Concrete
  - 2,900 Anchors
  - 420,000 CY Excavation
  - 78 Walls
  - 42,000 CY Leveling Concrete
  - 350,000 CY RCC
- Contractor's Forces - 750 Personnel at Peak
- 2 Shifts, 6 or 7 Days a Week
- Over 700,000 person/hours with no recordable incidents

Excavation – Blasting

Upper Scour Hole Excavation (Arena Cut)

Upper Scour Hole

May 30, 2017

August 21, 2017

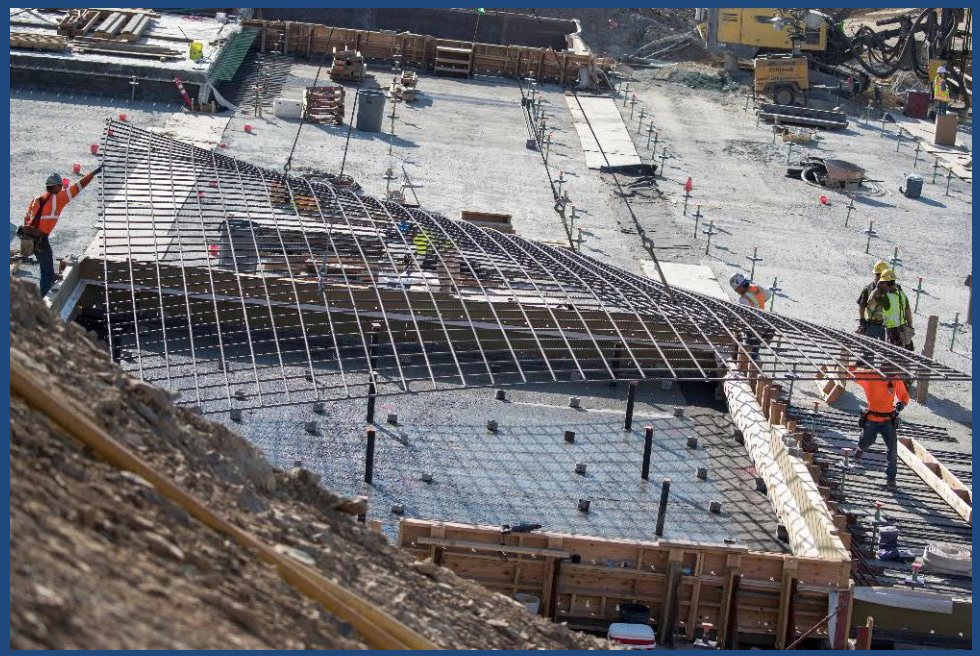
Looking Up From Bottom of Upper Scour Hole

FCO Chute - Leveling Concrete

7/18/17 – First Leveling Placement Upper Chute

FCO Chute - Foundation Anchors

FCO Chute – Forming and Panel Reinforcement

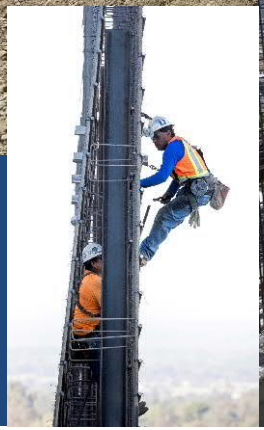


FCO Chute – Concrete Liquid Nitrogen

FCO Chute Structural Slabs

8/3/17 – Panel 90E Placement

FCO Chute - Structural Walls



2017 Upper Chute – “The Peak”

Sept. 16, 2017 – A Little Bit of Everything

Lower Scour Hole

May 31, 2017

June 28, 2017

July 19, 2017

Start of RCC in Lower Scour Hole

Started Thursday July 20, 2017 @ 7 PM

- **Bottom at El. 371**
- **Three 12-hour shifts**
- **About 2,000 CY Placed**

Lower Scour Hole

July 24, 2017

August 7, 2017

August 21, 2017

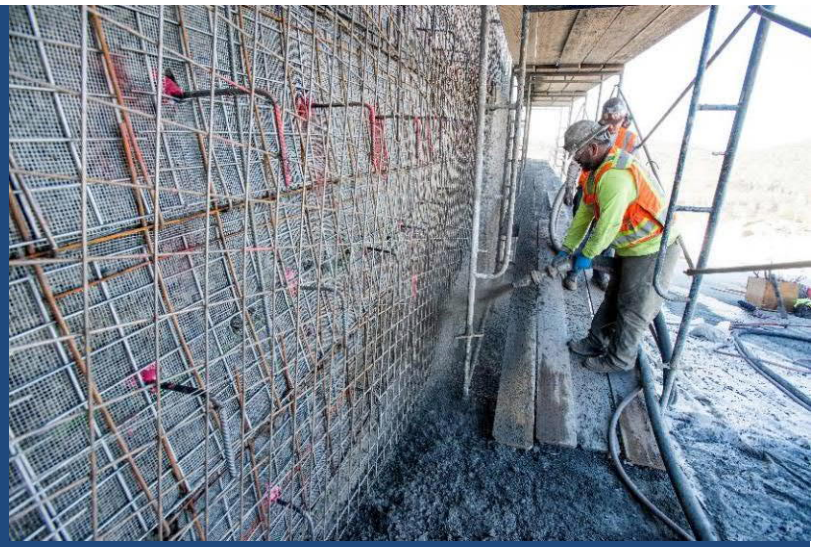

August 11, 2017

Upper Scour Hole

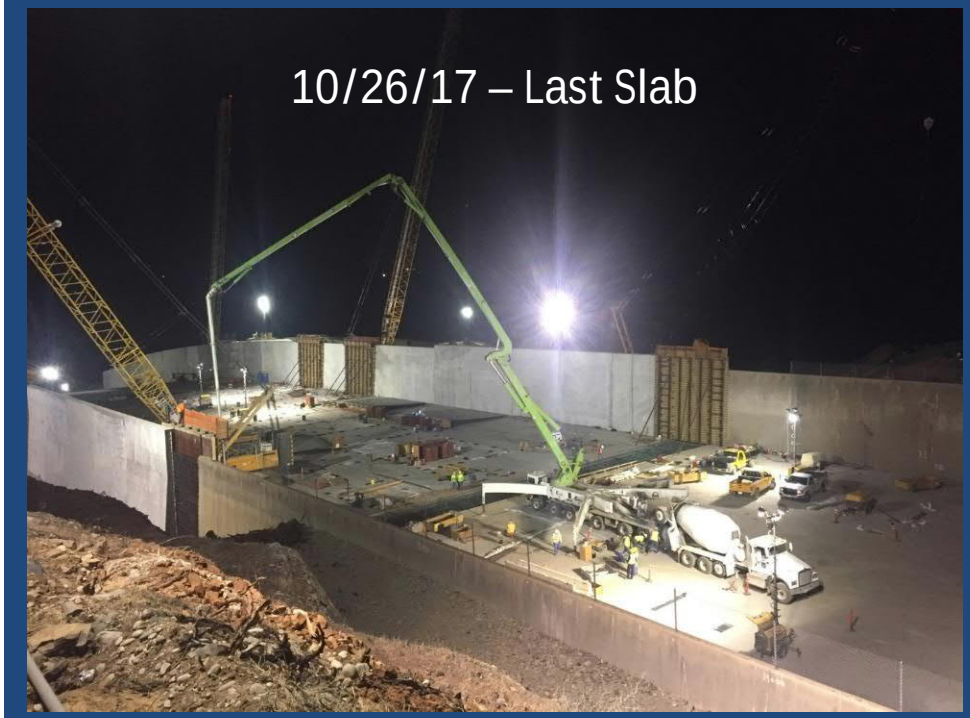
September 7, 2017

September 20, 2017

Interim RCC and Shotcrete Chute Walls

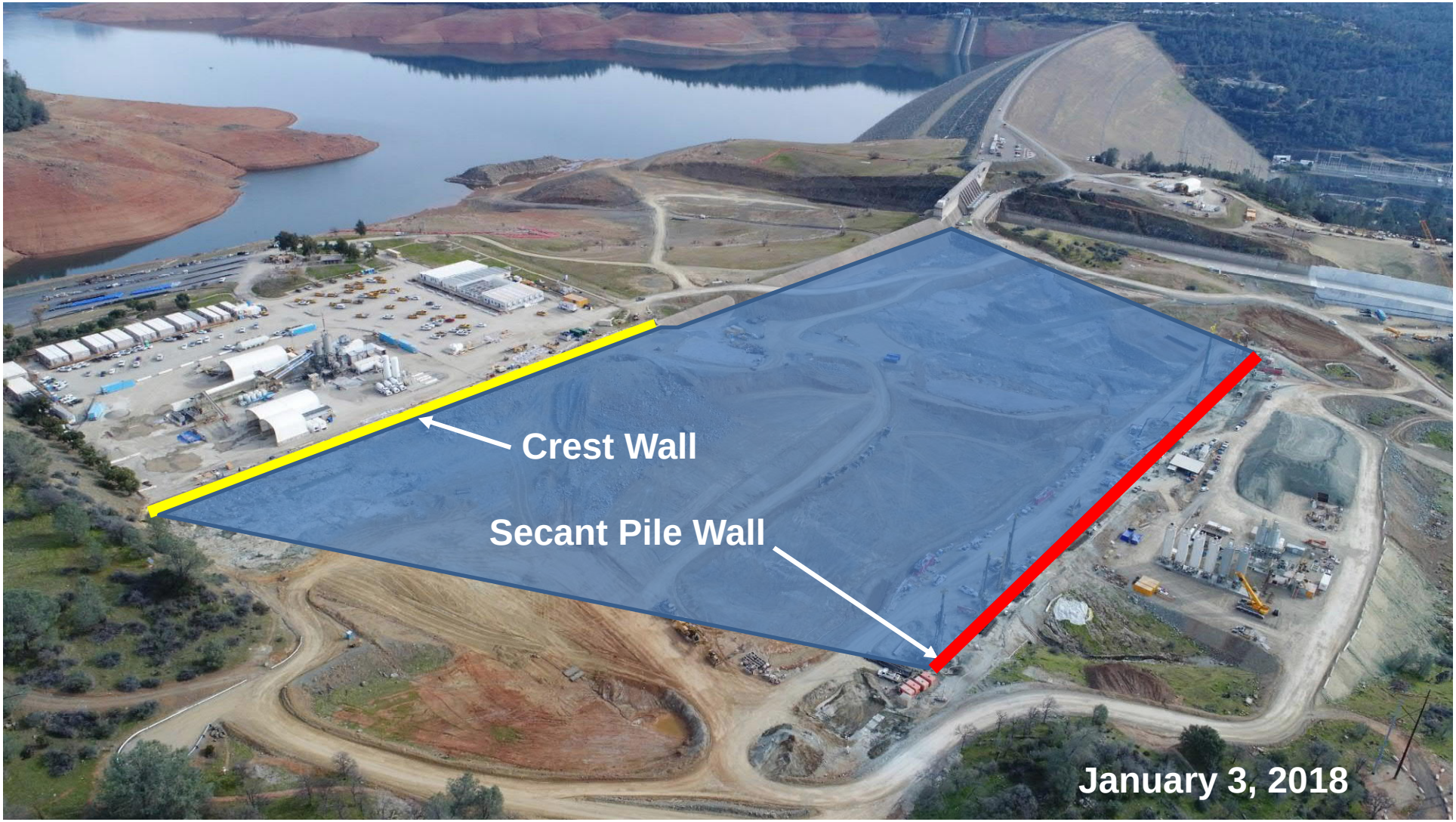


2017 Final Placements

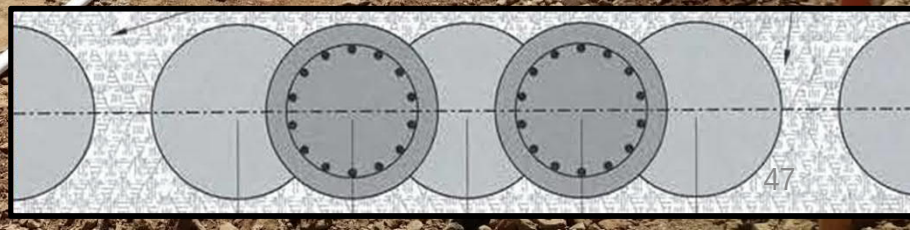


November 1, 2017

2017 Service Spillway Construction


Crest Wall
Secant Pile Wall
January 3, 2018

Secant Pile Wall
Working Pad and Guide Wall



Secant Pile Cut-off Wall

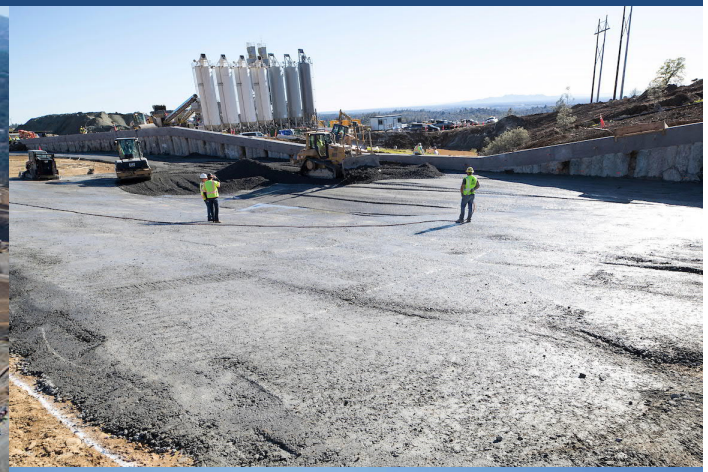
Top of Secant Pile Wall

2018 Construction Overview

- Quantities (October 22, 2018)
  - 378 Slabs
  - 53,000 CY Structural Concrete
  - 4,300 Anchors
  - 126 Walls
  - 25,000 CY Leveling Concrete
  - 700,000 CY RCC
- Contractor's Forces – 840 Personnel at Peak
- 2 Shifts, 6 or 7 Days a Week
- Over 750,000 person hours

Emergency Spillway Excavation

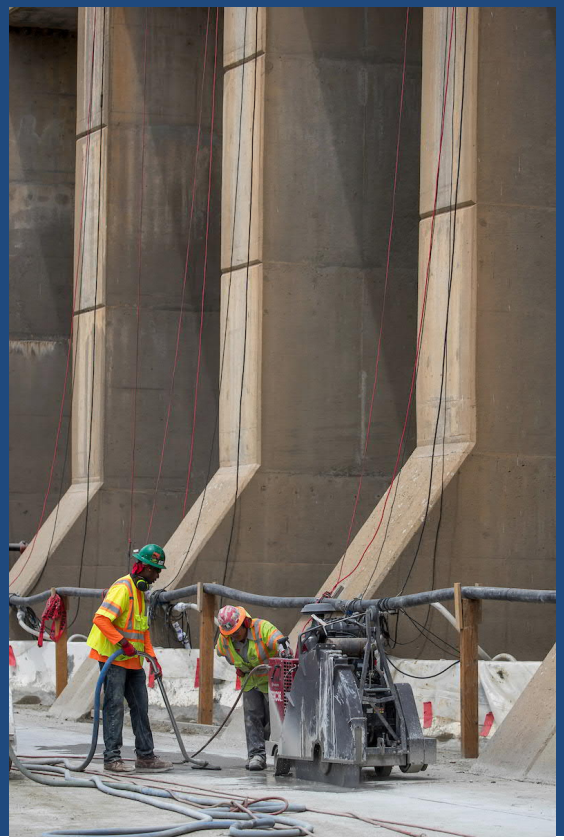
Emergency Spillway RCC - Phase 1



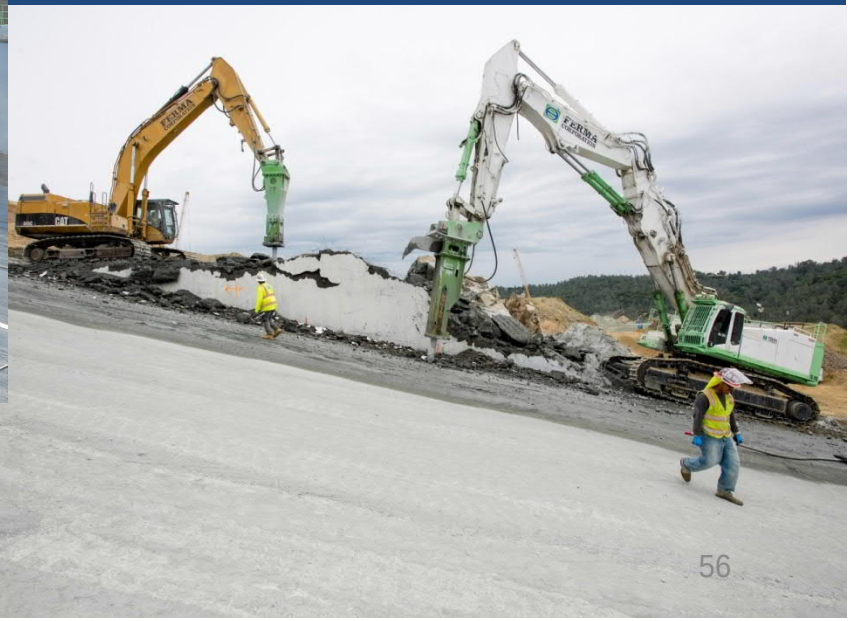
Emergency Spillway RCC - Phase 2

Emergency Spillway – October 19, 2018

Upper Chute Mechanical Demolition



RCC Wall Demo



Upper Chute Excavation, Cleanup, and Mapping

Drain and Anchor Installation on RCC

Upper Chute

October 19, 2018

Construction Management Success

- Partnering
  - Every other week
- Constructability Review
  - Design input
- Task Forces
  - Established for specific items
- Management and Design Team On-Site
- Open Communication
- Committed to Project Success


Thank You