Outline

• Project Description
• Summary of Rock Reinforcing Activities
• Lessons Learned / Best Practices
• Many contractors, many bolts
Folsom Dam Auxiliary Spillway (FAS) – Project Description

What is the FAS?
- Flood Risk Management / Dam Safety Project implemented jointly by US Army Corps of Engineers (USACE) and US Bureau of Reclamation (USBR).
  - Aka “Joint Federal Project” (JFP)
  - Meets USACE flood damage reduction goal by allowing more water to be safely released EARLIER in a storm event (200-yr storm)
  - Meets USBR Safety of Dams goal by passing a Probable Maximum Flood (PMF) in conjunction with Main Dam
  - Construction spanning 2008-2017
Main Dam and Auxiliary Spillway

- 3.8 Million Cubic Yards of Rock and Soil Excavation
  Enough to spread a ~1-inch layer of soil over the City of San Francisco
- One mile in length
Main Dam and Auxiliary Spillway

Main Dam (1955)
- Gross Pool
- Annual Avg. Pool
- Spillway Crest
- Service Gates 1 to 8
- Emergency Gates 1 to 8

Auxiliary Spillway (2017)
- ELEV. 468.34’
- 430.34’
- 420.34’
- 370.34’

Stilling Basin Floor – El. 115.00

50’
Regional Geology

- Highly fractured, variably weathered (joint-controlled) quartz diorite (Rocklin Pluton)
- Adjacent to: metavolcanic (Mesozoic) & volcanic formations (Miocene/Pliocene)
App Channel – 306 #28 Slab Anchors
Green – Deeper Shear Zone Anchors
Max Depth = 35 feet

Left Slope – 732 Rock Bolts
1-3/8 to 3” Dia
Max Depth = 80 feet

Right Slope – 316 Rock Bolts
1-3/8” to 1-3/4” Dia
Max Depth = 60 feet

Upper Chute – 1,056 #11 Slab Anchors
Green – Deeper Shear Zone Anchors
Max Depth = 20 feet

Stepped Chute – 203 #11 & #20 Slab Anchors
Green – Deeper “Rock Wedge” Anchors
Max Depth = 50 feet

Summary
2,657 Elements
88,000 lin. Ft.

Right Bank - 44 #9 Rock Bolts
Max Depth = 25 feet

By: K. Pattermann
Rock Bolting Approach Channel – Left Slope

Aerial

110'

25 MAR 2015
Rock Bolting Approach Channel – Right Slope
Aerial
Approach Channel Walls
Analysis of lateral support

- SAP2000 3D Model

Left Wall

Right Wall

Rock Bolts

Design by AECOM Oakland (URS)
Approach Channel Walls
Completed – just prior to first filling
Rock Bolting in Approach Channel
Predominant Joint Sets

Table 3-4. Attitude of Predominant Joint Sets

<table>
<thead>
<tr>
<th>Joint Set</th>
<th>Strike</th>
<th>Dip Direction (°)</th>
<th>Dip (°)</th>
<th>Fisher Dispersion Factor, K</th>
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<tbody>
<tr>
<td>A</td>
<td>N 23° W</td>
<td>85</td>
<td>69</td>
<td>18.4</td>
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<tr>
<td>B</td>
<td>N 87° E</td>
<td>177</td>
<td>74</td>
<td>31.9</td>
</tr>
<tr>
<td>C</td>
<td>S 45° W</td>
<td>315</td>
<td>81</td>
<td>117.5</td>
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<tr>
<td>D</td>
<td>S 45° W</td>
<td>315</td>
<td>27</td>
<td>17.3</td>
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</table>

Approach Channel Design TM – Dec 2012

5. Joint A-D casts present immediately beneath current bench surface.
Rock Bolting in Approach Channel
Spot bolts – 6 Blocks - Outside of Pattern Bolt Areas

10 FEB 2015
Left Slope - Looking Upstream
Rock Bolting in Approach Channel

Double Corrosion Protection (DCP) Bolts in Approach Channel

Prep – Bond zone, grout tubes, centralizers

Installation – from skid – 80’ long bolts

Proof Testing

17 DEC 2015

29 JAN 2015

14 JAN 2015
Rock Bolting in Approach Channel - Photos

Loading Jacks and stressing chair

Sealing Coupling Sections – heat shrink sleeve

Re-Test of Phase 3 Bolts

Drill - Atlas Copco – Hutte HBR 605
Developing Better Plans & Specs

Pattern bolting - each bolt location must be confirmed in the field by qualified geotech/geology staff. We developed a system for inspection of each bolt location alongside the contractor. 507 rock bolts just for the approach channel left and right slopes (110-ft slope height)

By: JFP Phase IV Contractor
Developing Better Plans & Specs (cont.)

Initially surveyed all bolts to pattern (nail and pink flags), then reviewed by gov’t geologist/engineer (green painted squares to include bearing pad), then final survey (green dot). Repeat for each bolt.
Bearing Pad (BP) Construction – very important consideration when locating bolts

Not much attention paid to BPs in specs or PTI. Suggest:
1) Wider than bearing plate (2 inches extra all four sides)
2) Taper to provide greater bearing width against rock
3) Reinforce with steel or fibers (require in spec)

Intricate plywood forming
Avoid oversized bearing pads:
• More prone to cracking or be hit by debris

• Don’t use bearing pads if possible - within 2 degrees of bolt normal axis.
• Pads are weak link when comparing compressive strength
Developing Better Plans & Specs (cont.)

- Don’t place bearing pads on fractures
  - Tensioning force can & will displace fractured rock
  - Consider rock face displacement when field-locating rock bolts (i.e. relocate away from fractured zone)
    OR reinforce the slope prior to bolting (e.g. reinforced shotcrete)
Centralizers -- If they become loose, there is potential to move towards the top while inserting, then bottom of rock bolt may not have adequate grout cover.

Don’t tie centralizer and grout tube together
Slab Anchors Approach Channel

03 JUN 2015

Actual Shear Zone Location shown in yellow

Plan View

Design Shear Zone Locations
Design Shear Zone Layout in Upper Chute
Actual Shear Zone Layout in Upper Chute
Slab Anchors in Approach Channel
Construction Photos

Prep

12 FEB 2015

Installation

11 FEB 2015
Developing Better Plans & Specs

Performance and Proof Testing – Add distance to nut and temporary un-grouted lengths.

4x6 timbers compressed!

Take Photos of your measurements!
Developing Better Plans & Specs (Cont.)

USACE Performance Test Elongation Plot

Graphical Analysis of Proof Test Data

Performance Test Plot: Subcontractor H & K

Figure 1. Proof-Test Check Spreadsheet Developed for Oroville
Developing Better Plans & Specs (Cont.)

Engineering Considerations and Instructions to Field Personnel (ECIFP)

- Provides info to field staff not found in plans & Specs (pocket-sized field guide)
- E.g. rock bolt installation procedure...

1) For pattern anchors, Contractor marks preliminary locations by licensed surveyor. Locations are inspected by USACE field geologist or geotechnical engineer and slightly adjusted, if necessary, to avoid fractures or to optimize location of rock anchor for block and slope stability (31 33 15 - 3.1.1).

2) Contractor surveys final location and drills borehole (3.1.1). Completes driller logs (3.4.5), checks alignment with down-hole survey (azimuth and inclination (2.3.5), and gets approval from USACE KO and Engineering.

3) Contractor conducts borehole watertightness testing (3.1.8) and submits results to USACE KO and Engineering for approval. Note: The pressure of 5 psi is to be above the existing groundwater level. If the watertightness test fails, the Contractor must grout the borehole, re-drill, re-water test; if it fails again, re-grout with thicker grout (sand-cement grout), re-drill borehole, re-water test (3.1.9).

4) The Contractor prepares the anchor: Centralizers secured, grout tubes secured (3.2.1.f);
   Installs anchors (3.2).

5) Grouts bonded zone (Grout Mix and UCS Tests for USACE Approval - 2.2.4)

6) Forms, reinforces, and installs bearing pad (3.2.1.m) and associated hardware (trumpet, bearing plates, nuts, washers).

7) Test anchors (3.3): Verify calibration sheets (2.3.3.f.j. & k)
   Submits Proof (3.4.4) and Performance Tests (3.4.3) to USACE KO and Engineering for approval (3.4.4.d and 3.4.3.k)

8) Locks-off (3.3.3) and tops-off grout (3.3.3.e).

9) Anchor Records submitted (3.4.6) and accepted by USACE KO and Engineering (3.5). Installs and grouts cover cap (3.3.3.e).
Developing Better Plans & Specs (Cont.)

ASTM D4435 - Standard Test Method for Rock Bolt Anchor Pull Test

• Useful, but allows for testing of non-representative test bolt, does not replicate production conditions

• Issues include:
  
  ➔ 5.2 Thus, to make sure the bolt response during the test is minimal and predictable, high strength, short-length (6 to 8 ft) bolts have been specified.
  
  ➔ 7.1.2 The hole need not be as deep as the proposed length of the rock bolts.
  
  ➔ 7.4.7 Failure is the peak load sustained by the bolt, or a total deflection of 0.5 in.

• Contractors won’t go to failure (safety). Typically use 90% of yield (GR75) or 80% of ultimate (GR150), which is typically still greater than max test load.
  
  Design load – 60% of fy (Gr75) or fu (Gr150)
  
  Lock Off load - 70% of fy or fu
  
  Max Test load - 80% of fy or fu
Right Bank Stabilization (RBS) Project – Dec 2017

Project Area

FLOW

Folsom Dam
Aux Spillway
RBS Project - Resin Grout Pump vs. Resin Grout Cartridges

- RESIN CARTRIDGE (SMALL BOREHOLE DIAMETERS)

![Diagram showing a resin cartridge and the components involved in the process]

- Bearing Pad
- Bearing Plate
- Watertight Cap
- Tensioned Rock Bolt
- Hex Nut
- Rock Face
- Drilled Hole

Working length "filled" with slow setting resin cartridges

Bond length (5') with fast-setting resin cartridges

Tensioned Rock Bolt Details (Resin Grouted)

Scale: Not to Scale
RBS Project - Resin Grout Pump

JENNCHEM offers pumping equipment and technical support.

Our goals are:

- Quickly assess your situation and recommend the appropriate grout.
- Supply the grout and pumping equipment, from our West Virginia, Illinois, and Utah facilities.
- Effectively demonstrate chemical grout injection techniques to your cement grout crews.

**RESIN PUMP**

TDS-240 (or Top Down Silicate 240) is a two component urea silicate grout that comprises a silicate and a modified polyurethane intended for strata consolidation, water control, and rock/cable bolt grouting.

This grout is designed to secure rock and cable bolts in tunnel and mine applications. It quickly develops a thixotropic characteristic that minimizes free flow but allows continuous as well as interrupted pumping overhead.

<table>
<thead>
<tr>
<th>TYPICAL CHEMICAL ANALYSIS</th>
<th>PART A (SILICATE)</th>
<th>PART B (UREA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity @70°F, ASTM D-1638</td>
<td>400 cps</td>
<td>285 cps</td>
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<tr>
<td>Physical State</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Color</td>
<td>Amber</td>
<td>Slightly yellow</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.17</td>
<td>1.51</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>Beads with water and evolves CO2 gas</td>
<td>Contains water</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>MATERIAL MIXING RATIOS</th>
<th>PART A (SILICATE)</th>
<th>PART B (UREA)</th>
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<tbody>
<tr>
<td>Parts by volume</td>
<td>50 parts</td>
<td>50 parts</td>
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<tr>
<td>Parts by weight</td>
<td>40 parts</td>
<td>50 parts</td>
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<table>
<thead>
<tr>
<th>REACTION PROFILE</th>
<th>3000 GRAMS (67)</th>
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<tr>
<td>Gel Time</td>
<td>4 – 6 minutes</td>
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<table>
<thead>
<tr>
<th>TYPICAL PHYSICAL PROPERTIES</th>
<th>RESULTS</th>
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<tbody>
<tr>
<td>Normalized Compressive Strength, 24 hour age</td>
<td>4100 psi</td>
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Looking Downstream

Looking Upstream

06 DEC 2017

BUILDING STRONG®
TEST RELEASES - FOLSOM AUXILIARY SPILLWAY

- 53,000 cfs flowrate during project commissioning in 2018
- Folsom Dam Aux Spillway and Right Bank area performed well
- ~$1B total project
- 9 years of construction
- Huge flood damage reduction benefit to Sacramento
- Special Thanks