FOLSOM DAM AUXILIARY SPILLWAY - ROCK ANCHOR INSTALLATION – BEST PRACTICES

17 SEPTEMBER 2018

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Outline

- Project Description
- Summary of Rock Reinforcing Activities
- Lessons Learned / Best Practices
  - Many contractors, many bolts

Folsom Dam Auxiliary Spillway (FAS) – Project Description

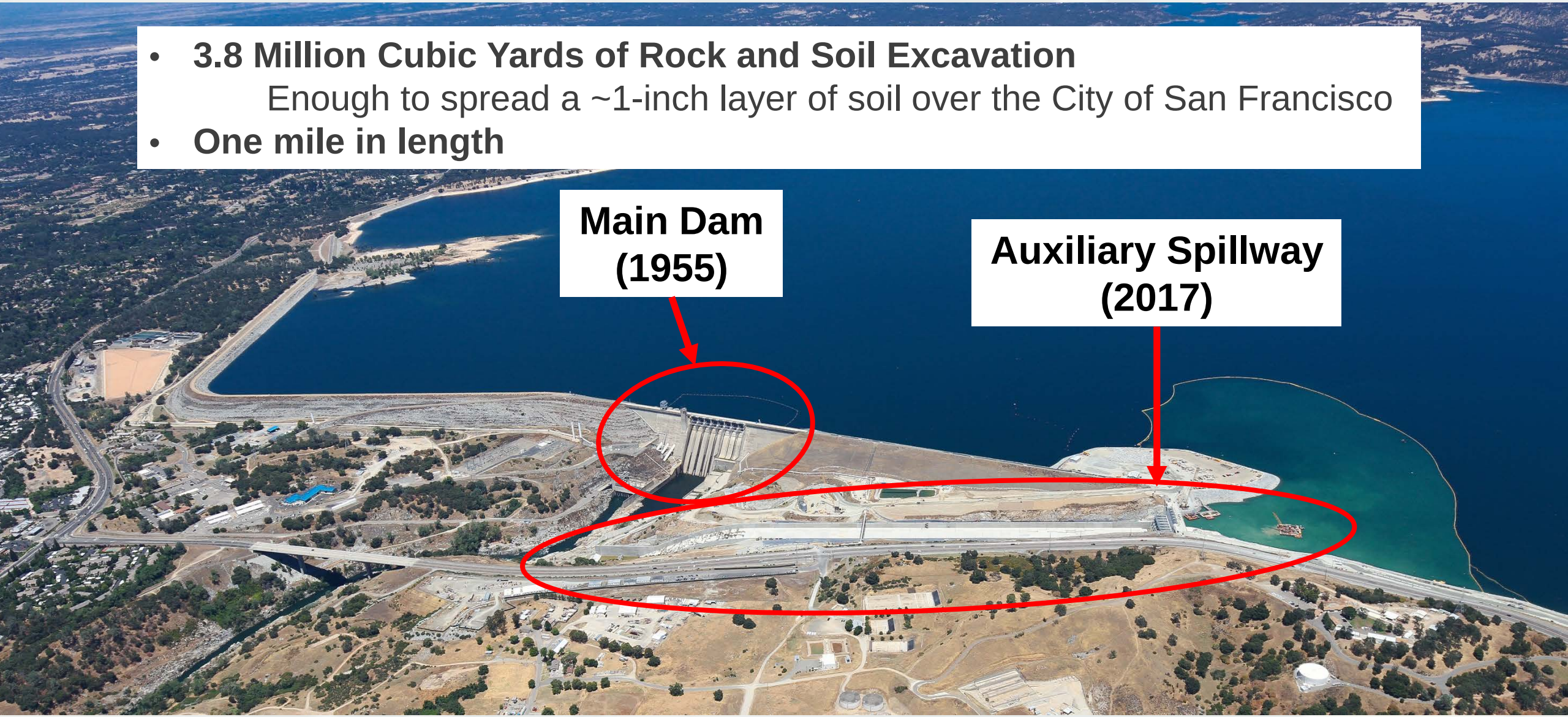
What is the FAS?

- 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

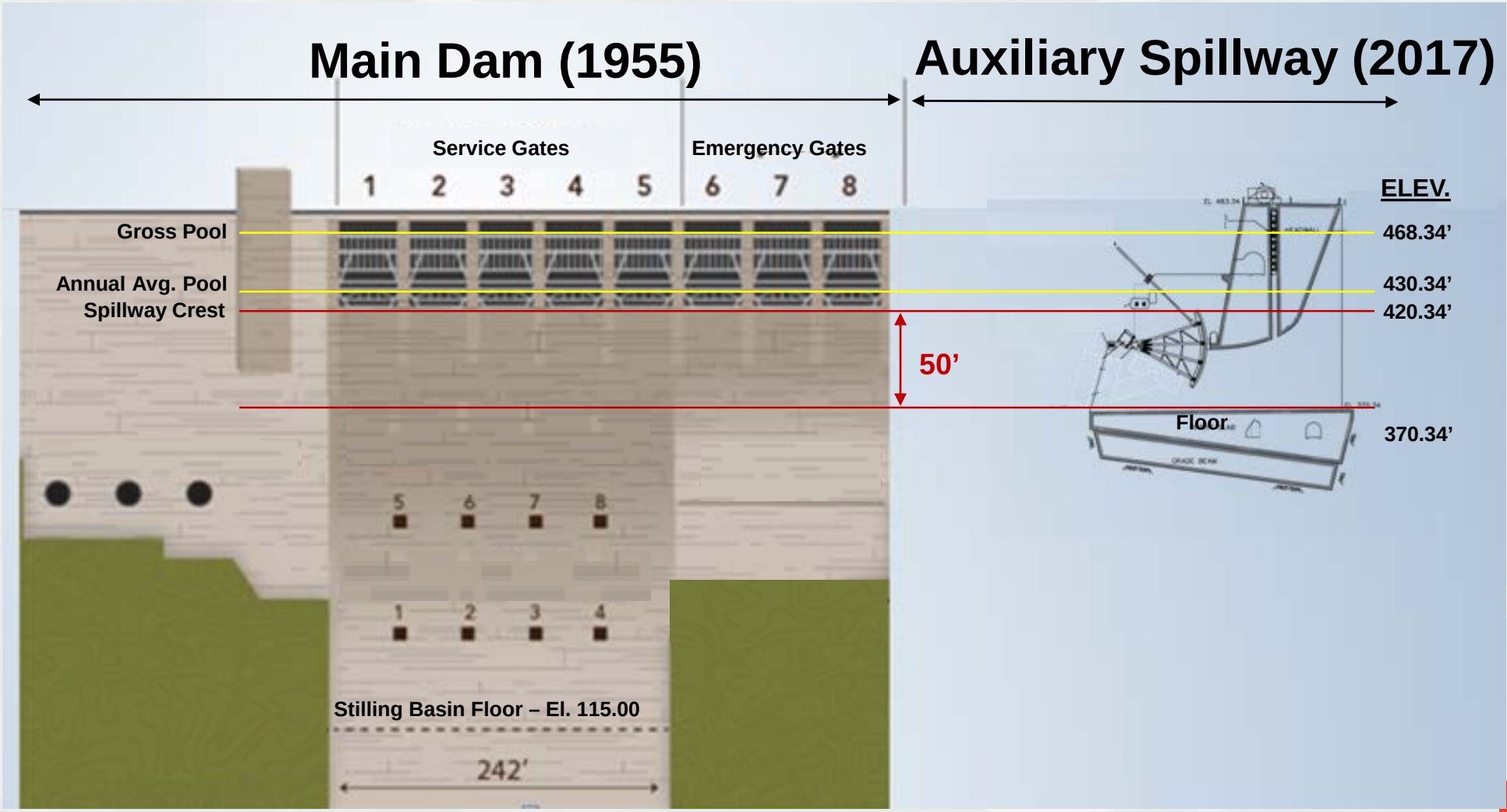
Main Dam and Auxiliary Spillway

06JUN16

- **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**

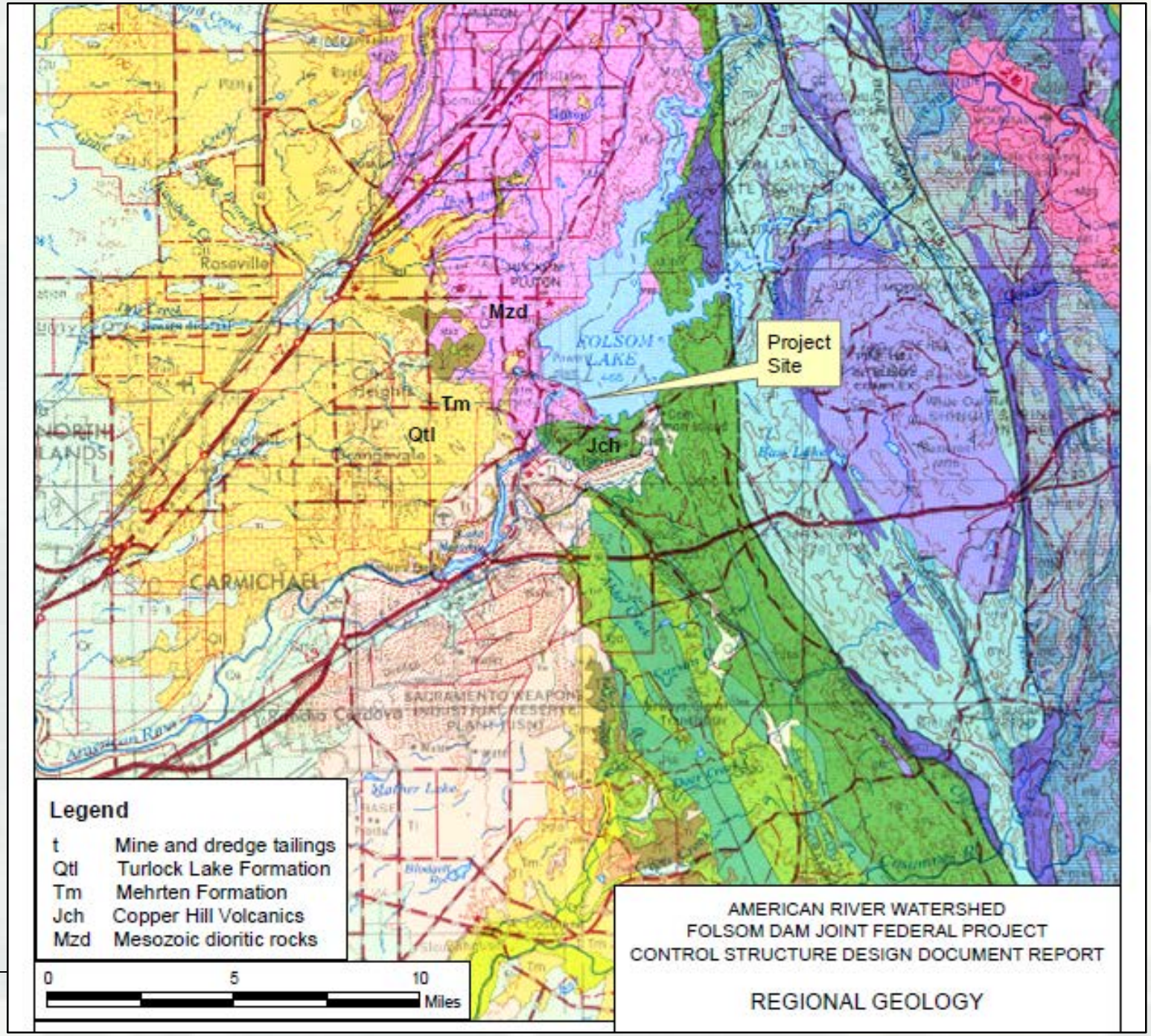


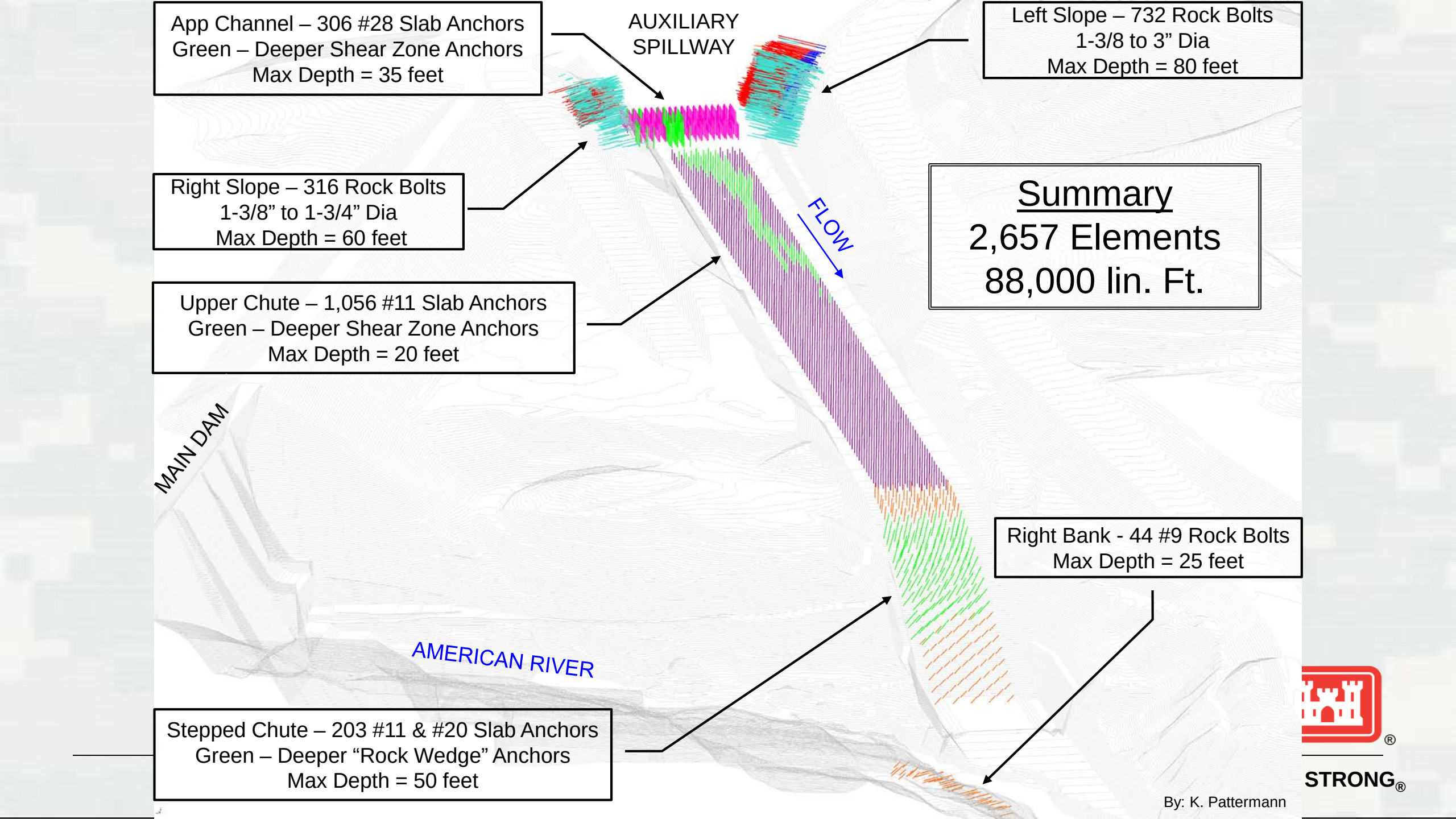
Main Dam and Auxiliary Spillway



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
AUXILIARY SPILLWAY
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
FLOW
Summary
2,657 Elements
88,000 lin. Ft.
Upper Chute – 1,056 #11 Slab Anchors
Green – Deeper Shear Zone Anchors
Max Depth = 20 feet
MAIN DAM
Right Bank - 44 #9 Rock Bolts
Max Depth = 25 feet
AMERICAN RIVER
Stepped Chute – 203 #11 & #20 Slab Anchors
Green – Deeper “Rock Wedge” Anchors
Max Depth = 50 feet
STRONG®
By: K. Pattermann

Rock Bolting Approach Channel – Left Slope

Aerial

Rock Bolting Approach Channel – Right Slope

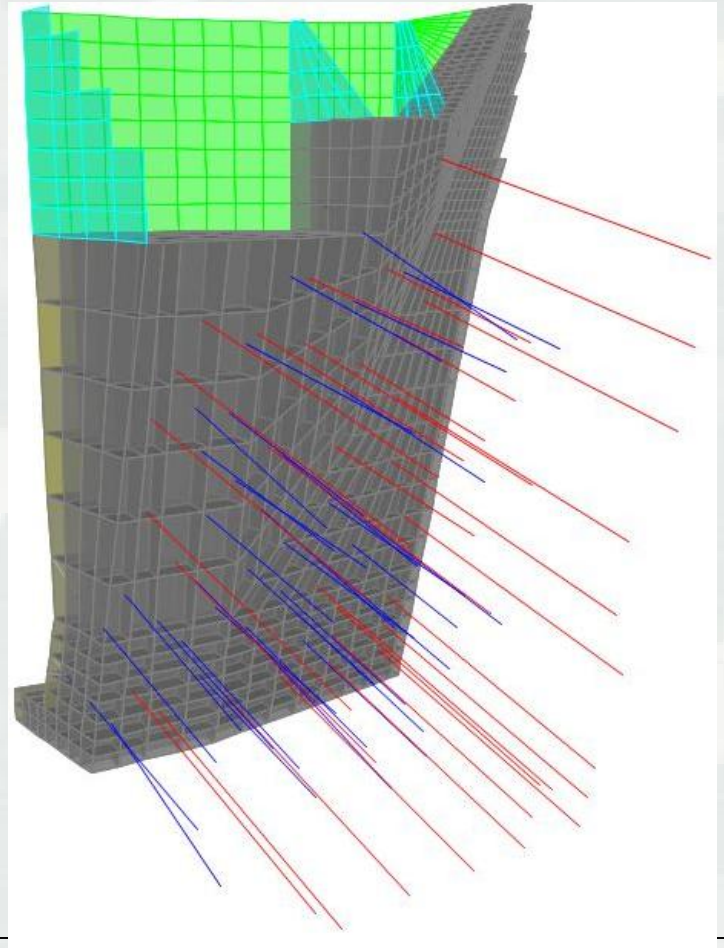
Aerial

Approach Channel Walls

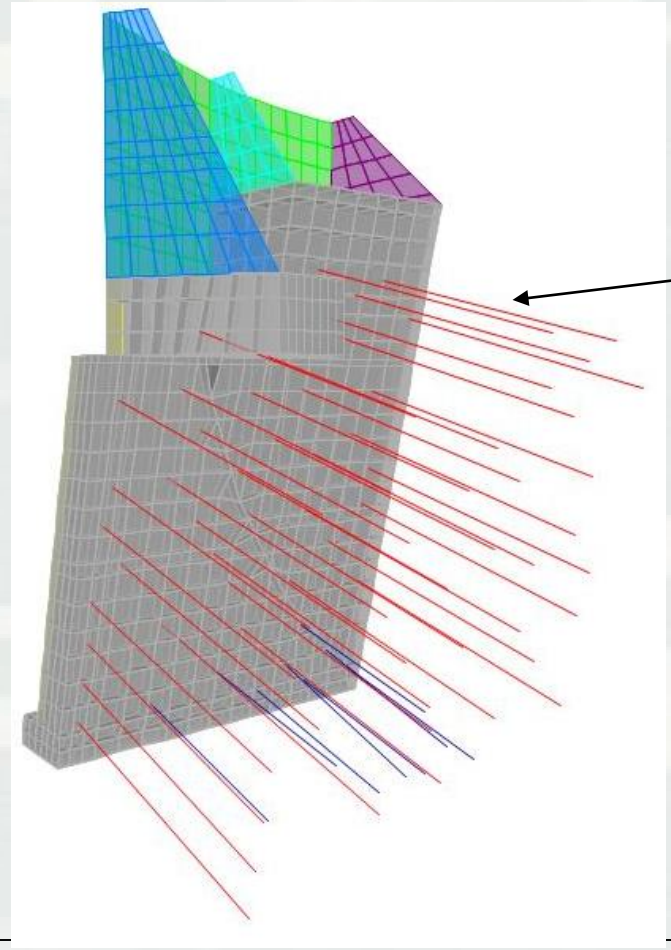
Analysis of lateral support

- SAP2000 3D Model

Left Wall



Right Wall



Rock Bolts

Design by
AECOM Oakland (URS)

Approach Channel Walls

Completed – just prior to first filling

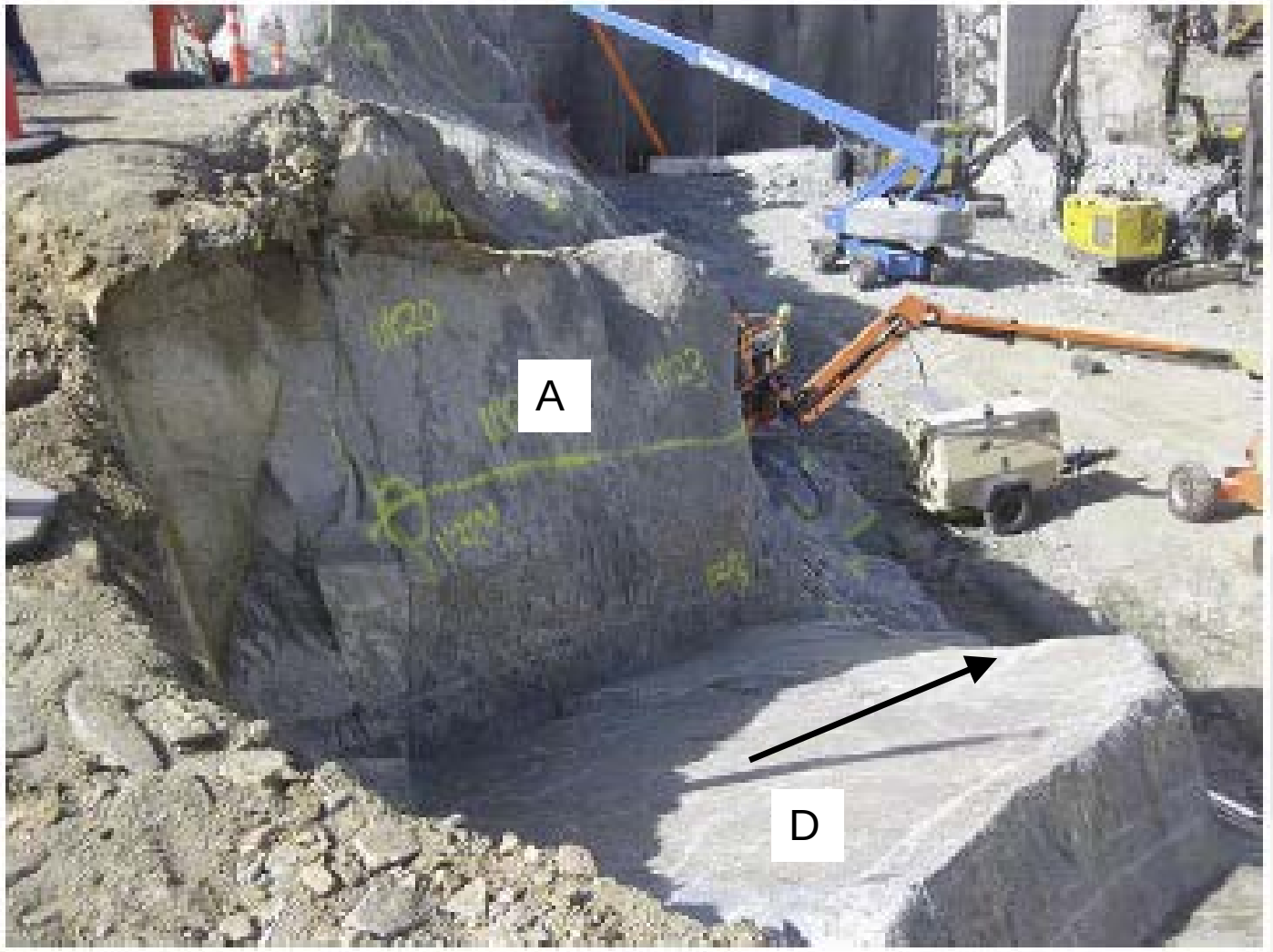
Rock Bolting in Approach Channel

Predominant Joint Sets

Table 3-4. Attitude of Predominant Joint Sets

Joint Set	Strike	Dip Direction (°)	Dip (°)	Fisher Dispersion Factor, K
A	N 25° W	65	69	18.4
B	N 87° E	177	74	31.9
C	S 45° W	315	81	117.5
D	S 45° W	315	27	17.3

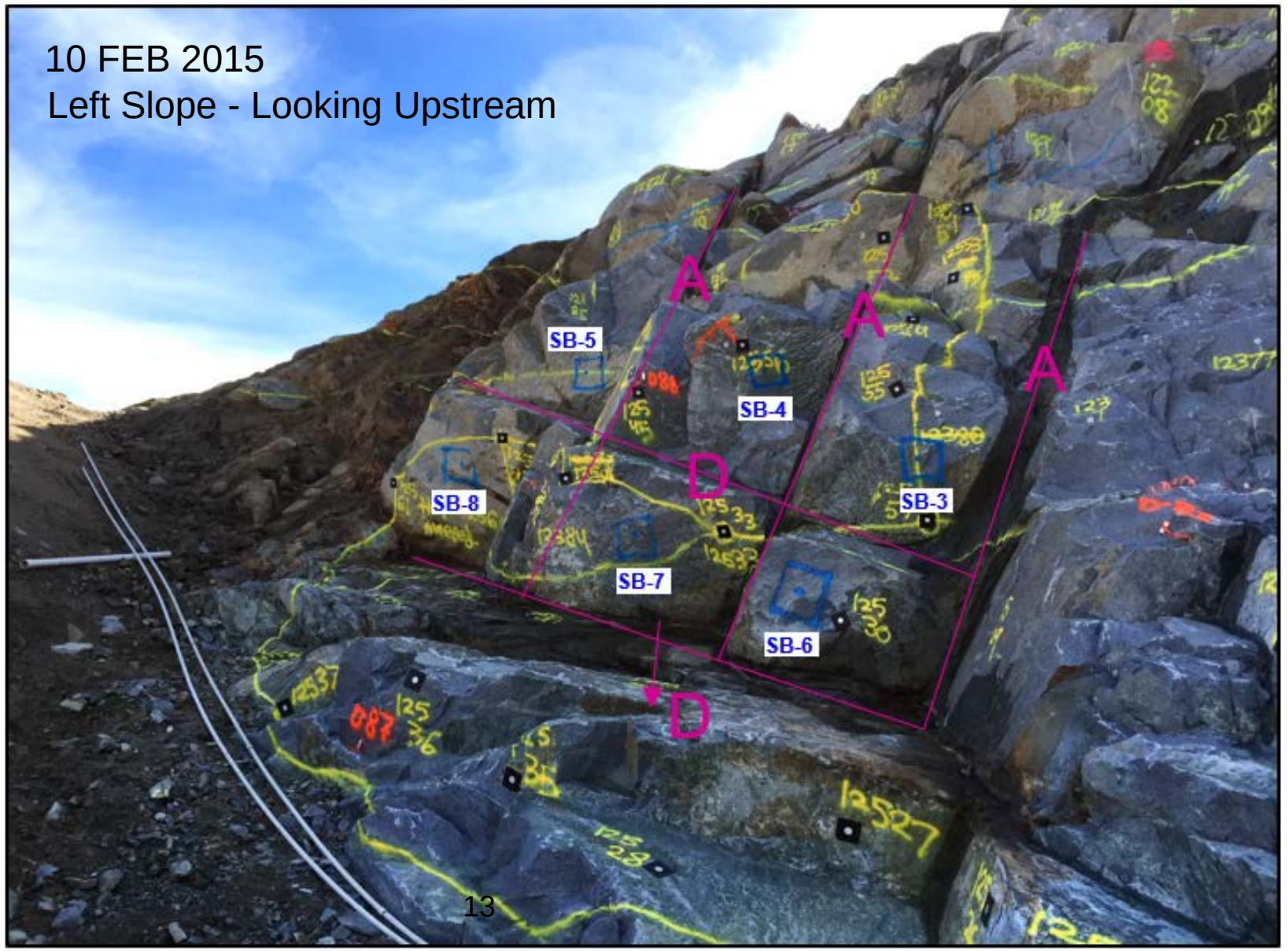
Approach Channel Design TM – Dec 2012



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



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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

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Rock Bolting in Approach Channel - Photos

Loading Jacks and stressing chair

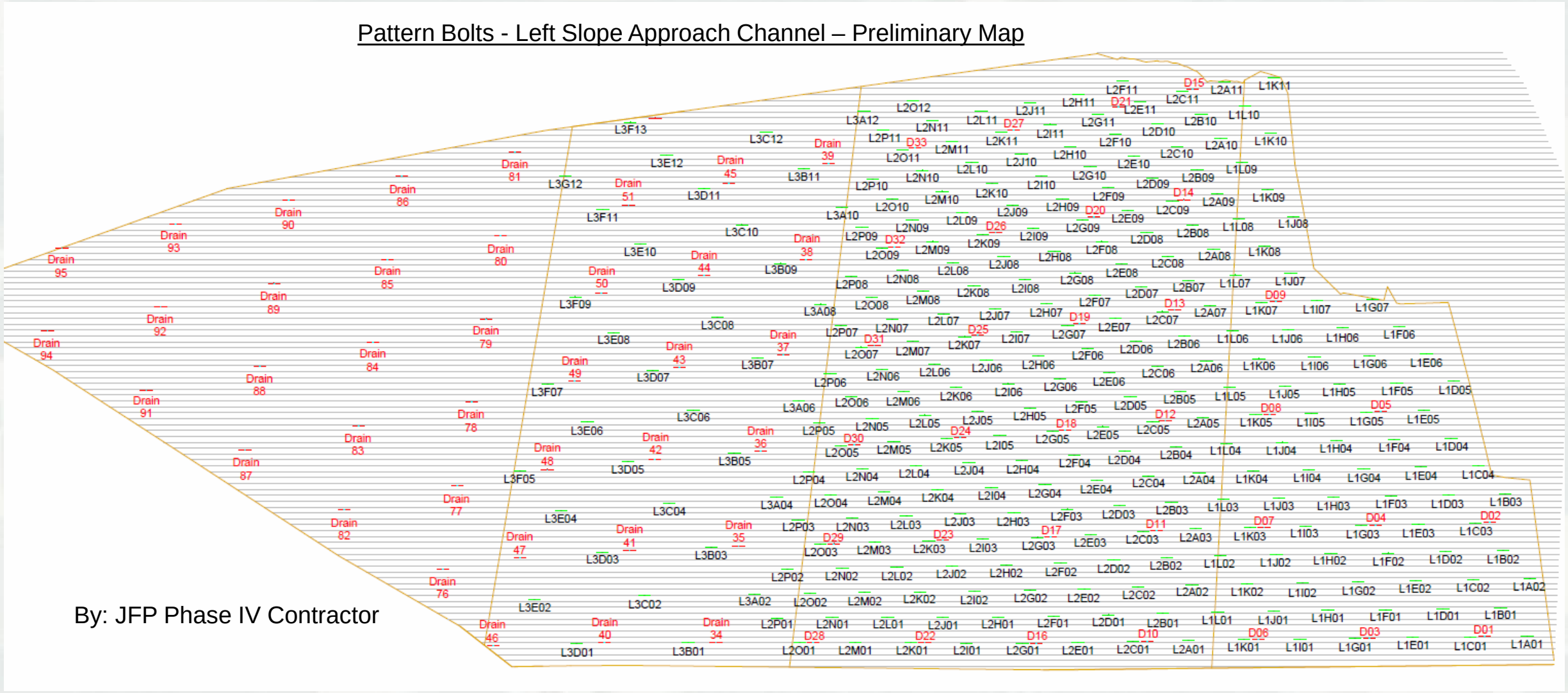
Sealing Coupling Sections – heat shrink sleeve

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)



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.

Developing Better Plans & Specs (cont.)

Bearing Pad (BP) Construction – very important consideration when locating bolts

Intricate plywood forming

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)

Developing Better Plans & Specs (cont.)

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

FAS Approach Channel Wall

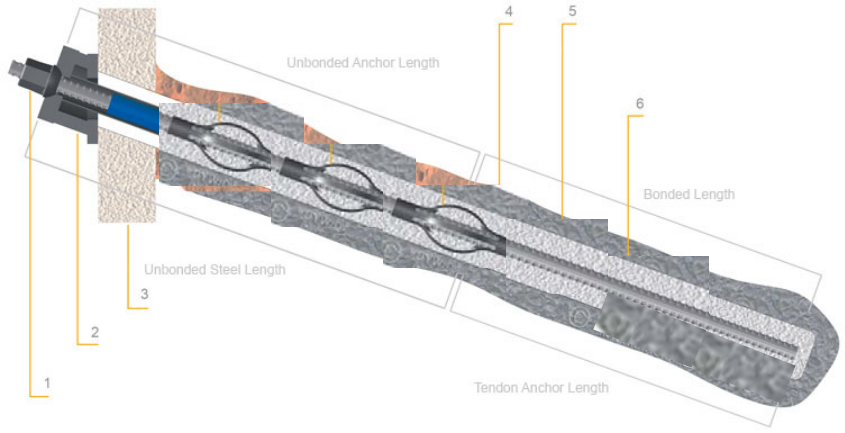
Folsom Right Bank Stabilization Project

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)

Developing Better Plans & Specs (cont.)

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.



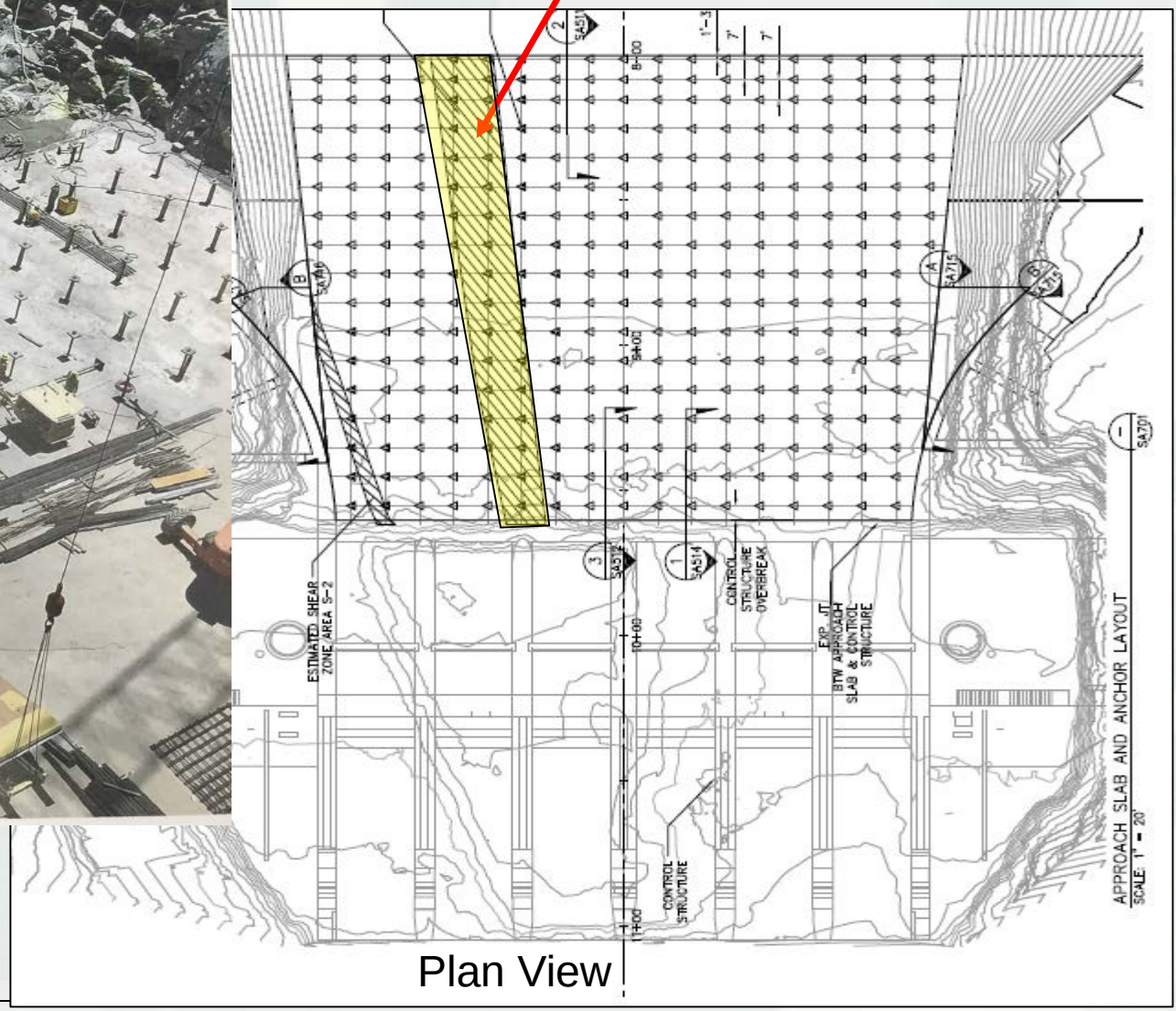
Don’t tie centralizer and grout tube together

Folsom

Slab Anchors Approach Channel

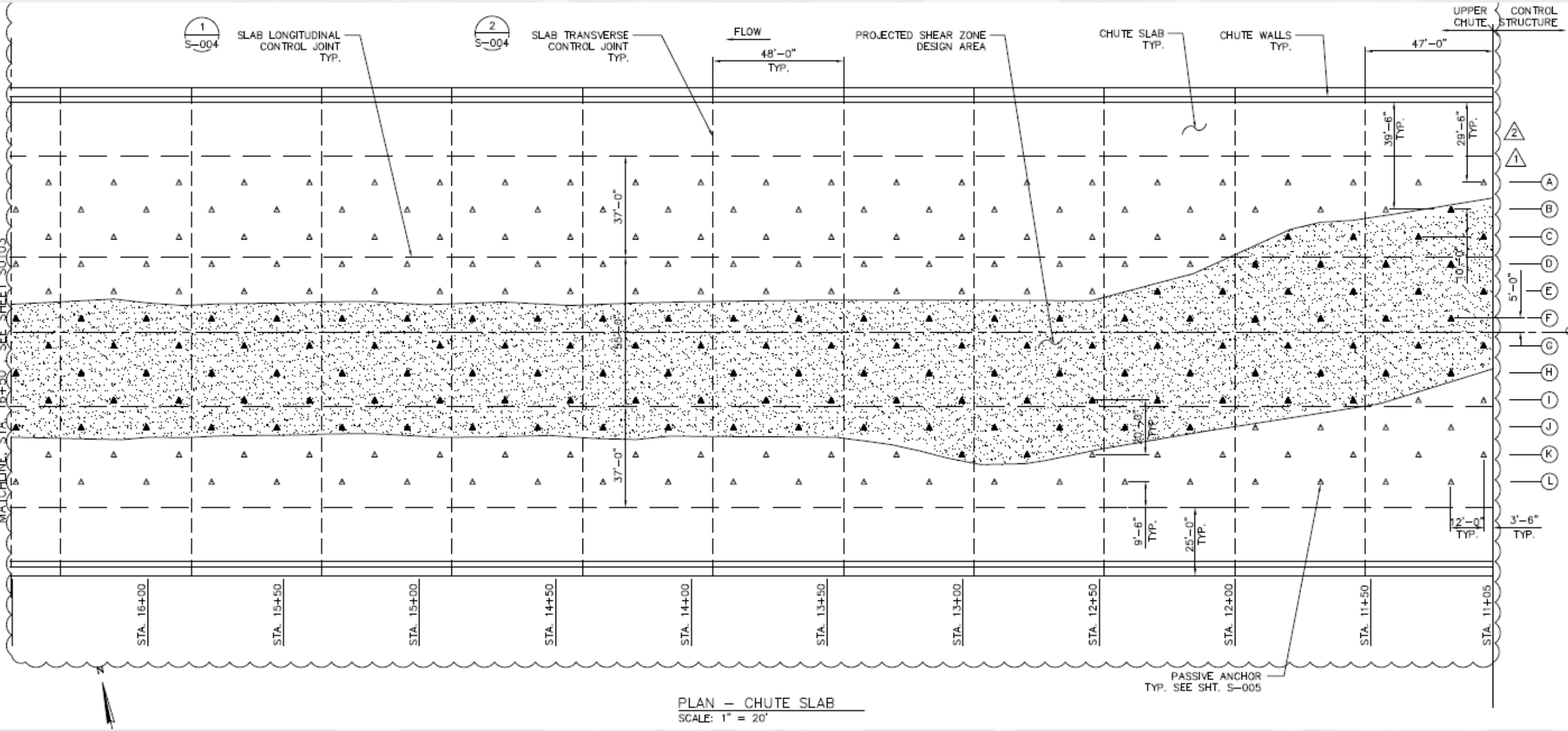
Actual Shear Zone Location shown in yellow

Design Shear Zone Locations

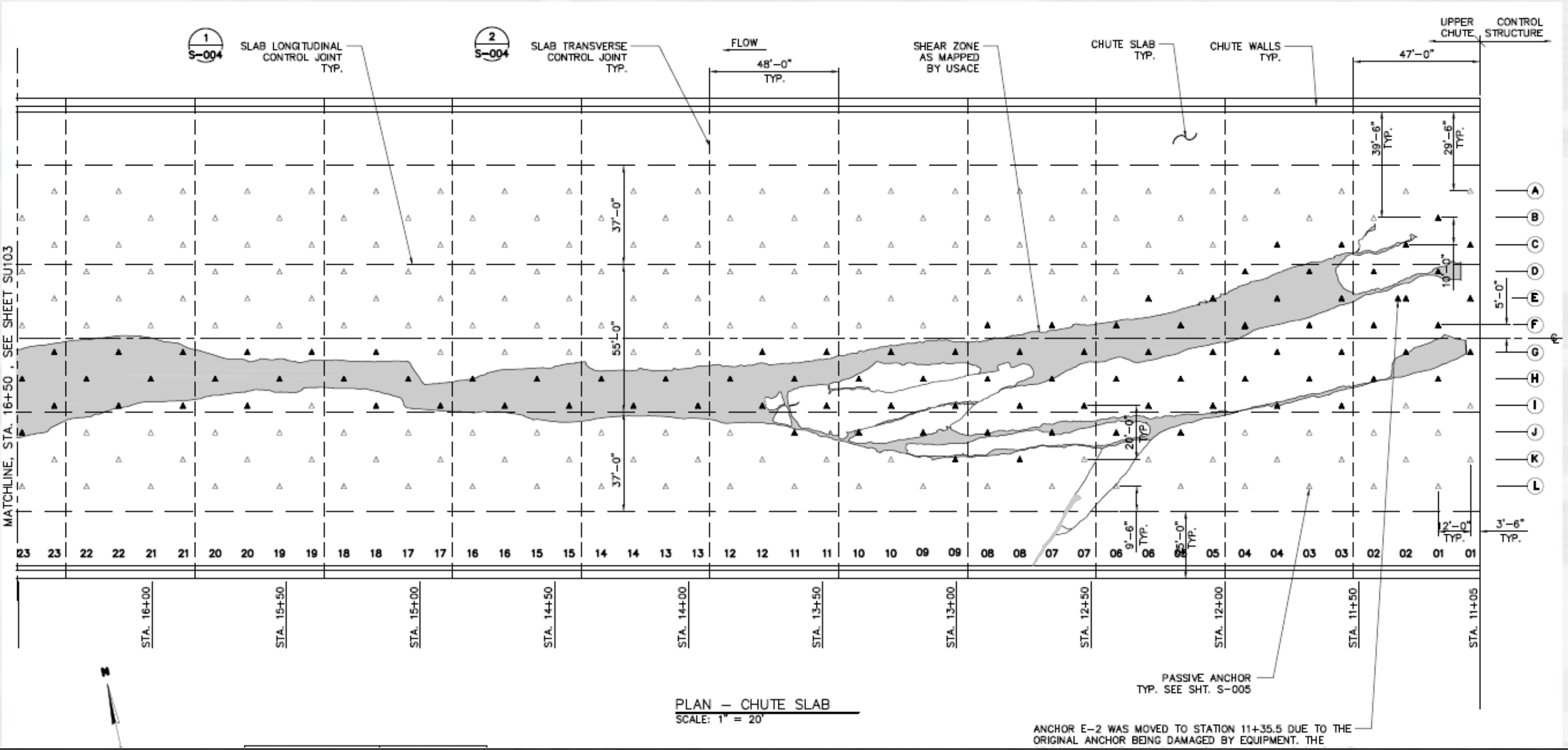


Plan View

Design Shear Zone Layout in Upper Chute



Actual Shear Zone Layout in Upper Chute



PLAN – CHUTE SLAB
SCALE: 1" = 20'

Slab Anchors in Approach Channel

Construction Photos

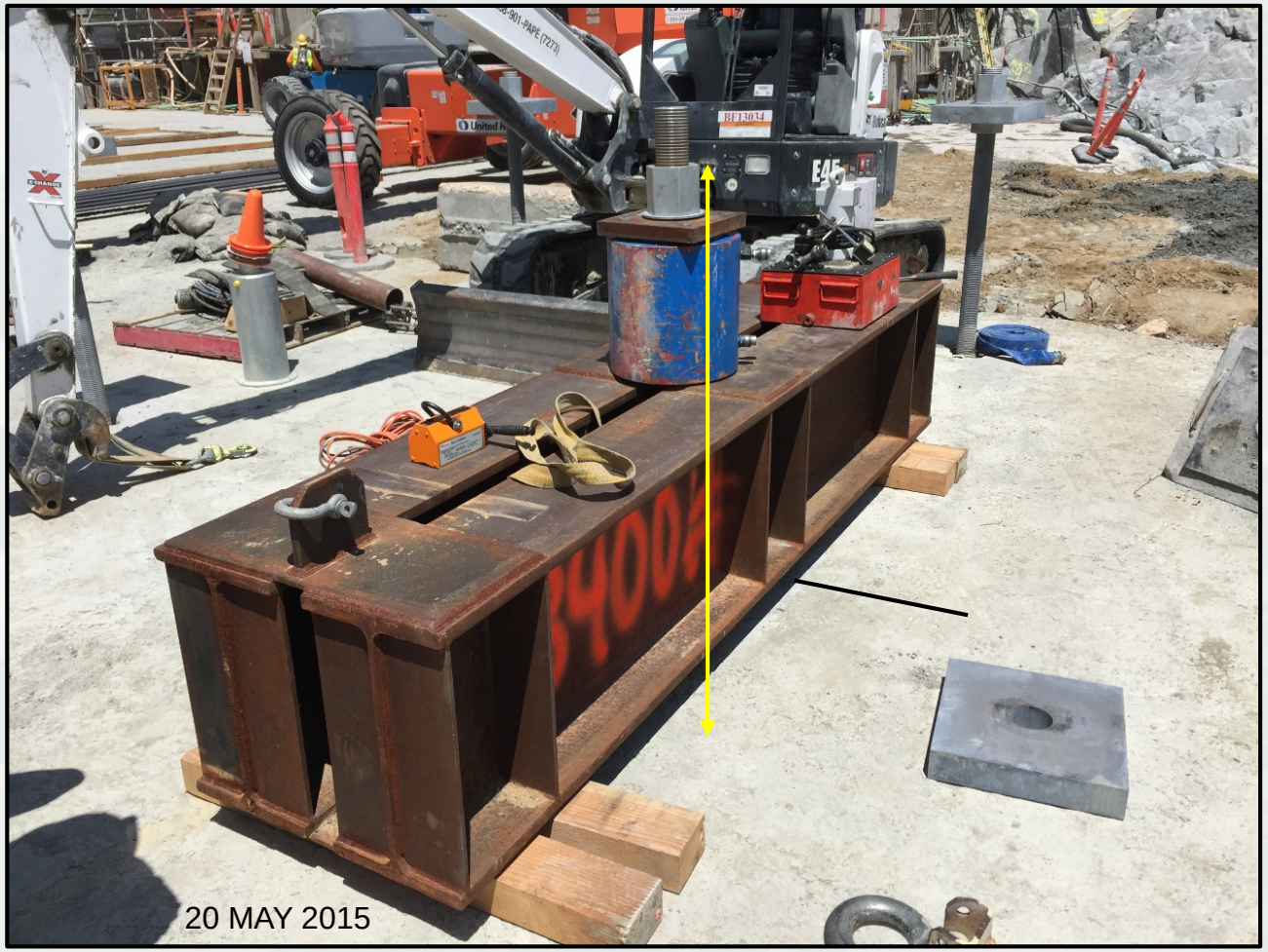
Prep

Prep

Installation

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!

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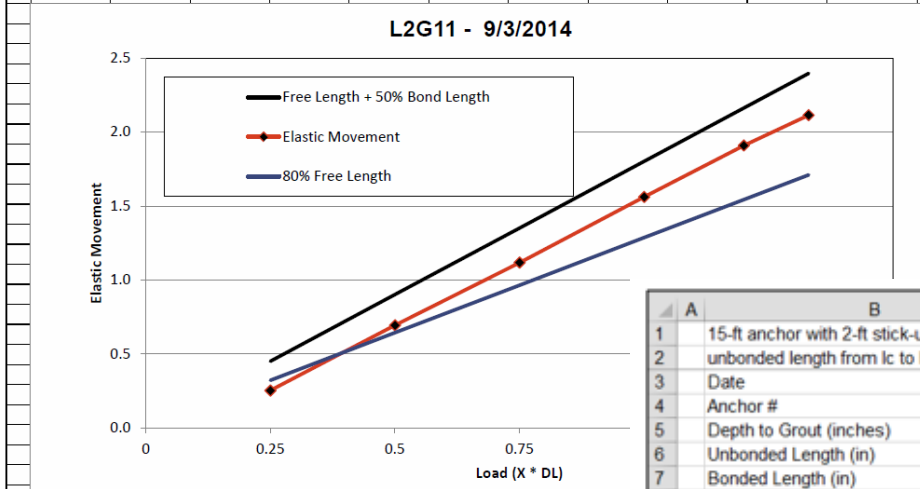
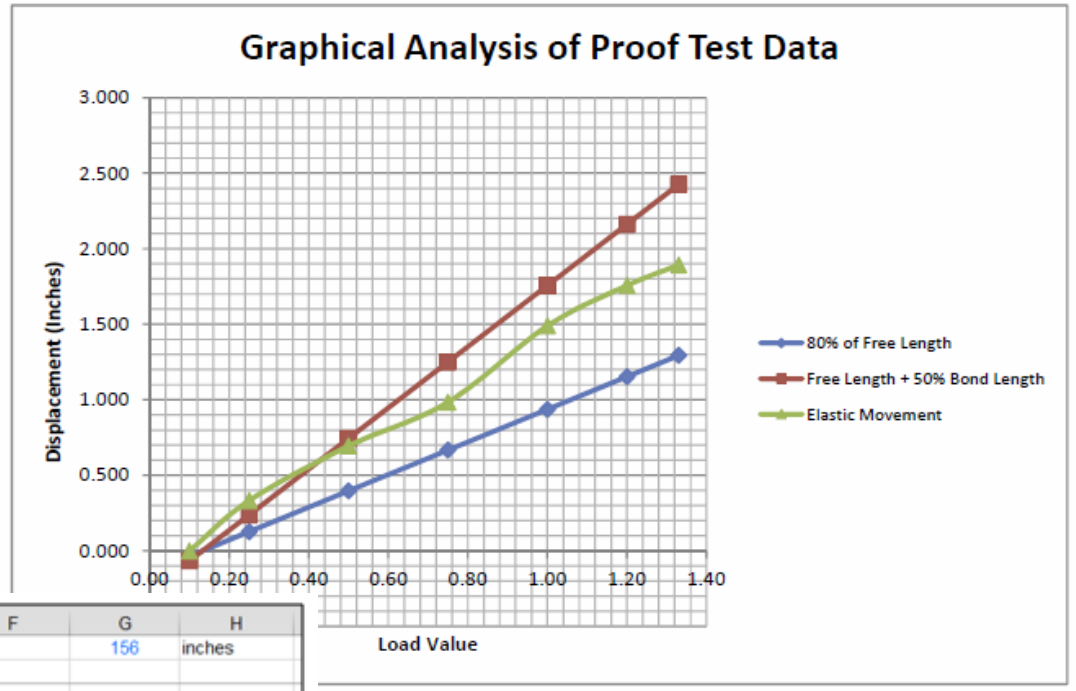
Developing Better Plans & Specs (Cont.)

USACE Performance Test Elongation Plot

L2G11	Inputs - Blue		Calcs - Red							
				Es	29000	psi	DL	110		
				Ab	1.58	in^2			80% FL	FL+50%BL
DL Inc	δe		Free Length (in)		744		DL Inc	kips	δe	δe
0.25	0.252		80% Free Length		595.2		0.25	27.5	0.322	0.450
0.5	0.693						0.5	55	0.643	0.901
0.75	1.117		Bond Length (in)		180		0.75	82.5	0.965	1.351
1	1.561		50% Bond Length		90		1	110	1.286	1.802
1.2	1.909						1.2	132	1.543	2.162
1.33	2.114		Free + 50% Bond Length (in)		834		1.33	146.3	1.710	2.397



			PERFORMANCE TEST	
Creep (10 min)	2.121	2.122	0.001	



Anchor: R1F05

Performance Test Plot: Subcontractor H & K

A	B	C	D	E	F	G	H
1	15-ft anchor with 2-ft stick-up (1.96 actual-Sheet 71) = 13 ft below leveling course (blc) =					156	inches
2	unbonded length from lc to hydraulic ram (jack) =		12	inches			
3	Date						
4	Anchor #	101-C-11	101-D-10	101-E-04	101-E-07	101-E-11	101-E-14
5	Depth to Grout (inches)	42	48	48	42	48	48
6	Unbonded Length (in)	54	60	60	54	60	60
7	Bonded Length (in)	114	108	108	114	108	108
8	DL Inc	Deflection Values					
9	0.25	0.020	0.008	0.012	0.001	0.005	0.017
10	0.5	0.037	0.028	0.028	0.014	0.029	0.038
11	0.75	0.057	0.069	0.049	0.041	0.062	0.065
12	1	0.075	0.074	0.064	0.062	0.092	0.089
13	1.2	0.091	0.094	0.082	0.077	0.118	0.108
14	1.33	0.100	0.107	0.085	0.089	0.135	0.12
15	AL (n/a = not available)	0.013	0.04	0.017	0.013	n/a	n/a
16	AL note (0.25*DL is too high)						
17	Errors in spreadsheet for bonded and unbonded lengths?	N	N	N	N	N	N
18							
19	Checks						
20	80% * FL at 1.33 * DL	0.067	0.075	0.075	0.067	0.075	0.075
21	Is Deflection > 80%*FL at 1.33 DL?	OK	OK	OK	OK	OK	OK
22							
23	FL + 50% BL at 1.33 * DL	0.173	0.178	0.178	0.173	0.178	0.178
24	Is Deflection < FL + 50%*BL at 1.33 DL?	OK	OK	OK	OK	OK	OK

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, <u>short-length (6 to 8 ft) bolts</u> have been specified.

→ 7.1.2 The <u>hole need not be as deep as the proposed length</u> of the rock bolts.

→ 7.4.7 <u>Failure is the peak load</u> sustained by the bolt, or a total deflection of 0.5 in.

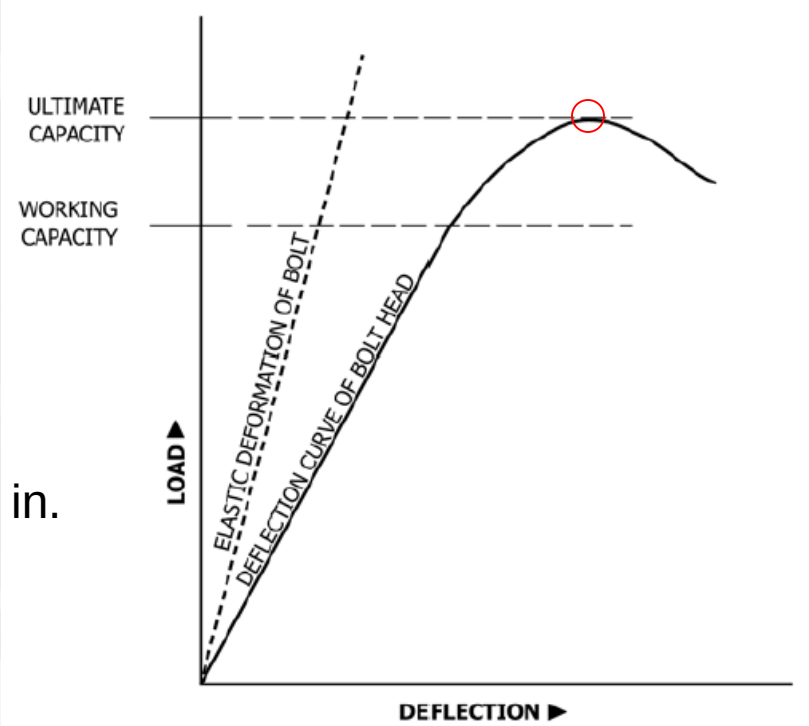


FIG. 3 Typical Load versus Deflection Curve for Rock Bolt Pull Test

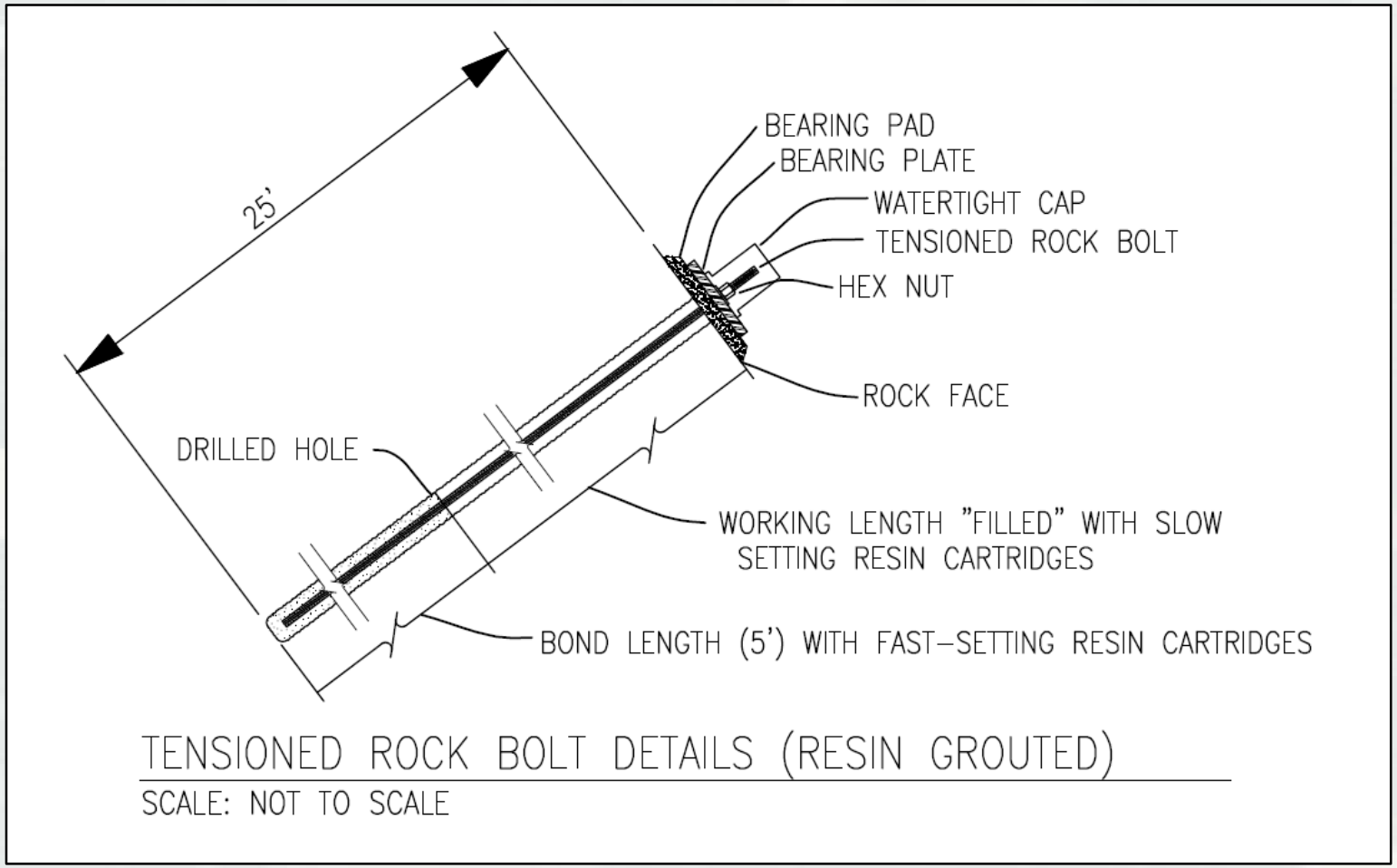
- Contractors won't go to failure (safety). Typically use 90% of yield (GR75) or 80% of ultimate (GR150), which is typically still greater than max test load.

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

RBS Project - Resin Grout Pump vs. Resin Grout Cartridges

- RESIN CARTRIDGE (SMALL BOREHOLE DIAMETERS)



RBS Project - Resin Grout Pump

- RESIN PUMP

JENNCHEM offers pumping equipment and technical support.

Our goals are:

- Quickly access 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.

TDS-240 (or Top Down Silicate 240) is a two component urea silicate grout that comprises a silicate and a modified polyisocyanate 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.

TYPICAL CHEMICAL ANALYSIS	PART A (ISOCYANATE)	PART B (SILICATE)
Viscosity @74°F, ASTM D-1638	400 cps	285 cps
Physical State	Liquid	Liquid
Color	Amber	Slightly yellow
Specific Gravity	1.17	1.51
Hygroscopicity	Reacts with water and evolves CO2 gas	Contains water

MATERIAL METERING RATIOS	PART A (ISOCYANATE)	PART B SILICATE
Parts by volume	50 parts	50 parts
Parts by weight	40 parts	50 parts

REACTION PROFILE	(100 GRAMS, 74°F)
Gel Time	4 – 6 minutes

TYPICAL PHYSICAL PROPERTIES	RESULTS
Nominal Compressive Strength, 24 hour age	4100 psi

Phenmatic one-to-one ratio pump.

Right Bank Stabilization Project - Basket for Access -

20 NOV 2017

BUILDING STRONG®

RBS Project - COMPLETION

Looking Downstream

Looking Upstream

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

Folsom Dam
Auxiliary Spillway

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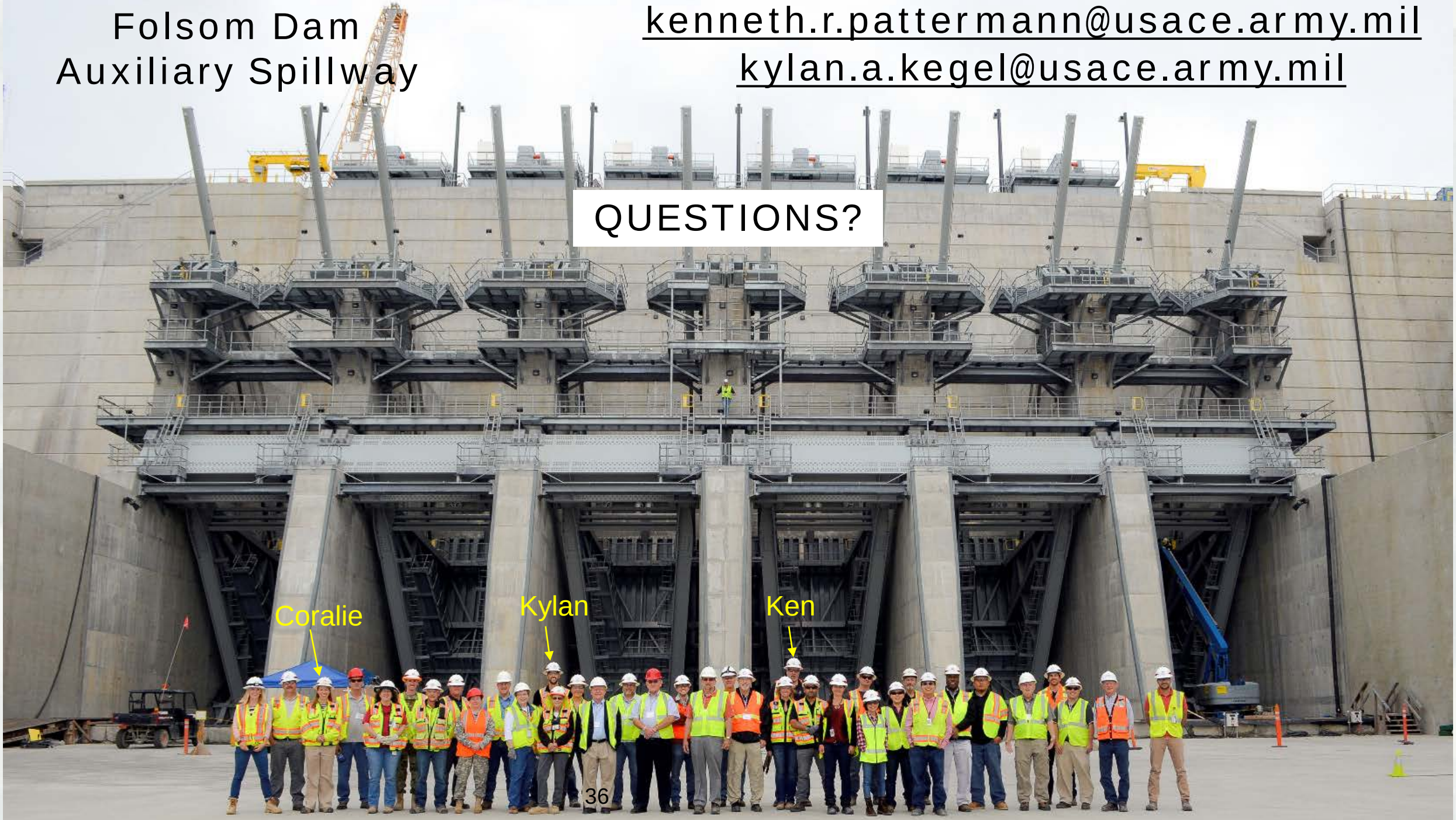
kylan.a.kegel@usace.army.mil

QUESTIONS?