Seepage Control Upgrade for Ruskin Dam Right Abutment

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Vancouver Geotechnical Society
21 October 2015

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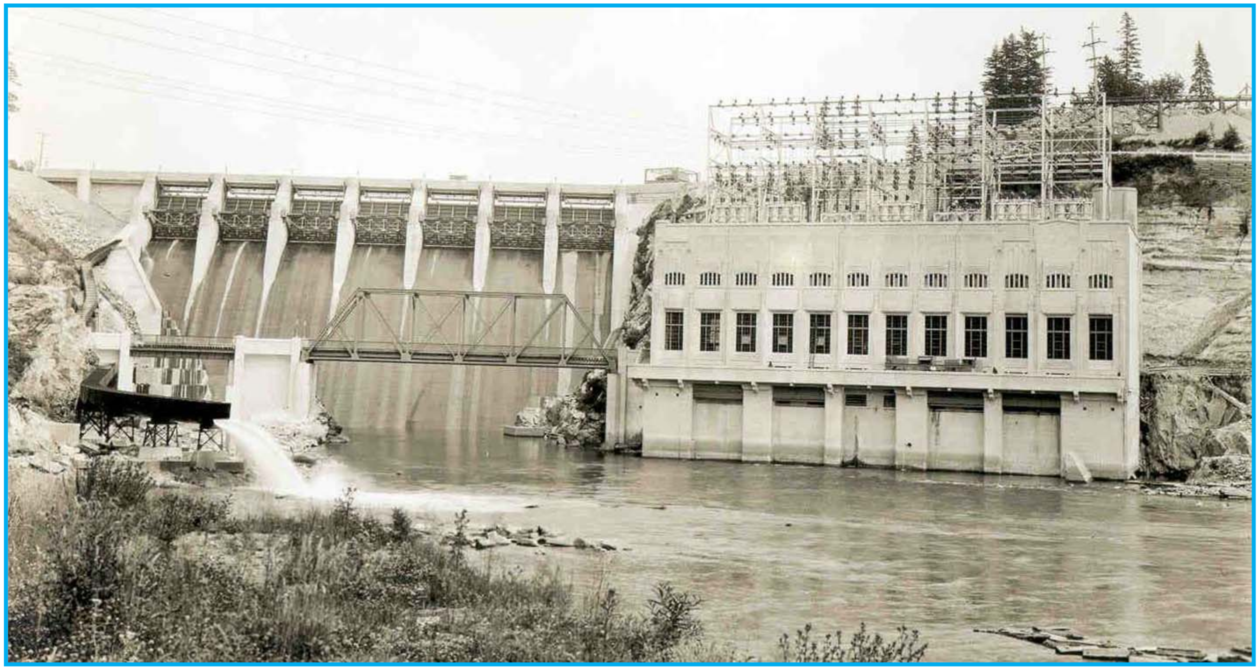
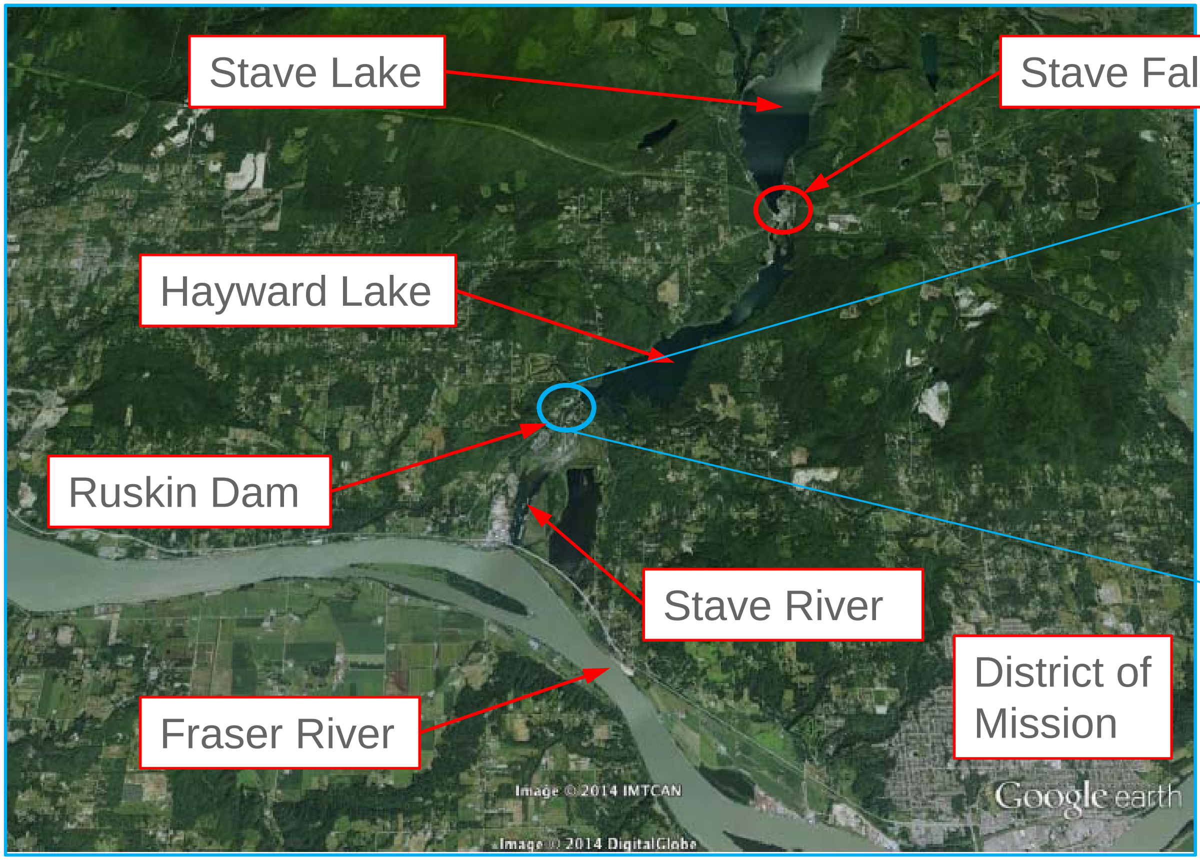
Presentation Outline

1. Description of the site
2. Dam safety issues
3. Design and analysis
4. Early contractor involvement
5. Construction



Project Location



- Located in southwest British Columbia, Canada
- Ruskin Dam is about 50 km east of Vancouver
- Dam impounds Hayward Lake

General Arrangement

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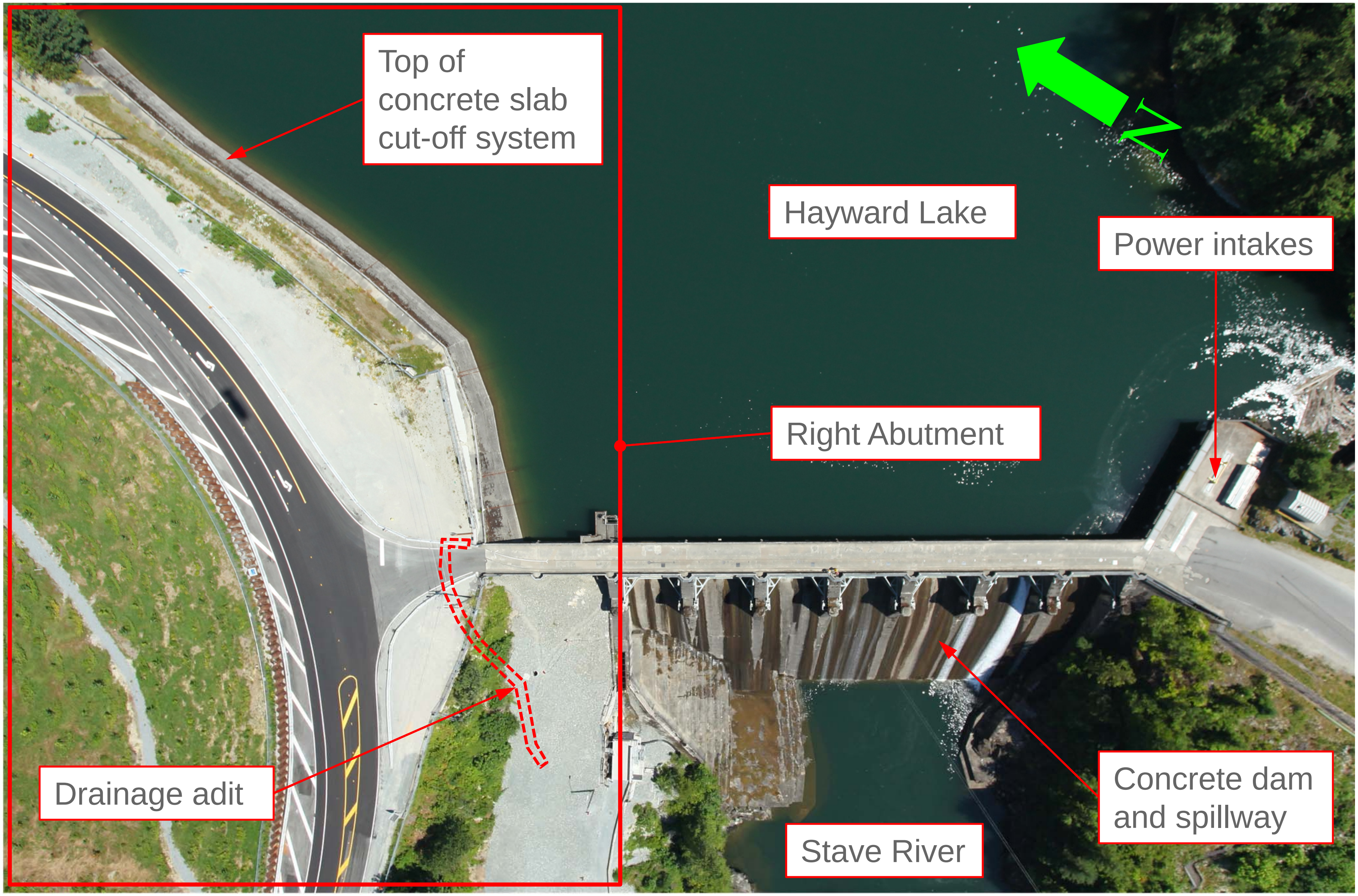

Ruskin Dam and Generating Station

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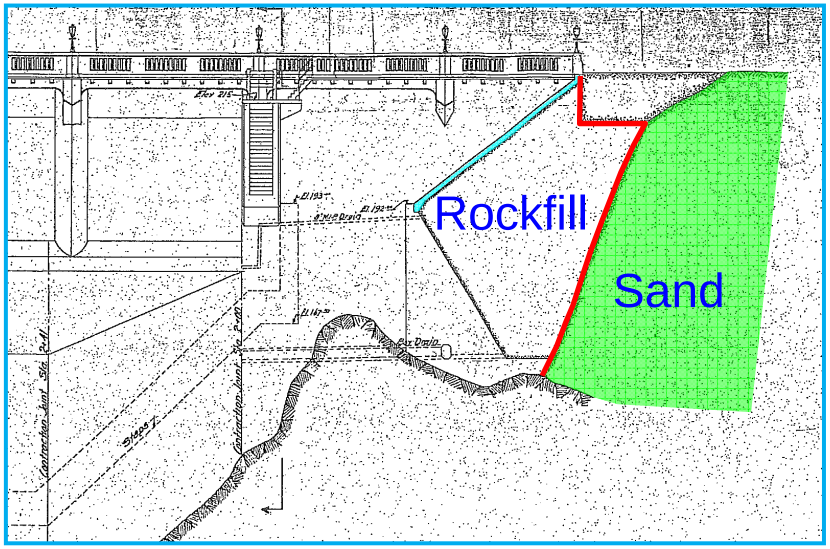

- Dam and generating station constructed between 1929-1931
- Generating station nameplate capacity is 105.6 MW
- Concrete dam is 113 m long and 59 m high concrete gravity structure founded predominantly on bedrock
- Sloping concrete slab cut-off wall system extends upstream of the dam on the right abutment

Ground Settlement Beneath Slabs

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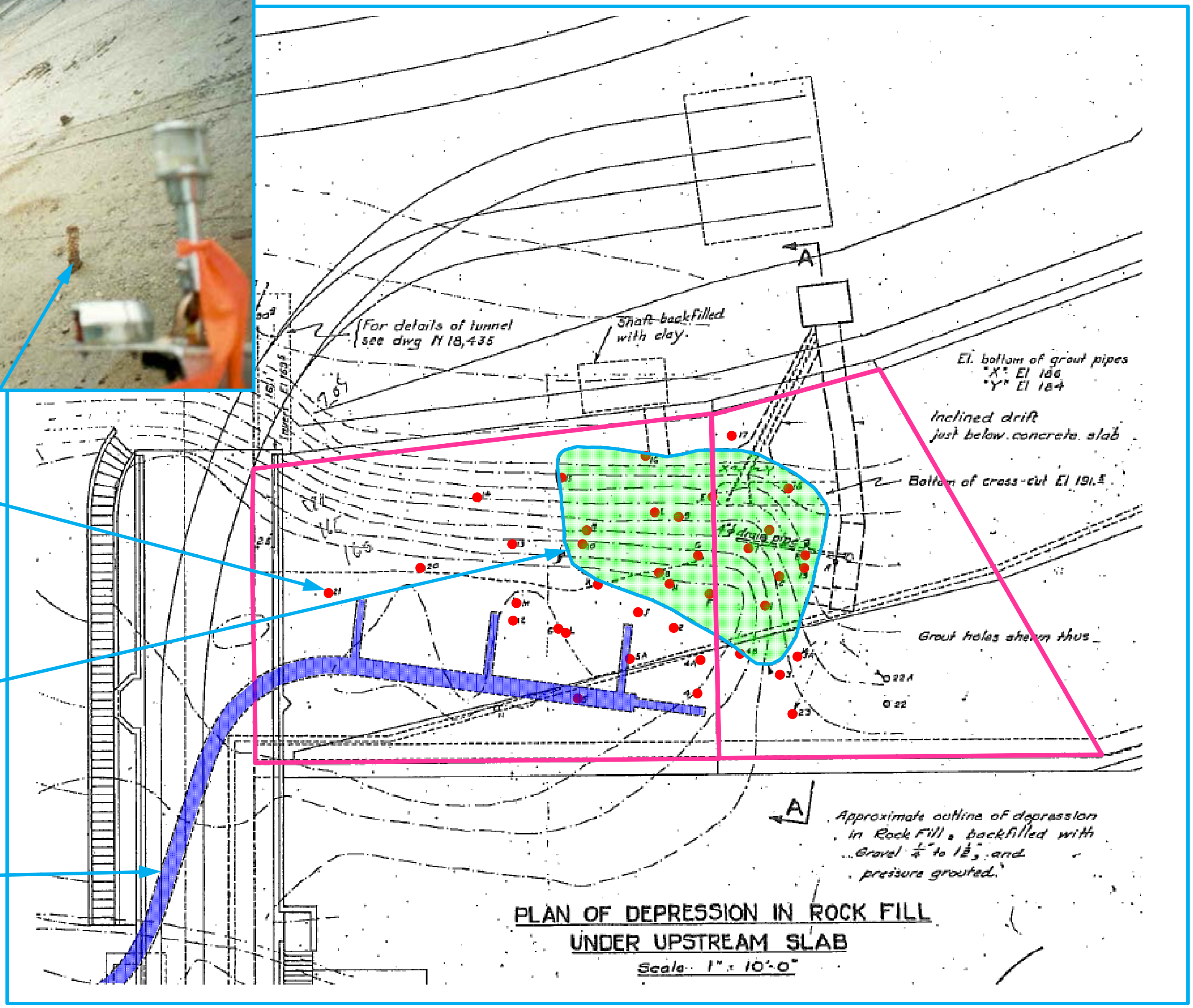

Grout holes

Outline of depression in rockfill

Gallery drain

Dam Safety Issues at Right Abutment

Normal Operation

- Piping of fine sands into the gallery drain and drainage adit
- Collapse/settlement behind the concrete slab
- Cracking in the slab caused by settlement
- Sinkholes and depressions – upstream and downstream of the dam

Seismic

- Right abutment seepage control concrete slabs do not meet the current seismic design requirements

Deficiency Investigations and Site Characterization

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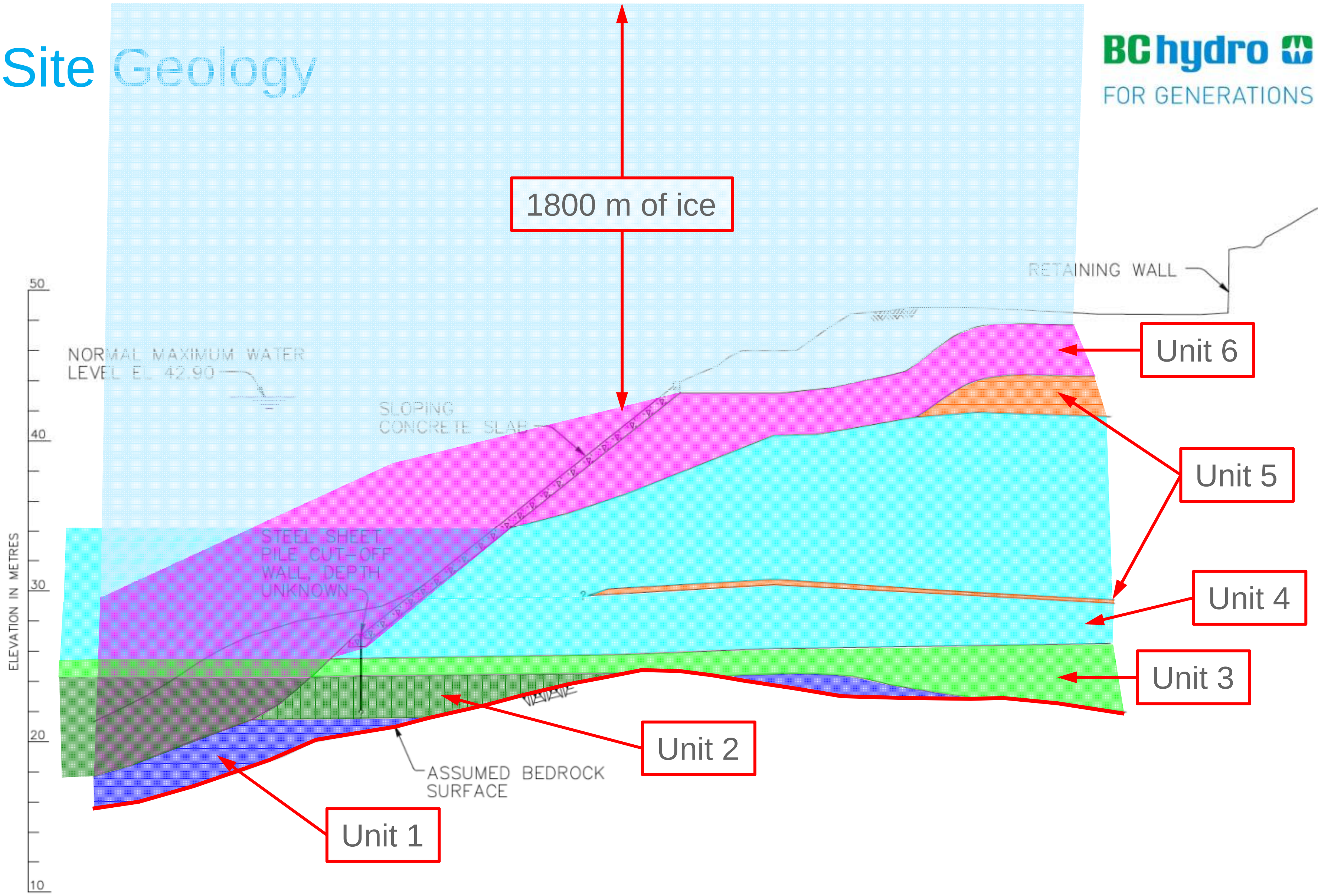
- Site investigations
- Geologic model
- Determine engineering parameters
- Characterize locations of loosened sand

- Becker drilling
- Mud rotary drilling
- Diamond drilling, sonic drilling
- Standard penetration testing (SPT)
- Cone penetration testing (CPT)
- Cross-hole and down-hole shear wave velocity measurements
- Non-intrusive geophysical measurements
- Pressuremeter testing

Site Geology



Site Geology – Quadra Sands

- Pro-glacial (outwash) deposited during the Fraser Glaciation
- Very dense (many $(N_1)_{60}$ > 100 blows/ft)
- Thickness of 15 to 20 m below dam
- Susceptible to seepage-caused erosion and piping

Quadra Sand

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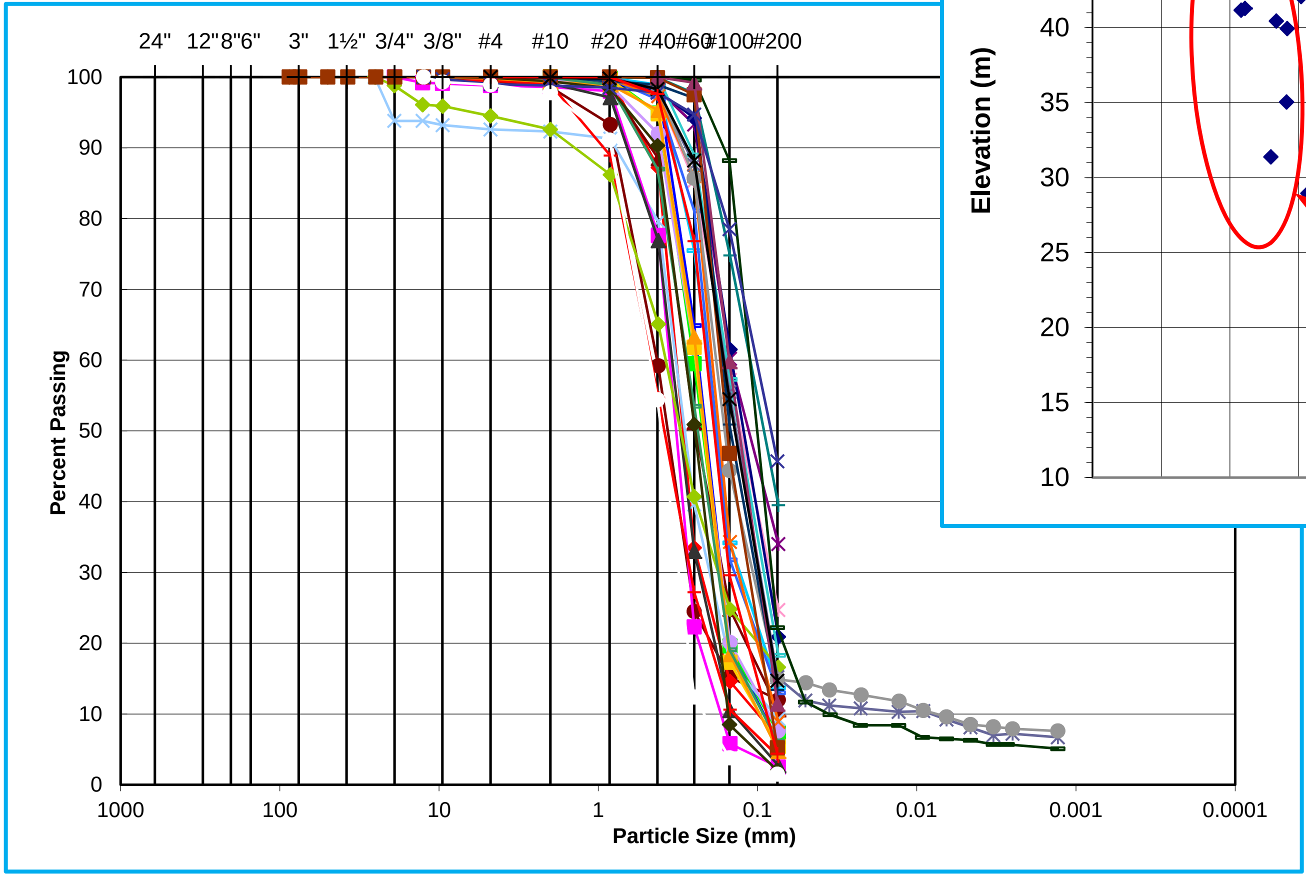

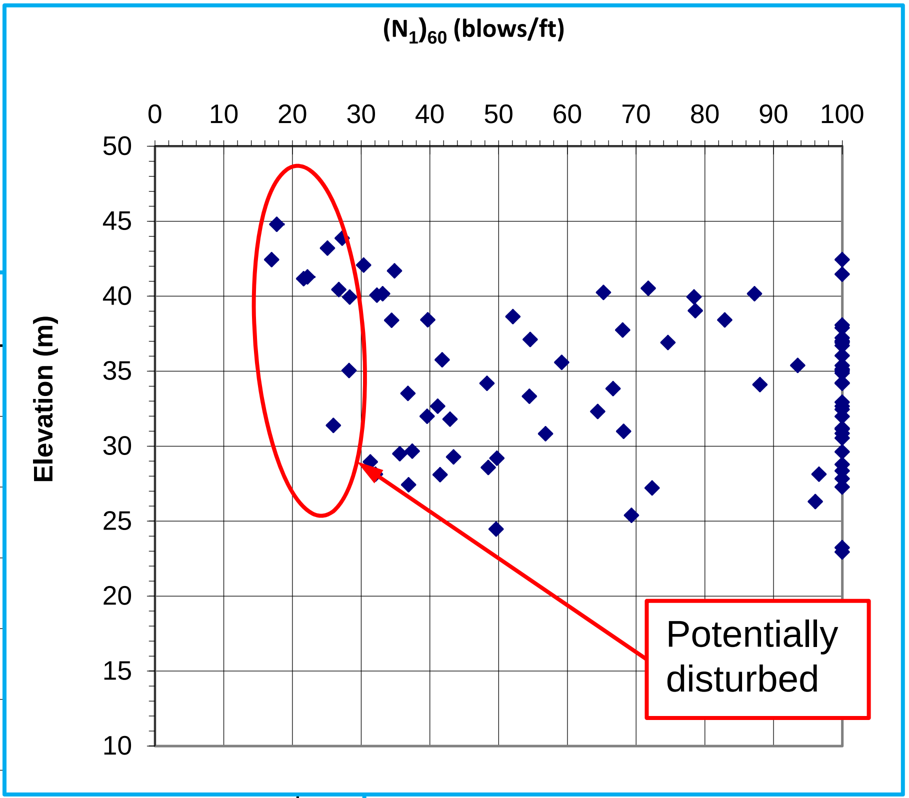

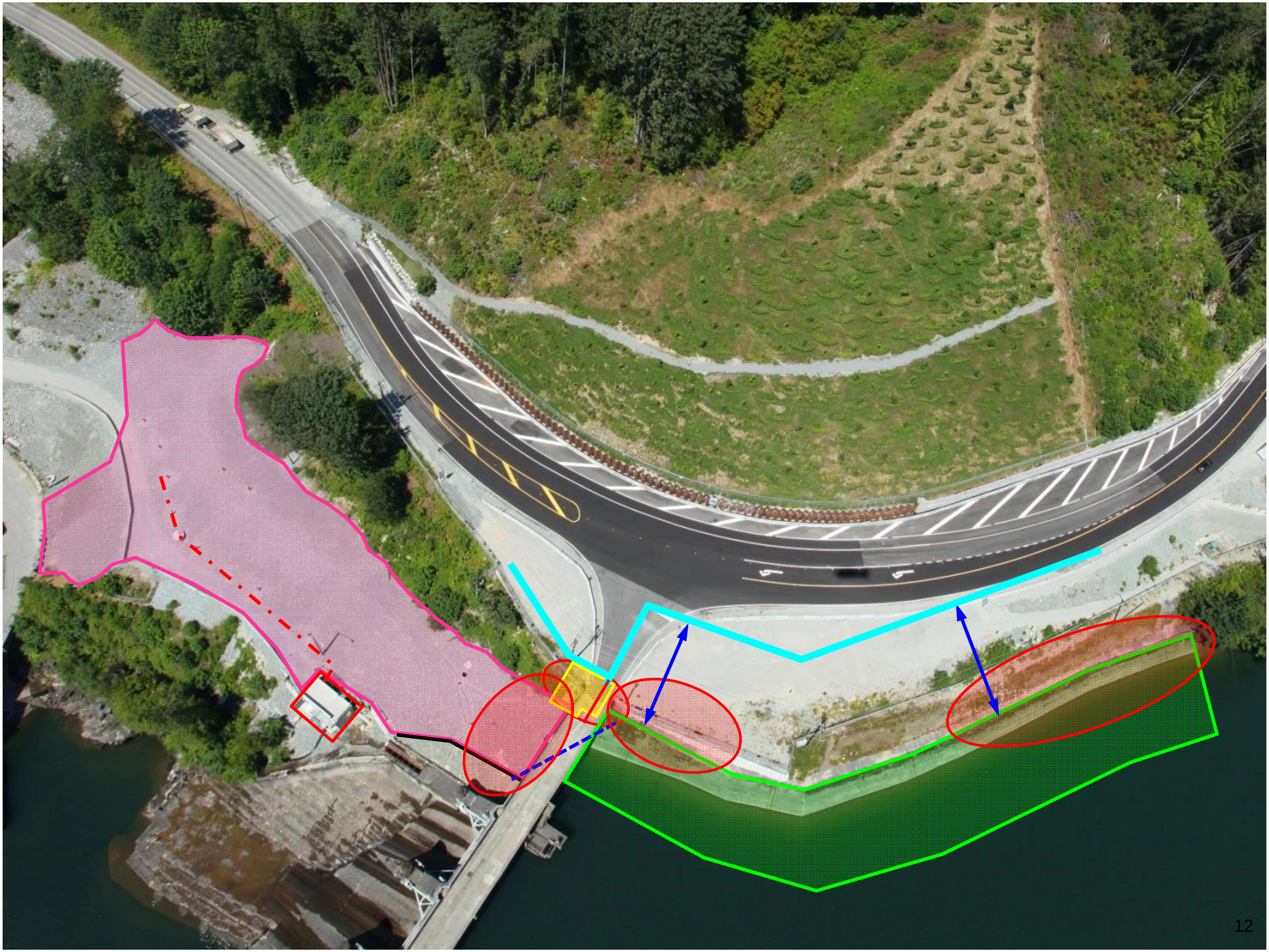

Key Design Considerations

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- Build new seepage cut-off system to withstand MDE
- Need to cut-off the different soil units in the abutment
- Key cut-off into bedrock
- Set-back distance from the edge of the slope
- Dimension and material of cut-off wall (length and width)
- Connection of cut-off system to concrete dam
- Dam safety risks during construction (disturbed ground and reservoir operation)

Seismic Design Basis

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Ruskin is “Extreme” Consequence Dam

- MDE from PSHA = M7.5, PGA = 0.71 g with a mean AEF of 1/10,000 – can accept damage, but no uncontrolled release of reservoir
- Consider aftershock of the MDE; M6.5 occurring at the same distance as the main shock
- Also check OBE from PSHA, PGA of 0.26 g corresponding to a mean AEF of 1/475 – no damage, able to maintain normal operation

Seismic Design and Performance Criteria

Upstream Cut-off Wall (slurry panel)

- Seepage barrier without existing concrete slabs
- Flexible to accommodate possible seismic ground movements near right abutment slope
- Sufficient length to control the hydraulic gradients to be less than the current values
- Post MDE damage (or cracking) is acceptable, provided any areas of localized shear is less than 50% of the wall width, and post earthquake heads not exceed the top of D/S training wall and filter blanket, and flows not exceed the capacity of the filter blanket and drainage system

Seismic Design and Performance Criteria

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Cut-off Tie-in to Concrete Dam

- shall be a flexible structure, capable of accommodating ground deformations, and concentrated lateral displacements of a minimum of 50 mm without cracking under the MDE loading
- shall be robust, with multiple lines of defense
- shall form an integral connection to the upstream cutoff wall and concrete dam such that a continuous, watertight barrier is formed, and shall be keyed into bedrock to form a watertight barrier.

Seismic Design and Performance Criteria

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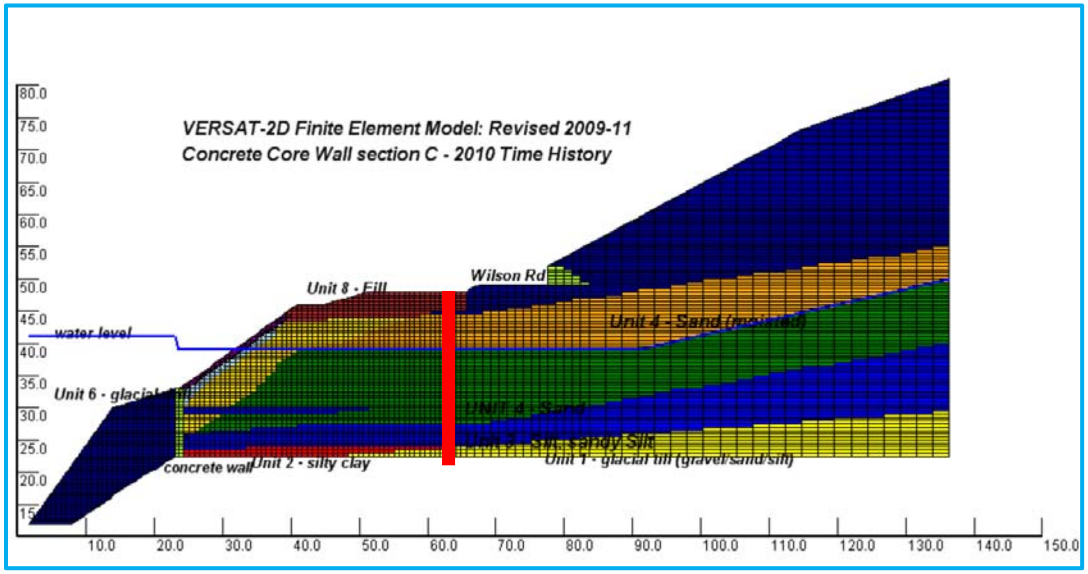
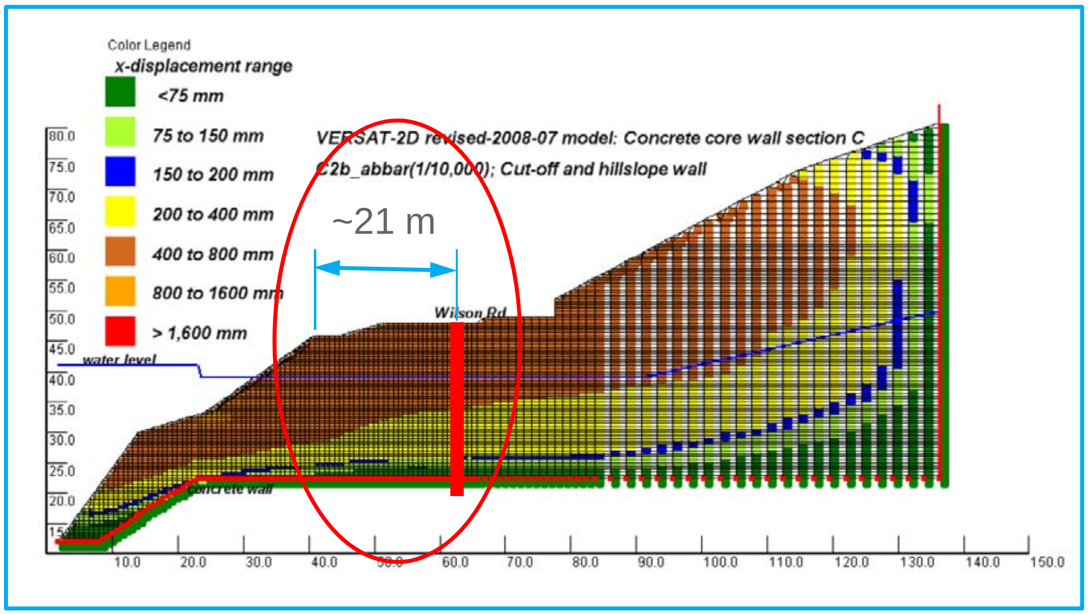
Downstream Seepage Training Wall

- Connected to U/S cut-off wall to form a barrier to keep the D/S slope of the concrete dam from becoming saturated during both normal operation and post earthquake
- Has to be flexible to accommodate possible seismic ground movements near right abutment slope
- Sufficient length to divert any seepage from hillslope and/or reservoir to D/S filter blanket to keep the area dry

Deformation Modeling of Cut-off Wall





FLAC Check – Displacement

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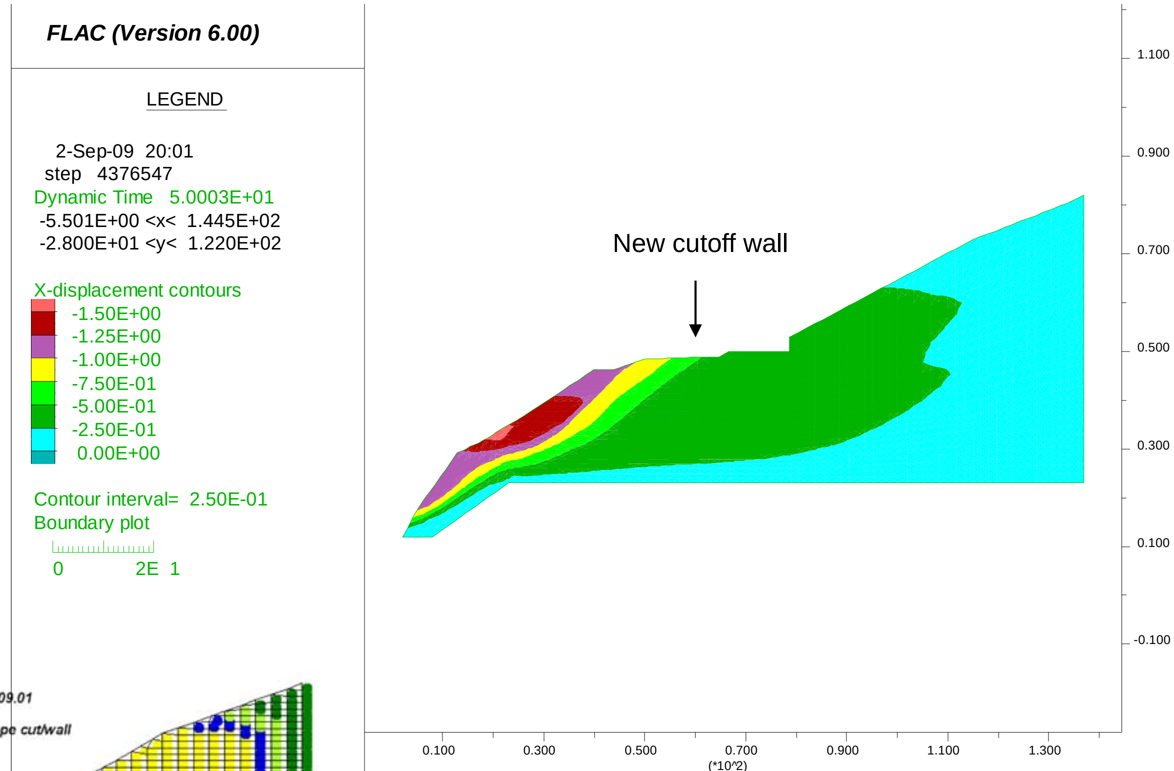

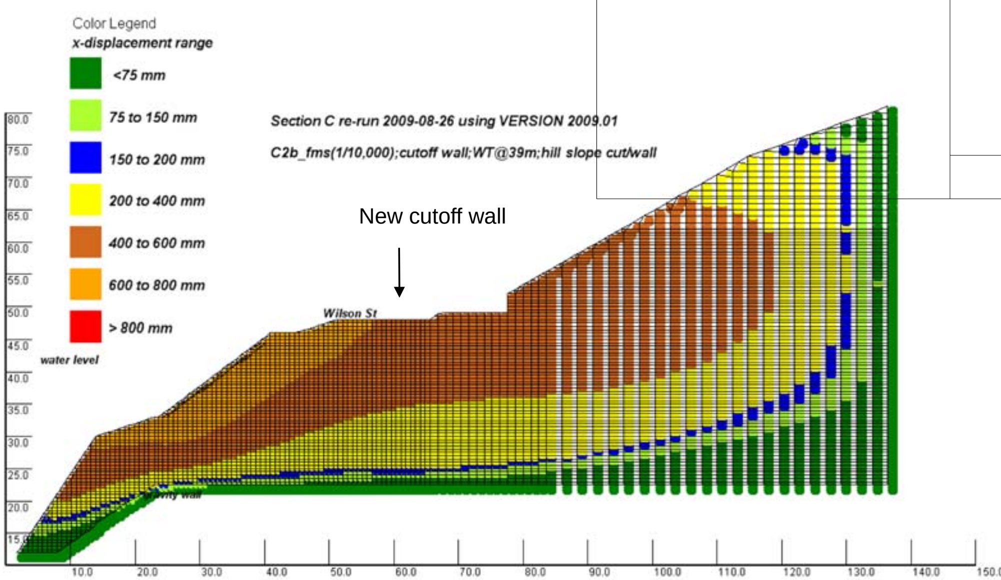

FLAC vs. VERSAT

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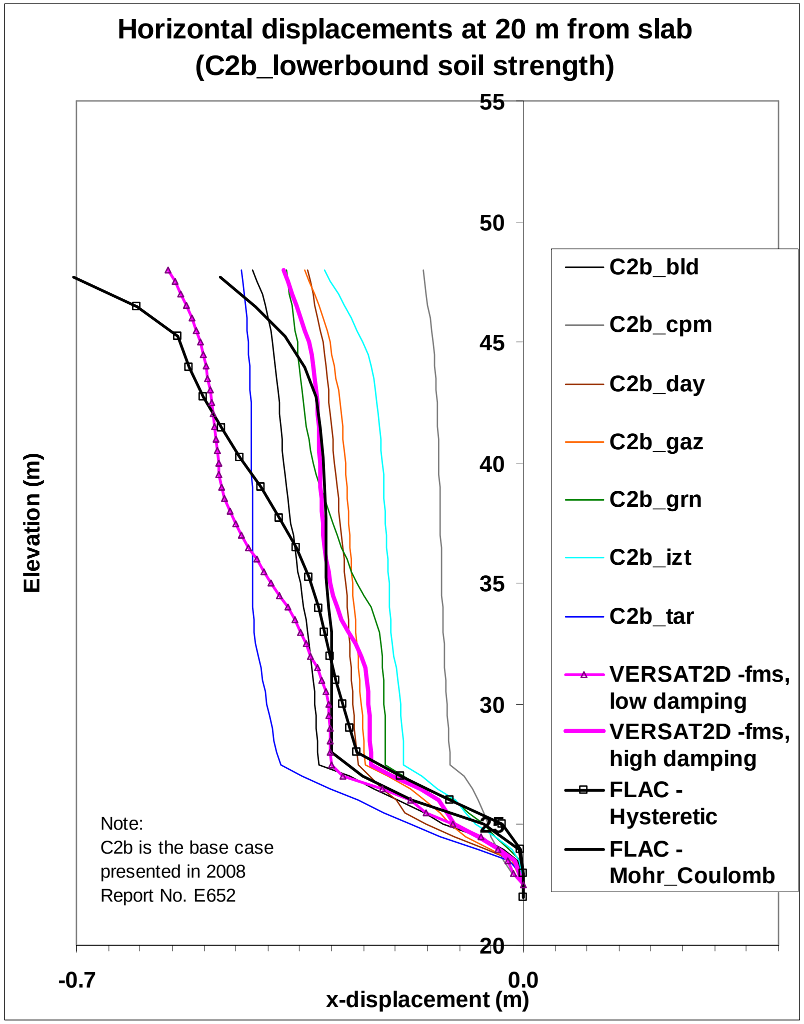
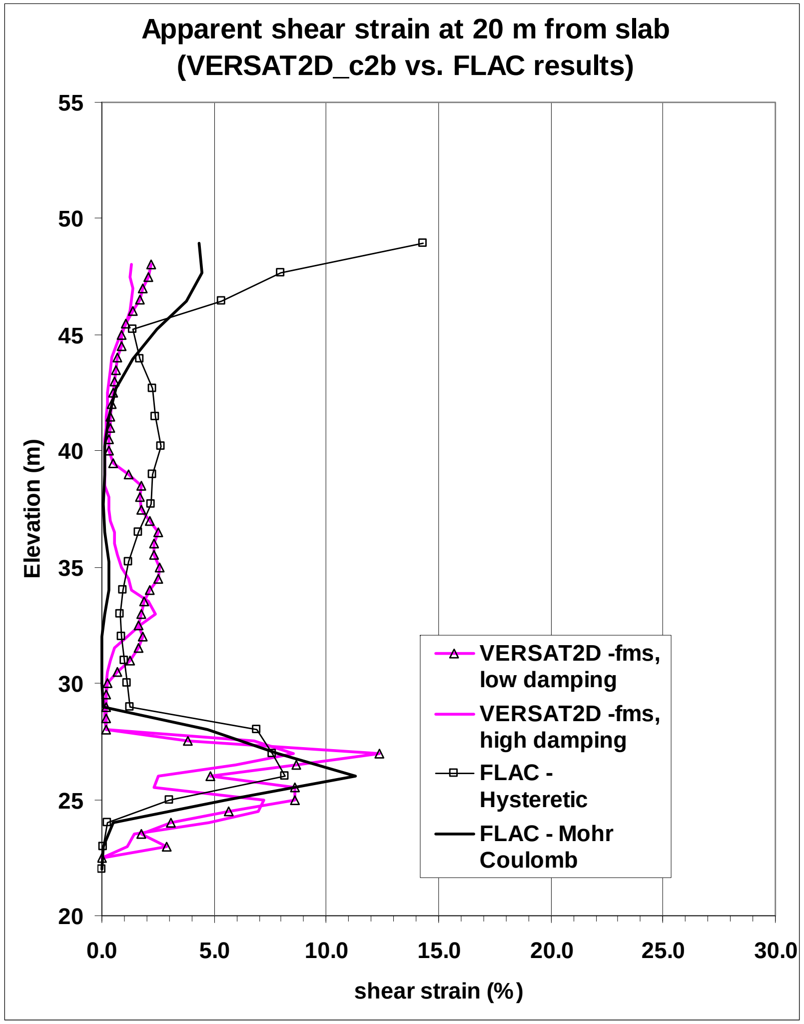
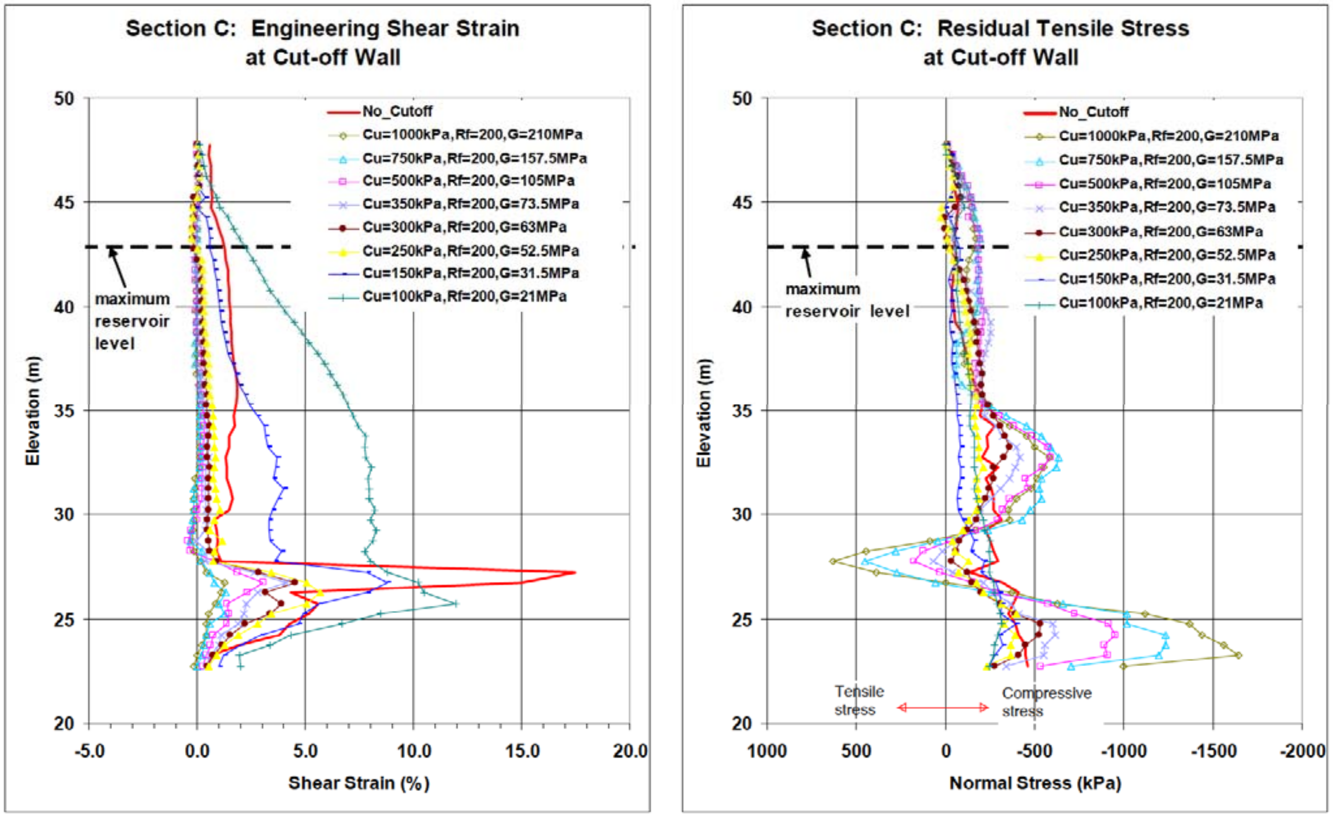


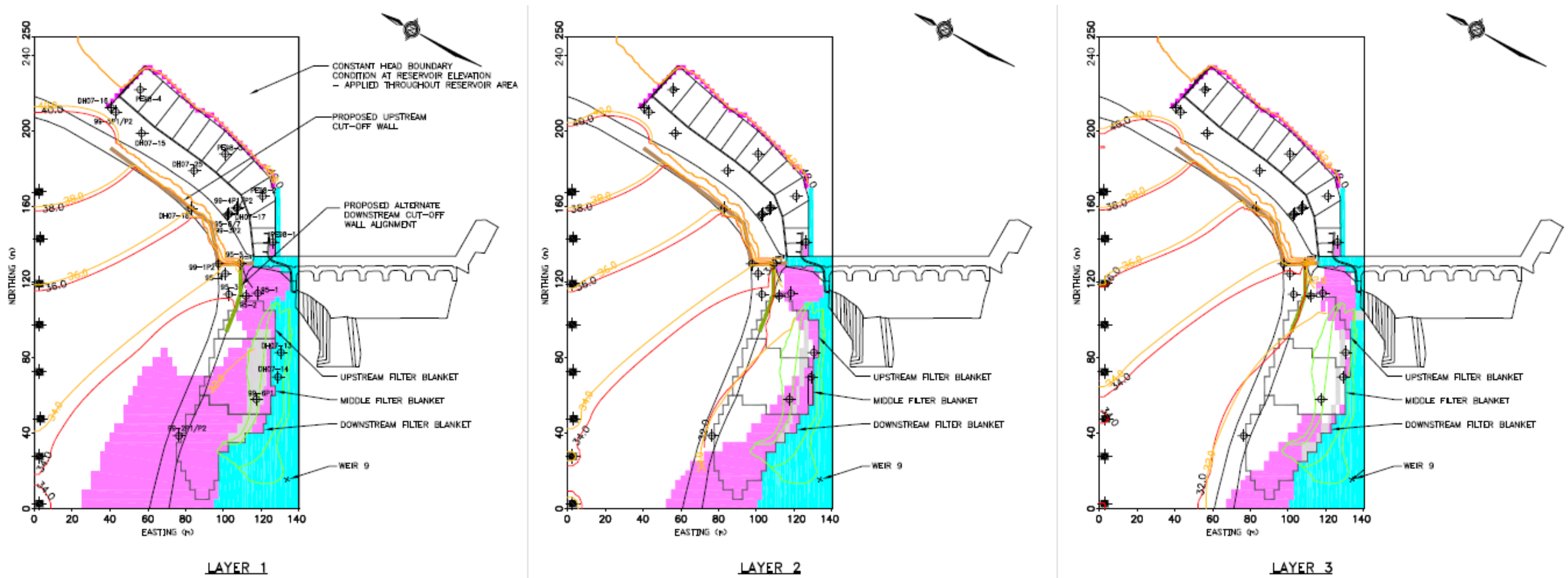


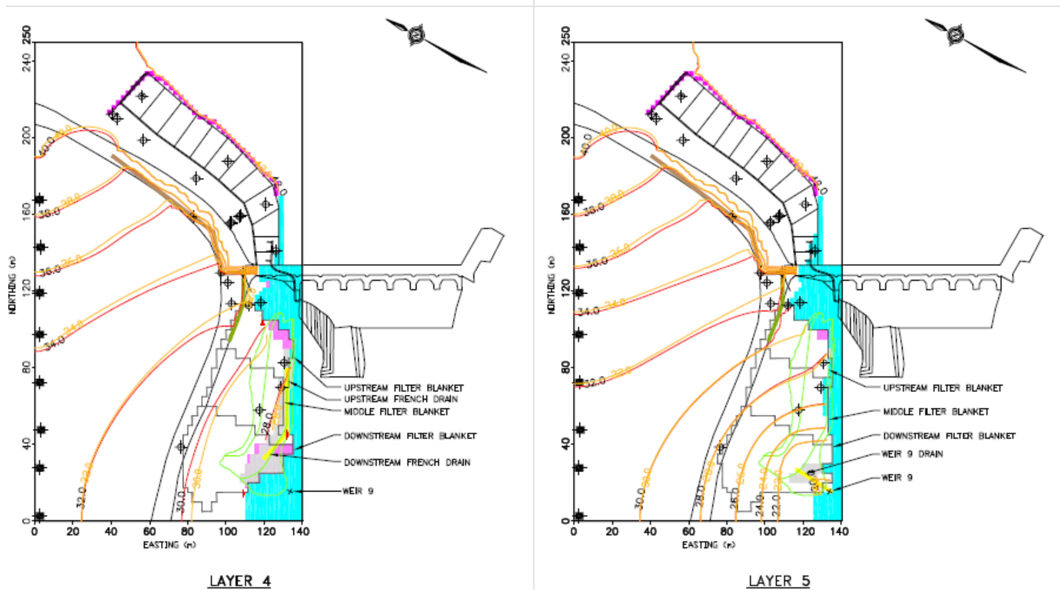
Selection of Material Properties



- Results of the deformation analyses used to select the properties of plastic concrete
- Maximum shear strain of 15%
- Maximum shear strength of 0.75 MPa (UCS of 1.5 MPa)
- Minimum of 200 kPa at 7 days

Seepage Modeling – 3D MODFLOW





The new upstream cutoff wall should have the similar length as the existing slabs to minimize increases of hydraulic gradients in the right abutment after failure of the existing slabs

LAYER 6

Cut-off Wall Tie-in to Concrete Dam

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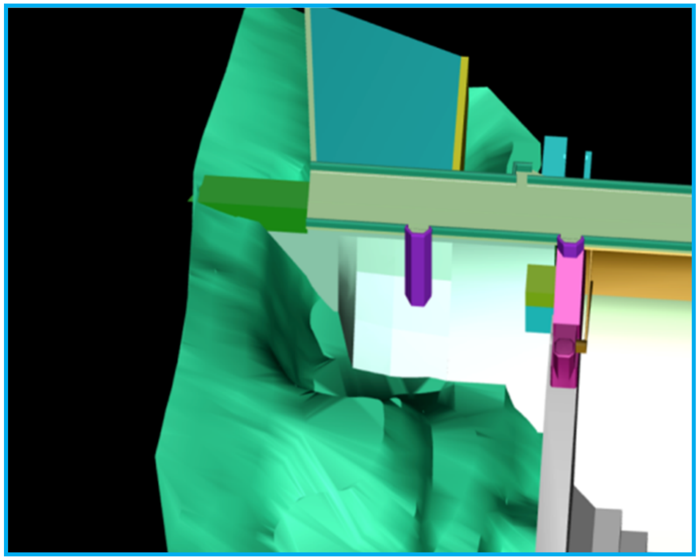

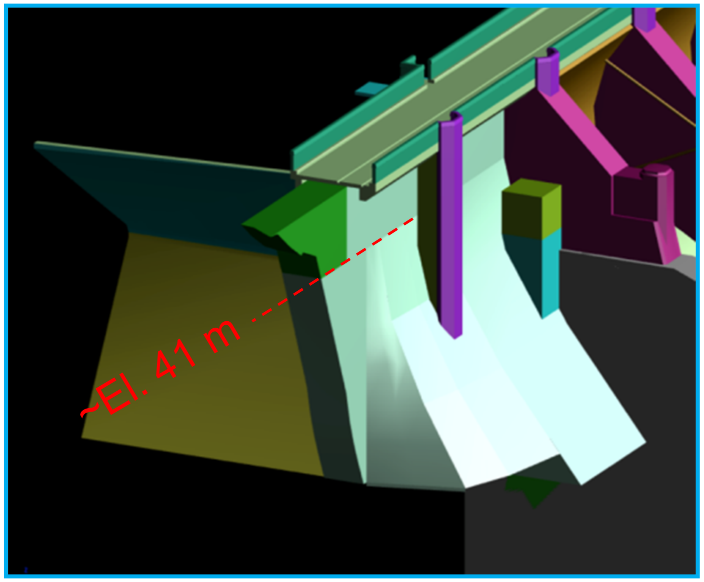

Challenges:

- Most critical component of the right abutment upgrade
- Complicated geometry – sloping concrete placed on excavated Quadra Sand
- Potential for differential deformations between the concrete dam and foundation soils
- Close distance to rockfill beneath concrete slabs

Cut-off Wall Tie-in to Concrete Dam

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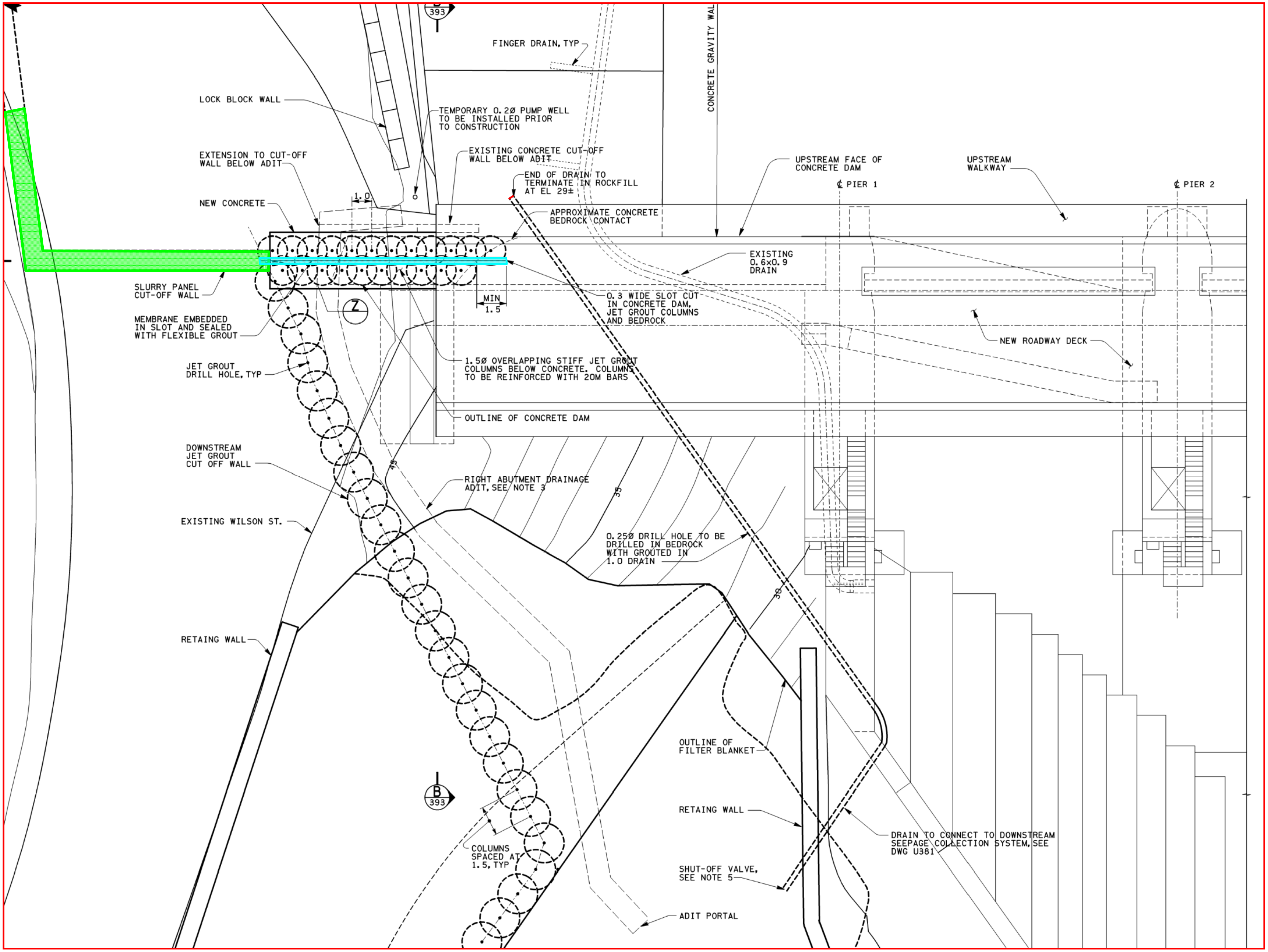
Base Design

- Strengthen soils beneath the abutment end of concrete dam by two rows of jet grout (minimum UCS of 6MPa)
- Cut a slot in concrete dam and jet grout columns
- Install geomembrane surrounded by cement-bentonite grout capable of withstanding 50 mm of concentrated deformation
- Constructability input required



393
FINGER DRAIN, TYP
CONCRETE GRAVITY WALL
LOCK BLOCK WALL
TEMPORARY 0.2Ø PUMP WELL
TO BE INSTALLED PRIOR
TO CONSTRUCTION
EXTENSION TO CUT-OFF
WALL BELOW ADIT
EXISTING CONCRETE CUT-OFF
WALL BELOW ADIT
END OF DRAIN TO
TERMINATE IN ROCKFILL
AT EL 29±
UPSTREAM FACE OF
CONCRETE DAM
UPSTREAM
WALKWAY
℄ PIER 1
℄ PIER 2
NEW CONCRETE
1.0
APPROXIMATE CONCRETE
BEDROCK CONTACT
EXISTING
0.6x0.9
DRAIN
SLURRY PANEL
CUT-OFF WALL
0.3 WIDE SLOT CUT
IN CONCRETE DAM,
JET GROUT COLUMNS
AND BEDROCK
MIN
1.5
Z
MEMBRANE EMBEDDED
IN SLOT AND SEALED
WITH FLEXIBLE GROUT
NEW ROADWAY DECK
JET GROUT
DRILL HOLE, TYP
1.5Ø OVERLAPPING STIFF JET GROUT
COLUMNS BELOW CONCRETE. COLUMNS
TO BE REINFORCED WITH 20M BARS
OUTLINE OF CONCRETE DAM
DOWNSTREAM
JET GROUT
CUT OFF WALL
45
RIGHT ABUTMENT DRAINAGE
ADIT, SEE NOTE 3
35
EXISTING WILSON ST.
0.25Ø DRILL HOLE TO BE
DRILLED IN BEDROCK
WITH GROUTED IN
1.0 DRAIN
30
RETAING WALL
OUTLINE OF
FILTER BLANKET
B
393
RETAING WALL
DRAIN TO CONNECT TO DOWNSTREAM
SEEPAGE COLLECTION SYSTEM, SEE
DWG U381
COLUMNS
SPACED AT
1.5, TYP
SHUT-OFF VALVE,
SEE NOTE 5
ADIT PORTAL

Cutoff Wall Tie-in to Concrete Dam

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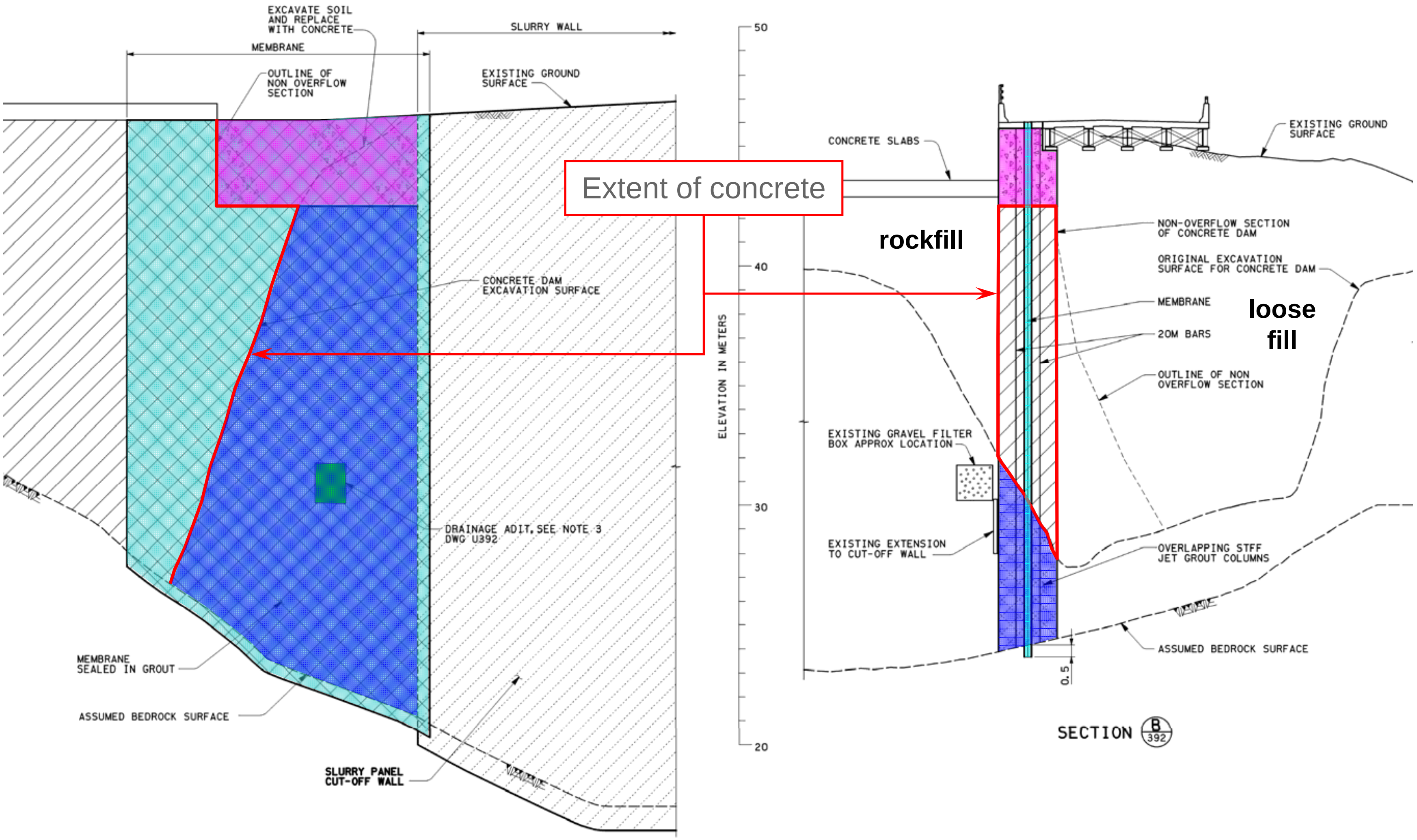

Slot Stability during Construction

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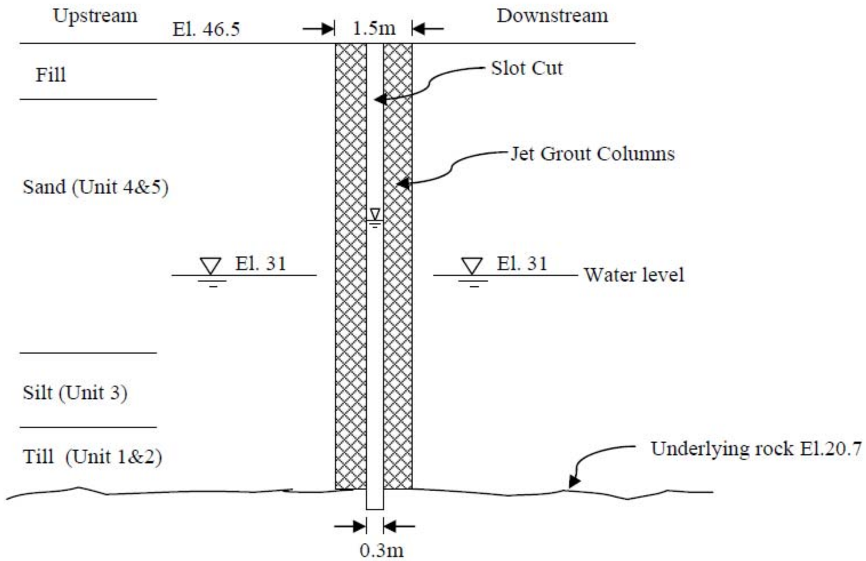
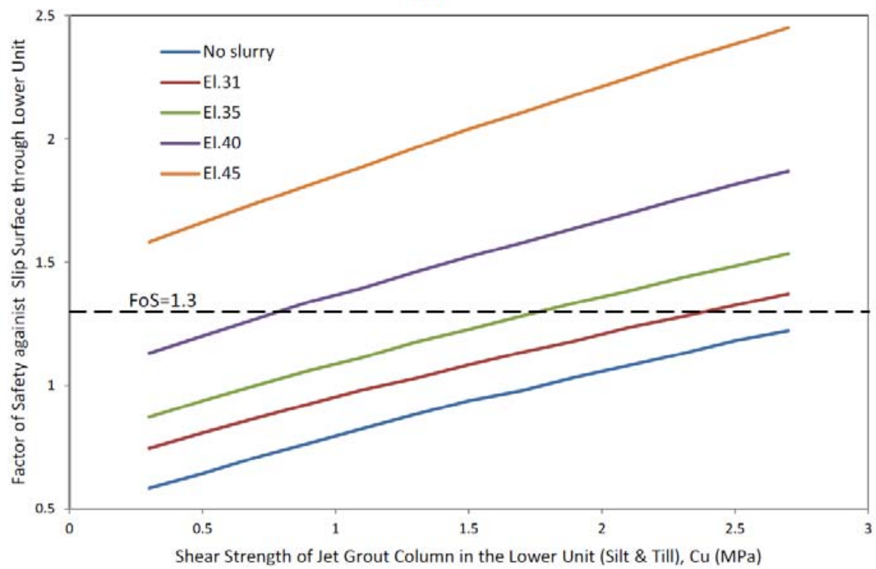




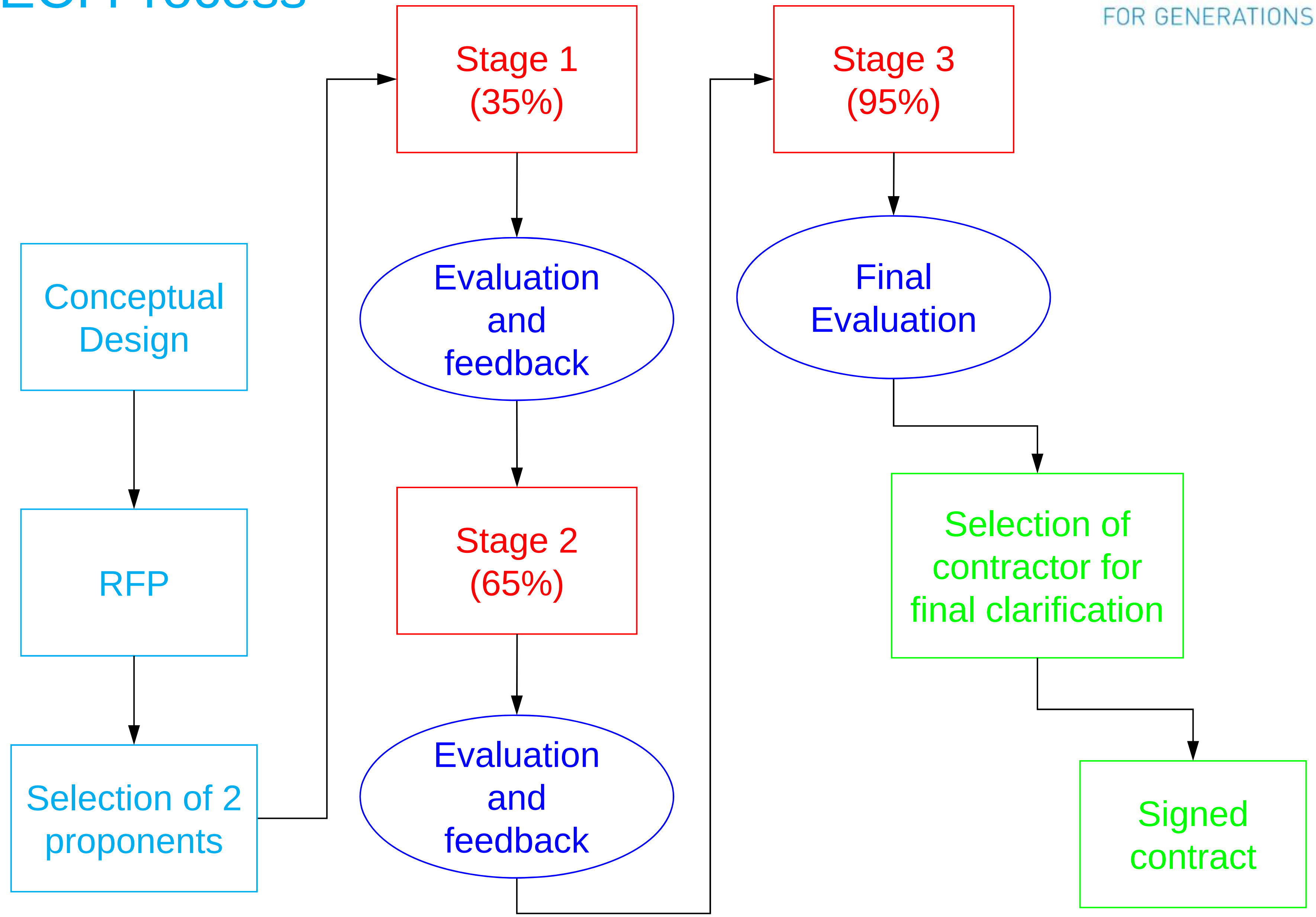
ECI Process

- High risk project combined with specialized work components good candidate for Early Contractor Involvement (ECI)
- BC Hydro's version of ECI:
  - Start with conceptual design and performance requirements
  - Develop multiple detailed designs with proponents in parallel
  - Collaborate with proponents in an open environment
  - Start with a target price, end with firm unit pricing; maintain cost competition throughout the process
  - Transfer knowledge about the site and potential risks (especially dam safety risks)
  - Develop safe and effective methodologies

ECI Process

- Request for proposal
  - Conceptual design provided, site visit
- Three proposals received
  - Evaluated based on previous experience on similar projects and proposed methodology
- Two contracts awarded for pre-construction ECI
  - $100,000 paid to each proponent
- Selection of a contractor for construction (including field trials)

ECI Process


Conceptual Design
RFP
Selection of 2 proponents
Stage 1 (35%)
Evaluation and feedback
Stage 2 (65%)
Evaluation and feedback
Stage 3 (95%)
Final Evaluation
Selection of contractor for final clarification
Signed contract

ECI Process

- Pre-construction ECI phase
  - Three stage process (35%, 65%, 95% design level)
  - Provided proponents the performance requirements (Project Requirements Document) and reference information
  - Frequent meetings with both proponents to discuss methodology, test results, and provide feedback
  - At the end of each stage proponent presented proposal and submitted deliverables
    - Detailed methodology, environmental protection plan, safety plan, quality plan, résumés, experience on other projects, target price
    - Formal review and feedback by BC Hydro for each stage
- Final Evaluation
  - Final proposals scored on technical, dam safety, safety, environmental, cost

Addressing Dam Safety Risks

- BC Hydro provided the proponents with a Dam Safety Management plan
- Dam safety workshops held with both proponents
- Options developed to mitigate dam safety risks during construction
- Develop monitoring and mitigation plans
  - Contractor’s dam safety management plan
  - New and existing instrumentation
  - Real-time monitoring of construction instrument data and instrument data by Contractor and BC Hydro
  - Identify high risk work requiring reservoir drawdown

Transition to Contract

- Final 95% submission included provision for contractor to state exceptions to BC Hydro’s Terms and Conditions
  - Exceptions allowed for appropriate transfer of risk during negotiations
- Contract released in 2 stages:
  - Site investigations and field trials
  - Permanent works released upon completion of first stage
- Contract allowed for re-pricing of the permanent work based on the results of the first stage
  - Contractor to understand the site and take ownership for the site conditions
  - Provided confidence in the design and methodology before the permanent works released

Innovation from ECI

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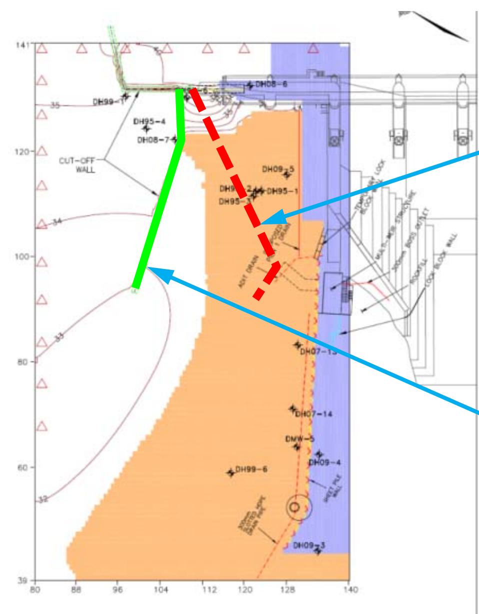
- Bitumen based material for slot backfill
  - Attractive as one material instead of two
  - Little precedent for this material and construction
  - BC Hydro accepted proposal, but required further material testing and field demonstration
- Realignment of training wall and change from jet grouting to slurry panel plastic concrete wall

Verification of training wall realignment



Jet Grouted Wall

Plastic Concrete Wall

Cutoff Wall and Training Wall

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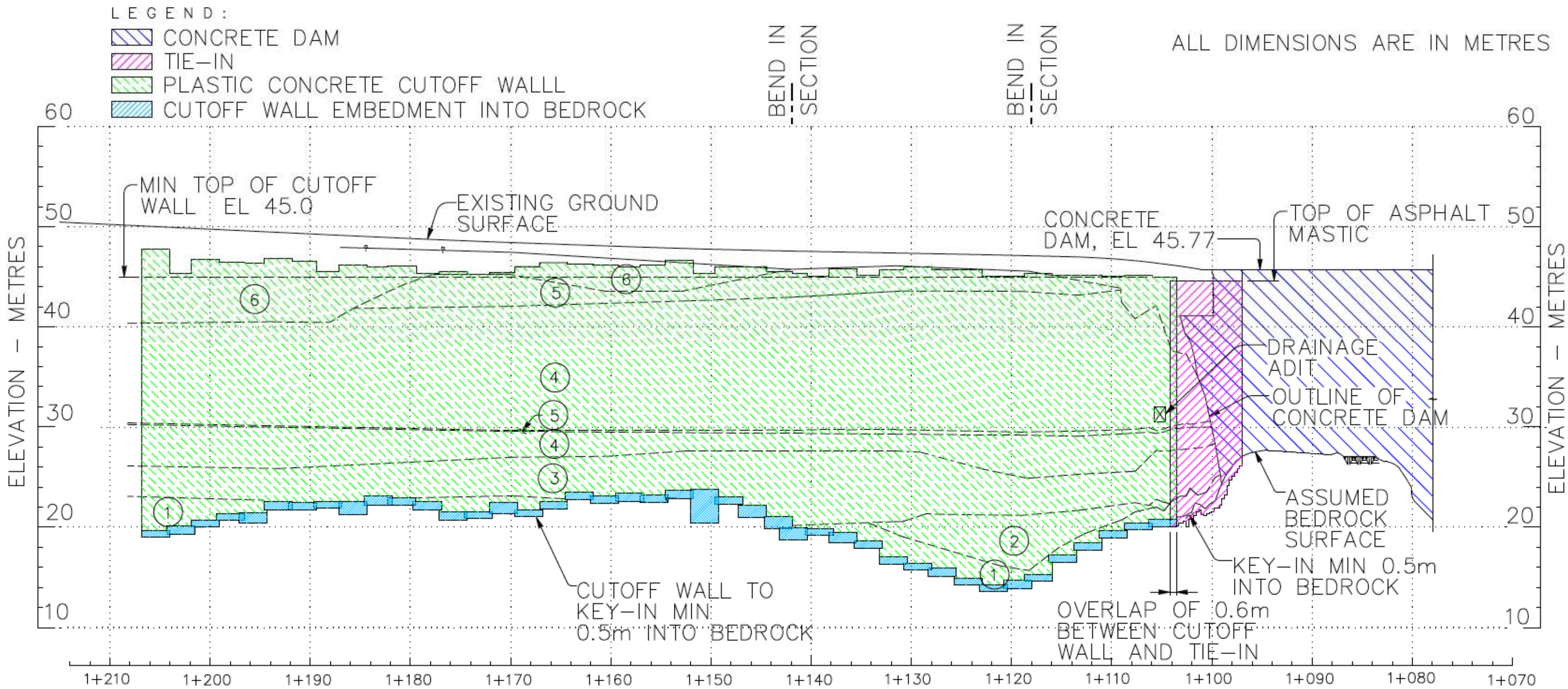
Summary:

- No of panels: 58
- Panel dimensions: 1 m by 2.8 m
- Maximum panel depth: ~35 m
- Minimum 0.5 m embedment into bedrock
- Panel overlap: 300 mm

Quality control/assurance:

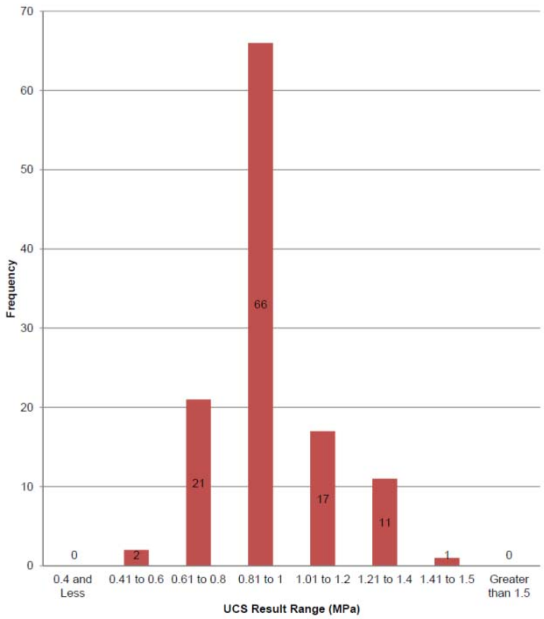
- Cutter response, examination of cuttings to determine bedrock
- Mix design trials, sampling and testing of plastic concrete, in-situ hydraulic conductivity testing
- Real-time alignment information, KODEN

Cut-off Wall



LEGEND:
CONCRETE DAM
TIE–IN
PLASTIC CONCRETE CUTOFF WALLL
CUTOFF WALL EMBEDMENT INTO BEDROCK
BEND IN SECTION
BEND IN SECTION
ALL DIMENSIONS ARE IN METRES
MIN TOP OF CUTOFF WALL EL 45.0
EXISTING GROUND SURFACE
CONCRETE DAM, EL 45.77
TOP OF ASPHALT MASTIC
DRAINAGE ADIT
OUTLINE OF CONCRETE DAM
ASSUMED BEDROCK SURFACE
KEY–IN MIN 0.5m INTO BEDROCK
OVERLAP OF 0.6m BETWEEN CUTOFF WALL AND TIE–IN
CUTOFF WALL TO KEY–IN MIN 0.5m INTO BEDROCK
ELEVATION – METRES
60
50
40
30
20
10
1+210
1+200
1+190
1+180
1+170
1+160
1+150
1+140
1+130
1+120
1+110
1+100
1+090
1+080
1+070

Cut-off Wall and Training Wall



Plastic Concrete – Triaxial Test

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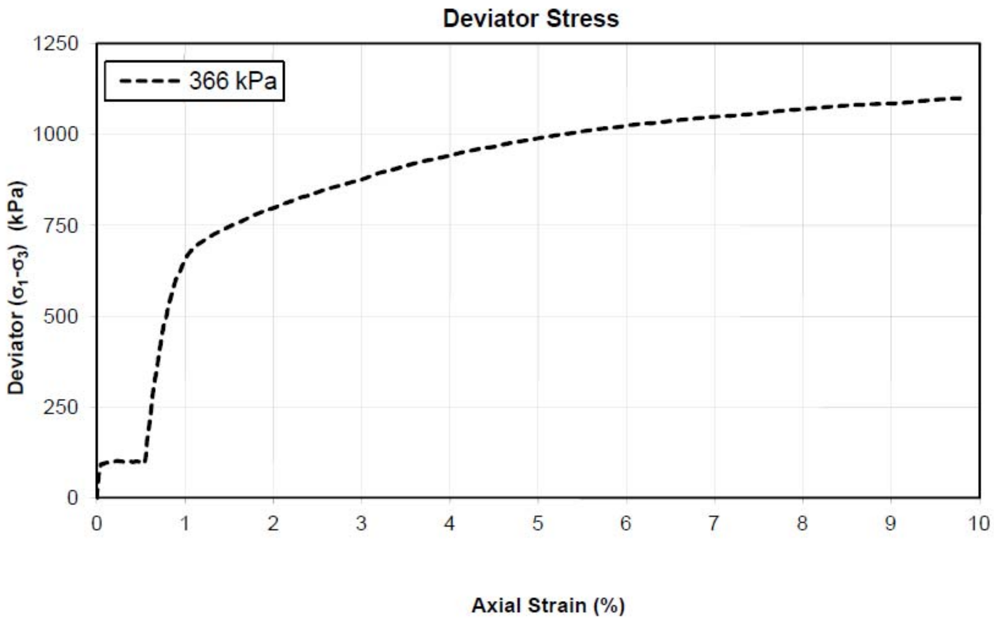
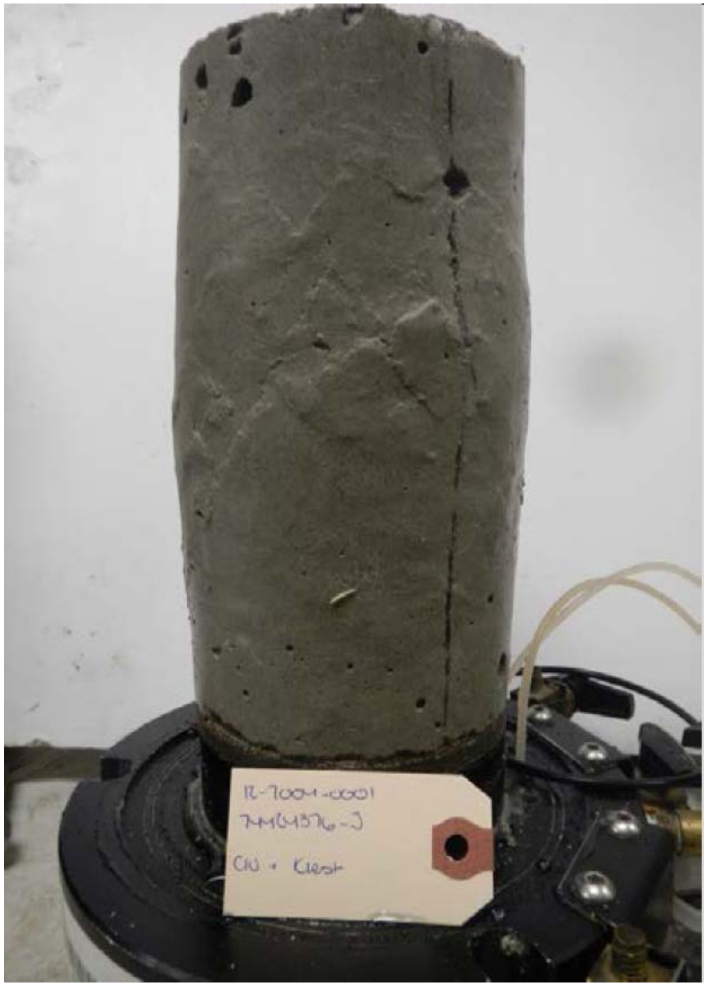
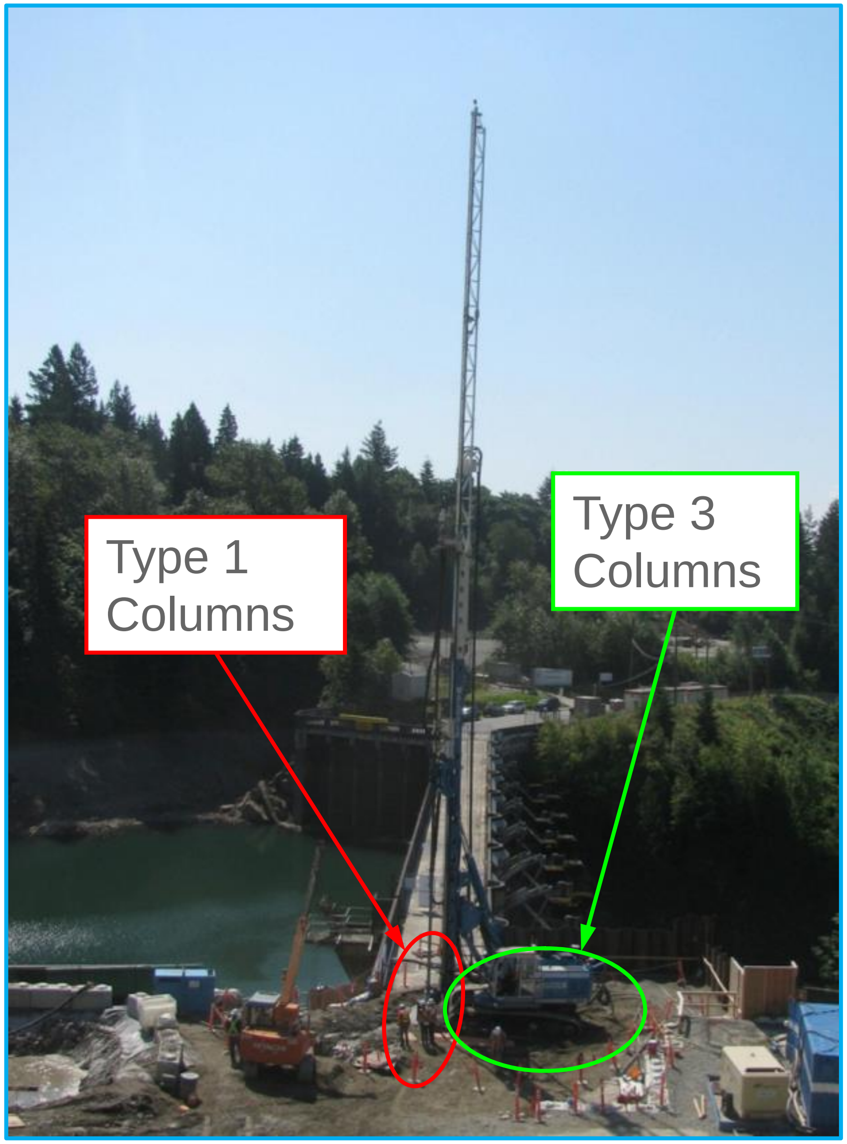




Jet Grouting – Dam Safety Risks

- High pressure (nozzle at 40 MPa) and high flow (370 lpm) operation – need to minimize dam safety risks
  - Reservoir drawdown for risk mitigation
  - No air in Type 1 columns
  - Real-time monitoring of pore-water pressures (1 reading per second)
- Jet grouting in voids or loose sand
  - Must maintain reflow at all times



Jet Grouting Field Trial

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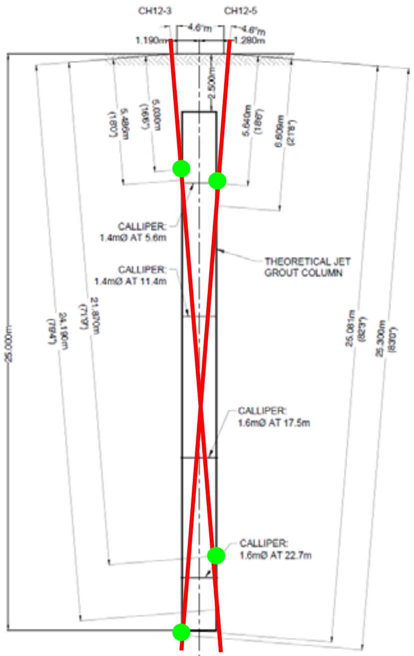
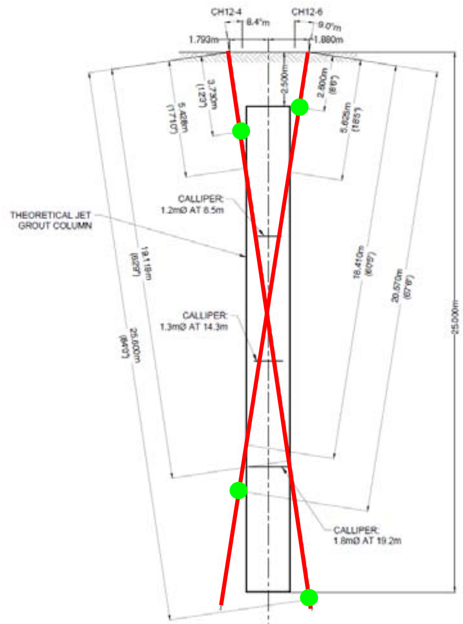
- Field trial required to demonstrate achievable diameters
- Ensure that the jet grouting could be completed safely, without significant dam safety risks



Type 1 Column (single fluid)
Diameter: 1.5 to 2.0 m



Type 3 Column (double fluid)
Diameter: 2.0 to 2.5 m

Pore Pressure Responses

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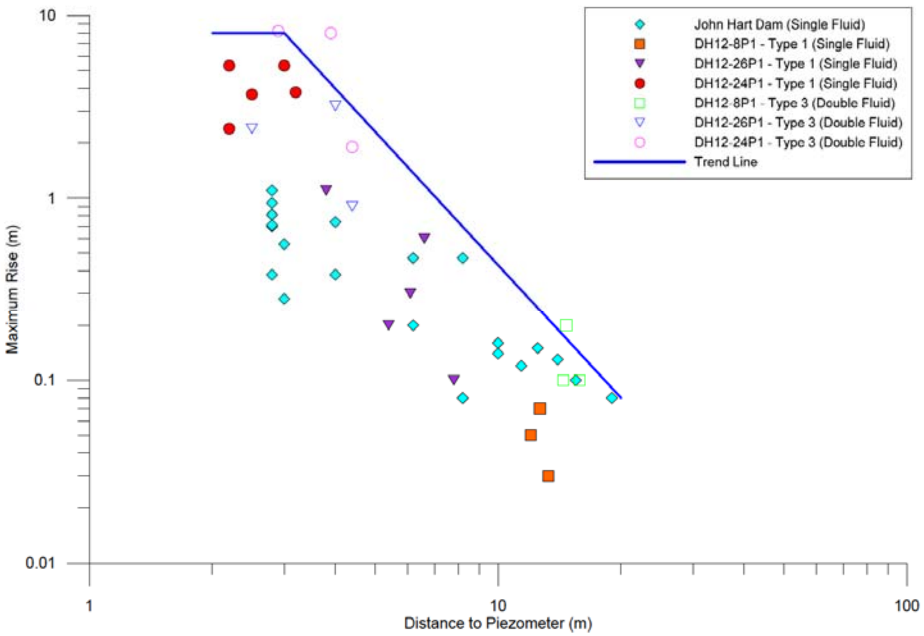
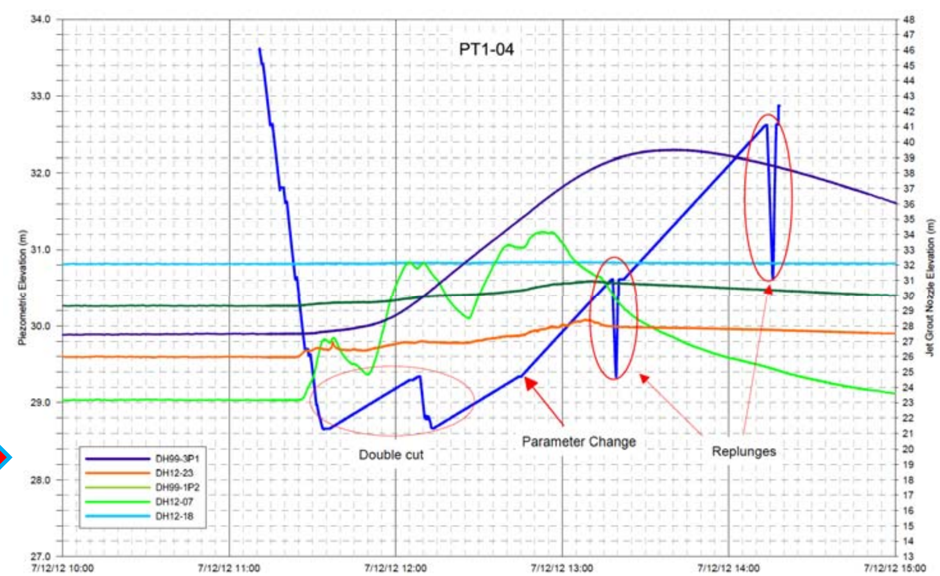


- Pore water pressures monitored at 1 to 2 second frequency
- Piezometers monitored at a range distances during field trial to determine expected response



Typical piezometric response plotted with location of jet grout monitor

Jet Grouting – Confirmation

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- Field trial results
- Very important to achieve and determine column diameters, especially for Type 1
- In-casing inclinometers provided deviations during drill down
- Confirmatory coring
- Televiewer and down-hole camera
- Sampling and testing of reflow, grab samples, HQ core samples

Jet Grouting – Confirmatory Coring

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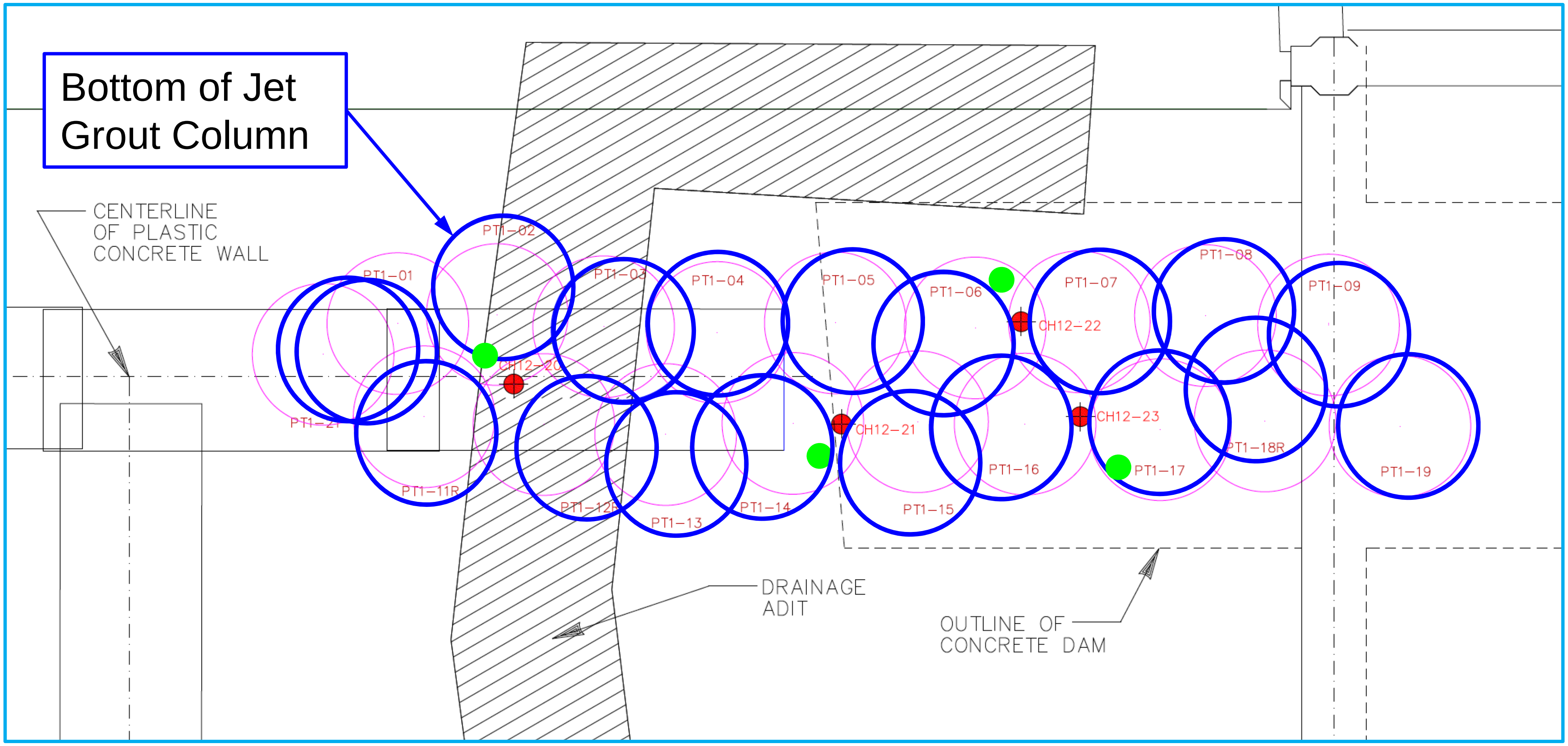

- Confirmatory coring targeted for gaps with columns assumed at 1.0 m diameter

Jet Grouting – Confirmation

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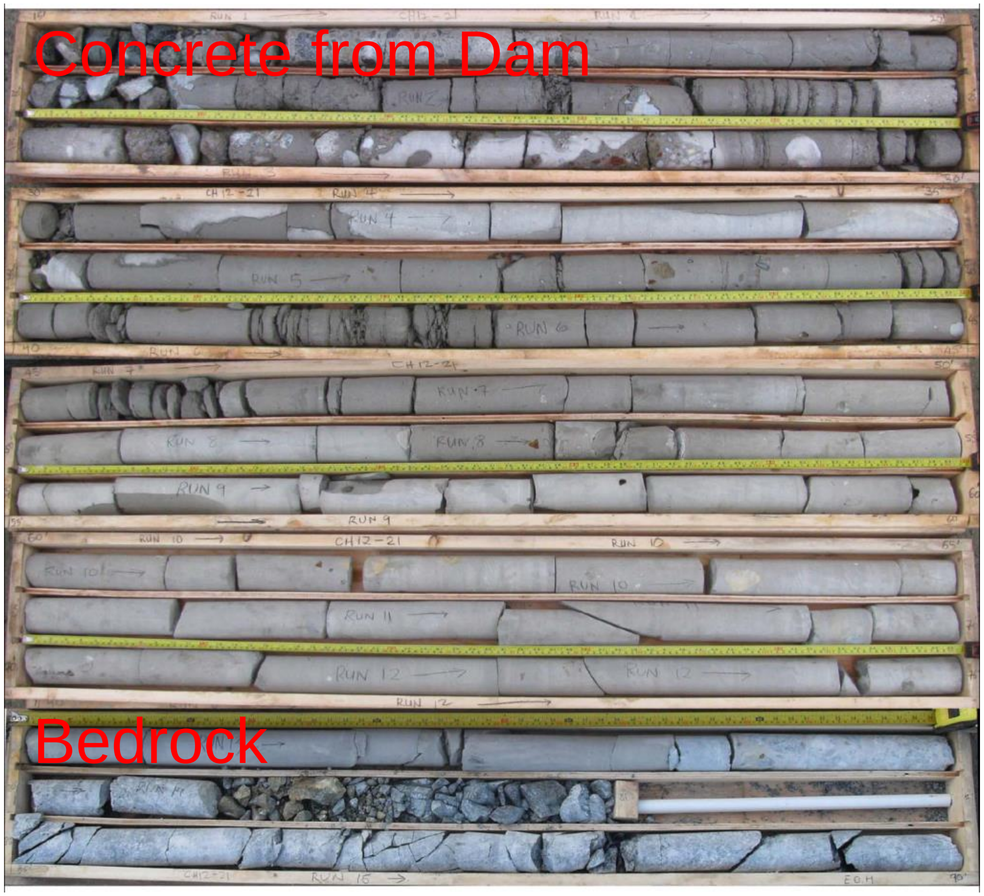

HQ Core from Type 1 Columns

Televiewer in Type 1 Columns

Jet Grouting – UCS Test Results

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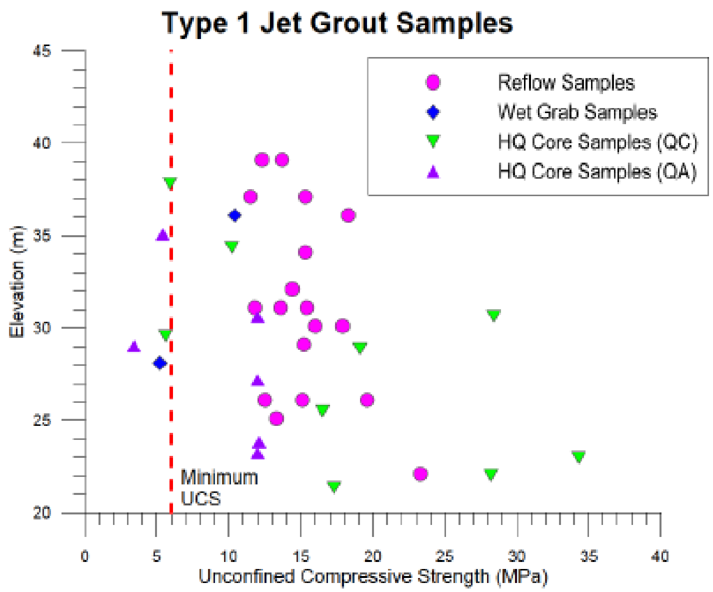
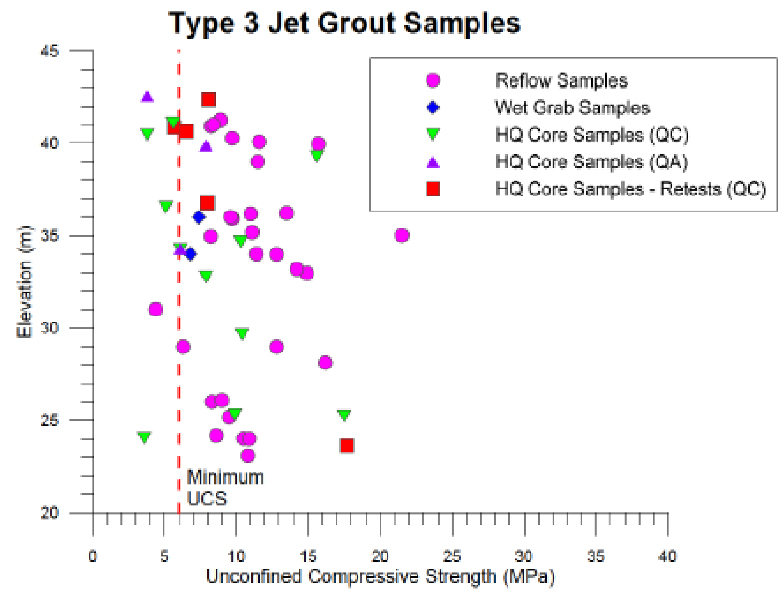
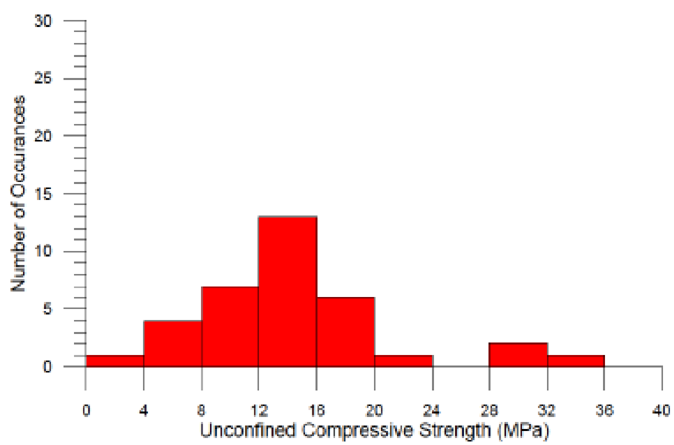
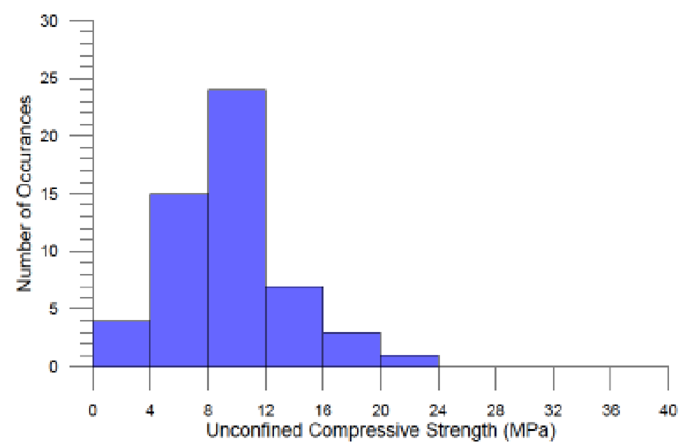
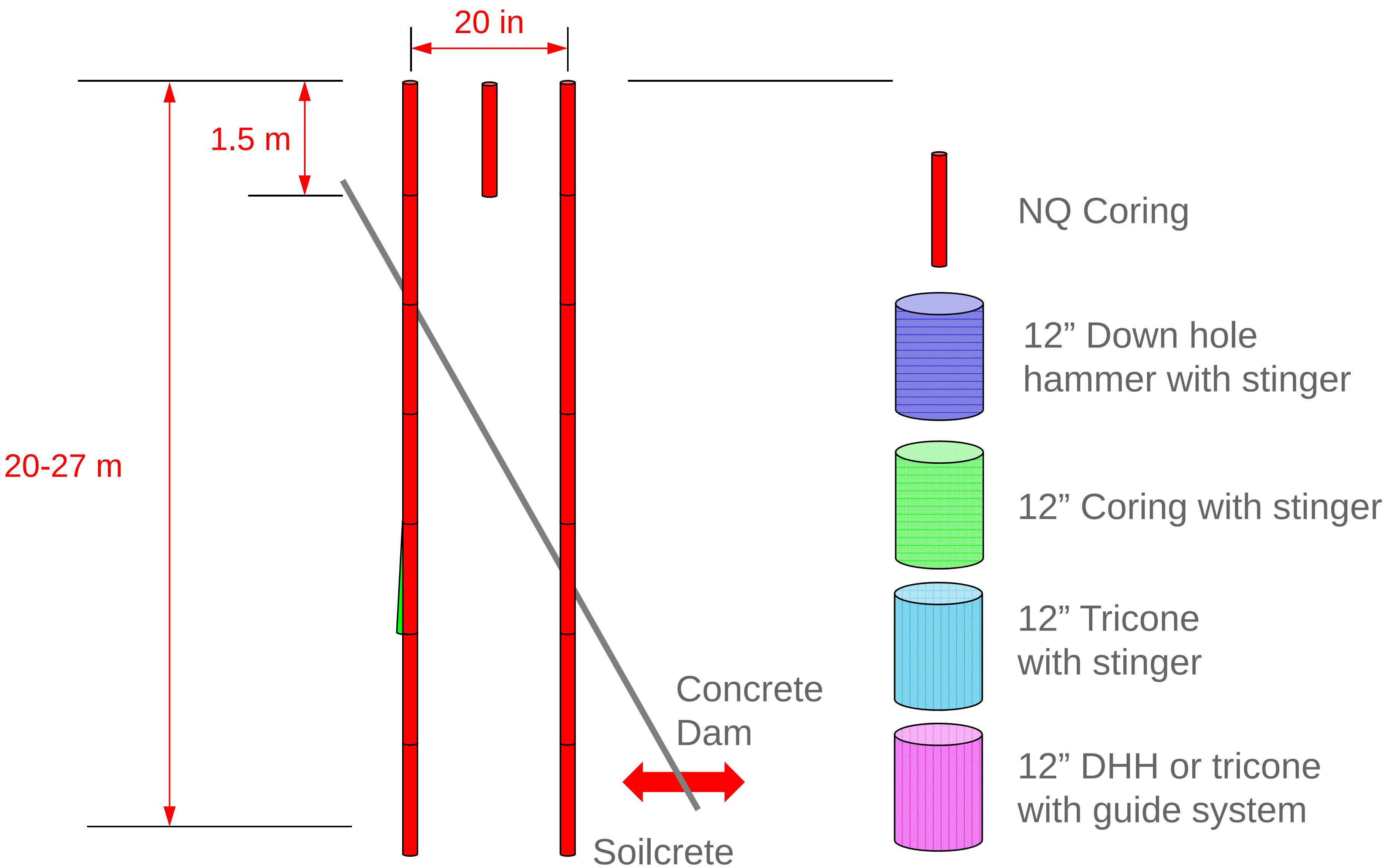






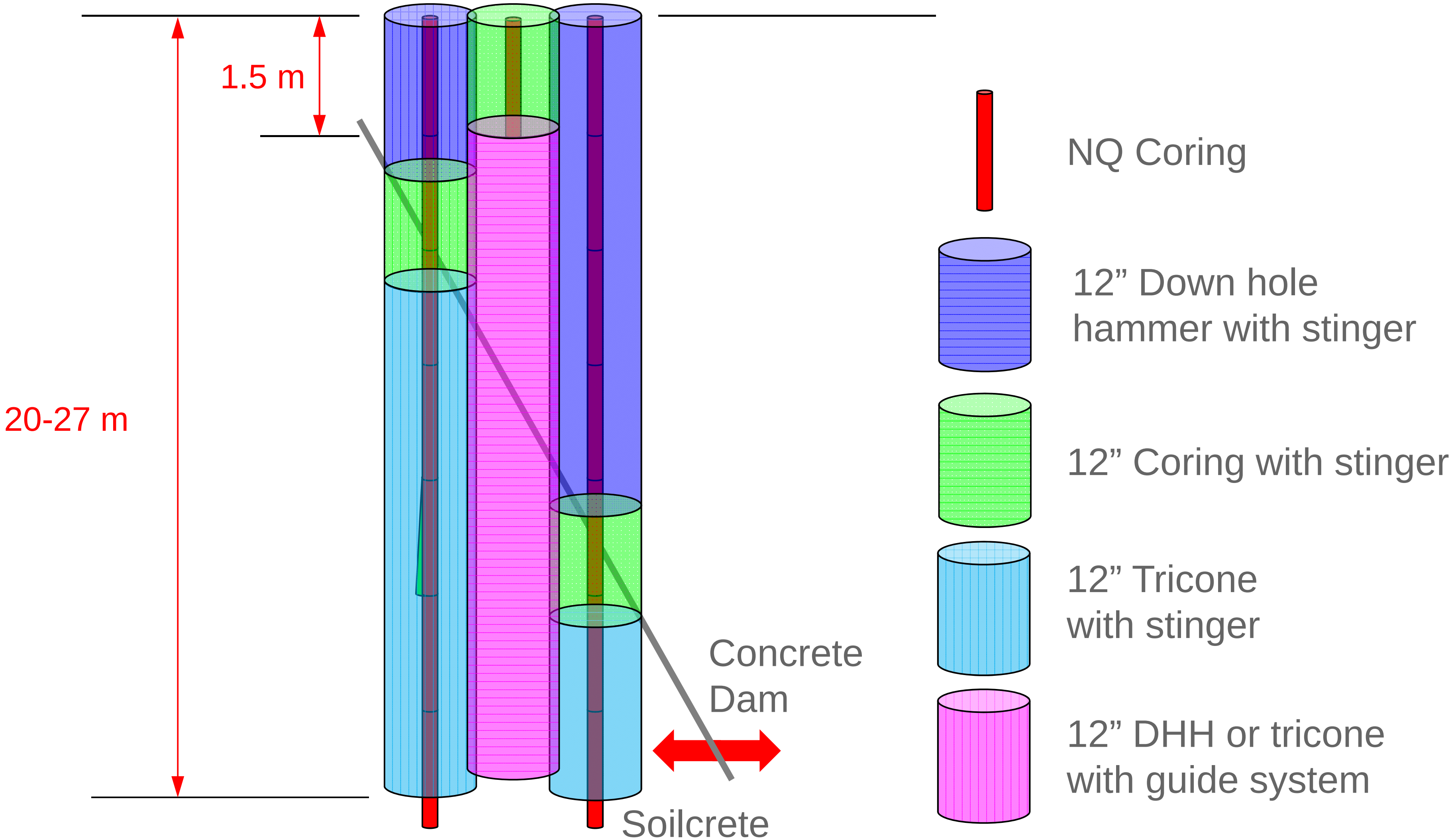


Methodology for Slot Construction



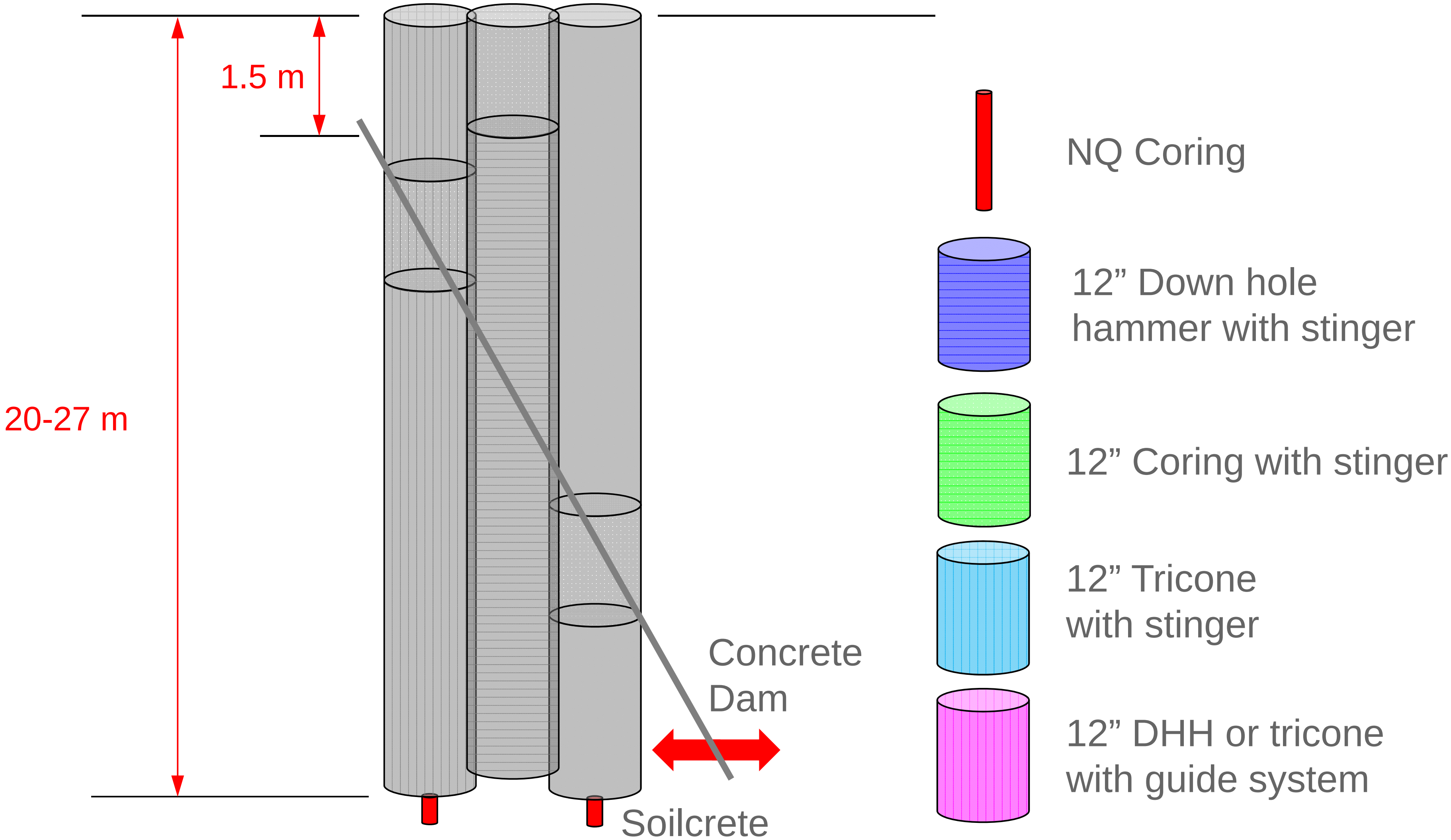
Methodology for Slot Construction

BChydro FOR GENERATIONS



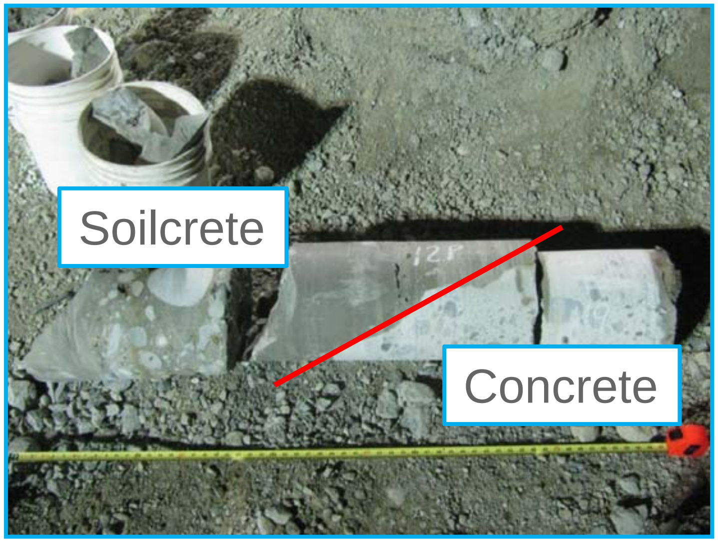
Methodology for Slot Construction

BC hydro FOR GENERATIONS



Tie-in – Slot Construction

BC hydro FOR GENERATIONS



Tie-in Slot Backfill Material

- Required a highly flexible material to accommodate differential deformation
- BC Hydro prepared base design consisting of a geomembrane and flexible grout
  - Contractor proposed an asphalt based product during ECI process
- Very little precedent with asphalt-based cut-offs
  - Some case histories in Japan and Upper Stillwater Dam
  - Required extensive product development and laboratory and field testing

Construction Field Trials

BC hydro FOR GENERATIONS

- Field trials carried out to understand material behaviour
  - Mastic placed at different temperature into wood formed slots
  - Establish flowability and temperature limits
- Field trial carried out in field trial slot to test proposed construction methodology
  - Only one shot!

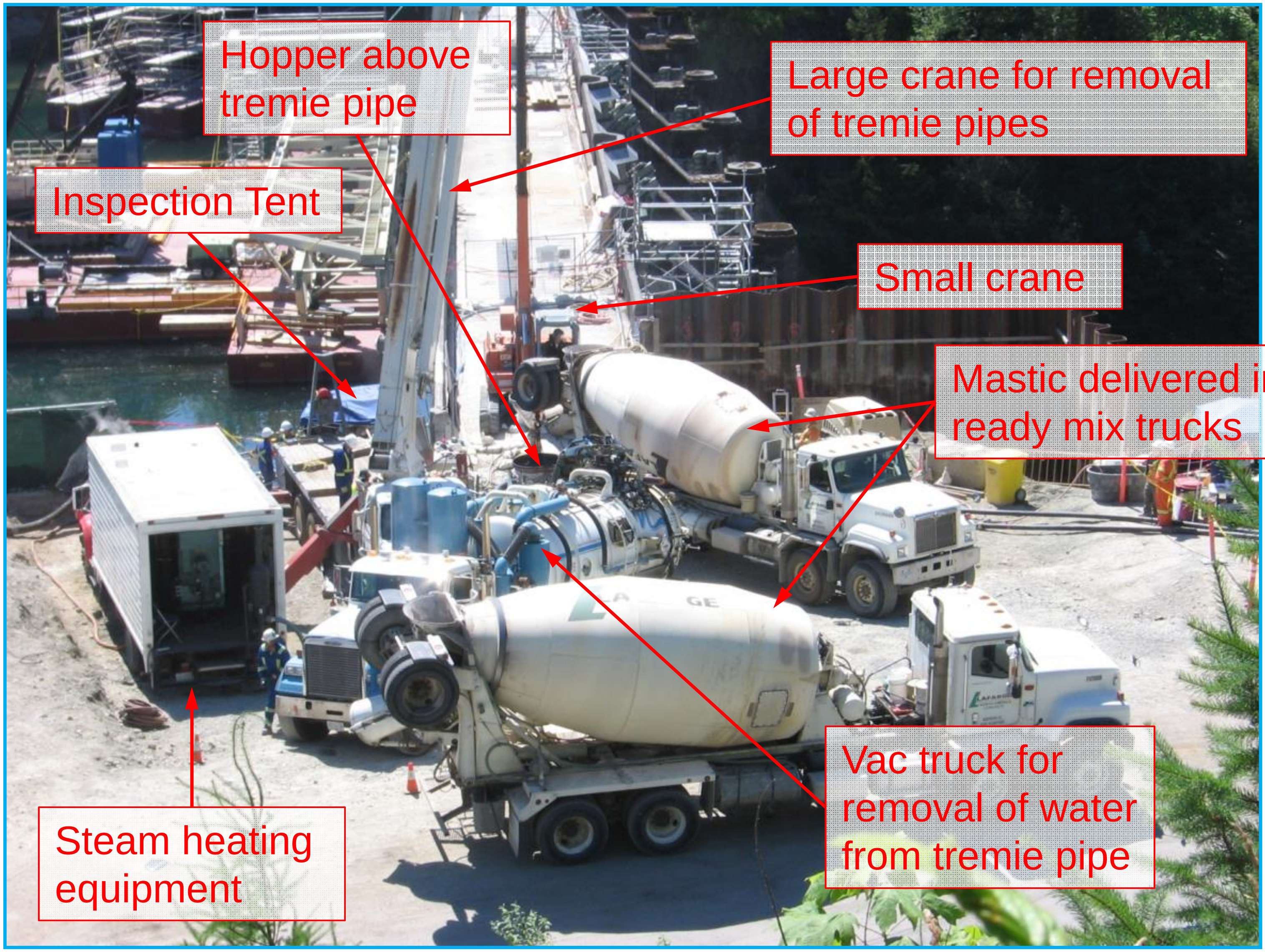
Mastic Field Trials

BC hydro
FOR GENERATIONS

Mastic Placement

- Needed to keep the mastic hot for it to be flowable at point of discharge
  - Minimum of ~120°C in the mastic at the bottom of the pipe
  - Temperature of mastic at start of pour ranged from about 137°C to 148°C
- Water in slot required placement of mastic by tremie method
  - Tremie pipe buried at least 0.5 m in mastic at all times
  - No mixing with water in the slot
  - Seal joints in tremie pipes
  - Cap at bottom of tremie pipe
  - Remove water from tremie pipe
  - Double wall tremie pipes used

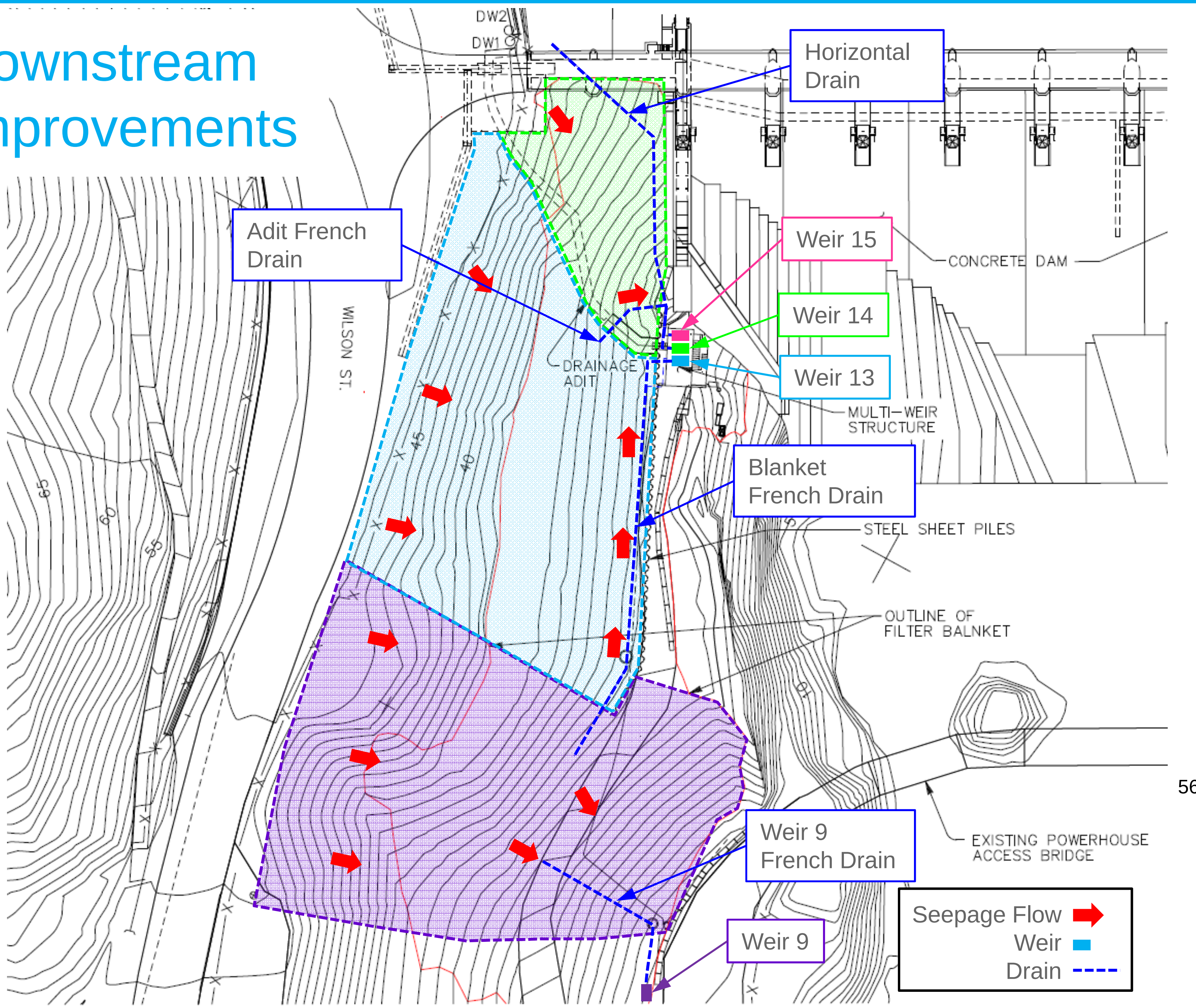
Mastic Placement – Set-up



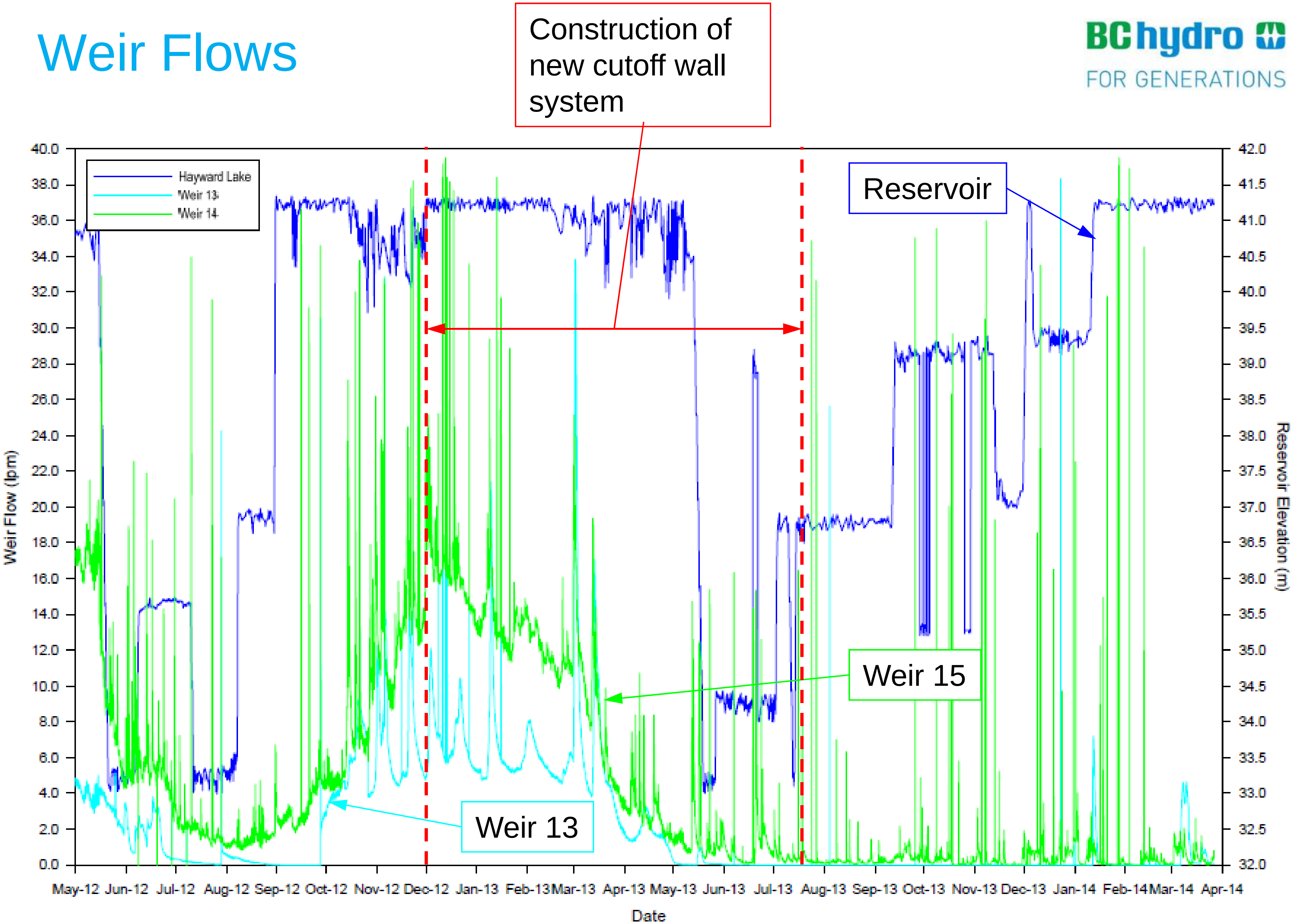
Mastic Placement

BC hydro
FOR GENERATIONS

Downstream Improvements



Weir Flows



Construction of new cutoff wall system
Reservoir
Weir 15
Weir 13
Hayward Lake
Weir 13
Weir 14
Weir Flow (lpm)
Reservoir Elevation (m)
Date
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
42.0
41.5
41.0
40.5
40.0
39.5
39.0
38.5
38.0
37.5
37.0
36.5
36.0
35.5
35.0
34.5
34.0
33.5
33.0
32.5
32.0
May-12 Jun-12 Jul-12 Aug-12 Sep-12 Oct-12 Nov-12 Dec-12 Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13 Oct-13 Nov-13 Dec-13 Jan-14 Feb-14 Mar-14 Apr-14

Thank-you

Acknowledgements

- BC Hydro
  - Peter Buchanan
  - Steve Garner
  - Jo Ho
  - Maoxin Li
  - Saman Vazinkhoo
  - Guoxi Wu
- Consultants
  - Andrew Holmes (seepage modeling)
  - Ernie Naesgaard (FLAC analysis)
  - Donald Bruce (project review)
  - Thurber (field inspection)
- Contractors
  - Golder Construction (general contractor, cut-off wall, mastic placement)
  - Malcom Drilling (jet grouting)
  - Foundex (drilling for slot construction, confirmatory coring)
  - Mud Bay (field investigations, well installation)

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