BONNEVILLE DOWNSTREAM SILL EMERGENCY REPAIR

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Portland District
Date: 25 February 2020

revised

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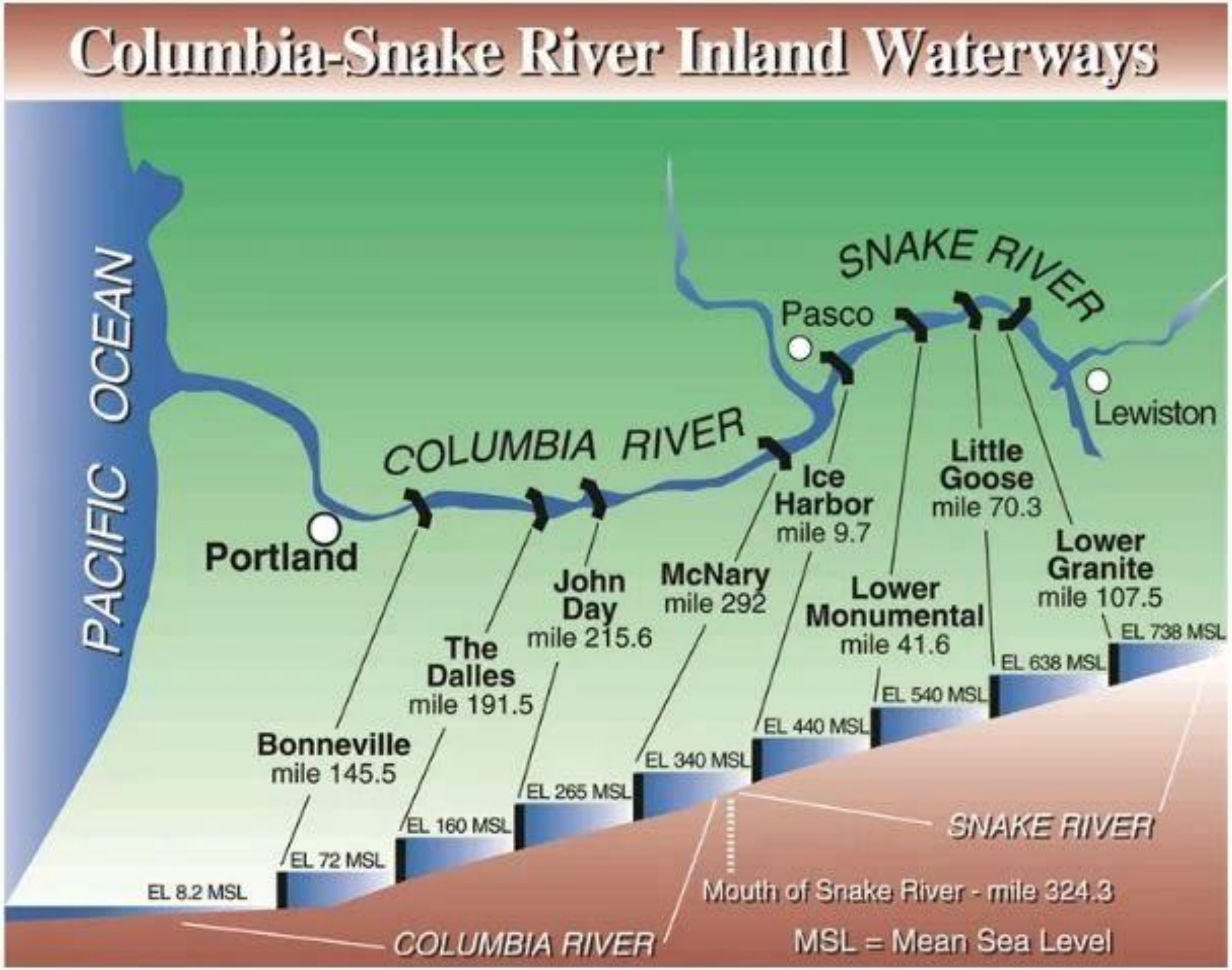

Columbia-Snake River Inland Waterways from the Pacific Northwest Waterways Association

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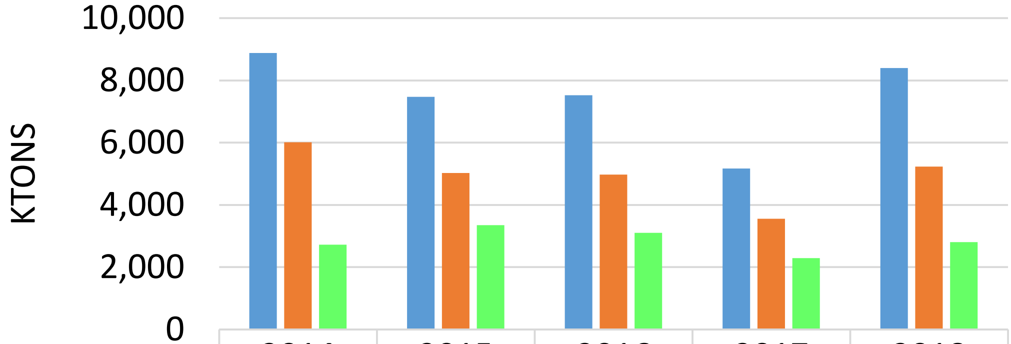
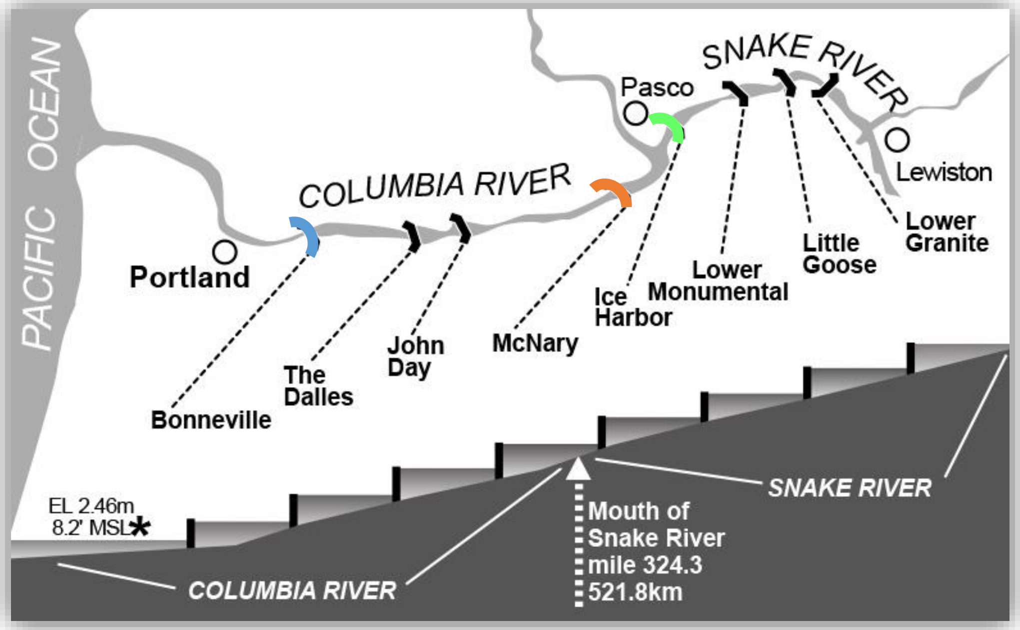
SYSTEM TONNAGE DISTRIBUTION

Annual Lock Tonnage
Bonneville - McNary - IceHarbor



	2014	2015	2016	2017	2018
Bonneville	8,881	7,475	7,521	5,173	8,402
McNary	6,014	5,025	4,973	3,557	5,235
Ice Harbor	2726	3355	3110	2291	2808

Bonneville McNary Ice Harbor



TIMELINE

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Summary of navigation lock operations from August 22 to September 5, prior to the lock closure:

- Aug 22, Thursday: Project maintenance crew performed an inspection on Miter gate 4 (south leaf) for an overtravel condition.
- Sept 1, Sunday, 8 lockages, Gate 4 jam reported at 1638, Gate 3 jam reported at 1640 on the 6th lockage of the day. Gates jam reported at 7% closed. Gate was then closed. Project maintenance staff performed a machinery check at 1730. Gate 3 Jam reported at 1800. Gate 4 jam reported at 1930.
- Sept 2, Monday, 10 lockages, unsure of reported gate jams.
- Sept 3, Tuesday, 3 lockages, maintenance crew did not find any problems. Two jams reported for Gate 3, five jams were reported for Gate 4. All cleared after jog to close.
- Sept 4, Wednesday, 11 lockages, 10 gate jam alarms all day.
- Sept 5, Thursday AM, 4 lockages, lock closed at 1325.
- Sept 6, AAC placed Stoplogs, lock dewatering operations started
- Sept 7, 0730, Engineering staff onsite for dewatered lock inspection

BONNEVILLE DOWNSTREAM MITER GATE ARRANGEMENT

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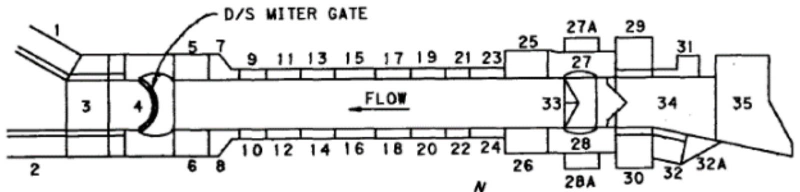
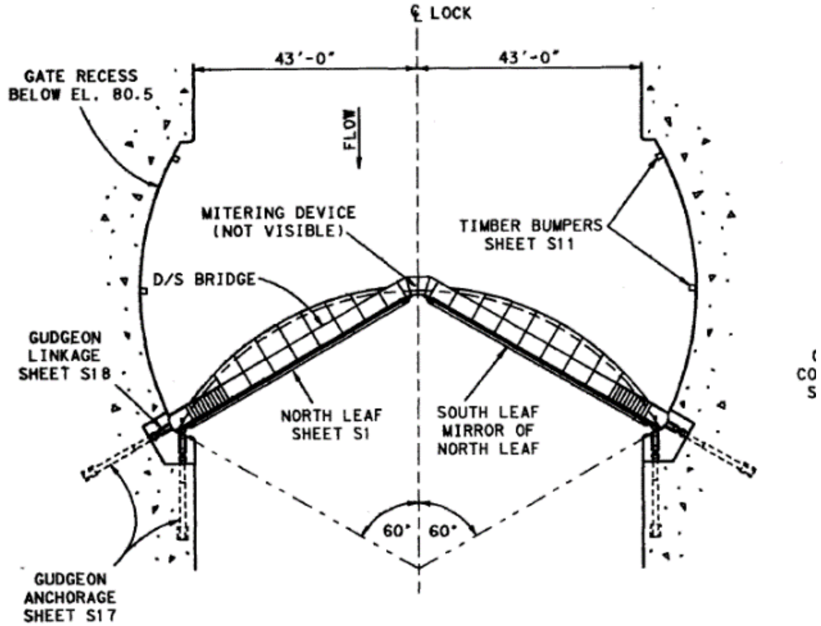
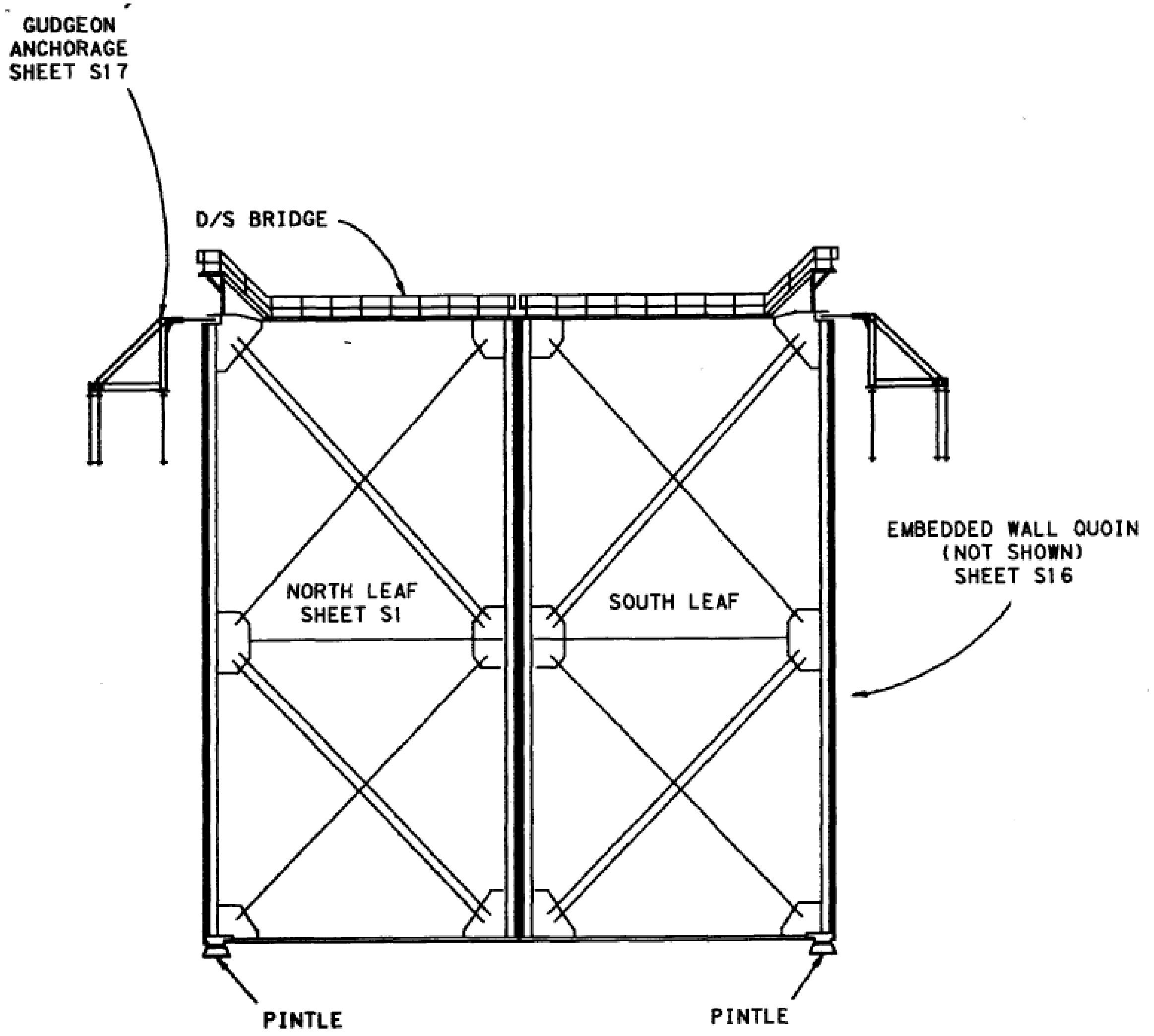
Miter gate arrangement of sill plate and concrete



KEY PLAN
NOT TO SCALE





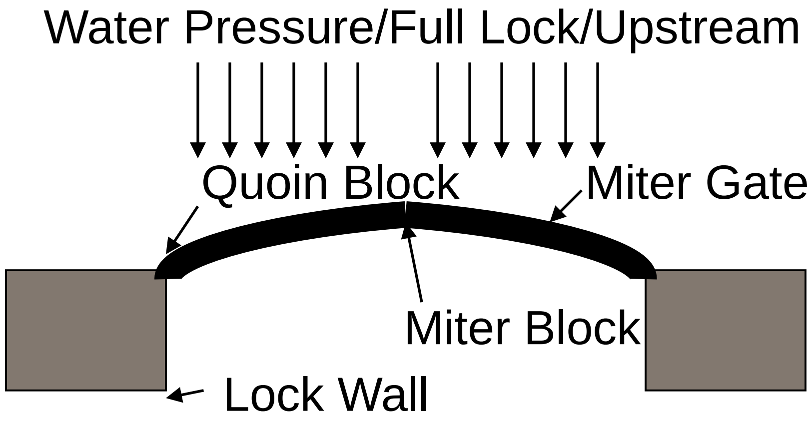
D/S ELEVATION
1/8"=1'-0"

DESIGN OF A MITER GATE

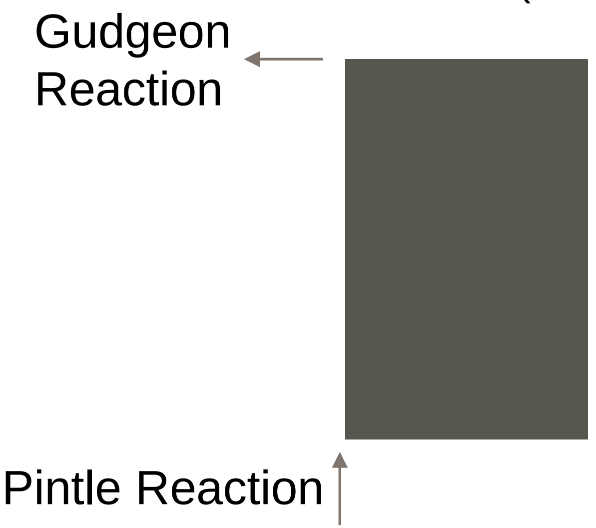
Miter gates have two fundamental load conditions, which drive their design:

- Chamber filled - gate acts as a three-hinged arch, carrying the load to the quoin blocks
- Chamber empty - gate must support its own weight. The entire weight of a leaf is supported on the *pintle*, which is a hemispherical casting at the bottom of the gate. The top of the gate is prevented from rotating by the *gudgeon*, where tension members carry the reaction load into the wall.

The sill block that failed does not carry any load from the gate, with only a rubber seal touching it. So the location of the sill block and its seal plate were critical to allow the lock to hold water.



PLAN VIEW (Chamber Full)



ELEVATION VIEW (Chamber Empty)

DESIGN OF A MITER GATE

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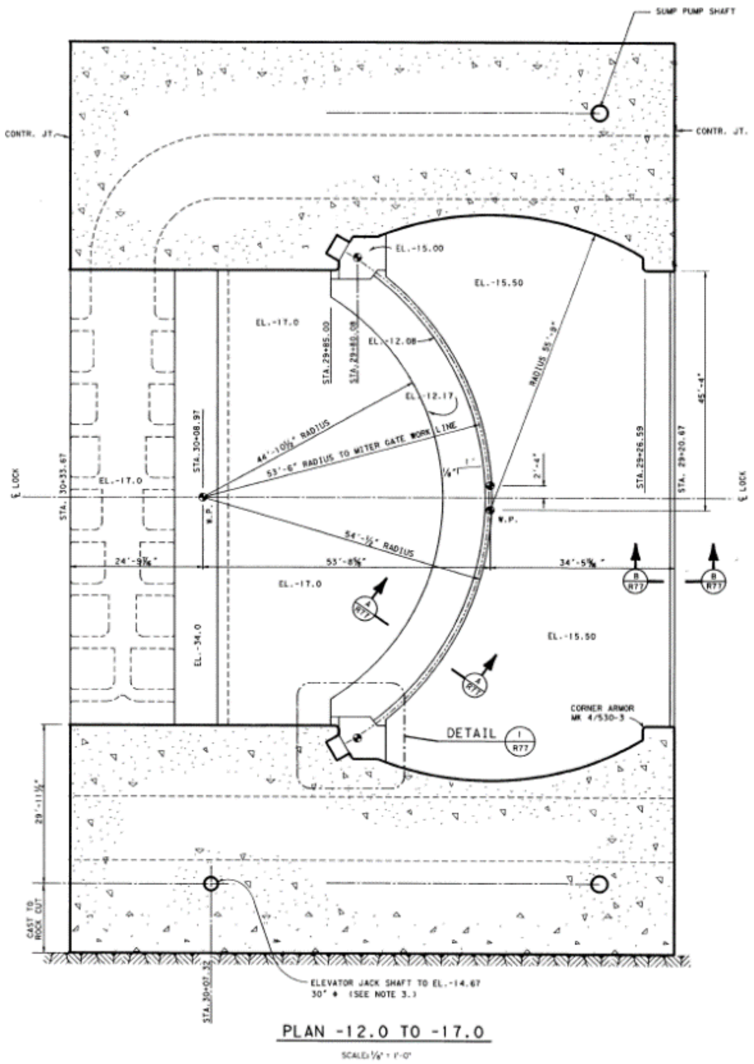

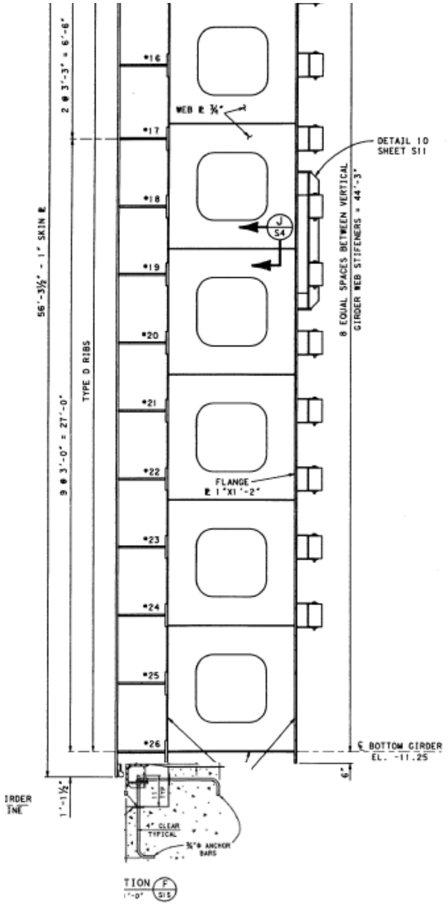

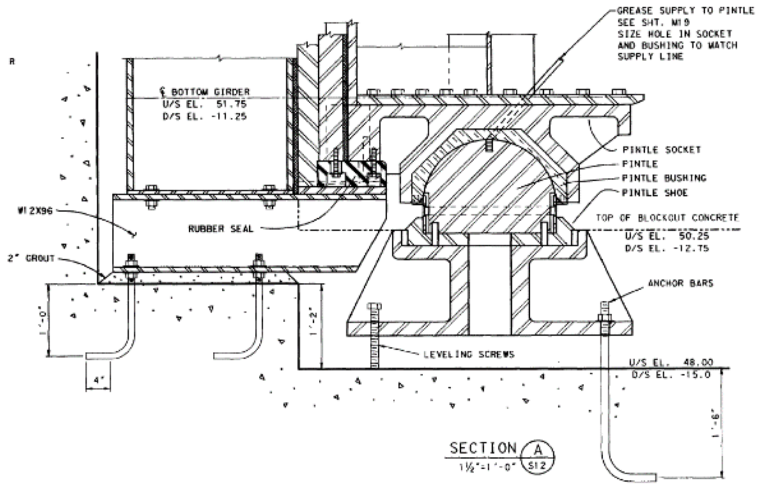

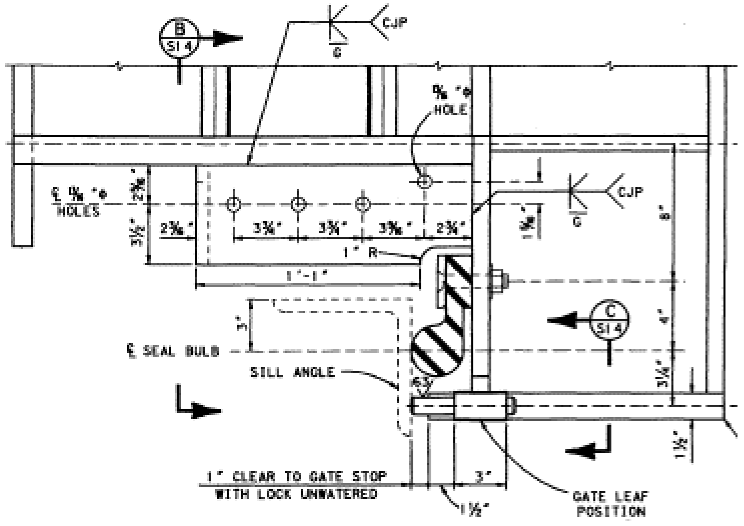

LOCK CHAMBER DEWATERED

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BONNEVILLE SILL DAMAGE

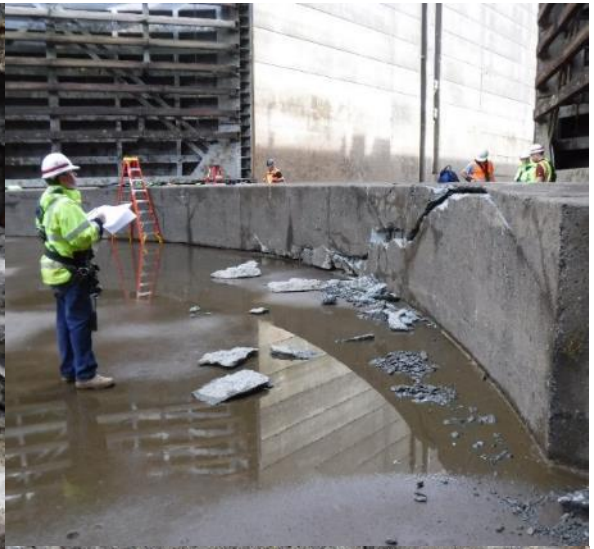
Inspection of damaged sill took place Saturday, September 7, 0900-1030

Primary failure of the downstream sill block from uplift

The south side of the sill uplifted 3.25”, center 1.75”, north side 0”

Sill lost integrity on downstream face with spalled concrete, fractured reinforcement

DOWNSTREAM SILL DAMAGE



BONNEVILLE SILL DAMAGE

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- Significant spalling
- Failed anchorage
- Uplifted sill in contact with the gate
- Evidence of cyclic loading on sill

- Gate components looked OK
- Pintles looked OK
- Operating Machinery had concerns
- Operating recorded data was lacking

BONNEVILLE LOCK DAMAGE SUMMARY

Downstream sill failed

Downstream miter gate appeared undamaged

Mechanical operations of the gate appeared undamaged

NECESSARY REPAIR

- Replace sill
- Minor changes to mechanical equipment and electrical controls

BONNEVILLE DOWNSTREAM SILL DESIGN

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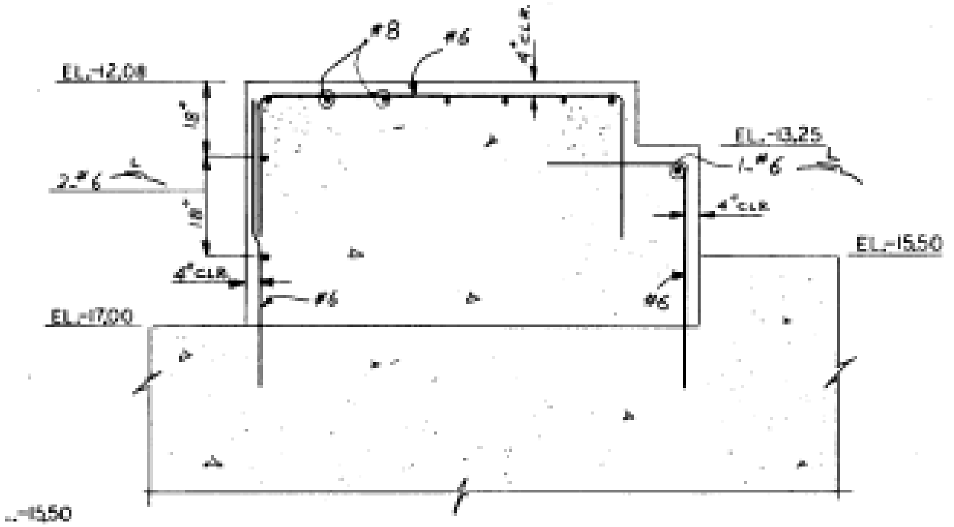
Original Design

- 18” vertical offset
- Anchorage into lock floor elevation -17.0
- Design for shear load only
- No uplift load design



BONNEVILLE DOWNSTREAM SILL DAMAGE
WHY DID IT FAIL?

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Likely cause of failure:

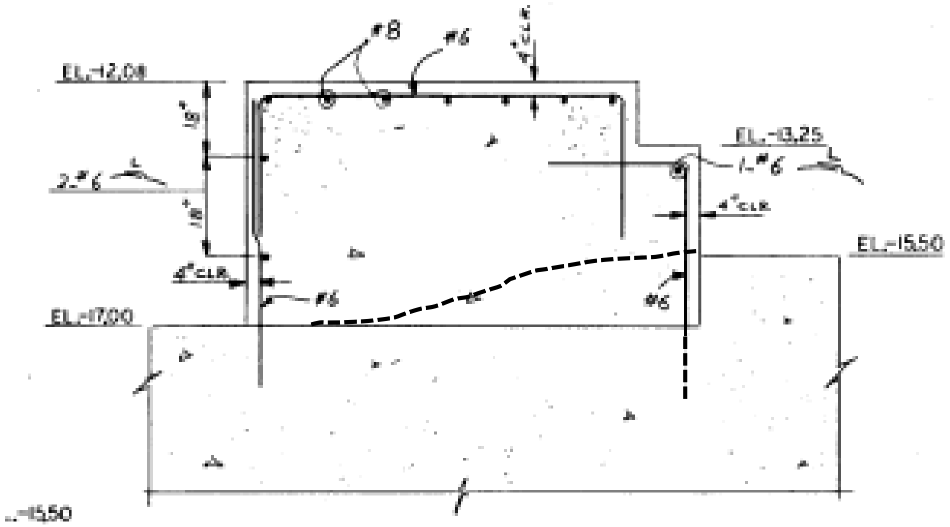
- Downstream sill not constructed according to original design assumptions, upstream interface El. -15.5

- Sill concrete to lock floor interface was likely not prepared adequately

- Upstream anchors were not installed into structural concrete

- Sill was not designed for uplift

- Failure over time from a cyclic loading on poor anchorage and poor bond to original concrete interface allowed uplift and bond failure to progress



EXISTING SILL DEMOLITION

BONNEVILLE LOCK REPAIR ACTIONS

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Design for new downstream sill block:

- Site visit performed September 7
- Remove existing sill (contract drawings produced by September 8)
- Design for full uplift across full width of sill (very conservative, but fast) 450 anchors original design at 8" spacing
- The design was ready by September 10
- Locate new sill according to actual gate position

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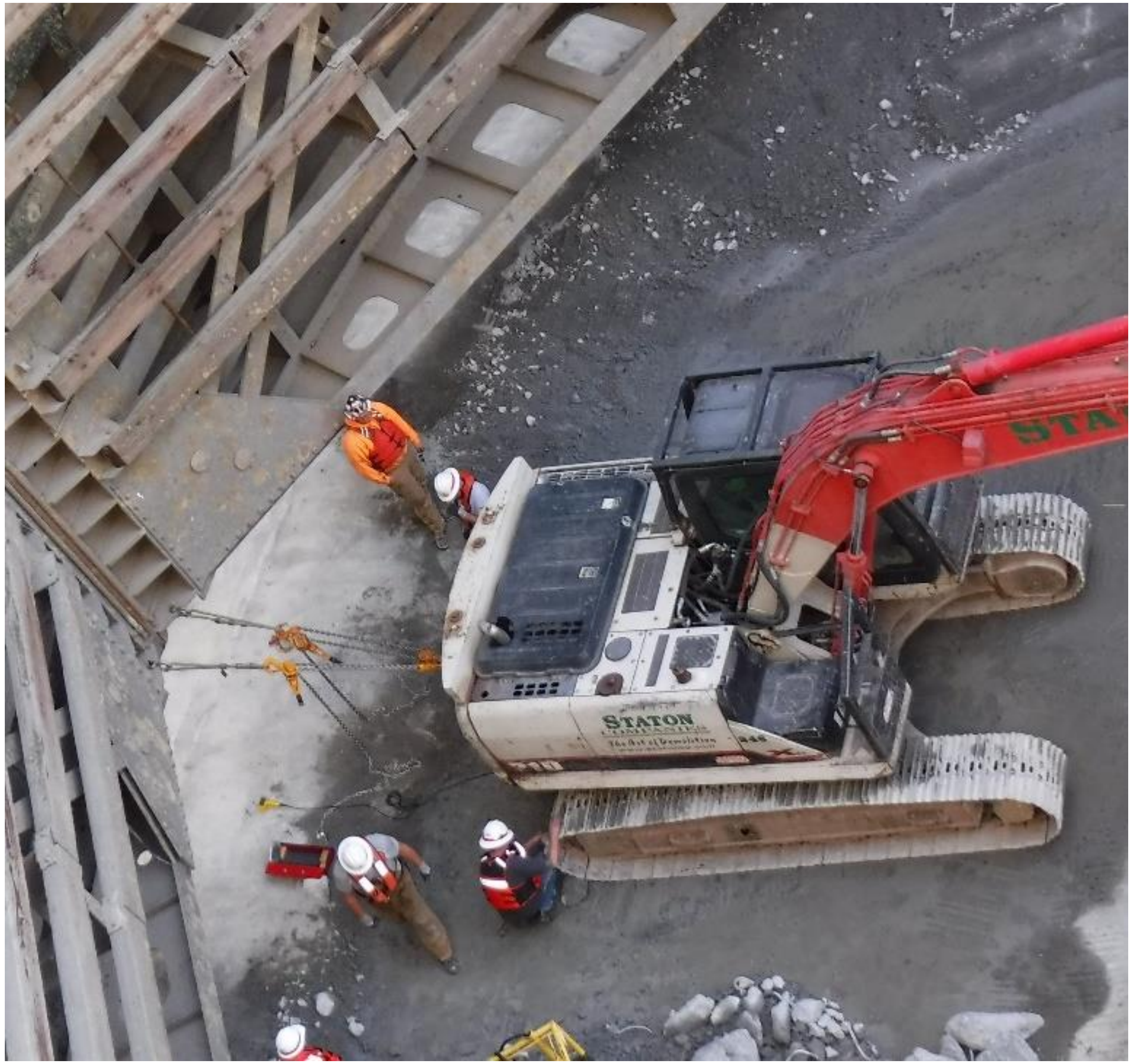
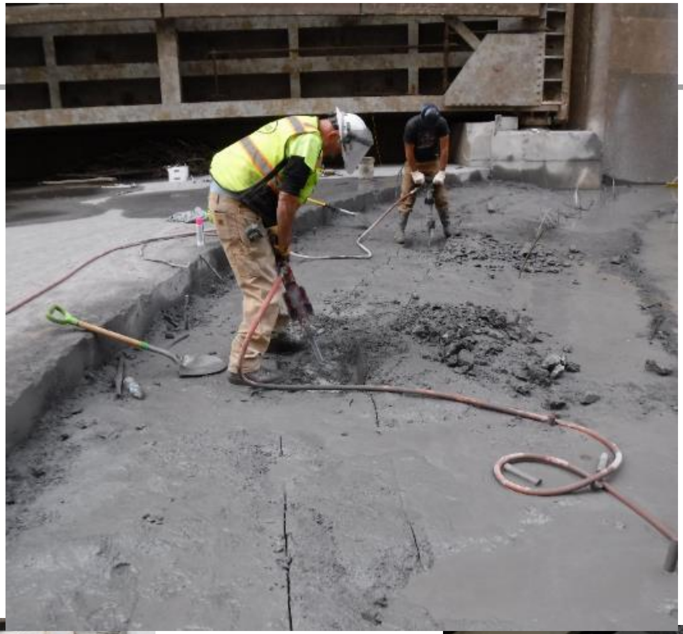
NEW SILL LOCATION

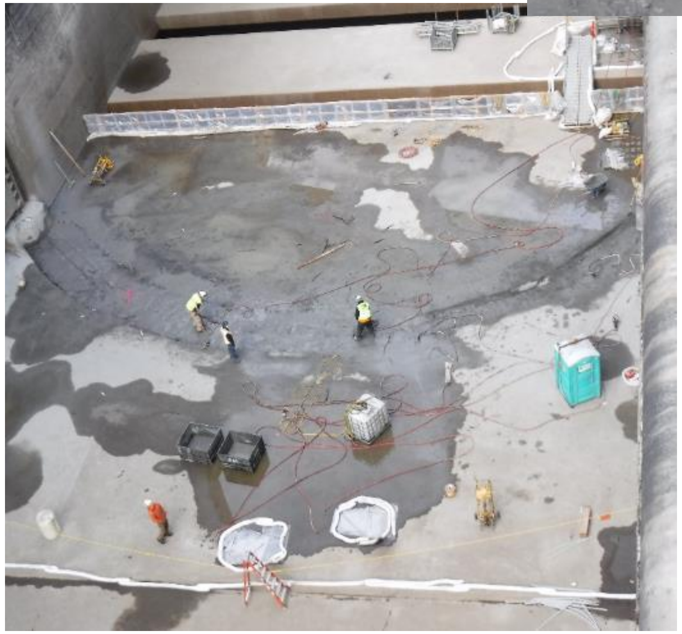
Sill survey September 10 to locate the sill

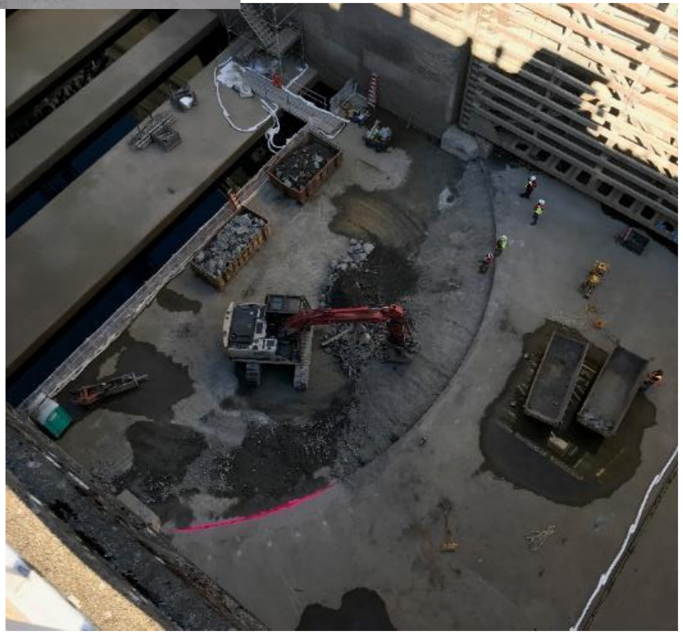
Upstream sill location to be determined on a second stage placement



LOCK CHAMBER PREPARATION FOR NEW SILL







NEW DOWNSTREAM SILL DESIGN

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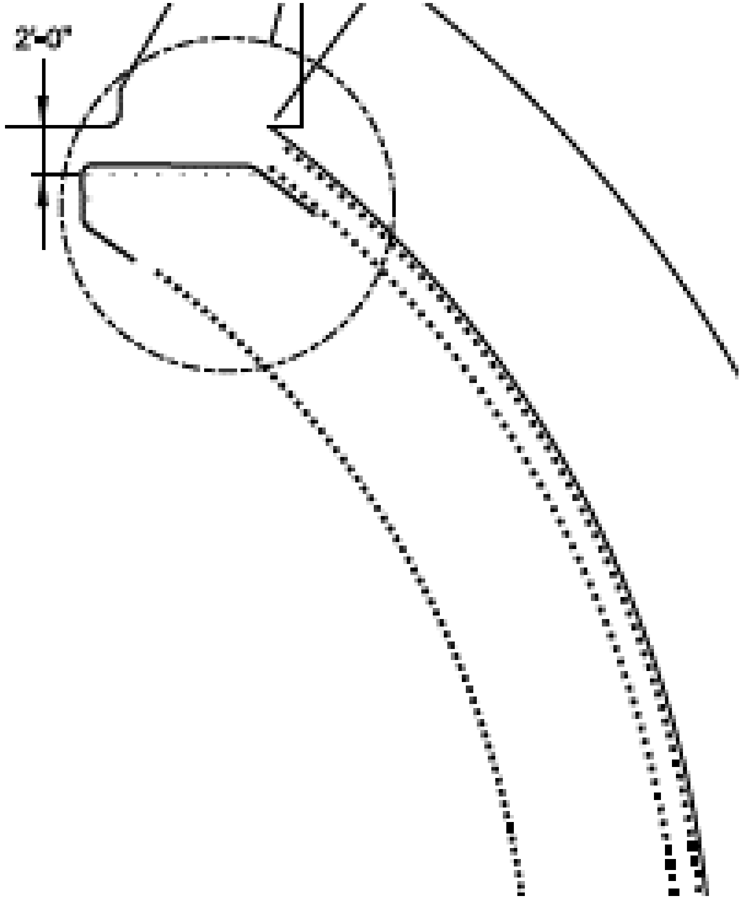
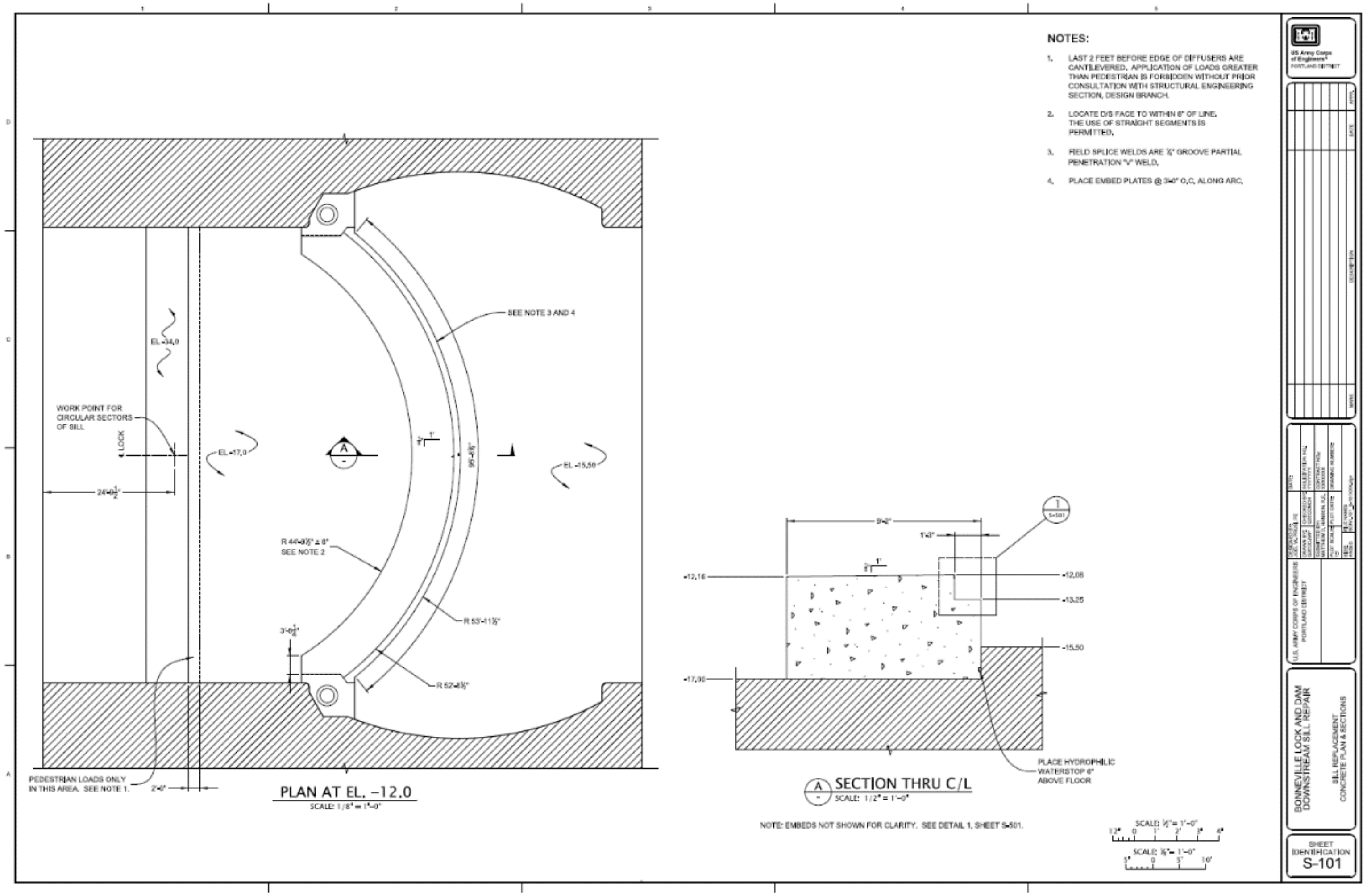
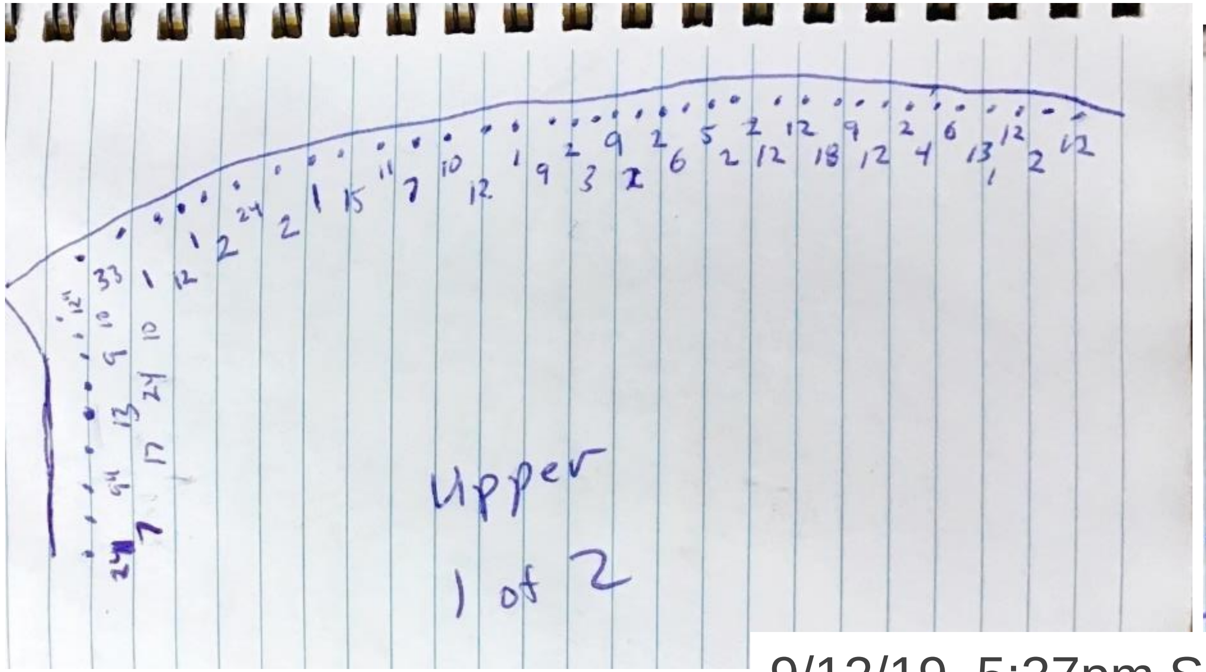
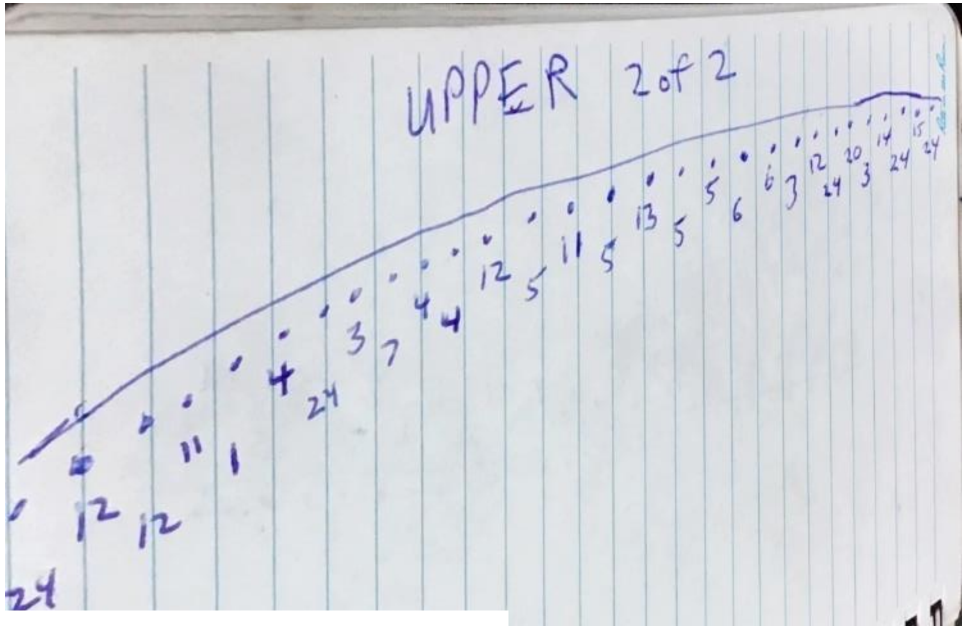




ANCHOR DRILLING PROBLEMS

- Anchor drilling commenced according to the original drilling plan.
- Note 1 hole to 33” depth out of 74 total holes
- The original success rate was about 6%
- The drill holes were hitting rebar at 7, 13, 18, 24 depth





9/12/19, 5:37pm Shad Huber, AAC Superintendent photos of field book

"Last night we completed the keyway demo and drilled 45 more holes with only 2 reaching 33 inches. Total count is as follows:

33 inch holes 25 total holes
20 inch holes 12 total holes

I estimate that we attempted drill over 500 holes in last few days."
-Shad Huber, AAC Superintendent, 9/15/19 7:23AM

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EXISTING LOCK CHAMBER U FRAME

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Why are we having this Problem?
Existing Reinforcement:

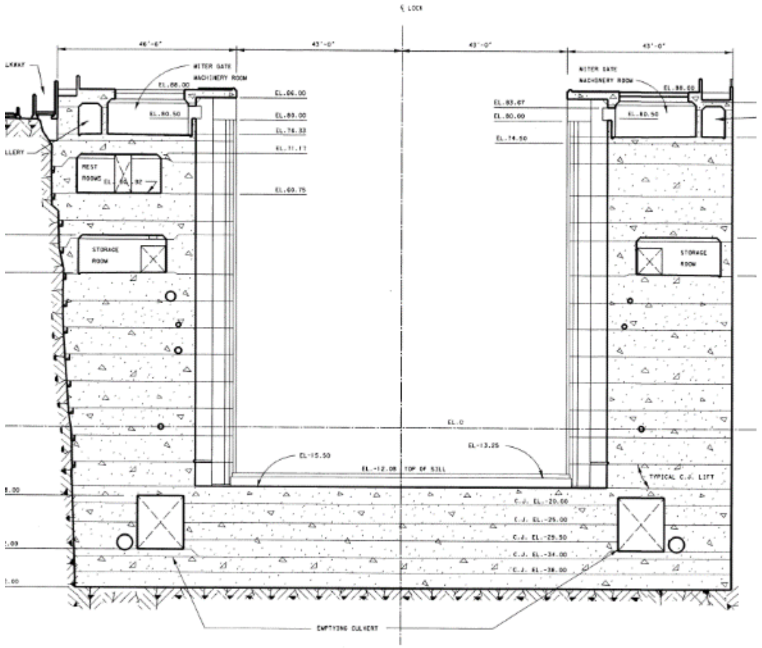
#11 bars 6” on center 4 layers transverse
#8 bars 12” on center 4 layers parallel
2 - 12’ long splice zones

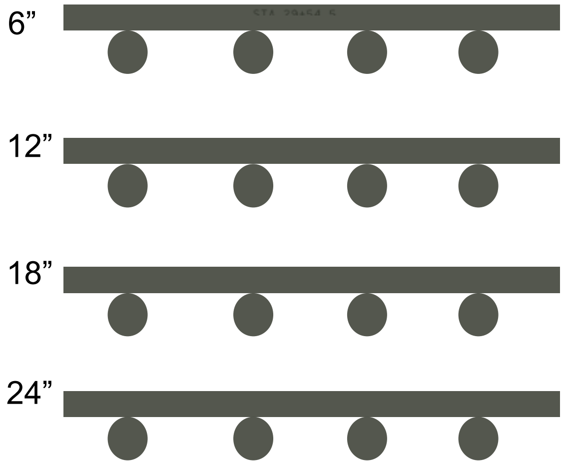
Best case gap 6”-1.41” = 4.59”

Anchor hole = 1.25” x 33”

Layers are not placed on top of each other to any tolerance in general

Percussion drills do not go through reinforcement, OK for Epoxy anchors





ANCHOR DRILLING PROBLEMS

This is the top layer of reinforcement

ANCHOR DRILLING PROBLEMS

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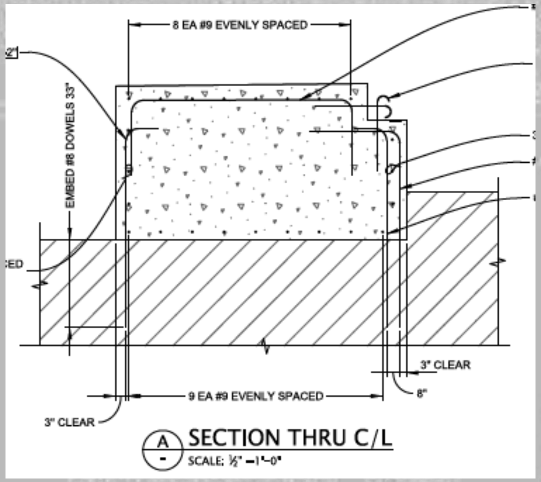
The drilling lack of success led to a change to the original anchorage design.

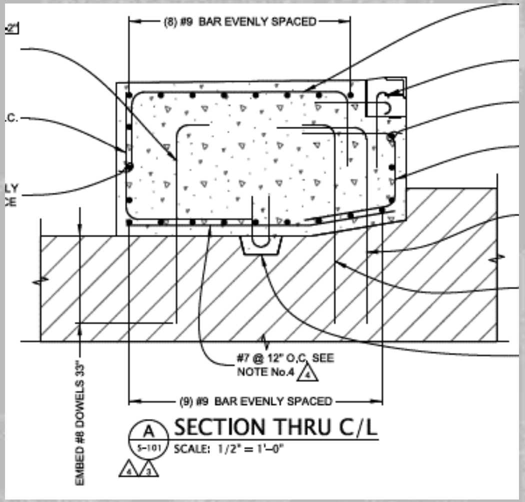
- Can we reduce the number of anchors?
- Can we use partial depth holes?
- Can we drill through reinforcement?

Final determination:

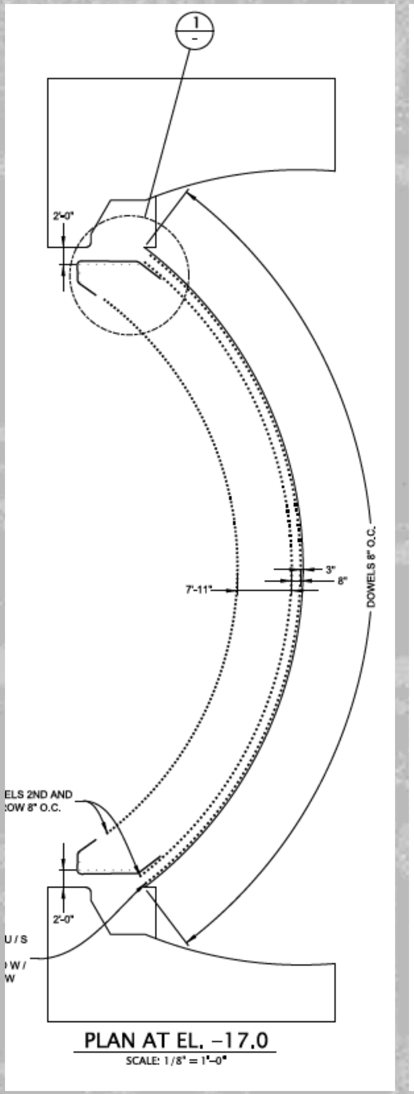
- Vary design load 100% upstream face to 50% the different between Pool and TW @ D/S face
- Use shear key, to take all horizontal load. Also, use shear key to expose reinforcement for drilling
  (Reduced the total number of #8 bar anchors from 450 to 302)
- Cannot use partial depth holes, use full depth anchor (33” depth, 1.25” dia)
  (partial depth holes consider cone breakout with cone overlap)
- Test 1 in 20 anchors to 90% of yield
- Do not damage existing reinforcement
- Drill anchors in zones to allow drilling in areas
- Full depth holes minimum spacing 6”
- Reinforce downstream sill as a beam to span potential gaps in anchors



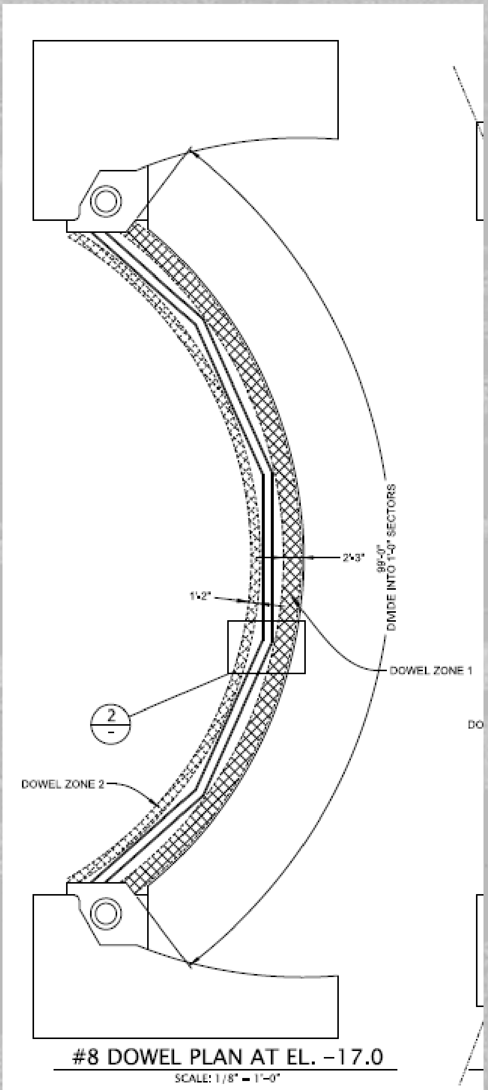
Original Design



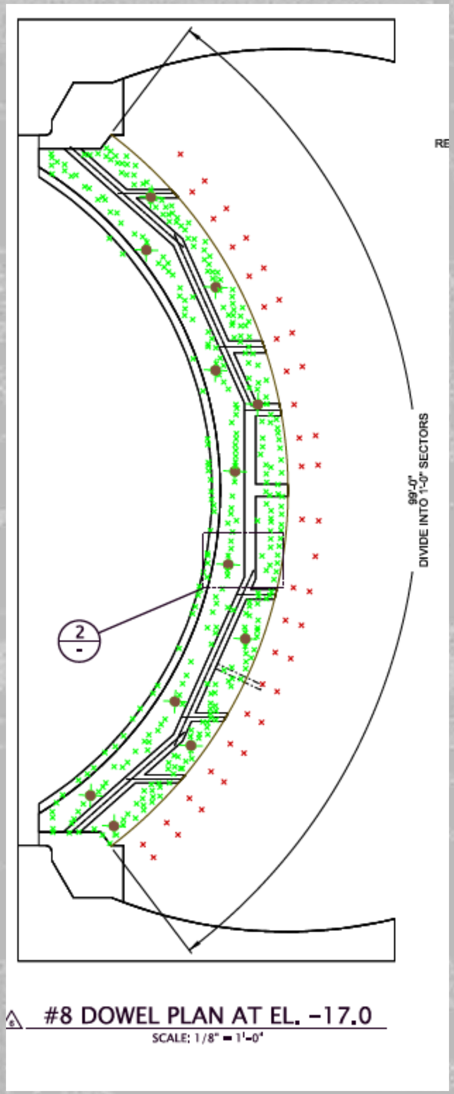
Revised Design



Original Design



Revised Design



Final As-Built

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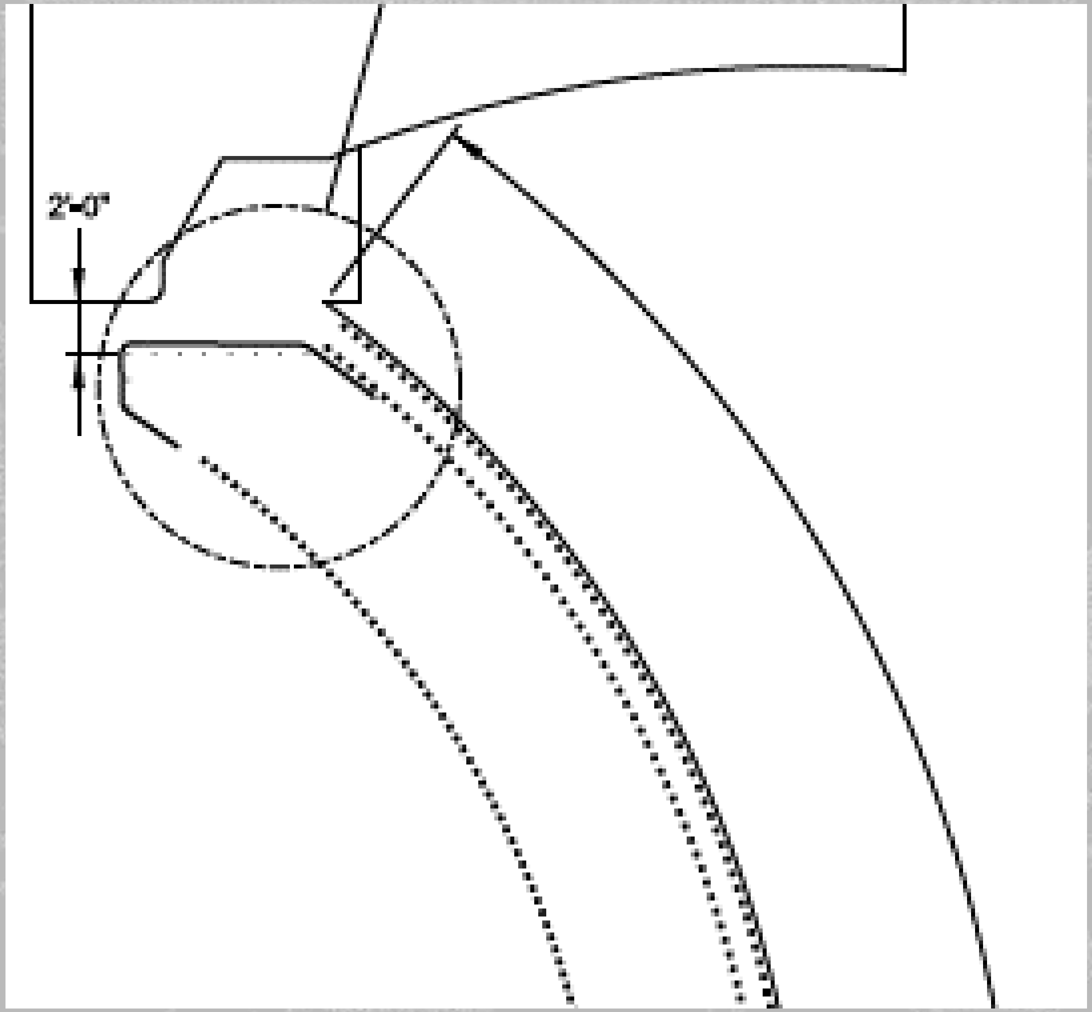
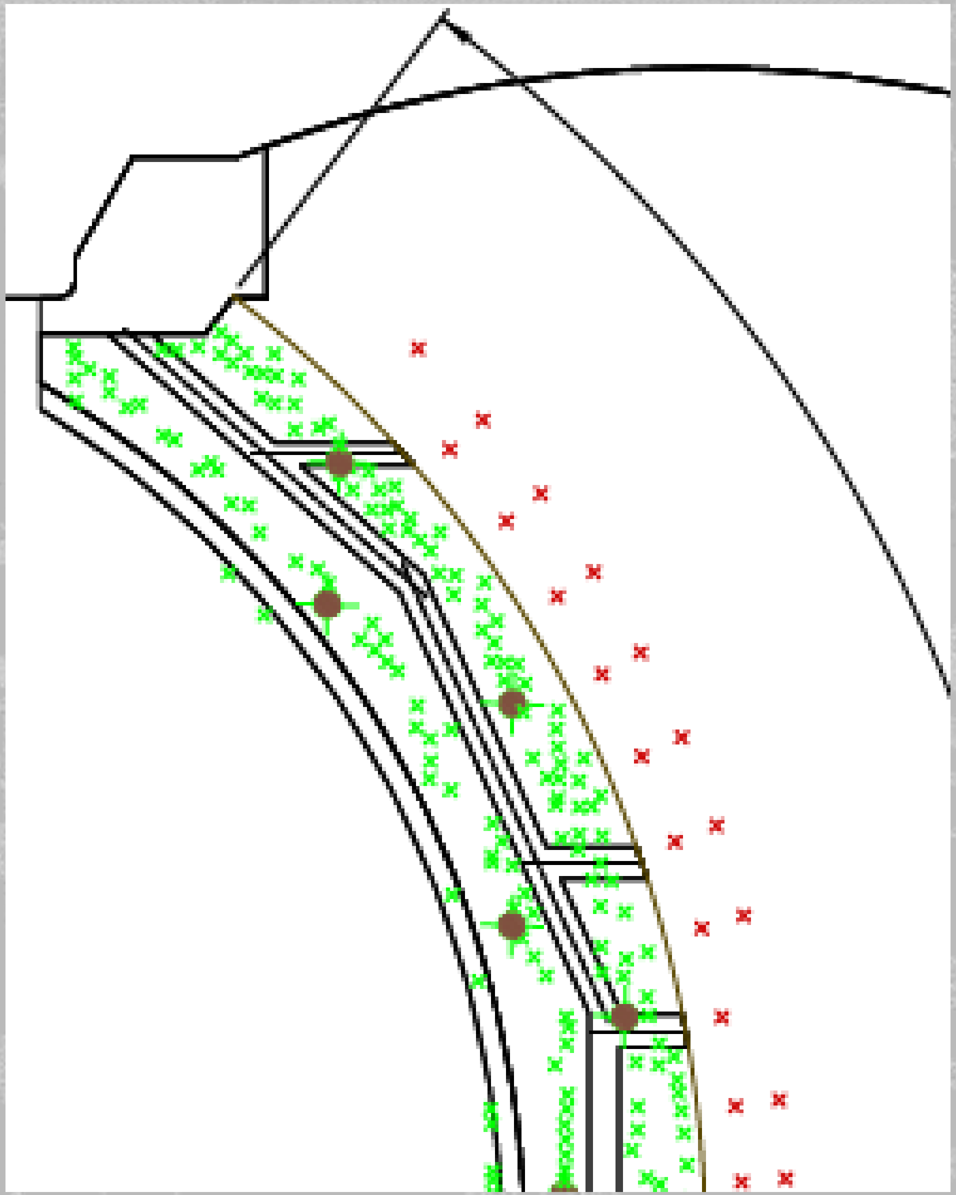


Original Design



Final As Built

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DRILLING CHALLENGES REQUIRED ADAPTATION

Anchor holes were drilled in "Quadrants" and "Zones"






12 total quadrants, R1-R6, L1-L6
16 holes per U/S zone, 8 holes per D/S zone.







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REINFORCEMENT ANCHORS, CAGE, AND PLACEMENT

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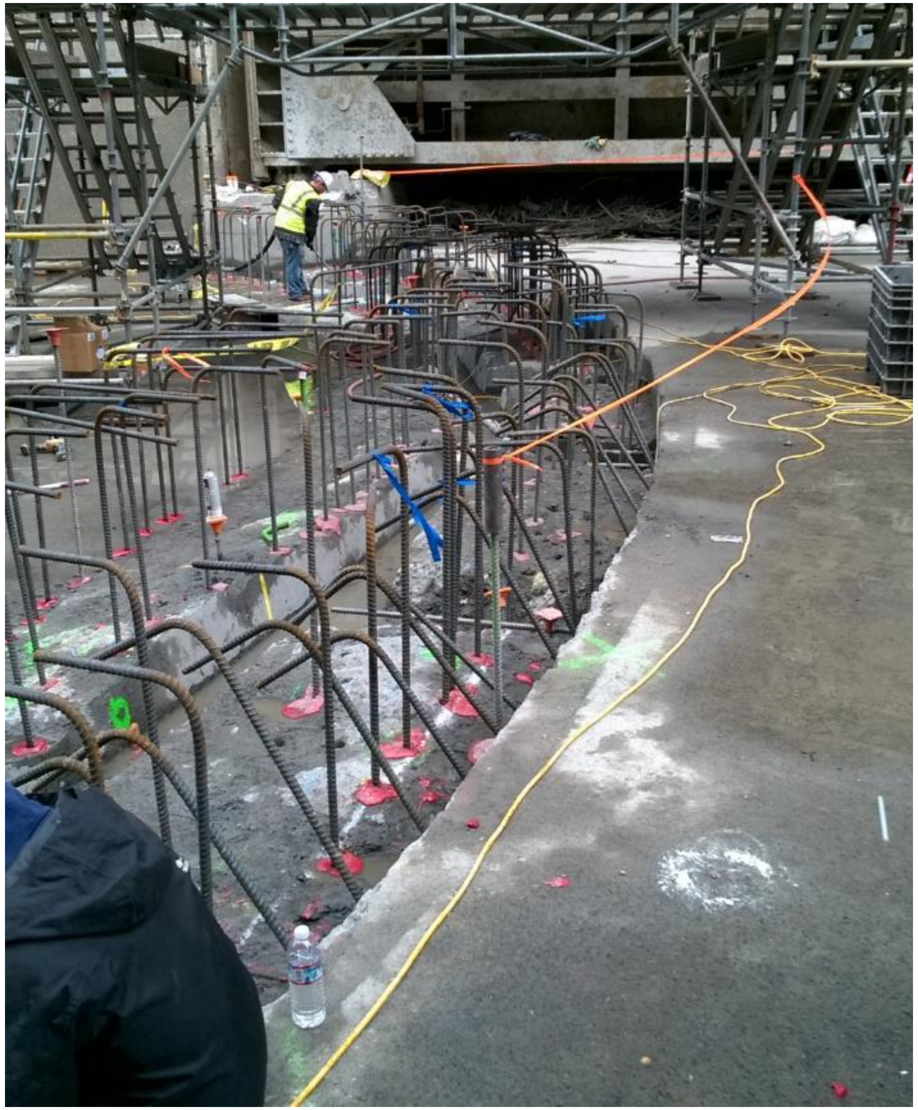
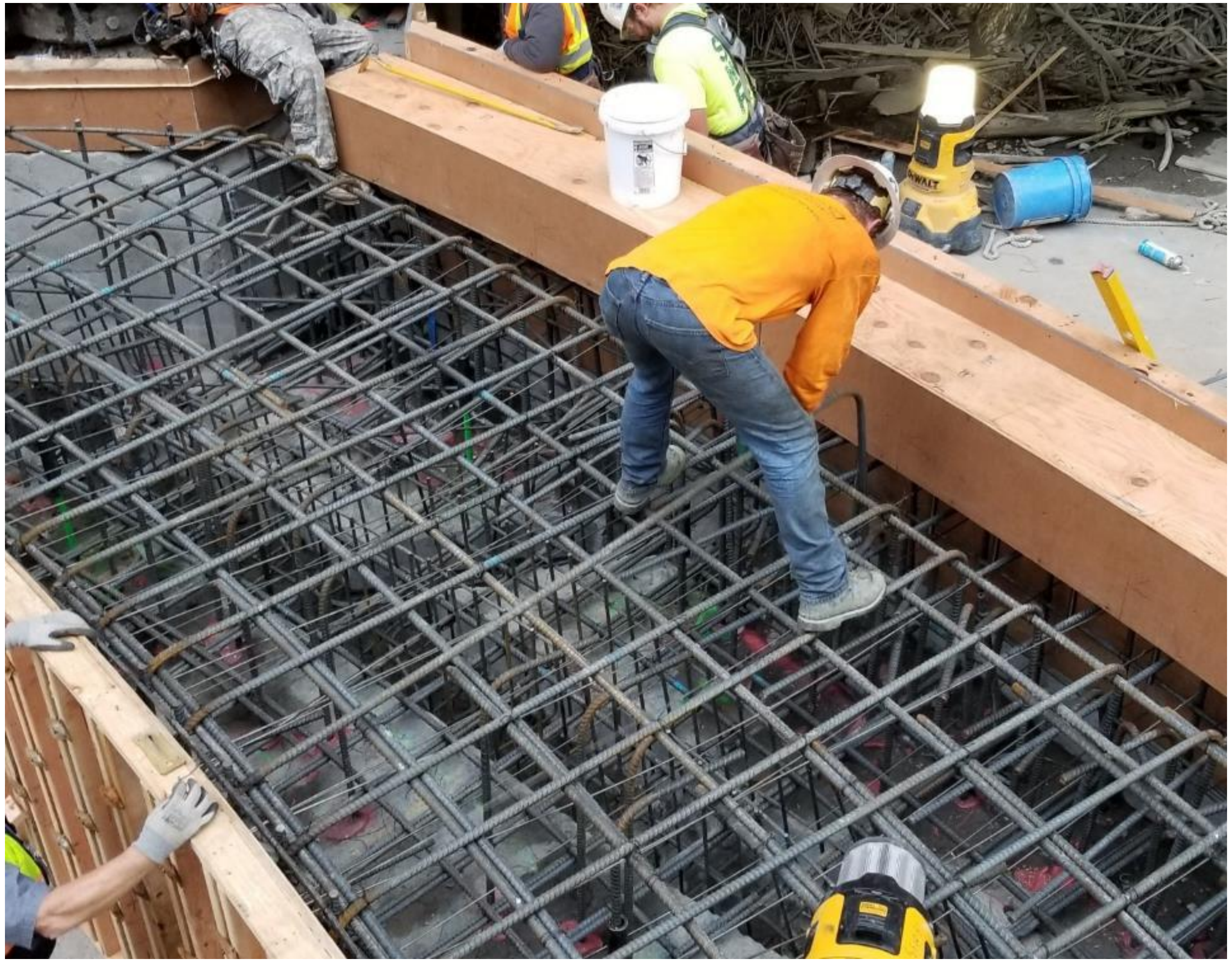



REINFORCEMENT ANCHORS, CAGE, AND PLACEMENT



SILL ANGLE PLACEMENT

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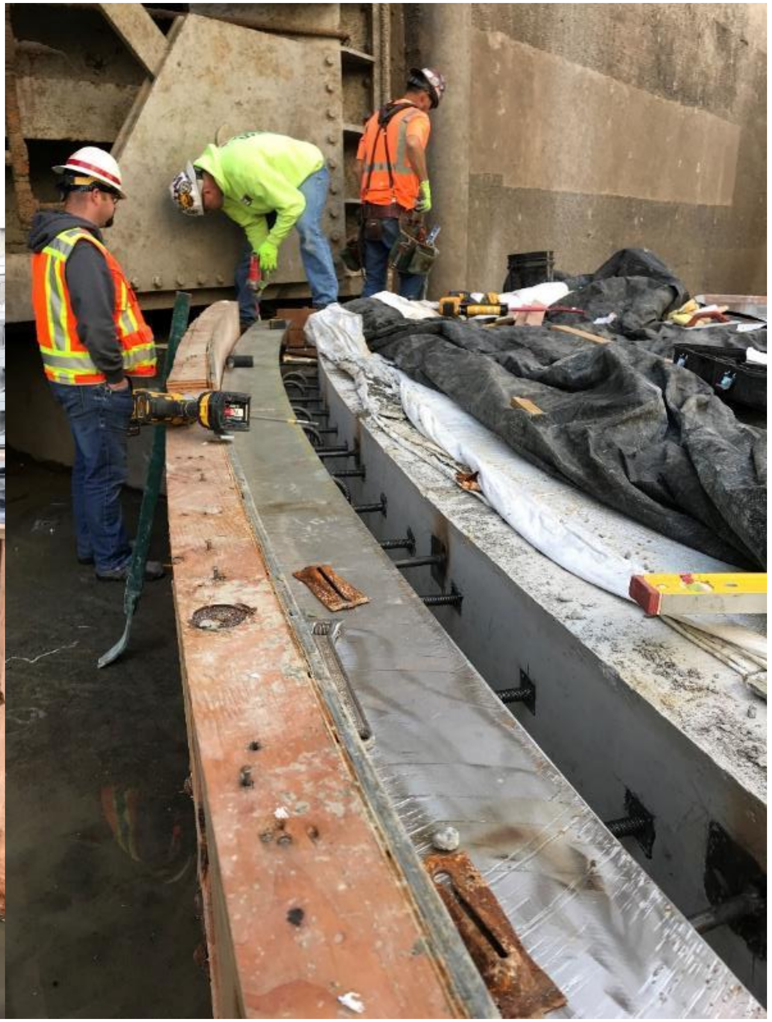
Grouting performed Wednesday, September 25
24-hour concrete test was at 1100 psi

Would we make 4000 psi design strength?



CONCRETE STRENGTH IN SILL BLOCK

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Compressive Strength of Concrete Cylinders									ASTM C 39
Specimen ID	Date Tested	Age (Days)	Diameter (in)	Length (in)	Area (in^2)	Type of Cap	Maximum Load (lbf)	Fracture Type / Remarks	Compressive Strength (psi)
07022433-8-C5\1	09/24/19	1	4.00	8.00	12.57	U	45070	3 FC	3590
07022433-8-C5\2	09/24/19	1	3.98	8.00	12.44	U	53150	4 FC	4270
07022433-8-C5\3	09/25/19	2	4.00	8.00	12.57	U	62430	5 FC	4970
07022433-8-C5\4	09/25/19	2	4.00	8.00	12.57	U	63490	4 FC	5050
07022433-8-C5\5	09/26/19	3	4.00	8.00	12.57	U	71260	3 FC	5670
07022433-8-C5\6	09/26/19	3	4.01	8.00	12.63	U	71940	5 FC	5700
07022433-8-C5\7	09/27/19	4	4.00	8.00	12.57	U	76906	2 FC	6120
07022433-8-C5\8	09/27/19	4	4.00	8.00	12.57	U	82121	3 FC	6530
07022433-8-C5\9		Hold						FC	
07022433-8-C5\10	09/30/19	7	4.00	8.00	12.57	U	82244	4 FC	6540
07022433-8-C5\11	10/21/19	28	4.00	8.00	12.57	U	101010	4	8040
07022433-8-C5\12	10/21/19	28	4.00	8.00	12.57	U	101365	3	8070
07022433-8-C5\13	10/21/19	28	4.00	8.00	12.57	U	106649	4	8490
07022433-8-C5\14		Hold							
								Average 28 Day Compressive Strength (psi)	8200
								Required Strength (psi)	5000

GROUT STRENGTH IN SECOND PLACEMENT

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Compressive Strength of Concrete Cylinders — ASTM C 39

Specimen ID	Date Tested	Age (Days)	Diameter (in)	Length (in)	Area (in²)	Type of Cap	Maximum Load (lbf)	Fracture Type / Remarks	Compressive Strength (psi)
07022433-11-C1\1	09/26/19	1	4.00	8.00	12.57	U	1050	3 FC	80
07022433-11-C1\2	09/26/19	1	4.00	8.00	12.57	U	1260	3 FC	100
07022433-11-C1\3	09/26/19	1	4.00	8.00	12.57	U	18560	4 FC	1480
07022433-11-C1\4	09/27/19	2	4.00	8.00	12.57	U	35310	4 FC	2810
07022433-11-C1\5	09/27/19	2	4.00	8.00	12.57	U	56047	5 FC	4460
07022433-11-C1\6	09/28/19	3	4.00	8.00	12.57	U	66380	4 FC	5280
07022433-11-C1\7	10/02/19	7	4.00	8.00	12.57	U	91897	5	7310
07022433-11-C1\8	10/02/19	7	4.01	8.00	12.63	U	91199	3	7220
07022433-11-C1\9		Hold				U			
07022433-11-C1\10		Hold							
07022433-11-C1\11	10/23/19	28	4.00	8.00	12.57	U	147290	5	11720
07022433-11-C1\12	10/23/19	28	4.00	8.00	12.57	U	151223	3	12030
07022433-11-C1\13	10/23/19	28	4.00	8.00	12.57	U	150695	3	11990
07022433-11-C1\14	09/27/19	2	4.00	8.00	12.57	U	57056	4 FC	4540
								Average 28 Day Compressive Strength (psi)	11920
								Required Strength (psi)	5000

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BONNEVILLE NAVIGATION LOCK SILL REPAIR TIMELINE

SEPTEMBER 5
Lock operators observe issues closing the lock gate and cease lock operations for inspection.

SEPTEMBER 6
Engineers conclude there is a leak in the lock. Contract awarded to de-water and inspect.

CONTRACT 1

SEPTEMBER 7
Lock is de-watered for inspection.

CONTRACT 2

SEPTEMBER 9
Engineers determine the concrete sill under downstream gate failed. Sill demolition begins.

CONTRACT 3

SEPTEMBER 11
Emergency contract awarded to construct new sill.

CONTRACT 4

SEPTEMBER 12
Demolition and clean-up of sill complete. Drilling through concrete for rebar begins.

CLOSURE → INSPECTION → DEMOLITION → ENGINEERING → CONSTRUCTION → COMMISSIONING → REOPENING

STAKEHOLDER ENGAGEMENT LEGEND

- Press Release
- Social Media
- Media Advisory
- Media Day/Open House
- Industry Partner Calls
- Teleconference

5 SEP 19 Lock Closure	PHASE 1 Inspection	PHASE 2 Demolition	PHASE 3 Engineering	PHASE 4 Construction	PHASE 5 Commissioning	27 SEP 19 Lock Reopening
	Public Affairs / Media & Stakeholder Engagment					

SEPTEMBER 16
Cutting and demolition to expose existing reinforcement.

SEPTEMBER 19
Drilling of holes for rebar complete.

SEPTEMBER 20
Rebar epoxy and anchoring installation complete.

SEPTEMBER 23
22 concrete trucks place 176 cubic yards of concrete to form the new sill. Concrete cures.

SEPTEMBER 26
Concrete placement complete. Metal seal fitted and grouted in place.

SEPTEMBER 27
Construction complete and return to service. First barges enter at 7:30 p.m. 23 barges pass in 1 day (typically 7 per day).

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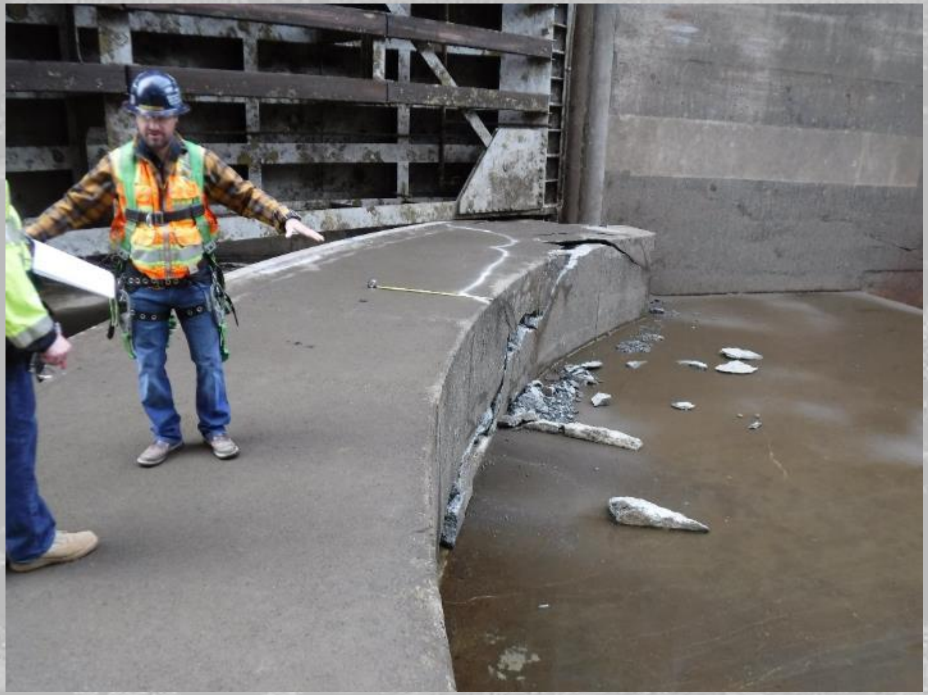
LESSONS LEARNED

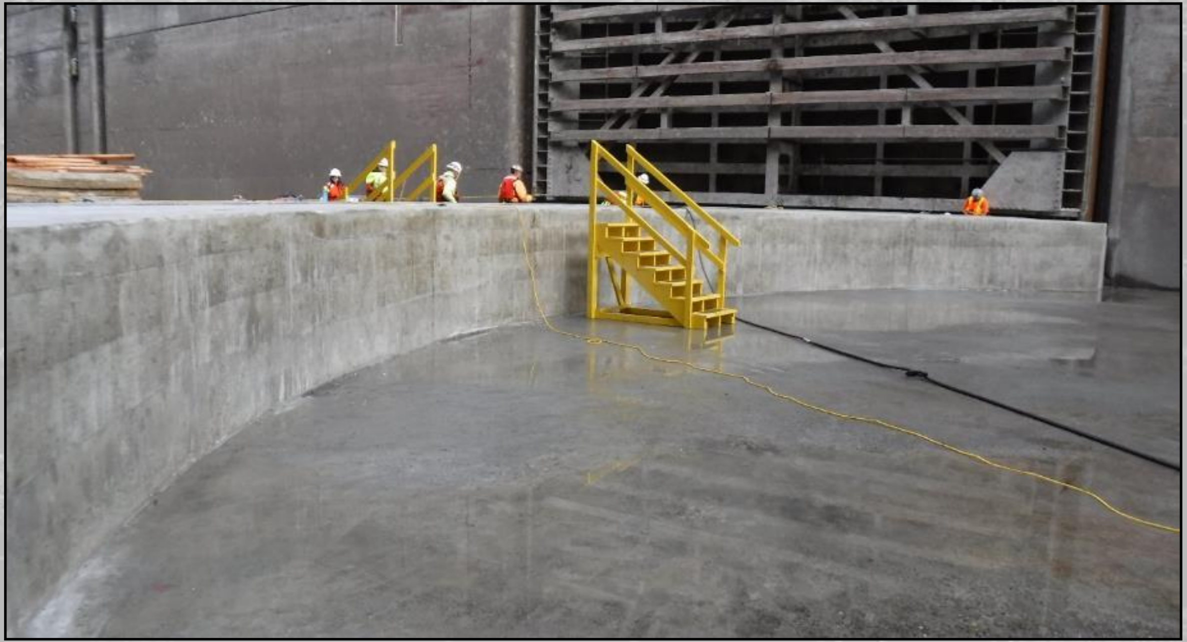
Could this failure have been avoided?

- Construction change to the design
- Different actual load than assumed
- Failure to prepare concrete properly, which produced a poor bond
- Could we have seen this during the 2017 inspection?
- Instrumentation to diagnose problems is being added

BONNEVILLE DOWNSTREAM SILL BLOCK

- The lock opened September 27 at 1900
- Great team; many different members
- Single goal





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