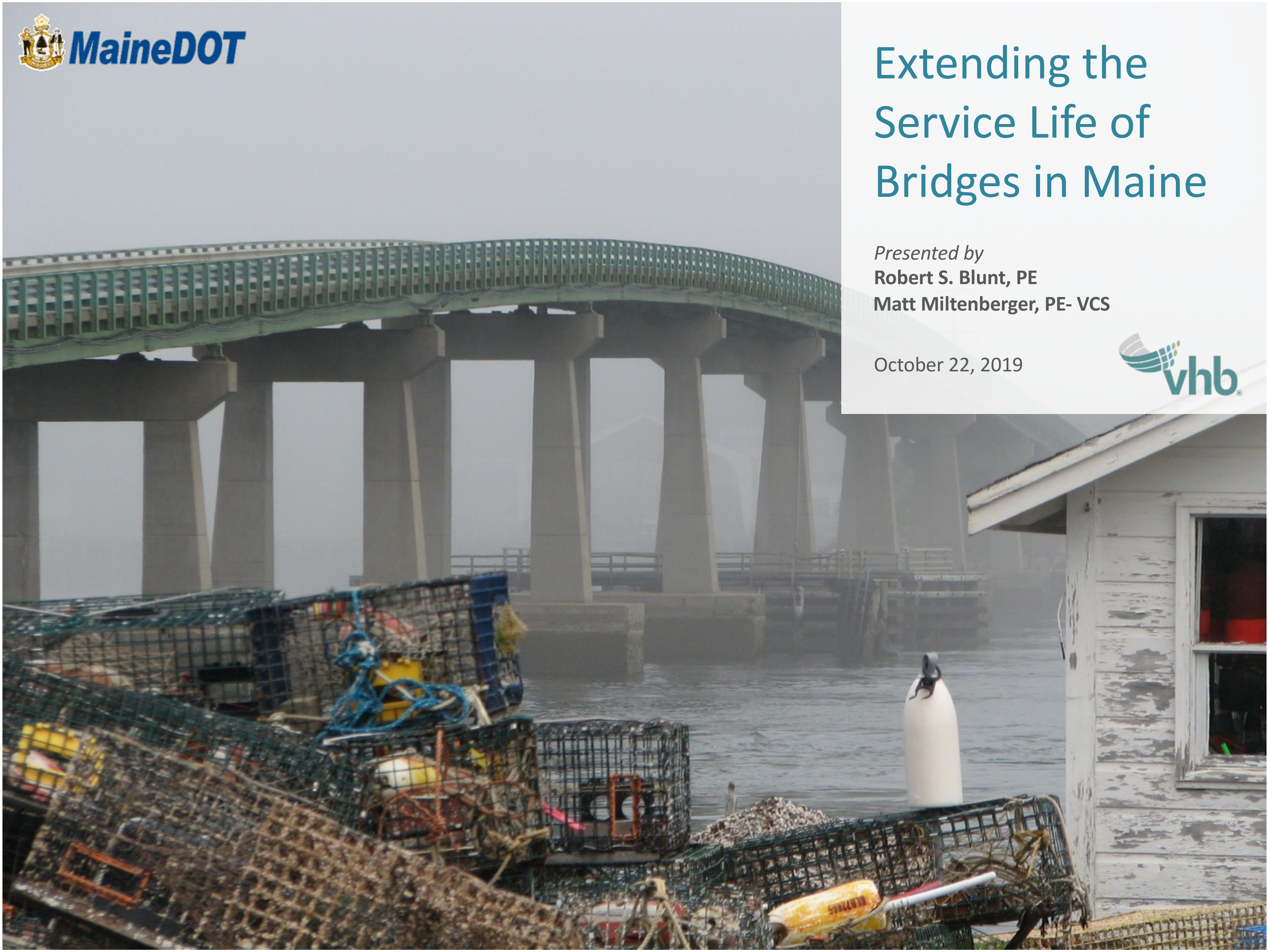


Extending the Service Life of Bridges in Maine

Presented by

Robert S. Blunt, PE

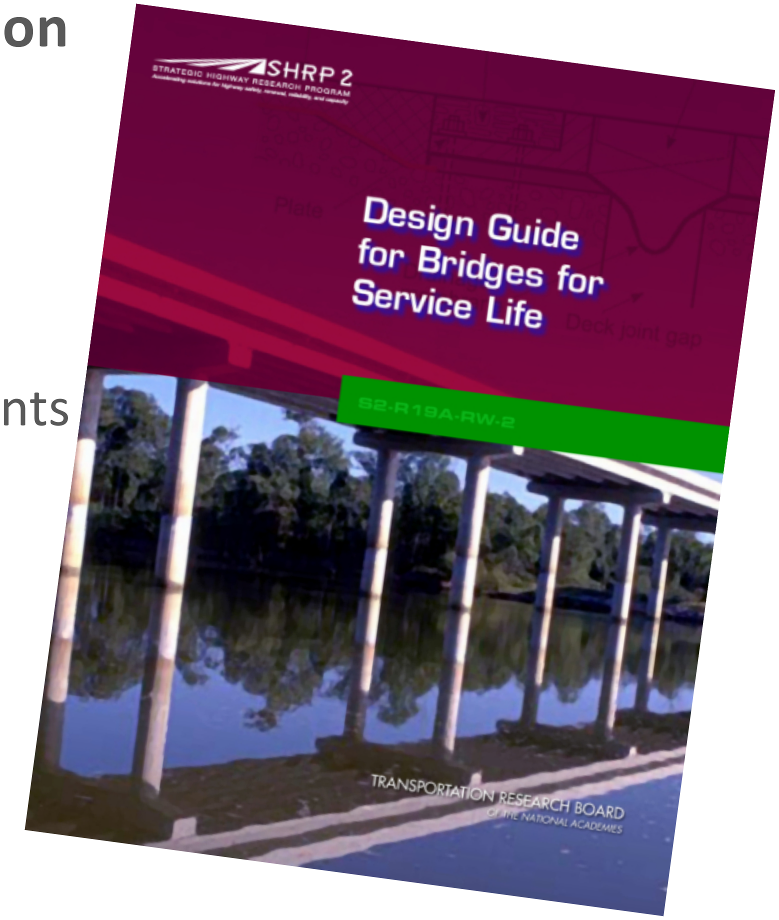
Matt Miltenberger, PE- VCS

October 22, 2019

SHRP2– Service Life Design of Bridges (R19A)

Goals of Maine’s R19A Participation

- Save $ bridges that last longer and require less maintenance
- Reduce user impacts
- Balance the life of bridge components



SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

Design Guide for Bridges for Service Life

S2-R19A-RW-2

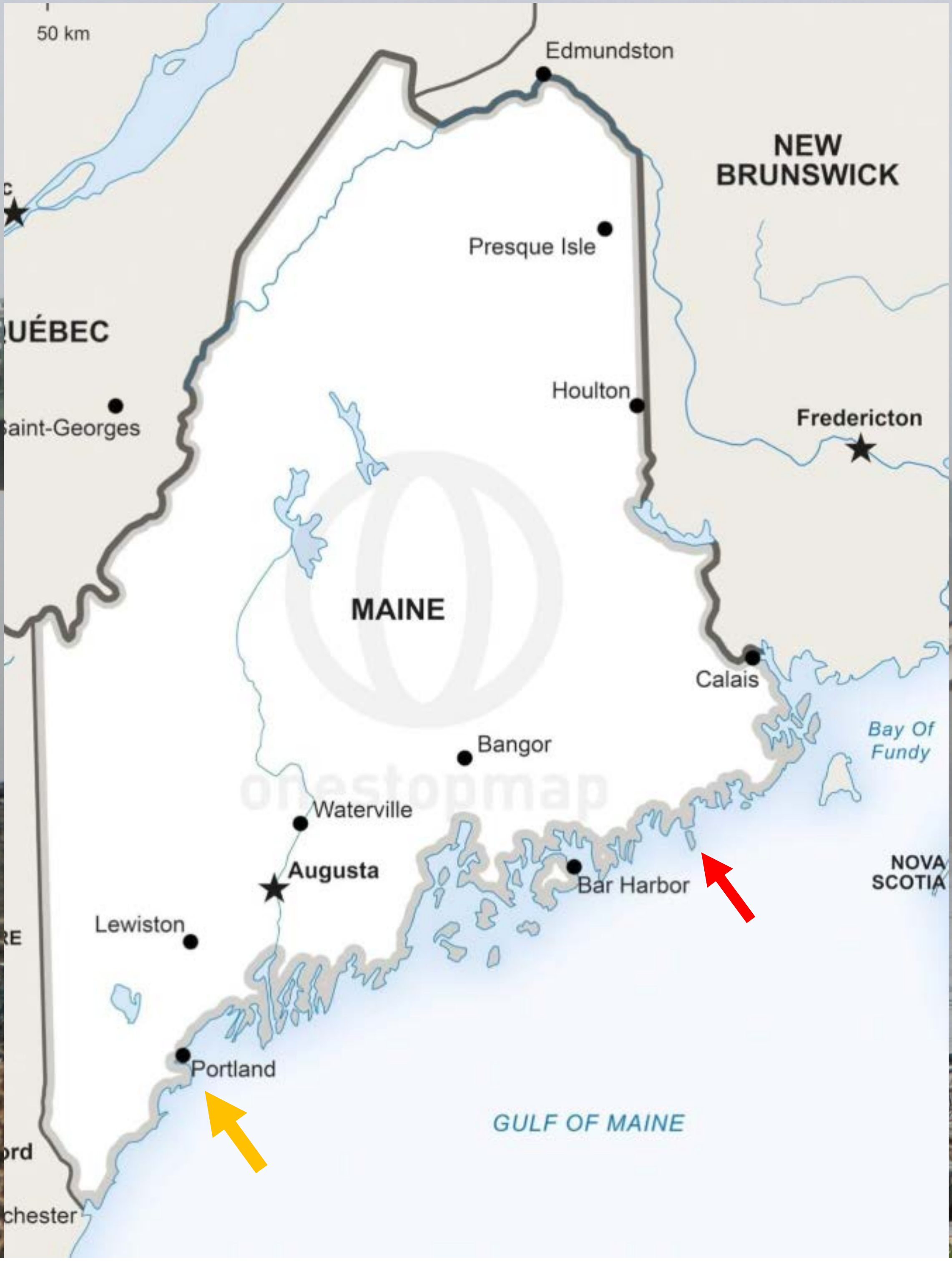
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Meeting Our Goal

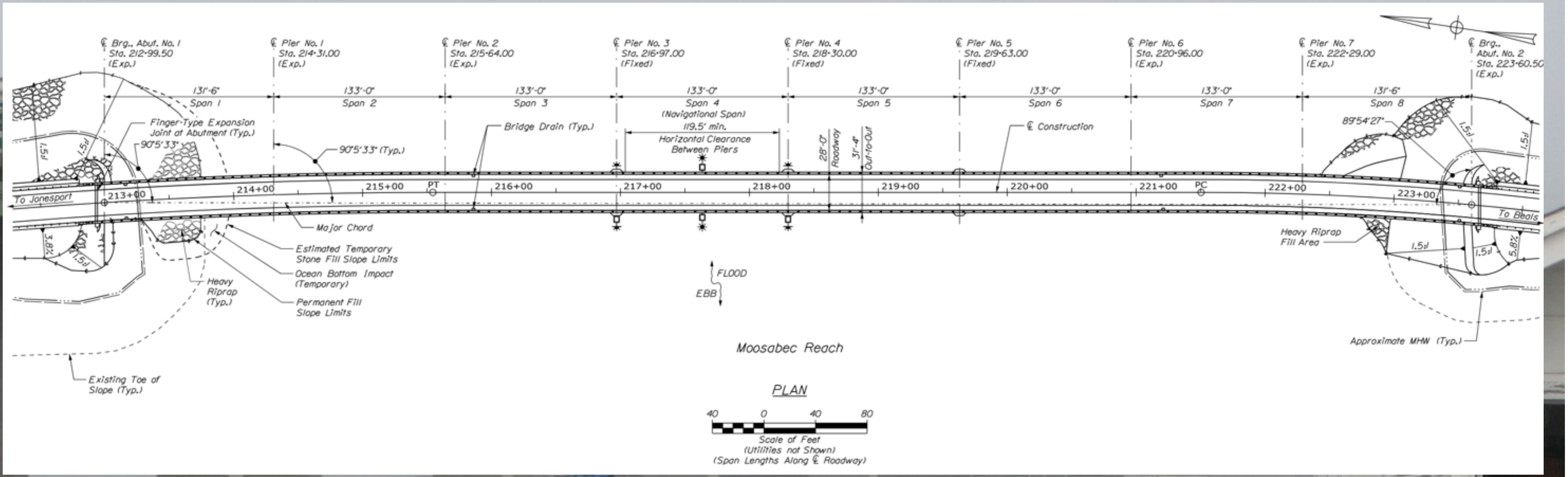
- Service Life Design Guide - R19A Lead Adopter State
  - A more scientific approach
- State-of-the-art materials
  - Reinforcing
  - Coatings
  - Composites
- Learning from the past
  - Bridge type selection
  - Better concrete
  - Jointless bridges
  - Better drains

Extending the Service Life of Bridges in Maine

- **Jonesport-Beals Bridge**
  - Environmental Challenges
  - Detailing and Design- deemed to satisfy
  - SHRP2 Grant Recipient – Lead Adopter State
    - Durability Review & Consultation
    - Testing Work Plan- Study
- **Concrete Durability Study**
  - Objectives
  - Evaluate Source Materials
  - Existing Bridge- What can we learn
  - Laboratory Work
    - MaineDOT Mix properties
  - Learning Outcomes

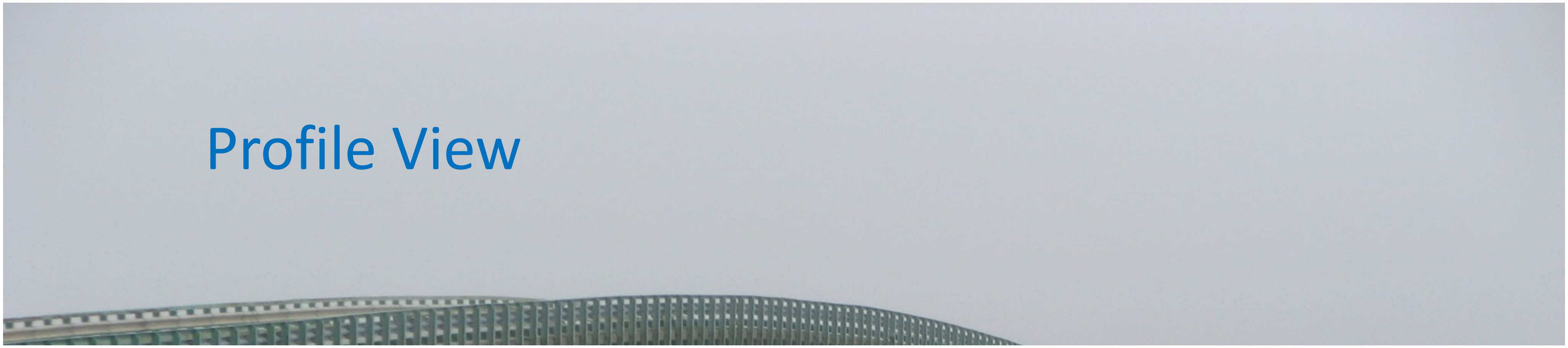

50 km
Edmundston
NEW BRUNSWICK
Presque Isle
UÉBEC
aint-Georges
Houlton
Fredericton
MAINE
Calais
Bay Of Fundy
Bangor
Waterville
Augusta
Bar Harbor
NOVA SCOTIA
Lewiston
RE
Portland
GULF OF MAINE
ord
chester

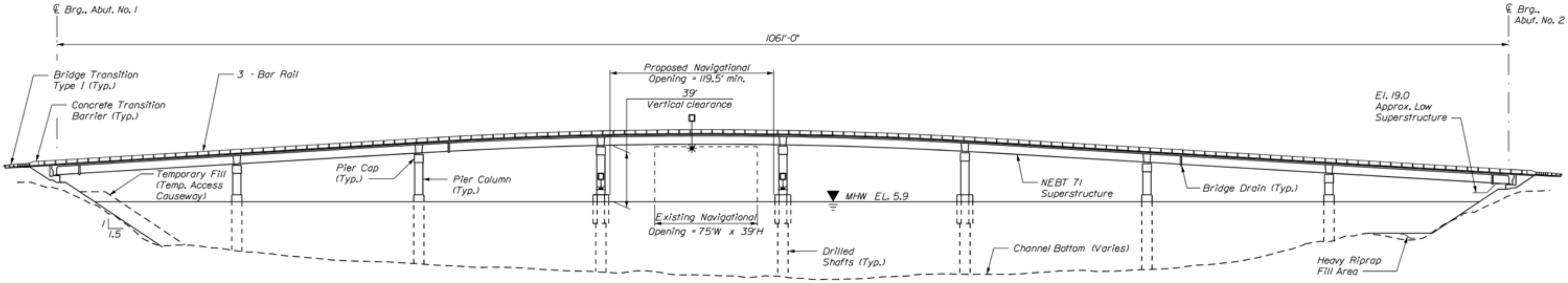
Plan View



- 7 Piers
- 8 Spans
- 1062ft

Profile View

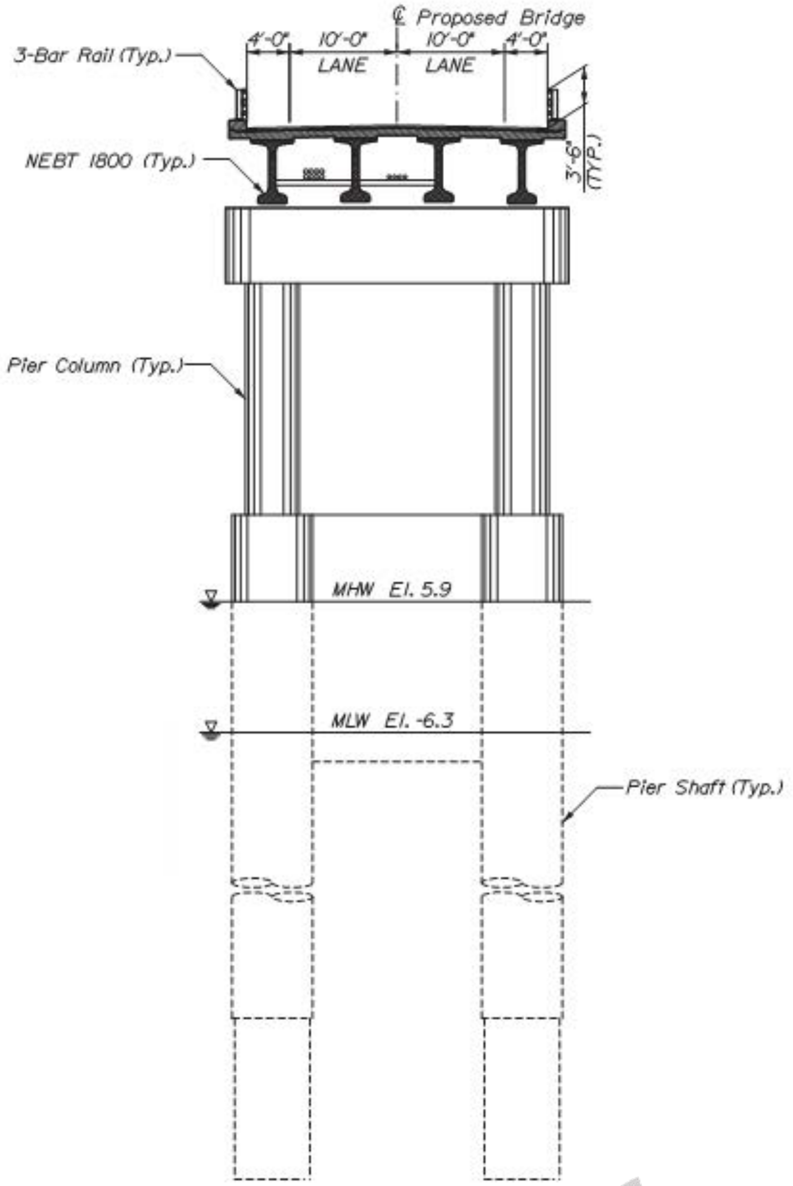




- 39ft Nav. Clearance
- 40ft Water Depth
- Founded on Drill Shafts

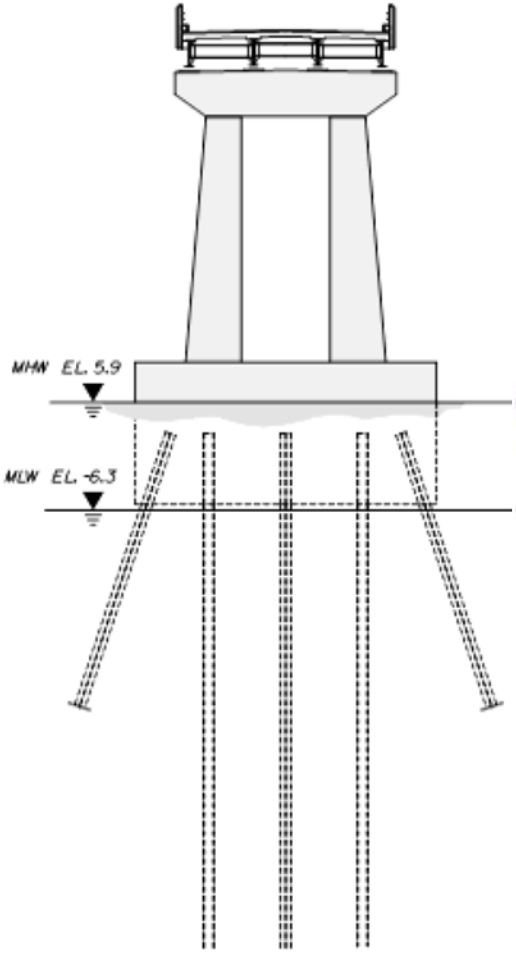
Corrosion Threat Mitigation

- Steel corrosion- failure mechanism in concrete bridges
- Early design - avoid corrosion
  - Avoidance Detailing Practices
    - Deck end and joint details
    - Encased beam ends
    - Increased Clear Cover
  - Beams
    - Zero tension under service conditions
    - Clear protective coating
    - Targeted approach to rebar
  - MaineDOT Standard Specifications
    - Low permeability concrete mixes
    - Reduction of concrete cracks
    - Addition of dci-s as applicable
    - ASR Mitigation- Risk Assesment

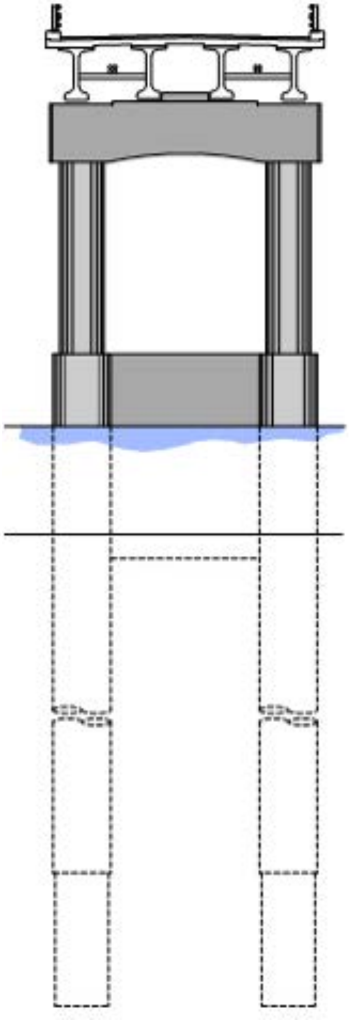


TYPICAL SECTION
(PIERS 1, 2, 6 AND 7)

Corrosion Regions & Design Options



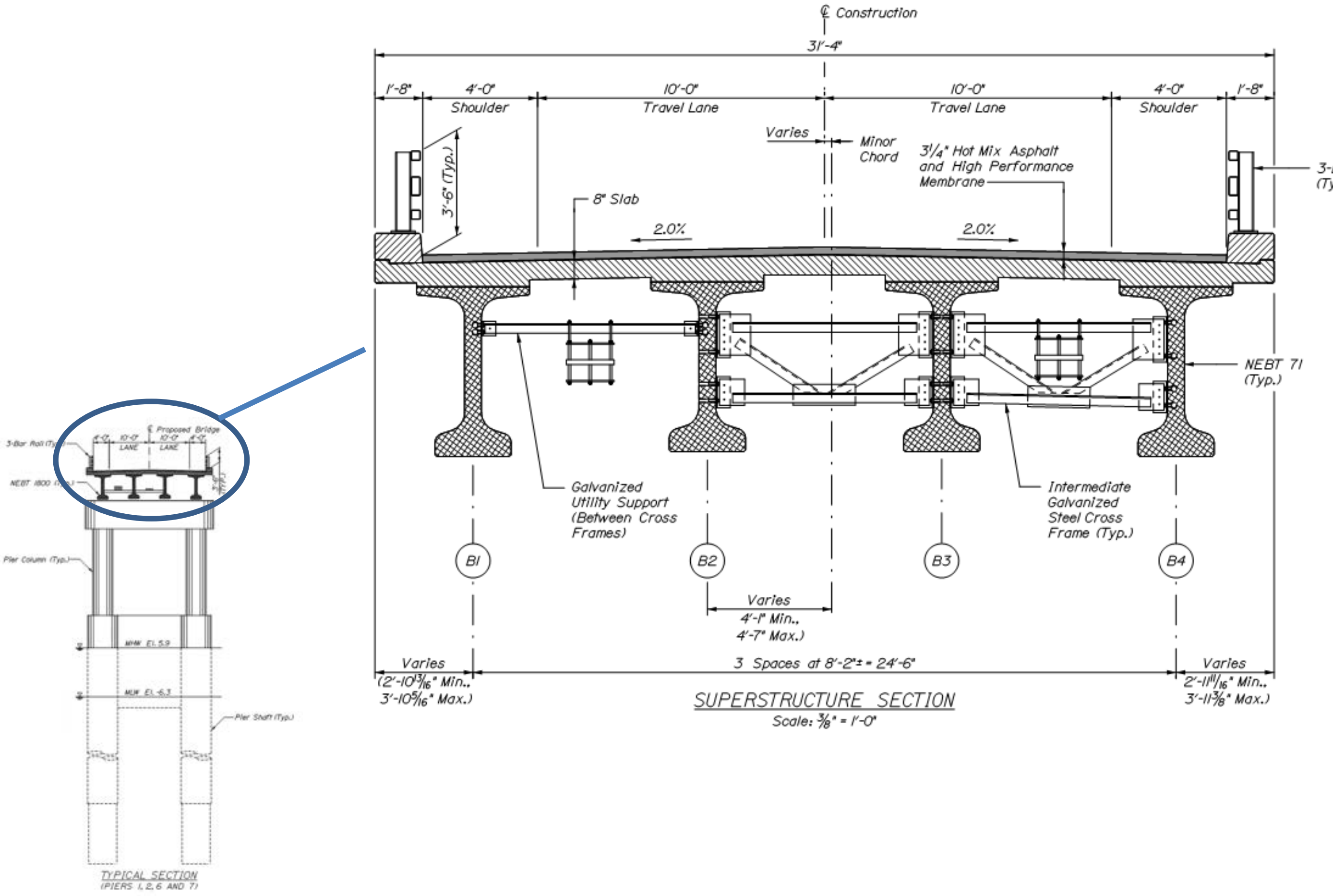
Existing Pier

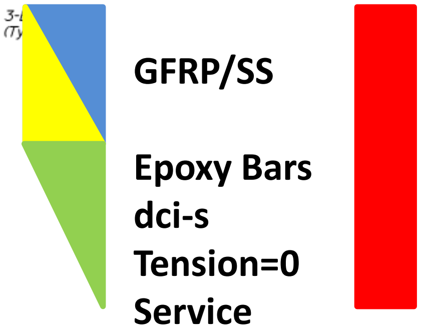


Proposed Pier

	Materials	Corrosion Threat
Deicing	**GFRP/SS/Epoxy** **dci-s**	**High**
Atmospheric	**Mild Steel** **Add cover 3”** **dci-s**	**Medium**
Splash **Tidal** **Submerged**	**Stainless Steel** **Add cover 6”** **1” Casing**	**High**
Mud Zone **Rock Socket**	**Mild Steel** **Add cover 6”** **1” Casing**	**Medium**

Superstructure





GFRP/SS

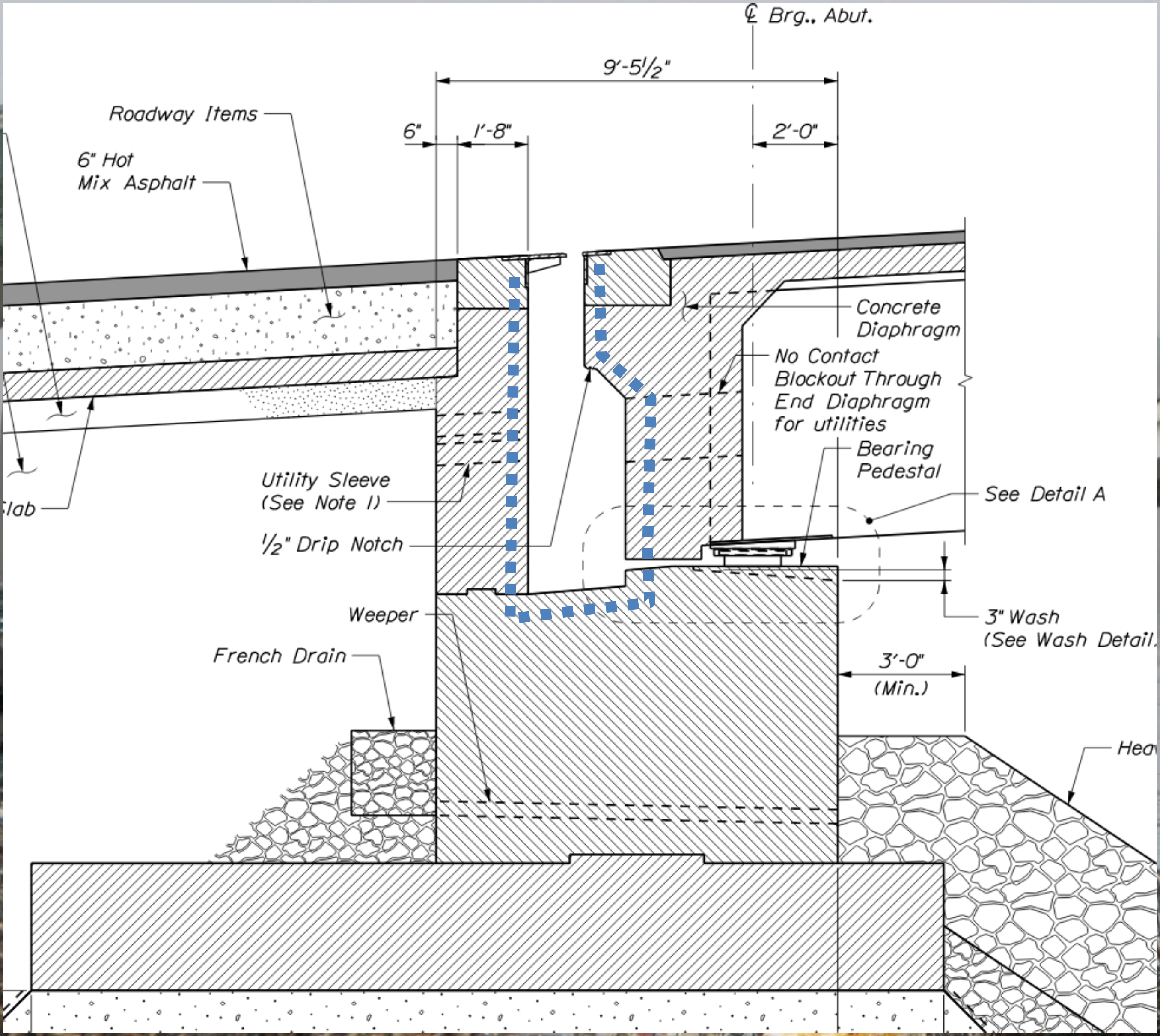
Epoxy Bars
dci-s
Tension=0
Service

High

Deicing Zone

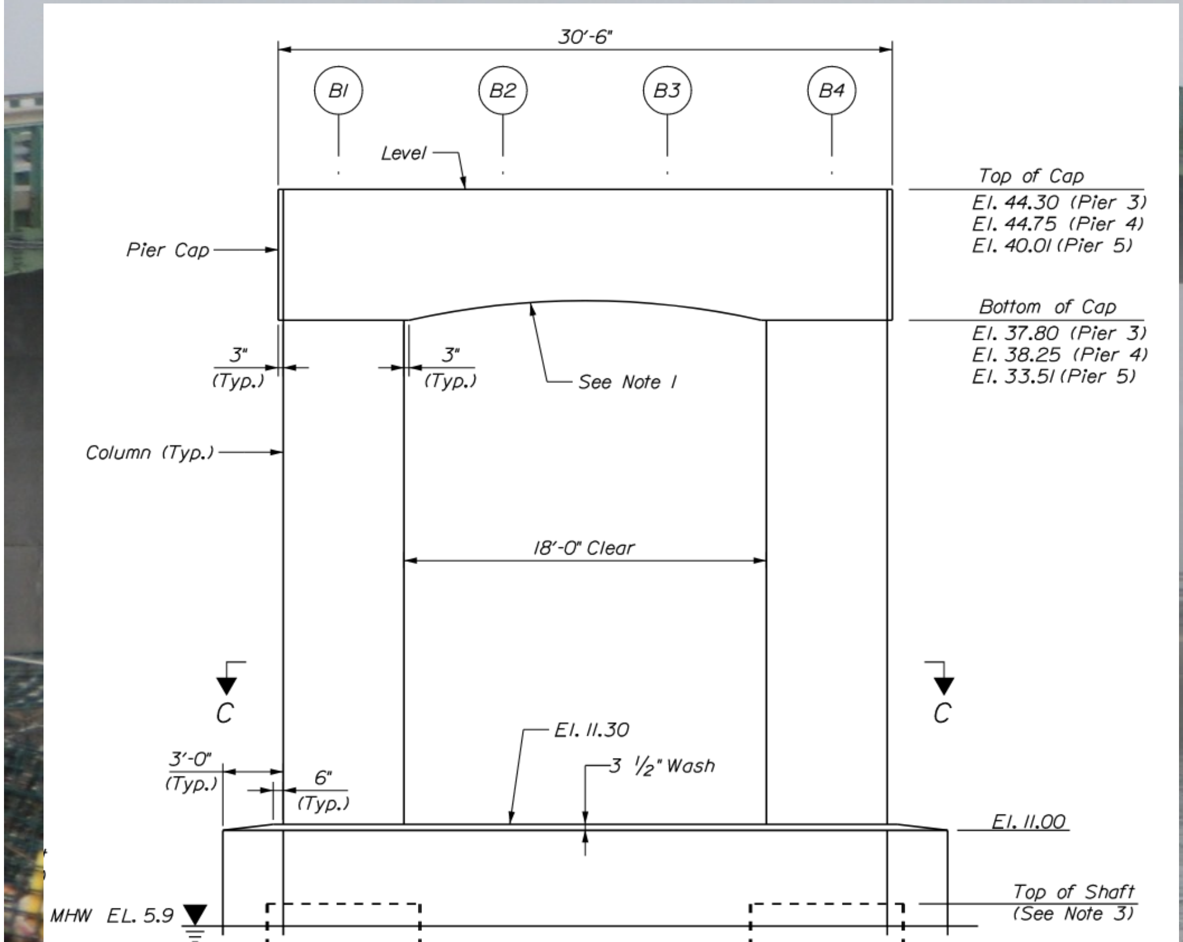
Details (Bridge Joint)

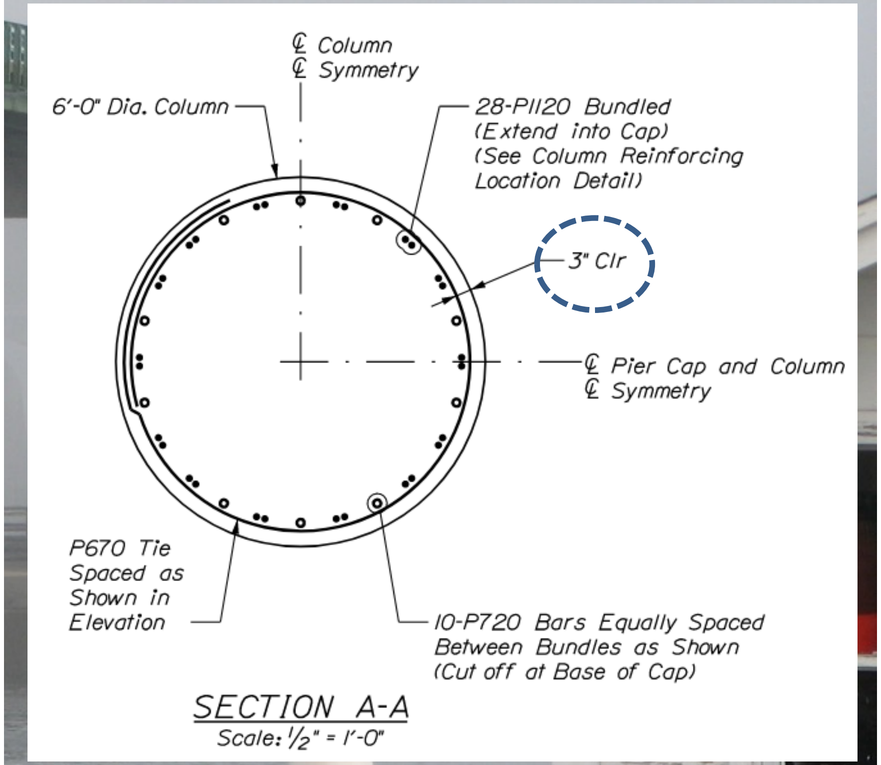
Deicing Zone



Column & Cap

Atmospheric



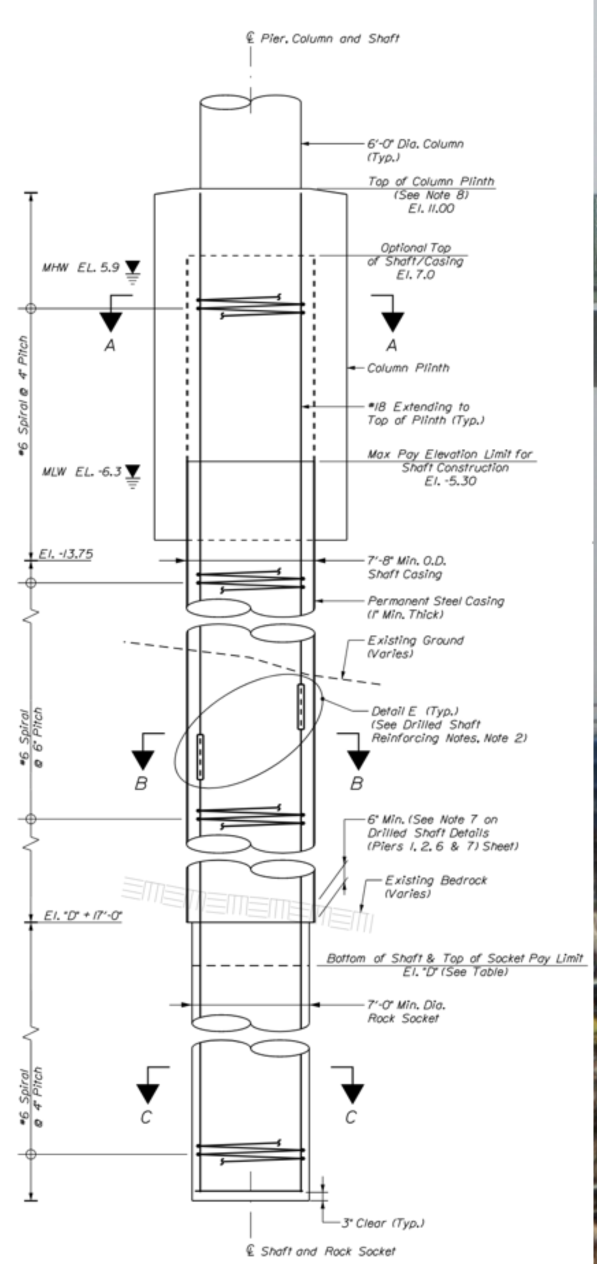


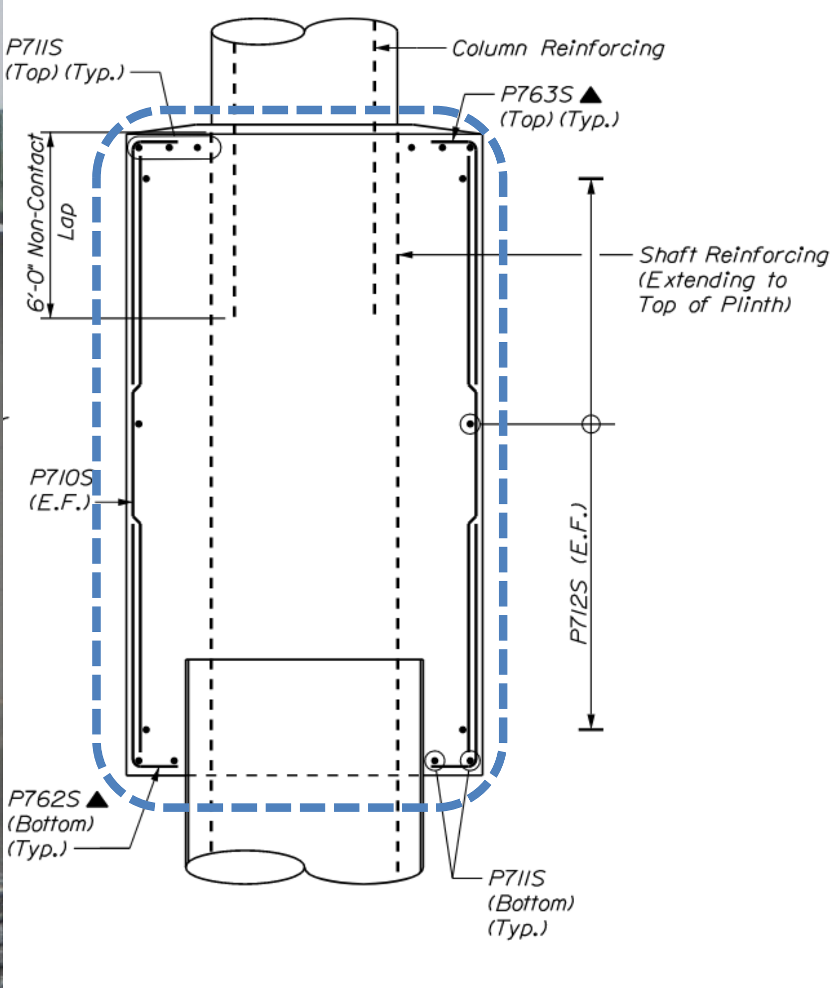
SECTION A-A

Scale: ½" = 1'-0"

Plinth Section

Splash/Tidal Zone



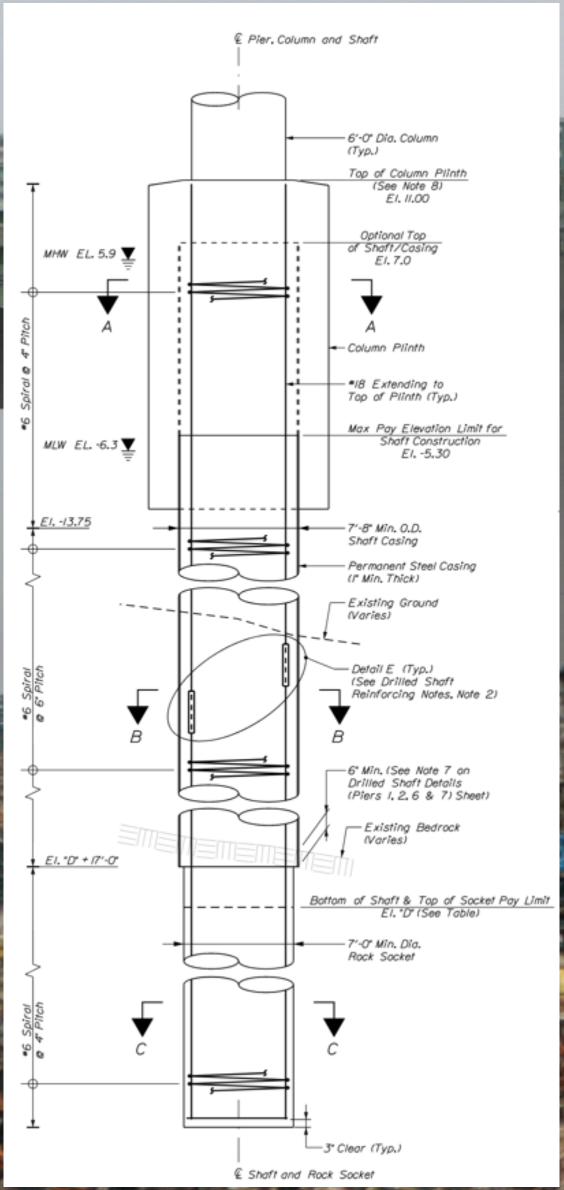


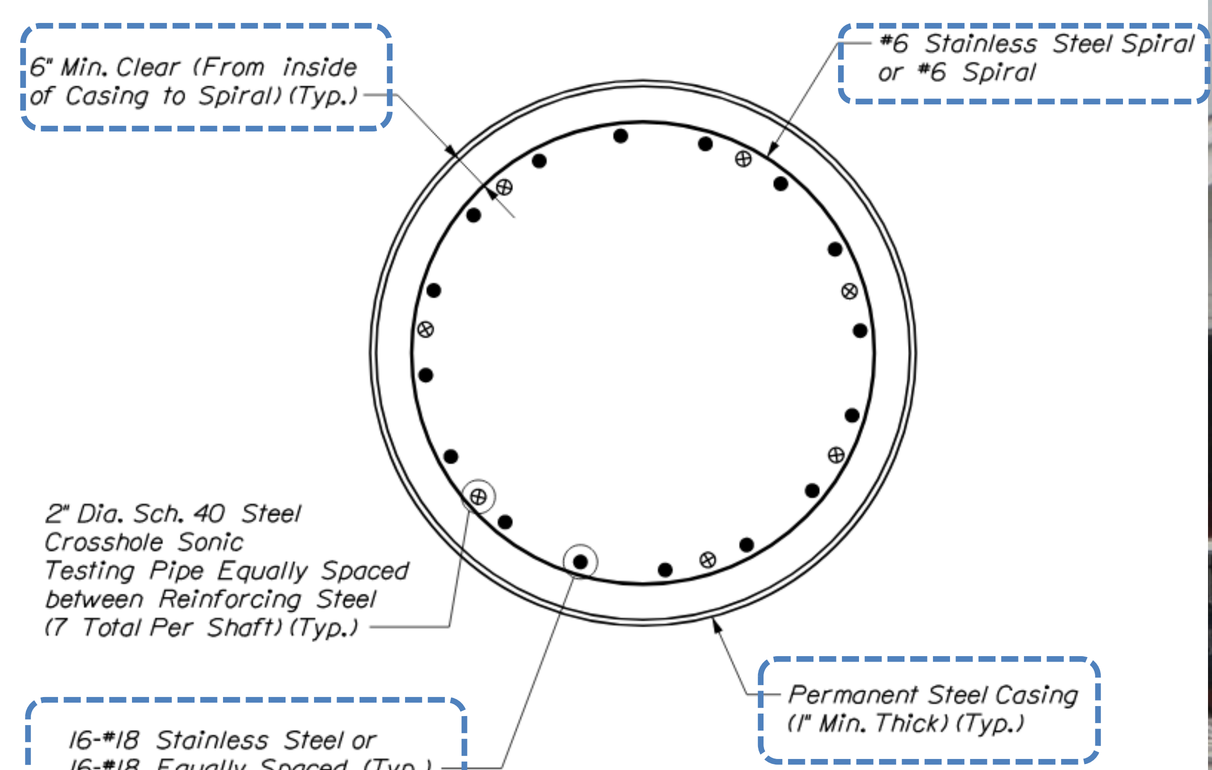
SECTION A-A

Scale: 1/4" = 1'-0"

Shafts

Submerged Zone





6" Min. Clear (From inside of Casing to Spiral) (Typ.)

#6 Stainless Steel Spiral or #6 Spiral

2" Dia. Sch. 40 Steel Crosshole Sonic Testing Pipe Equally Spaced between Reinforcing Steel (7 Total Per Shaft) (Typ.)

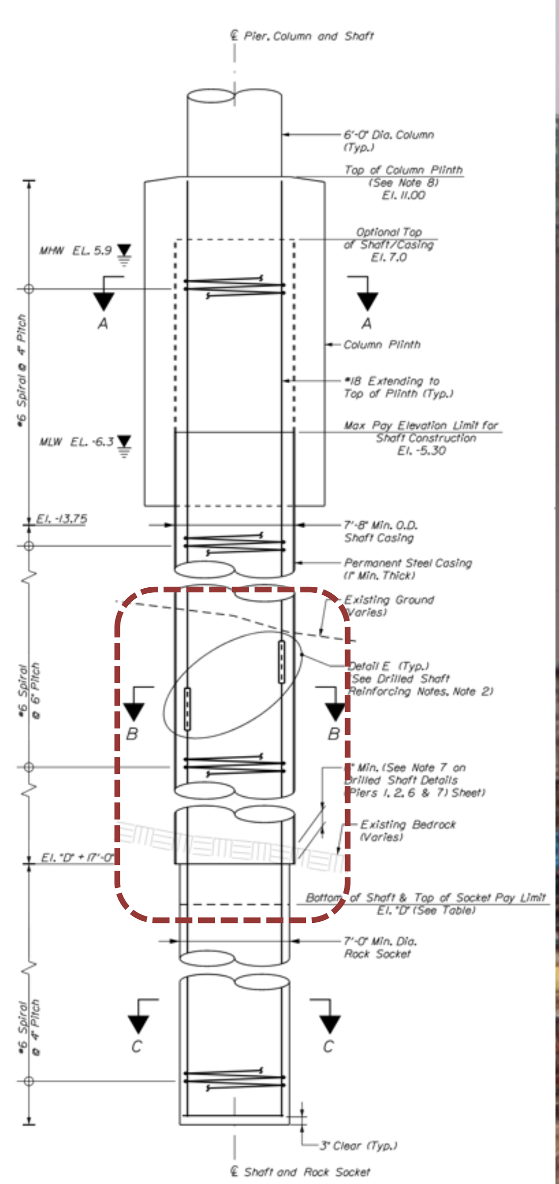
Permanent Steel Casing (1" Min. Thick) (Typ.)

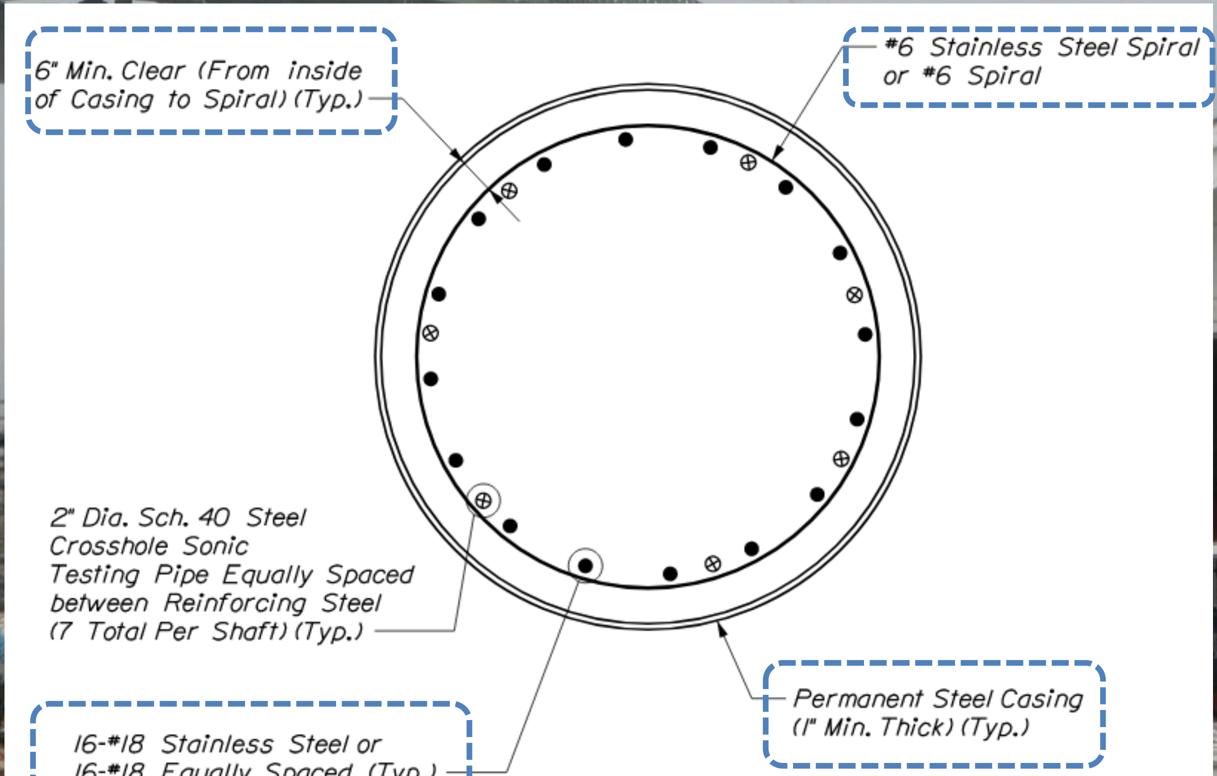
16-#18 Stainless Steel or 16-#18 Equally Spaced (Typ.)

SECTION B-B
(SHAFT W/ PERMANENT CASING)
Scale: ½" = 1'-0"

Shafts

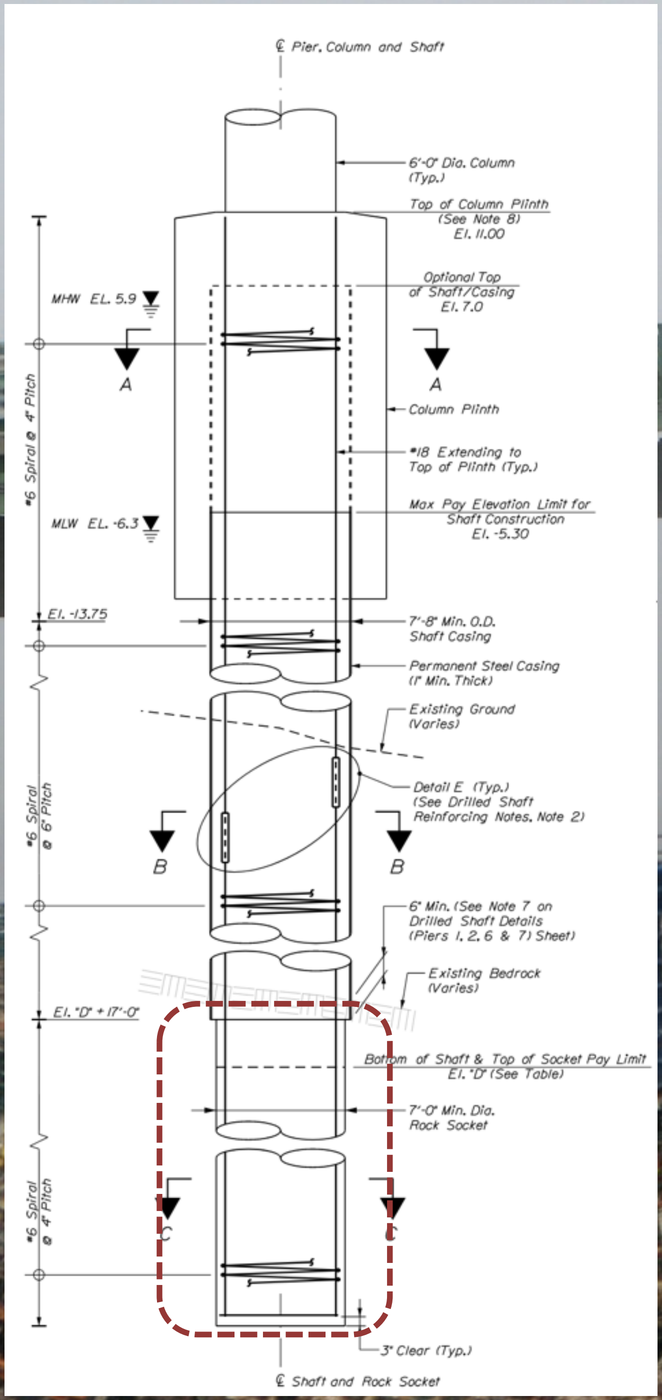
Mud Zone

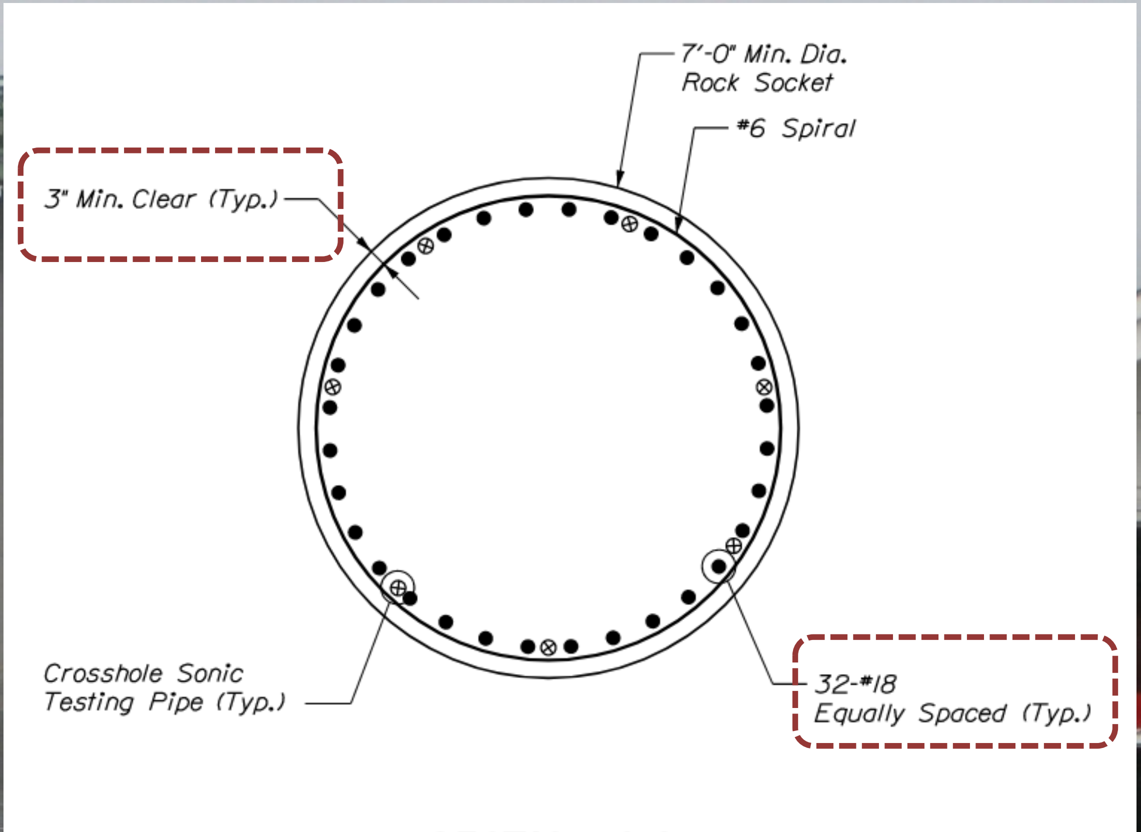




SECTION B-B
(SHAFT W/ PERMANENT CASING)
Scale: 1/2" = 1'-0"

Rock Socket



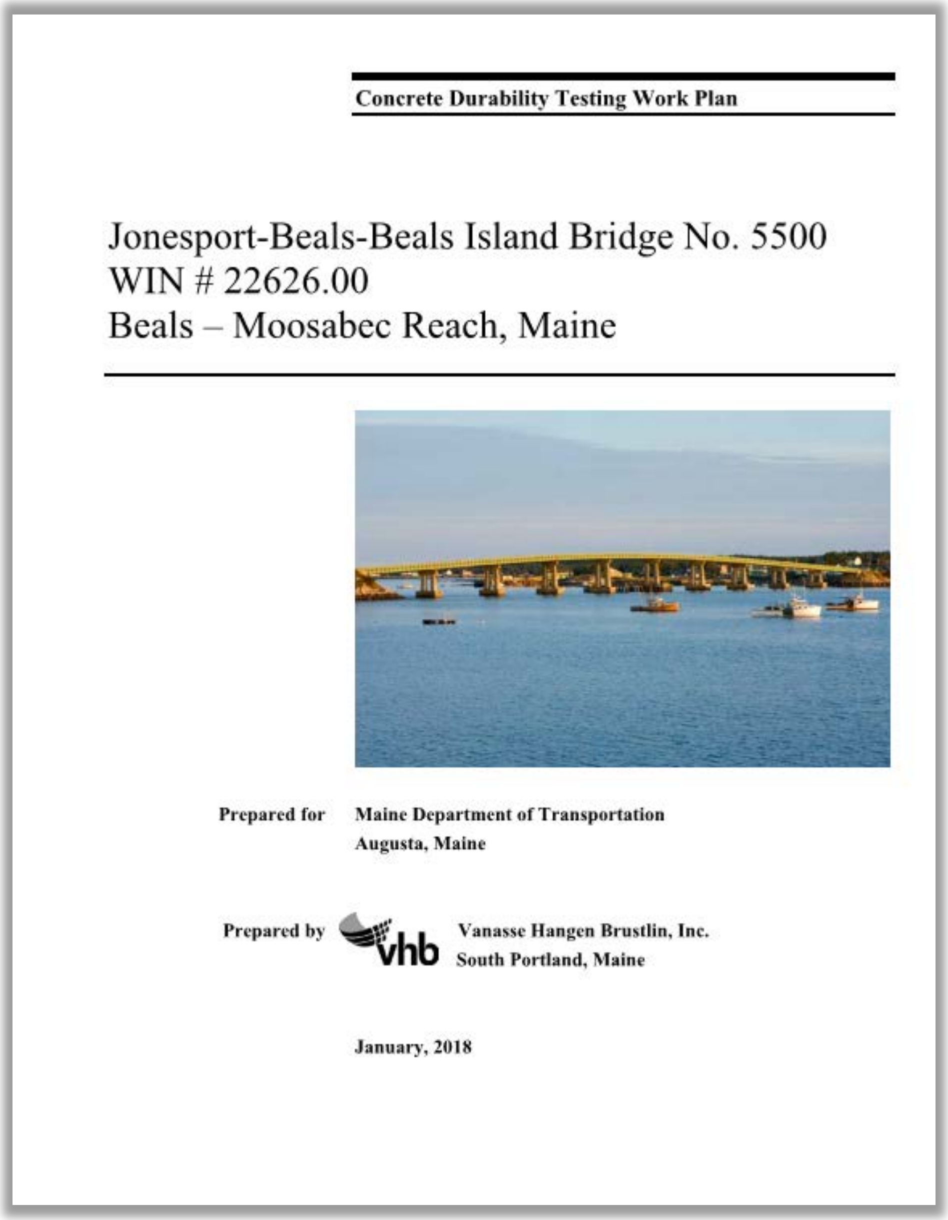


SECTION C-C
(ROCK SOCKET)
Scale: 1/2" = 1'-0"

Existing Bridge Testing

Testing Work Plan

- Validate 100-year design life
- Design Basis
  - Past Performance
  - Engineering Judgment
  - Environmental characterization
- Chloride Ingress Rate
  - Collect Existing Bridge Data
  - Modeling for Proposed
- Reduce Cracking
  - Freeze Thaw
  - Shrinkage
  - Mass Concrete - Thermal
  - Alkali-Silica Reactivity
    - Test Aggregate Sources
    - Mitigate Potential



Concrete Durability Testing Work Plan

Jonesport-Beals-Beals Island Bridge No. 5500
WIN # 22626.00
Beals – Moosabec Reach, Maine

Prepared for **Maine Department of Transportation**
Augusta, Maine

Prepared by **Vanasse Hangen Brustlin, Inc.**
South Portland, Maine

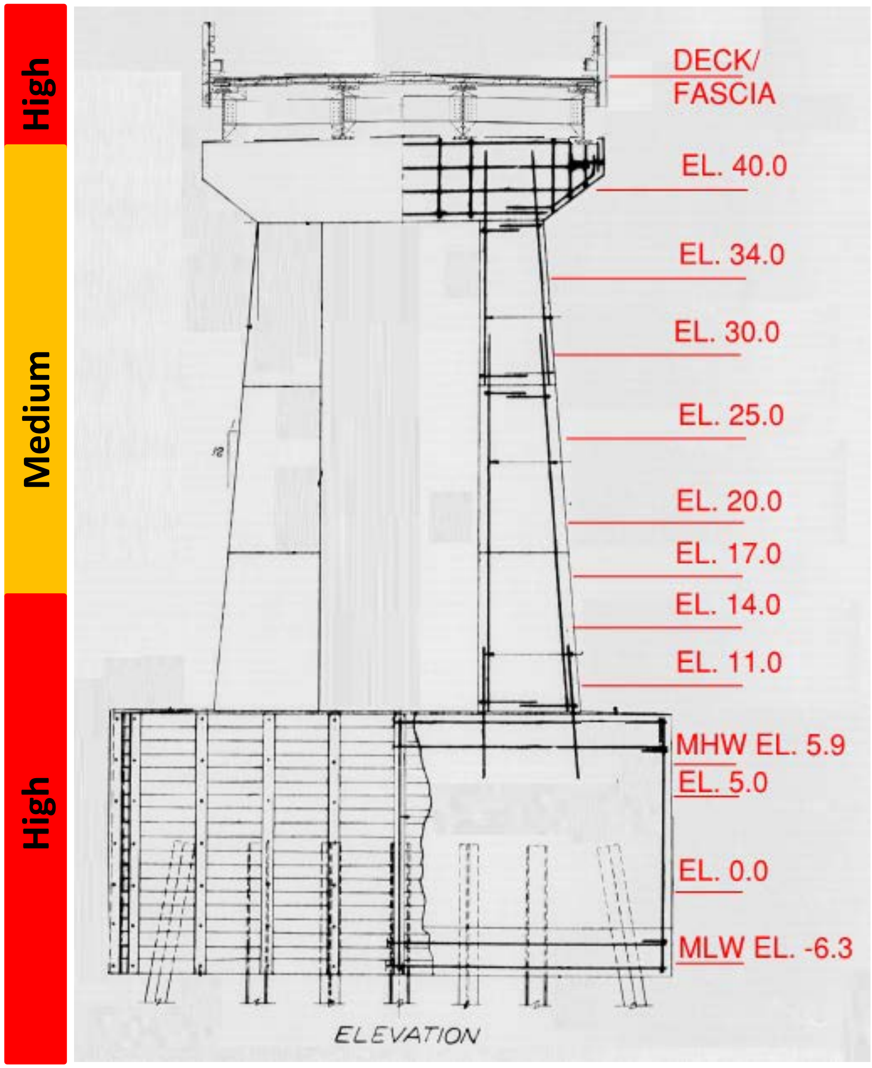
January, 2018

Concrete Durability Study- Objectives

- **Learn** more about Maine's concrete and its **raw material** sources.
- **Alkali Silica Reactivity** (ASR)- i.e. Bangor I-395, I-295 Concrete Pavement- closer look
- **Service Life Prediction Models**
  - Calibration parameters for Maine
  - fib Bulletin 34 – R19A or
  - ACI Life 365
- The Study may be used to **develop guidance** for the design of future Forever Bridges and Inventory Bridge.

Concrete Durability – Field Work

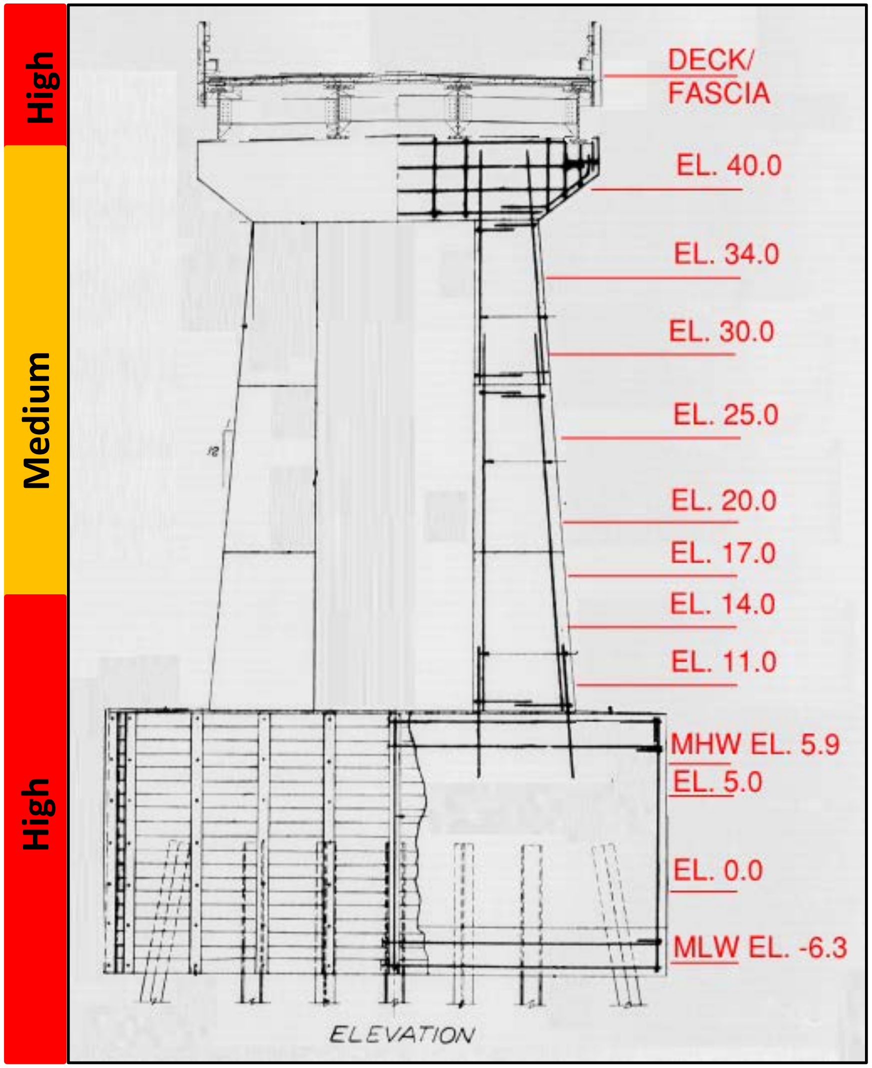
- Environment Characterization
  - Existing pier has performed well
  - Cover survey
  - Core samples
- Chloride profile - ASTM C1152
  - Surface Chloride concentration as a function elevation.
  - Measure the chloride ingress depth
  - ASTM 1556 Diffusion Coef.
- Petrographic Analysis - ASTM C856
  - air content, asr, aggregates, etc. etc.
- Field monitor internal and external concrete temps during curing.



Existing Pier Elevation

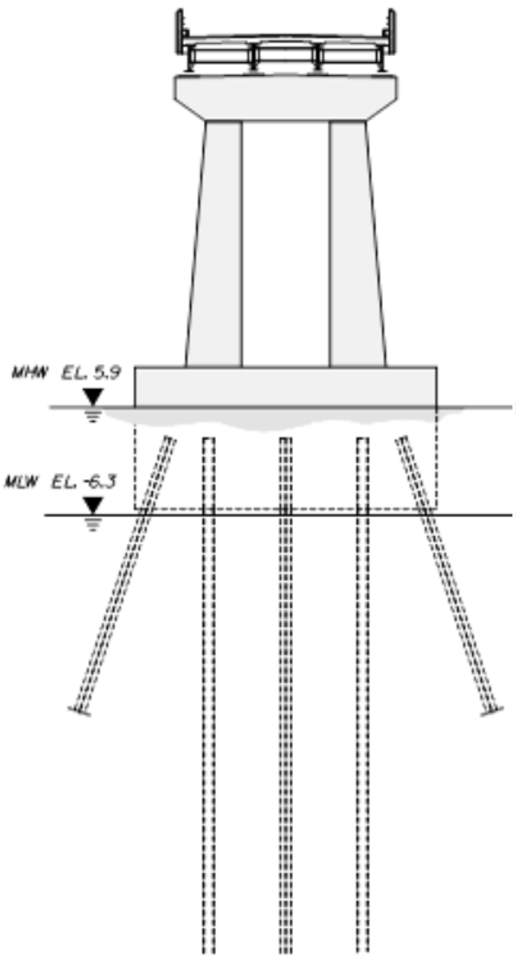
Concrete Durability – Evaluate the Past

- Calibrate Service Life Variables
  - Chloride Ingress
  - Cover survey
  - Core samples

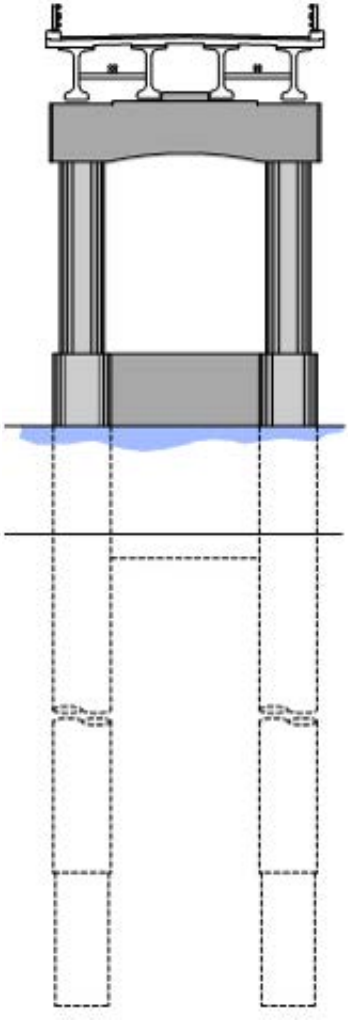


Existing Pier Elevation

Corrosion Regions & Design Options



Existing Pier



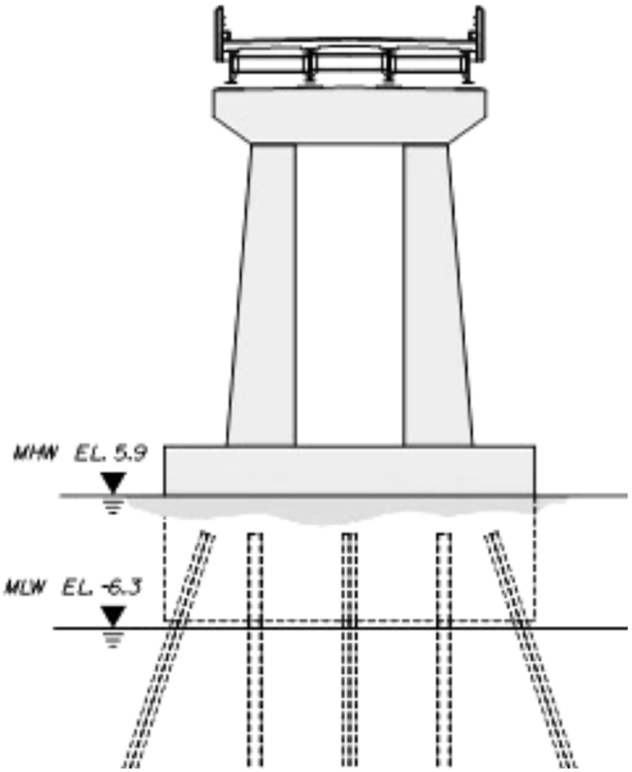
Proposed Pier

	Materials		Corrosion Threat
Deicing	🟨🟦🟩	GFRP/SS/Epoxy dci-s	🟥 High
Atmospheric	⬛	Mild Steel Add cover 3” dci-s	🟧 Medium
Splash Tidal Submerged	🟦	Stainless Steel Add cover 6” 1” Casing	🟥 High
Mud Zone Rock Socket	🟫	Mild Steel Add cover 6” 1” Casing	🟧 Medium

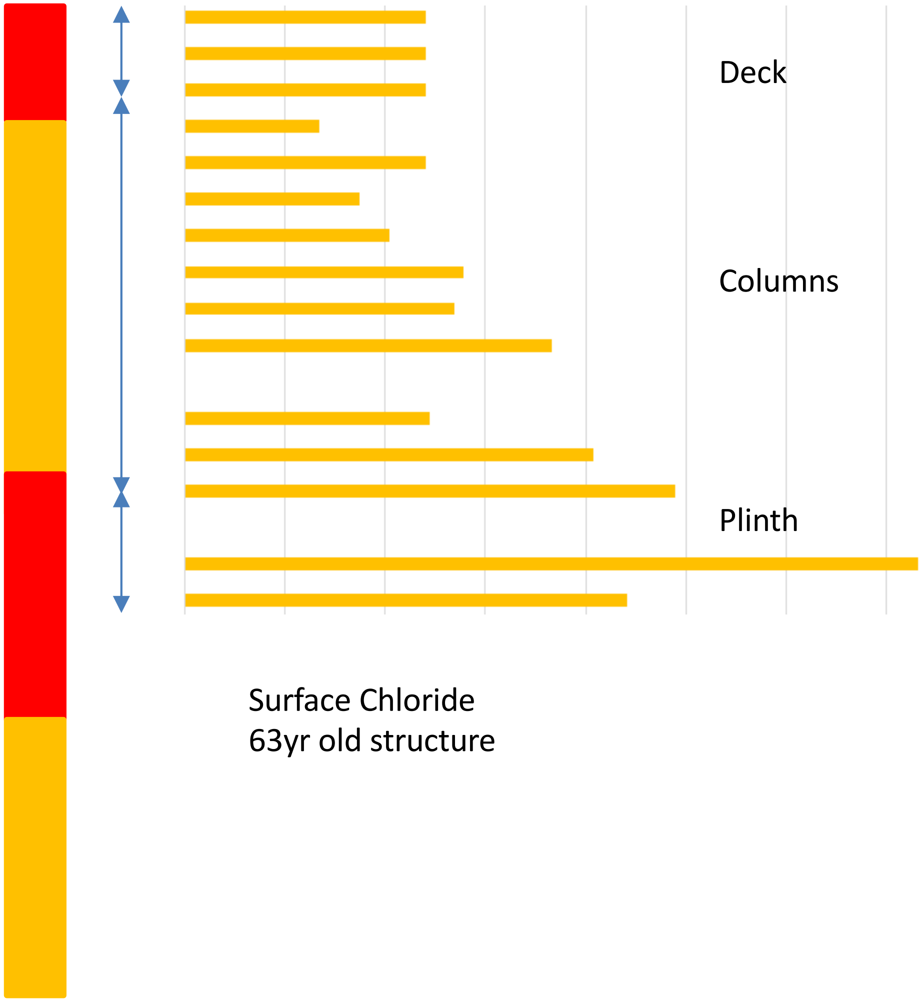
MaineDOT

vhb

Existing Surface Chloride Concentration



Existing Pier

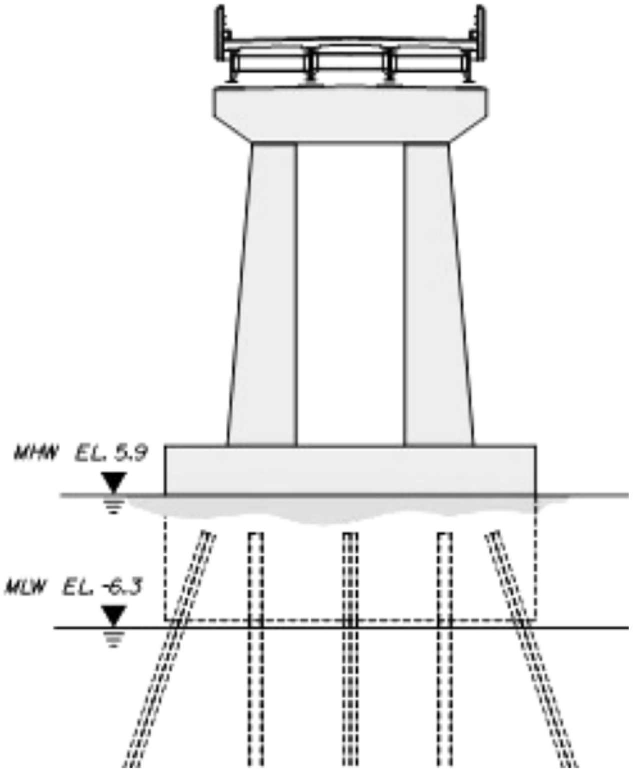


Surface Chloride
63yr old structure

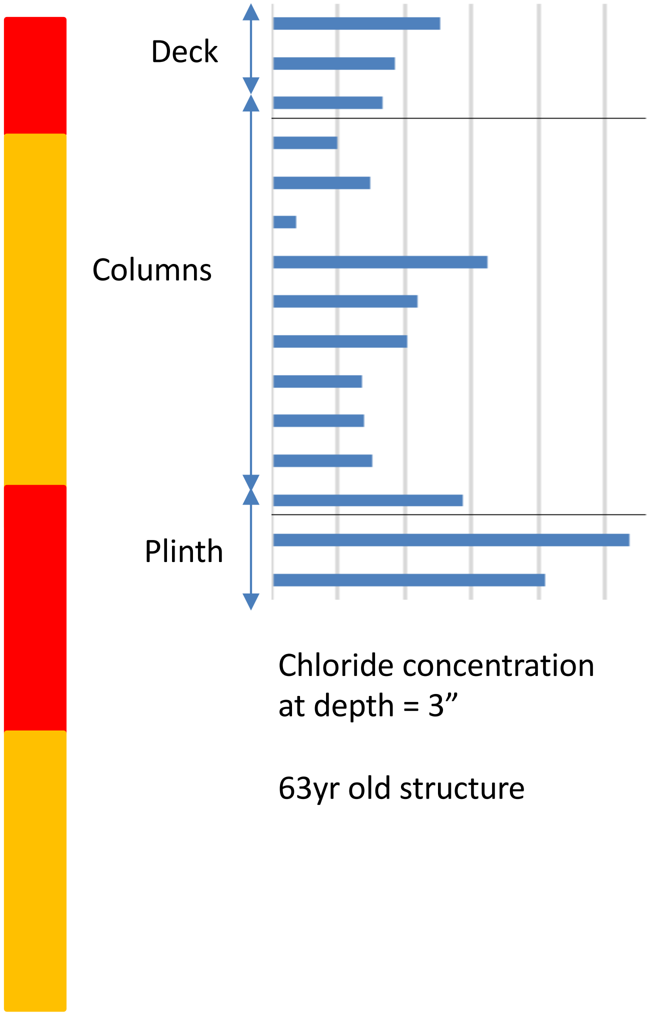
Predicted **Measured**

Corrosion Threat

Chloride Concentration at 3-inch Depth



Existing Pier



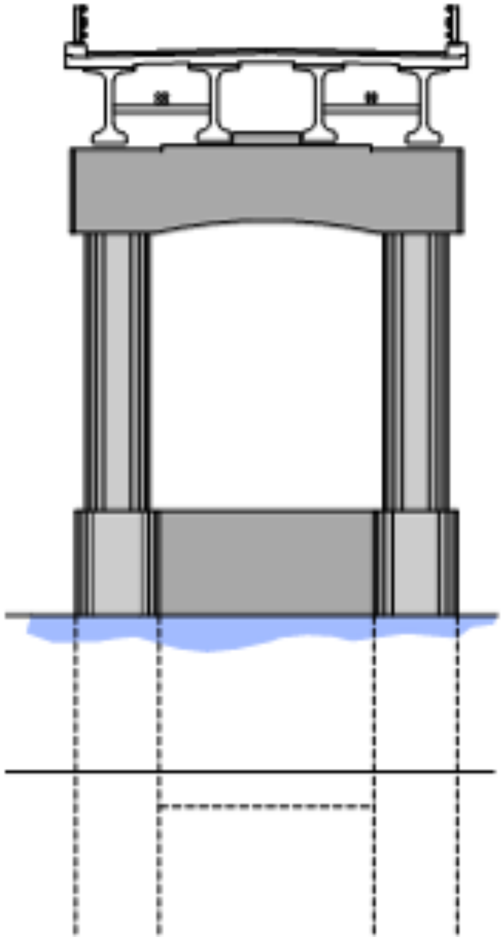
Chloride concentration
at depth = 3”

63yr old structure

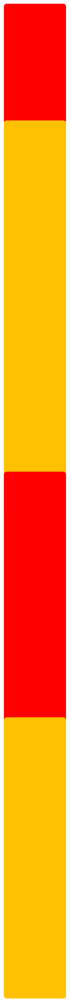
Predicted **Measured**

Corrosion Threat

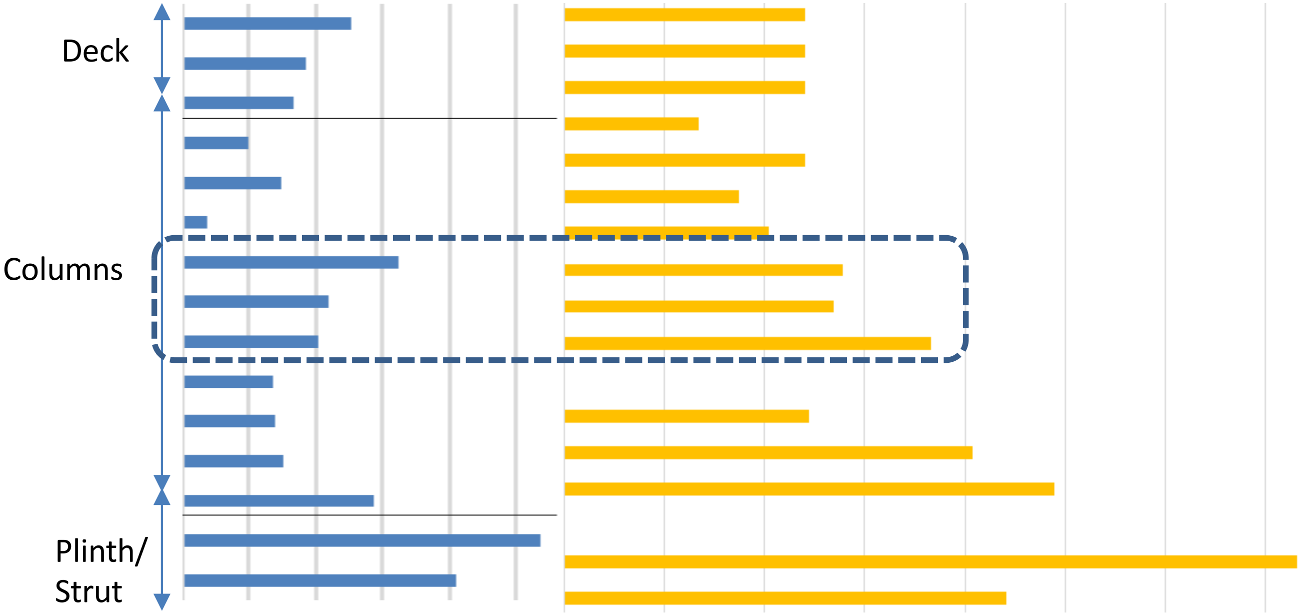
Corrosion Threat Regions at Piers



Proposed Pier



Predicted



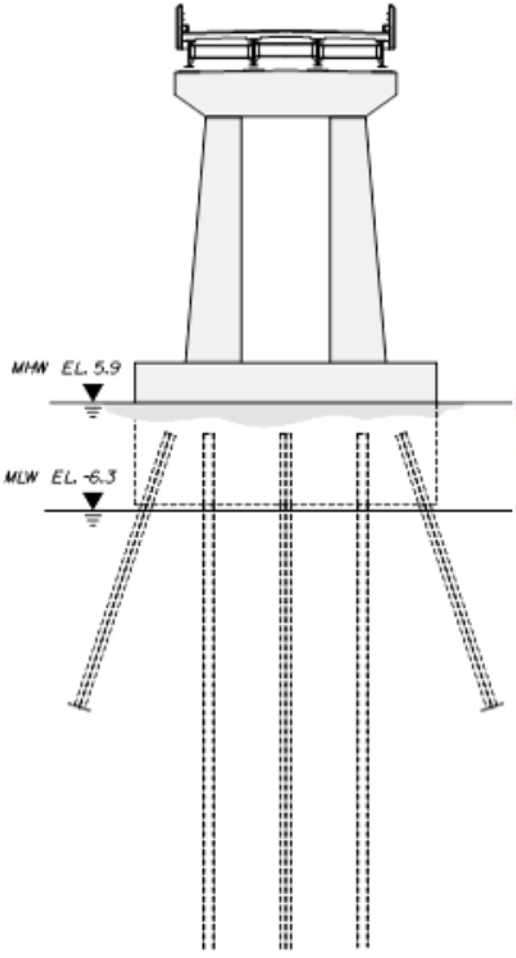
Chloride concentration
at depth = 3”

63yr old structure

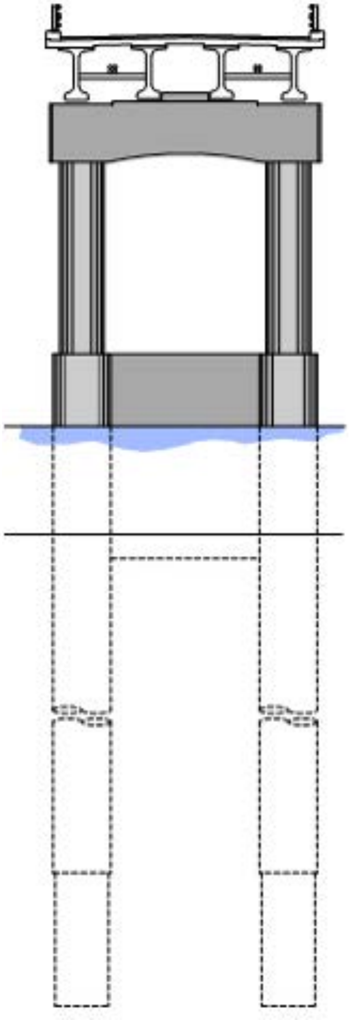
Surface Chloride
63yr old structure

Measured

Corrosion Mitigation at Piers



Existing Pier



Proposed Pier

GFRP/SS/Epoxy
dci-s

Mild Steel
Add cover 3”
dci-s

Stainless Steel
Add cover 6”
1” Casing

Mild Steel
Add cover 6”
1” Casing

High (deicing salts)

Medium
(atmospheric zone)

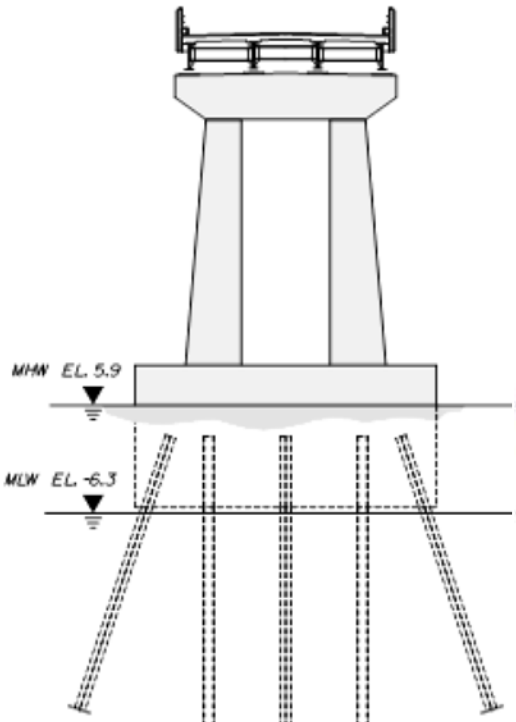
High (splash zone)

High (tidal range)

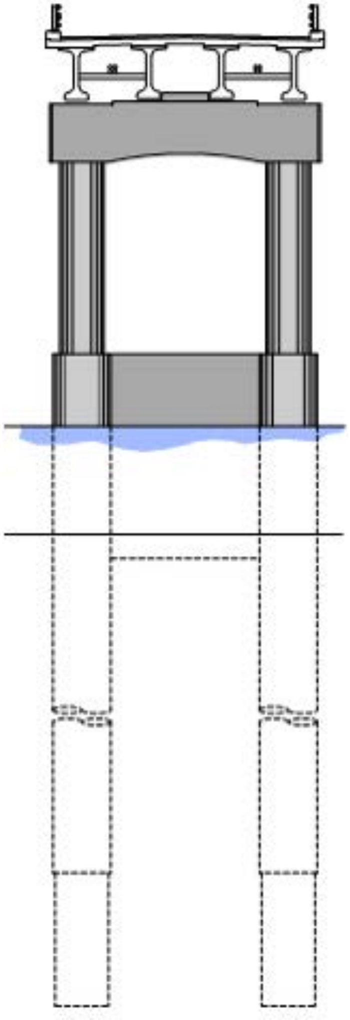
Medium (deep water)

Recommendation

Corrosion Mitigation at Piers



Existing Pier



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Recommendation

High (deicing salts)

Medium
(atmospheric zone)

High (splash zone)

High (tidal range)

Medium (deep water)


CIANBRO
CAPT. E
SOUTHPORT
KS1502

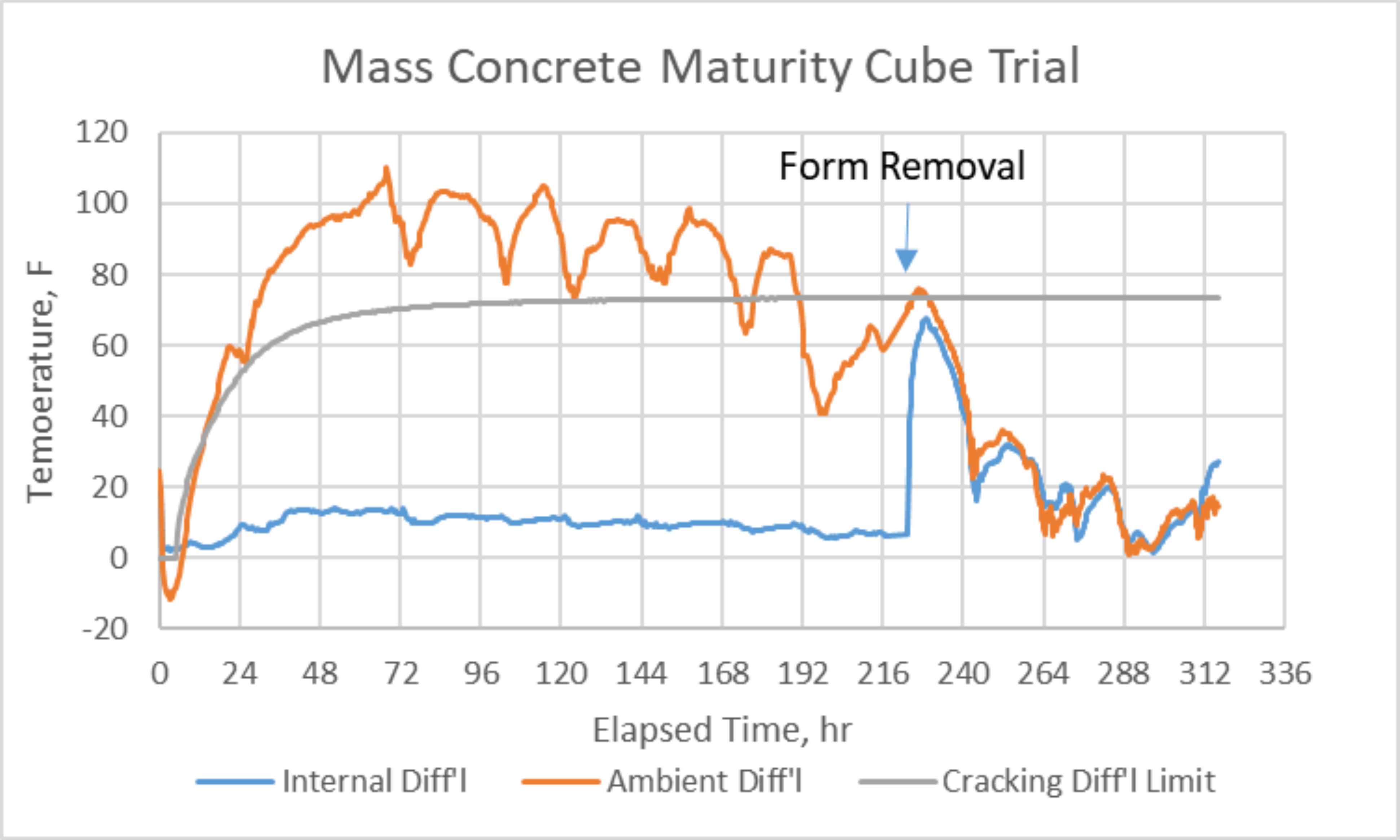
Concrete Durability- Laboratory Work

- Mass Concreting
  - Concrete maturity – In-situ strength, used for thermal modeling
  - Splitting tensile test
  - Elastic modulus
  - Concrete shrinkage
  - Coefficient of thermal expansion
  - Semi-adiabatic temperature rise- aka "The Cube"
- Chloride Ingress Rates (R19A)
  - Bulk diffusion
  - NT Build – (no corrosion inhibitors)
- Super Air Meter– air bubble sz. & volume
- ASR Evaluation- ASTM C1260, ASTM C1567, and ASTM C1778
  - *Standard of care* for design with *marginal* aggregate sources, and is particularly relevant given reactive aggregates present in Maine's quarries

Results

- ASR Decision Matrix
  - ASTM C1778 Standard Guide for Reducing the Risk of ASR
  - Outcome: Switched to Low Alkali Cement (McInnis)
  - 50% Slag Cement
- Diffusion Coefficient Testing
  - ASTM C1556 Bulk Diffusion
  - NT Build 492 Migration
- Temperature monitoring of mass placements during construction

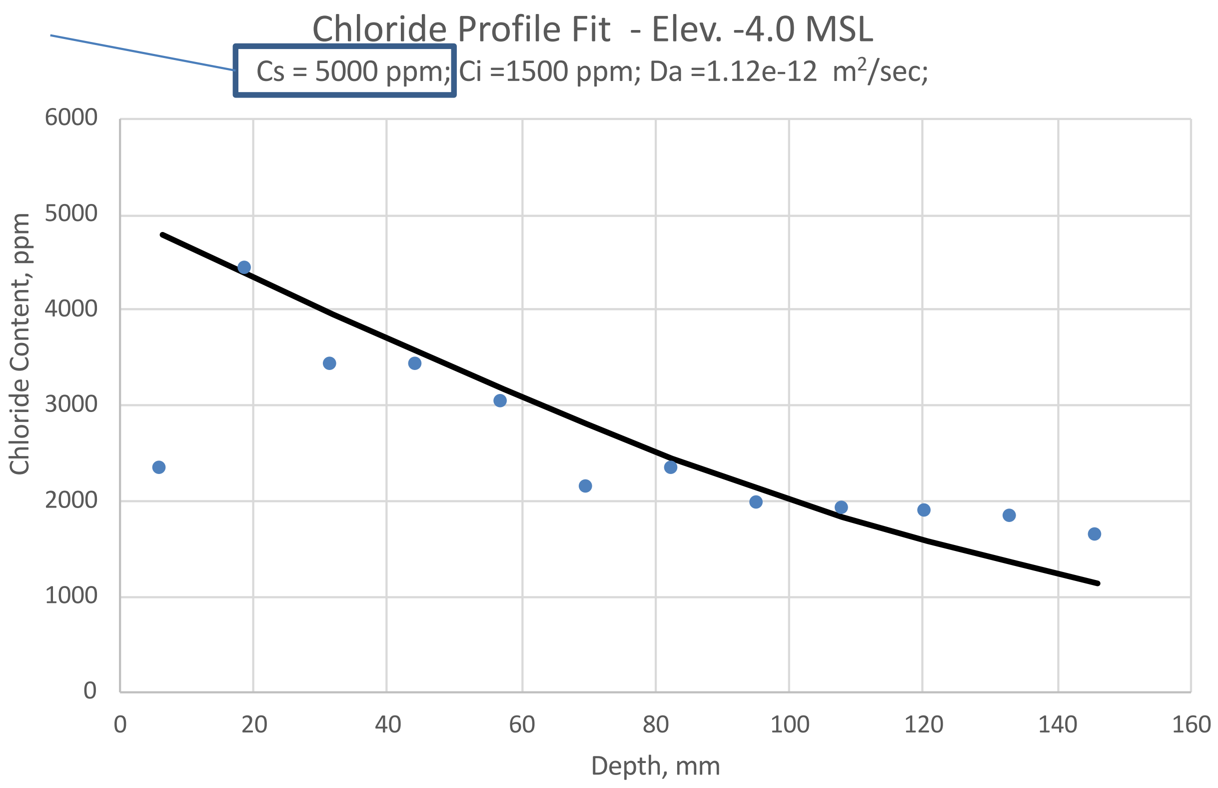
Maturity Results



Chloride Surface Concentration

Surface concentration is determined by taking a curve-of-best-fit to the data gathered from concrete cores, and projecting back to the surface. In the example below, Cs is given as 5000ppm.

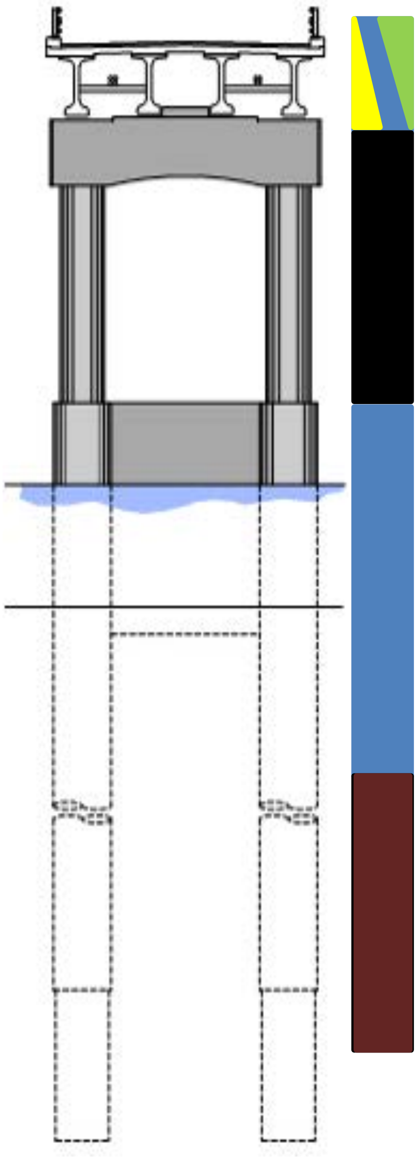
Extrapolated from Chloride profile



Chloride Surface Concentration

Surface concentrations are found for every sample:

			Class A			
Zone	Elevation	Cs (ppm)*	%/mass	Mean	Std deviation	COV
Deicing	Deck A	3000	1.89945	2.11	0.00	0.09
Deicing	Deck B	3500	2.216025			
Deicing	Deck C	3500	2.216025			
Airborne	15.92	4000	2.5326	1.82	0.00	0.33
Airborne	17.83	3300	2.089395			
Airborne	22.25	3500	2.216025			
Airborne	26.33	3000	1.89945			
Splash	9.5	4500	2.849175	2.43	0.00	0.20
Splash	11.5	4000	2.5326			
Splash	14.42	3000	1.89945			
Tidal	-4	5000	3.16575	3.96	0.00	0.28
Tidal	-2.5	7500	4.748625			



GFRP/SS/Epoxy
dci-s

Mild Steel
Add cover 3”
dci-s

Stainless Steel
Add cover 6”
1” Casing

Mild Steel
Add cover 6”
1” Casing

Chloride Surface Concentration

			Class A			
Zone	Elevation	Cs (ppm)*	%/mass	Mean	Std deviation	COV
Deicing	Deck A	3000	1.89945	2.11	0.00	0.09
Deicing	Deck B	3500	2.216025			
Deicing	Deck C	3500	2.216025			
Airborne	15.92	4000	2.5326	1.82	0.00	0.33
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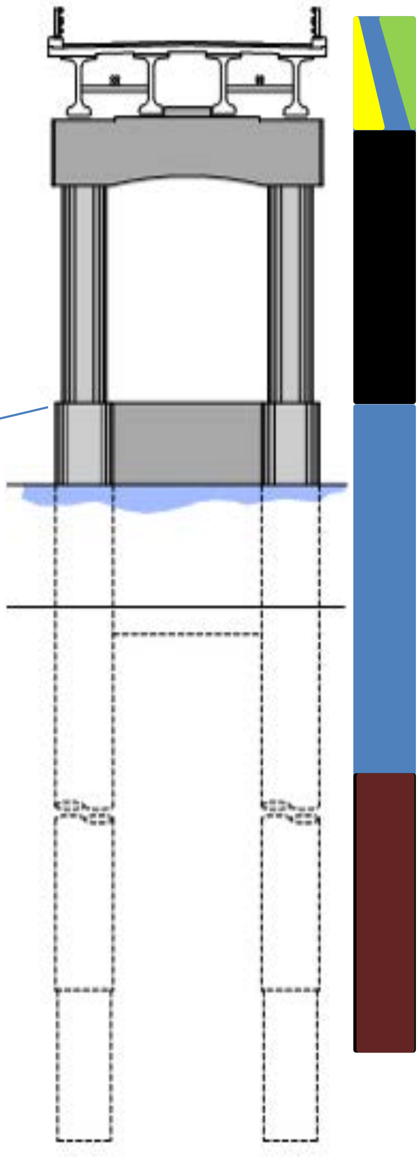

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dci-s

Mild Steel
Add cover 3”
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Stainless Steel
Add cover 6”
1” Casing

Mild Steel
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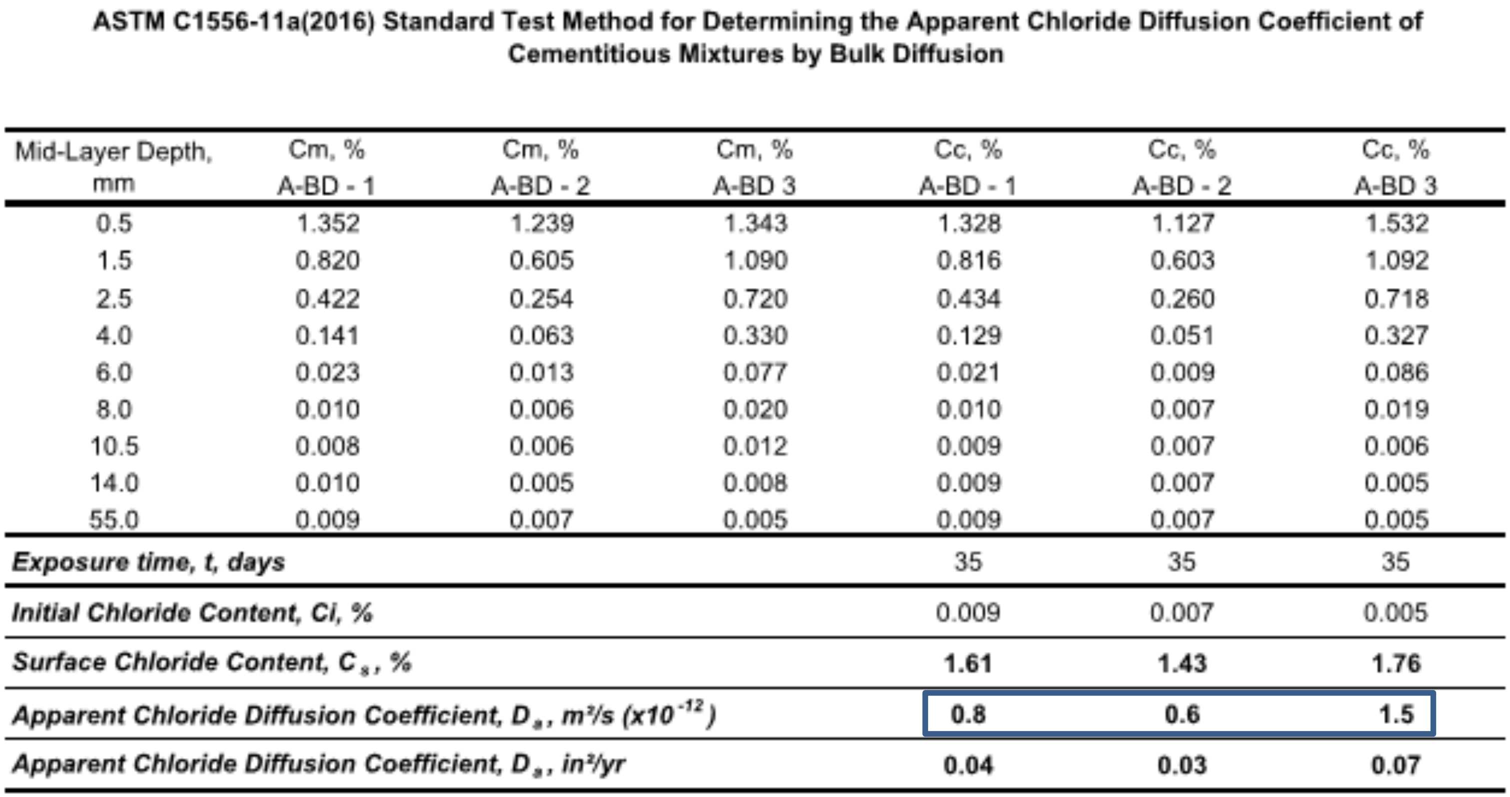
Chloride Diffusion Coefficient

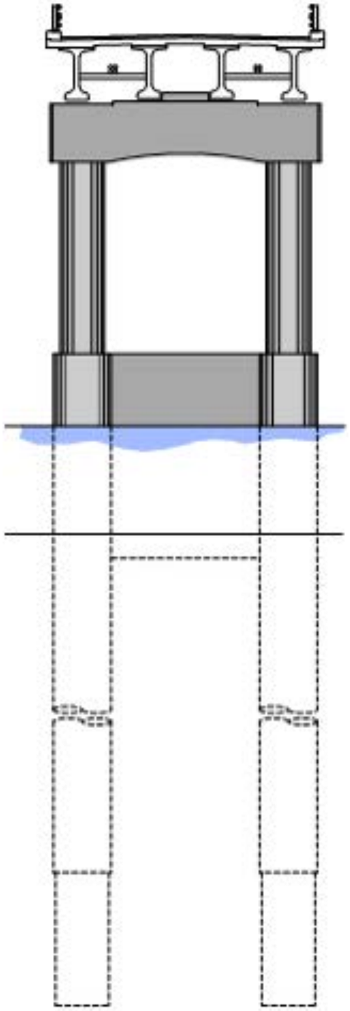
- Data from CTL Bulk Diffusion-
  ASTM 1556 -Class A

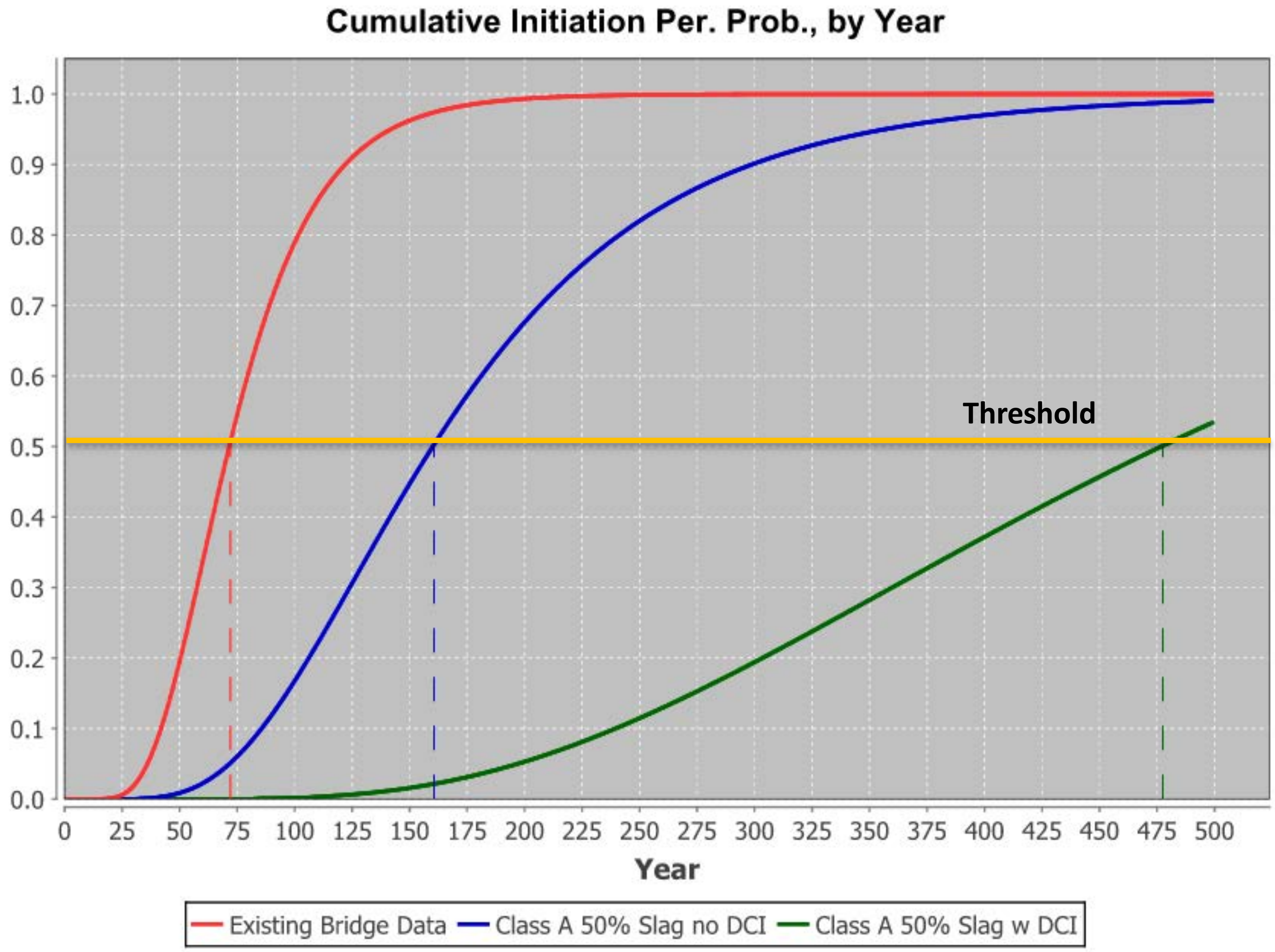


ASTM C1556-11a(2016) Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion

Mid-Layer Depth, mm	Cm, % A-BD - 1	Cm, % A-BD - 2	Cm, % A-BD 3	Cc, % A-BD - 1	Cc, % A-BD - 2	Cc, % A-BD 3
0.5	1.352	1.239	1.343	1.328	1.127	1.532
1.5	0.820	0.605	1.090	0.816	0.603	1.092
2.5	0.422	0.254	0.720	0.434	0.260	0.718
4.0	0.141	0.063	0.330	0.129	0.051	0.327
6.0	0.023	0.013	0.077	0.021	0.009	0.086
8.0	0.010	0.006	0.020	0.010	0.007	0.019
10.5	0.008	0.006	0.012	0.009	0.007	0.006
14.0	0.010	0.005	0.008	0.009	0.007	0.005
55.0	0.009	0.007	0.005	0.009	0.007	0.005
Exposure time, t, days				35	35	35
Initial Chloride Content, Ci, %				0.009	0.007	0.005
Surface Chloride Content, C_s, %				**1.61**	**1.43**	**1.76**
Apparent Chloride Diffusion Coefficient, D_a, m^2/s ($x10^{-12}$)				**0.8**	**0.6**	**1.5**
Apparent Chloride Diffusion Coefficient, D_a, in^2/yr				**0.04**	**0.03**	**0.07**

Service Life Prediction- Columns

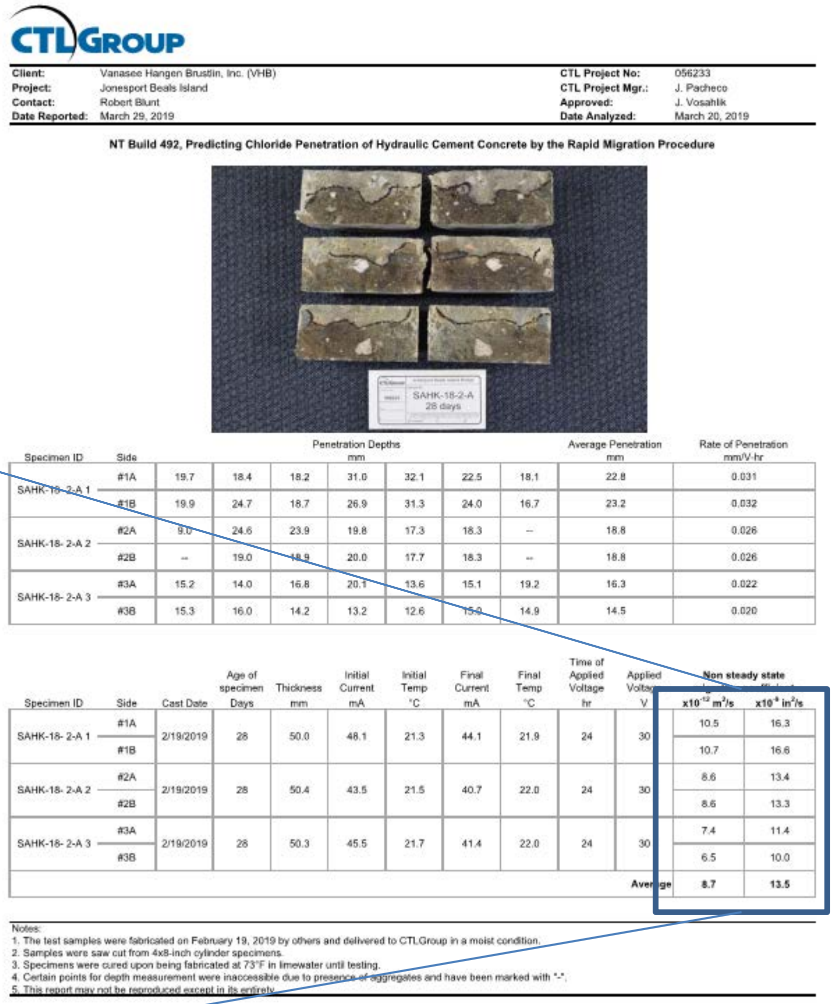




Mild Steel with 3” cover & dci-s

Chloride Migration Coefficient

- Data from CTL NT Build Results shows the migration coefficient of the SAHK-18-2-A concrete mix.



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Client:	Vanasee Hangen Brustlin, Inc. (VHB)	**CTL Project No:**	056233
Project:	Jonesport Beals Island	**CTL Project Mgr.:**	J. Pacheco
Contact:	Robert Blunt	**Approved:**	J. Vosahlik
Date Reported:	March 29, 2019	**Date Analyzed:**	March 20, 2019

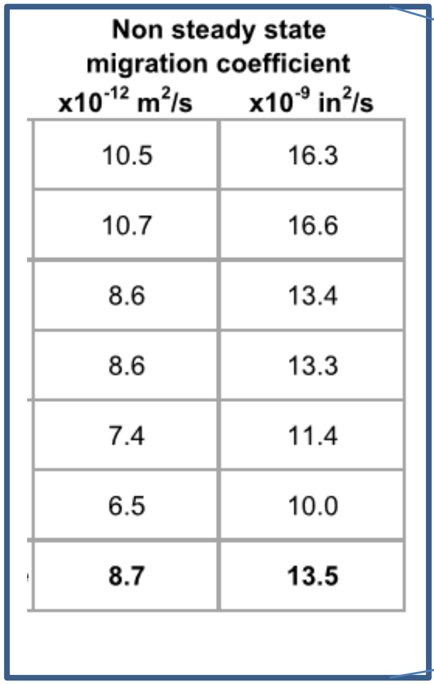
NT Build 492, Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure

SAHK-18-2-A
28 days

Specimen ID	Side	Penetration Depths mm							Average Penetration mm	Rate of Penetration mm/V-hr
SAHK-18- 2-A 1	#1A	19.7	18.4	18.2	31.0	32.1	22.5	18.1	22.8	0.031
	#1B	19.9	24.7	18.7	26.9	31.3	24.0	16.7	23.2	0.032
SAHK-18- 2-A 2	#2A	9.0	24.6	23.9	19.8	17.3	18.3	--	18.8	0.026
	#2B	--	19.0	18.9	20.0	17.7	18.3	--	18.8	0.026
SAHK-18- 2-A 3	#3A	15.2	14.0	16.8	20.1	13.6	15.1	19.2	16.3	0.022
	#3B	15.3	16.0	14.2	13.2	12.6	15.0	14.9	14.5	0.020

Specimen ID	Side	Cast Date	Age of specimen Days	Thickness mm	Initial Current mA	Initial Temp °C	Final Current mA	Final Temp °C	Time of Applied Voltage hr	Applied Voltage V	Non steady state migration coefficient x10^-12 m²/s	x10^-9 in²/s
SAHK-18- 2-A 1	#1A	2/19/2019	28	50.0	48.1	21.3	44.1	21.9	24	30	10.5	16.3
	#1B										10.7	16.6
SAHK-18- 2-A 2	#2A	2/19/2019	28	50.4	43.5	21.5	40.7	22.0	24	30	8.6	13.4
	#2B										8.6	13.3
SAHK-18- 2-A 3	#3A	2/19/2019	28	50.3	45.5	21.7	41.4	22.0	24	30	7.4	11.4
	#3B										6.5	10.0
										Average	**8.7**	**13.5**

Notes:
1. The test samples were fabricated on February 19, 2019 by others and delivered to CTLGroup in a moist condition.
2. Samples were saw cut from 4x8-inch cylinder specimens.
3. Specimens were cured upon being fabricated at 73°F in limewater until testing.
4. Certain points for depth measurement were inaccessible due to presence of aggregates and have been marked with "-".
5. This report may not be reproduced except in its entirety.



Non steady state migration coefficient x10^-12 m²/s	x10^-9 in²/s
10.5	16.3
10.7	16.6
8.6	13.4
8.6	13.3
7.4	11.4
6.5	10.0
8.7	**13.5**

fib Bulletin 34 Chloride Ingress Model

SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Input Parameters

				Normal Distr Coefficients			Log-Normal Distr Coeffs		Beta Distr Coeffs			
Parameter	**Description**	**Units**	**Distribution Function**	**Mean, μ**	**Std Dev, σ**	**Coeff of Variation, σ/μ**	$\ln\mu - \ln((\sigma/\mu)^2+1)/2$	$\sqrt{\ln((\sigma/\mu)^2+1)}$	**Lower Bound, a**	**Upper Bound, b**	**α**	**β**
$D_{RCM,0}$	Chloride Migration Coefficient (from Nordtest NT Build 492 - results are given in m^2/sec)	in^2/yr	Normal	0.426	0.085	0.20						
		mm^2/yr		274.8	55.0							
		m^2/sec		8.71E-12	1.74E-12							
b_e	Regression variable, (limited to 3500 °K to 5500 °K)	°K	Normal	4800	700							
T_{real}	Temperature (from Local Weather Data)	°F	Normal	44.5	1.30							
		°C		6.9	0.72							
		°K		280.09	0.72							
T_{ref}	Standard test temperature	°F	Constant	67.6								
		°C		19.8								
		°K		292.9								
k_e	Environmental transfer variable	n/a	n/a									
k_t	Transfer parameter	n/a	Constant	1.0								
α	Aging exponent - PCC w/ Blast Furnace Slag	n/a	Beta	0.45	0.2				0	1	2.33	2.85
t_o	Reference point of time (28 days = 0.0767 yrs)	yrs	Constant	0.0767								
A(t)	Aging function	n/a	n/a									
C_o	Initial Chloride Content of Concrete	mass% of binder	Normal	0.04	0.00	0.013						
C_s or $C_{s,\Delta x}$	Chloride Concentration at surface, or at substitute surface Δx	mass% of binder	Log-Normal	2.40	0.96	0.40	0.8	0.39				
Δx	Transfer function - splash/spray zone	in	Beta	0.35	0.22	0.629			0	1.97	1.90	8.77
		mm		8.90	5.60				0	50	1.90	8.77
cover, a	Concrete cover	in	Log-Normal	3.00	0.50	0.167						
		mm		76.20	12.70		4.32	0.17				
C_{crit}	Critical chloride content (0.25% plain reinforcing)	mass% of binder	Beta	1.65	0.4125	0.25			0.75	1.9	0.25	0.07
t_{SL}	Design service life	yrs	n/a	100								
β	Target Reliability	n/a	n/a	1.3								

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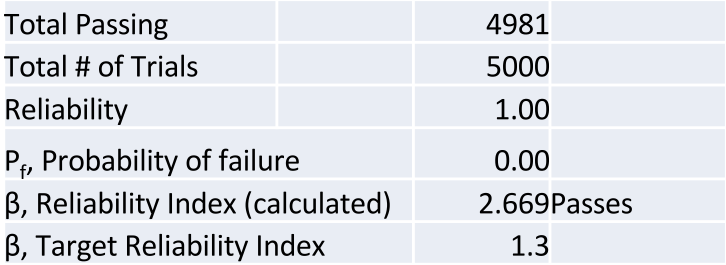
100 yr Results for Chloride Ingress Model

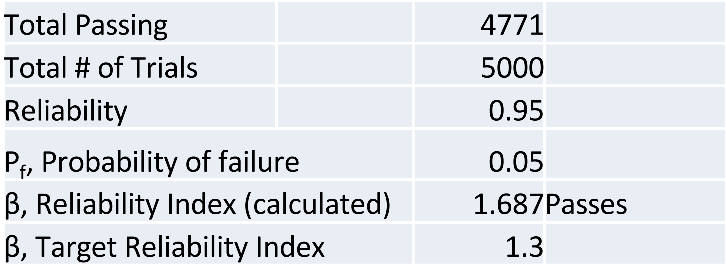
Monte Carlo Trial Results:

- ASTM C1556 Diffusion Coef. Used:



Total Passing	4981	
Total # of Trials	5000	
Reliability	1.00	
P_f, Probability of failure	0.00	
β, Reliability Index (calculated)	2.669	Passes
β, Target Reliability Index	1.3	

- NT Build Migration Coef. Used:



Total Passing	4771	
Total # of Trials	5000	
Reliability	0.95	
P_f, Probability of failure	0.05	
β, Reliability Index (calculated)	1.687	Passes
β, Target Reliability Index	1.3	

Concrete Durability Study- Outcomes

- **Environmental Characterization – Marine Exposure Zones**
- **Detailing Practices**
- **Alkali Silica Reactivity** (ASR) ASTM C1260/C1567/C1778
  - Evaluate material sources and determine project ASR risk profile
- **Freeze Thaw Durable**
- **Mass concrete can handle 70 degree differential**
- **Service Life Prediction Calculations**
  - Calibration parameters for Maine Concrete
  - fib Bulletin 34 – R19A
  - ACI Life 365- complete

Service Life Design in Maine

- Bridge Design Guide Revisions
- Service Life Calculations?
- NCHRP 12-108
  - Guide Specification for Service Life Design of Highway Bridges
- Expand Conc Mix Standard Specifications
- Similar to other states, Maine can develop performance requirements for DB & CMGC

Future Specifications For Maine

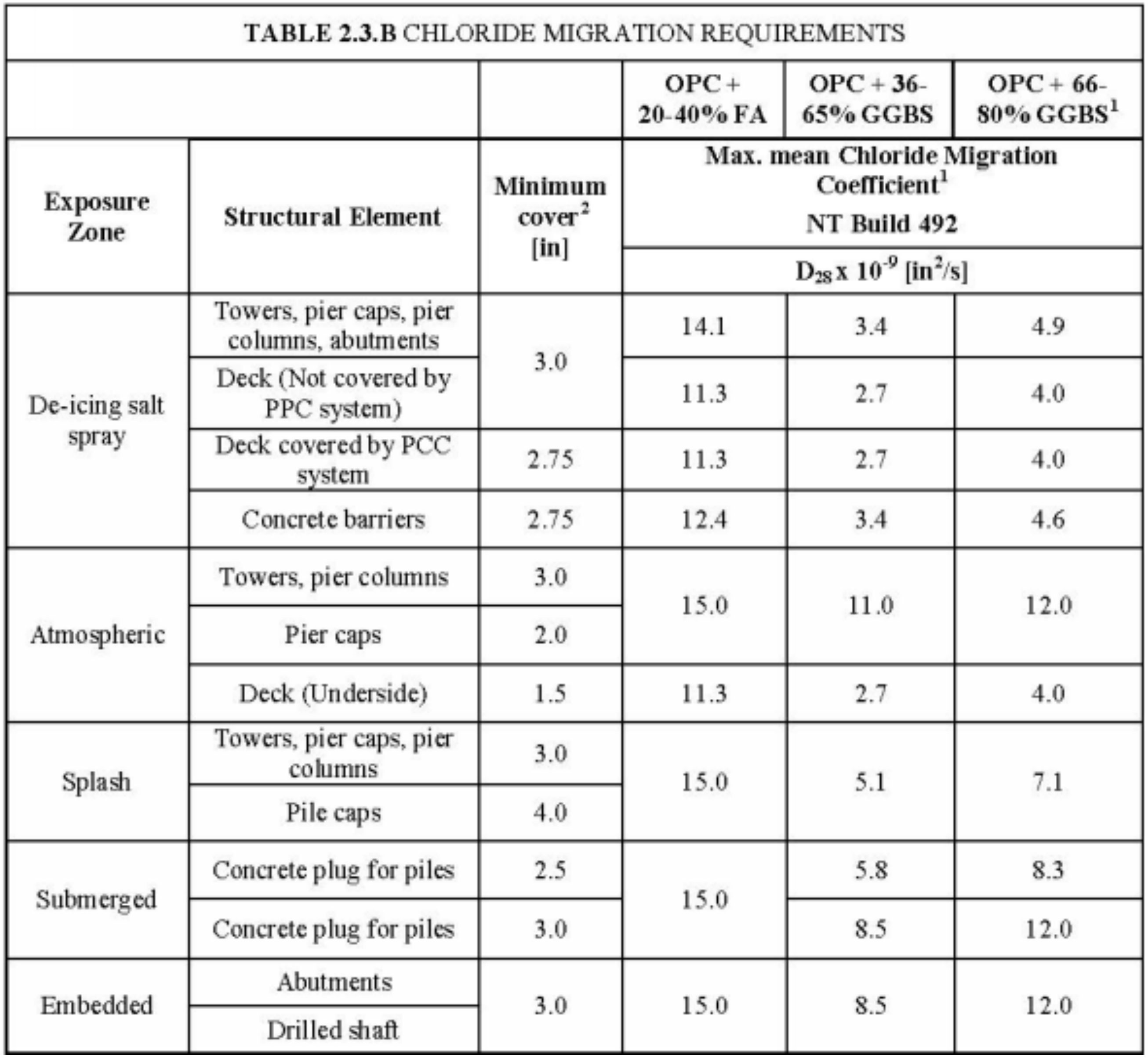


TABLE 2.3.B CHLORIDE MIGRATION REQUIREMENTS

Exposure Zone	Structural Element	Minimum cover[2] [in]	OPC + 20-40% FA	OPC + 36-65% GGBS	OPC + 66-80% GGBS[1]
			Max. mean Chloride Migration Coefficient[1] NT Build 492		
			D_{28} x 10^{-9} [in^2/s]		
De-icing salt spray	Towers, pier caps, pier columns, abutments	3.0	14.1	3.4	4.9
	Deck (Not covered by PPC system)		11.3	2.7	4.0
	Deck covered by PCC system	2.75	11.3	2.7	4.0
	Concrete barriers	2.75	12.4	3.4	4.6
Atmospheric	Towers, pier columns	3.0	15.0	11.0	12.0
	Pier caps	2.0			
	Deck (Underside)	1.5	11.3	2.7	4.0
Splash	Towers, pier caps, pier columns	3.0	15.0	5.1	7.1
	Pile caps	4.0			
Submerged	Concrete plug for piles	2.5	15.0	5.8	8.3
	Concrete plug for piles	3.0		8.5	12.0
Embedded	Abutments	3.0	15.0	8.5	12.0
	Drilled shaft				

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