Protocols for Chloride Sampling of Concrete

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National Bridge Preservation Partnership Conference 2018
April 11, 2018
Orlando, FL

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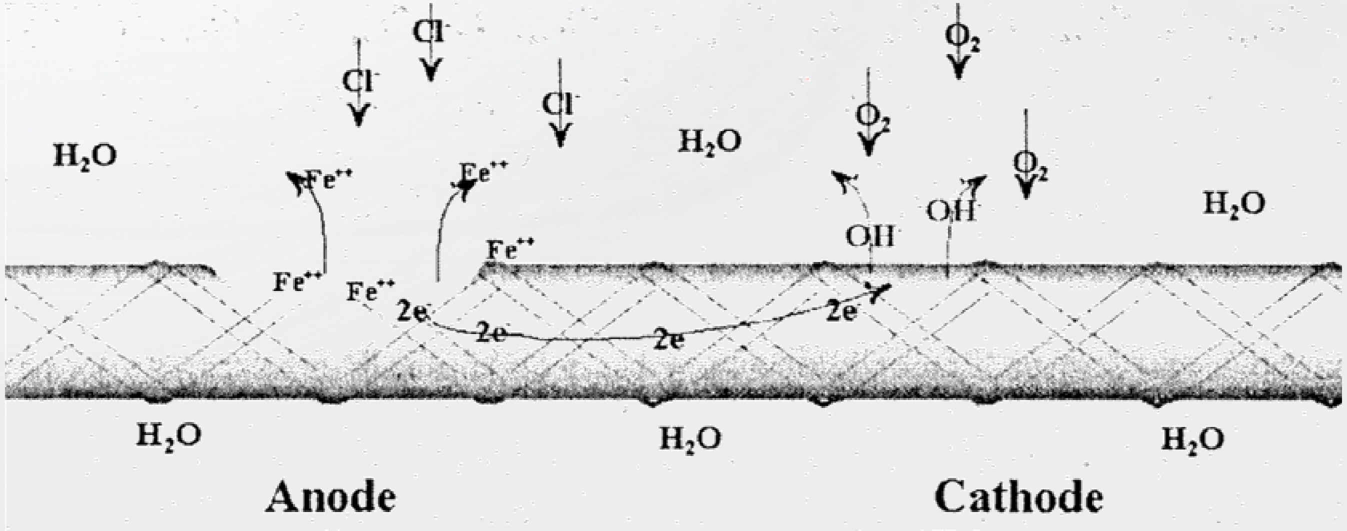
Purpose and Outline

Describe a common-sense approach to obtaining and testing samples of concrete for chloride contamination to assess impact on service life

- Overview of chloride-induced corrosion in concrete
- Sampling parameters and location selection
- Field sampling methods and procedures
- Lab testing methods
- Evaluation of results

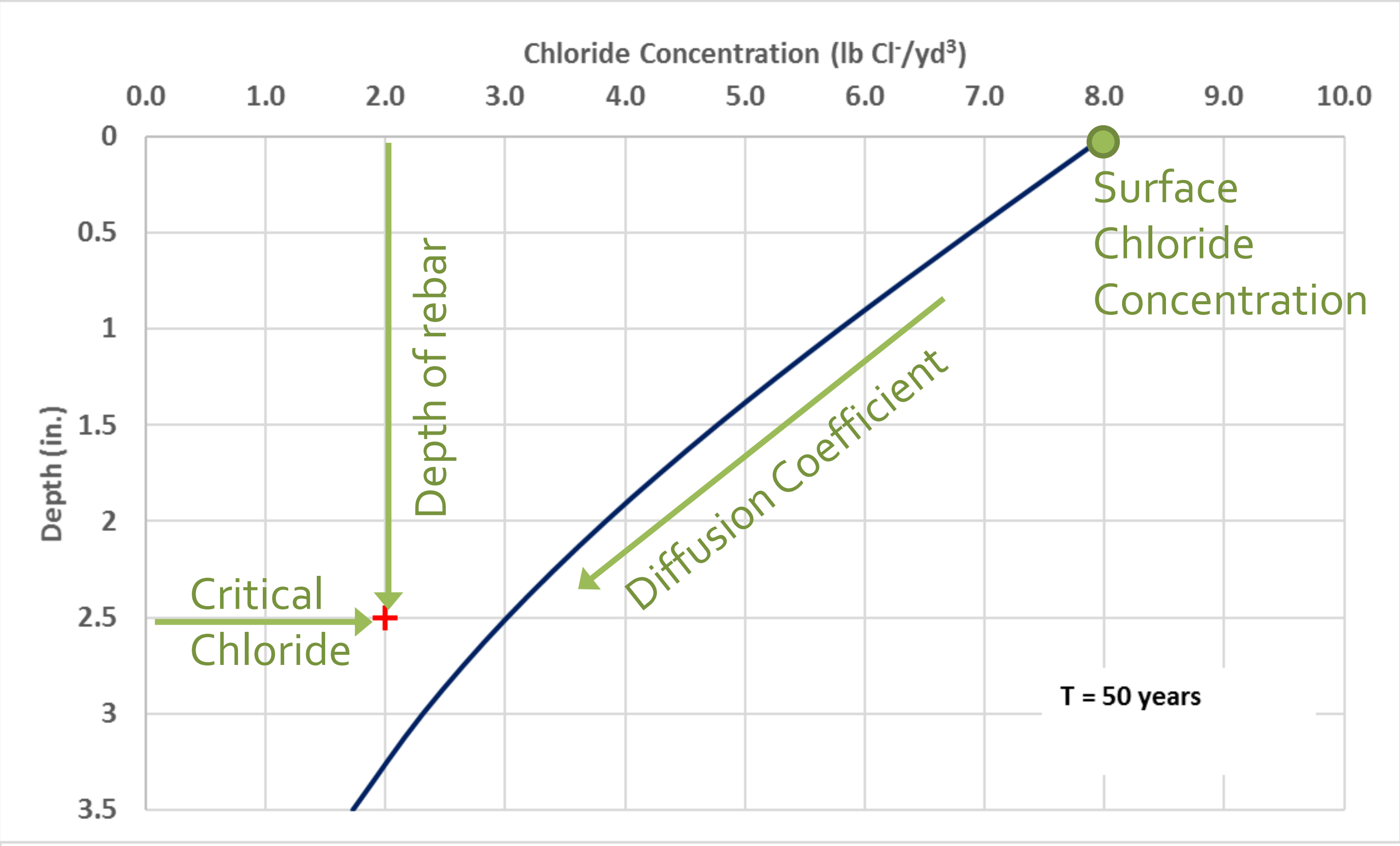
Chloride-Induced Corrosion in Reinforced Concrete

- Steel is stable in high-pH concrete environment, Cl^- disrupts passivity



- Reinforced concrete corrosion results in loss of concrete cover, reinforcement section, and ultimately serviceability and strength

Chloride Profile Development



Chloride Diffusion

One-dimensional solution to Fick's Second Law of Diffusion

$$C_{(x,t)} = C_o\left[1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right]$$

where,

$C_{(x,t)}$	= chloride concentration (lb. Cl^-/yd^3 concrete) at depth *x*
C_o	= driving chloride concentration at surface (usually approximate at 0.5 in.)
x	= depth (in.)
t	= age of the element (yr.)
erf()	= statistical error function
D_c	= apparent diffusion constant to be determined (in^2/yr)

An apparent value for D_c *is derived from a least-squares fit, where* chloride contents = measured minus background

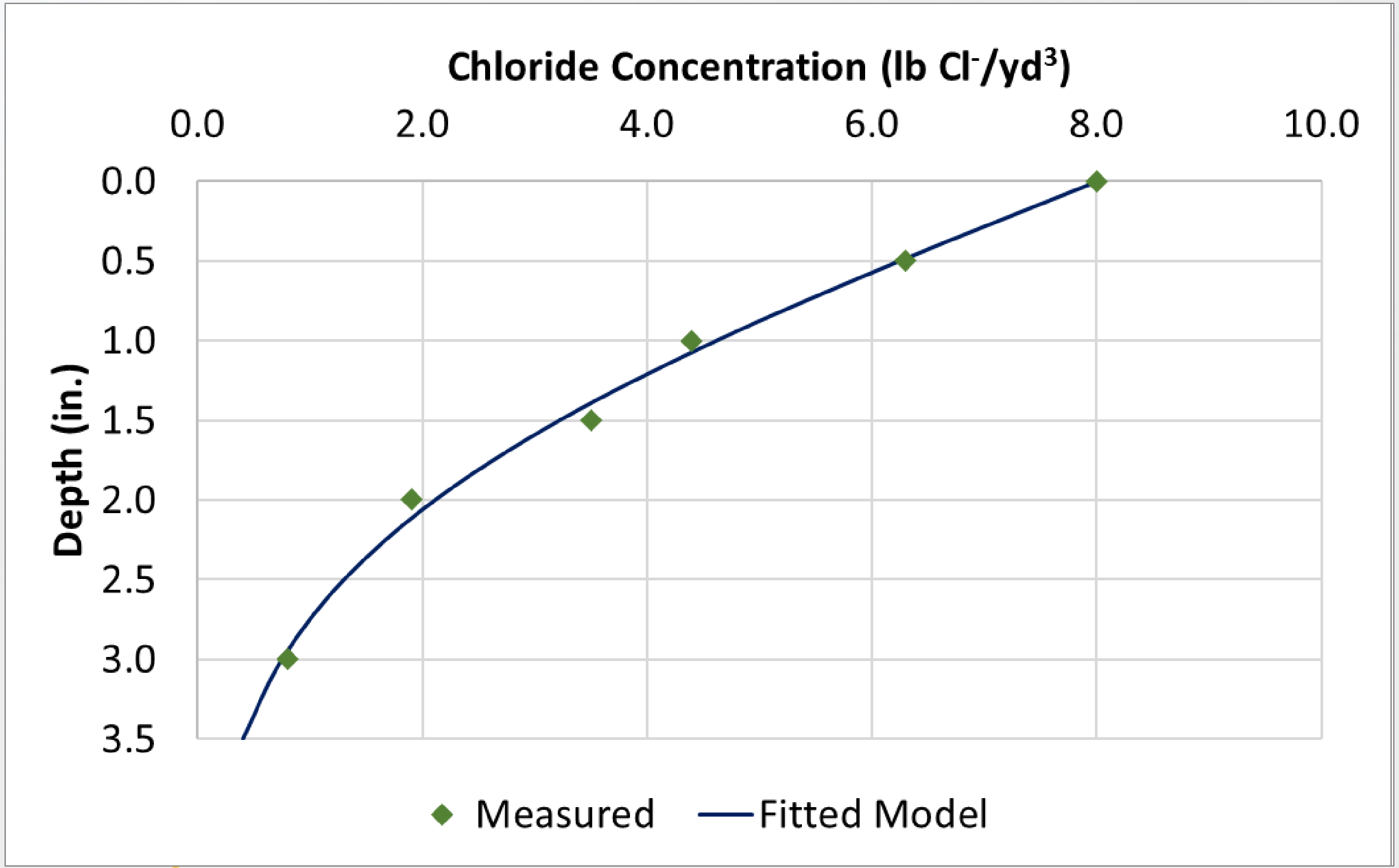
Chloride Profile Depth Increments

Increment #	Base unit (U.S. Customary)		Metric Equivalent (S.I.)	
	Nominal Depth (inches)	Depth range (inches)	Nominal Depth (mm)	Depth Range (mm)
1	0.5*	0.25-0.75	13	6-19
2	1.0	0.75-1.25	25	19-32
3	1.5	1.25-1.75	38	32-44
4	2.0	1.75-2.25	51	44-57
5	2.5	2.25-2.75	64	57-70
6	3.0+	2.75-3.25	76	70-83

* Concentration at this depth is to be used as driving chloride concentration, C_o, for diffusion calculations.

+ Generally considered as background chloride; assess all values for a location to determine background

Chloride Diffusion Profile



Generalized Procedure - Field

- Evaluate available documentation (e.g., as-builts, inspection reports)
- Determine the number of samples
- Identify core locations
- Locate and outline reinforcement at desired core locations
- Perform concrete coring or powder sampling
- Extract and store the sample
- Repair sample holes with approved materials

Generalized Procedure – Lab/Office

- If specimens collect by wet-coring, subdivide cores and pulverize
- Test for acid-soluble chlorides at depth increments to form a profile
- Calculate apparent surface concentration and diffusion coefficient
- Use modeling to project remaining time to corrosion

Pre-Planning

- Number of specimens to be determined as part of the comprehensive evaluation plan

- Identify probable sources of chloride (e.g., marine environment or deicer salts.) Document features of the structure and/or element of interest that may bear relevance to chloride exposure (i.e. drainage patterns, location of vehicle wheel paths, etc.)

- Location of sampling should be selected in accordance with the bridge element of interest

Pre-Planning

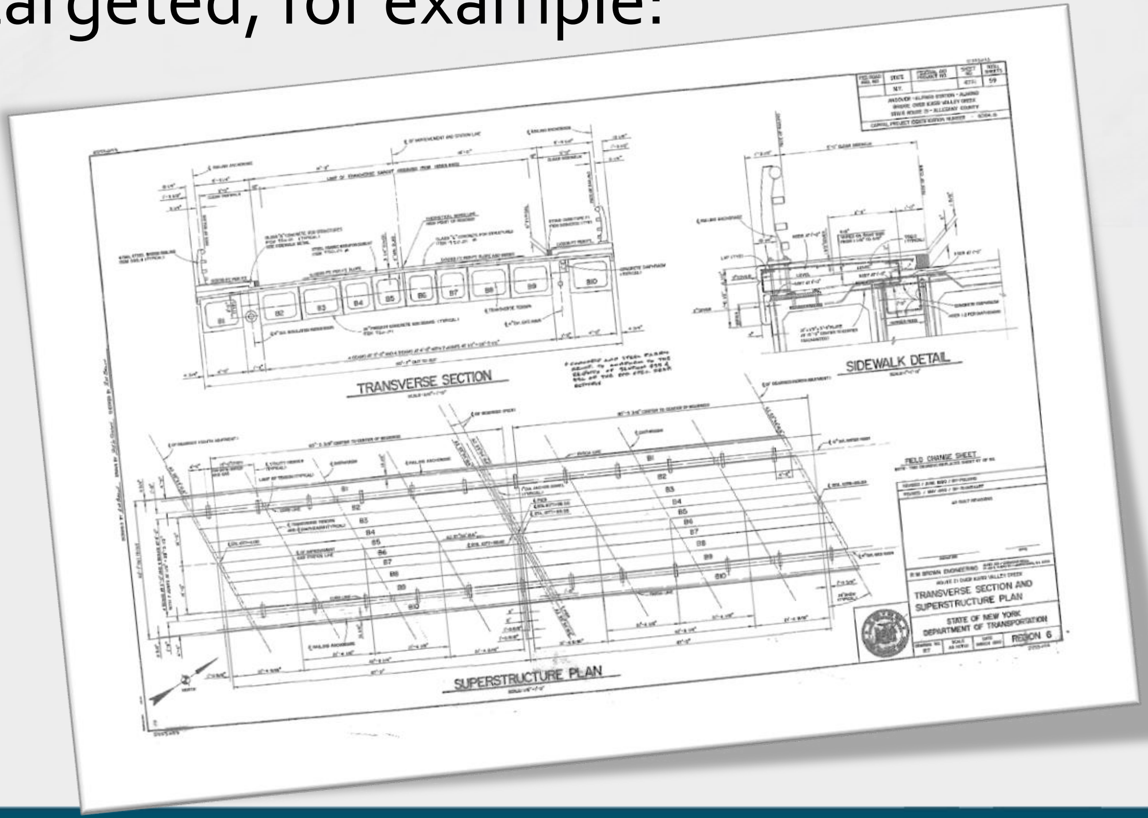
- Predetermine concrete characteristics to be determined, the number cores to be representative (statistically), and randomly or heuristically determine core locations based on exposure and element type.

- Select sample sizes and depth increments based on structure/element-specific criteria and tests to be performed.

- For example, for chloride determination, if nominal maximum aggregate size = 0.75 in., minimum drill diameter should be ~1.5 in.

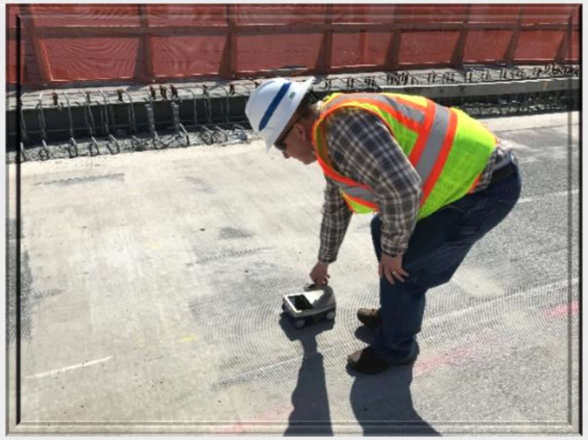
Location Selection

- Predetermine approximate locations using as-built documents
- Determine features to be avoided or targeted, for example:
  - Avoid delaminations
  - Avoid reinforcing steel, prestressing
  - Target map cracking areas (if of interest)
  - Target areas where traffic and drainage directs salt-laden run-off
  - Consider wheel-paths on decks or low areas adjacent to curbs ad parapets
  - Target areas on substructures beneath leaking/open joints and scuppers



Identifying Reinforcement and Embedded Items

- Pachometer & GPR measure the top steel mat, typically not the bottom steel mat.
- Conventional pachometers work only on magnetic (ferrous) steels.
- For stainless steel (nonferrous), use GPR or specially designed pachometers.
- GPR may also be useful for locating embedded ducts or other concealed elements in the concrete.
- Neither type of instrument will detect through metal conduit or stay-in-place metal formwork.



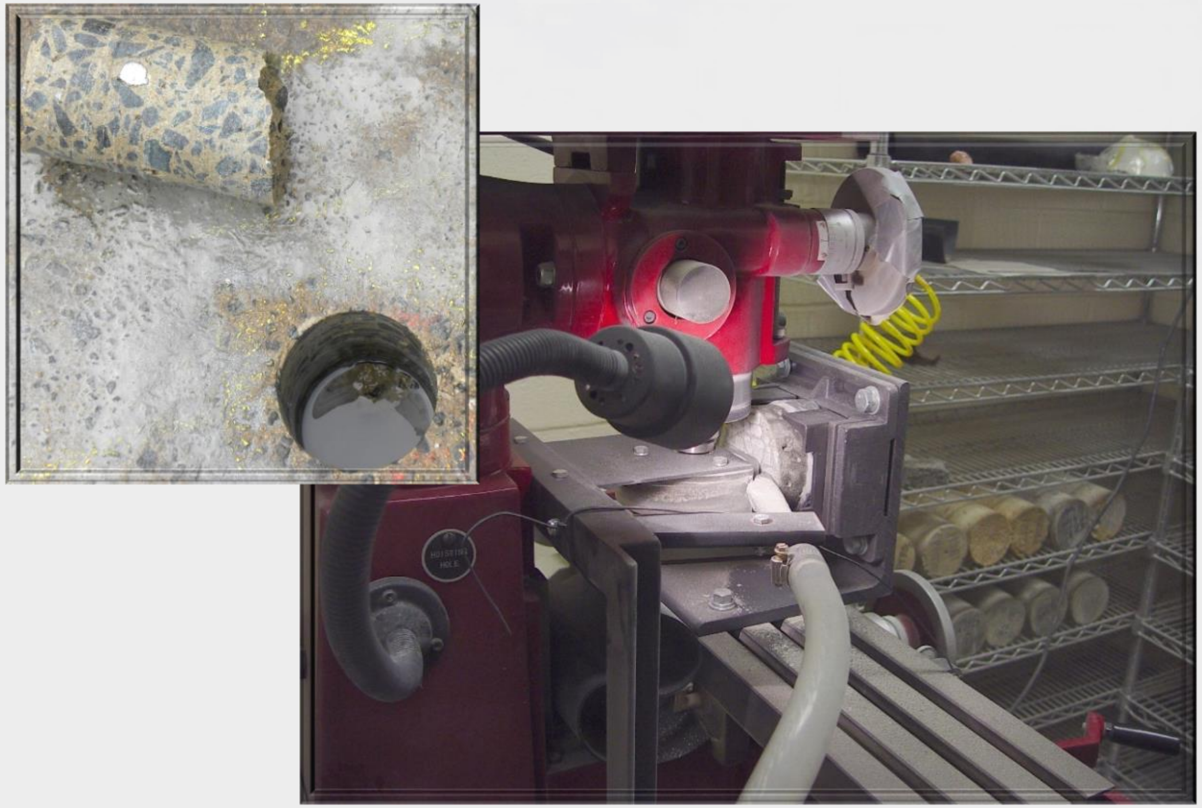
Identify and Mark Core Locations

- Identify specific coring locations and document relative to permanent bridge features
- Using a cover meter or GPR, lay out reinforcing grid locations and mark using temporary marker
- Measure and record cover depths of reinforcement at each core location.

Field Sampling Methods

Powder from w/rotary impact drill , OR

Core, then Cut-and-pulverize or Mill



Coring/Drilling Precautions

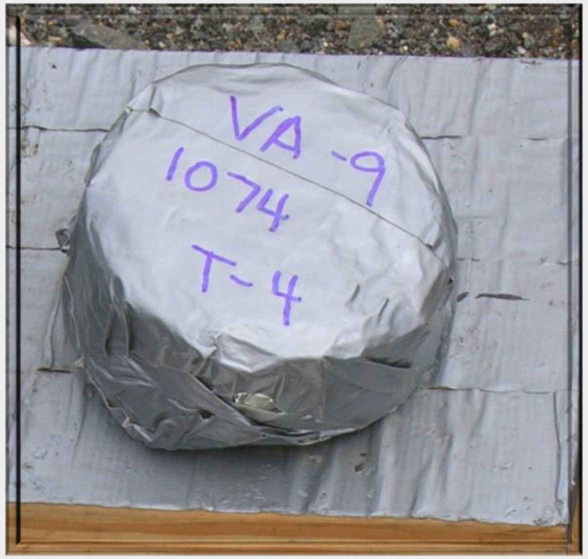
- Priority should be given at all times to preserving the safety of personnel, property and traveling public when working
- Review as-built plans; avoid features such as electrical conduits, prestressed and post-tensioned strands that may be damaged
- Mark the coring/drilling location with a temporary marker
- Mark maximum depth on core/drill bit
- Take precautions when coring/drilling to within 2 inches of full element thickness (e.g., 6 inches or deeper on an 8-inch deck)

Coring Operation

- Core to depth at least 1 inch greater than required length, as cores rarely break off even at the bottom
- For full depth cores on decks with stay-in-place forms
  - drill water will be lost when form is cut; stop drilling before formwork
- For full depth cores on decks without stay-in-place forms
  - access to underside position is needed to catch the cores

Core Sample Storage

- Let core surface dry, then with a permanent marker write ID on core
- Measure and record core lengths, diameter and other features such as maximum aggregate size, cracks, voids, reinforcements, deleterious reactions, etc.; take photographs
- Wrap the core specimen:
    1. 4-mil polyethylene sheet – insulating layer
    2. Aluminum foil - moisture impermeable layer
    3. 4-mil polyethylene - protective layer
    4. Duct tape - binding layer
- Mark core number on wrapping
- Place in transport container



Patching

- Before leaving the site, repair locations where physical sampling resulted in a hole in the concrete element
- Rapid set cementitious repair materials are generally recommended; get owner approval
- Polymer or cementitious dry-pack, no-slump materials for vertical and overhead
- Repairs to overlays or membranes should be compatible
- Allow repair materials time to reach adequate strength before opening to traffic on decks.

Lab Processing and Subsampling

- Unwrap core and verify ID on the wrapping and core body
- Reduce solid concrete cores specimens to powder test specimens, typically in ½-inch depth increments by:
  1. Cutting into discs according to required depth increments and pulverizing, or
  2. Grinding/milling the core cross-section to required depth increments
- Procedures for powdering should be controlled to prevent cross-contamination from one depth increment to the next and between core samples.

Lab Processing and Subsampling

Concrete Milling

Chloride Testing Methods

- Potentiometric chemical titration
  - Acid-soluble
    (ASTM C1152 or AASHTO T260)
  - Water-soluble
    (ASTM C1218)

- Specific Ion Probe
  - Acid-soluble
    (AASHTO T332)



Standard Method of Test for
Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
AASHTO Designation: T 260-97 (2016)
Release: Group 1 (April 2016)

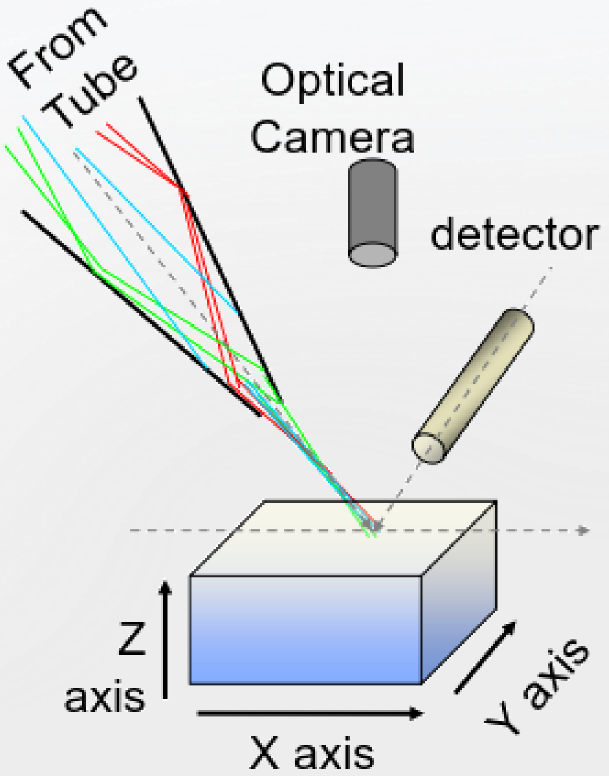
Standard Method of Test for
Determining Chloride Ions in Concrete and Concrete Materials by Specific Ion Probe
AASHTO Designation: T 332-07 (2016)[1]
Release: Group 1 (April 2016)

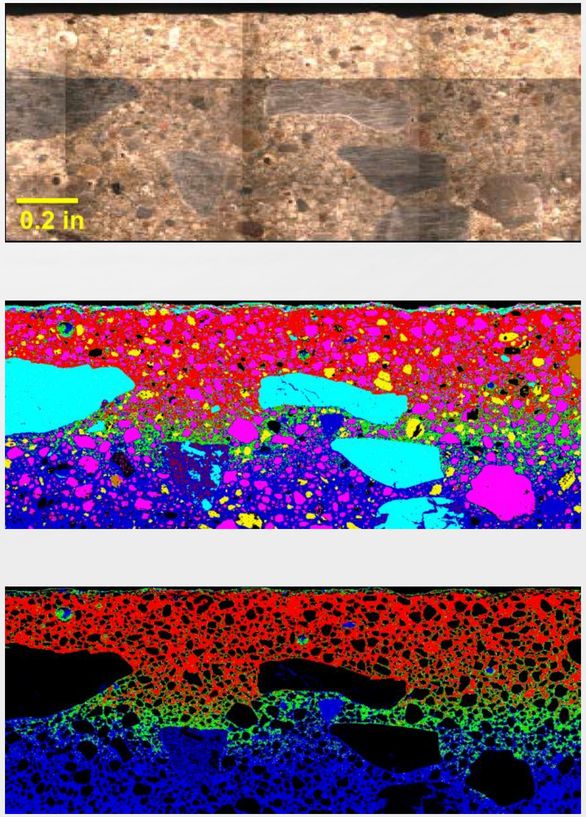
Designation: C1218/C1218M – 15
Standard Test Method for
Water-Soluble Chloride in Mortar and Concrete[1]

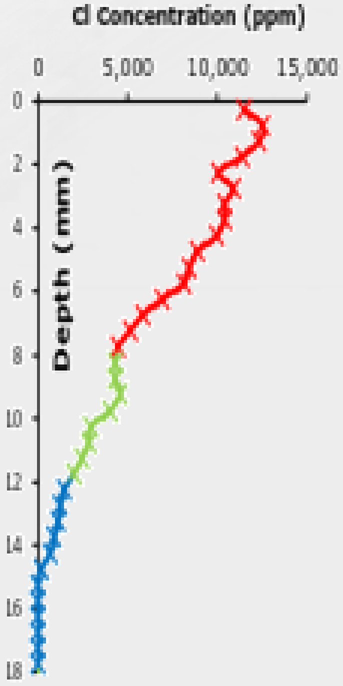
Designation: C 1152/C 1152M – 04[ε1]
Standard Test Method for
Acid-Soluble Chloride in Mortar and Concrete[1]

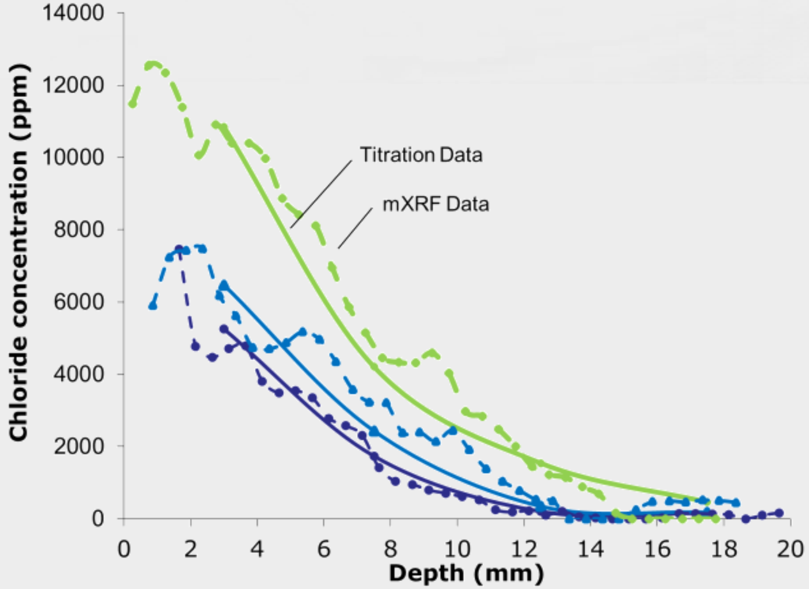
Chloride Testing Methods

A promising future method: Micro X-ray Fluorescence (μXRF)







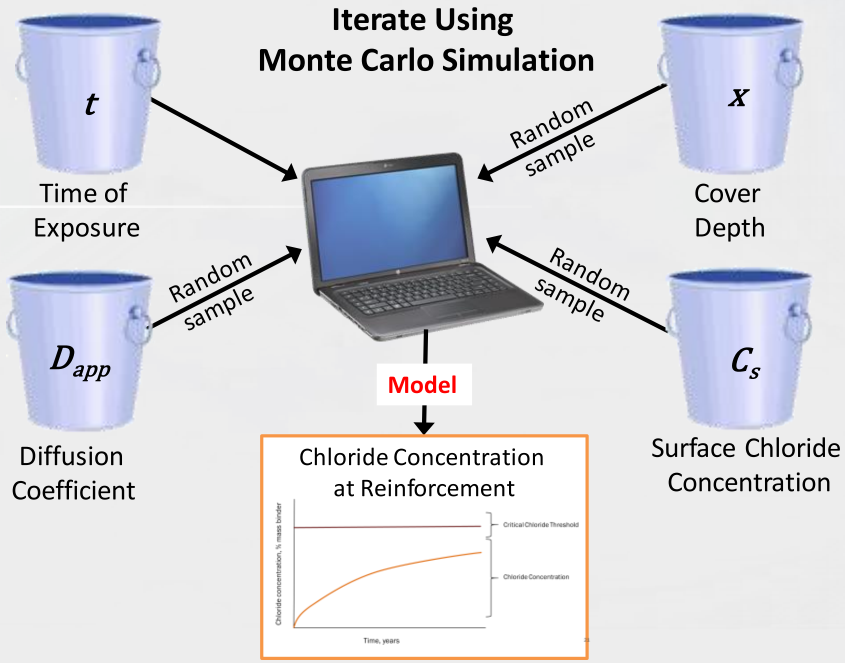


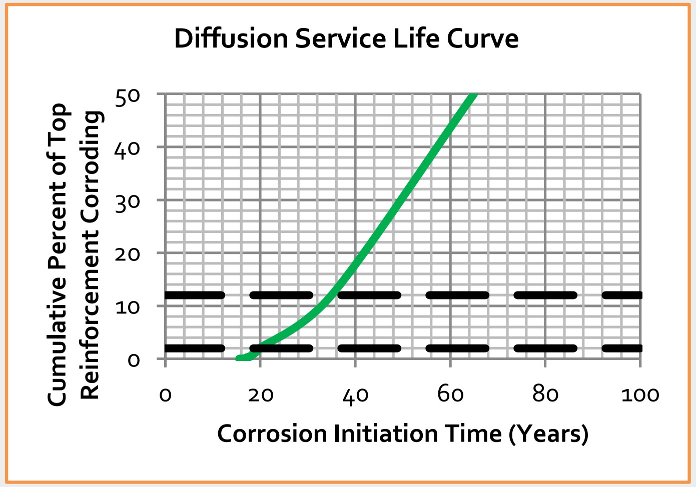
Estimating Service Life

$$C_{(x,t)} = C_o\left(1 - erf\frac{x}{2\sqrt{D_c t}}\right)$$

Chloride-induced corrosion

- Use measured defects, chloride profiles, cover depths, age and material properties
- Project probabilistic time to corrosion
- Estimate time to rehabilitation





Thank you!

Questions?

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