Crack Attack!
Incorporating the Effect of Cracking on Probabilistic Service Life Predictions

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ACI Spring Convention
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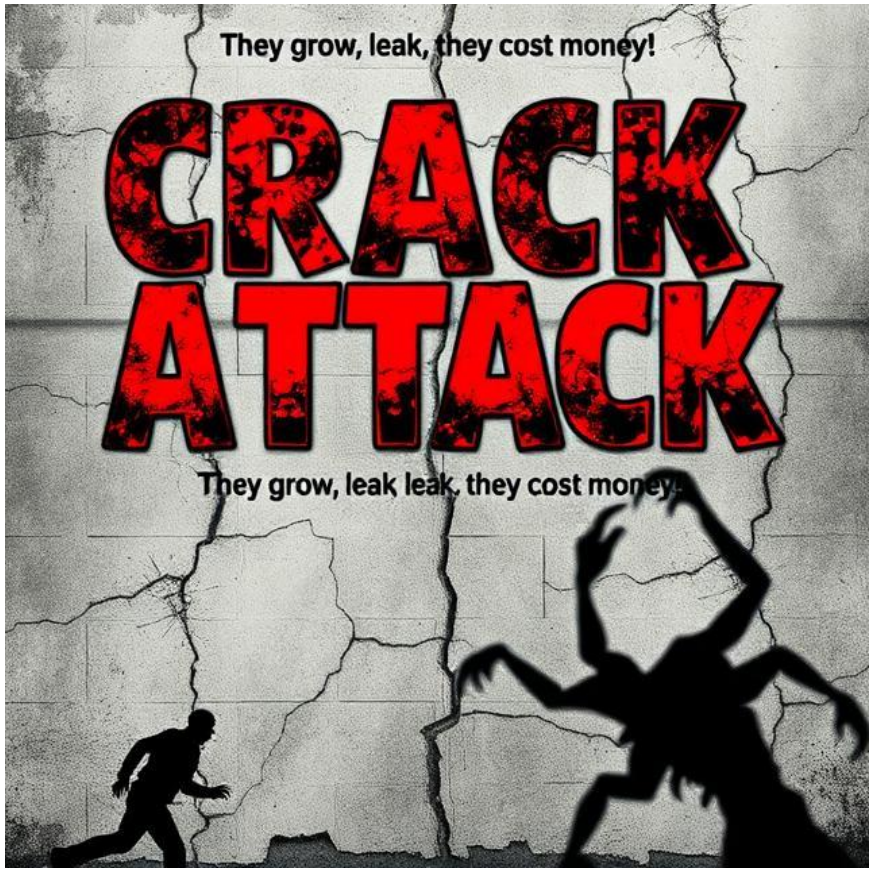
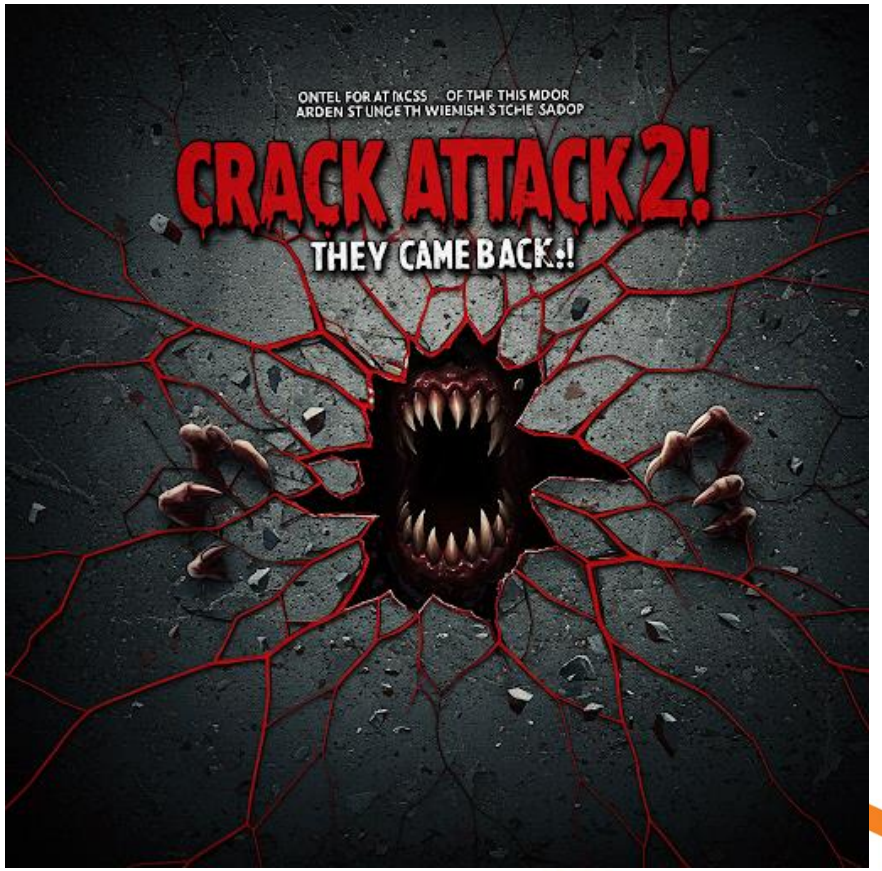
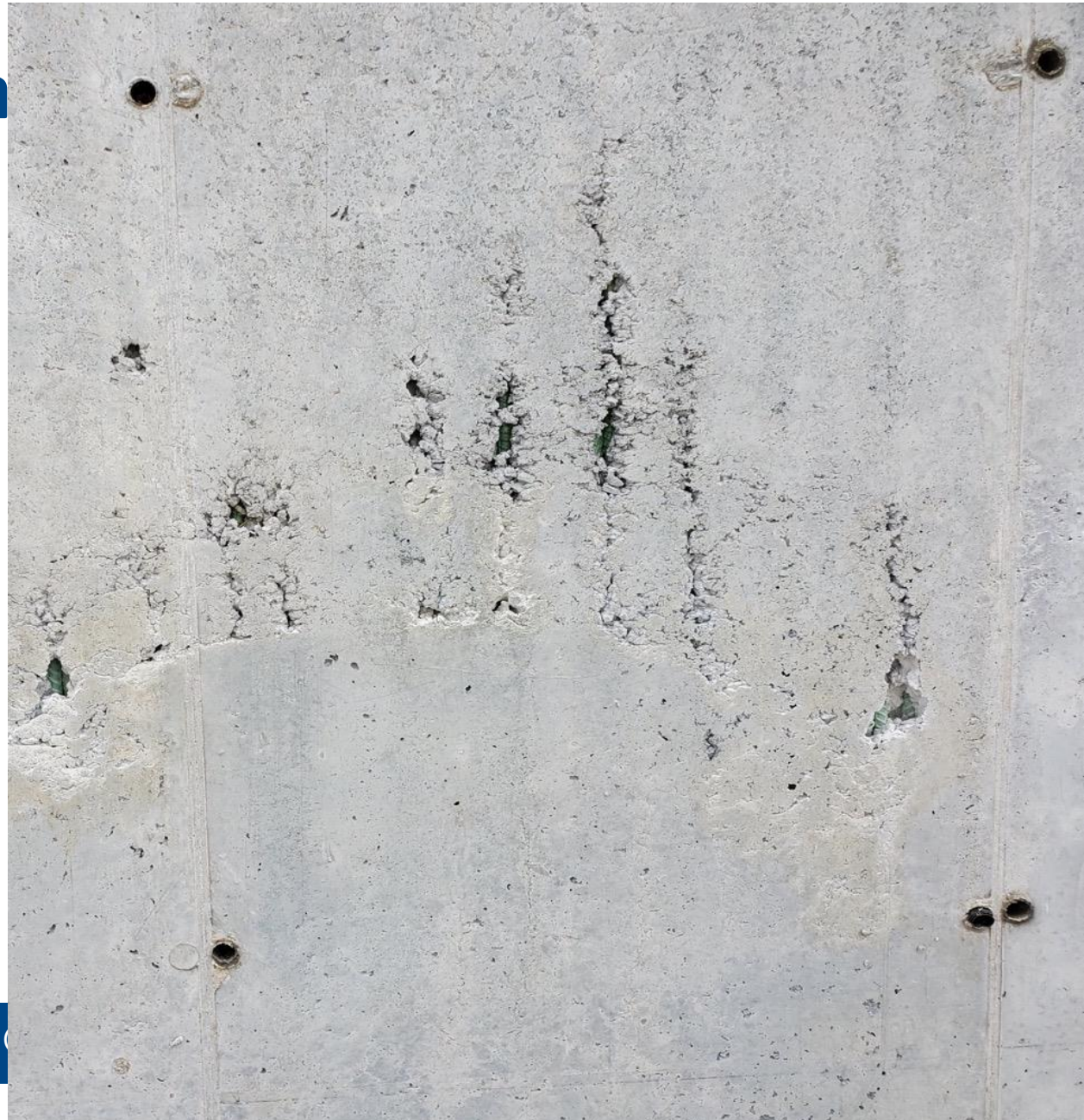
Scariest movie this summer… (and every summer)





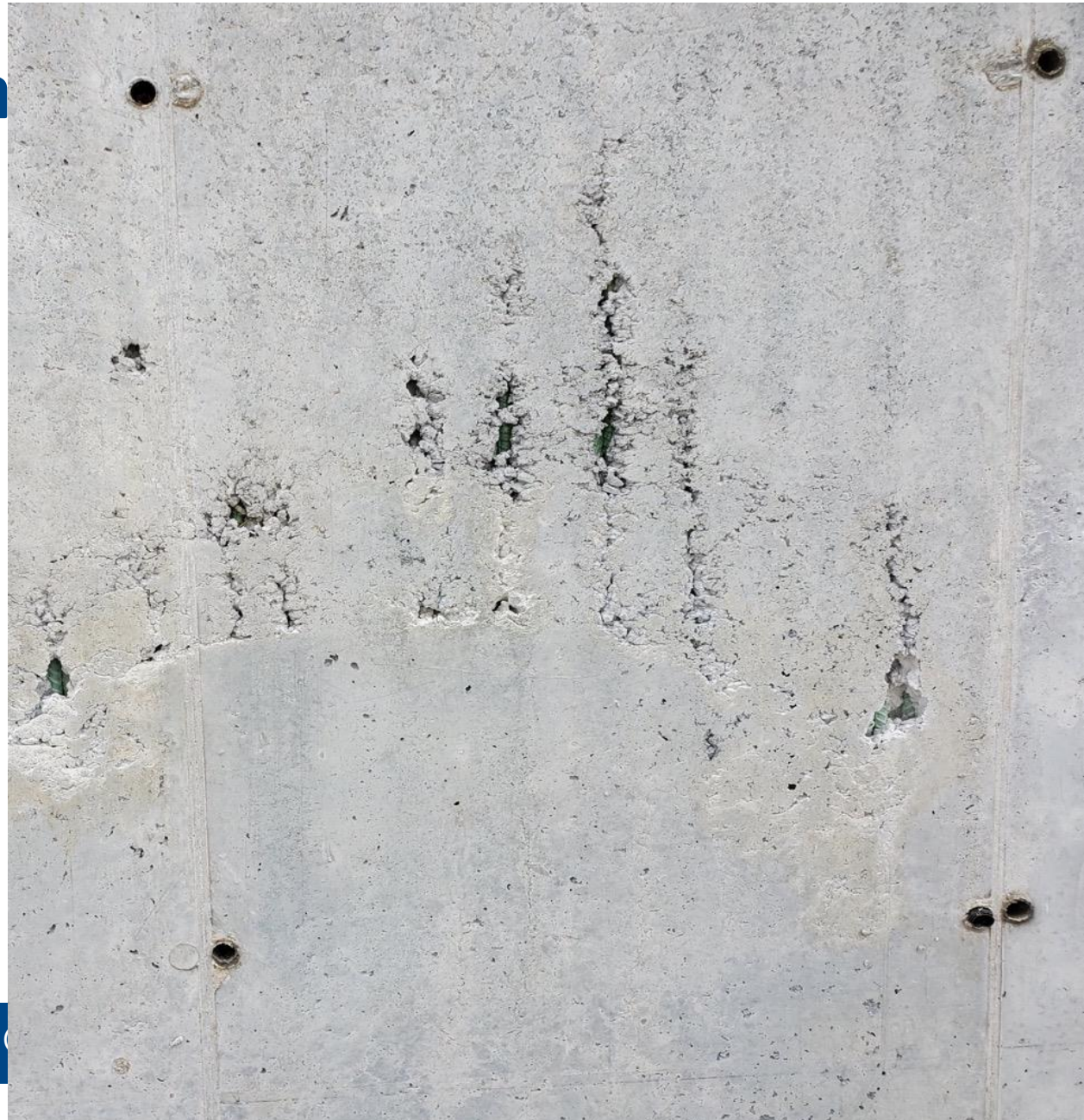
Cracks during Construction

- Cracks During Construction
  - *Feature or Bug?*
- Assessing the Cracks
  - *Identification*
- Challenges & Constraints
  - *Technical & Non-technical*
- Repair Procedures & Materials
  - *Special cases*
- Durability of Repairs
  - *Often required when service life is specified*
- Remarks



Cracks during Construction

- Part of the Construction Industry
  - *Defective vs. repairable*
- Specified vs. Goal-oriented
  - *One-size-fits-all or performance-based*
- Durability
  - *Durability of repair & maintenance considerations*
- Execution
  - *Expertise may not be the same as in new construction*
- Schedule
  - *Delays, adjacent work*
- Cost



Assessing the Cracking

- Identification
  - *Visual inspection, NDE, etc.*
- Can it be repaired?
  - *Magnitude of issue*
- Impact on Schedule
  - *Include repair preparation & execution*
- Orientation
  - *Horizontal, vertical, and overhead*
- Accessibility
  - *Elevated, confined spaces*
- Stakeholders
  - *Owner, Contractor, Material Supplier(s), QA/QC*
- Accountability

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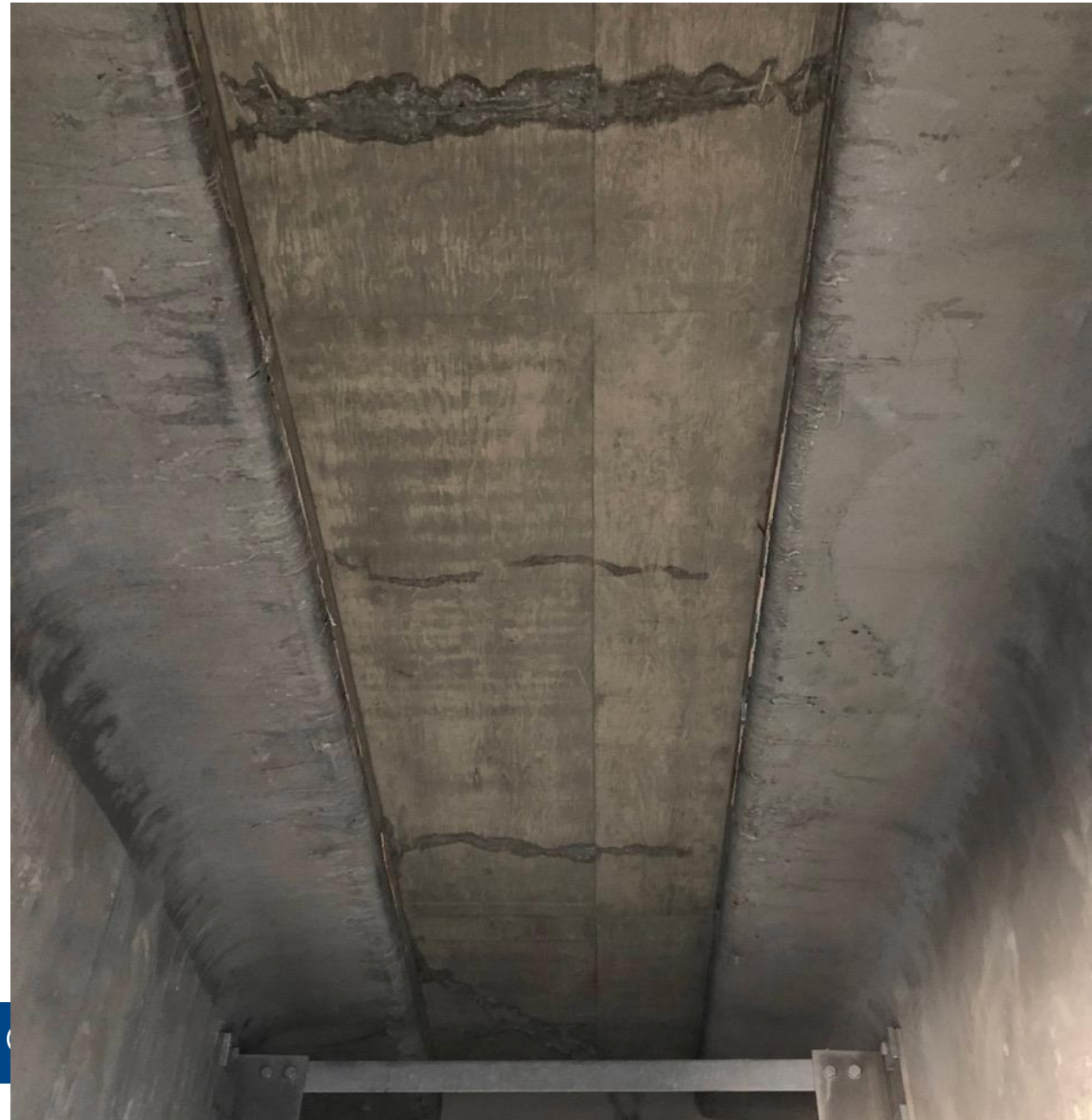
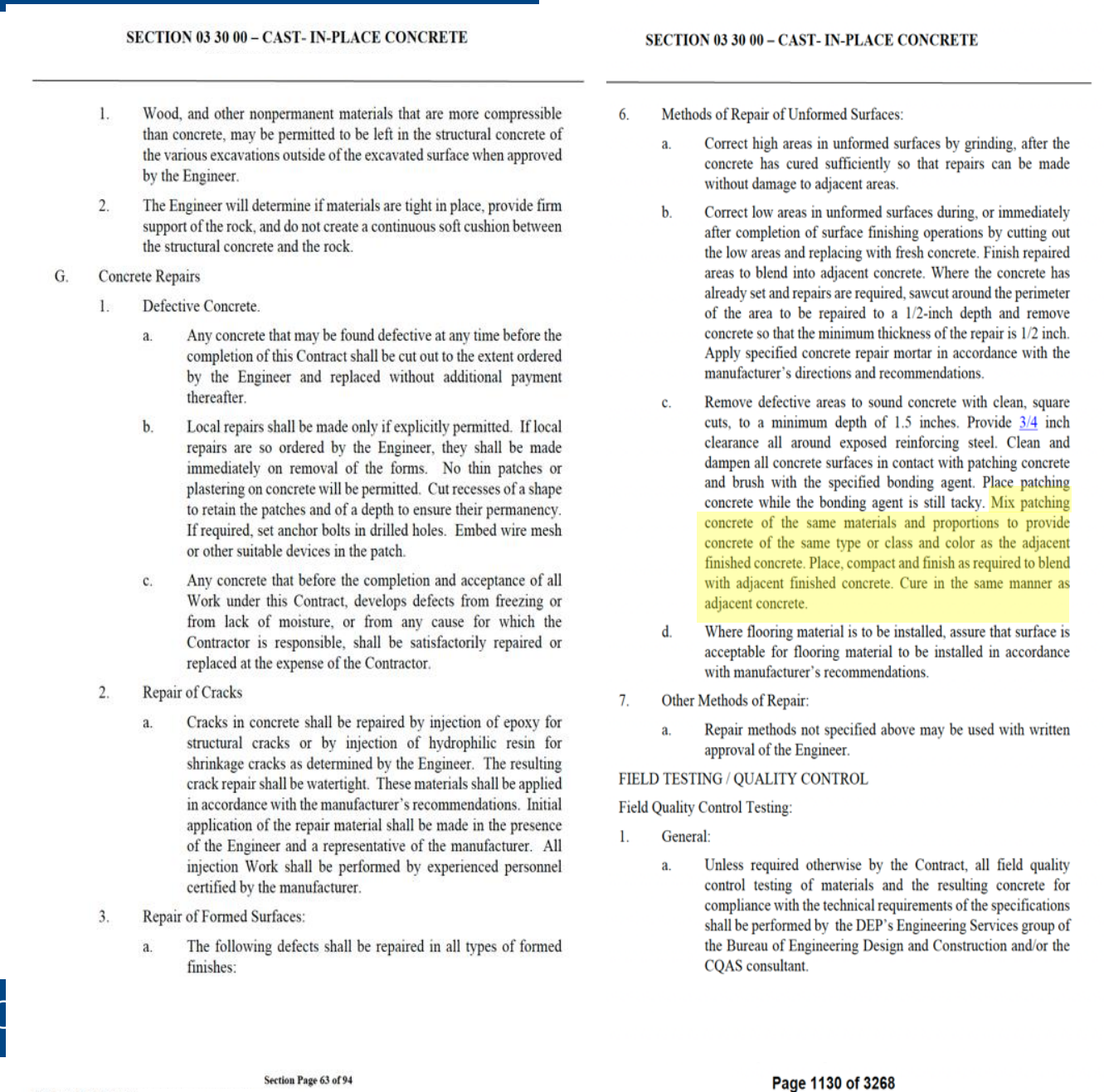


Challenges

- Technical
  - Specification Requirements
  - Mandatory or specified
  - Project-specific repair conditions
  - Repair material & method selection
  - Execution
  - Acceptance
- Non-technical
  - Limited time
  - Cost
  - Stakeholder relationship & communication



SECTION 03 30 00 – CAST- IN-PLACE CONCRETE

1. Wood, and other nonpermanent materials that are more compressible than concrete, may be permitted to be left in the structural concrete of the various excavations outside of the excavated surface when approved by the Engineer.
2. The Engineer will determine if materials are tight in place, provide firm support of the rock, and do not create a continuous soft cushion between the structural concrete and the rock.

G. Concrete Repairs

1. Defective Concrete.
   a. Any concrete that may be found defective at any time before the completion of this Contract shall be cut out to the extent ordered by the Engineer and replaced without additional payment thereafter.
   b. Local repairs shall be made only if explicitly permitted. If local repairs are so ordered by the Engineer, they shall be made immediately on removal of the forms. No thin patches or plastering on concrete will be permitted. Cut recesses of a shape to retain the patches and of a depth to ensure their permanency. If required, set anchor bolts in drilled holes. Embed wire mesh or other suitable devices in the patch.
   c. Any concrete that before the completion and acceptance of all Work under this Contract, develops defects from freezing or from lack of moisture, or from any cause for which the Contractor is responsible, shall be satisfactorily repaired or replaced at the expense of the Contractor.
2. Repair of Cracks
   a. Cracks in concrete shall be repaired by injection of epoxy for structural cracks or by injection of hydrophilic resin for shrinkage cracks as determined by the Engineer. The resulting crack repair shall be watertight. These materials shall be applied in accordance with the manufacturer's recommendations. Initial application of the repair material shall be made in the presence of the Engineer and a representative of the manufacturer. All injection Work shall be performed by experienced personnel certified by the manufacturer.
3. Repair of Formed Surfaces:
   a. The following defects shall be repaired in all types of formed finishes:

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SECTION 03 30 00 – CAST- IN-PLACE CONCRETE

6. Methods of Repair of Unformed Surfaces:
   a. Correct high areas in unformed surfaces by grinding, after the concrete has cured sufficiently so that repairs can be made without damage to adjacent areas.
   b. Correct low areas in unformed surfaces during, or immediately after completion of surface finishing operations by cutting out the low areas and replacing with fresh concrete. Finish repaired areas to blend into adjacent concrete. Where the concrete has already set and repairs are required, sawcut around the perimeter of the area to be repaired to a 1/2-inch depth and remove concrete so that the minimum thickness of the repair is 1/2 inch. Apply specified concrete repair mortar in accordance with the manufacturer's directions and recommendations.
   c. Remove defective areas to sound concrete with clean, square cuts, to a minimum depth of 1.5 inches. Provide 3/4 inch clearance all around exposed reinforcing steel. Clean and dampen all concrete surfaces in contact with patching concrete and brush with the specified bonding agent. Place patching concrete while the bonding agent is still tacky. Mix patching concrete of the same materials and proportions to provide concrete of the same type or class and color as the adjacent finished concrete. Place, compact and finish as required to blend with adjacent finished concrete. Cure in the same manner as adjacent concrete.
   d. Where flooring material is to be installed, assure that surface is acceptable for flooring material to be installed in accordance with manufacturer's recommendations.
7. Other Methods of Repair:
   a. Repair methods not specified above may be used with written approval of the Engineer.

FIELD TESTING / QUALITY CONTROL

Field Quality Control Testing:

1. General:
   a. Unless required otherwise by the Contract, all field quality control testing of materials and the resulting concrete for compliance with the technical requirements of the specifications shall be performed by the DEP's Engineering Services group of the Bureau of Engineering Design and Construction and/or the CQAS consultant.

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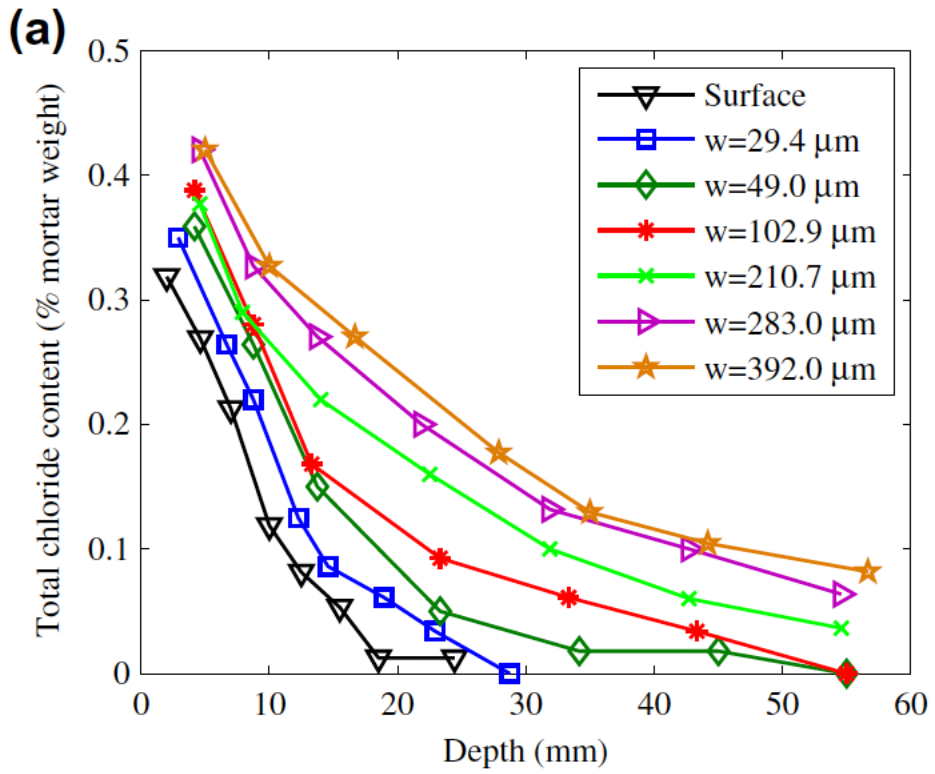
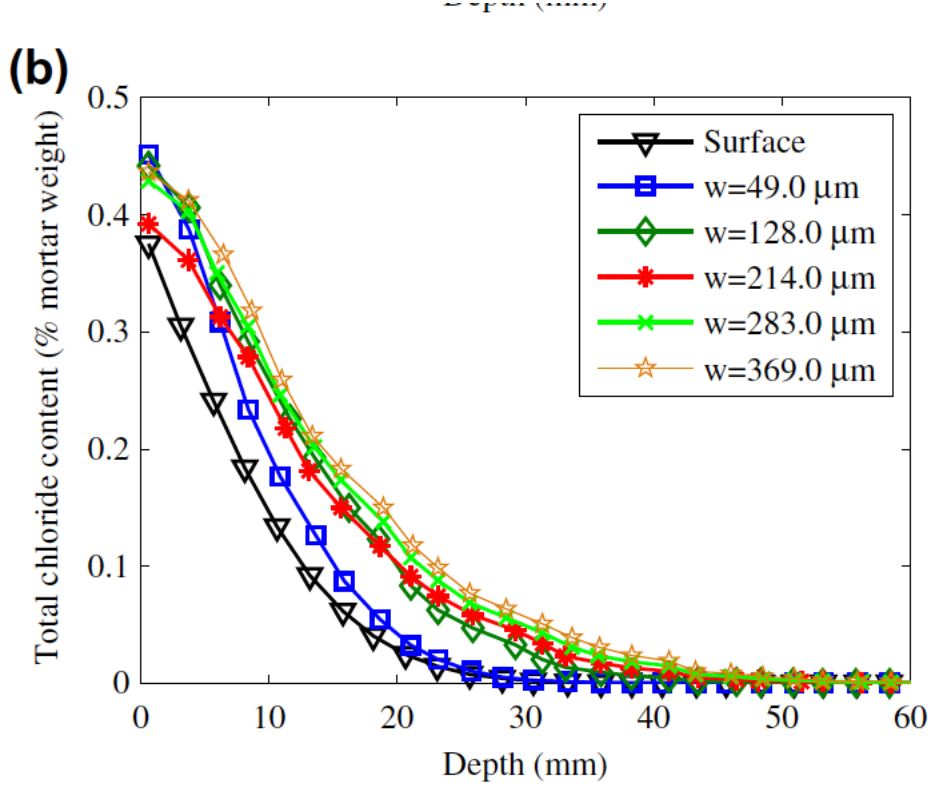
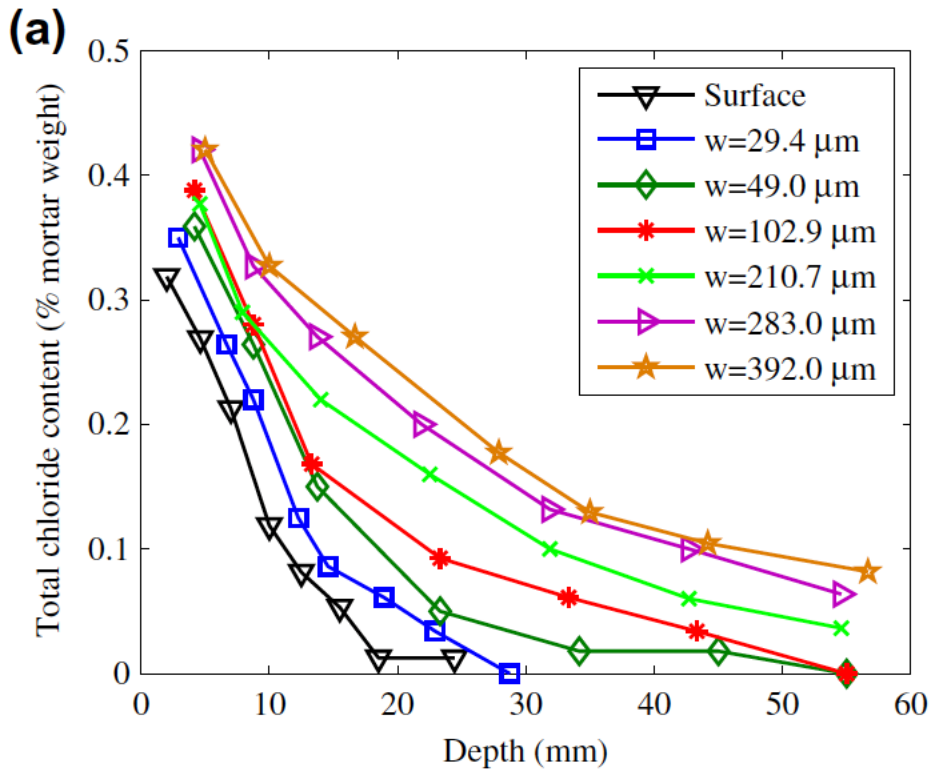
Crack Features

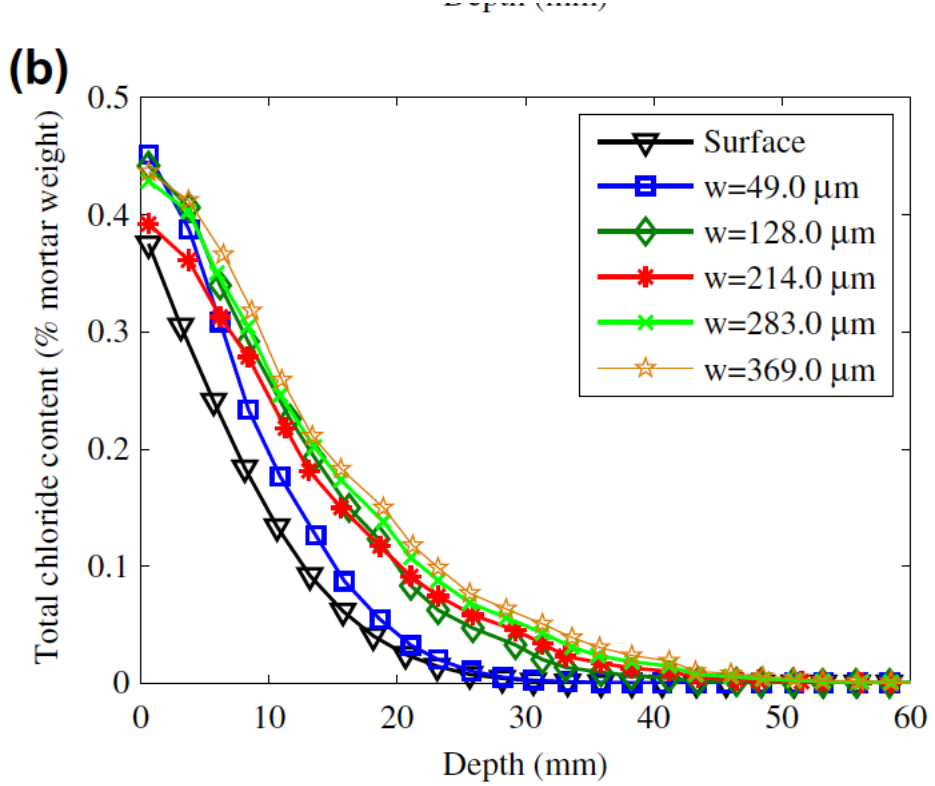




Šavija, B., Pacheco, J., & Schlangen, E. (2013). Lattice modeling of chloride diffusion in sound and cracked concrete. *Cement and Concrete Composites*, *42*, 30-40.

Crack Features





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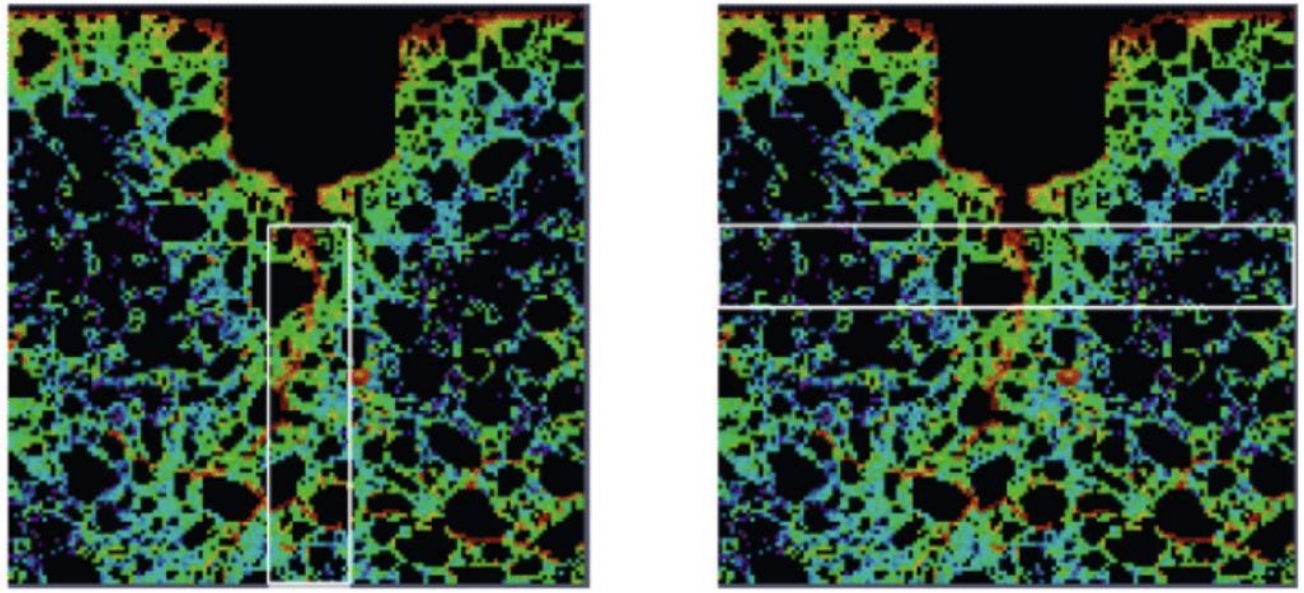
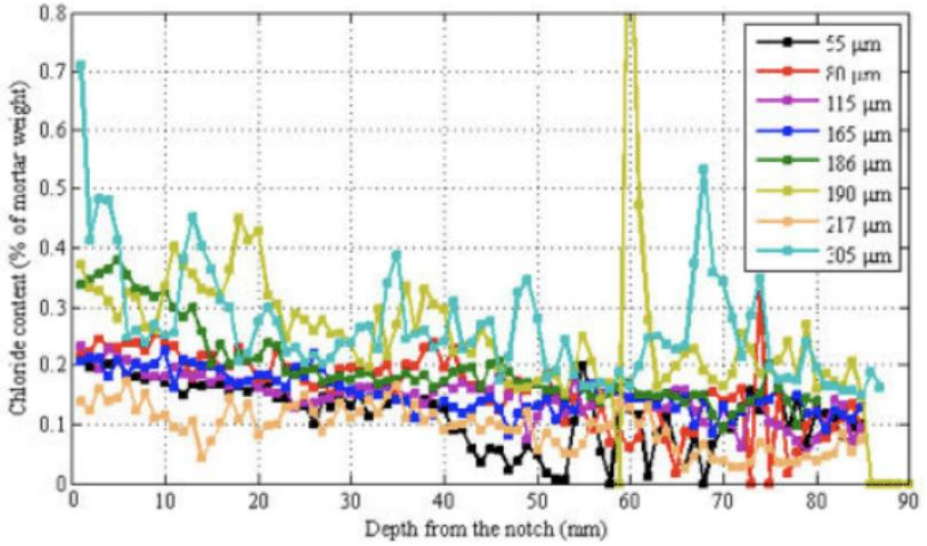
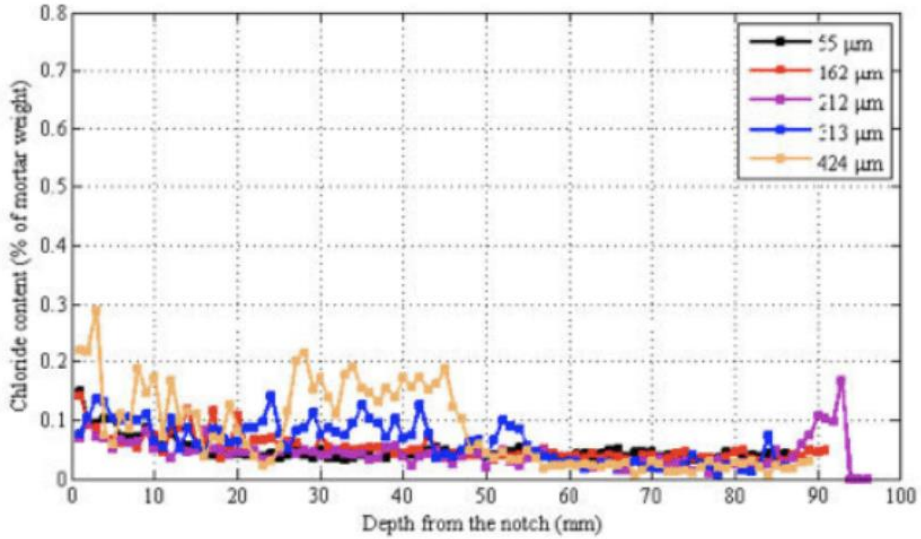


a) Vertical subset (b) Horizontal subset

Fig. 27 Definition of subsets for averaging of chloride content.



(a) OPC



(b) Slag

Šavija, B., Schlangen, E., Pacheco, J., Millar, S., Eichler, T., & Wilsch, G. (2014). Chloride ingress in cracked concrete: a laser induced breakdown spectroscopy (LIBS) study. Journal of advanced concrete technology, 12(10), 425-442.

Incorporating Cracking

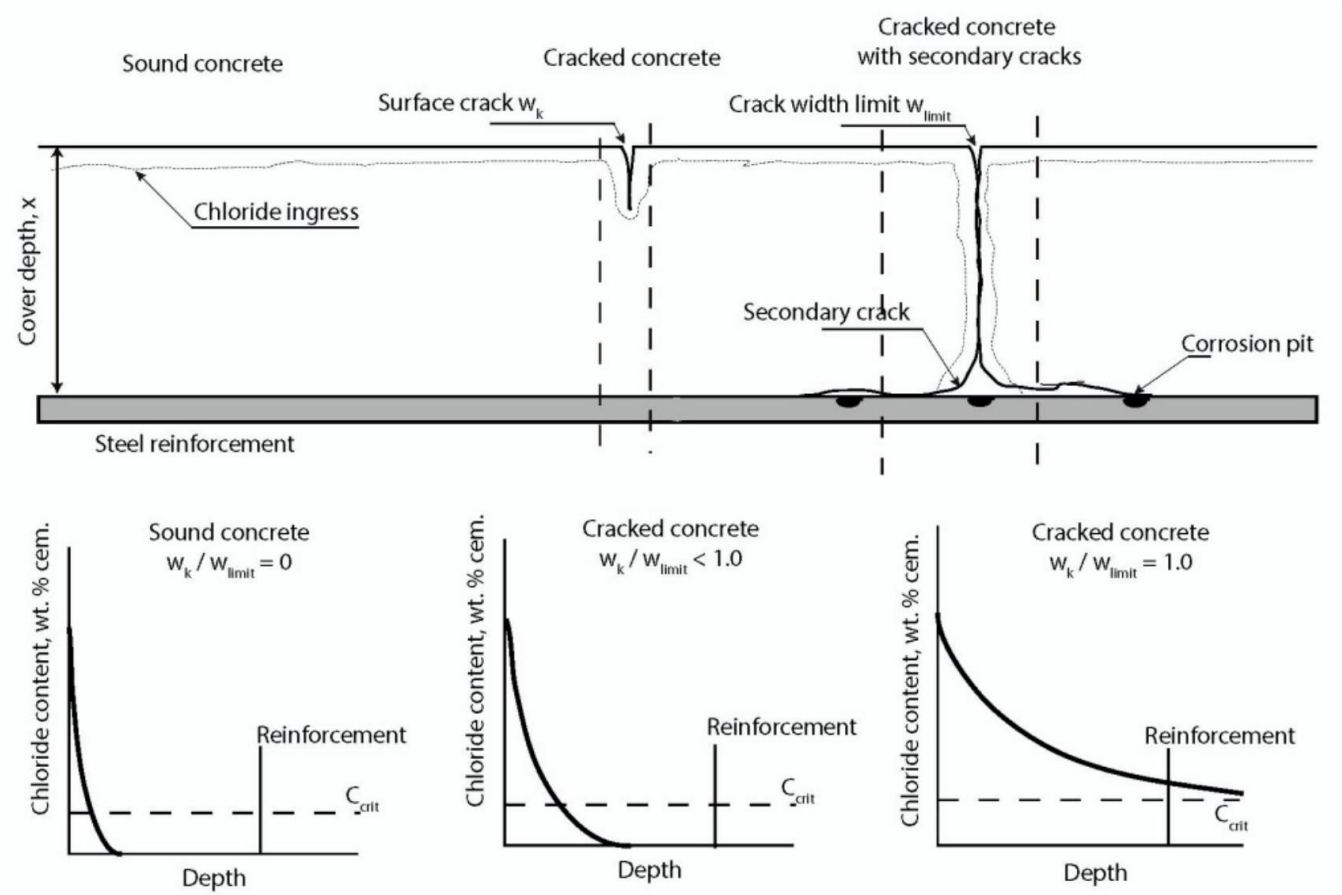


Figure 5: Conceptual model for estimating chloride ingress in cracked concrete.

$$D_{cr} = \frac{D_0}{1 - \frac{w_k}{w_{limit}}}$$

Pacheco, J. (2019). Incorporating Cracks in Chloride Ingress Modeling and Service Life Predictions. ACI Materials Journal, 116(5).

Pacheco, J., & Polder, R. (2016). Incorporating cracking of concrete on chloride ingress and service life modeling of concrete structures. In *Corrosion 2016: Collaborate, Educate, Innovate, Mitigate*.

Case Study — Bridge in MB

- Constructed in 2020
  - *Noticeable deck cracking before the commission*
- Concrete met specification requirements
  - *Compressive strength, chloride penetration*
- Exposure to severe deicing salts
  - *Cracking is a concern for durability*
- Investigation of the potential cause(s)
  - *Document review, coring, petrography, etc.*
- Responsibility
  - *MT, EOR, contractor, material supplier, etc.*
- Repair recommendations
  - *Crack repair vs. crack repair plus overlay*

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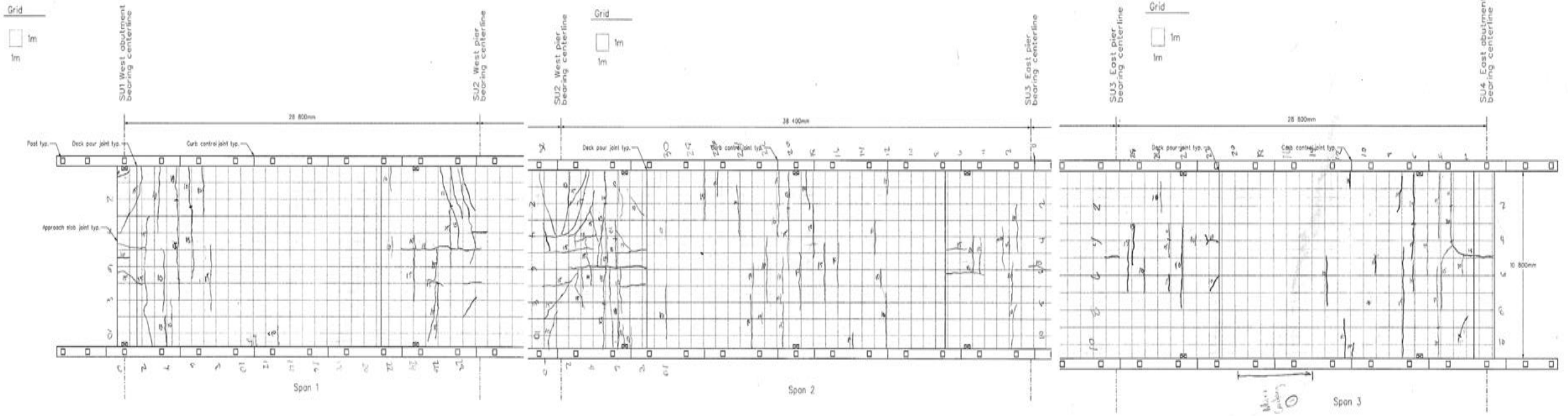


Case Study — Bridge in MB

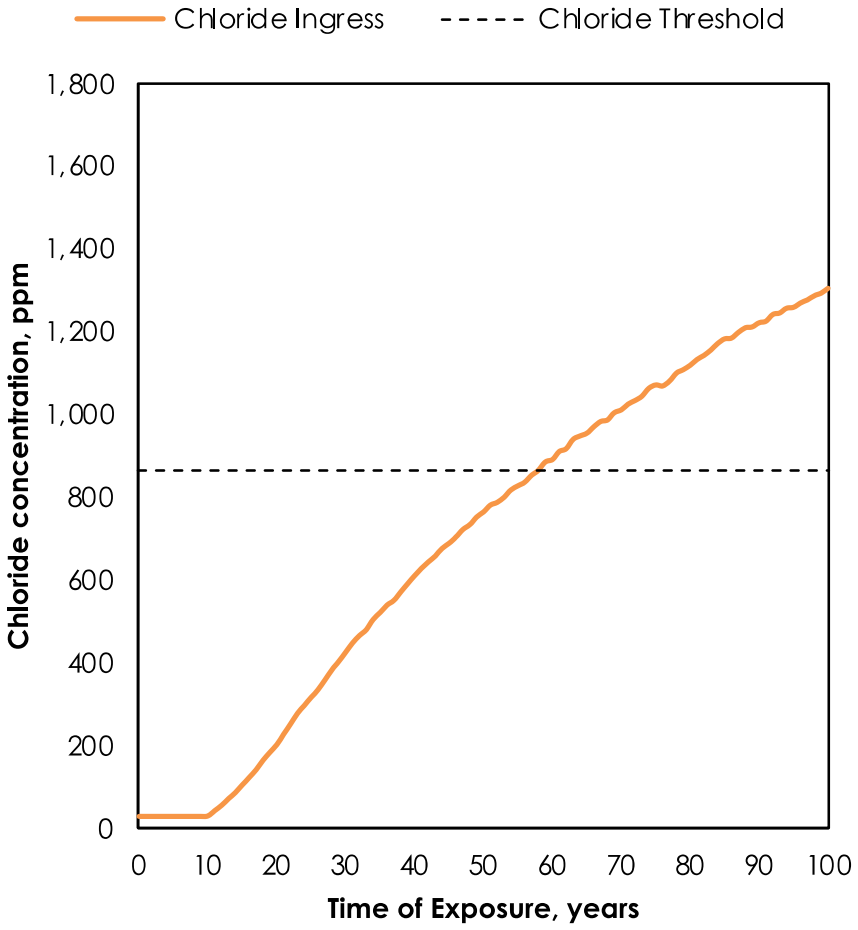
- Crack width range (0.009 to 0.016 in.)
  - Lognormal distribution
- Effect on chloride transport
  - Increased chloride ingress
- Repairable?

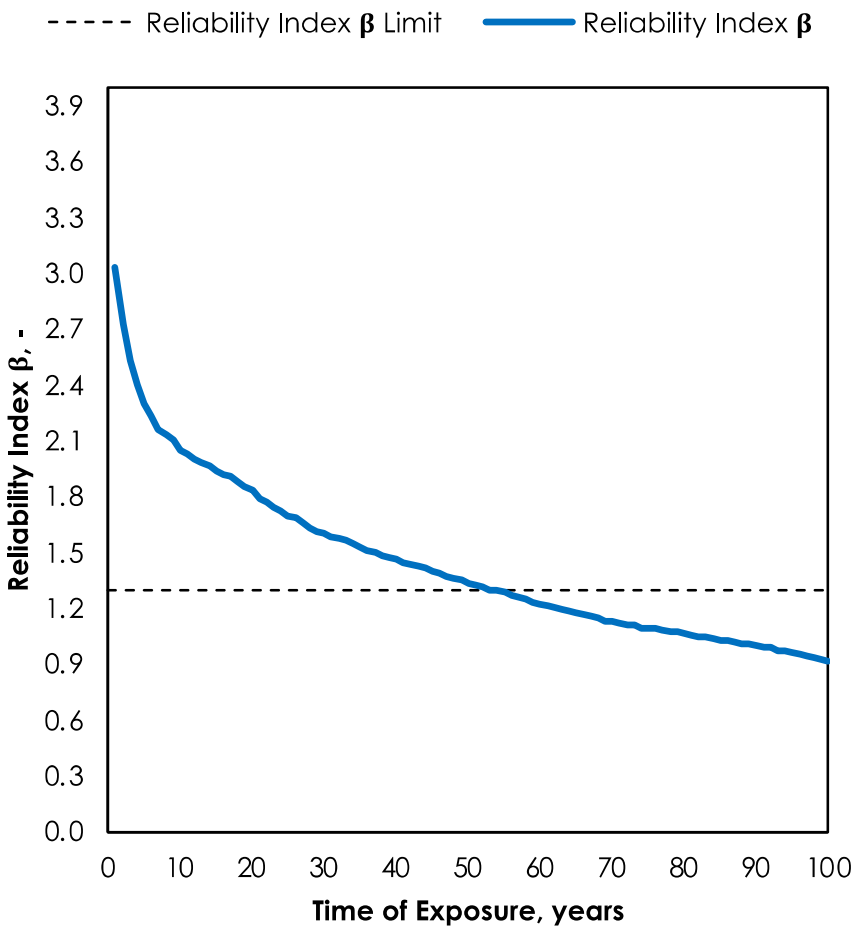
Table 4.1 Guide to reasonable* crack widths, reinforced concrete under service loads

Exposure condition	Crack width	
	in.	mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water-retaining structures†	0.004	0.10

*It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement *[sic]*.
†Exclusing *[sic]* nonpressure pipes.
Note: Table 4.1, Guide to Reasonable Crack Widths, Reinforced Concrete Under Service Loads, was reproduced from ACI 224R-01 (Reapproved 2008) *Control of Cracking of Concrete Structures* with permission from the American Concrete Institute.

Case Study — Bridge in MB





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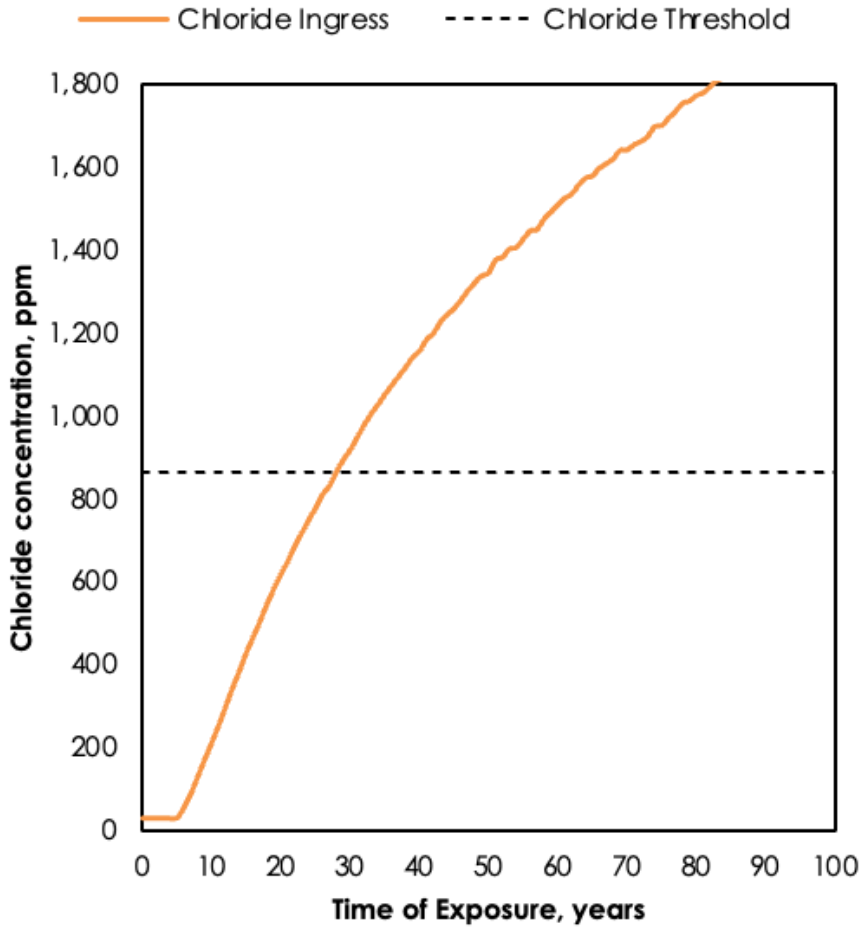
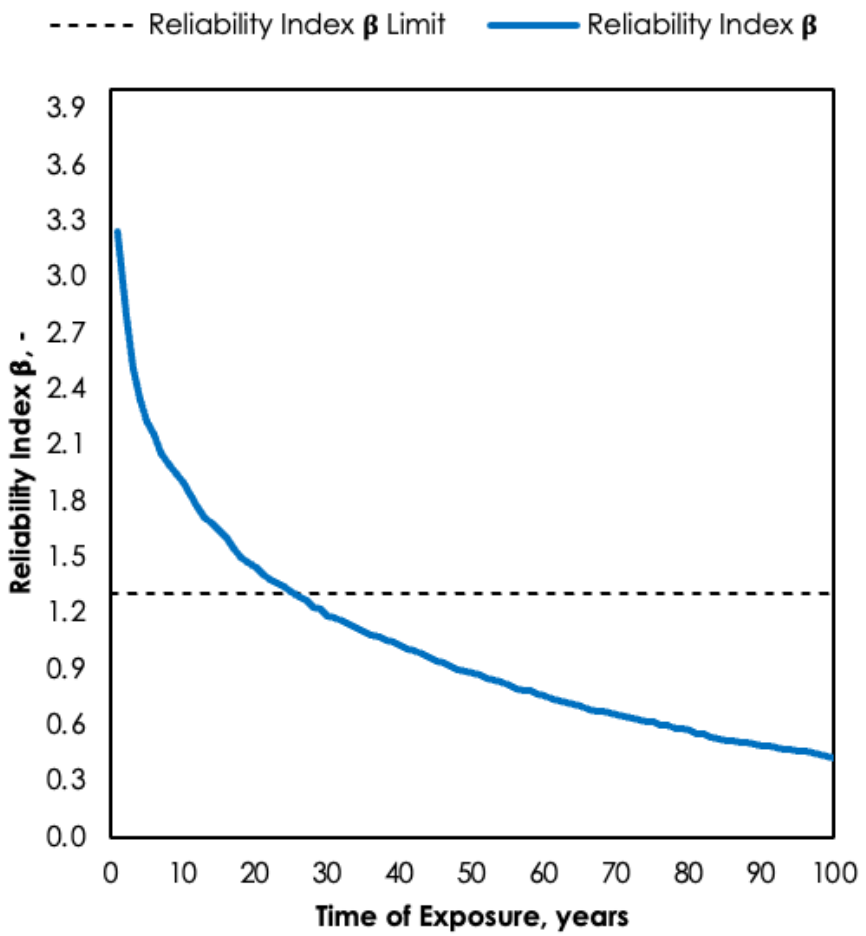
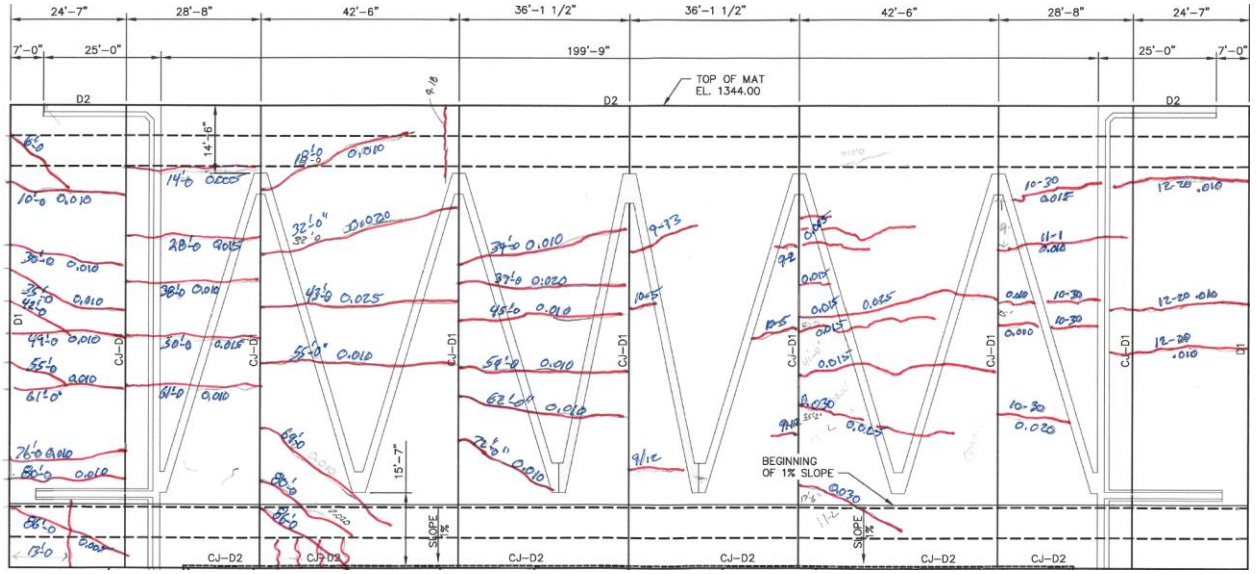


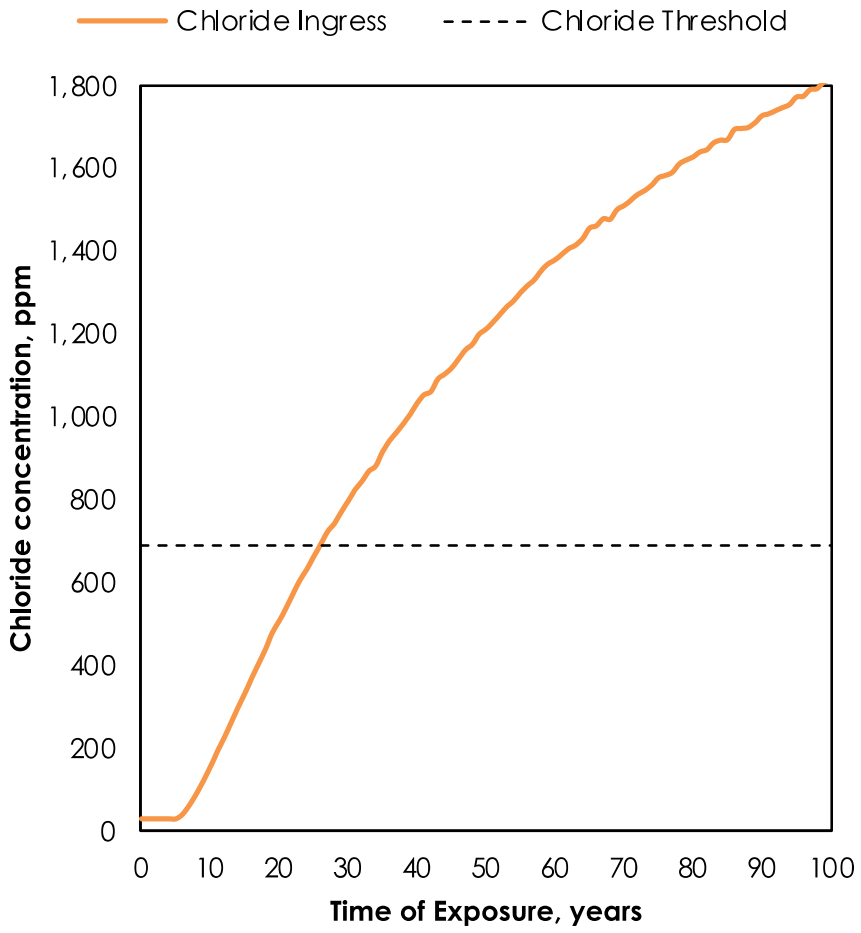


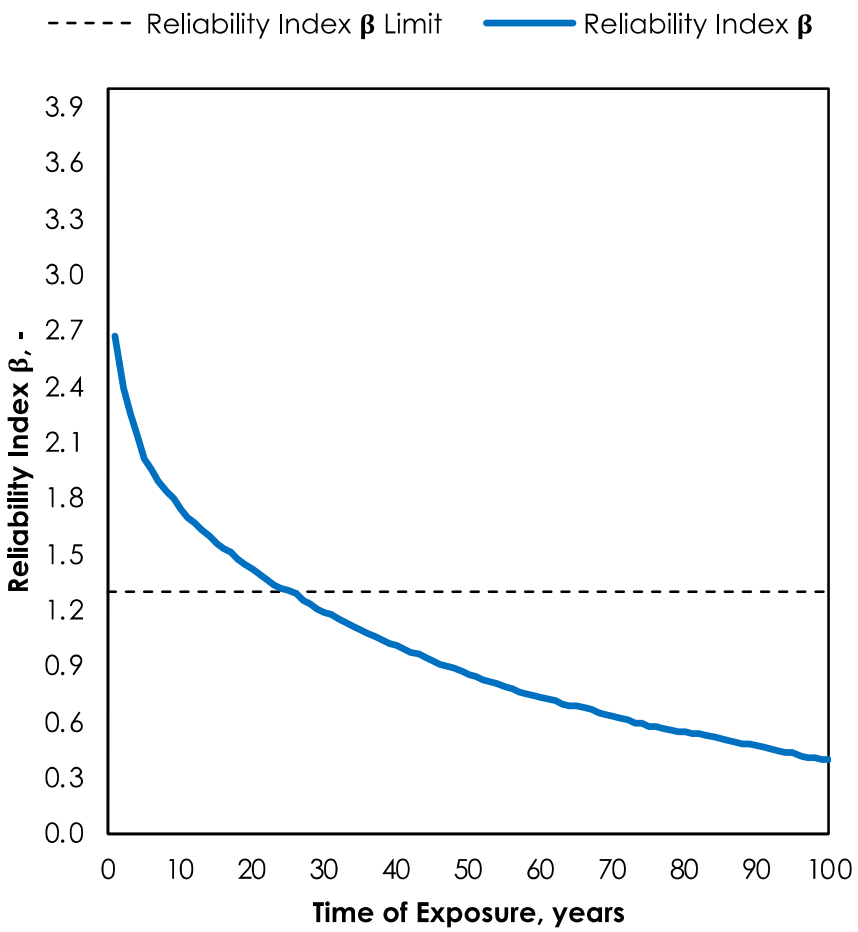
Case Study — Weir Slab and Walls

- Constructed in 2022
  - *Cracking on weir slab and weir walls*
- Reinforcing steel layout
  - *Potential cracking*
- Exposure to submerged conditions (brackish)
  - *Cracking is a concern for durability*
- Crack width ranged 0.010 to 0.030
  - Normal distribution



Case Study — Weir Slab and Weir Walls





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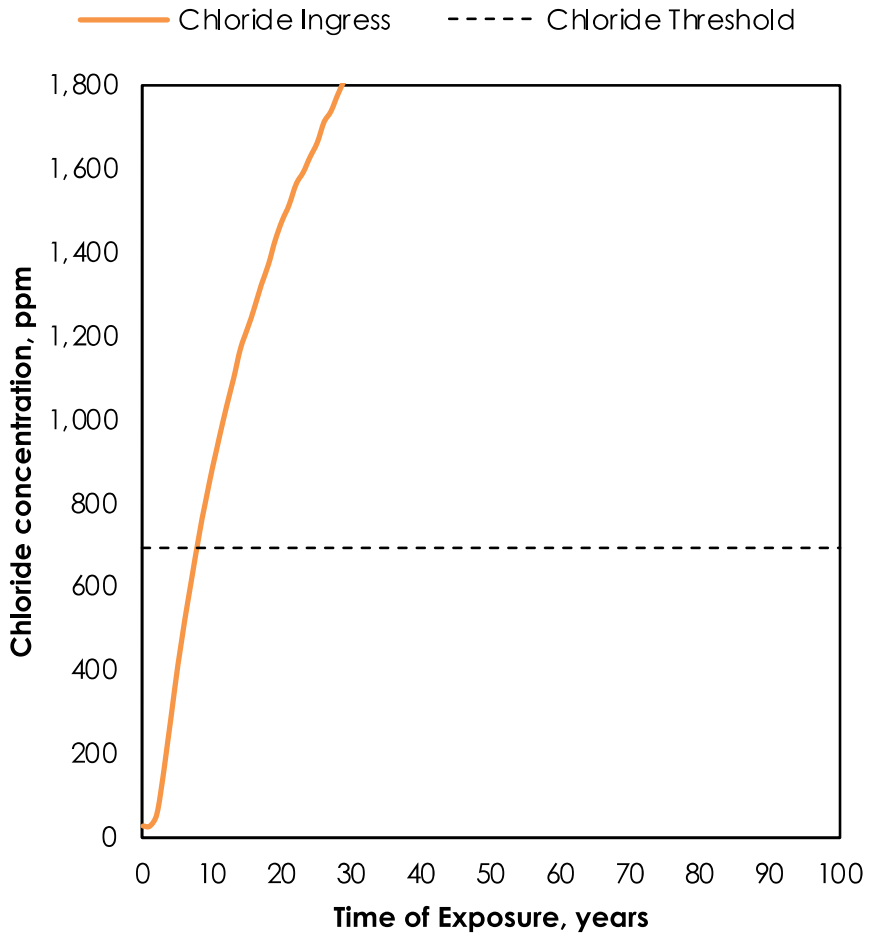

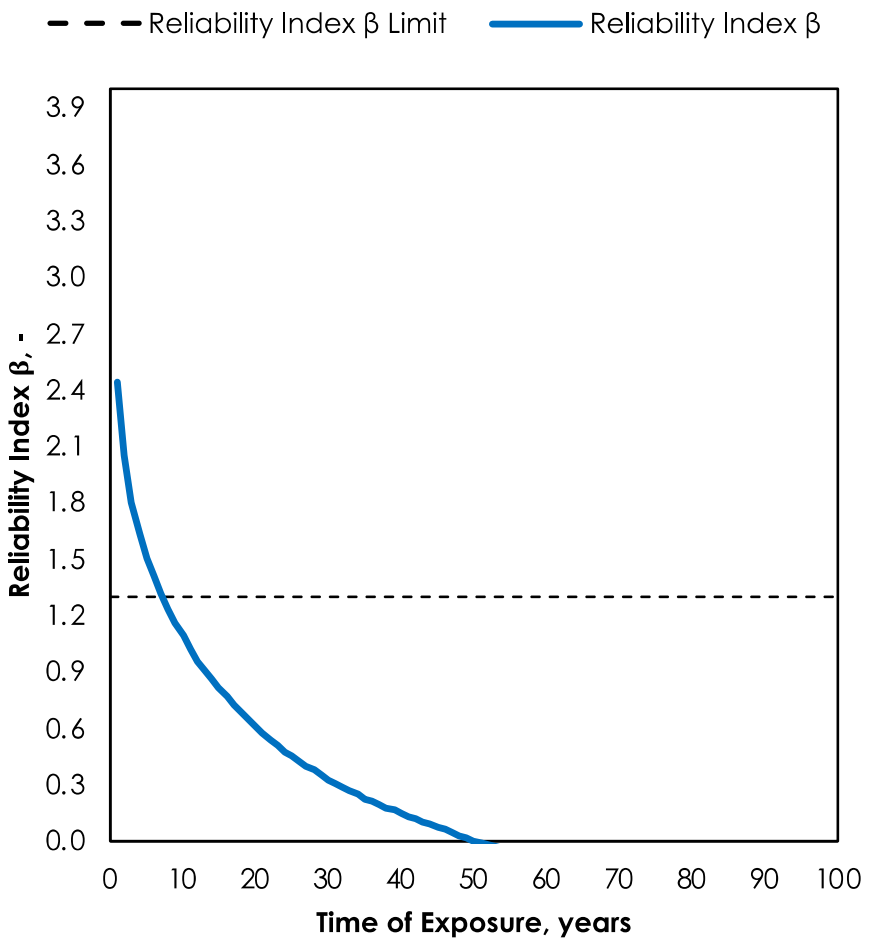

Remarks

- Cracking during construction is frequent (but not desirable)
- Service life predictions cannot omit the effect of cracking
- Understanding the cracking and concrete materials is crucial
- Stakeholder communication — make or break
- Aim for durable (and sustainable) repairs
- Challenges with repair execution
- Responsibility & accountability

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