Extending the Service Life of Concrete Structures in Harsh Environment: How Long Each Strategy May Last?

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INTRODUCTION

With the current economic situation and aging infrastructures, the concrete industry is facing two major challenges:

- How to design and construct new concrete structures that will perform during their design service life with minimum maintenance and repair

- How to maintain or extend the service life of existing concrete structures; how to rehabilitate, repair, and protect them so they continue to serve their intended purpose.

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ICRI TERMINOLOGY

MAINTENANCE

Taking periodic action that will delay damage or deterioration or both

PROTECTION

The process of maintaining a concrete structure in its present or restored condition by minimizing the potential for deterioration or damage in the future

REPAIR

To replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structure

ICRI TERMINOLOGY

SERVICE LIFE

An estimate of the remaining useful life of the structure based on the current rate of deterioration or distress, assuming continued exposure to given service life without repairs

DESIGN LIFE

Period of time on which the statistical derivation of transient loads is based (i.e. 50, 75, 100 years)

DURABILITY

The ability of a structure or its components to maintain serviceability in a given environment over a specified time

SERVICE LIFE VS. DESIGN LIFE

Service Life → **Durability**

Design Life → **Structural Reliability**

Many reinforced concrete structural failures are mainly due to durability issues

CONTRIBUTING FACTORS IN DURABILITY OF NEW CONSTRUCTIONS AND REPAIRS

- Design (structural, detailing)
- Exposure Condition → (Rebar Concrete Cover, Mix Design)
- Mixing, placing, finishing, and curing
- QC/QA

- Maintenance (from simple items such as cleaning of the drains to routine inspections, repairs, etc.)
- Service conditions (are they remain per design assumptions: exposure, loading, etc.)

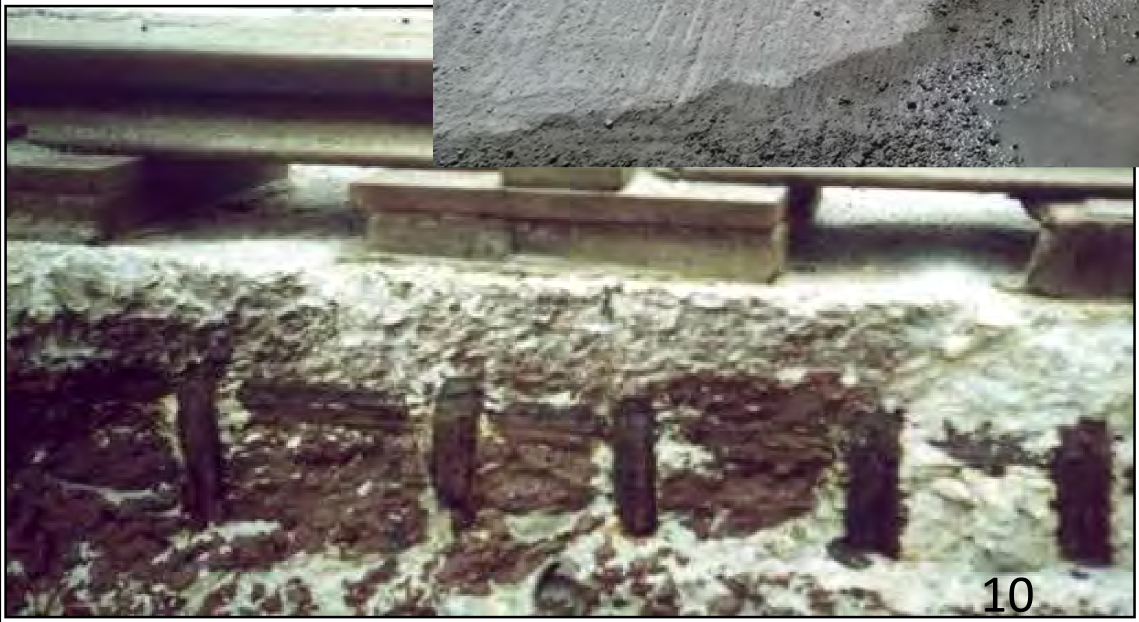
HISTORICAL FACT

Many infrastructures are kept in service longer and with larger loads or stress than expected at the design stage.

HARSH EXPOSURES

- Chlorides (Marine structures, bridge decks,…)
- Sulphates
- Sewage
- Freeze-thaw
- Abrasion, Erosion, and Cavitation
- …..
- …… a combination of two or more of the above

CHLORIDES (MARINE STRUCTURES, BRIDGE DECKS, PARKING, ETC.)




SULPHATE ATTACK

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SEWAGE EXPOSURE

CONCRETE ABOVE EFFLUENT LINE

FREEZE-THAW (SCALING)

PERFORMANCE-BASED DESIGN FOR DURABILITY DESIGN

- Avoidance of deterioration approach
- Deemed-to-satisfy approach
- Partial factor design approach
- Full probabilistic approach

PERFORMANCE-BASED DESIGN FOR DURABILITY DESIGN

- Avoidance of deterioration approach: Separation of the environmental action from the structure, Using non-reacting materials, Separation of reactants, Suppressing the harmful reaction e.g. by electrochemical methods

- Deemed-to-satisfy approach: Workmanship, concrete composition, exposure class, possible air entrainment, cover thickness to the reinforcement, crack width limitations and curing of the concrete

- Partial factor design approach (semi-probabilistic): Limit State: $a_d - x_{c,d}(t_{SL}) \geq 0$

- Full probabilistic approach: $p\{\} = p_{dep.} = p\{C_{Crit.} - C(a,t_{SL}) < 0\} < p_0$

PERFORMANCE-BASED DESIGN FOR DURABILITY DESIGN

- Avoidance of deterioration approach
- Deemed-to-satisfy approach

} Codes and Standards

Table 2
Requirements for C, F, N, A, and S classes of exposure
(See Clauses 4.1.1.1.1, 4.1.1.1.3, 4.1.1.3, 4.1.1.4, 4.1.1.5, 4.1.1.6.2, 4.1.1.8.1, 4.1.1.10.1, 4.1.2.1, 4.3.1, 4.3.5.2.2, 4.3.7.2, 4.3.7.3, 7.4.1.1, 8.7.5.1, 8.12.1, 9.4, 9.5, L.1, L.3, and R.3 and Table 1.)

Class of exposure*	Maximum water-to-cementing materials ratio†	Minimum specified compressive strength (MPa) and age (d) at test†,***	Air content category as per Table 4	Curing type (see Table 19)			Chloride on penetrability requirements and age at test‡
				Normal concrete	HVSCMN-1	HVSCM-2	
C-XL or A-XL	0.40	50 within 56 d	1 or 2§	3	3	3	< 1000 coulombs within 91 d
C-1 or A-1	0.40	35 within 56 d	1 or 2§	2	3	2	< 1500 coulombs within 91 d
C-2 or A-2	0.45§§	32 at 28 d	1	2	2	2	—
C-3 or A-3	0.50	30 at 28 d	2	1	2	2	—
C-4** or A-4	0.55	25 at 28 d	2	1	2	2	—
F-1	0.50	30 at 28 d	1	2	3	2	—
F-2 or R-1 or R-2	0.55	25 at 28 d	2††	1	2	2	—
N	As per the mix design for the strength required	For structural design	None	1	2	2	—
N-CF or R-3	0.55	25 at 28 d	None	1	2	2	—
S-1	0.40	35 within 56 d	1 or 2§	2	3	2	—
S-2	0.45†††	32 within 56 d	1 or 2§	2	3	2	—
S-3	0.50†††	30 within 56 d	1 or 2§	1	2	2	—

**See Table 1 for a description of classes of exposure.*
†The minimum specified compressive strength may be adjusted to reflect proven relationships between strength and the water-to-cementing materials ratio provided that freezing and thawing and de-icer scaling resistance have been demonstrated to be satisfactory. The water-to-cementing materials ratio shall not be exceeded for a given class of exposure.

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DESIGN AND CONSTRUCT NEW CONCRETE STRUCTURES

PERFORMANCE-BASED DESIGN FOR DURABILITY DESIGN

- Avoidance of deterioration approach
- Deemed-to-satisfy approach

} Codes and Standards

- Partial factor design approach: design equations
- Full probabilistic approach: Probabilistic models

} Service Life Modeling

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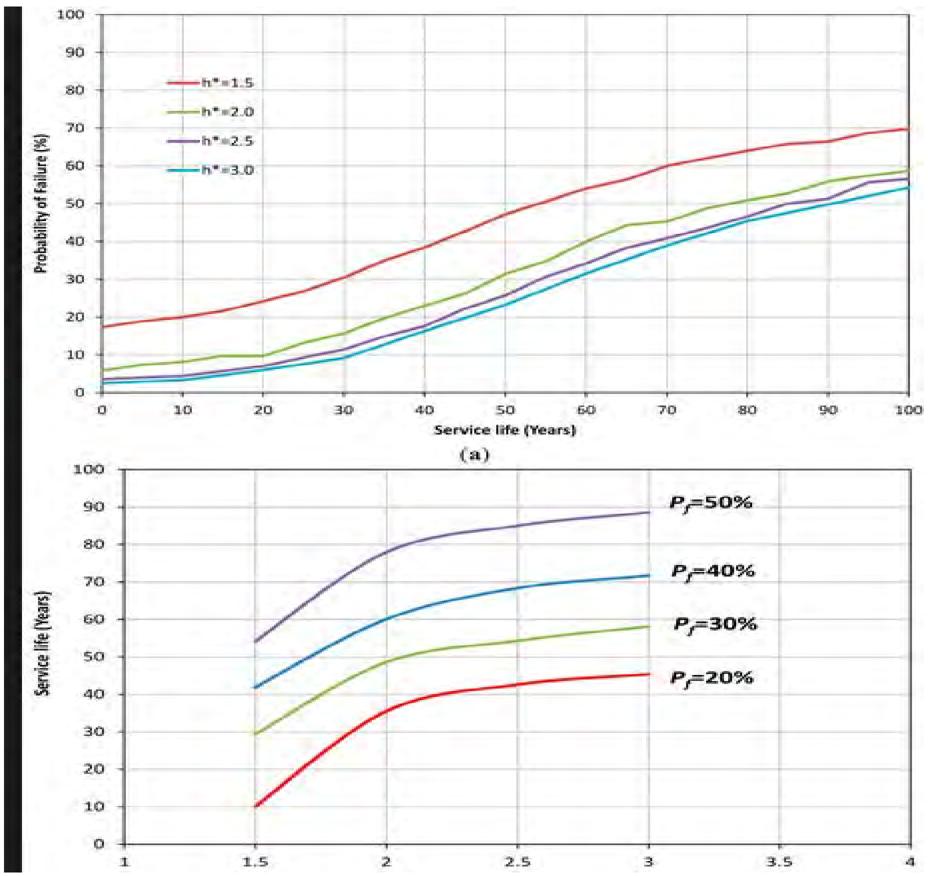
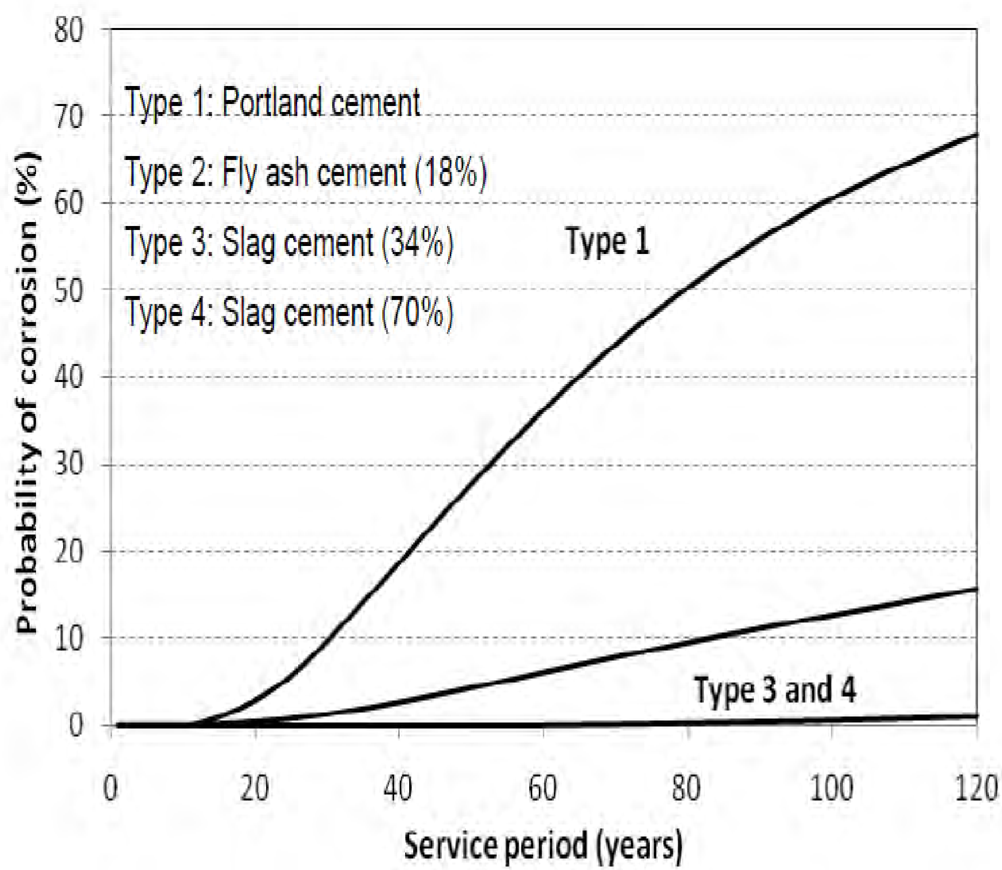
SEMI-PROBABILISTIC APPROACH

FULL PROBABILISTIC APPROACH

Full probabilistic approach: only for chloride induced corrosion





SERVICE LIFE MODELING

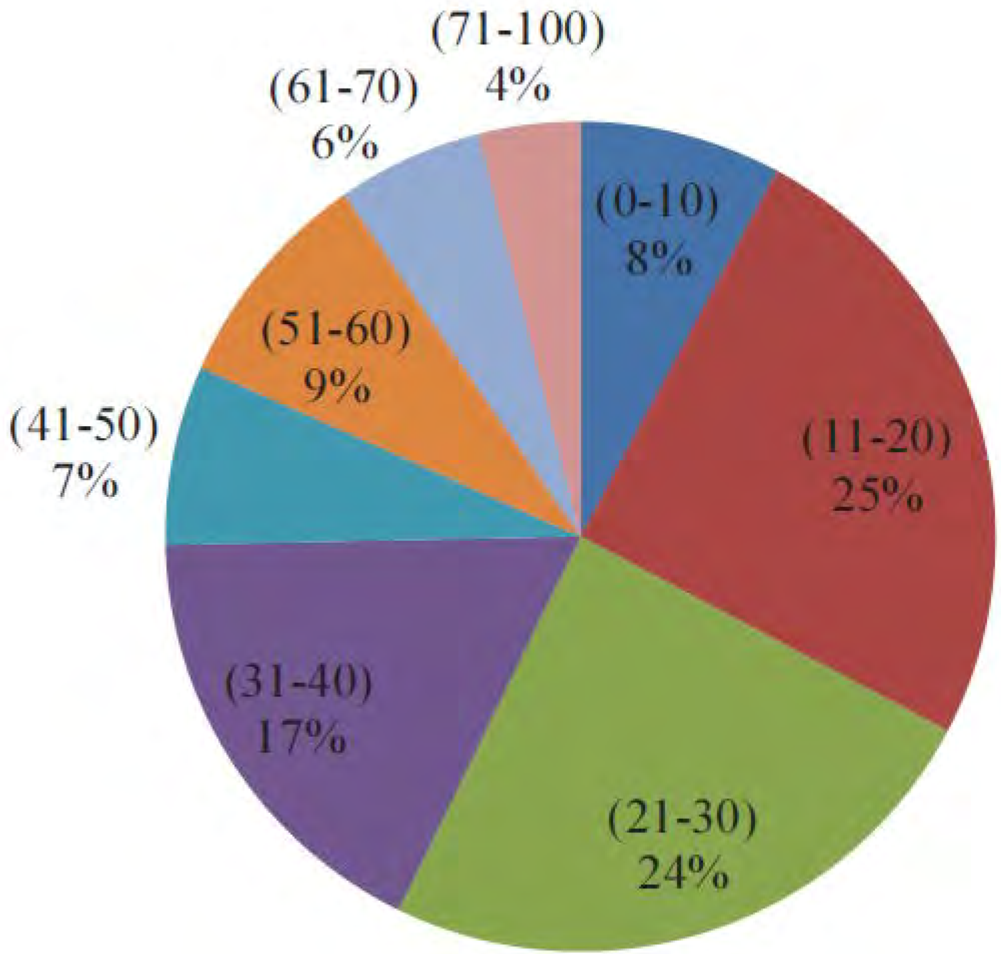
Service Life Modeling:

1. Deterioration Mechanism(s)

2. Mathematical model (assumptions, equations, probabilistic, …)

3. Input parameters (similar local structures, laboratory testing, literature review)

AGE OF THE STRUCTURES AT REPAIR



Ref. W. Taffesea, E. Sistonen. Service Life Prediction of Repaired Structures Using Concrete Recasting Method: State-of-the-Art , Procedia Engineering, 2013

SERVICE LIFE OF REPAIRS

- The performance of repaired concrete structures continues to be a major global concern.

- Regardless of improvements in repairing materials and methods, several repaired concrete structures still fail prematurely, leading to costly and time consuming repairs of repairs.

- It is estimated that 50% of concrete repairs fail within 10 years or less

SERVICE LIFE OF REPAIRS

- Service life modeling can also be used in predicting the remaining service life of existing structures

- Prediction can be more accurate compared to the design stage as the model uses the actual field data of the structure for the input parameters

- There are very few service life prediction models for repaired concrete structures

- While there have been many interest for intended 100-150 years service life design (with probabilistic modeling approach) of new construction in the past few years, service life modeling of repaired concrete structures is not very common and is mostly an estimate which relies on past experience

COMMON CAUSE OF REPAIR FAILURES

- Wrong diagnosis of the cause of the initial damage or deterioration of the structure
- Inappropriate specification or choice of the materials used
- Poor workmanship
- Change in service conditions compared to the design assumptions (structurally ok but not durability)
- Inadequate or lack of maintenance

FACTORS INVOLVED IN THE DURABILITY OF REPAIRS

Concrete
w/c-ratio
Mineral additives
Chemical additives
Aggregate
Super plasticizer

Reinforcement
Black steel
Stainless steel
Steel fibres
Non-metallic material
No reinforcement

Design
Beam/Arch
Post-tensioning
End-beam
Expansion joint
Construction joint
Aesthetic

Production
Cover (tolerances)
Compaction
Curing

Existing structure
Type of damage
Extent of damage

Maintenance plan
Impregnation
Sideways movement of traffic
Level of expansion joint
Cleaning
Inspection
Service book

Expected service life

Costs

Environment

Source: Jonatan Paulsson, Service Life of Repaired Concrete Bridge Decks, Royal Institute of Technology, Sweden, 1999

MAINTENANCE IMPORTANCE

- The work doesn't end once the structure is constructed or the repairs are complete.

- Many repairs are nothing but lack of or delayed maintenance

- A maintenance program should be implemented after the construction/repairs have been completed.

- Restoring a structure does not eliminate all the conditions that contributed to the premature deterioration in the first place.

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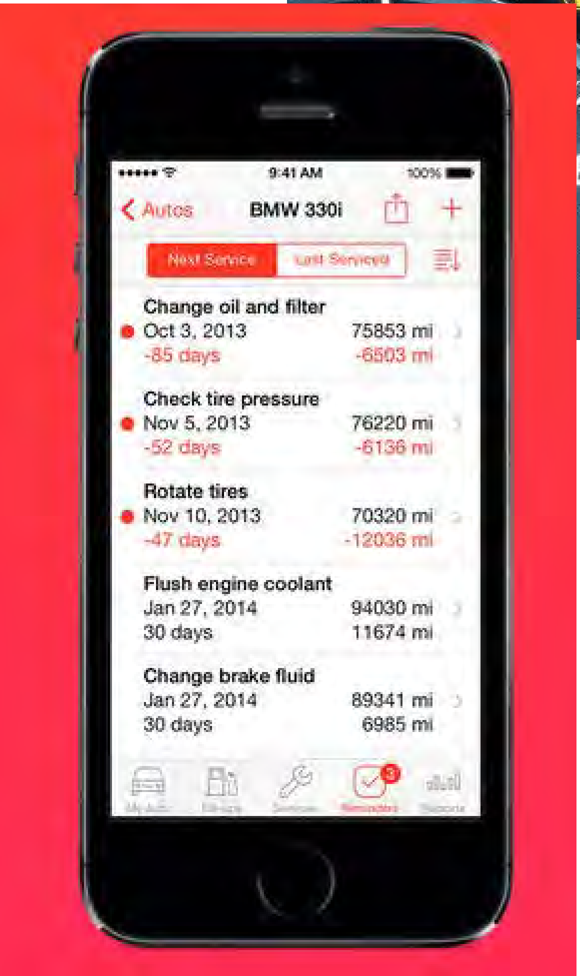
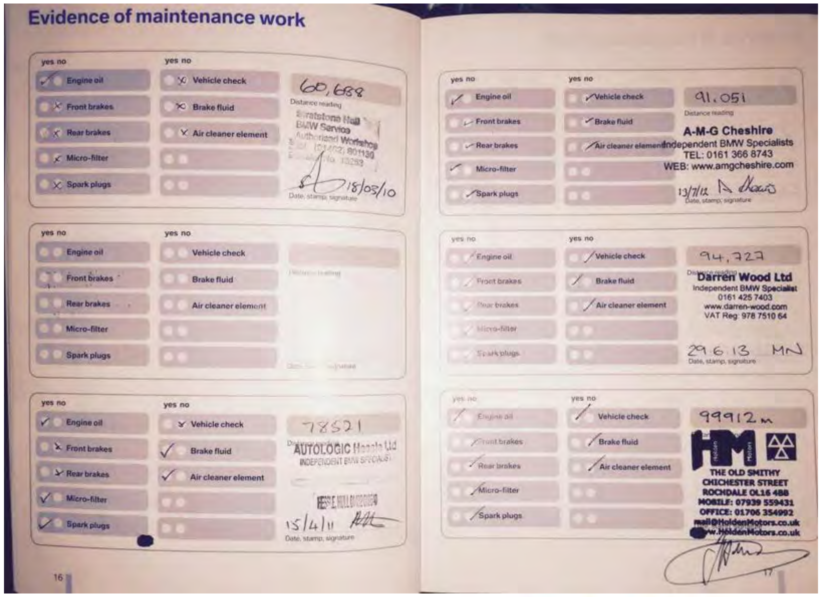
MAINTENANCE IMPORTANCE

Developed “Maintenance Program” based on “Project Maintenance Manual” may decrease the risk of neglected maintenance. The maintenance authority should be forced to sign every year fulfilled.





MAINTENANCE IMPORTANCE

The typical situation during operation of the structures is that maintenance and repairs are mostly reactive AND NOT proactive

The need for taking appropriate measure is usually realized at a very advanced stage of deterioration which are both technically difficult and disproportionately expensive compared to carrying out regular condition assessments and preventive maintenance.

All concrete structures where high safety, performance, and service life are of special importance, regular condition assessment and preventive maintenance should be carried out

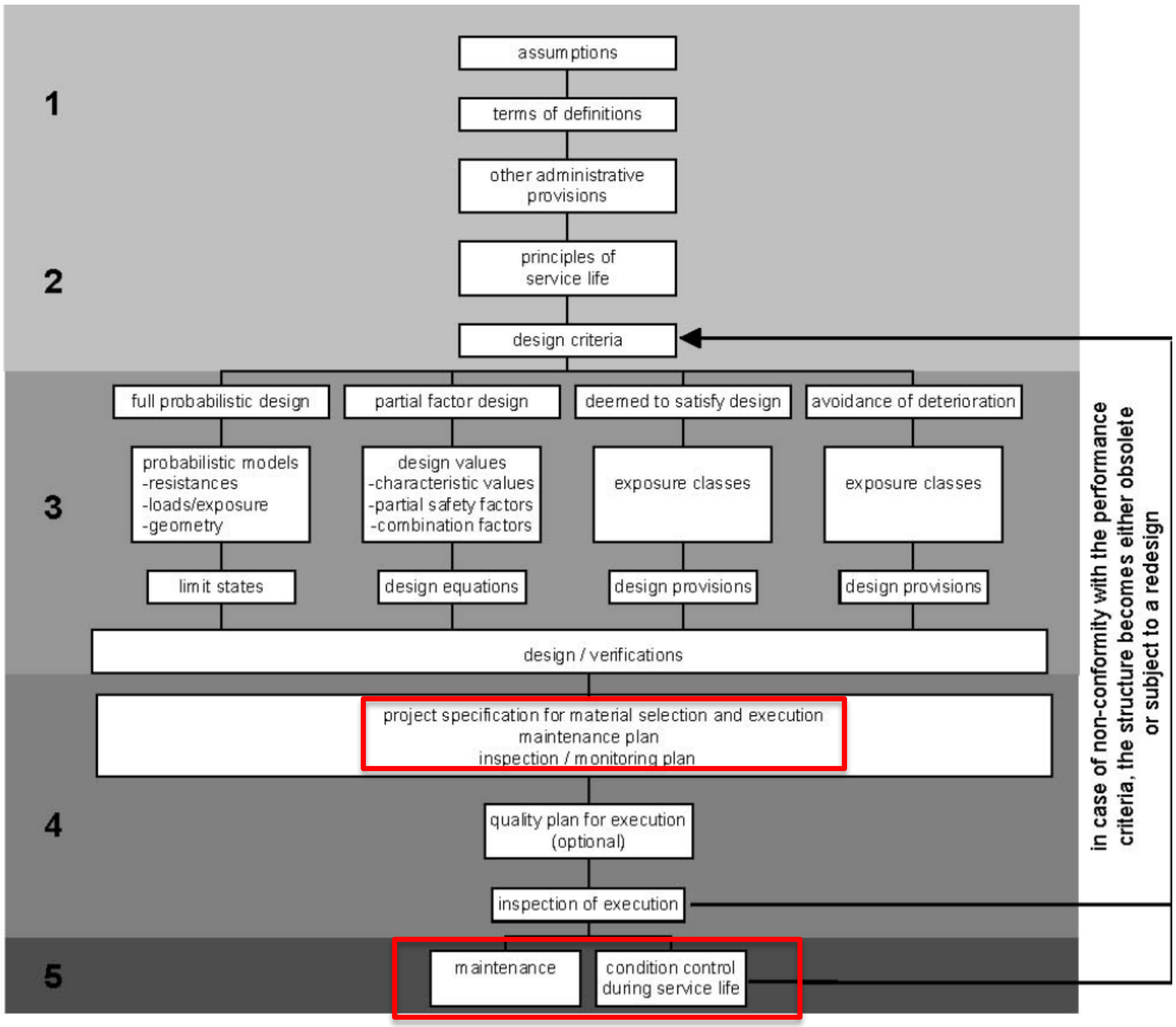
LACK OF MAINTENANCE

Lack of maintenance/repairs- No redundancy in the system to isolate the flow and conduct the inspection and repairs

UNREALISTIC MAINTENANCE PROCEDURES

Project spec/maintenance: "…..*Do not use road salts*…."!!!!!!

SERVICE LIFE DESIGN FLOWCHART (FIB BULLETIN 34)



FIB- BULLETIN 34: MODEL CODE FOR SERVICE LIFE DESIGN

5.3.1 Inspection and monitoring during service life

(1) In this document "inspection" means activities to evaluate conformity with the design data for actions and/or material and/or product properties used in the SLD on a periodic basis during the service life of the structure, while "monitoring" means the same activities, but on a continuous basis.

5.3.2 Condition control plan

(1) The plan shall state:

- What types of inspection / monitoring that shall take place
- What components of the structure to be inspected / monitored
- The frequency of the inspections
- The performance criteria to be met
- Possible documentation of the results
- Action in the event of non-conformity with the performance criteria

5.4 Action in the event of non-conformity

(1) If the inspection/monitoring reveals that the original SLD assumptions are not met, one or more of the following actions shall be taken:

- Widening the scope of the performance survey to improve the quality and representativeness of the data.
- Performing a recalculation of the original SLD to assess the residual service life of the structure. The new calculation shall be supplemented with the data for action, materials and products derived from the field-exposed structure. The redesign shall conform to the requirements given in Chapter 2 of this document.
- The structure shall be repaired or strengthened to bring its performance back to the agreed design assumptions. The repair shall be based on a partial or full recalculation of the original SLD as stated under 2.
- The structure shall be protected to reduce the action. The protection shall be based on a recalculation of the original SLD as stated under 2.
- The structure shall become obsolete.

Table A6-1: Conditions Control Levels (CCL)

Condition Control Levels	Characteristics	Requirements
CCL3	Extended inspection	Systematic inspection and monitoring of relevant parameters for the deterioration process(es) that is (are) critical in the SLD
CCL2	Normal inspection	Regular visual inspection by qualified personnel
CCL1	Normal inspection	No systematic monitoring nor inspection
CCL0	No inspection	No possible inspection, for instance due to lack of access

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PREVENTIVE MAINTENANCE

To ensure the structure's protective systems are functioning:

- Remove debris
- Sealing the cracks
- Spot repairs of sealants, expansion joints, membranes
- Periodic reapplication of the sealers
- ……..

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ECONOMICS OF MAINTENANCE/REPAIR/REPLACEMENT

- A major repair could cost five times what routine maintenance would have cost.

- A replacement could cost five times what major repair would have cost.

- The longer you defer your capital spending, the bigger the bill when it is finally due!

ASSET MANAGEMENT PROGRAMS

Asset managements: To ensure that the assets continue to perform their intended purpose and to maintain the owner's investment

Routine condition assessment of concrete structures as part of asset management programs:

- Provide information regarding the present condition of the concrete
- Determine the rate of deterioration of the concrete components

ASSET MANAGEMENT

Rating	Description of Condition	Maintenance Priority and Urgency of Repair	Urgency
1	New condition - no defects.	Not Applicable.	10 years or <
2	Acceptable, functioning as intended but routine inspection required.	Not required before next principal inspection.	
3	Functioning as intended, maintenance required.	Preventative maintenance required within specified time period.	< 5 years
4	Unacceptable, not functioning as intended. Major rehabilitation required.	Remedial work required within specified time period.	< 2 years
5	Potentially unsafe condition.	Danger to users - immediate repair required.	ASAP

FAILURE DIAGNOSIS

- The first step in the selection of effective concrete repair is diagnosing the cause of failure.

- If the repaired area is not resistant to the original cause of failure, the repair will fail, or, the damage will be extended to adjoining parts of the structure.

REPAIR MATERIALS

Compatibility with the concrete substrate: Large discrepancies in properties (for example, stiffness or coefficient of expansion) may result in shortened repair life and promote damage to adjoining, sound concrete.

Performance Record: proven performance record for similar failure modes and service conditions

Bonding: Proper Surface preparation, Substrate conditioning, concrete mix (low water, low shrinkage, etc.)

Modulus of Elasticity: When materials with widely different moduli are in contact with each other, differences in deformability will cause problems under certain loading conditions

Permeability: Large impermeable patches, overlays or coatings can impair the escape of moisture from the base concrete, leading to blistering at the bond line or within the weaker of the two materials.

Electro-Chemical Compatibility: If there is a large permeability or chloride content differential between the repaired area and the rest of the concrete, anodic regions are produced on either side of the patch, accelerating the rate of corrosion and causing premature failure of the patch or adjoining concrete.

SERVICE LIFE EXTENSION SYSTEMS

LOCAL SYSTEMS:

- **Patching**
- **Patching with Discrete Galvanic Anodes**
- **Coated Reinforcement**
- **Corrosion Inhibitors**

GLOBAL SYSTEMS

- **Resurfacing**
- **Sealers and Surface Coatings**
- **Impressed Current Cathodic Protection (ICCP) System**
- **Distributed Galvanic Anodes**

LOCAL SYSTEMS- PATCHING

The service life of the patches somewhat depends on the type of patch (full- or partial-depth) and the patch material.

The service life of the patches ranges from 4 years to 10 years

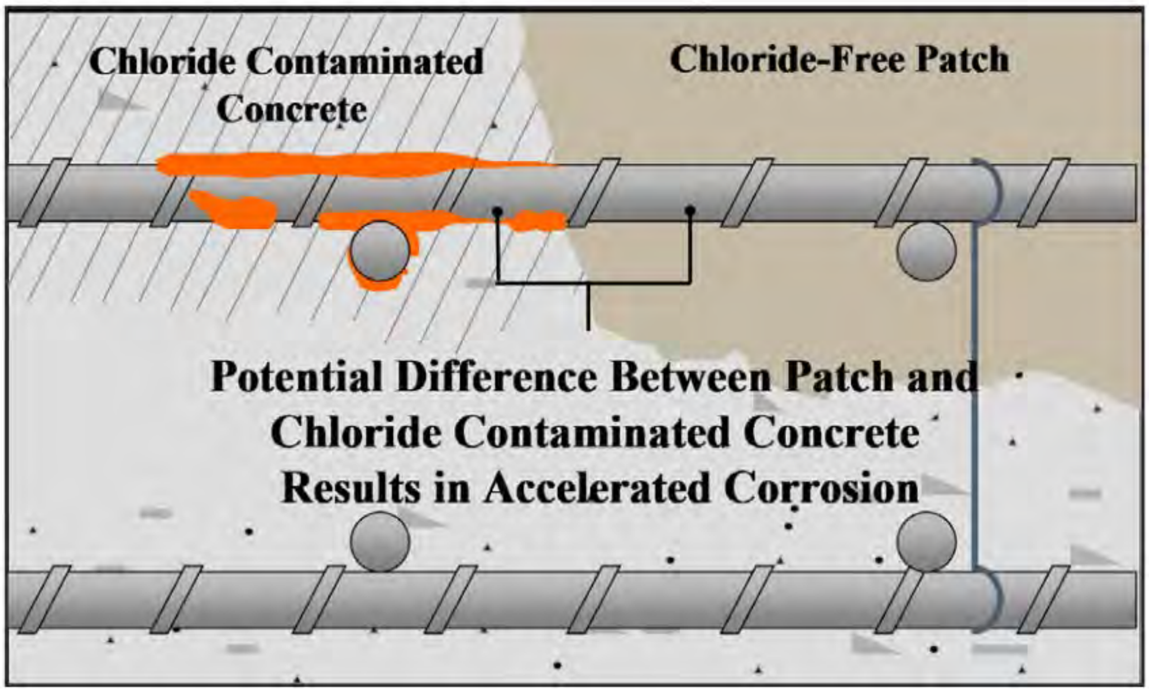
FHWA: the service life of a patch ranges from 4 years to 7 years.

The service life of the patch depends largely on the corrosivity of the surrounding concrete and the development of the halo effect.

HALO EFFECT (RING-ANODE EFFECT)

If no provisions are made to mitigate corrosion, the installation of a repair patch creates a potential difference between the old and new concrete.

Repairs completed in this manner can accelerate corrosion in the parent concrete in the areas immediately surrounding the patch.



Source: Vector Corrosion

HALO EFFECT (RING-ANODE EFFECT)

LOCAL SYSTEMS- *PATCH REPAIRS WITH DISCRETE GALVANIC ANODES*

PATCH REPAIRS WITH DISCRETE GALVANIC ANODES

Galvanic anode systems are based on the principles of dissimilar metals such as typically used in batteries or marine applications. In this system, no external power source is required and the protection is provided by means of sacrificial galvanic anodes.

LOCAL SYSTEMS- *PATCH REPAIRS WITH DISCRETE GALVANIC ANODES*

PATCH REPAIRS WITH DISCRETE GALVANIC ANODES

- Zinc is the most commonly used anode
- The corrosion of zinc produces a relatively small volumetric expansion compared to other metals such as aluminium, magnesium, or iron
- Embedded galvanic anodes provide localized corrosion protection
- Installed around the perimeter of the concrete repair patch as close as possible to the interface of the parent concrete to prevent or delay the concrete deterioration due to the ring-anode effect
- If the area of chloride contamination and corrosion damage is widespread or a greater level of protection is required over a larger area, discrete anodes can be installed into drilled or cored holes on a grid pattern.
- Depending on the mass of the anode and its consumption rate, the available discrete anodes are expected to have a service life of 7 to 15 years when applied in patch repair areas. Service life of less than 5 years have also been reported for this type of system.

LOCAL SYSTEMS- PATCHING/*REINFORCING BAR COATING*

PATCHING/REINFORCING BAR COATING

- ✓ Polymer-modified cement slurries, non-passivating epoxies, and epoxies filled with passivating fillers (e.g., zinc phosphate and cement clinker) have been found to be prone to undercutting as isolate the reinforcement from the highly alkaline repair mortar, it keeps the reinforcement from being passivated

- ✓ Passivating fillers appear to be fully bound in the polymer/epoxy film and offer little benefit.

- ✓ Polymer-modified cement slurries containing rust inhibitors, silica fume, and sand can give better results and are not subject to undercutting. Field experience with these particular repair coatings is limited.

- ✓ Zinc-rich epoxy (one part) repair coatings: reinforcement bars with zinc-rich coating can suffer from accelerated corrosion damage if the chloride content in the concrete adjacent to the patch is very high and the surrounding reinforcing bar mat has a high corrosion rate.

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LOCAL SYSTEMS- *PATCHING AND CORROSION INHIBITORS*

PATCHING AND CORROSION INHIBITORS

- Calcium nitrite and Organic bases

- The effectiveness of nitrite as a corrosion inhibitor for reinforcement embedded in concrete when used as an admixture in new construction has been established through a number of independent studies and through field experience.

- SHRP study found that corrosion inhibitors (both nitrite and organic bases), when used as admixtures in conjunction with patch repair on field structures, did not provide any benefit applied_either to the surface of the exposed reinforcement or to both the surface of the exposed reinforcement and the surface of the patch repair

GLOBAL SYSTEMS- COMPLETE RESURFACING

COMPLETE RE-SURFACING

The whole surface area of the wall or slab will be removed and replaced.

This approach would be used if the total surface of the delamination is high (i.e. exceed ????% of the total surface area of the element)

PARTIAL RE-SURFACING

The whole surface area of a specific area will be removed and replaced.

Examples: Concrete above the effluent level in sewage structures, concrete above the submerged area of marine structures

APPLICATION METHODS: Form and pour, Shotcrete, etc.

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COMPLETE RESURFACING

OVERLAYS (BRIDGE DECKS)

- Polymer modified asphalt concrete (PMAC) over membrane: ~15 years
- High performance fibre reinforced concrete (HPFRC): ~ 20-25 years
- High Performance Fibre Reinforced Concrete with Stainless Steel Top Mat: 35-40 years
- Polyester Polymer Concrete: ~25 years
- Liquid epoxy-urethane polymer mixed on the job site and a blend of broadcast hard aggregates: 10-20 years
- Epoxy Asphalt Concrete (EAC): San Francisco-Oakland Bay Bridge was surfaced with EAC in 1977: +30 years

GLOBAL SYSTEMS- *SEALERS AND SURFACE COATINGS*

SEALERS AND SURFACE COATINGS

- Chloride ions that already exist in the concrete, especially near the surface, will diffuse into the concrete after the sealer or coating is applied and may critically contaminate the concrete at the reinforcement level over time.
- Penetrating sealers and surface sealers: Several environmental exposure conditions may influence the service life of sealers applied to bridge decks. These include ultraviolet light, moisture, and surface wear due to traffic.
- The service life of penetrating sealers ranges from 5 to 7 years. Typically, penetrating sealers should be reapplied every 5-6 years.
- Surface sealers not exposed to abrasive wave or ice action have a service life of 1 to 3 years.
- Coatings: epoxies, acrylics, methacrylate, and urethanes
- Unlike sealers, the vapor permeability of a coating is very low

GLOBAL SYSTEMS- DISTRIBUTED GALVANIC ANODES

Installed where the area of chloride contamination and corrosion damage is widespread or a greater level of protection is required over a larger area or during resurfacing

Photos: Vector Corrosion

GLOBAL SYSTEMS- DISTRIBUTED GALVANIC ANODES

DISTRIBUTED GALVANIC ANODES

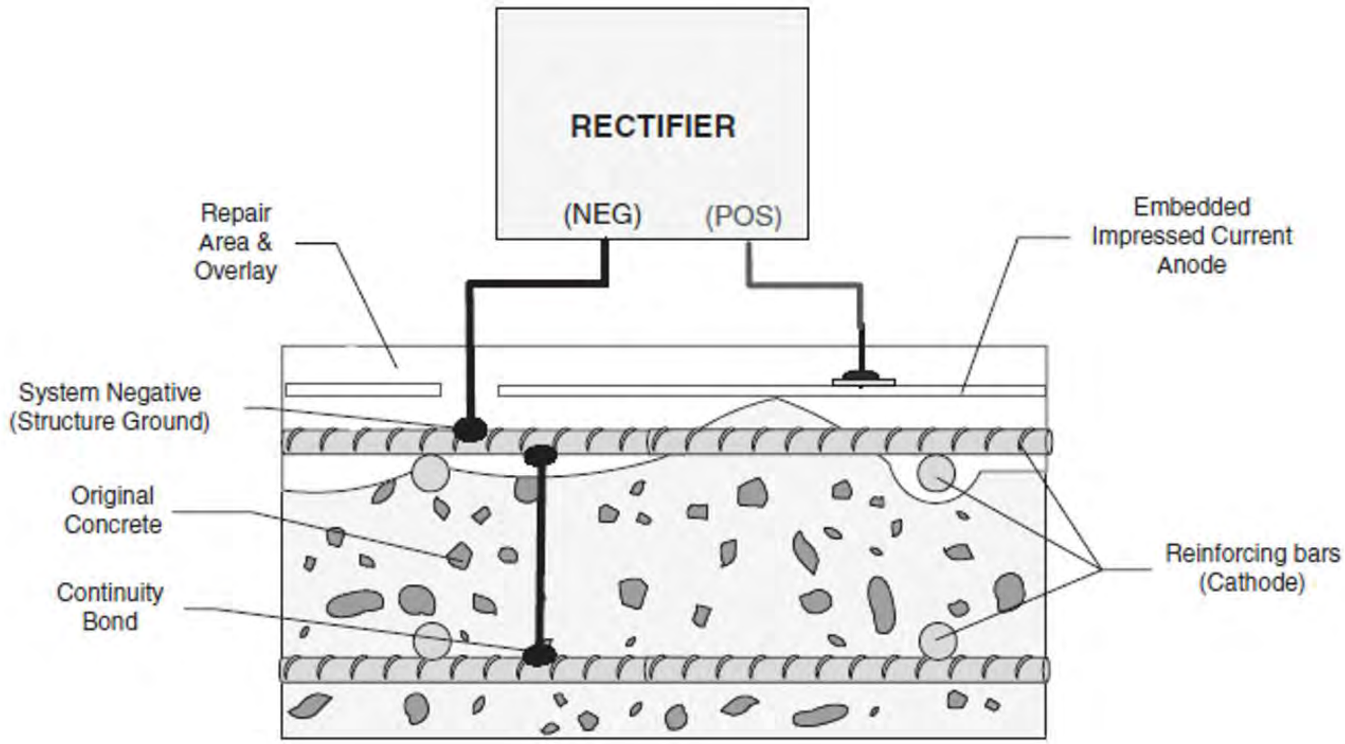
- The surface area of steel to be protected, exposure conditions, and desired service life are important factors used to determine the sizes and spacing of the anodes

- The longest track history of satisfactory performance for this type of application is approximately 12 years. May be extended to 20-25 years (no track history yet!)

GLOBAL SYSTEMS- IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEM

IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEM

Uses a low voltage external electrical power source to distribute a current from an anode to the reinforcing steel.



GLOBAL SYSTEMS- IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEM

US FEDERAL HIGHWAY ADMINISTRATION (FHWA): *"… The only method that can stop the corrosion of reinforcement in concrete structures"*

ADVANTAGE:

Amount of the current can be adjusted at any time to optimize the protection provided to the existing steel within the area of influence of the rectifier and anode

DISADVANTAGE:

Electrical systems must be periodically monitored and maintained (typically every three to six months)

Some components of the system may need to be periodically maintained or replaced.

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GLOBAL SYSTEMS- IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEM

IMPRESSED CURRENT CATHODIC PROTECTION (ICCP) SYSTEM

Anode selection depends on various factors including element type, element geometry, costs, ambient conditions, etc.

Cathodic protection systems are used when a minimum extension to the service life of ten years is desired and no other alternative method is available or expected to work

Photo Source: Corrpro

LONG-TERM EXPERIENCE WITH CATHODIC PROTECTIONSYSTEMS

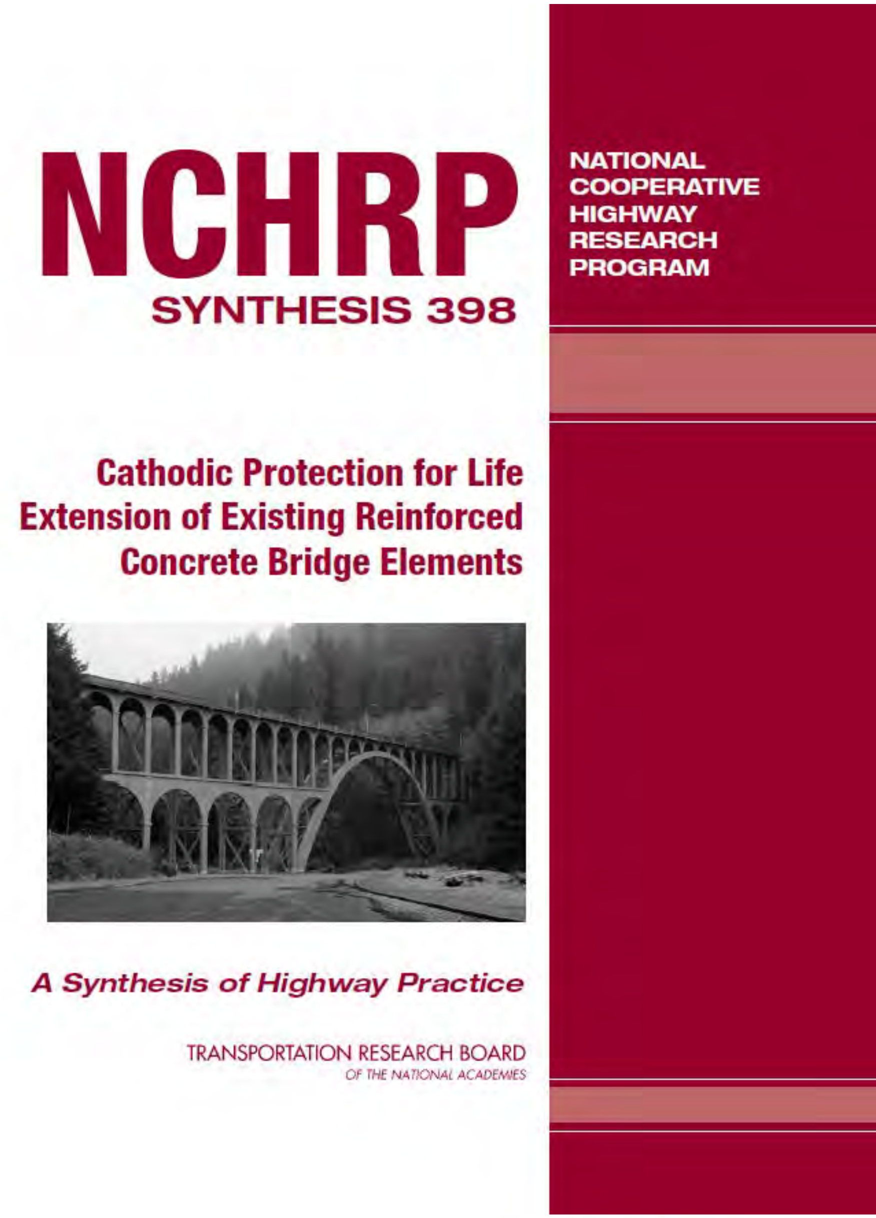
NCHRP (2009):

586 bridges in North America with 389 located in USA and 197 in Canada. Of this number, 279 of the systems have been installed on bridge decks.

Only three states in the USA - Florida, Missouri, and Oregon and three Canadian provinces-Alberta, New Brunswick, and Ontario, have adapted this technology and are actively implementing it.

Other agencies have either not implemented the technology, implemented it on select projects with no commitment to extend it to larger scales, or have not had a satisfactory experience with this technology.

There are only a few examples of the systems with a documented operational life of more than fifteen years



MAINTENANCE OF ICCP SYSTEMS

- Monitoring and maintenance of cathodic protection systems are somewhat complex, especially for impressed current systems.

- Many transportation agencies (State DOTs, Ministries of Transportation, etc.) have found it difficult and costly to monitor and maintain ICCP systems and have favoured the use of galvanic anode systems.

- In NCHRP survey, most respondents indicated that "***the monitoring and maintenance are the main reasons for not selecting the cathodic protection systems***."

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MAINTENANCE OF CP SYSTEMS

- Maintenance and system adjustments must be conducted by qualified personnel. Many agencies do not have qualified in-house personnel for monitoring and maintenance.

- NCHRP survey: "the failure of their impressed current protection system is due to improper setting and insufficient current system which indicates a lack of proper monitoring and maintenance."

PERFORMANCE OF INSTALLED CP SYSTEMS

Anode Material & Configuration	Environment	No. of Systems	Age of Systems (years)	Protection Provided	Estimated Service Life (years)
Impressed-current Cathodic Protection Systems					
Arc-sprayed zinc	Semi-marine & deicing	2	2	Poor(1)	10 to 15
Arc-sprayed zinc	Marine	1	1	Excellent	7 to 12
Arc-sprayed zinc	Deicing	1	8	Not determined(2)	10 to 15
Titanium mesh	Deicing	3	6 to 12	Excellent	>25
Titanium mesh	Marine	1	1	Excellent	>25
Titanium ribbon	Deicing	1	9	Excellent	15 to 25
Arc-sprayed titanium	Semi-marine & deicing	1	1	Poor(1)	Not determined(3)
Arc-sprayed titanium	Marine	1	1	Poor	Failed in 1 year
Conductive paint	Deicing	2	4 to 9	Good	5 to 10
Conductive polymer slotted	Deicing	1	12	Fair	5 to 10
Conductive polymer mounded	Deicing	1	15	Poor	5 to 10
Coke breeze	Deicing	3	5 to 9	Excellent	10 to 15
Galvanic Cathodic Protection Systems					
Arc-sprayed zinc	Marine	3		Excellent	7 to 10
Zinc foil with adhesive	Deicing	1	1	Excellent	7 to 10
Expanded zinc mesh & bulk	Marine	1	3	Good	15 to 20

Source: Sohanghpurwala, A. A., and W. T. Scannell, Long-Term Effectiveness of Cathodic Protection Systems on Highway Structures, Report No. FHWA-RD-01-096, Federal Highway Administration, 2000

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LONG-TERM EXPERIENCE WITH CATHODIC PROTECTIONSYSTEMS

- An ICCP system that incorporates a titanium anode mesh with a concrete overlay is the only system that may be expected to provide a service life of more than 25 years for a bridge deck.

SOME FINAL NOTES

Nothing can replace the actual field performance

Almost All laboratory and simulated test methods have their own limitations

Laboratory results for new materials/systems are good as a filtering method

PREVENTION OF BACTERIAL CORROSION OF CONCRETE

Reference

Protected

CONCLUSIONS

- **No strategy can replace proper initial design, construction, and maintenance practices for the desired service life**

- **Repair/Maintenance for desired or extended service life**

- **Developed "Maintenance Program" based on "Project Maintenance Manual" may decrease the risk of neglected maintenance. The maintenance authority should be forced to sign every year fulfilled.**

- **Conduct routine condition assessments as part of asset management programs to identify the rate of deterioration or potential repairs as early as possible**

CONCLUSIONS

- Use service life modeling with actual structure’s input values to predict the remaining service life of structure
- Diagnose the cause of failure prior to any further action
- Need to develop models for predicting of the service life of repairs
- Need for reliable prediction of performance of concrete repairs based on short-term tests

THANK YOU

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