American Concrete Institute

Code Requirements for Durability

Fred Goodwin, Fellow Scientist
BASF Construction Chemicals

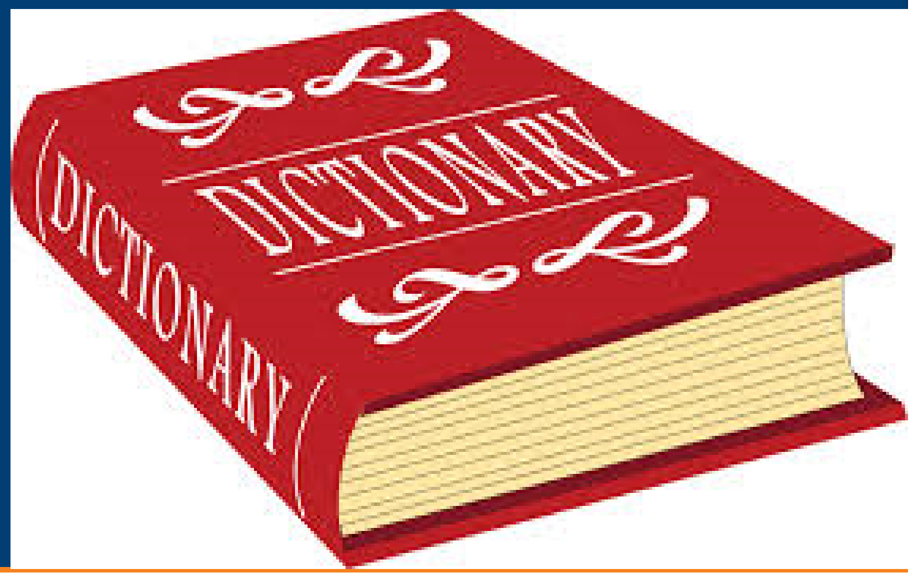
Outline

Chapter 8—Durability

- 8.1—General
- 8.2—Cover
- 8.3—Cracks
- 8.4—Corrosion and deterioration of reinforcement and metallic embedments
- 8.5—Surface treatments and coatings

Durability (CT)

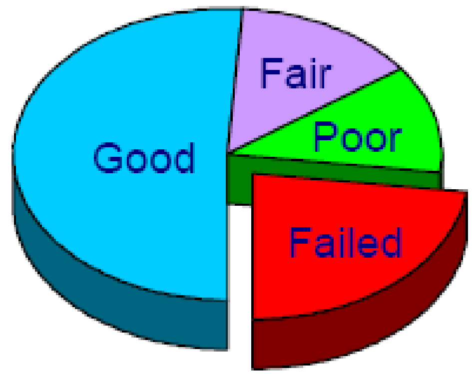
- **Durability-**the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.



Repair Material Performance

Vision 2020
A Vision for the Concrete Repair, Protection and Strengthening Industry

Repair Performance of Repairs



Source After REMR-CS-2 Report

Causes

Design
Installation
Materials

"A little more than 50% of the repairs performed on the Corps structures are performing satisfactorily, which is an unacceptable rate.

Failures of repairs are attributable to

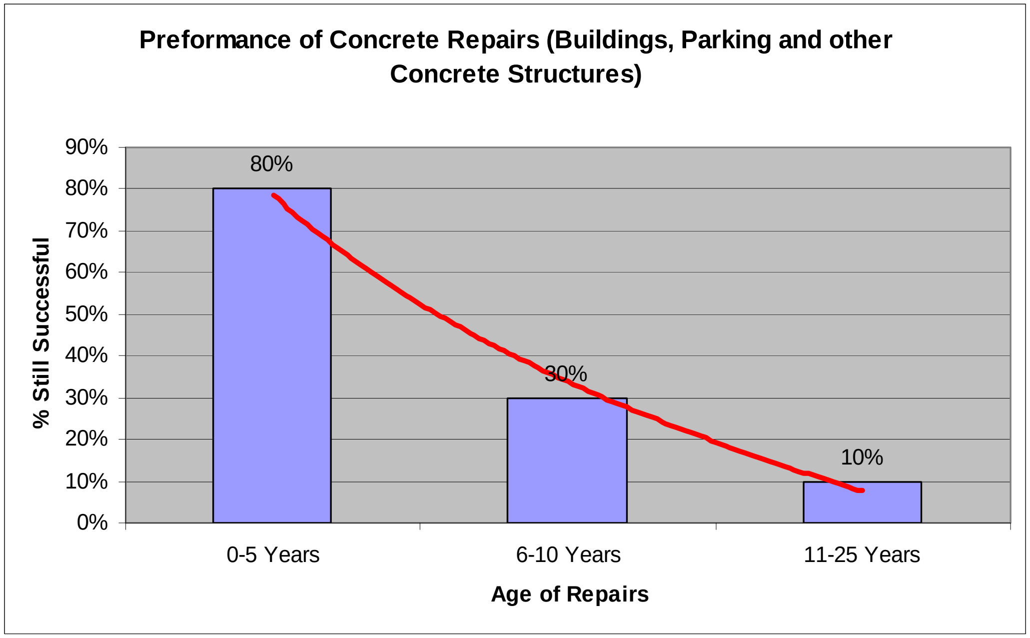
design or evaluation errors,

→ material performance, and ←

installation or construction errors.

The Corps experience is not unusual."

How many repairs fail?



50% Successful Repairs Survival

215 useable case-histories

- 50% Successful and exhibiting no signs of deterioration.
- 25% Exhibiting evidence of deterioration, …not necessarily requiring remedial action.
- 25% Failure, clearly requiring remedial action.

http://projects.bre.co.uk/conrepnet/pages/default.htm

MISTAKES

It Could Be that the Purpose of Your Life Is
Only to Serve as a Warning to Others.

Flowchart For Concrete Repair Problem Resolution

8.1—General

- **8.1.1** Durability of all materials incorporated into a repair shall be considered for individual repairs, the overall durability of the repaired structure, and the interaction of the repair system with the existing structure.

Depends on the compatibility between

- repair materials
- the structure
- and the surrounding environment

Interaction of chemical, electrochemical, and physical behavior

Compatibility

- a balance of physical, chemical, and electrochemical properties and dimensions between a repair material and the existing substrate;

- the capacity of two or more materials to combine or remain together without undesirable aftereffects

mutual tolerance.

INTERNATIONAL CONCRETE REPAIR INSTITUTE

CONCRETE REPAIR TERMINOLOGY

8.1—General

- **8.1.2** Repair materials and methods shall be selected that are intended to be compatible with the structure, durable within the service environment, and consider the anticipated maintenance.
- Design Service Life

Considerations

•Cracking Resi

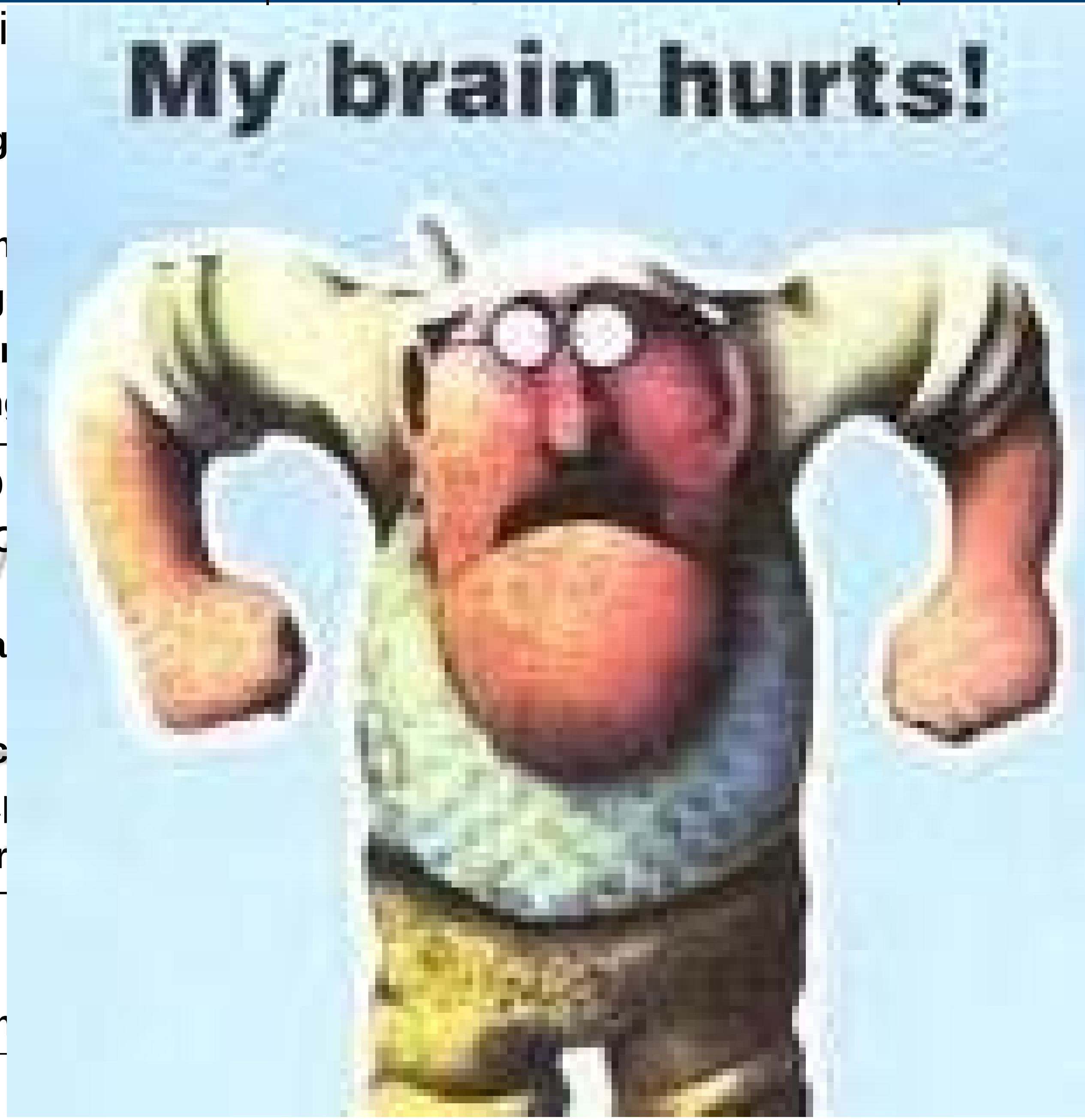
- Creep
- Tensile Streng
- Modulus
- Bond Strength
- Length Chang
- Thermal Expa
- Flexural Stren

Application Co

- Environmental C
- Utilities
- Surface Prepara
- Access
- Return to Servic
- Orientation of A
- Volume of Mater

Next Steps

- Coating
- Tile/Carpet/Vi



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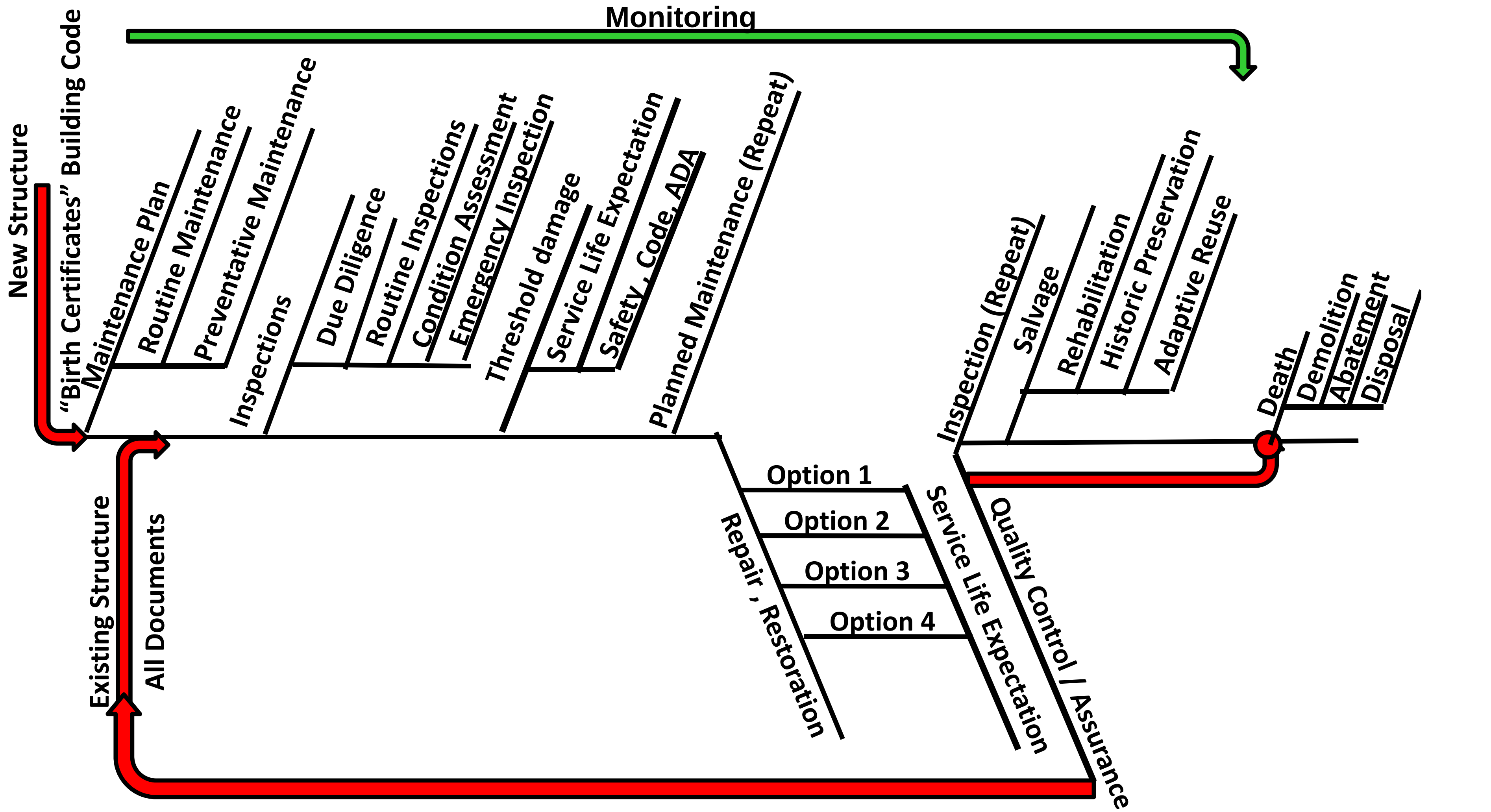
Design Service Life

- = a goal established by the licensed design professional (LDP) to achieve an economical repair that satisfies both safety and serviceability requirements
- estimated by LDP in consultation with the owner and consideration of the properties of the materials

Time Line of ICRI 140 Service Life Draft



End of Service Life

Includes:

- Structural safety is unacceptable due to material degradation or the actual strength is less than the required strength.
- Maintenance requirements exceed resource limits.
- Aesthetics become unacceptable.
- Structural functionality is no longer sufficient.
- Deformation capacity of the structure has been degraded due to a seismic event.

The BIGGEST ROI for concrete repair:

De Sitter’s Law of Fives

$1 spent Monitoring =

$5 spent on Preventative Maintenance Before Corrosion Initiation =

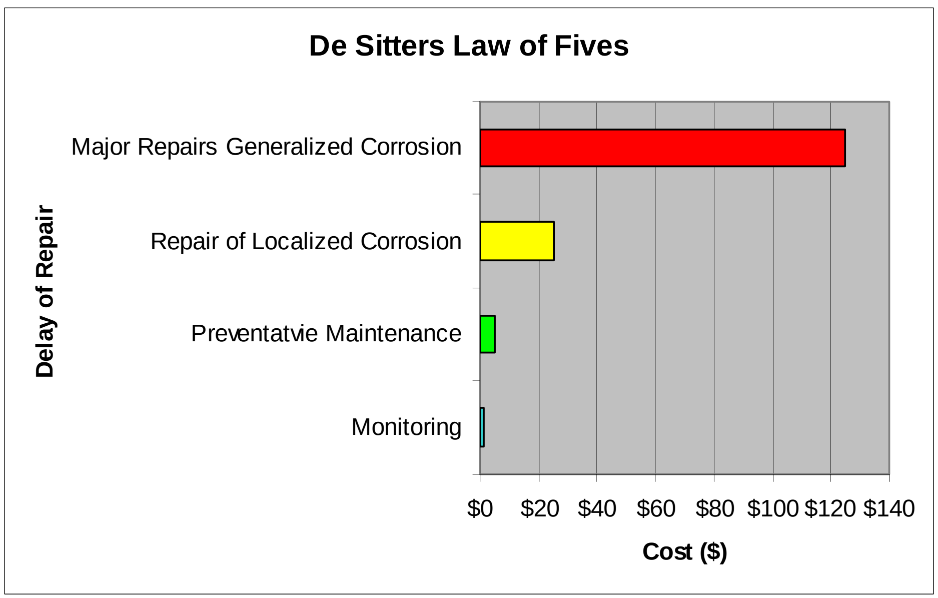
$25 spent on Repair and Maintenance after Localized Corrosion Initiation =

$125 spent on Repair & Replacement after Generalized Corrosion

Pay Me NOW

OR

Pay Me LATER



BRE Client report number Oct. 02 Draft
Commercial in confidence

Why does concrete fail?

- **Concrete has (compared to other building materials)**
- **-low tensile strength** (~10% of compressive strength),
- **-low ductility** (it's brittle),
- **-low strength-to-weight ratio** (it's heavy),
- **-responds to environment** (it changes with time)
- **-has permeability**(ingress of deleterious materials)
- **-is susceptible to chemical attack**(acids, AAR, etc.)
- **-and it cracks.**
- **Steel corrodes**

  Chloride, carbonation, and polarization interaction

  Rust expands, causing cracking, spalling, and eventual failure

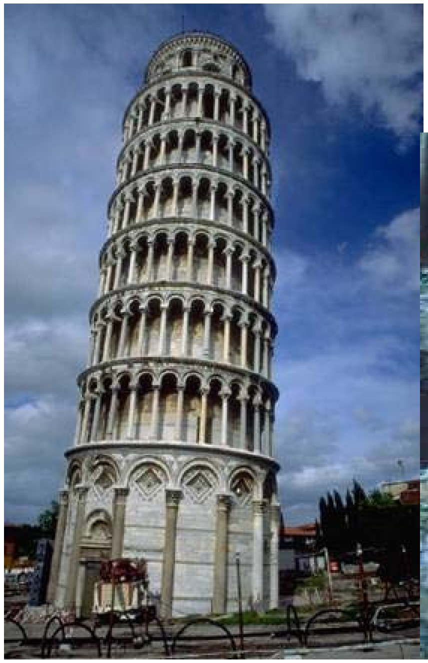
Causes of degradation

- Mechanical- abrasion, fatigue, impact, overload, settlement, explosion, vibration, excessive displacement, loads, or ground motion from a seismic event.
- Chemical- alkali-aggregate reaction, sulfate attack, acid dissolution, soft water leaching, and biological action.
- Physical- freezing and thawing, scaling, differing coefficients of thermal expansion, salt crystallization, radiation exposure, fire, and differential permeability between materials.
- Reinforcement corrosion- carbonation, corrosive contaminants, dissimilar metals, stray currents, and stress corrosion cracking.

Why does concrete fail?

Concrete requires repair and strengthening due to the 3 D's

- Design and Construction Errors
- Deterioration
- Damage



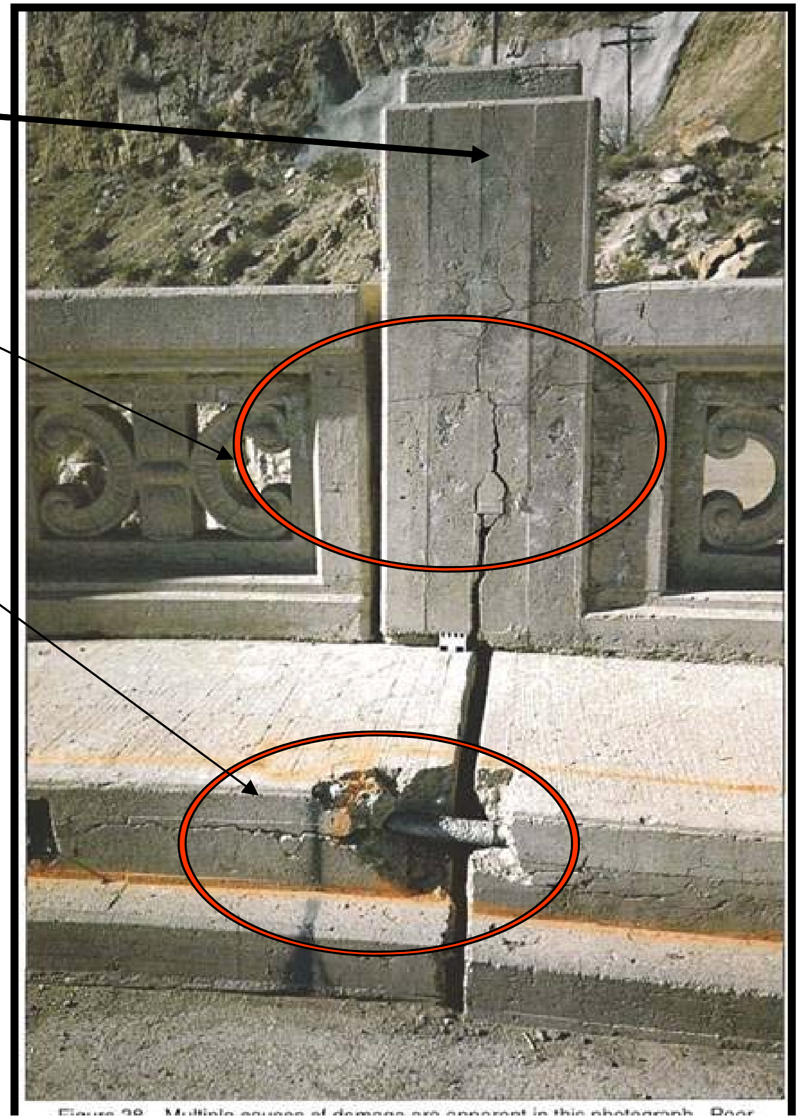
Why does concrete fail?

Combination of Effects

Deterioration

Design

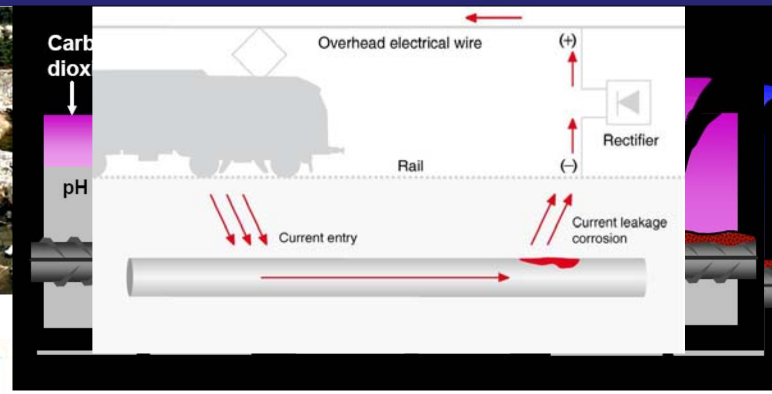
Damage

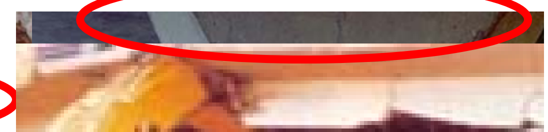


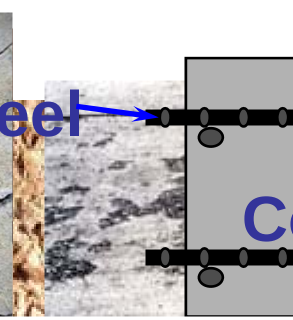
How does concrete fail?

Frost damage, concrete not air entrained

Concrete Matrix







8.2—Cover

- In accordance with the design basis code.
- Alternative materials and methods, an equivalent cover that provides sufficient corrosion protection and fire protection shall be in accordance with 1.4.2 *.
- Sufficient anchorage and development for the reinforcement shall be provided regardless of methods used to provide corrosion protection.

  - *shown to be adequate by successful use, analysis, or testing
  - present the data for approval to the building official or to a board of examiners appointed by the building official.

Cover

- **cover** — the least distance between the surface of embedded reinforcement and the surface of the concrete (CT)
  - *effective-producing a desired effect*

    (i.e., low permeability, proper thickness, good quality, etc.)
- **equivalent cover**—a system to supplement insufficient concrete cover to improve durability or fire protection to that equivalent to the minimum cover specified in the design basis code (562).

8.2—Cover

- **8.2.2** *Corrosion* —Where concrete cover for existing reinforcement is insufficient to provide corrosion protection for the design service life of the structure, additional concrete cover or an alternate means of corrosion protection shall be provided to mitigate corrosion of reinforcement within the repair area.
- Consider existing reinforcement corrosion, chloride contamination, and carbonation
- Application of waterproof membranes, corrosion inhibitors, and forms of cathodic protection.

8.3—Cracks

- **8.3.1** The design of repairs shall consider the effects of cracks on the expected durability, performance, and design service life of the repair.
- Consider the causes, movement, size, orientation, width, complexity of the network of cracks, characteristics of the substrate, location, and evidence of water transmission

8.3—Cracks

- **8.3.2** The cause and repair of cracking shall be assessed and considered in repair design.
- Not all cracks need to be repaired.
- All cracks have the potential to become active cracks.
- Crack injection should not be used to repair cracks caused by corrosion of steel reinforcement and alkali aggregate reaction unless supplemental means are employed to mitigate the cause of the cracks

Concrete Cracks!

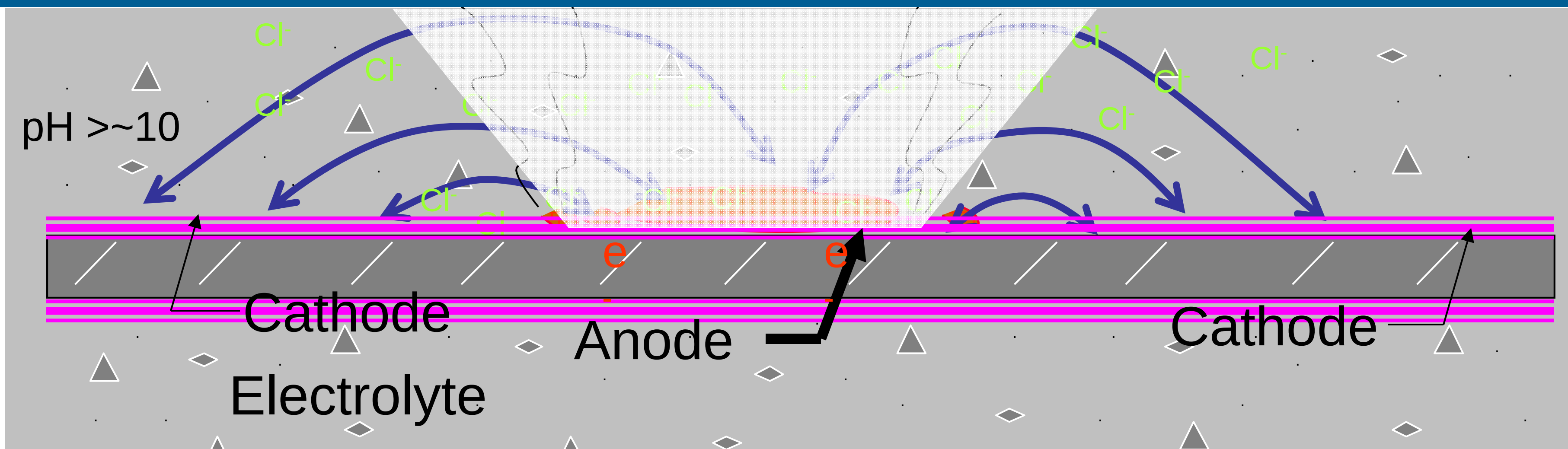
8.4—Corrosion and deterioration of reinforcement and metallic embedments

- Considered in the durability design
- Not contain intentionally added constituents that are corrosive to reinforcement within the repair area.
- Aggregates conform to the requirements of ACI 318-11
- Existing reinforcement corrosion encapsulated within new repair materials to be considered for long term durability and strength
- Quality of existing concrete and ability to protect reinforcement from corrosion and deterioration shall be considered.
  - address anodic ring effect

8.4—Corrosion and deterioration of reinforcement and metallic embedments

- Existing & added steel reinforcement protected from corrosion and deterioration to satisfy durability requirements.
- Galvanic corrosion between electrochemically dissimilar materials shall be considered.
- Protection of bonded + unbonded prestressing materials & prestressing components addressed during the repair design.
- Interaction of electrochemical protection system with repaired elements, the entire structure, and environment to be considered.
- Characteristics of repair material & reinforcement do not adversely affect the durability of other materials or existing concrete and reinforcement

8.4—Corrosion and deterioration of reinforcement and metallic embedments



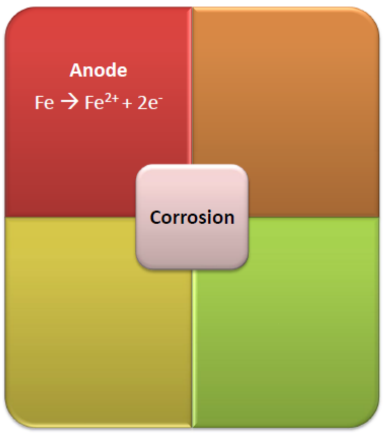
Corrosion = Iron + Oxygen + Moisture

Either

- the pH falls due to carbonation or other chemicals
- chlorides reach the steel above the threshold concentration
- an electrical charge destroys the natural protection of the steel
- Electrons flow and ions migrate
- Rust expansion causes cracking
- Rapid deterioration
- Spalling

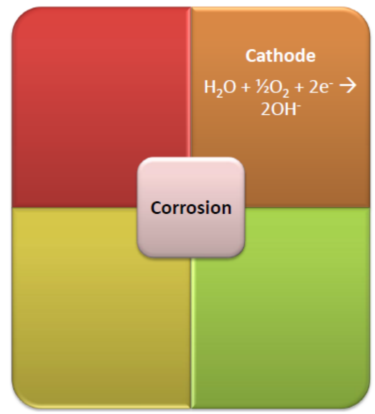
Breaking the Links of Corrosion

Anode



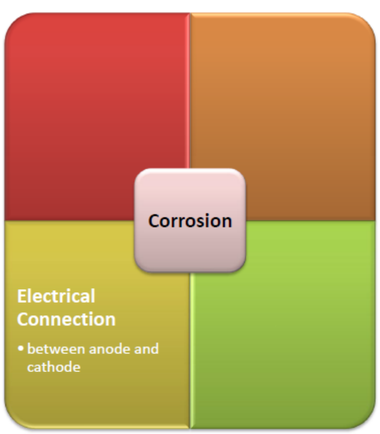
- Concrete permeability
  - w/c, pozzolans, chemical additions
  - Membrane, silane
- Chloride threshold
  - Inhibitor
  - Change metal (stainless)
- Reduce reactive surface
  - Coatings
- Reduce corrosion rate
  - Dry out concrete
- Force opposite reaction
  - Cathodic protection

Cathode



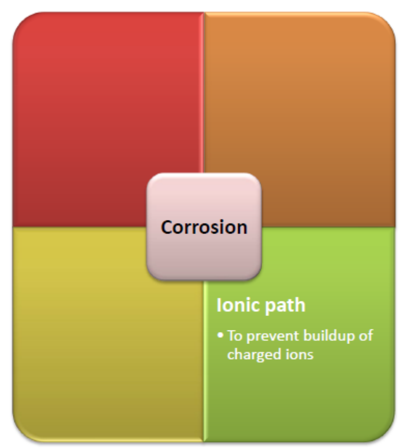
- Reduce area of reactive surface
  - Coatings
- Dry concrete
- Reduce oxygen
- Reduce cathode effectiveness
  - Inhibitors

Electrical continuity



- Disconnect anode and cathode
- Electrical separation of bars
  - Coatings
  - Electrical separation

Ionic Path

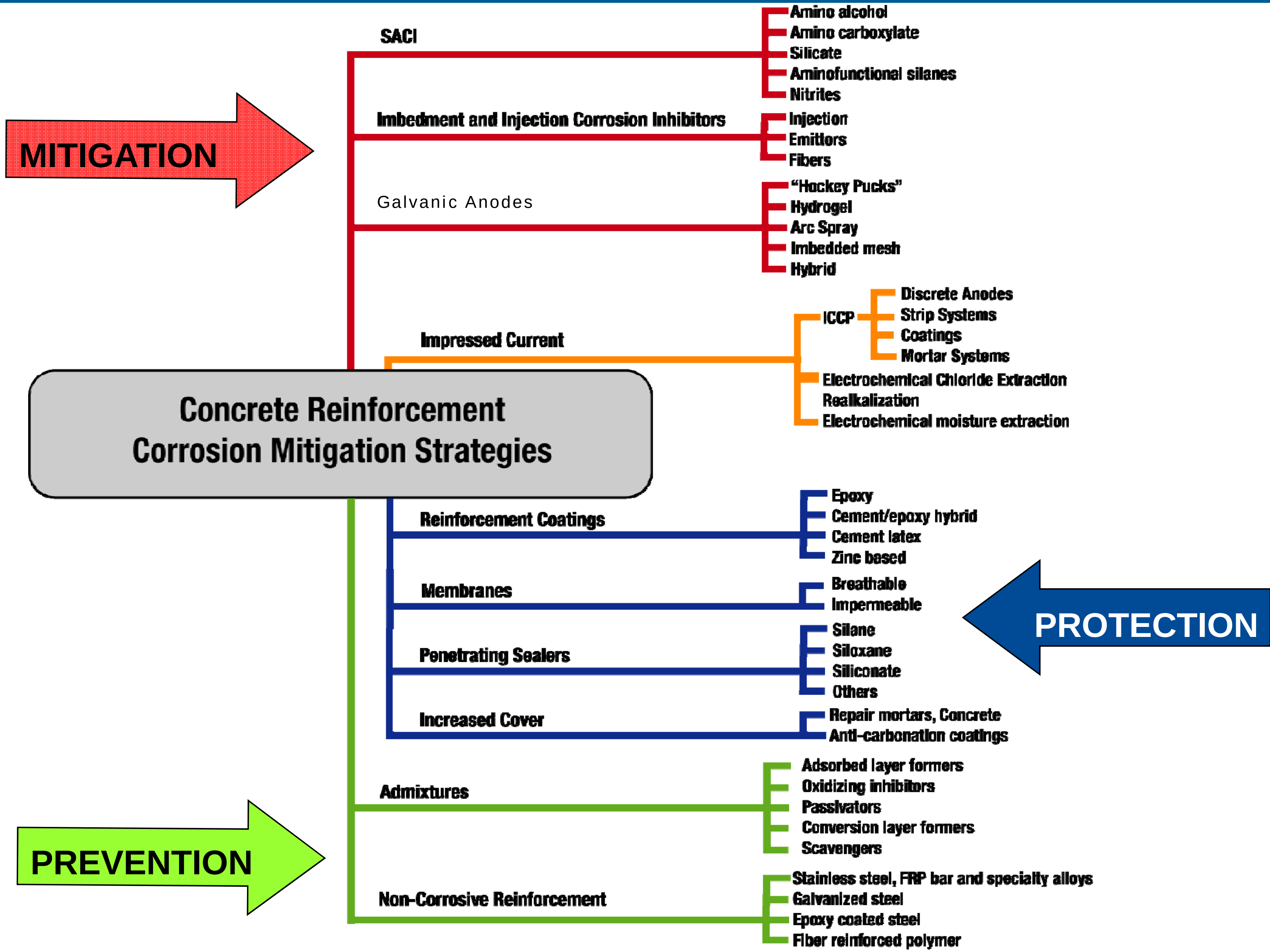


- Make pathway between anode and cathode more difficult
  - High resistivity concrete
  - Low moisture content

EIG CRSI
EPOXY INTEREST GROUP

D. McDonald, May 2010
SDC

Corrosion Control Options



8.5—Surface treatments and coatings

- 8.5.1 Consider moisture transmission through the structure & influence of surface treatment on the durability of the structure.
  - Surface treatments, coatings, sealers,and membranes may have a shorter service life than the concrete
  - Encapsulation of moisture and deleterious materials by surface treatment may cause or accelerate deterioration
- 8.5.2 surface treatments applied to concrete surfaces shall consider existing cracks within the concrete and the potential for movement

Durability Summary

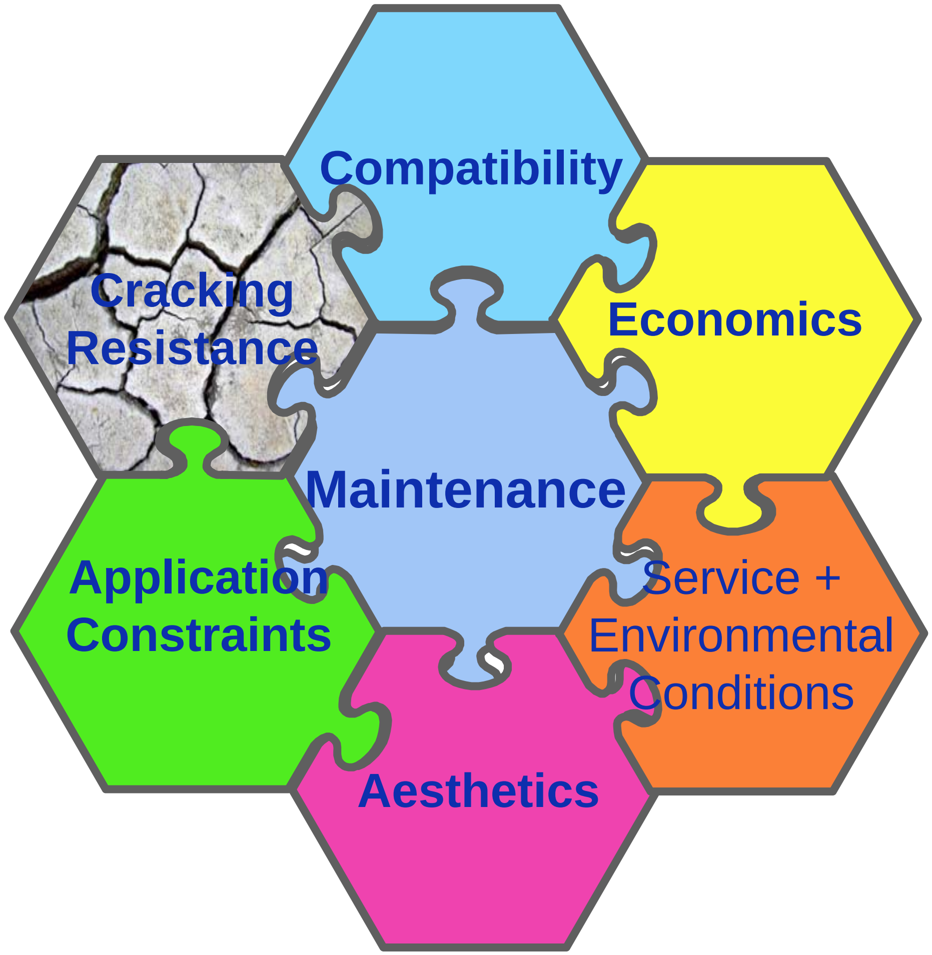
Repairs must be

- **Durable within the service environment**
  (exposure conditions)
- **Consider the anticipated maintenance**
  (cost effective delay of repairs)
- **Compatible between repair materials, the structure, and the surrounding environment**
  (similar and adequate properties)

Repairs must resist aggressive forces from

- **Mechanical forces**
- **Chemical attack**
- **Physical effects**
- **Reinforcement corrosion progression**

Durability Considerations



Outline

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Thank you

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www.concrete.org

Fred Goodwin, Fellow Scientist

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