Service Life Modeling of Repairs

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Presented by
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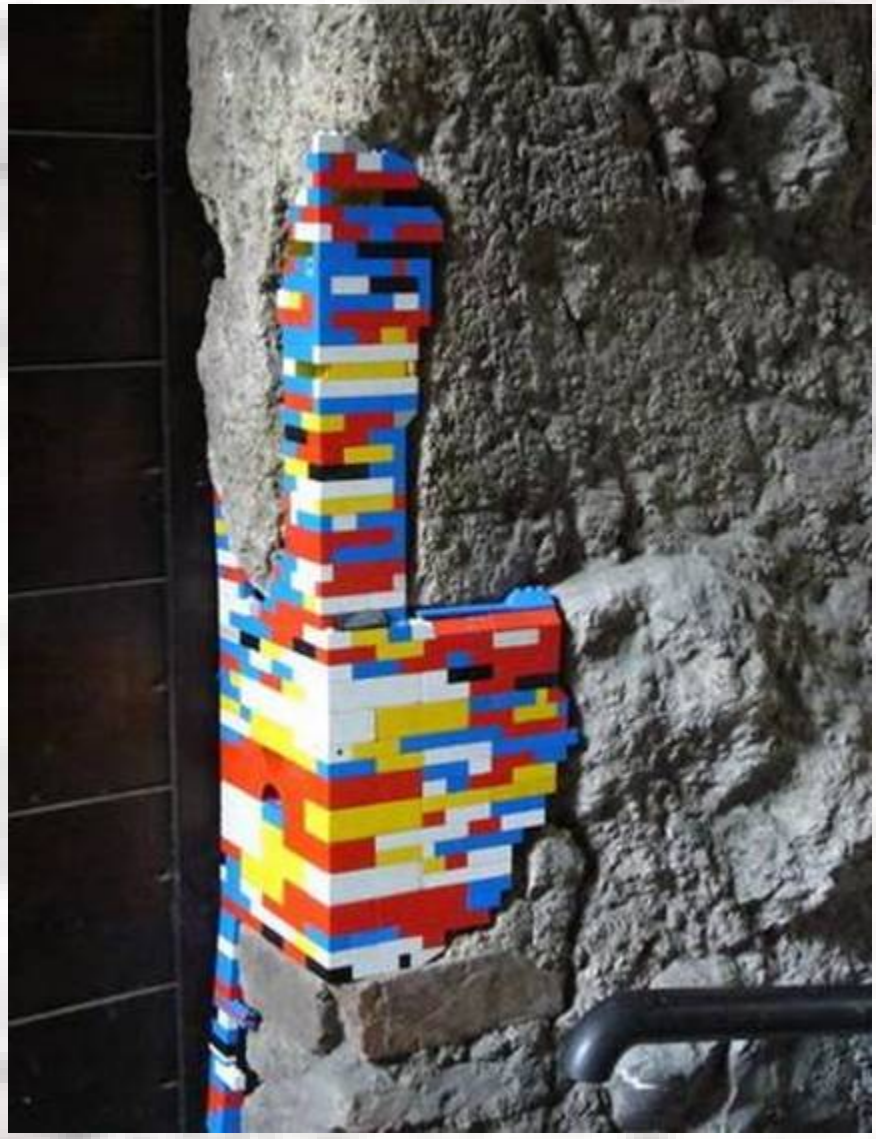
INTERNATIONAL CONCRETE REPAIR INSTITUTE

Current State



Today's Take Aways

Service Life Prediction and Modeling

- Service Life Expectations - Definition
- Performance Criteria
- Using Science for Performance Requirements
- Sustainability and Service Life

Modeling Concrete Performance

- Service Life software
- Testing & Quality Control
- Repair Protocol
- Repair Service Life

Who worries about or needs to know?

- Owners
- Agencies
- Engineers
- Architects
- Contractors
- Material Suppliers
- Operations / Management
- Financial / Insurance Organizations
- **ALL OF US**

What is Service Life?

- ACI 365.1

Service life (of building component or material) is the period of time after installation (or in the case of concrete, placement) during which all the properties exceed the minimum acceptable values when routinely maintained. Three types of service life have been defined. **Technical service life** is the time in service until a defined unacceptable state is reached, such as spalling of concrete, safety level below acceptable, or failure of elements. **Functional service life** is the time in service until the structure no longer fulfills the functional requirements or becomes obsolete due to change in functional requirements, such as the needs for increased clearance, higher axle and wheel loads, or road widening. **Economic service life** is the time in service until replacement of the structure (or part of it) is economically more advantageous than keeping it in service.

Service Life Performance Criteria

Canadian Standards Association CSA S478-95, *Guideline on Durability in Buildings*, CSA, Etobicke, Ontario, Canada.

- **Service life** The predicted service life of any building or component is based on the assumed environmental conditions and on installation, operating, and maintenance procedures.
- The predicted service life of components or assemblies assessed by one or more methods:

  1) Demonstrated effectiveness

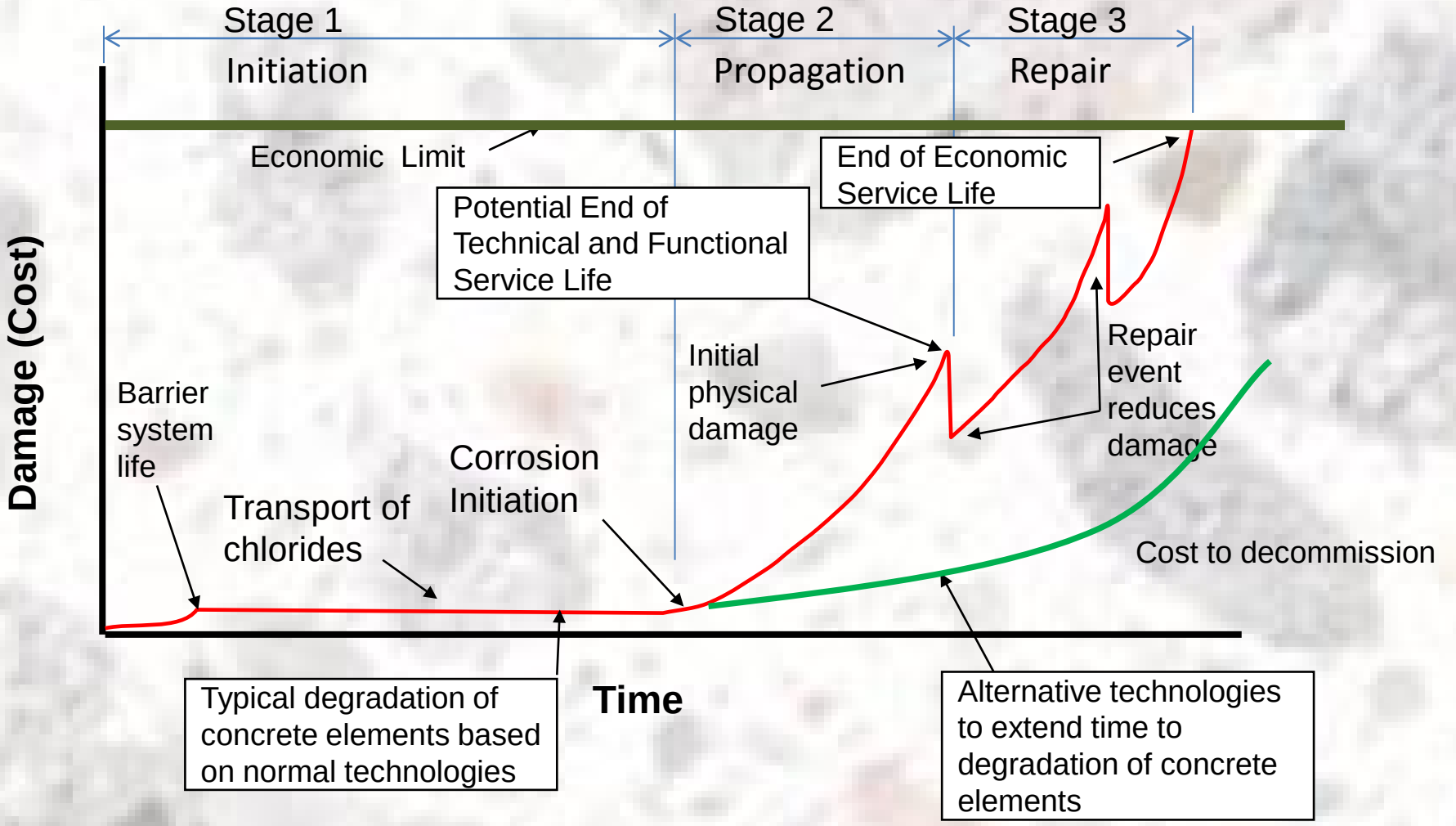
  2) Modeling of the deterioration process

  3) Testing

Measures of Performance

- Sustainability: Life Cycle Assessment (LCA)
  - Environmental Accounting cradle-to-grave (or cradle-to-cradle)
  - Athena Environmental Impact Estimator
- Resiliency: Resistance to Degradation
  - Assessment of Demonstrated effectiveness , testing, modeling
  - Life 365, STADIUM, and other Testing or Modeling
- Life Cycle Cost Analysis(LCCA)
  - Economic Value
  - Analysis Maintenance & Repair Alternatives
  - ASTM Life Cycle For Buildings

Service Life (Reinforced Concrete)



Service Life Engineering

- New construction durability designs / reviews.
- Performance-based specifications
- **Restoration designs / reviews**
- Product technical reviews
- Construction variance resolutions

Top Three Critical Issues of Service Life Management

1. Commitment to Service Life Analysis

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2. Formalize Expectation and Definitions

YEARS

Top Three Critical Issues of Service Life Management

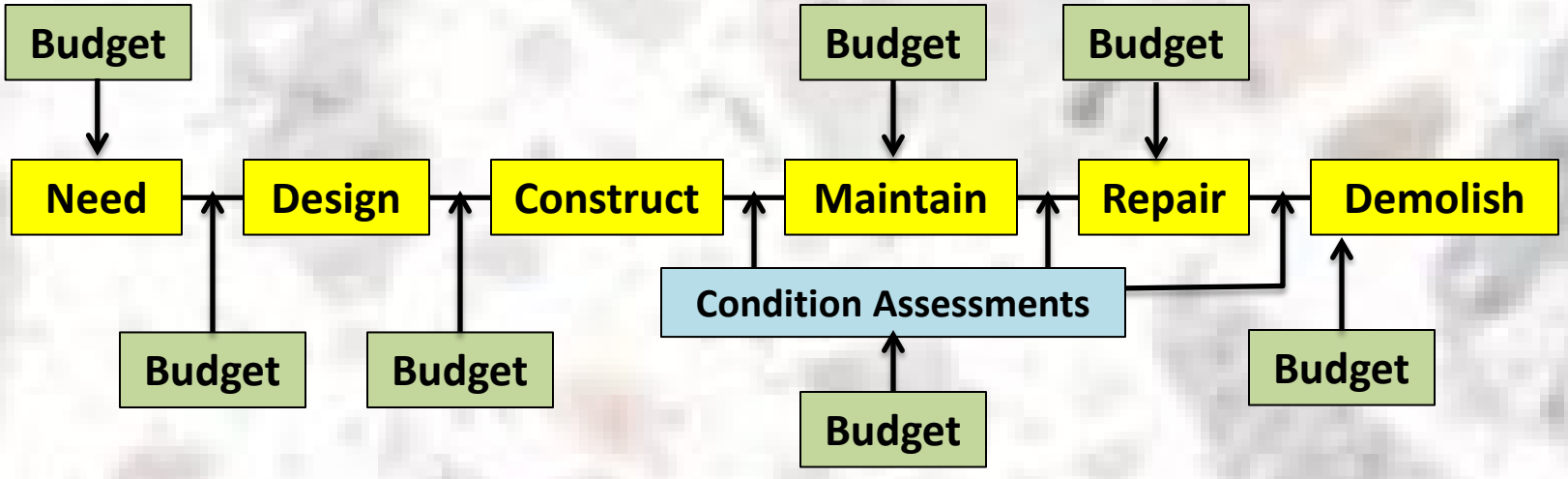
1. Commitment to Service Life Analysis

2. Formalize Expectation and Definitions

3. Budget Accordingly

Life Cycle of Concrete Structures

Life Cycle of Concrete Structures



Structural End Point

Demolish Structure

Condition Assessment Tools

- Materials Characterization – Detailed assessment to determine concrete properties (transport and chemistry) and degradation mechanisms---corrosion, microcracking, alkali-silica reaction (ASR), delayed ettringite formation (DEF), decalcification, carbonation, sulfate attack, etc.
- Service Life Computer Models – Validated numerical computer software models that predict future conditions.
- Materials Repair Protocol Characterization – Detailed assessment to determine concrete repair materials properties

Condition Assessments

- Field Survey

Condition Assessment

- Field Survey
- Corrosion Measurements

Repair & Protection Plans
Mitigate Degradation Mechanisms

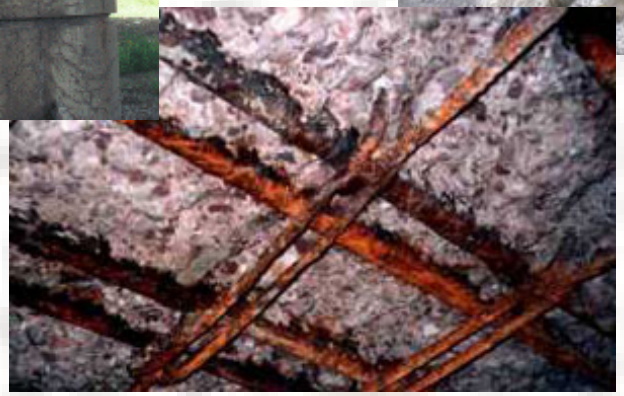
Degradation	Environmental Exposure
1. Corrosion	1. Deicing Salts, Marine, Industrial
2. Cracking	2. All Buildings & Infrastructure
3. Shrinkage	3. All Buildings & Infrastructure
4. Alkali Silica Reaction, ASR	4. Exterior Soil/moisture, Industrial
5. Freeze thaw	5. Temperature cycles below freezing
6. Scaling	6. Weathering or wet dry /cycles
7. Sulfate Attack, DEF	7. Soils, Heat, Water
8. Decalcification	8. Natural Water, Acid, Sodium Chloride / Seawater
9. Abrasion	9. Loading
10. Structural Fatigue	10. Loading

Admiral Clarey Bridge, Pearl Harbor, HI

Mechanisms of Deterioration

Mechanisms of Deterioration

- Corrosion



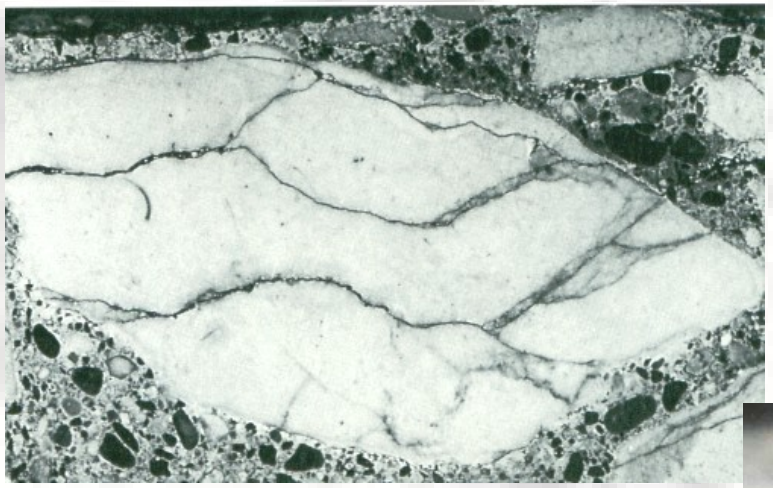

Precast Concrete Tee Joint
Deterioration

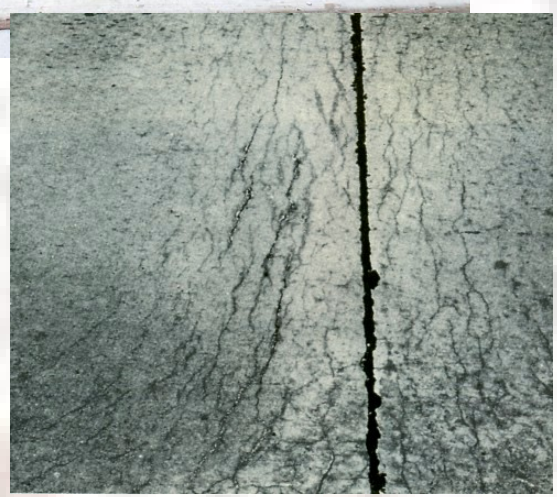
Corrosion Testing and Analysis

- Visual Inspection
- Delamination Survey
- Concrete Cover Survey
- Chloride Sampling and Analysis
- pH Testing (Carbonation)
- Corrosion Potential Measurements
- Corrosion Rate Measurements

Mechanisms of Deterioration

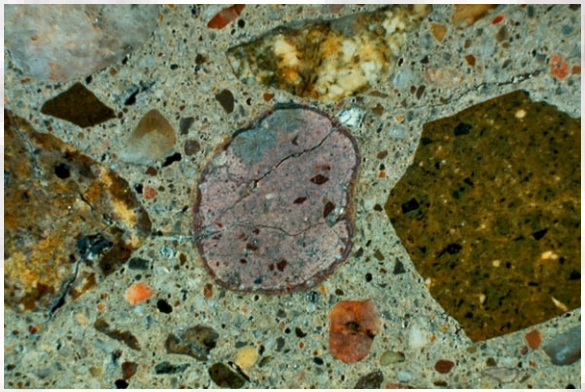
- Freeze-thaw

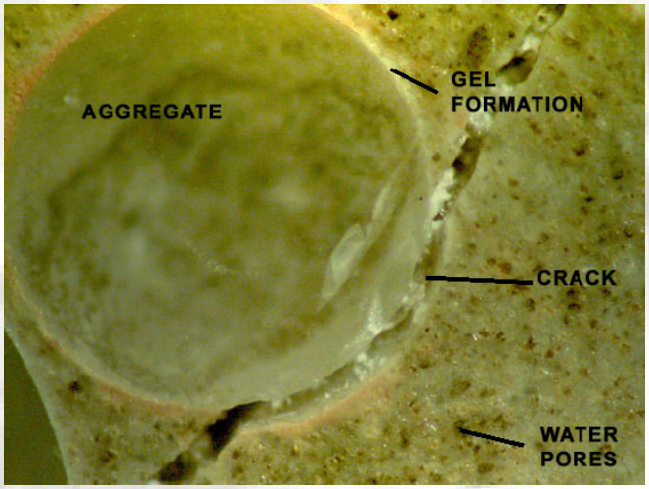




Mechanisms of Deterioration

- ASR



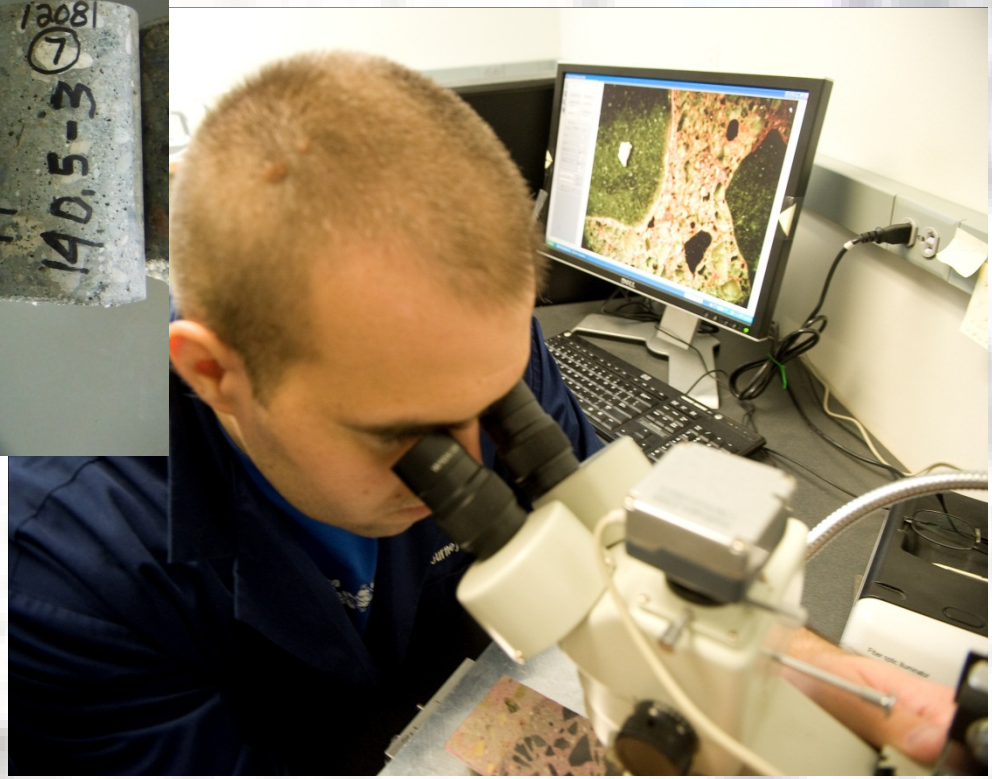


Mechanisms of Deterioration

- Sulfate attack

Condition Assessments

- Materials Testing



Concrete Characterization for Service Life Analysis

Guidelines of ACI 365 – Service Life Prediction

Standard Tests

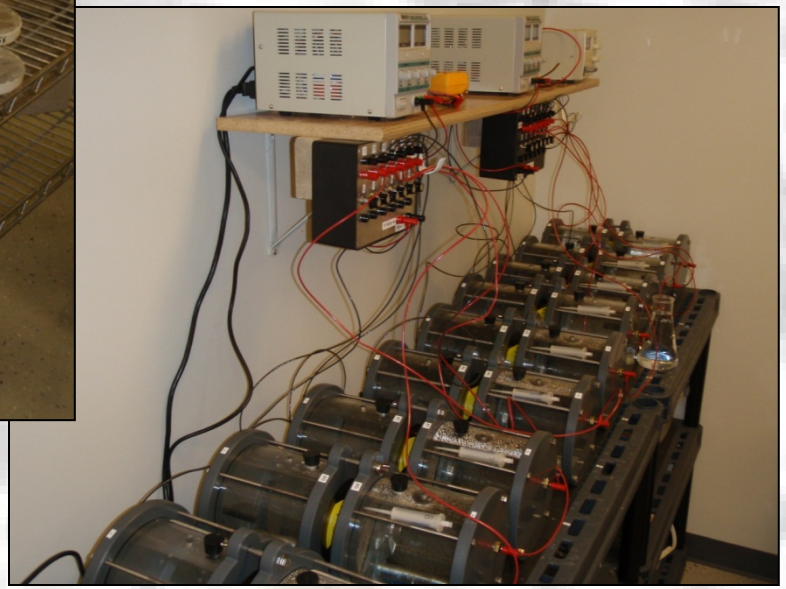
- Strength, Slump, Unit Weight, & Air Entrainment
- ASR potential
- Shrinkage

Transport Properties

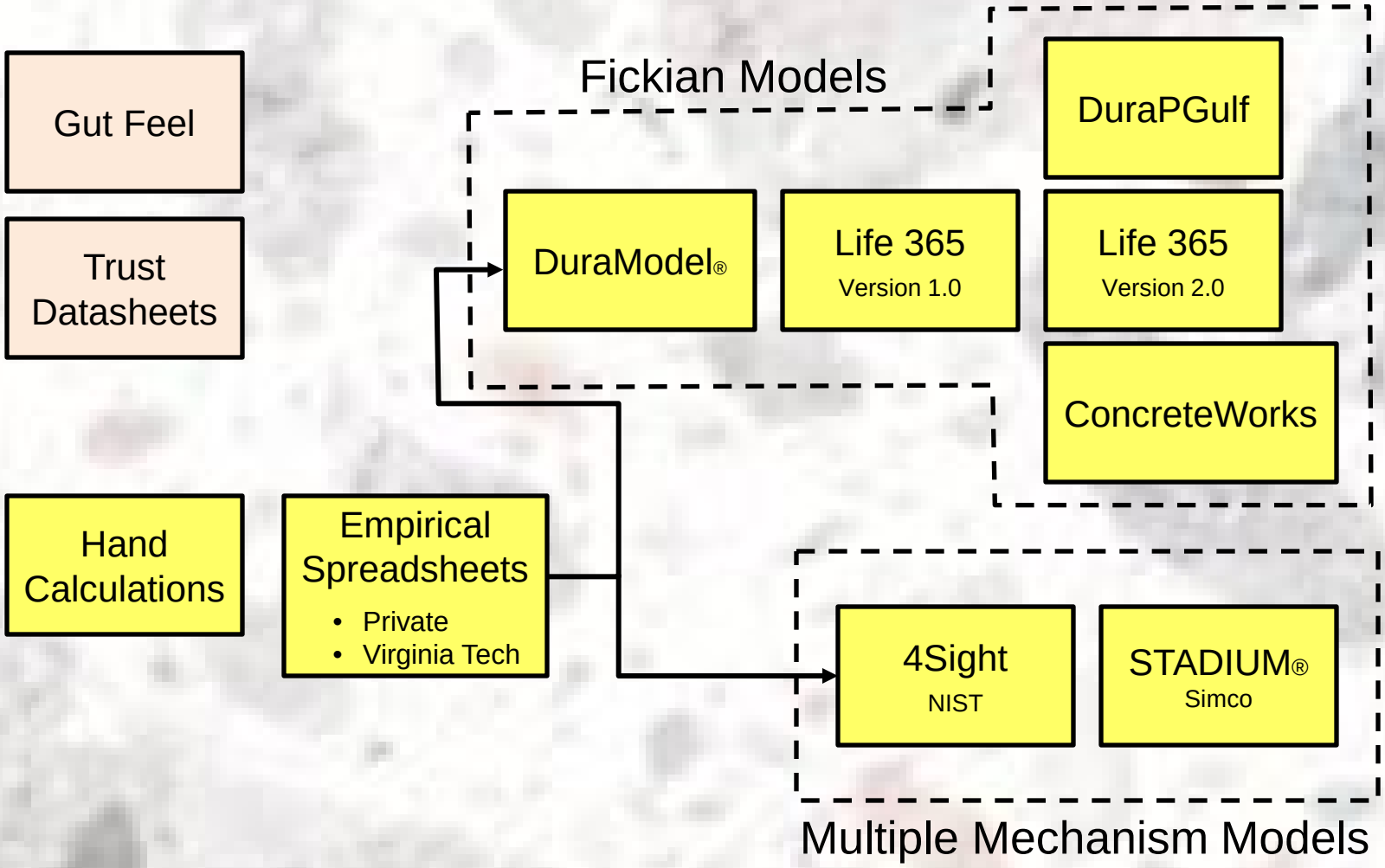
- Porosity , Density and Unit weight ASTM 642
- Pore Solution
- Drying properties
- Diffusion Coefficients

Condition Assessments

- Materials Testing



Simplified History of SLM



STADIUM®

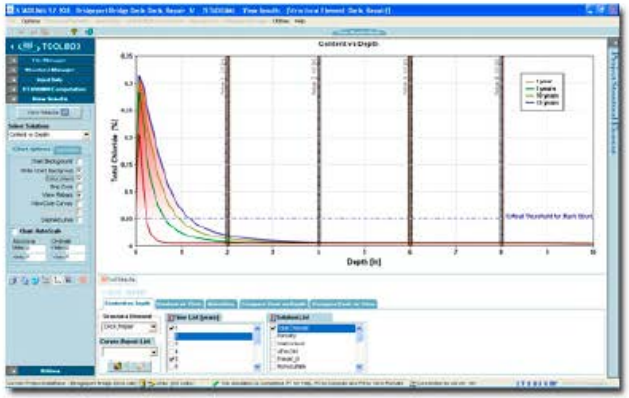
OVERVIEW

- *Accurate concrete service life prediction*
- *Predicts onset of rebar corrosion due to chlorides*
- *Models other chemical reactions (e.g. sulfates)*
- *Accounts for specific geometry of structural elements*
- *Creates and saves comparative scenarios*
- *Clear and easy to read reports in print or PDF*
- *Central (web) storage for easy access*

STADIUM® is a modeling and simulation software used by owners and engineers of concrete structures who place a premium on public safety, convenience, and deferment of capital costs.

It reliably predicts the service life of concrete structures exposed to aggressive environments such as deicing salts, seawater and sulfate-bearing groundwater while explicitly using local materials.

Series of results can be viewed such as Content vs. Depth, Content vs. Time, Animations and Structural Element Comparisons.

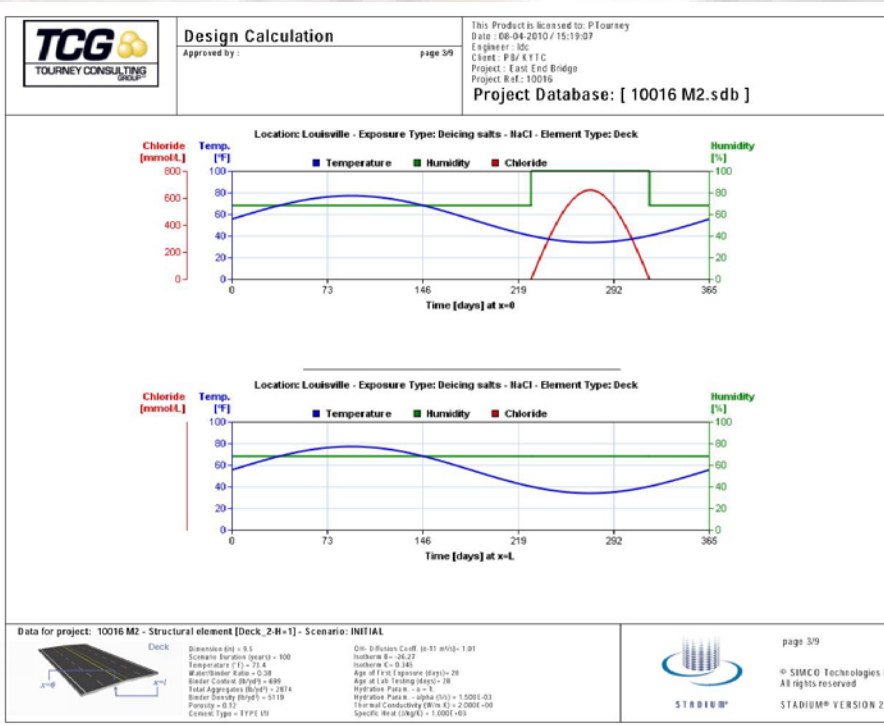


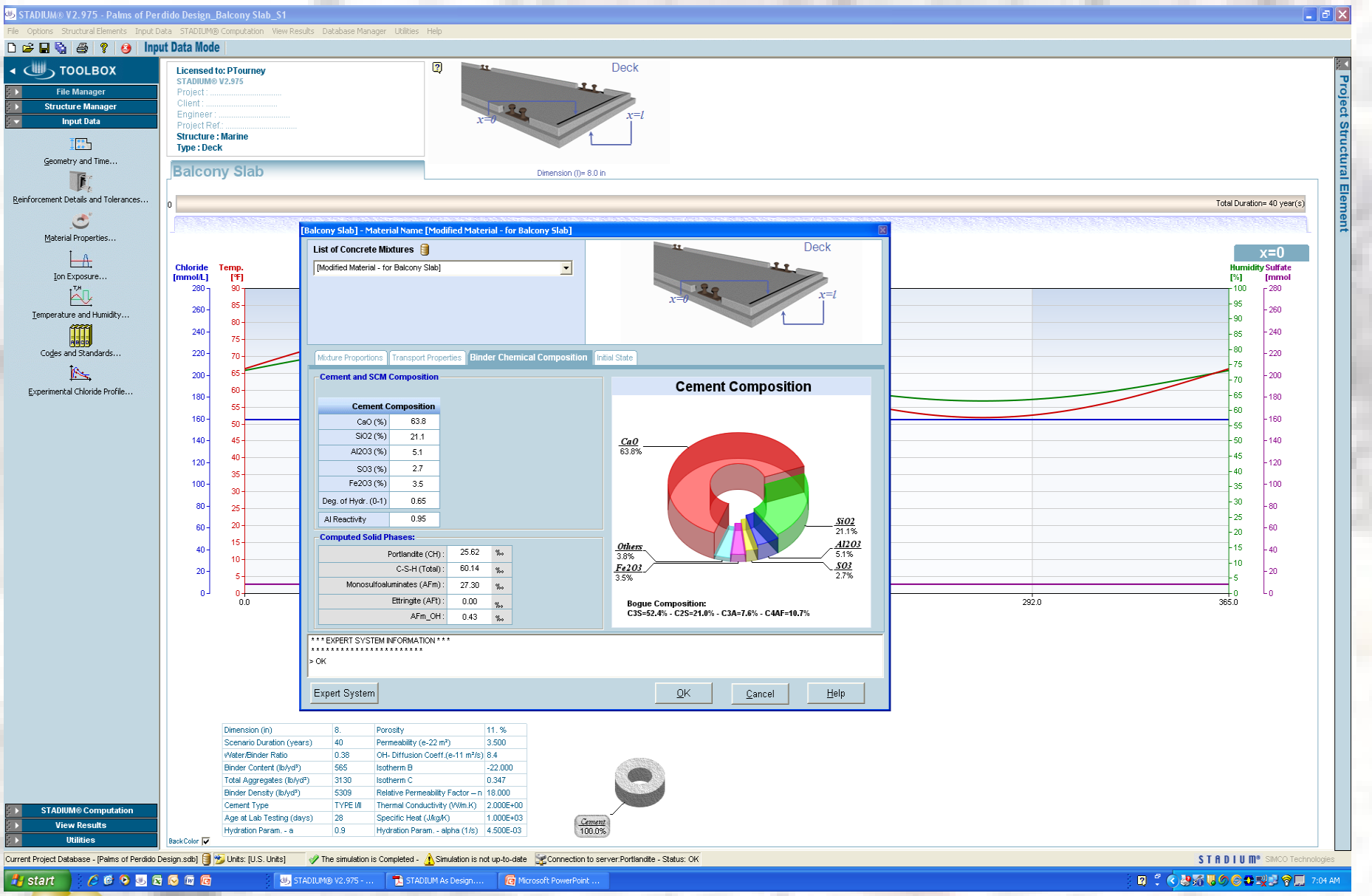
Modeling Concrete Performance

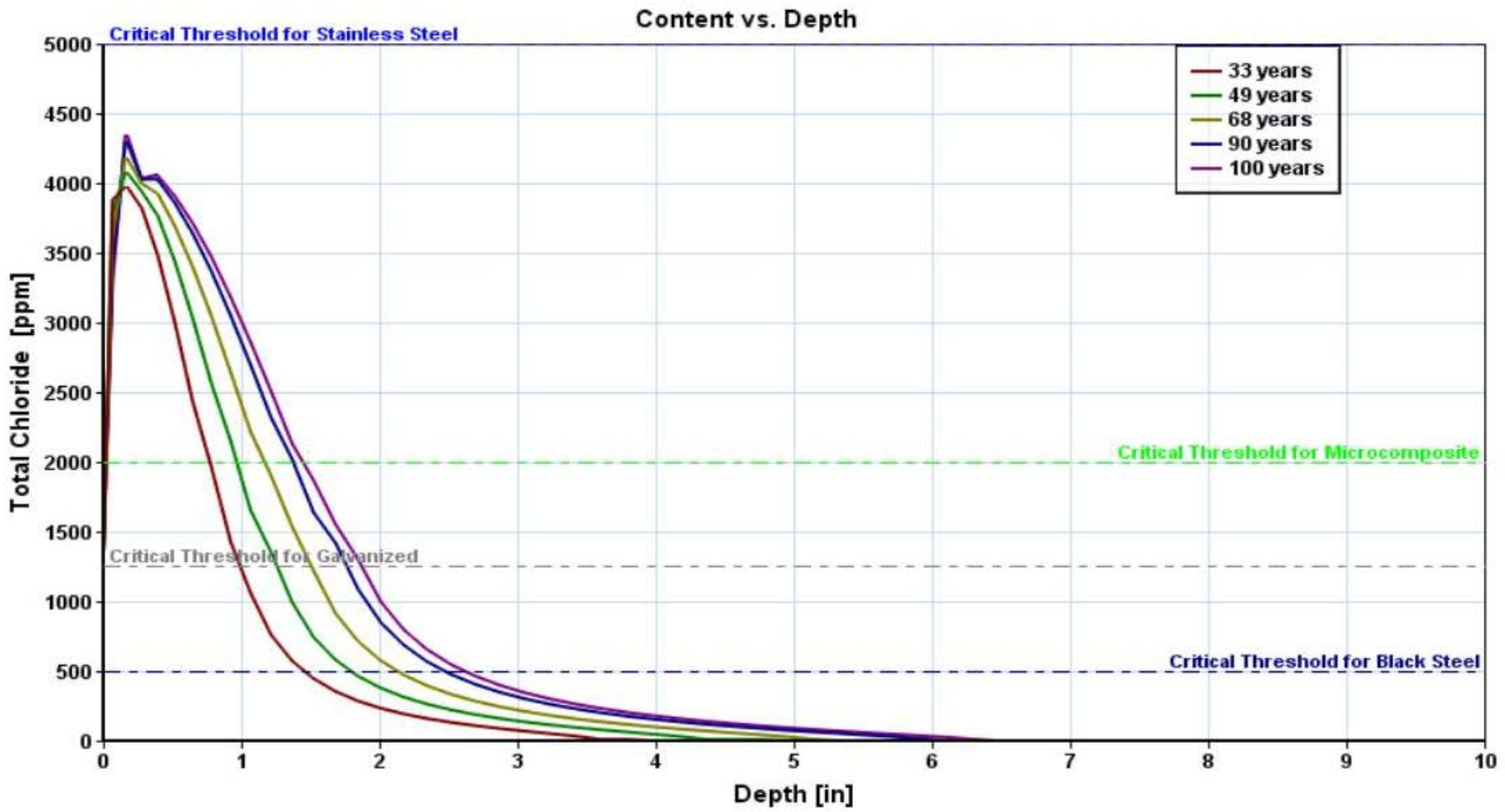
Concrete Elements Considered in Analysis
Environmental Conditions
- Temperature and Humidity
- Ion Exposure

Concrete Durability Assessment
Concrete Properties
- Transport Properties
- Concrete Mixture Composition
- Test Results
- Reinforcing Steel Options
- Reinforcing Steel Comparisons

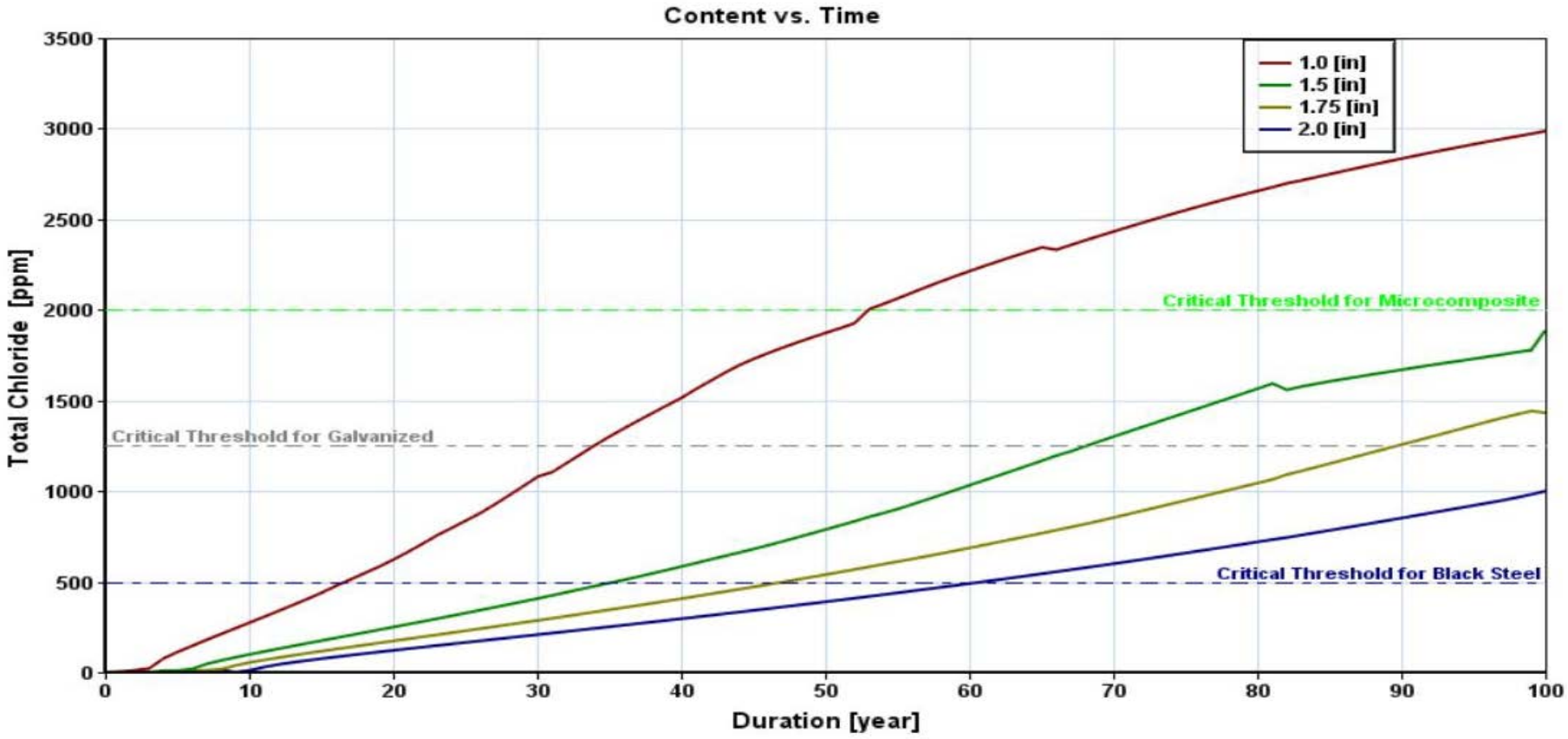
Predictive Service Life Modeling




STADIUM® V2.975 - Palms of Perdido Design_Balcony Slab_S1
File Options Structural Elements Input Data STADIUM® Computation View Results Database Manager Utilities Help
Input Data Mode
TOOLBOX
File Manager
Structure Manager
Input Data
Geometry and Time...
Reinforcement Details and Tolerances...
Material Properties...
Ion Exposure...
Temperature and Humidity...
Codes and Standards...
Experimental Chloride Profile...
STADIUM® Computation
View Results
Utilities
Licensed to: PTourney
STADIUM® V2.975
Project :
Client :
Engineer :
Project Ref :
Structure : Marine
Type : Deck
Deck
x=0
x=l
Dimension (l)= 8.0 in
Balcony Slab
Total Duration= 40 year(s)
[Balcony Slab] - Material Name [Modified Material - for Balcony Slab]
List of Concrete Mixtures
[Modified Material - for Balcony Slab]
Mixture Proportions
Transport Properties
Binder Chemical Composition
Initial State
Cement and SCM Composition
Cement Composition
CaO (%) 63.8
SiO2 (%) 21.1
Al2O3 (%) 5.1
SO3 (%) 2.7
Fe2O3 (%) 3.5
Deg. of Hydr. (0-1) 0.65
Al Reactivity 0.95
Computed Solid Phases:
Portlandite (CH) : 25.62 %
C-S-H (Total) : 60.14 %
Monosulfoaluminates (AFm) : 27.30 %
Ettringite (AFt) : 0.00 %
AFm_OH : 0.43 %
Cement Composition
CaO 63.8%
SiO2 21.1%
Al2O3 5.1%
SO3 2.7%
Fe2O3 3.5%
Others 3.8%
Bogue Composition:
C3S=52.4% - C2S=21.0% - C3A=7.6% - C4AF=10.7%
* * * EXPERT SYSTEM INFORMATION * * *
> OK
Expert System
OK
Cancel
Help
Chloride [mmol/L]
Temp. [°F]
x=0
Humidity [%]
Sulfate [mmol
0.0
292.0
365.0
Dimension (in) 8. Porosity 11. %
Scenario Duration (years) 40 Permeability (e-22 m²) 3.500
w/Water/Binder Ratio 0.38 OH- Diffusion Coeff.(e-11 m²/s) 8.4
Binder Content (lb/yd³) 565 Isotherm B -22.000
Total Aggregates (lb/yd³) 3130 Isotherm C 0.347
Binder Density (lb/yd³) 5309 Relative Permeability Factor – n 18.000
Cement Type TYPE I/II Thermal Conductivity (W/m.K) 2.000E+00
Age at Lab Testing (days) 28 Specific Heat (J/kg/K) 1.000E+03
Hydration Param. - a 0.9 Hydration Param. - alpha (1/s) 4.500E-03
Cement 100.0%
Back Color
Project Structural Element
Current Project Database - [Palms of Perdido Design.sdb]
Units: [U.S. Units]
The simulation is Completed -
Simulation is not up-to-date
Connection to server:Portlandite - Status: OK
STADIUM® SIMCO Technologies
start
STADIUM® V2.975 - ...
STADIUM As Design...
Microsoft PowerPoint ...
7:04 AM



Data for project: 10016 M2 - Structural element [Deck_2-H=1]


Content vs. Time
Total Chloride [ppm]
Duration [year]
1.0 [in]
1.5 [in]
1.75 [in]
2.0 [in]
Critical Threshold for Microcomposite
Critical Threshold for Galvanized
Critical Threshold for Black Steel
0
500
1000
1500
2000
2500
3000
3500
0
10
20
30
40
50
60
70
80
90
100

Performance Evaluation

- Modeling (Base + What if's)
- Product Data Sheets
  - Variability
  - Standard Codes
  - Mechanisms
- Service Life Predictions
- LCCA
- Repair Materials – Repair Protocol

Protection/Repair Technologies

- Surface treatments
- Electrochemical/CP
- Patch
- Overlay
- Sealants

Mechanisms of Protection

Surface Applied Corrosion Inhibitors

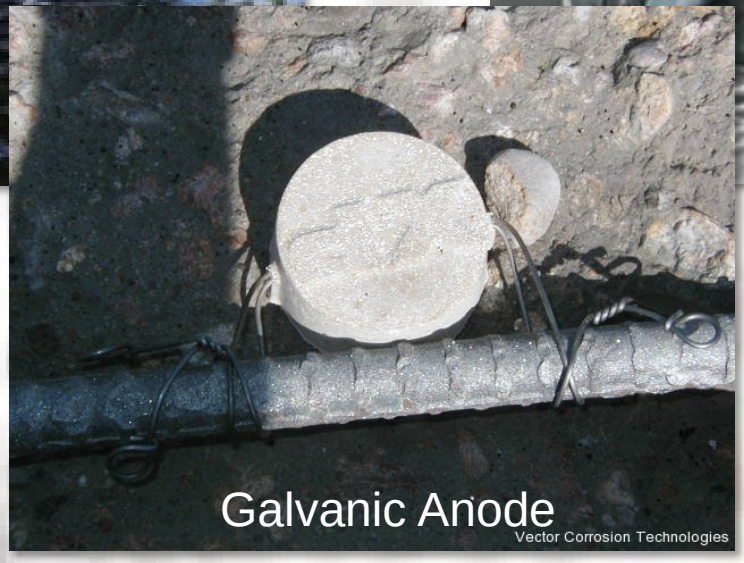
Penetrating Silane Sealers

Traffic Bearing Membranes (Deckcoating)

Galvanic Cathodic Protection

LifeJacket

Spray Arc Metalizing



Galvanic Anode

Service Life of Repairs

- Patch

Spot Patch Repairs

Advantages

- Low Initial Cost
- Fast
- Addresses Current Symptoms
- Service Life 1-3 with Sealer
- Service Life 3 -5 years with Membrane

Disadvantages

- Short Term Approach
- Overall Corrosion Problem not Addressed
- Long Term Cost and Disruption may be High


30
MPH
30
MPH

Block or Strip Patch Repairs

Advantages

- Higher Initial Cost
- Overall Corrosion Problem Addressed
- Service Life 10 to 15 years

Disadvantages

- Short Term Approach
- Less Fast with some removal of Sound Concrete
- Long Term Cost and Disruption may be High

Full Depth and Alternative Repairs

Advantages

- Addresses Long term Symptoms
- Sustainable
- Lowest Long Term Cost
- Often Performance Based
- Service Life more than 25
- Service Life potential to more than 75 years

Disadvantages

- Higher Initial Cost
- May Require more Evaluation, Testing, Modeling
- Short Term Disruption may be High


3
C3

Historical Performance
Repair Service Life

1 - Patch and Seal	1- 3 yr.
2 - Patch & Membrane	3-5 yr.
3 - Strip Patch & Membrane	10-15 yr.
4 - Overlay	15-20 yr.
5 - Full Depth Slab Replacement	25+ yr.

Extending Service Life for Restoration

- Service Life Criteria
- Assessments of Deterioration
- Repair & Materials Alternatives
- Modeling and Cost Assessments
- Sustainability Assessments
- Potential for Innovations and Creativity
- Construction to Performance Requirements
- Commissioning
- Applications

Mechanisms of Protection

- Surface treatments
- Electrochemical/CP
- Patch
- Overlay

How do you know what value to assign protection and repair technologies?

“Evaluation of an Industry Suggested Protocol for Measuring the Performance of Reinforcing Steel Corrosion Mitigation Technologies for Concrete Repairs”

Contract No. R10PC80497

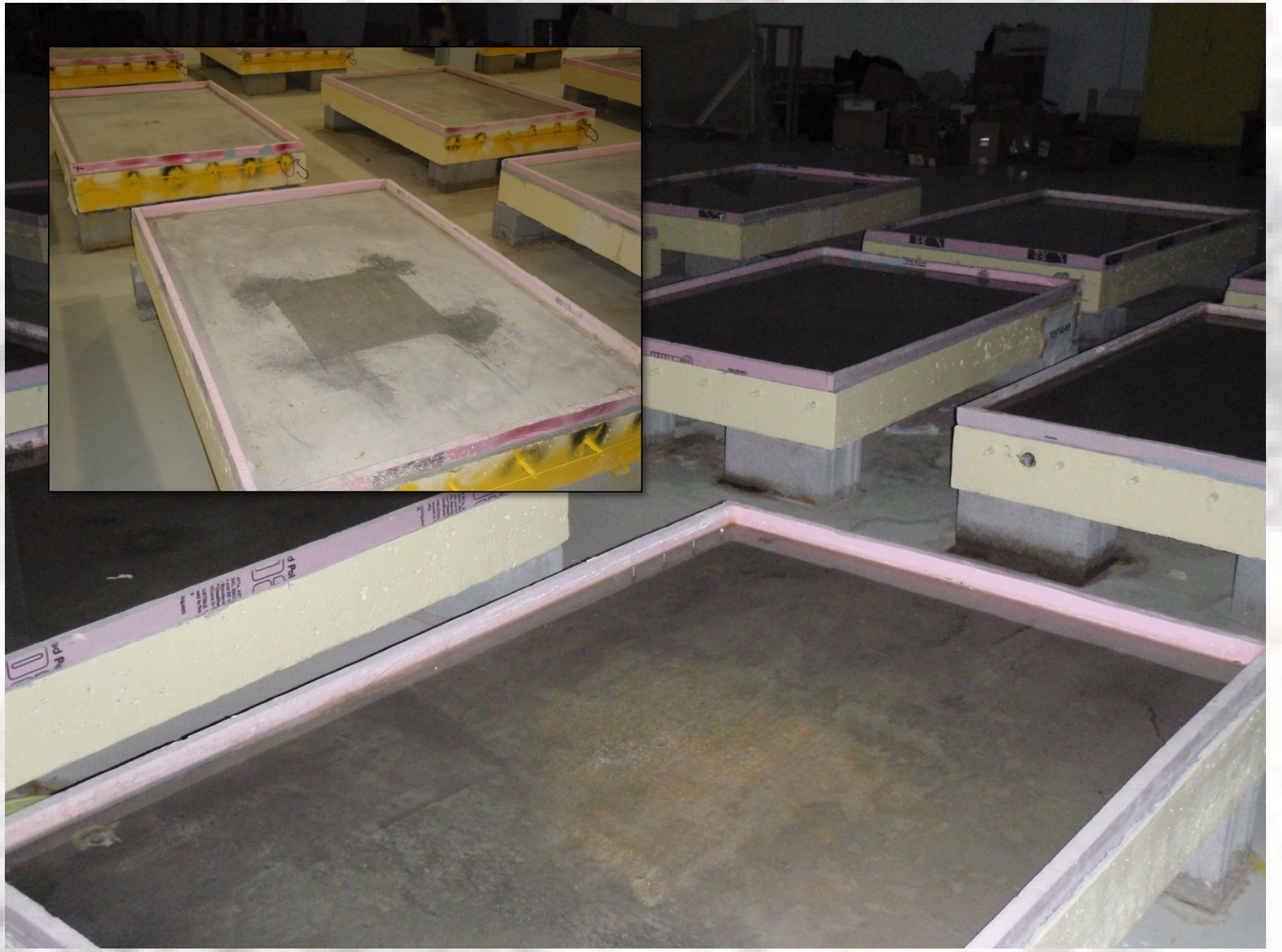
Contracted By:

Bureau of Reclamation (MERL)
Denver, CO

Contractor:

Tourney Consulting Group, LLC
Kalamazoo, MI


50 P(15)5
I150-LA40
40 P(10)5
I105-LA40
29-P9-I150
LA40




V34
V35

Thank You