Proactive Through-Life Management of Bridges

Presented by: Mike Bartholomew, PE
CH2M HILL

AASHTO Sub-Committee on Bridges & Structures Meeting
T-9 – Technical Committee for Bridge Preservation
T-18 – Technical Committee for Bridge Management, Evaluation & Rehabilitation
May 24-27, 2010
Sacramento, CA
Discussion Topics

- Current US Bridge Management Practice
- Proactive Through-Life Management
  - Service Life Design
  - Construction
  - In-Service Maintenance & Inspection
  - Rehabilitation & Preservation
  - Dismantling Plan
- Bridge Inventory Management Tools
  - Birth Certificate
  - Life Rating
- Planning, Funding & Sustainability
Why Am I Interested in Bridge Management?

- Unable to Adequately Respond to:
  - We’re designing bridges to last 75 years, aren’t we?
  - Design bridge for 100 year life span.
  - Explain how you will achieve the design service life of the structure.
  - We just need to get 5-10 more years of use. Design the repair for that.

- Pass What I’ve Learned on to Others
fédération internationale du béton (The International Federation for Structural Concrete)

– Writing new Model Code to include Service Life Design
– Publication of 1st draft scheduled for:

The Third International fib Congress & PCI Convention

– Washington, DC
– May 29 to June 3, 2010
Some key objectives of Commission

- Probabilistic performance based service life design.
- Inspection, assessment and performance monitoring.
- Development and validation of deterioration mechanisms.

Task Group 5.10: Through-Life Management
Through-Life Management

- Integrating All Stages in the Life of a Structure
  - Design
  - Construction
  - In-Service Maintenance & Inspection
  - Intervention (Repair & Rehabilitation)
  - Dismantling

- Future Oriented toward Sustainable, Life Cycle Thinking
Current US Bridge Management – Reactive Strategy

- Routine Inspections rely primarily on Visual Observations
- No deterioration observed
  - No actions taken
- Observed deterioration
  - In-depth inspection
  - Assessment to determine repair type
  - Repairs based on available funds
Disadvantages of Reactive Strategy

- When deterioration is observed on surface, the degree of damage is well advanced
- Possibility for intervention with preventative maintenance has passed
- Repairs are extensive and expensive
Disadvantages of Reactive Strategy

- Funding not readily available for unplanned repairs, resulting in...
- Delays in performing the needed repairs, which increases...
  - Cost
  - Negative Public Perception
- Prompts questions without good answers
A reflection upon problems and their solutions

“We can’t solve problems by using the same type of thinking we used when we created them!”

Albert Einstein
Proactive Bridge Management

- Based on knowledge of how materials deteriorate with time
- Monitoring performance against predicted behavior
  - through testing sufficiently in advance of initiation of visual damage
- Part of overall concept of Through-Life Management of Structures
Service Life Design Principles

- **Deterioration**
  - Materials deteriorate at a unique rate, depending on exposure conditions

- **Durability Resistance**
  - Function of quality of concrete cover
  - Cover depth over reinforcement
Deterioration Models

Deterioration Models / Limit States

Events related to the service life.

- **1** Depassivation
- **2** Cracking
- **3** Spalling
- **4** Collapse

Initiation → Propagation
Service Life Design Procedure

- Establishing Life Expectancy
- Identifying
  - Environmental Exposure Conditions
  - Deterioration Mechanisms
  - Material Resistance to Deterioration
- Establishing Mathematical Modeling Parameters to Predict Deterioration
- Setting Acceptable Damage Limits
Service Life (Durability) Design


- Establishes design procedures
  - to Resist Deterioration
  - from Environmental Actions
  - by Mathematical Modeling
Establishing Life Expectancy

- 50, 75, 100, 150 years...

- Expected Service Life is based on
  - Owner’s desires and expectations

- Actual Service Life will depend on
  - Exposure conditions of structure
  - Quality of materials, design and construction
  - Level of maintenance performed
Exposure Conditions
Deterioration Mechanisms

- Reinforced Concrete
  - Chloride Induced Corrosion (Seawater, de-icing salts)
  - Carbonation Induced Corrosion (Normal CO₂ from atmosphere and RH from 60% to 80%)
Chloride Induced Corrosion Models

- **Fick’s 2\textsuperscript{nd} Law Models Time to \textit{Initiate} Corrosion in Uncracked Concrete (Cracks < 0.3 mm or 0.012\textquotedbl)\)**

\[
C(x, t) = C_0 + (C_s - C_0) \cdot \left(1 - \text{erf}\left(\frac{x}{2 \cdot \sqrt{D_{\text{app,C}} \cdot t}}\right)\right) \leq C_{\text{crit}}
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>C(x,t)</td>
<td>Chloride concentration at depth &amp; time</td>
<td>kg/m\textsuperscript{3}</td>
</tr>
<tr>
<td>x, t</td>
<td>Depth from surface / time</td>
<td>mm, yr</td>
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<tr>
<td>\text{erf}</td>
<td>Mathematical error function</td>
<td>-</td>
</tr>
<tr>
<td>C_{\text{crit}}</td>
<td>Critical chloride content (to initiate corrosion)</td>
<td>kg/m\textsuperscript{3}</td>
</tr>
<tr>
<td>C_0</td>
<td>Initial chloride content of the concrete</td>
<td>kg/m\textsuperscript{3}</td>
</tr>
<tr>
<td>C_s</td>
<td>Chloride concentration at surface</td>
<td>kg/m\textsuperscript{3}</td>
</tr>
<tr>
<td>D_{\text{app,C}}</td>
<td>Apparent coefficient of chloride diffusion in concrete</td>
<td>mm\textsuperscript{2}/yr</td>
</tr>
</tbody>
</table>
New Design Considerations

- Exposure Classes & Parameters
- Specifying Material Durability Properties
  - Concrete Coefficient of Chloride Diffusion (permeability)
  - Reinforcement Critical Chloride Content
- Defining Maintenance & Inspection Schedule & Work Items
Example Service Life Designed Structures

- Confederation Bridge, PEI, Canada
  - 100 yrs – completed 1997
Confederation Bridge Design

Exposures 2-4
Tidal, Splash & Spray Zones (most critical)

\[ C_s, \text{ Chloride Concentration at Surface} = 17.7 \text{ kg/m}^3 \]
Confederation Bridge Design

- **High Performance Concrete (HPC)**
  - Cement 400 kg/m$^3$
  - Silica fume 50 kg/m$^3$
  - $D_{app,c}$, Apparent Coeff. of Chloride Diffusion $= 4.8 \times 10^{-13}$ m$^2$/sec $= 15.1$ mm$^2$/yr
  - $C_0$, Initial Chloride Content $= 0$ kg/m$^3$

- **Plain Reinforcing (with electrical connectivity for possible future cathodic protection)**
  - $C_{crit}$, Critical Chloride Content $= 0.4\%$ of cement $= 1.6$ kg/m$^3$
Chloride Content vs. Time – at Various Cover Depths

Chloride Content, kg/m³

Time, yrs

50 mm

75 mm

100 mm

C_{crit}
Chloride Content vs. Depth – at Various Structure Ages

Chloride Content, kg/m$^3$

Depth, mm

$C_{crit}$

$C_s$

10 yr

50 yr

100 yr

120 yr
Construction

- Most important stage for achieving the target service life of structure
- Deviations from intended design parameters are inevitable
- Documentation of actual constructed material properties and geometry – Birth Certificate
Construction Monitoring Issues

- Concrete Cover Mapping
  - Cover Meters
  - Pachometers

- Concrete Durability Property Testing
Concrete Durability Testing

- Bulk Diffusion Test (ASTM C1556)
- Rapid Chloride Permeability Test (RCPT) - AASHTO T 277 (ASTM C1202)
- 90 Day Salt Ponding Method - AASHTO T 259 (ASTM C1543)
- Rapid Migration Test (RMT) - AASHTO TP 64-03
In-Service Planning

- Maintenance, Inspection and Monitoring Tasks and Schedules established during design
- Tailored specifically to the structure
- Creates awareness for potential damage susceptible details
In-Service Maintenance Plan

- Written Plan defining routine tasks
  - flush drainage piping
  - remove vegetation
  - etc.
- Identifies schedule for replaceable or serviceable items
  - Expansion Joint Seals
  - Coatings & Sealers
In-Service Maintenance Plan

- Flexible for modifying Activities & Schedule based on observed performance
Inspection & Monitoring Plan

- Initial (End of Construction)
  - Birth Certificate documentation
- Routine Inspections (current ~ 2 yrs)
- Special Inspections (Scour, FCM)
- Damage (EQ, Flood, Fire, Collision)
- In-Depth Monitoring (~ 10-20 yr)
  - Chloride penetration tests
  - Depth of Carbonation tests
In-Depth Monitoring Plan

**Chloride penetration tests**

```
Chloride Content, kg/m³

10 yr  50 yr  100 yr  120 yr

C_{crit}

* - actual (10 yr)
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Life Rating

- Compares actual behavior against performance anticipated in design
- Facilitates on-going (through-life) evaluation of remaining service life
Intervention

**Scheduled Major Repairs**
- Components not economically feasible to achieve full service life
  - Deck Overlay
  - Deck Replacement

- Implement pre-planned Cathodic Protection system

- Chloride Extraction Techniques
Dismantling

- Final Step in Through-Life Plan
- Structures designed for 75+ yrs service life will outlive designers
- Provide opportunity to capture designer’s knowledge
Dismantling

- Demolition Plan should identify
  - List of Hazardous Materials used
  - List of Recyclable Materials used
  - Material Disposal Strategies
  - Special Demolition Details required
    (Post-tensioning)
  - Details to Maintain Structural Stability
    (Falsework)
  - Future Replacement Strategies
Service Life Stages

Fig. 2-1: Complete service life from birth to death, adapted from [28]
Sustainability / Future Planning

- **Sustainability 101**
  - Promotes making structure inventory last longer

- **Planning**
  - Knowledge of when structure will be rehabilitated or taken out of service
  - Allows better scheduling of funding needs
What is Needed to Implement a Through-Life Design Process?

- Further Development of
  - Deterioration Models (especially for Propagation phase)
  - Limit States for Acceptable Damage (including critical chloride content)
- Creating Design Examples / Workshops
- Transfer Concrete Service Life Design Process to Steel and Other Materials
- Get the Attention of FHWA & AASHTO State Bridge Engineers
Through-Life References


- Short version published in Structural Concrete, Volume 10, nos. 2-3, (2009)
Through-Life References

- **fib Bulletin 51** – Structural Concrete Textbook on behaviour, design and performance (2010)

- **fib Bulletin xx** – Condition control and assessment of reinforced concrete structures (2010 ?)
Concluding Remarks

- **Service Life Design & Inventory Management**
  - Addresses the whole life of the structure
  - Requires a new proactive mindset for the industry
  - Has huge potential for predicting the future health, safety, and allocation of funding of our infrastructure

- **Process in its Infancy**
  - Better prediction tools need to be developed
  - But, we need to start somewhere
Questions?

Thank you