Designing For 100 Year Service Life:
Integrating Durability and Structural Design

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Agenda

• Introduction
• *fib* Bulletin 34 Model Code for Service Life Design
  – Case Studies
    • The New NY (Tappan Zee) Bridge
    • Ohio River Bridges: Downtown Crossing
• Conclusion
Service Life Challenges for Infrastructures

• Structural concrete:
  – A universal building material
  – A possible universal building problem
• Severe environmental exposures
• Reactive materials
• Poor structural detailing
• Premature degradation leads to:
  – Loss of serviceability
  – Increased operations and maintenance costs
  – Premature end of service life
How is service life currently considered?

- **Structural design standards:**
  - Do not specifically account for service life
  - Fail to quantify durability limit states

- **Codes and standards as design basis:**
  - Assumed life is typically 75 years
  - Take no account of specific environment
  - Take no account of specific material properties
  - Make no use of deterioration models
  - No metric to quantify durability
  - Knowledge base is 10-30+ years
  - "Deemed to satisfy rules"
Solutions?

• Performance and design requirements that owners and designers can use
• Service life design using a rational probabilistic approach
• Transform subjective concept of "durability" into a actual design methods and tools for designers that permit optimization of design for service life
• Further improvements in understanding of:
  • environmental loadings – exposure
  • service life resistance - deterioration mechanisms
  • modeling methods for deterioration
• Optimization of life-cycle costs
**fib Bulletin 34 Model Code for Service Life Design**

- Written and distributed by the International Federation of Structural Concrete (fib)
- A reliability-based service life design methodology for concrete structures
  - Similar to Load-Resistance Factor Design
- ISO 16204:2012 Service Life Design of Concrete Structures
• All degradation mechanism addressed with 1 of 2 strategies
• Avoidance approach applied for:
  – Carbonation-induced corrosion
  – Sulfate attack
  – DEF
  – AAR
  – Freeze/thaw degradation
• Full probabilistic approach for:
  – Chloride-induced corrosion
1. Define exposure zones and degradation mechanisms
2. Select limit state
3. Design Parameters
   - Materials
   - Concrete quality
   - Concrete cover
4. Project Specifications
5. Construction → pre-testing and production testing
New NY Bridge (Tappan Zee)

• **Project description**
  – Total length: 16,013 ft.
  – Main span length: 1,200 ft.

• **B&T’s role**
  – Structural design for the main span bridge
  – Corrosion Protection Plan for the main span bridge and approach span bridges
  – Operations and maintenance planning
  – Structural health monitoring system design
  – Ship impact assessment

• **Project requirements**
  – 100-year service life before major maintenance for non-replaceable components
1. Define exposure zones and degradation mechanisms
2.) Select limit state
   – Depassivation of reinforcement marks end of service life
   – Occurs when critical chloride threshold is reached at reinforcement
   – Serviceability limit state:
     • 10% probability that corrosion will initiate within the service life
     • 90% probability that it will not!
3.) Design Parameters

- Depassivation of reinforcement marks end of service life
- Fick's 2nd law-based model provides time, depth where critical chloride threshold reached
- Probabilistic consideration of cover thickness ($d_c$), critical chloride threshold
- All input are probabilistic variables.
## Service Life Assessment

### 3.) Design Parameters

### 4.) Input in Project Specification

<table>
<thead>
<tr>
<th>Exposure Zone</th>
<th>Structural Element</th>
<th>Mix 1</th>
<th>Mix 2</th>
<th>Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nominal cover</td>
<td>Max. w/cm</td>
<td>Max. mean Chloride Migration Coefficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[in]</td>
<td>[\text{-}]</td>
<td>$D_{28} \times 10^{-9}$ [in$^2$/s]</td>
</tr>
<tr>
<td>De-icing salt spray</td>
<td>Towers, pier caps, abutments</td>
<td>3.0</td>
<td>14.1</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>Deck</td>
<td>0.40</td>
<td>11.3</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>Concrete barriers</td>
<td>2.75</td>
<td>12.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Atmospheric</td>
<td>Towers, pier caps, pier columns</td>
<td>3.0</td>
<td>15.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Splash</td>
<td>Towers, pier caps, pier columns</td>
<td>3.0</td>
<td>15.0</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Pile caps</td>
<td>4.0</td>
<td>9.9</td>
<td>12.0</td>
</tr>
<tr>
<td>Submerged</td>
<td>Concrete plug for piles</td>
<td>2.5</td>
<td>15.0</td>
<td>5.8</td>
</tr>
</tbody>
</table>
5.) Construction → Pre-testing and production testing
   - fib Model Code is based on NT Build 492: Rapid Chloride Migration Test
     • measure the migration coefficient of concrete at 28 days
     • direct input parameter

![Diagram with labels](image)

- a: rubber sleeve
- b: solution of 0.2 M KOH
- c: anode (stainless steel)
- d: concrete specimen
- e: solution of 3-10% NaCl in 0.2 M KOH
- f: cathode (stainless steel)
- g: plastic support
- h: container
• **Project description**
  – Interstate 65 corridor Kentucky-Indiana
  – Total length: 2,106 ft.

• **B&T's role**
  – Structural design for the main span bridge
  – Corrosion Protection Plan for the main span bridge

• **Project requirements**
  – 100-year service life for non-replaceable components
How does this concrete durability study affect the structural design?

- Quantifiable requirements for the concrete quality
- Concrete cover
- Type of reinforcing steel

<table>
<thead>
<tr>
<th>Ohio Structural Element</th>
<th>Originally Planned</th>
<th>Analysis Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile caps</td>
<td>2.5 inch Epoxy bars</td>
<td>2.0 inch Black bars</td>
</tr>
<tr>
<td>Tower leg exterior</td>
<td>1.5 inch Epoxy bars</td>
<td>2.0 inch Black bars</td>
</tr>
<tr>
<td>Barriers (front face)</td>
<td>2.5 inch Epoxy bars</td>
<td>2.75 inch Black bars</td>
</tr>
</tbody>
</table>
What about the non-concrete elements?

- Structural steel
  - No deterioration models available
  - Use of coating systems
    - ISO, NACE, and other documentation to help quantify the time to a full overcoat depending on the exposure conditions and type of coating system
    - Use of sacrificial thickness
      - ISO and other documentation to help quantify the sacrificial thickness depending on the exposure conditions
  - Selection of alternative materials, resistant to corrosion in the prevailing exposure conditions
- Replaceable structural components such as bearings, joints, stay cables, drainage pipes, access equipment, etc.
  - No deterioration models available
  - Rely on best practices, past experience, and manufacturers recommendations
How can one implement service life design?

- First-time implementation provides greater value on a **new** structure located in a **typical/common** environment
  - Characterize the local environment
    - Study is transferable to other structures exposed to a similar environment
  - Address service life requirements for all key components:
    - Non-replaceable components: foundations, substructure, superstructure
    - Replaceable components: joints, bearings, barriers
  - Solid base for technical and practical knowledge
    - Build knowledge and understanding through a typical case, then expand to tackle more complex problems (existing structures and rehabilitation, use of non-conventional materials)
  - Increased understanding will benefit the RFP process of future projects
    - Know what you need and what to ask for
Conclusion

• Owners and designers need a modern service life design standard, current North American design standards are lacking
• Scientific approach to quantify service life
  – fib Bulletin 34 / Probability-based mathematical modelling
  – Environmental loads and materials resistances
  – Defined durability requirements
• First-time implementation on a new structure in a typical environment provides greater value
• Durability requirements integrated into structural design, construction, operations & maintenance
Questions?

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