SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

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

May 2015

Anne-Marie Langlois, P.E.
Don Bergman, P.E.
Brad J. Pease, Ph.D.

U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Agenda

- Introduction
- *fib* Bulletin 34 Model Code for Service Life Design
- 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

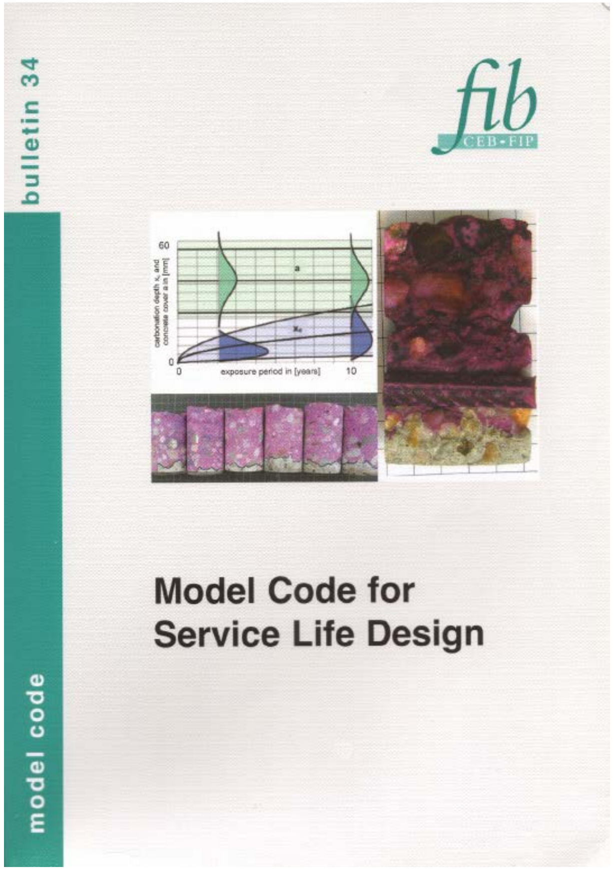
- Codes and standards as design basis:
  - Assumed life is typically 75 years
  - Take no account of specific environment
  - Take no account of specific material properties
  - Make no use of deterioration models
  - No metric to quantify durability
  - Knowledge base is 10-30+ years
  - "Deemed to 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 structure
  - Similar to Load-Resistance Factor Design
- ISO 16204:2012 Service Life Design of Concrete Structures

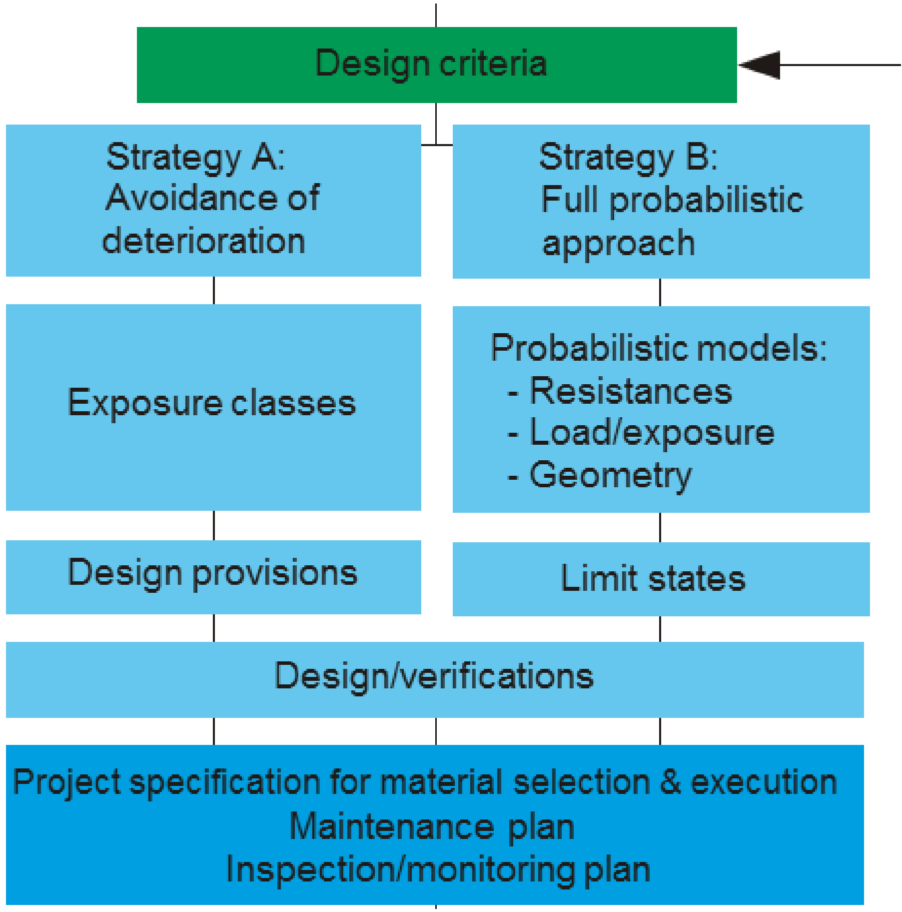


fib Bulletin 34 Model Code for Service Life Design

- 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



fib Bulletin 34 Model Code for Service Life Design Strategy - Probabilistic Analysis

1. Define exposure zones and degradation mechanisms

2. Select limit state

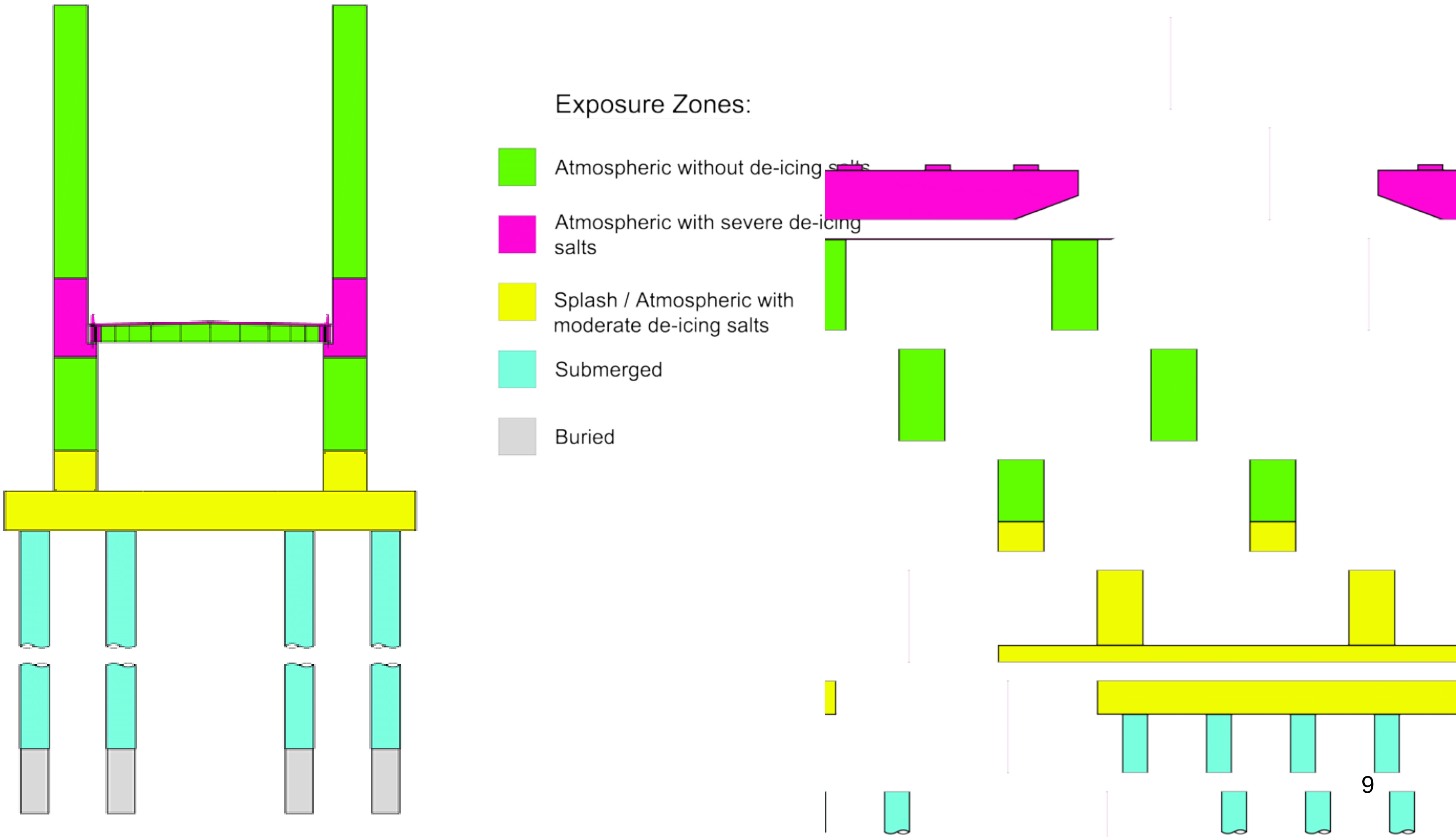
3. Design Parameters
   - Materials
   - Concrete quality
   - Concrete cover

4. Project Specifications

5. Construction → pre-testing and production testing

Service Life Assessment

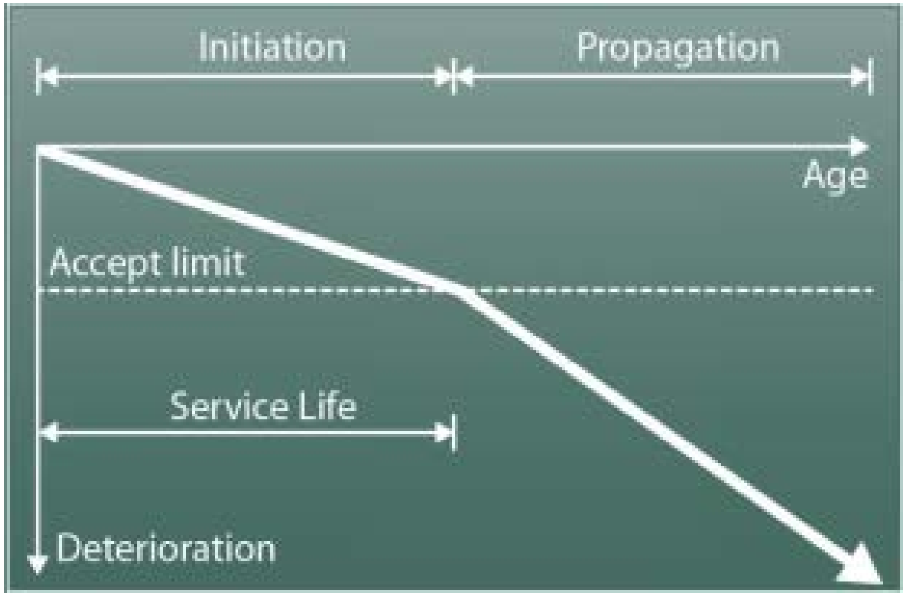
1. Define exposure zones and degradation mechanisms



Modelling Chloride-induced Corrosion

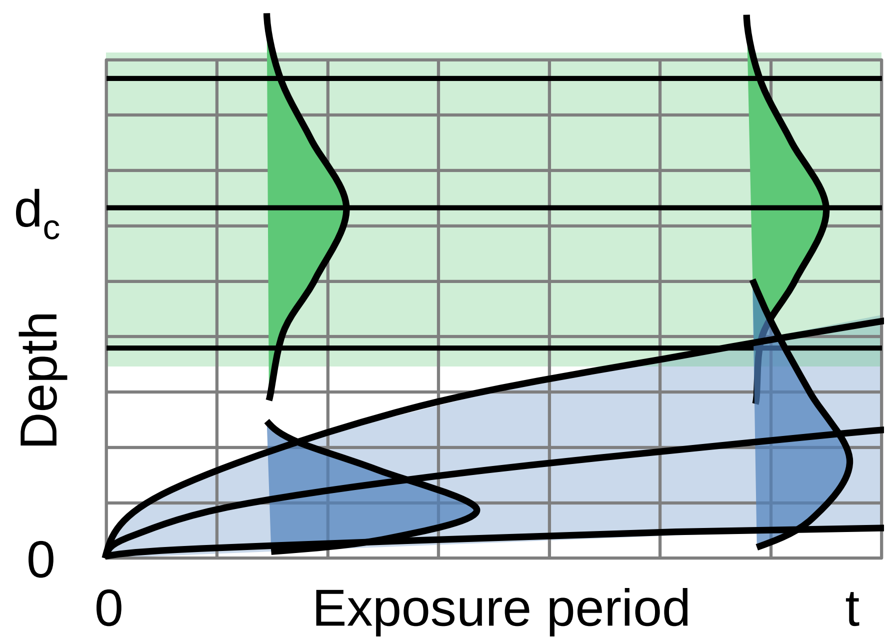
2. Select limit state

- 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!



Modeling Chloride-induced Corrosion

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

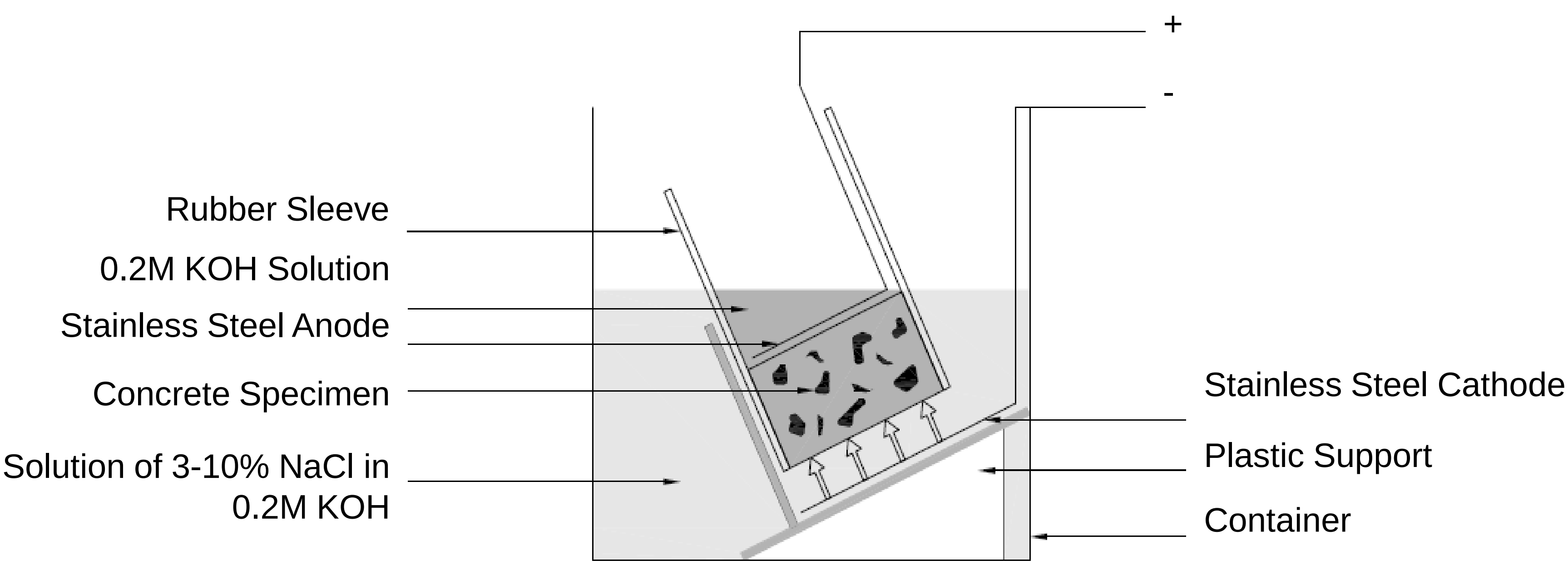
Exposure Zone	Structural Element	Nominal cover [in]	Max. w/cm [-]	Max. mean Chloride Migration Coefficient $D_{28} \times 10^{-9}$ [in^2/s] Mix 1	Mix 2	Mix 3
De-icing salt spray	Towers, pier caps, abutments	3.0	0.40	14.1	3.4	4.9
	Deck			11.3	2.7	4.0
	Concrete barriers	2.75		12.4	3.4	4.6
Atmospheric	Towers, pier caps, pier columns	3.0	0.40	15.0	11.0	12.0
Splash	Towers, pier caps, pier columns	3.0	0.40	15.0	5.1	7.1
	Pile caps	4.0			9.9	12.0
Submerged	Concrete plug for piles	2.5	0.40	15.0	5.8	8.3

Service Life Assessment

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



How does this concrete durability study affect the structural design?

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

Structural Element	Originally Planned	Analysis Results
Pile caps	2.5 inch Epoxy bars	2.0 inch Black bars
Tower leg exterior	1.5 inch Epoxy bars	2.0 inch Black bars
Barriers (front face)	2.5 inch Epoxy bars	2.75 inch Black bars

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?

- Anne-Marie Langlois amln@b-t.com
- Don Bergman dwb@b-t.com
- Brad Pease brpe@b-t.com