



SHRP2 SOLUTIONS

STRATEGIC HIGHWAY RESEARCH PROGRAM

Concrete Deterioration Mechanisms

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AASHTO

TRANSPORTATION RESEARCH BOARD
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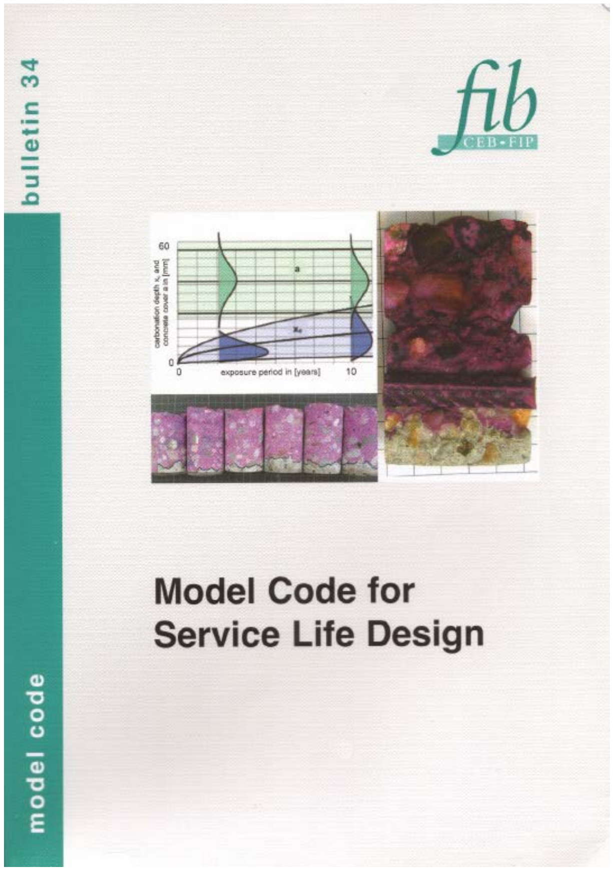
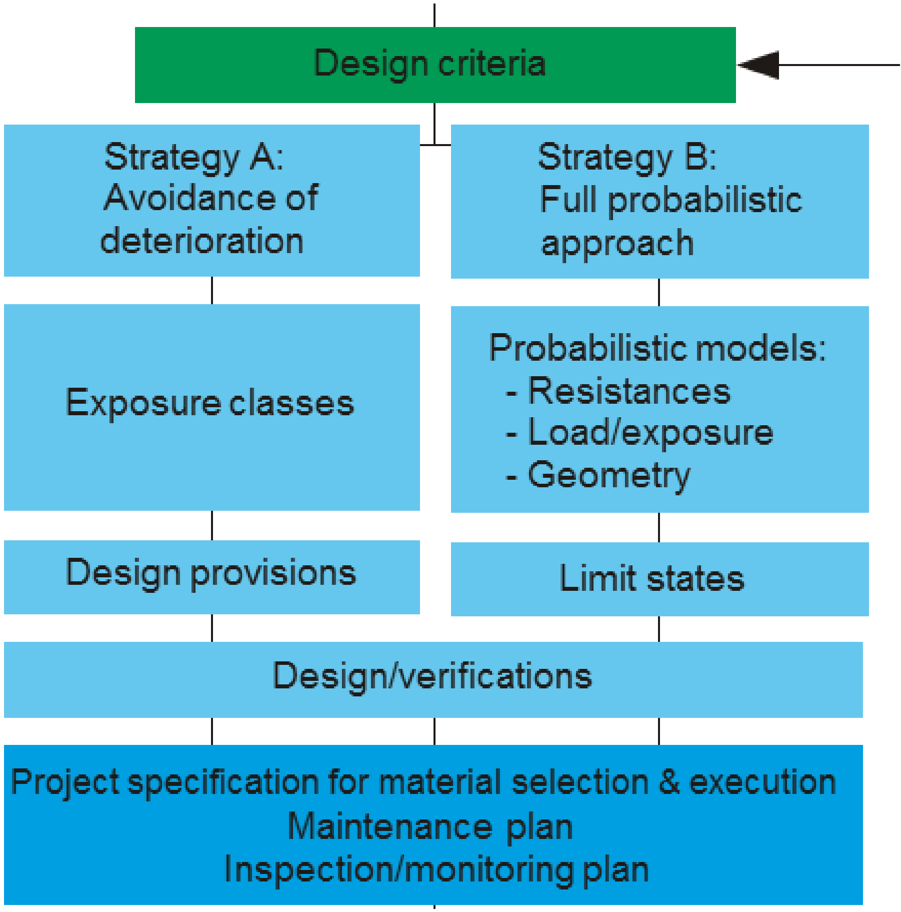
fib Bulletin 34 Model Code for Service Life Design

- 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



Carbonation-Induced Corrosion

- Carbon dioxide from air penetrates the concrete and reacts with calcium hydroxide to form calcium carbonate
- Slow and continuous process that lowers the alkalinity of the concrete
- Leads to uniform corrosion around the steel reinforcement and usually develops later and at slower rates than chloride-induced corrosion
- Mitigation methods similar than for chloride-induced corrosion
  - low permeability concrete
  - increased concrete cover
- Mitigation for chloride-induced corrosion are sufficient to prevent carbonation

Sulfate Attack

- Portland cement with a moderate to high tricalcium aluminate (C3A) content is used in concrete in contact with sulfate bearing soil or groundwater
- Effects include extensive cracking, expansion, loss of bond between the cement paste and aggregates, and alteration of the paste composition which will cause an overall loss of the concrete strength
- Mitigation methods include using Portland cement with a low C_3A content, providing a concrete with low permeability and a low water-cement ratio, and the use of supplementary cementitious material
- CSA A23.1 and ACI 318 provide guidelines

Alkali-Aggregate Reaction

- Alkali aggregate reaction (AAR) is a chemical reaction between certain minerals such as reactive, non-crystalline silica present in some aggregates and the alkalis present in the concrete
- Cause expansion and cracking of the concrete
- Mitigation methods include selection of non-reactive aggregates as determined by standard test methods, use of low alkali cement (<0.6% equivalent Na_2O) and supplementary cementitious materials
- AASHTO PP65 and CSA A23 proposes mitigation methods based on:
  - the level of reactivity of the aggregates
  - the protection level required

Alkali-Aggregate Reaction

- Level of reactivity of the aggregates:

Aggregate-Reactivity Class	Description of Aggregate Reactivity	One-Year Expansion in CPT (%)	14-Day Expansion in AMBT (%)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	$> 0.04, \leq 0.12$	$> 0.10, \leq 0.30$
R2	Highly reactive	$> 0.12, \leq 0.24$	$> 0.30, \leq 0.45$
R3	Very highly reactive	> 0.24	> 0.45

Alkali-Aggregate Reaction

- Risk level:

	Aggregate-Reactivity Class			
Size and exposure conditions	**R0**	**R1**	**R2**	**R3**
Non-massive[2] concrete in a dry[3] environment	Level 1	Level 1	Level 2	Level 3
Massive[2] elements in a dry[3] environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service[4]	Level 1	Level 4	Level 5	Level 6

Alkali-Aggregate Reaction

- Prevention level:

	Classification of Structure (Table 4)			
Level of ASR Risk (Table 2)	S1	S2	S3	S4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	††

- For each protection levels, mitigation methods are proposed such as:
  - limiting alkali content of the concrete
  - using supplementary cementitious materials

Delayed Ettringite Formation

- Form of internal sulfate attack which can occur in concrete cured at elevated temperatures.
- It can be affected by concrete composition, curing conditions and exposure conditions.
- Mitigation methods through proper temperature control during concrete placement and curing (i.e. max core temp = 150^{o}F to 160^{o}F)
- Guidelines in most construction specs by limiting maximum temperature requirements
- Thermal Control Plan

Delayed Ettringite Formation

http://www.fhwa.dot.gov/publications/transporter/04jul/index.cfm

http://civildigital.com/significance-delayed-ettringite-formation-damage-mechanisms/1typicaldamage/

Freeze-Thaw Degradation

- Freeze-thaw cycles can cause deterioration when the concrete is critically saturated: the water in the pores freezes to ice and expands.
- Typical signs of freeze-thaw damage include cracking, spalling and scaling of the concrete surface and exposure of the aggregates.
- Mitigation methods include air entrainment and freeze-thaw resistance aggregates
- ACI 318 and CSA A23.1 provide guidelines

Scaling

- Additional precautions may be required if exposure to deicing salts: scaling can occur.

Scaling

- Scaling resistance of concrete surfaces exposed to deicing chemicals
  - ASTM C672
  - Test duration: 50 days after a 28 day cure
  - Test known to be very severe
  - Test result is a visual rating (subjective?)

Rating	Condition of surface
0	No scaling
1	Very slight scaling (3mm depth, max, no coarse agg. visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

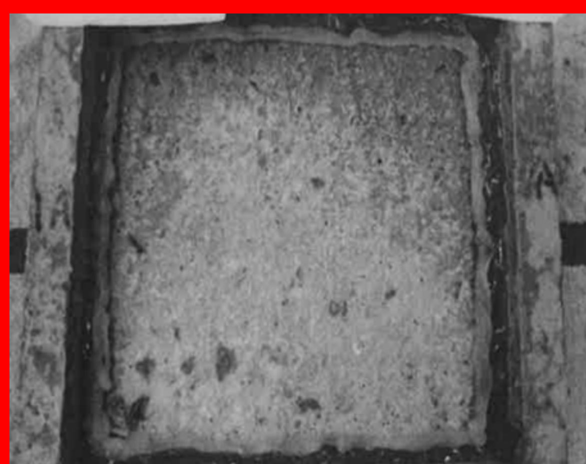
Scaling

Mix A

Passed

Mix B

Fail



Scaling

- How could we improve this situation?
  - Add a quantitative requirement to the ASTM C672:
    - ex: maximum of 0.5 kg/m^2 of mass loss
  - Use an alternative test
    - measurable requirement
    - better correlation to in-situ performance
    - CSA A23.2-22CCSA

Other

- Ice Abrasion
- Chemical attacks
- Often few guidelines exist
- Have to rely on past experience, conditions of existing structures in similar environments
- Engineering judgement

Developing Final Specifications

- Identify applicable deterioration mechanisms
- Identify mitigation measures for each deterioration mechanisms
- Develop comprehensive requirements that will sufficiently protect the concrete against all applicable deterioration mechanisms
  - Some mitigation methods are incompatible with each other or will make construction non-practical
  - Specialist's role to define comprehensive requirements that will consider all aspects of the work

Conclusion

- Multiple deterioration mechanisms exist for concrete structures
  - chloride-induced corrosion
  - carbonation-induced corrosion
  - delayed ettringite formation
  - alkali-aggregate reaction
  - freeze-thaw degradation
  - others (ice abrasion, chemical attacks, etc.)
- Most deterioration mechanisms cannot be modeled numerically
- Final Concrete Specifications:
  - consider all these deterioration mechanisms
  - comprehensive, not-conflicting

Questions?

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AASHTO SHRP2 R19A Website:
http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx

FHWA GoSHRP2 Website:
www.fhwa.dot.gov/GoSHRP2/