How Long Will Your Bridge Last?

- The Need to Predict Service Life of Bridge Components

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Western Bridge Engineer’s Seminar

Boise, Idaho

September 23-26, 2007

Introduction

- What are current US code requirements for expected service life for bridges?
- What is the standard of care in the industry?
- How do you predict service life?

Discussion Topics

- Design Life vs. Service Life
- Current US Code Durability Requirements
- Foreign Standards for Durability
- Need for Durability Design
- Durability Design Concepts
- Service Life Prediction Methods
- Durability Design vs. Structural Design
- Current US Research & Goals

Design Life vs. Service Life

- AASHTO LRFD Bridge Design Specifications – Section 1.2 – Definitions
  - Design Life – Period of time on which the statistical derivation of transient loads is based – 75 years for these Specifications.
  - Service Life – The period of time that the bridge is expected to be in operation.

LRFD Design Life vs. Service Life

- 75-Year prescribed Design Life is an indicator of structural safety & reliability.
- Service Life is an indicator of Durability.
- No expected duration for Service Life. No direct correlation between Design & Service Life.

Durability

- The power of resisting agents or influences which tend to cause changes, decay, or dissolution (Webster, 1913)
- Able to exist for a long time without significant deterioration (Merriam-Webster)
- (*Engineering*) The quality of equipment, structures, or goods of continuing to be useful after an extended period of time and usage.

What's a Reasonable Service Life?

- 50, 75, 100, 150 years, … more?
- 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

Service Life Designed Structures

- Great Belt Bridge, Denmark (100 years)

Service Life Designed Structures

- Confederation Bridge, Canada (100 years)

Service Life Designed Structures

- San Francisco – Oakland Bay Bridge (150 years)

AASHTO LRFD Durability Design Requirements

- 2.5.2.1.1 – The contract documents shall call for quality materials and for the application of high standards of fabrication and erection.
- C2.5.2.1.1 – The intent of this Article is to recognize the significance of corrosion and deterioration of structural materials to the long-term performance of a bridge.

AASHTO LRFD Durability Design Requirements

- 2.5.2.1.1 – Structural steel shall be self protecting or have long-life coating systems or cathodic protection.

AASHTO LRFD Durability Design Requirements

- C5.4.2.1 – There is considerable evidence that the durability of reinforced concrete exposed to saltwater, deicing salts, or sulfates is appreciably improved if, as recommended by ACI 318, either or both the cover over the reinforcing steel is increased or the W/C ratio is limited to 0.40.

AASHTO LRFD Durability Design Requirements

- 5.12.1 – Concrete structures shall be designed to provide protection of the reinforcing and prestressing steel against corrosion throughout the life of the structure....Protective measures for durability shall satisfy the requirements specified in Article 2.5.2.1.

AASHTO LRFD Durability Design Requirements

- Expectations for durability exist
- Code gives no guidance on how long a structure should remain in service
- No metrics to define if a durable design is achieved
- Lacks models for prediction of deterioration of structures

Foreign Standards for Durability

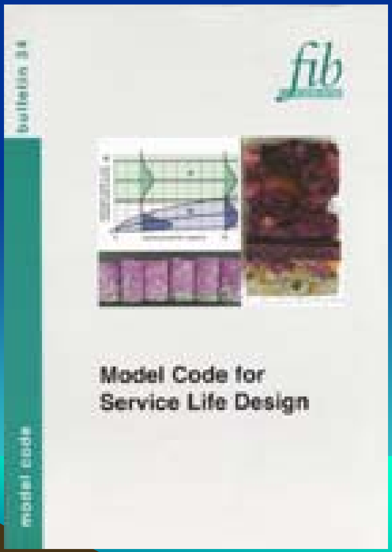
- British Standards, BS5400 – Design of Bridges
  – Design Life of 120 years has been required since 1988
    - Doesn't mean structure is no longer fit for its purpose after that period, or…
    - That it will continue to be serviceable for that length of time without maintenance
  – Like LRFD, there's not an expected service life requirement

Foreign Standards for Durability

- DuraCrete , General Guidelines for Durability Design and Redesign.
  - The European Union-Brite-EuRam III, Project No. BE 95-1347, "Probabilistic Performance based Durability Design of Concrete Structures", Report No. T 7-01-1, 1999.

Foreign Standards for Durability

- *fib* New Model Code
  - Special Activity Group 5 (SAG5) began update of 1990 CEB-FIP Model Code in 2004, and targeted for release in 2008
  - Incorporates integrated life cycle perspective
  - Structures will have:
    - Defined service life
    - Inspection & maintenance plan
    - Dismantling plan



Foreign Standards for Durability

- *fib* New Model Code
  - Contains mathematical deterioration models
  - Defines a service life design process

Need for Durability Design Requirements

- Purpose – To establish an Expected Service Life
- Safety – Defines when it is time to remove structure from service

Need for Durability Design Requirements

- Sustainability Goals
  – Reduce Maintenance & Life Cycle Costs
  – Conserve Resources
  – Re-direct Tax Dollars to other Important Public Needs
- Infrastructure Cost Planning Goals
  – Maintenance
  – Rehabilitation
  – Replacement

Need for Durability Design Requirements

- Assist Owner's in Evaluating Alternatives
  - Life Cycle Cost Analysis (LCCA) – example, Concrete vs. Steel design alternatives
  - Consultant Design Proposals
  - Design/Build Proposals
  - Specialty Products (Joints, Bearings & other Proprietary components)

Need for Durability Design Requirements

- AASHTO Subcommittee on Bridges & Structures
  - **Grand Challenges: A Strategic Plan for Bridge Engineering, June, 2005**
    - #1 – Extending Service Life (of existing structures)
    - #2 – Optimizing Structural Systems
      - Development of new materials… and procedures aimed at safety, durability and economy will help achieve … low maintenance, long-life structures.

Need for Durability Design Requirements

- FHWA Highways for Life Program
  - Status of the current highway system:
    - First, it's overcrowded.
    - **Second, it's not lasting as long as it should.**
    - We're not building them safe enough.
  - Goals of Highways for Life:
    - Improve safety during and after construction,
    - Reduce congestion caused by construction, and
    - **Improve the quality of the highway infrastructure.** *(By making it last longer.)*

Durability Design

- Iterative, Multi-Step Process
  - Identify Environmental Exposure Conditions
  - Define Expected Service Life
  - Select Materials, Details & Protective Systems
  - Determine Deterioration Mechanisms

- Concurrent with Structural Design

Site Exposure Conditions

- Aggressivity of Environment
  - Sea water
  - De-icing agents
  - Chemical attack
  - Wet / Dry cycles
- Temperature
  - Freeze / thaw cycles
  - Tropical (every +10º C doubles rate of corrosion)

Member Exposure Conditions

- Marine
  - Submerged, tidal, splash, atmospheric zones
- Geographic Orientation
  - N-S-E-W, seaward, landward
- Surface Orientation
  - Ponding, condensation, protection from wetting, corners

Member Exposure Conditions

- Deck Surfaces
  - Traffic volume, and use of chains & studded tires
  - Method of snow removal (de-icing agents and plowing)
  - Degree of Cracking from standard design loads and overloads

Protection Systems

- Material’s Own Ability to Resist Deterioration (Permeability)
- Protective Coatings
- Membranes & Overlays
- Cover (for Reinforced Concrete)

Deterioration

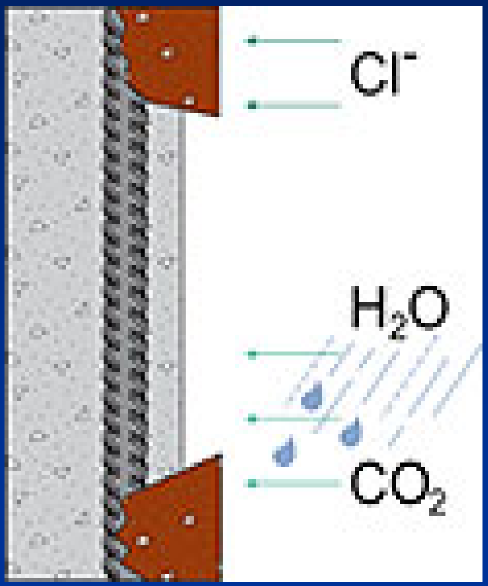
- Nothing lasts forever
- Every material deteriorates at a unique rate
- Deterioration rate is dependent on exposure conditions

Deterioration Mechanisms

- Moisture, Relative Humidity (99% of all deterioration involves water)
- Temperature
- Ultraviolet Radiation
- Traffic Abrasion

Deterioration Mechanisms

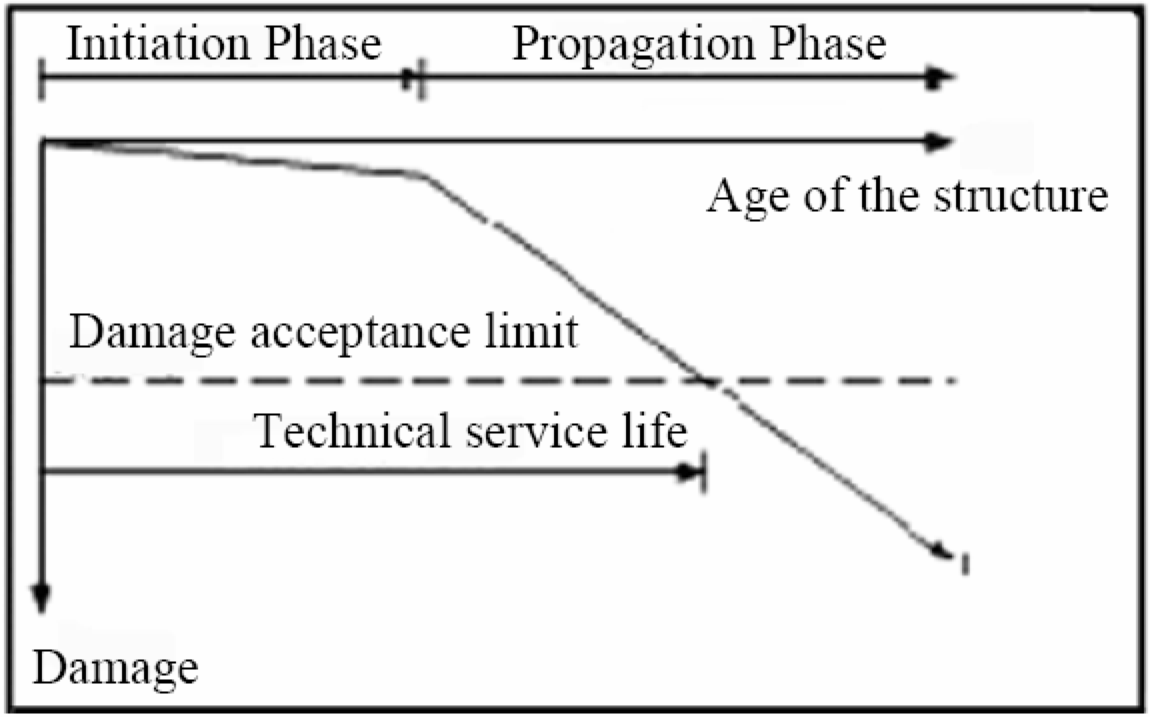
- Reinforced Concrete
  - Chloride Induced Corrosion (Seawater, de-icing salts)
  - Carbonation Induced Corrosion (Normal CO_2 from atmosphere)



Deterioration Mechanisms

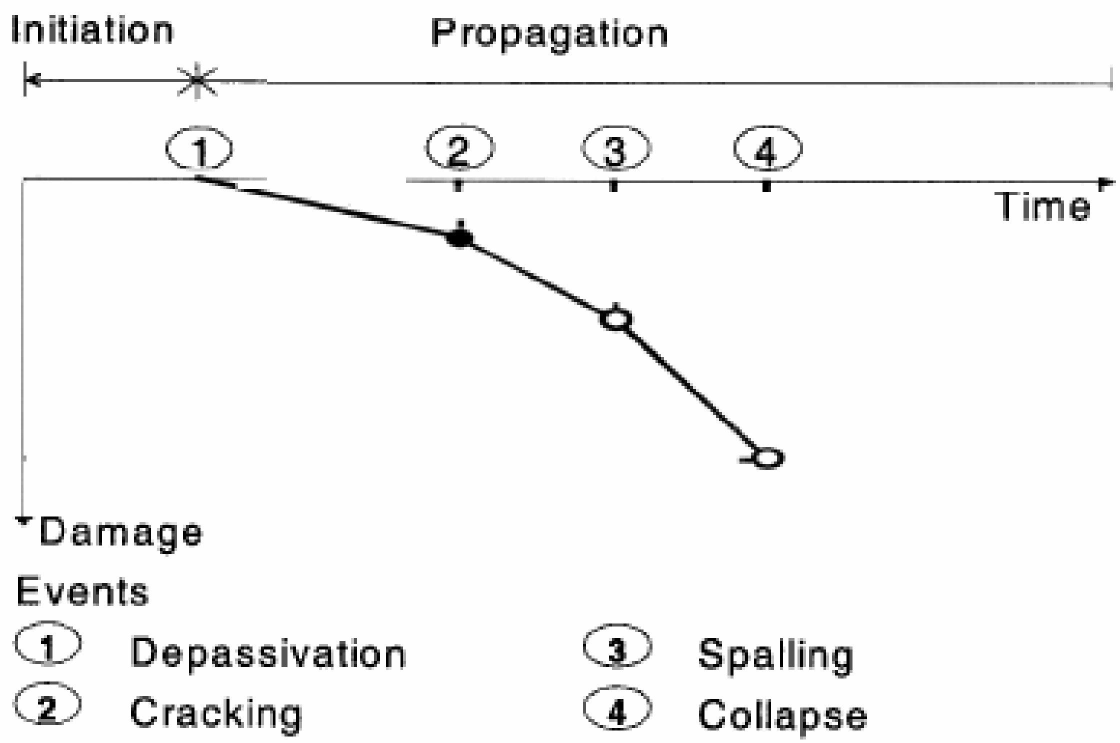
- Structural Steel
  - Breakdown of Coating Systems

Deterioration Models



Service life of concrete structures. A two-phase modelling of deterioration.
[Tuutti model (1982)]

Deterioration Models



Events related to the service life.

Chloride Induced Corrosion Models

- Fick's 2nd Law Models Time to Initiate Corrosion in Uncracked Concrete

$$C_{d,t} = C_o \cdot \left(1 - \mathrm{erf}\left(\frac{d}{2\sqrt{D_c \cdot t}} \right) \right)$$

$C_{d,t}$ – Chloride concentration at depth & time

D_c – Diffusion coefficient (permeability)

C_o – Chloride concentration at surface

d – Depth

t – Time

erf – Error function

Tools to Evaluate Service Life

- Computer programs
  - Life 365
  - Duramodel by W.R. Grace

- Analytical Procedures
  - DuraCrete
  - fib Model Code (in 2008)

Durability Design vs. Structural Design

- Exposure Conditions
- Exposure Factors
- Deterioration Protection
- Deterioration Factors

- Loads
- Load Factors
- Nominal Capacity
- Resistance Factors

Durability Design vs. Structural Design

- LRFD Structural Design Process can be replicated for Durability Design
- Both methods are reliability based

What is Needed to Implement a Process?

- Defining Environmental Exposure Conditions & Load Factors
- Further Developing Deterioration Models
- Defining Limit States for Acceptable Damage
- Create a Durability Design Procedure
- Get the Attention of FHWA & AASHTO State Bridge Engineers

Current US Research & Goals

- Strategic Highway Research Program (SHRP2)
  - Project R19-A, Bridges for Service Life beyond 100 Years: Innovative Systems, Subsystems, and Components (due September 18, 2007)
  - Project R19-B, Bridges for Service Life beyond 100 Years: Service Limit State Design (release date March 2008)

Summary

- Lots of Deterioration Model Research Available, but Lacks Standardization
- No Current US Code Requirements for Expected Service Life
- Durability Design Process is Non-existent in US
- Foreign Countries Embracing Durability & Service Life Design

Questions?

Thank you