Durability Design for Concrete Structures

A Review of International Building Codes

by

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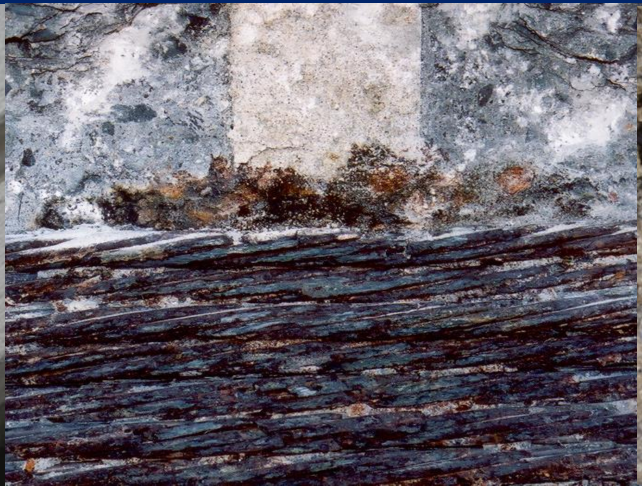



Overview

- Why the interest in Global Durability & Service Life Requirements?
- What is durability and service life?
  - How do you describe it?
  - Terminology around the world
  - Standards + Codes
- Process + Findings
- Recommendations

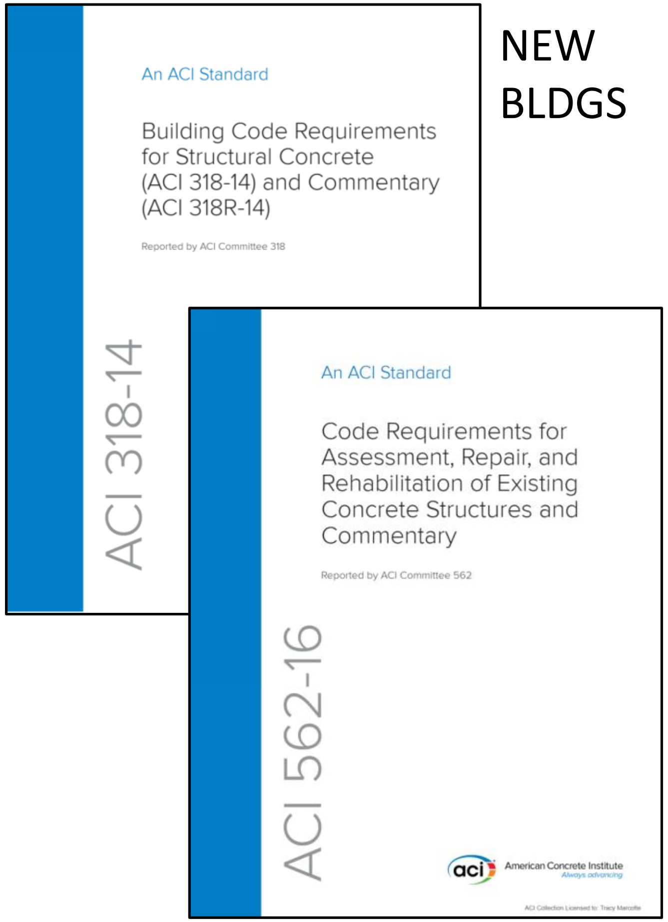
Durability Design - Review of Global Codes and Standards

- Assess durability provisions in concrete design
- Are ACI 318 provisions adequate?
- What can we learn from global colleagues?
- Are durability provisions being implemented successfully?

USA – Building Design

General Building Code (IBC / IEBC) → ASCE 7 (loads / load combinations) →

- Concrete code requirements are designed to plug into the general building codes
- ASCE 7 has loads and requirements indicating a 50 year return period
- NO GUIDANCE AVAILABLE TO ACHIEVE AND VERIFY DESIGN SERVICE LIFE

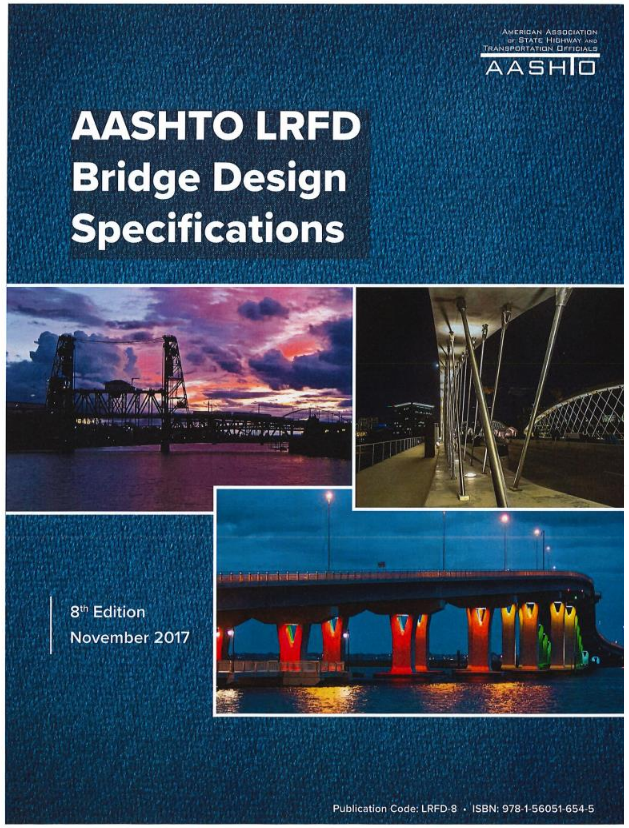


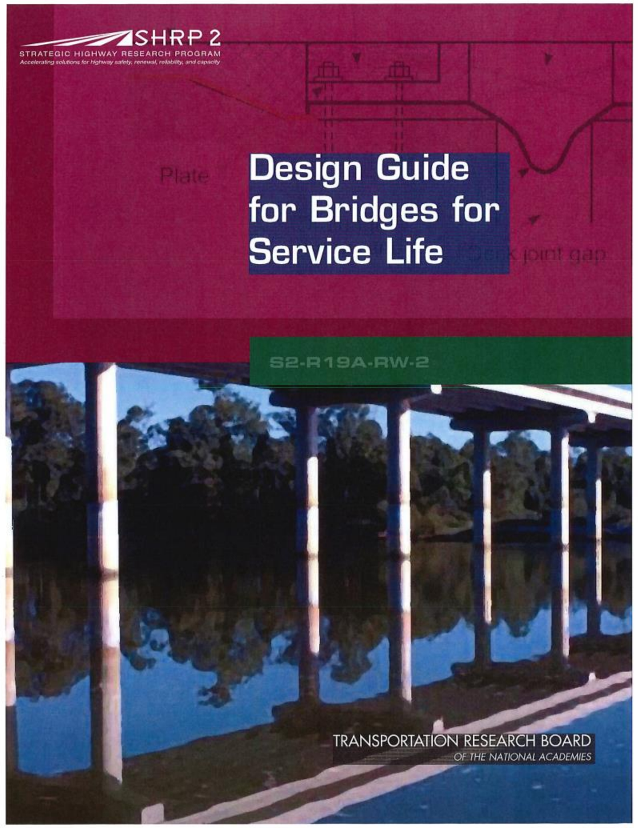
NEW BLDGS

EXIST BLDGS

USA – Bridge Design

- 75 year design service life requirement
- SHRP2 project helpful but still incomplete
- **No guidance as to how to get there or verify your choices**





What is wrong with US concrete design?

- Codes result in “least durable structure you are legally allowed to build”
  - Repair is an $18 to $21 billion dollar (US) business
- Focus on “structural” design in education
  - Service life is not considered
- ACI 318 lacks an integrated approach to durability
- End result?
  - Service life not achieved
  - Premature repair cycle
  - Lack of sustainability
  - Negative perception

Do we know how to design this for 100 years?

- University building
  - Concrete primary structure
  - Metal/glass curtainwall cladding
  - Exterior environment: conventional Philadelphia; no marine
  - Interior environment:
    - conventional comfort, 68-72°F; 15-30% RH winter; 25-55% RH summer
- ACI 318 OK?

CVM, Temple University - Morgan Hall, Philadelphia

100 year service life for this structure?

- Residential high-rise
  - Concrete primary structure
  - Lightweight concrete exoskeleton
  - Exterior environment: conventional **Miami** – HOT, HUMID, MARINE
  - Interior environment: conventional comfort, 68-72°F;
25-90% RH
  - **ACI 318 OK?**

"Undulating Exoskeleton"
Zaha Hadid, Miami
Photo courtesy of José A. Iglesias, Miami Herald, 2017

Origin of Durable Concrete Structures

- Durability – ability of a material or structure to survive in its service environment for a desired service life

- Achieved through design, construction, and operational maintenance
  - Design – strength, serviceability, durability
  - Construction – starting point to service life
  - Operational maintenance – how is structure maintained

- Service life
  - When does it end?
  - How is it defined?

Durable Concrete Structure Characteristics

- Constructed to promote drainage
- Limited number and width of cracks
- Low drying shrinkage
- Low permeability and high chloride penetration resistance
- Adequate air void system
- Suitable aggregates to prevent AAR
- Resistant to sulfate attack
- Redundant corrosion protection mechanisms

Multi-National (International) Codes/Standards

- International Codes
  - ACI 318 and 562
  - Eurocodes (EU members)
  - *fib* Model Code 2010
- International Standards
  - ASTM
  - EN
  - ISO
- National Codes
  - Australia
  - Canada
  - China
  - **Japan – JSCE 15, 16 and 17**

Overall Impressions

- Planning for durability - significant variation in practice
  - No planning (ACI 318)
  - Mandatory service life modeling
- Service life (varying definitions)
  - User defined (function of structure type)
  - Open ended (undefined)
- Design codes formats (vary widely)
  - Prescriptive
  - Performance-based
  - Hybrid
- Maintenance requirements (vary widely)
  - Not part of typical US practice (except ACI 562)

Key Attributes of Select Codes and Standards

Document	Design Service Life (excl. or ranges)	Modeling Requirements	Performance Metric Verification	Construction Requirements & QA/QC	Maintenance/Repair[1]
ACI 318	No	No	No	Yes	No
fib MC2010	To be specified by user	Yes	Yes	Yes	Yes
EN 206	To be specified by user	No	N/A – verification governed by EN 1990 and EN 1991-1-1	Yes	Yes
AS-3600	40-60 years	No		Yes	No
A23.1-14/A23.2-14	Yes, by reference to other Canadian stds	Yes, for special concretes.	N/A	Yes	No
JSCE Guidelines for Concrete No. 15	To be specified by user	No	Yes	Included as part of JSCE Guidelines for Concrete No. 16	Included as part of JSCE Guidelines for Concrete No. 17
JSCE Guidelines for Concrete No. 16	To be specified by user	No	Yes	Yes	Included as part of JSCE Guidelines for Concrete No. 17
AASHTO LRFD Design	75 years	No	No	No	No

Select Concrete Durability Requirements

Document	Prescriptive, Performance-based, or Hybrid	f'c	w/cm Ratio	Concrete Cover	Cementitious Materials Content	Air Content	Cement Type	Chloride Content Limits	Performance Requirements
ACI 318	Prescriptive, with select provisions containing performance alternatives	Yes	Yes	Yes	Yes	Yes	Yes	Yes	ASTM C1012 in lieu of sulfate exposure cement type restrictions.
fib MC2010	Hybrid—allows entirely prescriptive or entirely performance-based concrete classes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No specific requirements or methods listed.
EN 206	Hybrid – allows for entirely prescriptive or entirely performance-based concrete classes	Yes	Yes	No	Yes	Yes	Yes	Yes	No specific requirements or methods listed.
AS-3600	Typically prescriptive but allows for one concrete class to be entirely performance-based	Yes	No	Yes	No	Yes	No	Yes	Class U concrete properties are specified by the user "to ensure durability under the particular exposure environment."
JSCE Guidelines for Concrete No. 15	Performance limit states, with informative prescriptive means by which the performance requirements can be met	No	No	No	No	No	No	No	All durability requirements are performance-based.
JSCE Guidelines for Concrete No. 16	Performance limit states, with informative prescriptive means by which the performance requirements can be met	No	Max. 0.65	No	No	Limited to assume air-entrainment	No	Limited to max. 0.3 kg/m^3	All durability requirements are performance-based, with limited max requirements.
AASHTO LRFD Design	Typically prescriptive, with some performance classes	Yes	Yes	Yes	Yes	Yes	Yes, by reference to other AASHTO stds	Yes, by reference to other AASHTO stds	As specified by user

Common Features (not in ACI Documents)

- Durability planning as a multi-discipline process
- Extensive consideration of cracking / crack width
- Service life modeling as predictive tool
- Requirements varying with design service life
- Performance-based requirements for concrete materials
- Maintenance considerations

Durability Planning

- Australia - CIA Z7/01
  - Comprehensive guide for durability planning
  - Recognizes need for integration of design details and durability
- Canada – CSA S478
  - Durability and design service life concepts addressed
- JSCE No. 15 and 16
  - Treat durability as a process with limit states and verification steps
- ISO
  - Multiple documents on durability planning with respect to service life
- ACI
  - Not covered in a comprehensive manner

Service Life Modeling

- Typically not part of codes and specifications
- United Facilities Guide Specification (UFGS–03 31 29)
  - Mandatory use
  - Proprietary software specified
- JSCE 15 and *fib* model code
  - Performance limit states
    - Verify chloride / carbonation levels at the end of service life
- ACI 365
  - Developing a standard procedure for service life modeling

Cracking

- JSCE 15
  - Crack width as function of environment and cover

Table 8.3.2 Limit value of crack width w_a

Type of reinforcement	Environmental conditions for reinforcement corrosion		
	Normal	Corrosive	Severely corrosive
Deformed bars and plain bars	$0.005c$	$0.004c$	$0.0035c$
Prestressing steel	$0.004c$	----	----

- ACI 318
  - No longer directly considered
  - Reinforcement spacing limits

Design Service Life

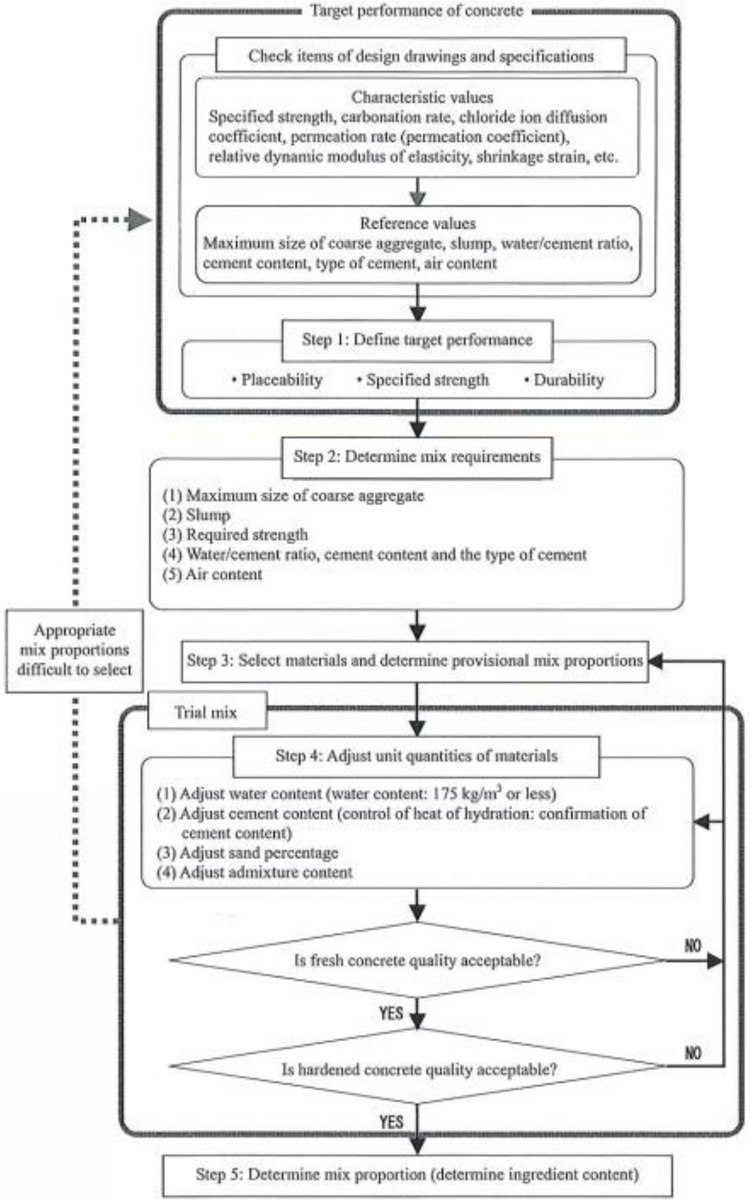
- JSCE 15
  - Consideration given so that durability, safety, serviceability and restorability are maintained throughout design service life
  - Provisions provided for variable service life

- EN 1990
  - Select service life based upon expected use of structure

- ACI 318 and 562
  - Not directly considered
  - Loads are based upon a 50 year return period

Performance-based Concrete Requirements

- Prescriptive measures most common
  - Specified strength, f'c, w/c ratio, etc.
- JSCE
  - Performance-based
  - Prescriptive options
  - Service life considerations
- ACI 318
  - Prescriptive based upon exposure

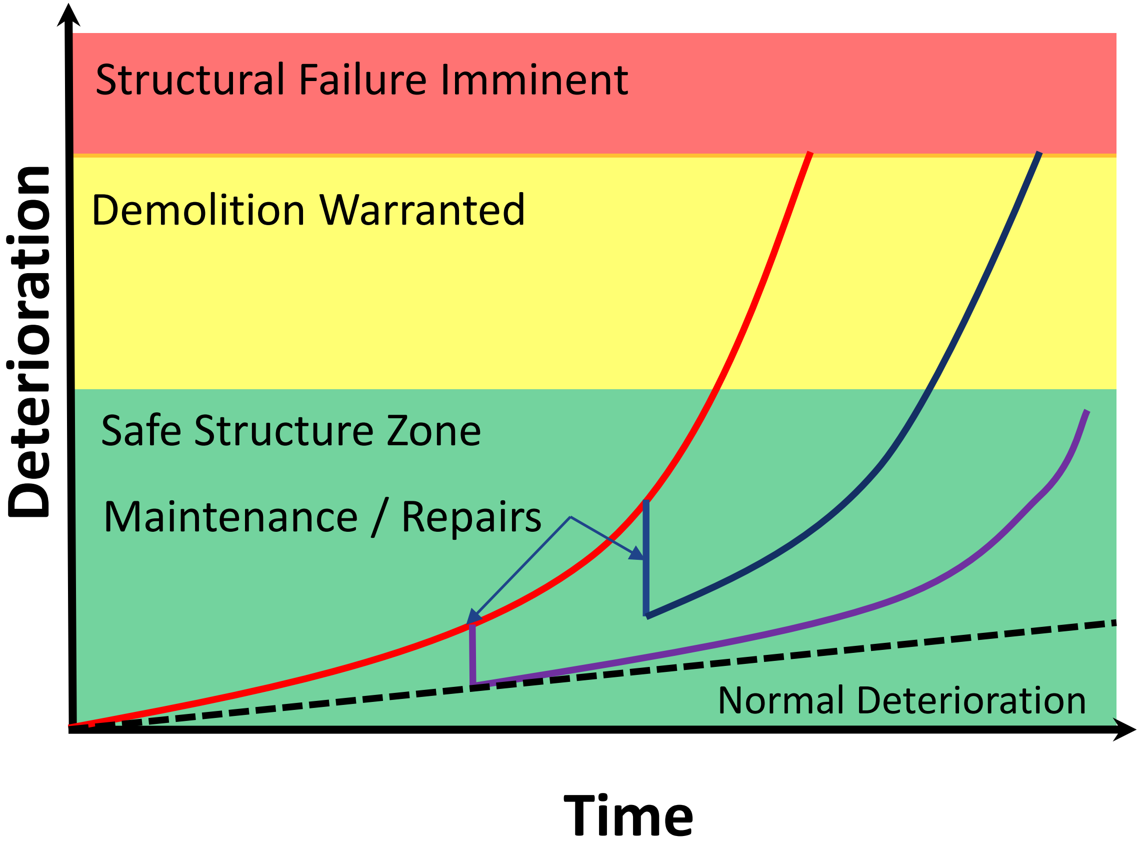


From JSCE 16

Maintenance / Repair

- Birth to dismantlement common in international codes
  - JSCE 15 (3.2) – part of design process
  - ISO, *fib*, EN – all have repair codes

- US Practice
  - IBC (new) versus IEBC/IPMC (existing)
  - ACI 318 – not considered
  - ACI 562 – maintenance requirements
    - Very controversial
    - Inform owner
    - Protect design professional



Adapted from: Extending the Service Life of Parking Structures, Shiu, K, and Stanish, K. Concrete International V. 30 No. 4

ACI compared to International Codes

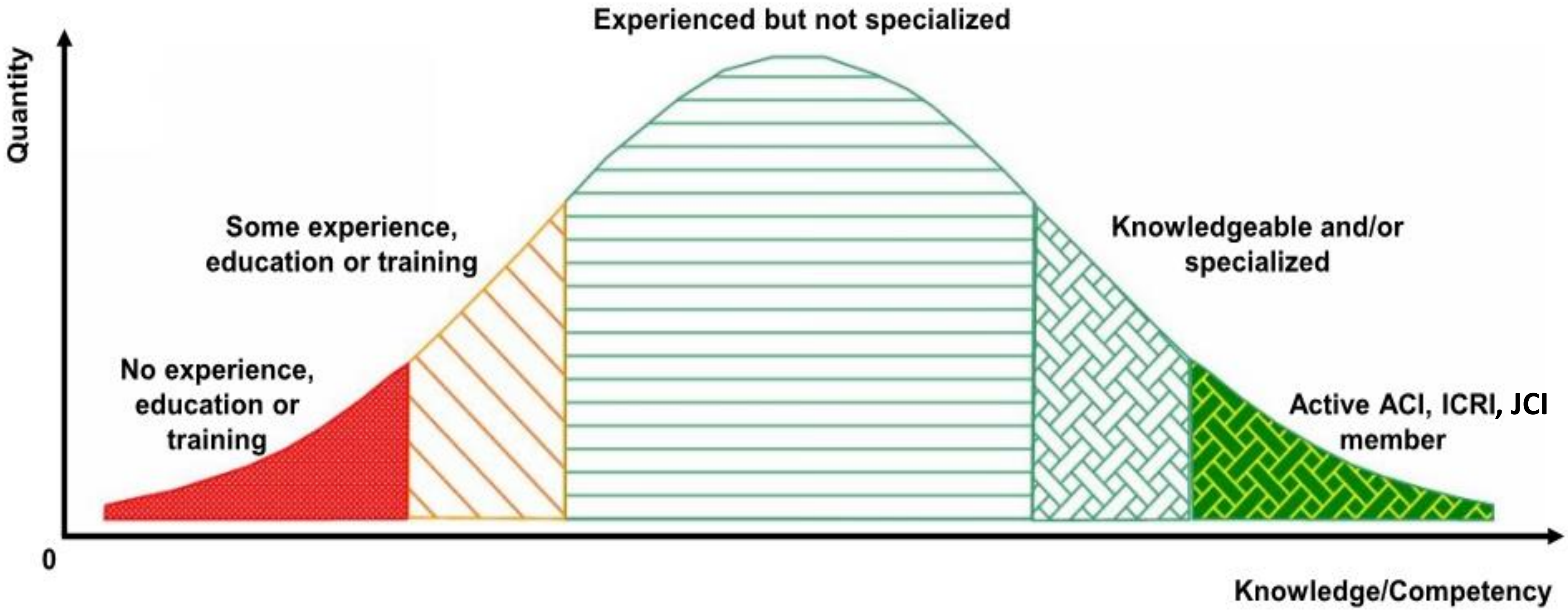
- Durability planning is not considered
- Prescriptive requirements for concrete materials
  - Similar to many international codes
- Lack of integrated approach to durability
  - Limited commentary on how to achieve durability
  - Reinforcement not integrated with materials
  - Limited consideration of service life and maintenance

- But, do codes work?

Design Professional Interviews

- ACI 318
  - Durability design is learned “on the job” and not taught
  - Provisions are simple, limited and “cookbook”, but understanding is limited
  - Durability needs to come from codes provisions otherwise it will not occur in a cost competitive environment
  - Special inspection process is key to proper construction
- CSA A 23.1
  - Provides better flexibility than fib 2010, and better requirements than ACI 318
- JSCE
  - Majority of structures achieve acceptable durability but problems occur
  - More education on durability is needed

Design Professionals



Improving ACI Documents

- Education of design professionals
  - Academic training
  - Continuing education
- Standardize terminology
- Integrate structural and durability design
- Develop durability planning guide
- New standards development
  - Durability design
  - Service-life prediction
- Learn from best international practices

Acknowledgements

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- Interview participants

CVM

PIVOT

Thank You

Questions?