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Durability and Service Life of Reinforced Concrete Structures in the Arabian Peninsula

By

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Service Life

- The period of time during which a structure meets or exceeds the minimum requirements set for it
- Requirements limitation can be technical, functional or economical
- Durability
  - ASR
  - Sulfate attack
  - Corrosion

What is Durability

Durability by definition is the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties

- Concrete ingredients, proportions and interaction
- Placement and curing

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Degradation Mechanisms

Physical attack

- Salt crystallization
- Freezing-and-thawing attack
- Abrasion, erosion, and cavitation
- Thermal damage

Chemical attack

- Leaching
- Acid and base attack
- **Alkali-silica reactions**
- **Delayed ettringite formation**
- **Sulfate attack**
- **Steel reinforcement corrosion**

Alkali Silica Reactivity

- This is caused by reaction of certain aggregates with alkali in cement to form expansive gel that eventually leads to craking

Sulphate Attack

- A reaction between sulphate ions and calcium hydroxide and form gypsum and ettringite.
- BRE and ACI 201 Classification in AP
- Low w/c ration and use of SCM

What is Corrosion

- Deterioration of a material as a result of reaction with its environment-M.G. Fontana
- Destructive attack of a metal by chemical or electrochemical reaction with its environment-H.H. Uhling.
- Metal corrode because they have a strong driving force to return to their natural state

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Corrosion Deterioration

- Corrosion of reinforcing steel in concrete
  - Chloride induced corrosion
  - Carbonation corrosion

Chloride-Induced Corrosion of Steel in Concrete

- Cathode and anode sites co-exist on the Steel
- The steel is the conductor, and
- Concrete acts as electrolyte
- Passivity layer is damaged by chloride ions

Service Life

One Century of Service Life

Is Required???

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100 Years Service Life?!!?

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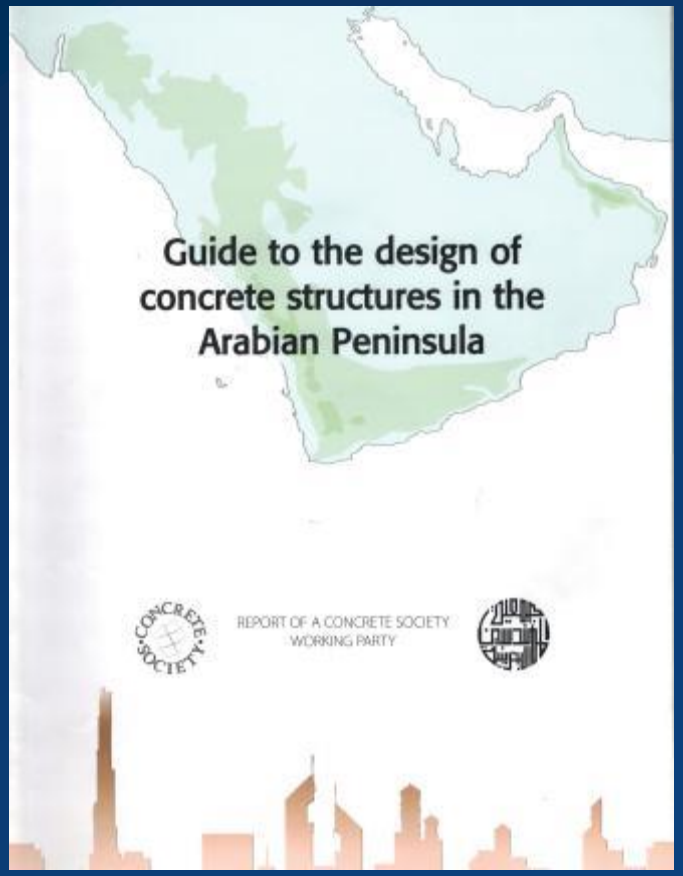
Designing Durable Structures

- ACI 318
- AASHTO
- EUROCODE 2
- BS 5400
- BS 8500
- CS 163



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Service Life Prediction Models

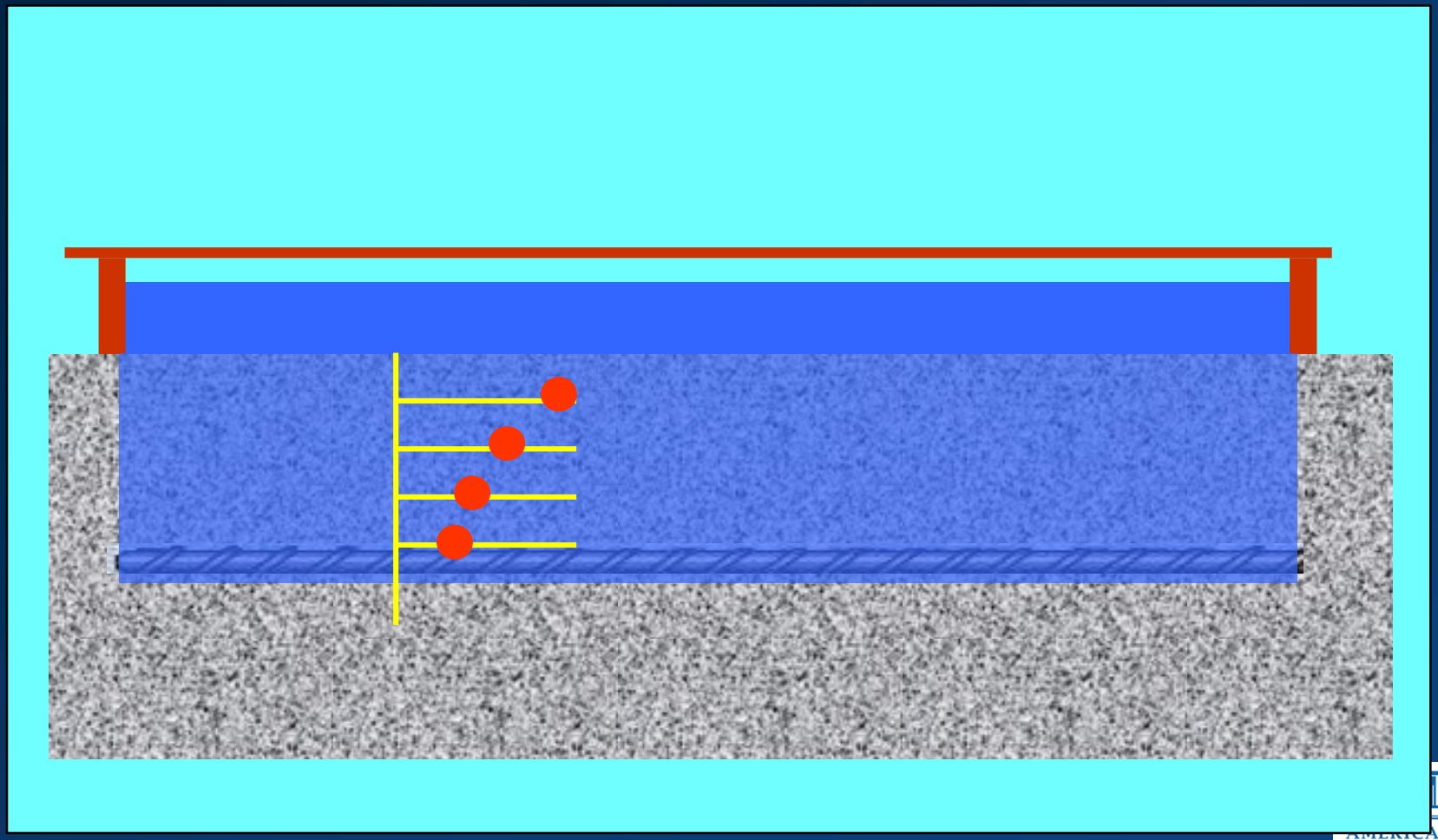
- Deterministic Models
  - Empirical relationship
- Probabilistic Models
  - Based on the idea that service life cannot be accurately predicted
  - Service life = Initiation time + Propagation time of corrosion

Establish the Deterioration Model

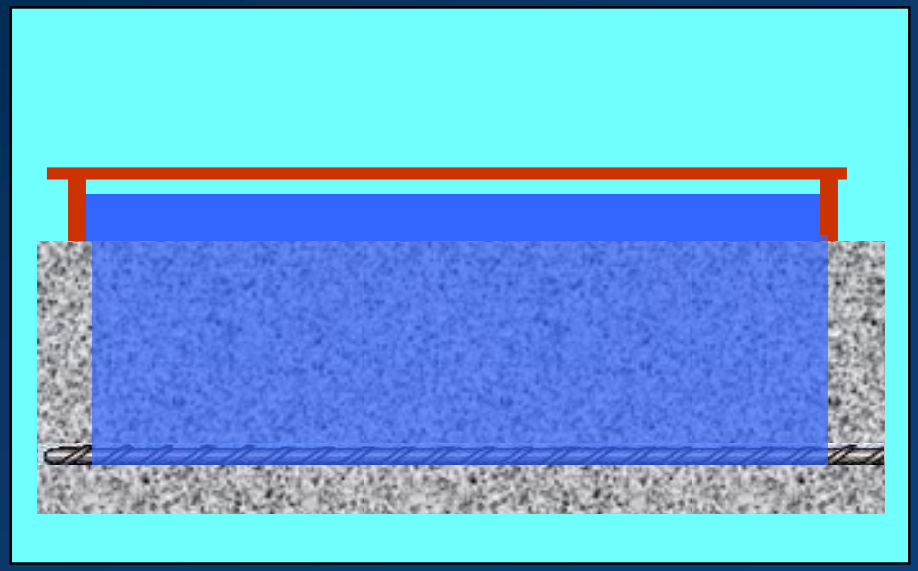
Deterioration Model can be considered in three parts:

- Diffusion process where chlorides diffuse from the concrete surface to the reinforcement
- Initiation process where reinforcement corrosion initiates and rust product develops on the reinforcement
- Cracking/spalling process where sufficient corrosion develops on the bar to form a tensile crack or rust stain at the surface

Kyosti Tuuti's Service Life Model



Kyosti Tuuti's Service Life Model



"When the chloride content exceeds a certain value, termed the chloride-corrosion threshold, corrosion can occur provided that oxygen and moisture exist to support the corrosion reactions"

ACI 222R-01

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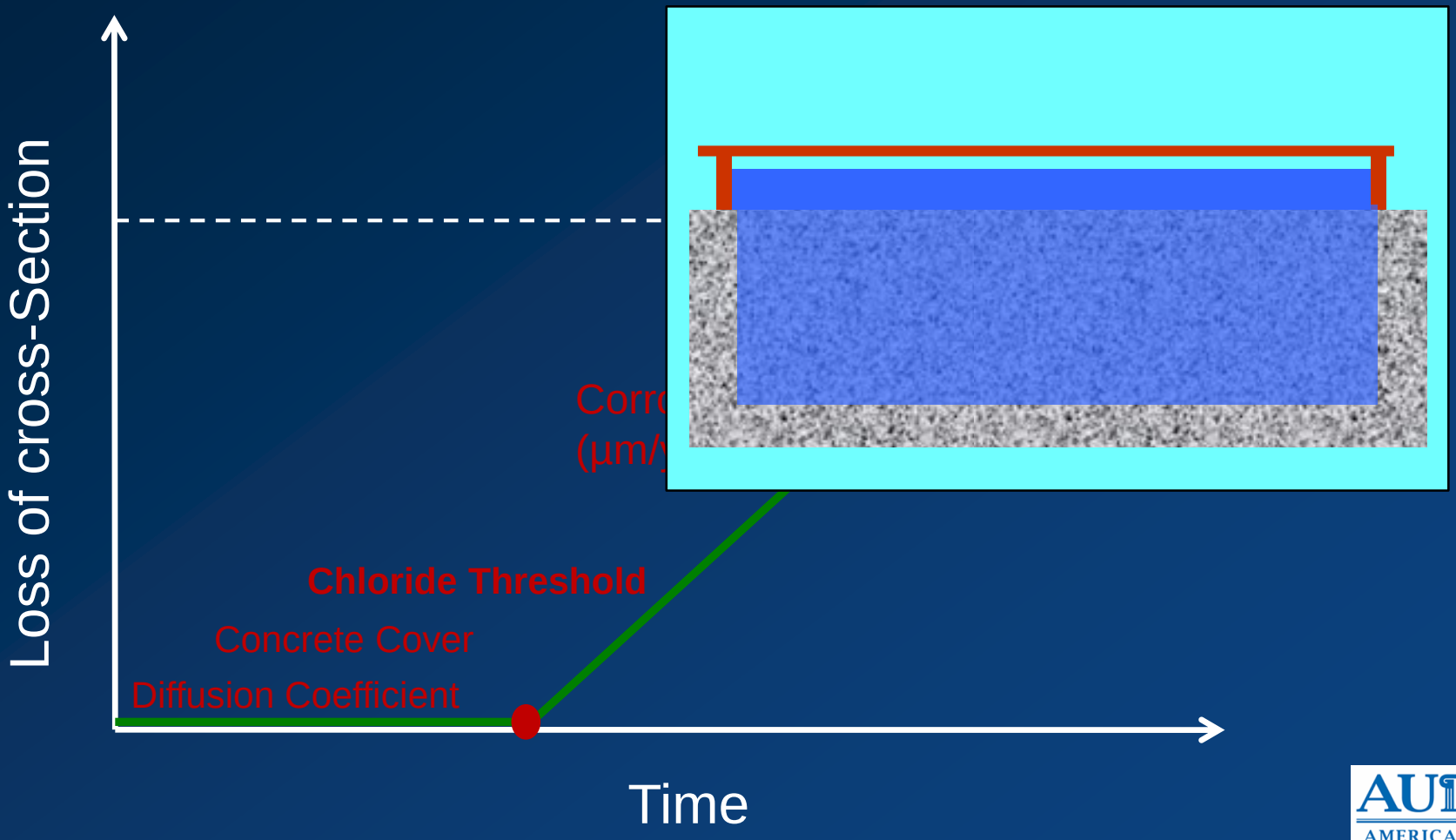
Kyosti Tuuti's Service Life Model



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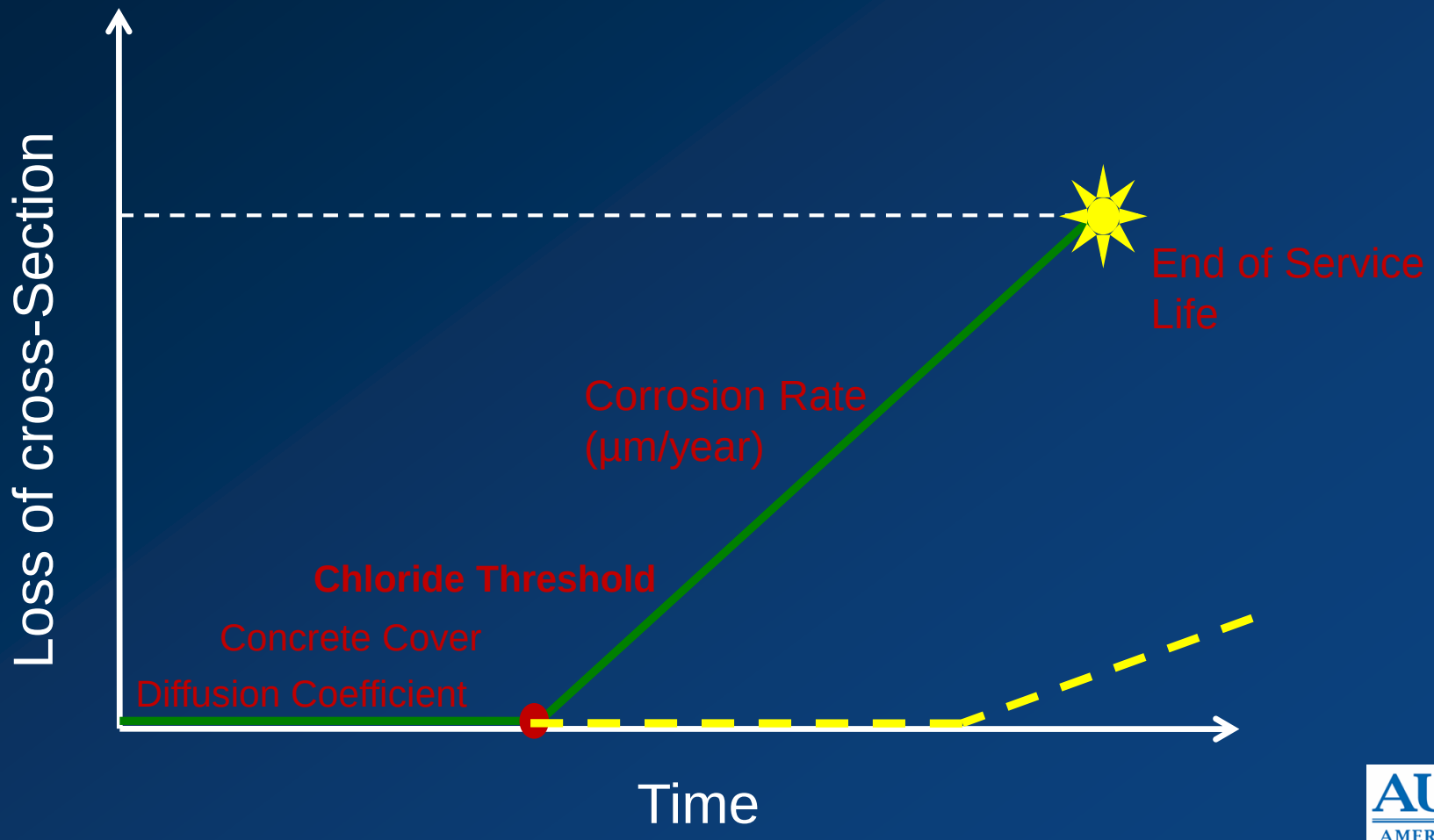
Kyosti Tuuti's Service Life Model



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How to Achieve it- Role of Concrete Tech.

- Concrete Mix Design
- Use of corrosion inhibitor and other corrosion preventive methods.
- Construction practice
  - Curing, surface protection, curing temperature
- QA/QC procedures

MEDRC Experimental Program

- Selected Concrete Mix Design.
- Laboratory Tests
- Service Life Prediction
- Field Testing Stations

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Studied Mixes

- Portland Cement
- Type V Cement (SRC)
- Ground Granulated Blast Furnace Slag
- Fly Ash
- Silica Fume
- GGBS/Silica Fume
- Fly Ash / Silica Fume

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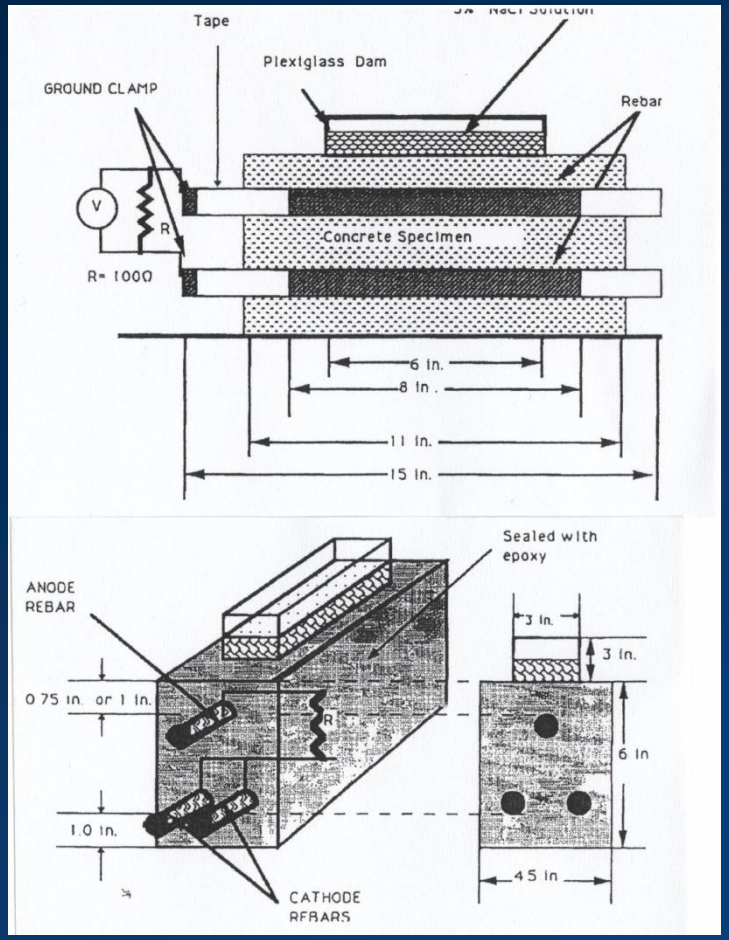
ASTM G 109 Test



ASTM G 109 Specimens

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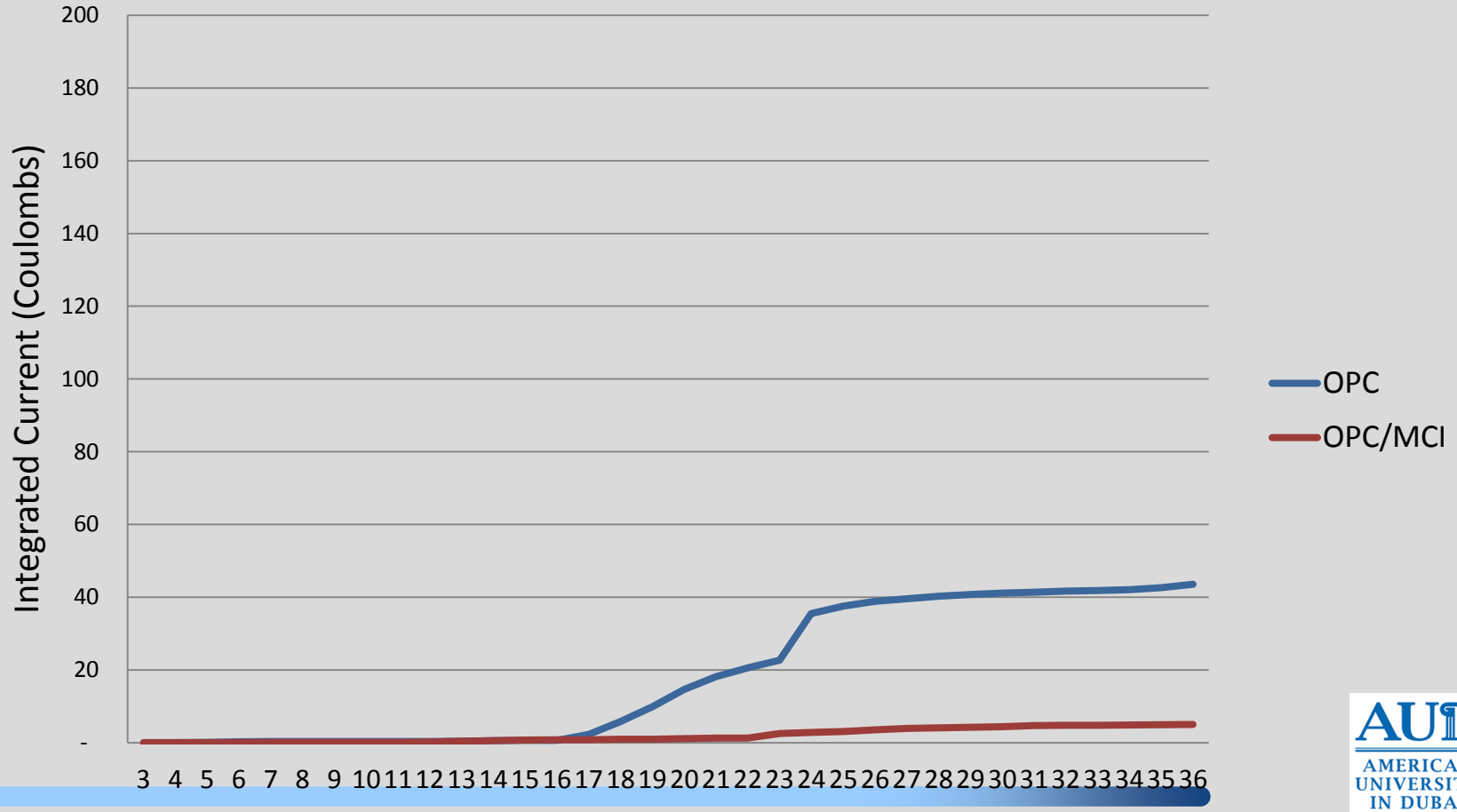
Further Research to Improve our Understanding of SLP



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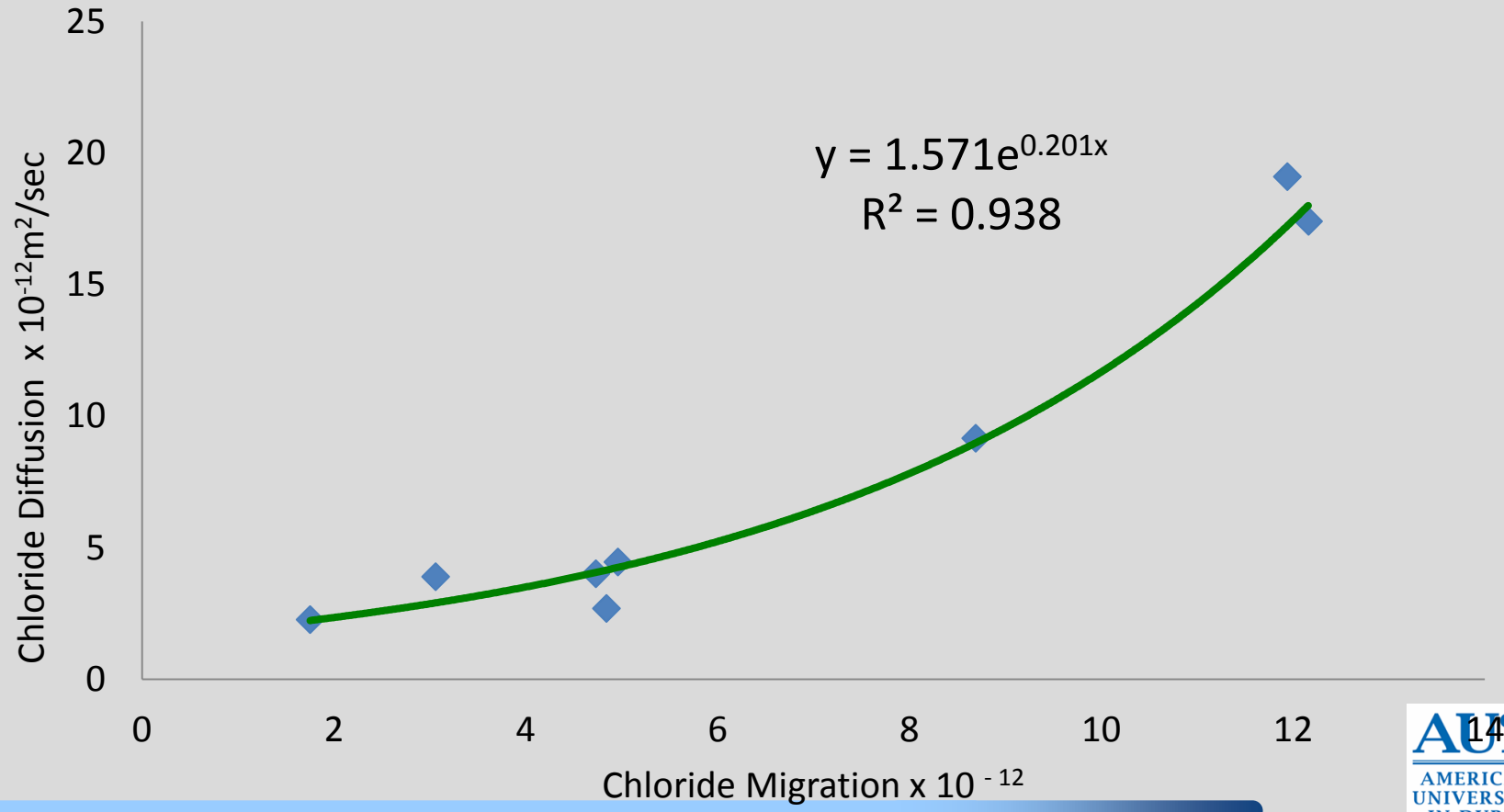
Further Research to Improve our Understanding of SLP

Chloride Migration vs. Diffusion



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Determination of SL-Case Studies

- Existing Structures
  - Chamberlain Bridge
  - Existing Building (Marine Exposure)
- New Structures
  - Burj Khalifa
  - Convention Center
  - Jumeirah Bridges

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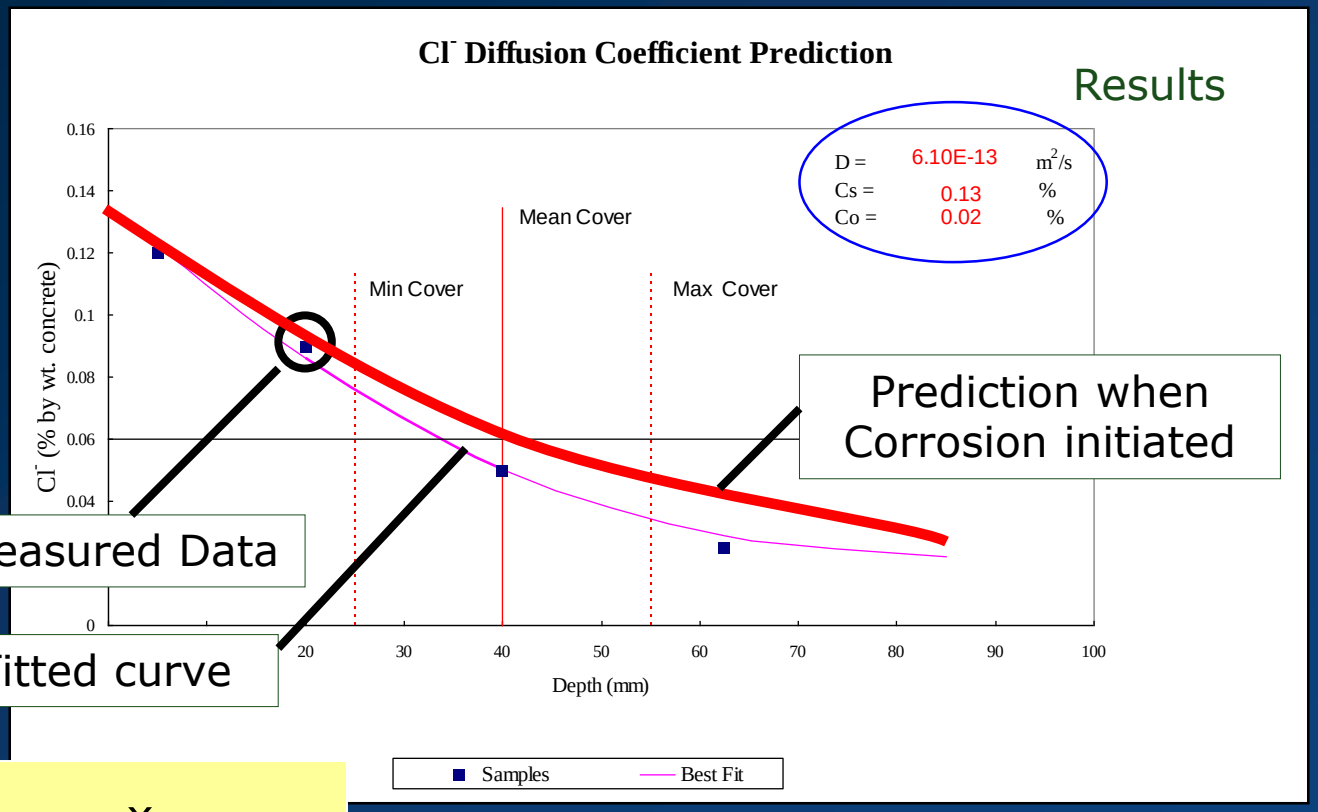
Chloride Diffusion Analysis



$$C_x = C_{sn}\left(1 - \operatorname{erf}\frac{x}{2\sqrt{D_{ca}.t_o.\left(\frac{t}{t_o}\right)^n}}\right)$$

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Enhancing Service Life of Existing Structures

- Adequate repair
- Coating and sealer application
- Use of migrating corrosion inhibitors
- Use of sacrificial anode CP

Convention Center Doha

- Durability Study
- 100-year service life assessment

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Pre-Construction Service Life Assessment

- Deterioration scenarios
- Ground Conditions
  - Level of chloride up to 21 g/L
  - pH between 7.1 and 7.6

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Scenarios-Buried Concrete

Scenario	Mix	Diffusion Coefficient ($x10^{-12}$ m^2/s)	CoV	Cover (mm)	Bar size (mm)
BC 1	40% PFA + SF	1.5	15%	75, 100	12, 16, 16 (ASTM A 1035 steel)*, 32^
BC 2	70% GGBS + SF	2.0	15%	75, 100	12, 16, 16 (ASTM A 1035 steel)*, 32^

*Assumes ASTM A1035 steel – corrosion threshold is increased

^assumes main bars with additional cover due to tie bars (typically T12)

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Scenarios- Atmospheric Concrete

Scenario	Mix*	Diffusion Coefficient ($x10^{-12}$ m^2/s)	CoV	Cover (mm)	Bar size (mm)
AC 3 (Exterior columns)	25% PFA + SF	2.0	15%	55, 65, 75	16, 32

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Calculated Reliability Index-Atmospheric Exposure

Scenario	Bar diameter (mm)	RI 100 y (55 mm cover) (dry) $D=2.0x10^{-12}m^2/s$	RI 100 y (65 mm cover) (dry) $D=2.0x10^{-12}m^2/s$	RI 100 y (75 mm cover) (dry) $D=2.0x10^{-12}m^2/s$
AC 3	16	0.9	2.3	4.2
	32	0.3	1.6	3.2

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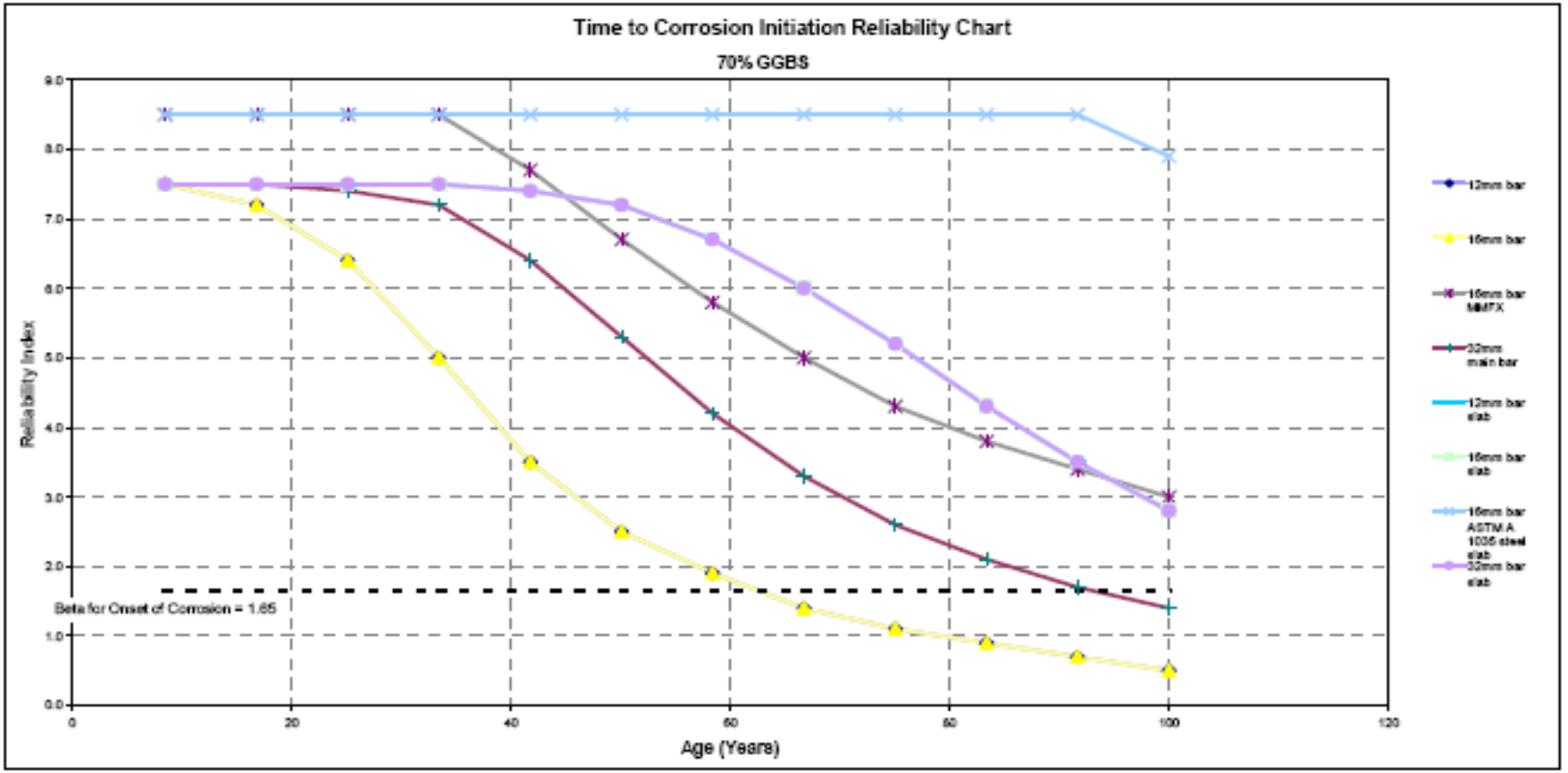
Time to Corrosion



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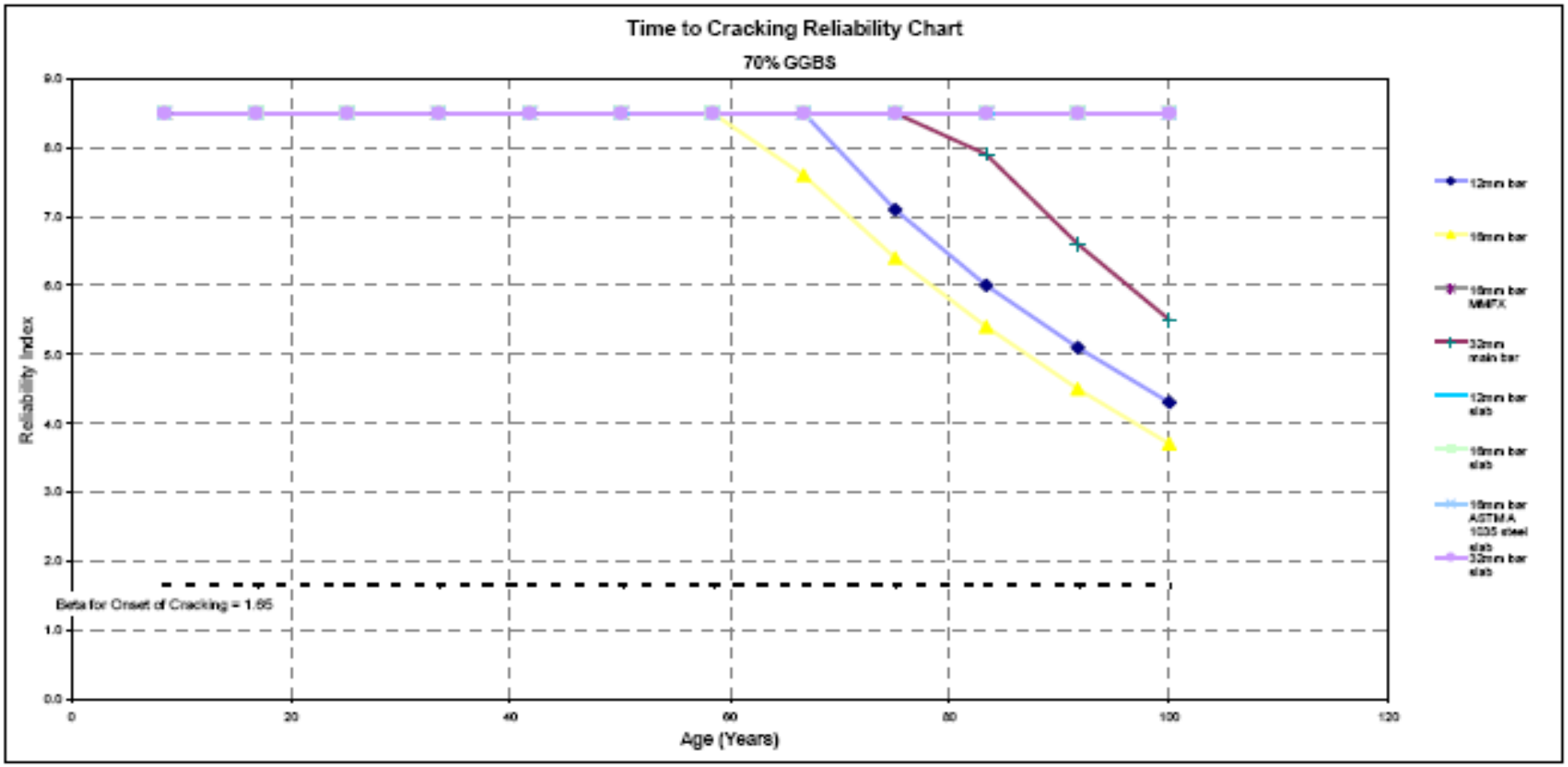
Time to Cracking



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Burj Khalifa

- Durability Study
- 100-year service life assessment
- High quality Concrete
- Use of MCI Inhibitor in the Podium
- Use of CP system for deep foundation
- QA/QC and IVTA

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Moderate Exposure Conditions Structures

- 100-year service life
- Moderate sulfate and chloride exposure
- Normal concrete with relatively low w/c
- Use of SRC
- Adequate cover

Implementation of Performance-Based Specification for Concrete Durability

- What are performance-based specifications
- Challenges with implementing Performance-based specifications
- What is the concrete industry doing to move toward a performance-based Specifications

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Conclusions

- The Gulf region is considered the most corrosive location in the world
- Corrosion is the main durability factor leads to deterioration of concrete structures
- Use of SCM will improve the performance of RC structures and extend their service life
- Use of Quality Concrete and good QA/QC system are the key to achieve the required service life
- Use of corrosion protection systems such as corrosion inhibitors extend the service life of structures as well

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Thank you
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Questions?

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