American University in Dubai
A School of Engineering
Infrastructure Sustainability
and
Assessment Center

Evaluation of Service Life of Reinforced Concrete Structures in the Middle East

By

MEDRC

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

Concrete Sustainability and Durability

- Concrete is **Durable** Construction Material
- Enhancing Concrete Durability
  - Use of Supplementary Cementing Materials (SCM)
  - Extend the Structure Service Life
  - Minimize maintenance

Construction in the Middle East

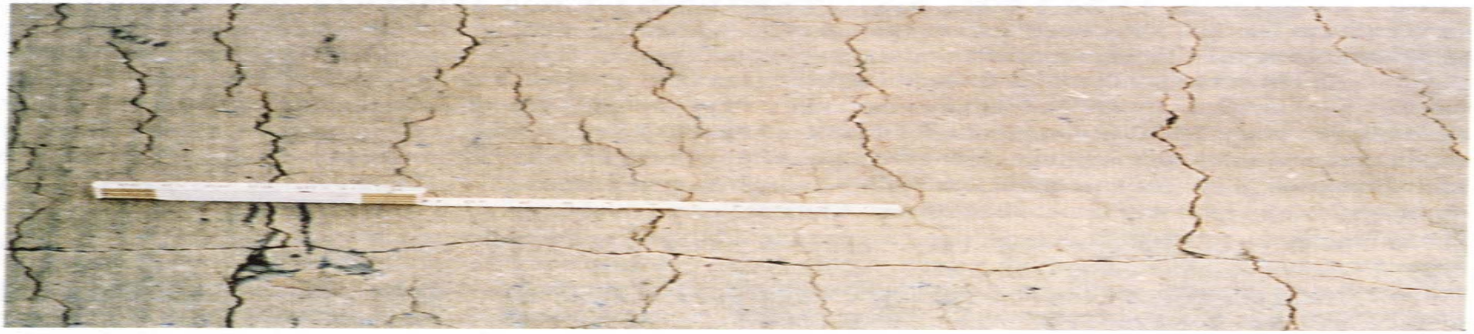
- First Generation of Construction (1970's)
  - Foreign codes
  - Ignorance of the unique environment of the region
  - Poor quality concrete
  - Severe deterioration

Concrete Durability Parameters

- Alkali Silica Reactivity (ASR)
- Delayed Ettringite Formation
- Sulphate Attack
- Corrosion of reinforcing steel

Alkali Silica Reactivity

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



Delayed Ettringite Formation

- DEF is mainly associated with steam cured precast members.
- Curing temperature higher than 70° C leads to formation of DEF cracking.
- Thermal effects (mass concrete)
- Use of SCM

Sulphate Attack

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

Long-Term Sulfate Attack Study (PCA)

Corrosion

- Deterioration of a material as a result of reaction with its environment-M.G. Fontana

What is Corrosion

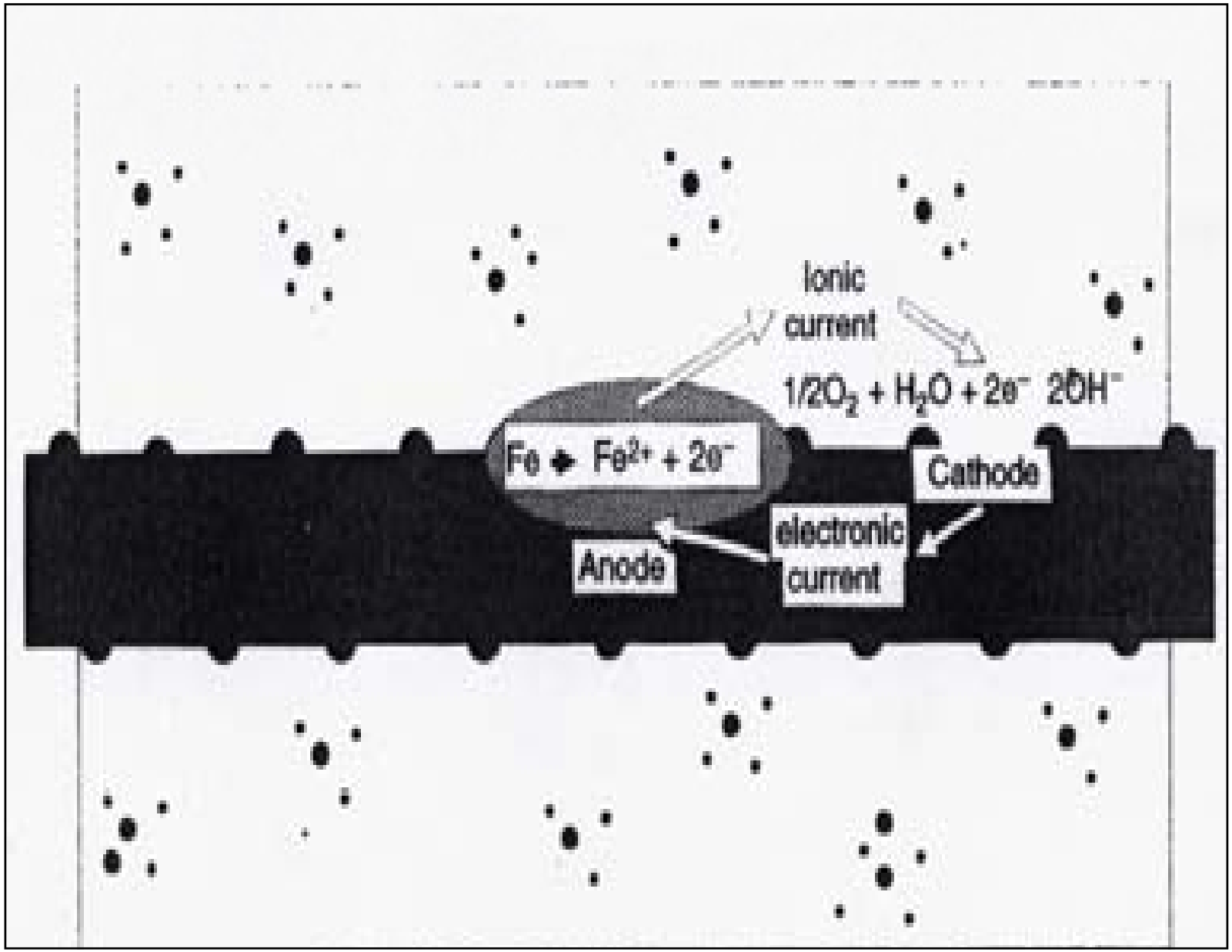
- Destructive attack of a metal by chemical or electrochemical reaction with its environment-H.H. Uhling.
- Metal corrode because they have a strong driving force to return to their natural state

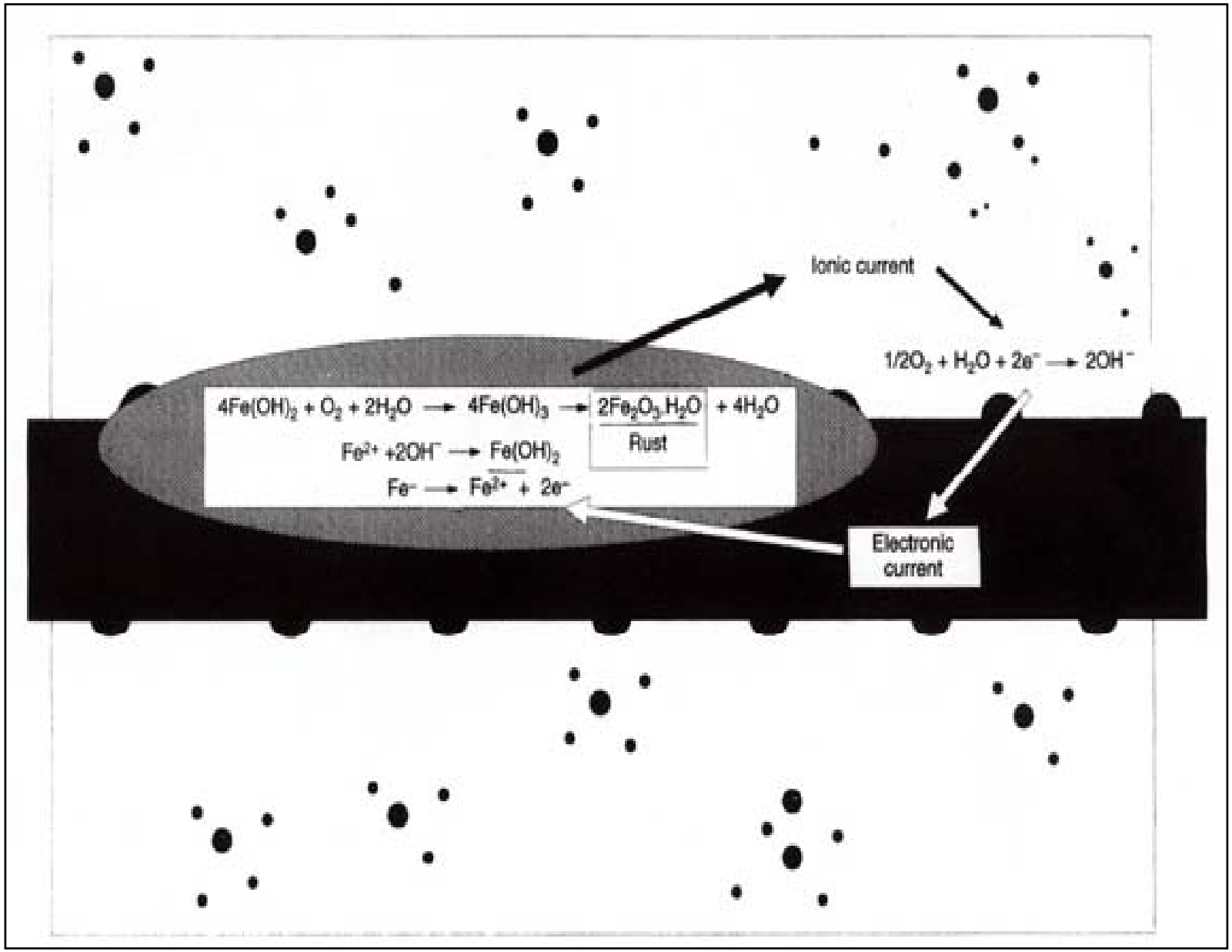
Requirements for Corrosion

- Cathode
- Anode
- Electrolyte
- Electrical connection between anode and cathode

Corrosion of Steel in Concrete

- Cathode and anode sites co-exist on the Steel
- The steel is the conductor, and
- Concrete acts as electrolyte

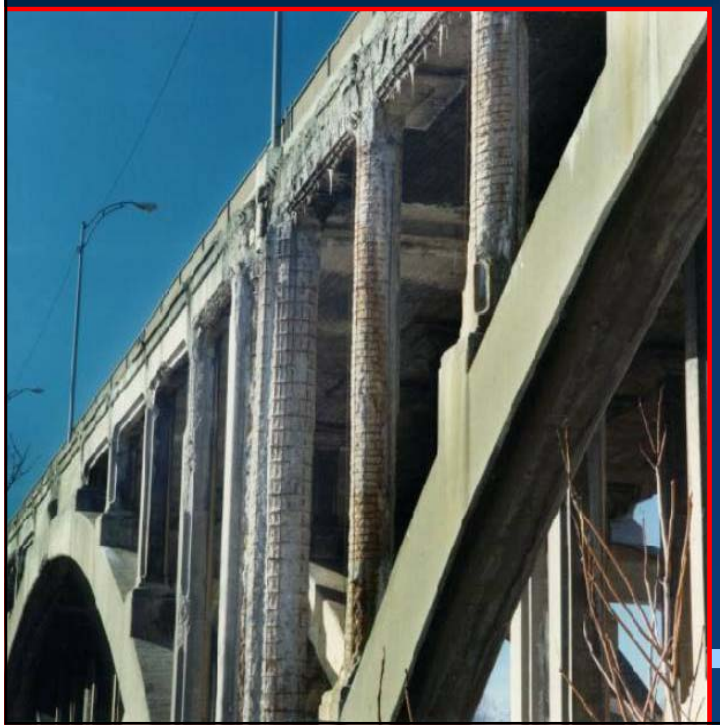

Ionic
current
$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$
$Fe \rightarrow Fe^{2+} + 2e^-$
Cathode
electronic
current
Anode

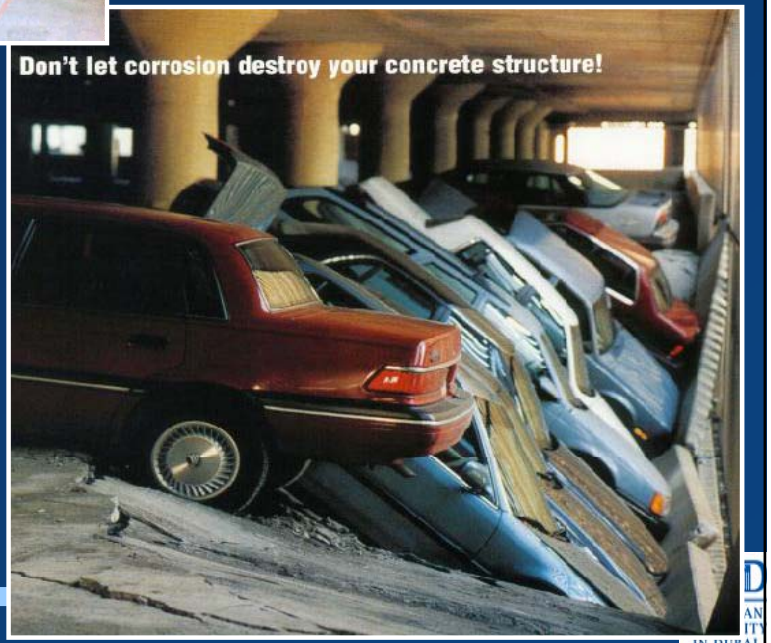

Ionic current
$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$
$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \rightarrow 2Fe_2O_3.H_2O + 4H_2O$
Rust
$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$
$Fe^- \rightarrow Fe^{2+} + 2e^-$
Electronic current

Industrial Structures

Marine Structures

Corrosion damage on reinforced concrete bridge structures





Corrosion damage and catastrophic failure in parking garages

Why Should We Care About Corrosion

Why Should we Care about Corrosion

- Safety
- Conservation of Resources
- Cost

Cost of Corrosion

- 1995 report:
  - $300 Billion/yr (4.2% of the GNP)
- 2002 NACE Report:
  - $276 Billion/yr (3.1% of the GNP)

Utilities	35%
Transportation	22%
Infrastructure	16%
Government	15%
Production & Mfg.	13%

Cost of Corrosion in the GCC States-2004

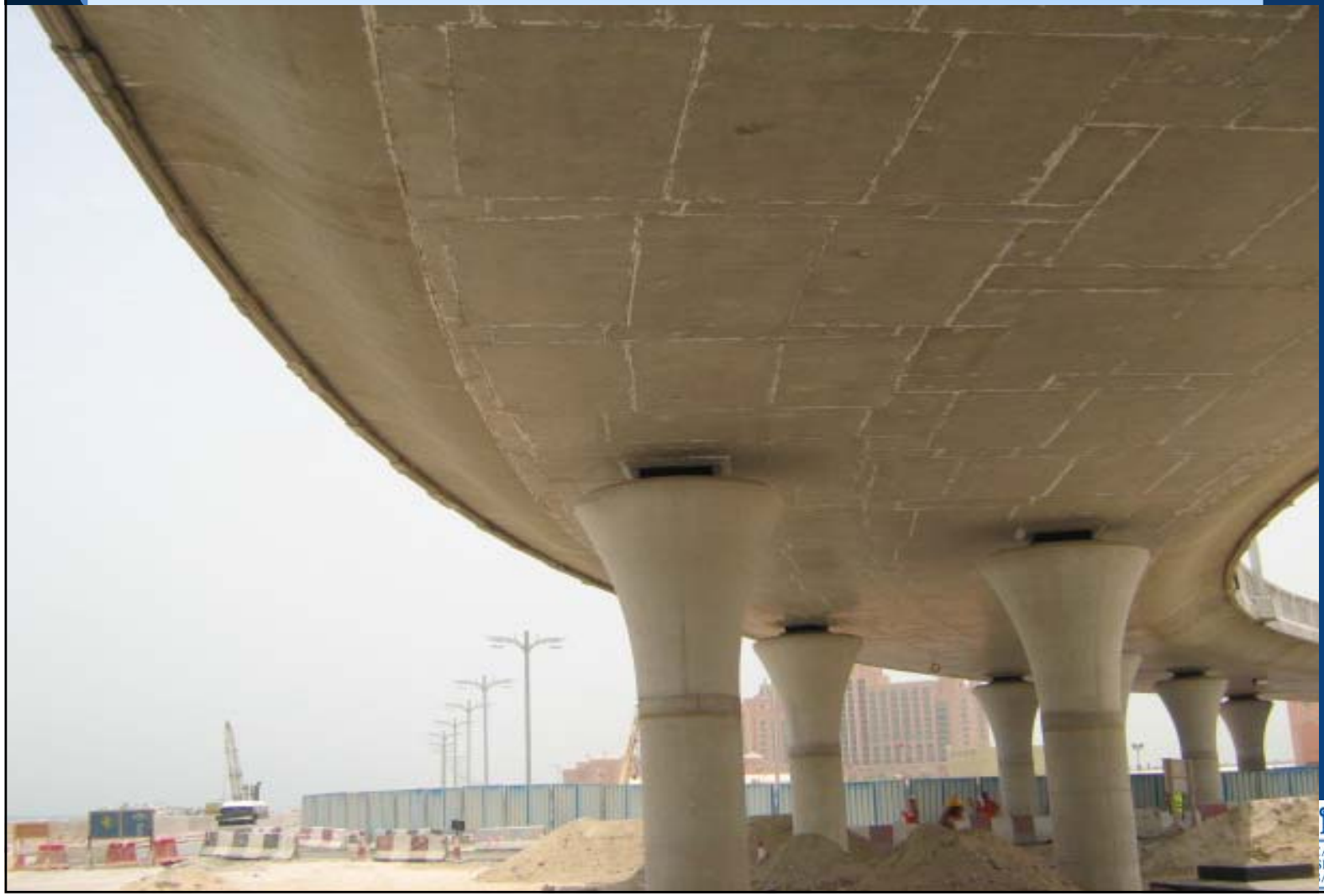
- Kingdom of Bahrain 0.5 B.
- State of Kuwait 2.17 B.
- Sultanate of Oman 1.3 B.
- State of Qatar 1.1 B.
- Kingdom of Saudi Arabia 13.0 B.
- United Arab Emirates 3.7 B.

Why Should We Care About Corrosion

Middle East Durability Research Consortium Program

Service Life

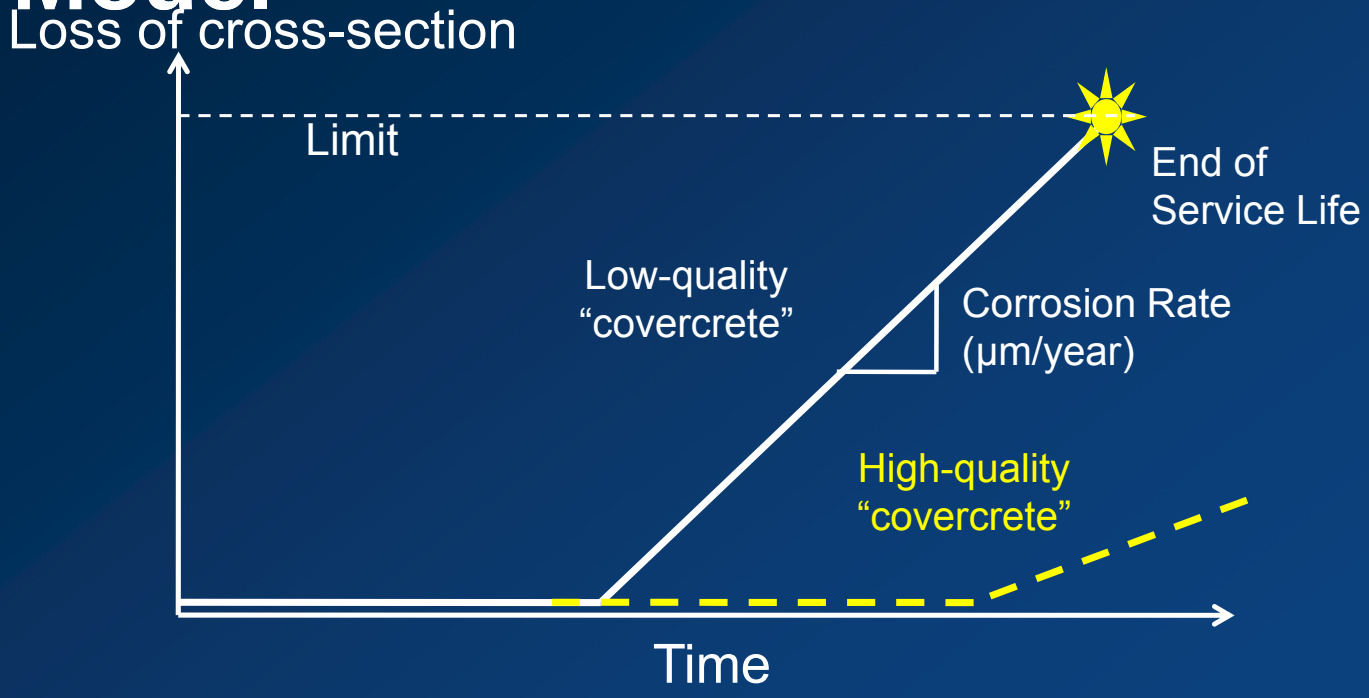
Hundred-Year Service Life Requirement in the Region



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

Kyösti Tuutti´s Service Life Model



$$DC/dt = D.\ d^2C/dx^2$$

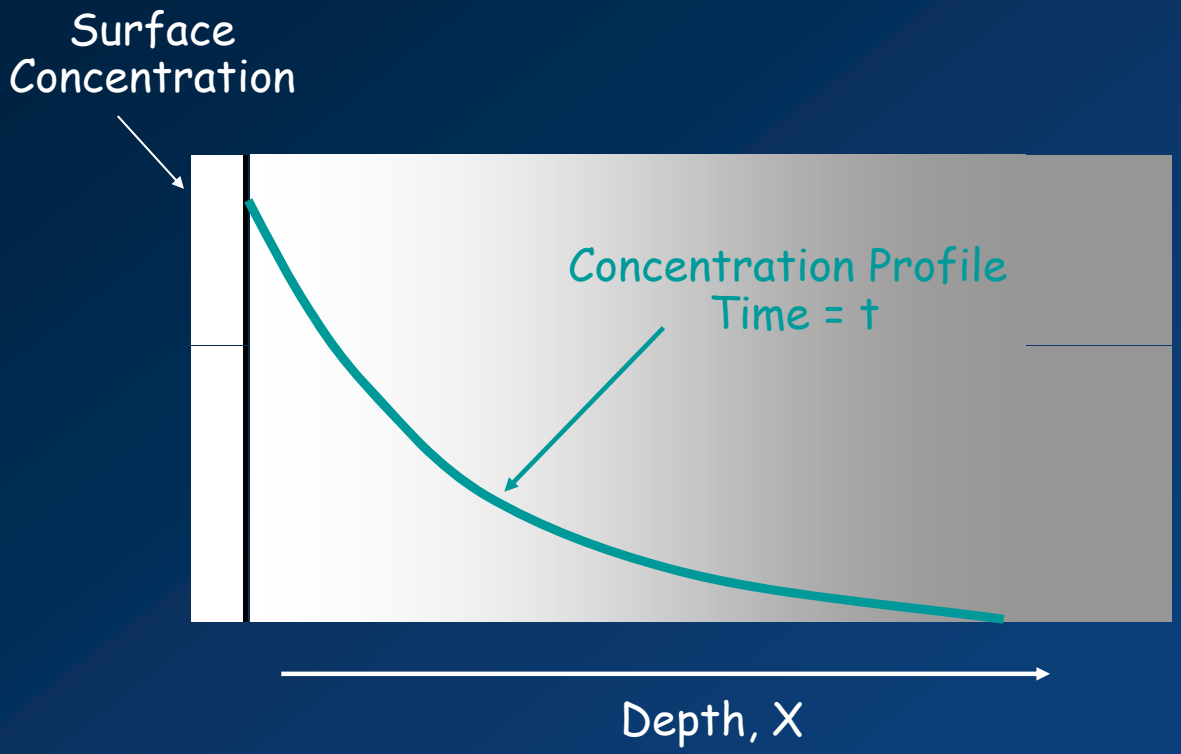
C Chloride content

T time

X depth (from exposed surface)

D apparent diffusion coefficient

Diffusion



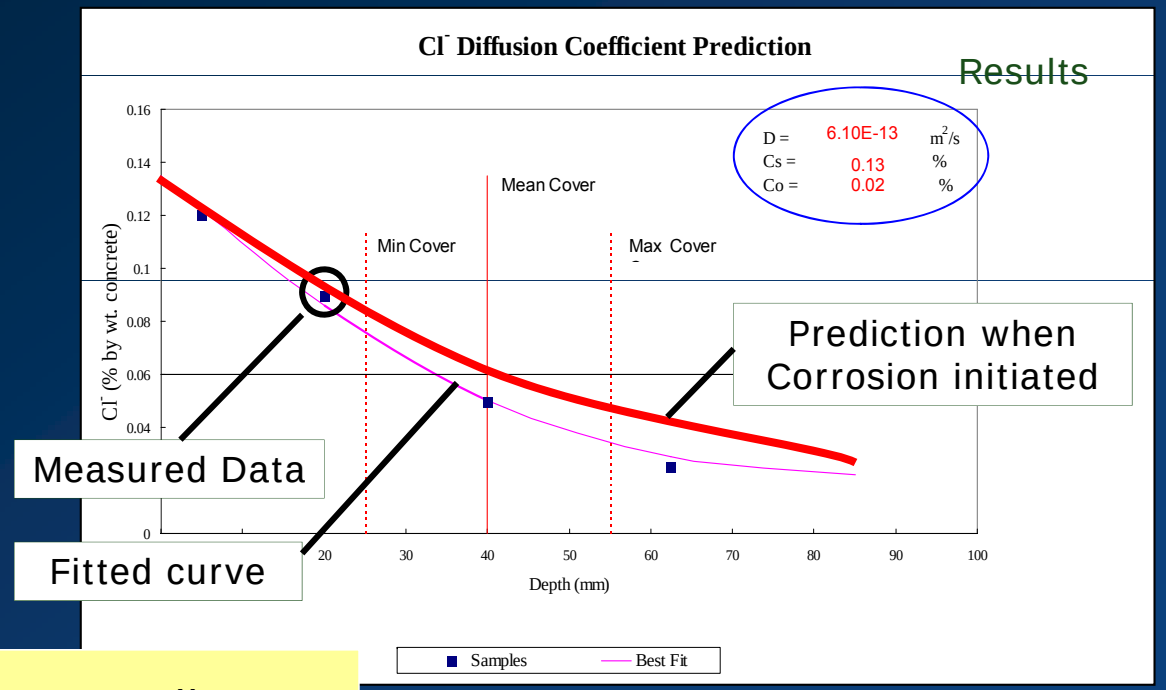
Courtesy: N. Carino

Fick´s Second Law Solution

$$C_{x,t} = C_s - (C_s - C_i) \times \mathrm{ERFC}\left(x/\sqrt{Dt}\right)$$

$C_{x,t}$ = the chloride concentration at concrete depth x and time t
C_s = the chloride concentration at the surface,
C_i = the initial chloride concentration,
D = the apparent chloride diffusion coefficient (m^2/sec, in.^{2}/year), and
ERFC is an error function

Chloride Diffusion Analysis



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

Service Life

Hundred-Year Service Life

How to achieve it???

How to Achieve it

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

How to Achieve it,cont.

- For Deep tunnels (inner tunnel), use of in-situ concrete liner and HDPE liner
- Closed Monitoring of Design Parameters
  - Crack limits
  - Concrete cover

MEDRC Experimental Program

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

Selected Mix Designs

Mix Des.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
OPC	400	400	400	400	136	
SRC						400
GGBS					264	
MS						
Fly Ash						
Total Cement	400	400	400	400	400	400
Water	200	200	200	160	160	160
w/c	0.50	0.5	0.5	0.4	0.4	0.4

Selected Mix Designs, cont.

Mix Des.	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	
OPC	400	400	400	400	136	
SRC						
GGBS			264		264	
MS		32	20	20		
Fly Ash	120			120	80	
Total Cement	400	400	400	400	400	
Water	160	160	160	160	160	
w/c	0.40	0.4	0.4	0.4	0.4	

Concrete Mixing

Concrete Mixing

Laboratory Testing Program

- Standard Durability tests.
- ASTM G 109 Testing Program
- Service Life Monitoring Parameters

Standard Durability Tests

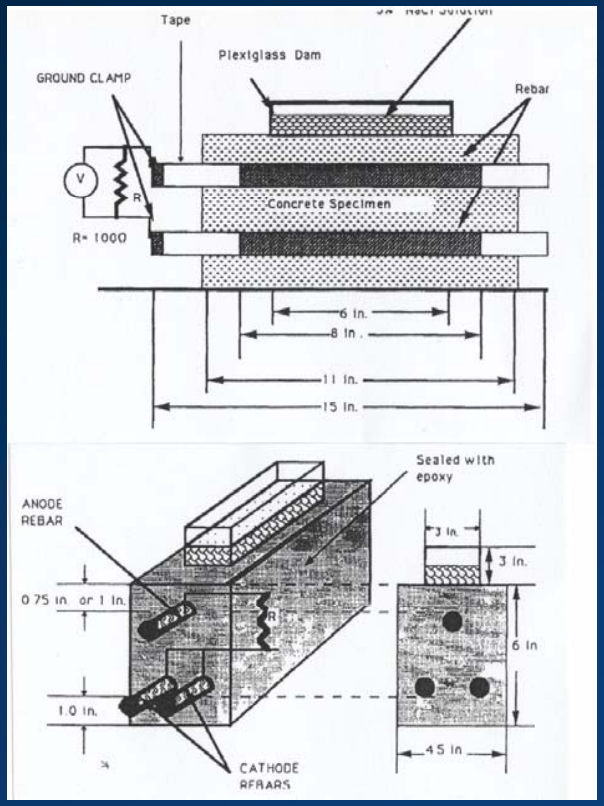
- Water Permeability, BS EN 12390/DIN 1048
- Water Absorption, BS 1881-122
- Rapid Chloride Penetration, ASTM C 1202

RCPT

Rapid Chloride permeability Test

An Acceptance Test???

ASTM G 109 Test



ASTM G 109 Test

ASTM G 109 Specimens

Specimen Preparation

Specimens Preparation

Specimens Preparation

Specimens Preparation

ASTM G 109 Specimens

ASTM G 109 Specimens

Service Life Prediction Parameters

- Chloride Migration Coefficient Test NT Build 492
- Diffusion Coefficient Test NT Build 443

Chloride Migration Coefficient NT 492

Chloride Migration Coefficient NT 492

NT Build 443 Diffusion Coefficient

- Coating specimens
- Immersion in salt solution for 35 days
- Use grinded powder samples for chloride measurement and developing chloride profile
- Curve-fitting chloride profile to Fick's second law.

Field Testing Stations

- Selected Concrete mixes
- Relatively large-scale specimens
- Long-term marine exposure
- Corrosion activity monitoring
- Correlation with Laboratory finding

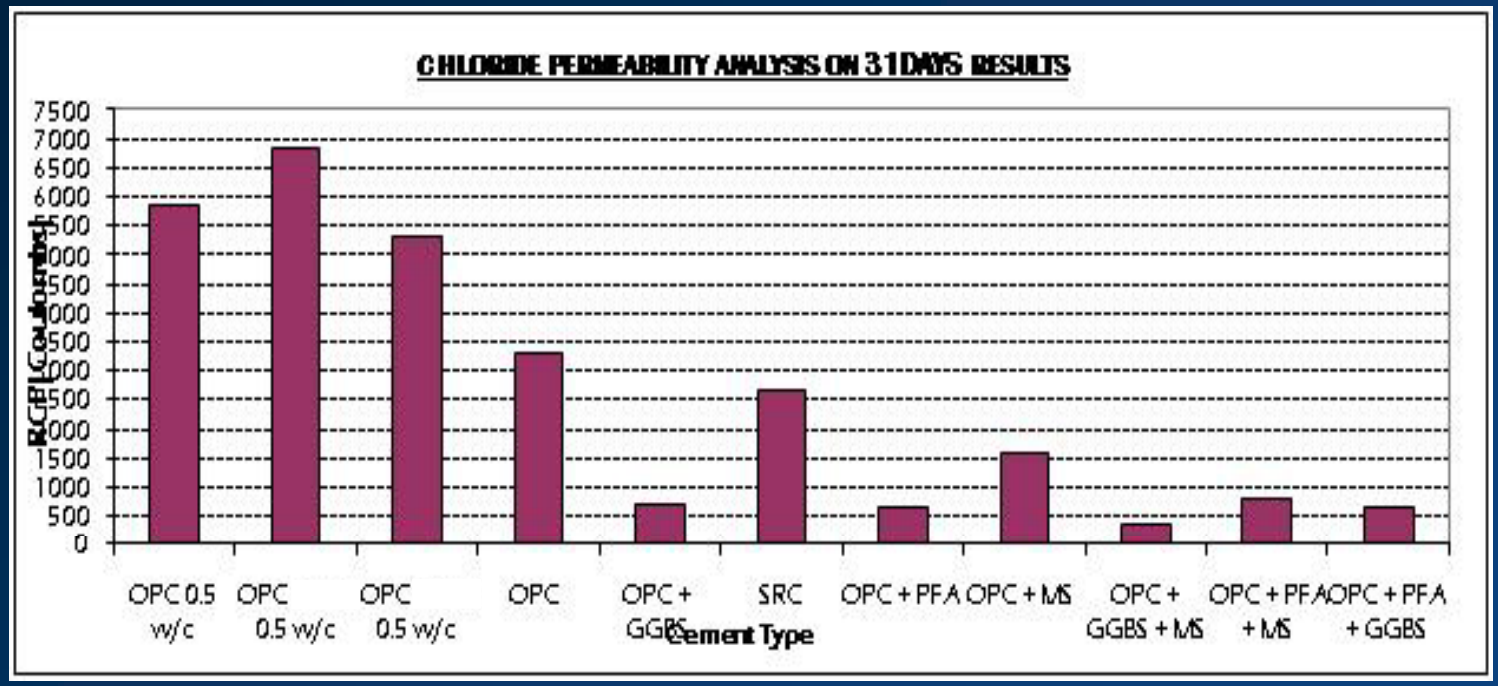
Selected Sites

- The selected sites cover most of the ME marine exposure conditions
- Arabian Gulf exposure (Dubai)
- Dead Sea
- Mediterranean Sea

Progress Test Results

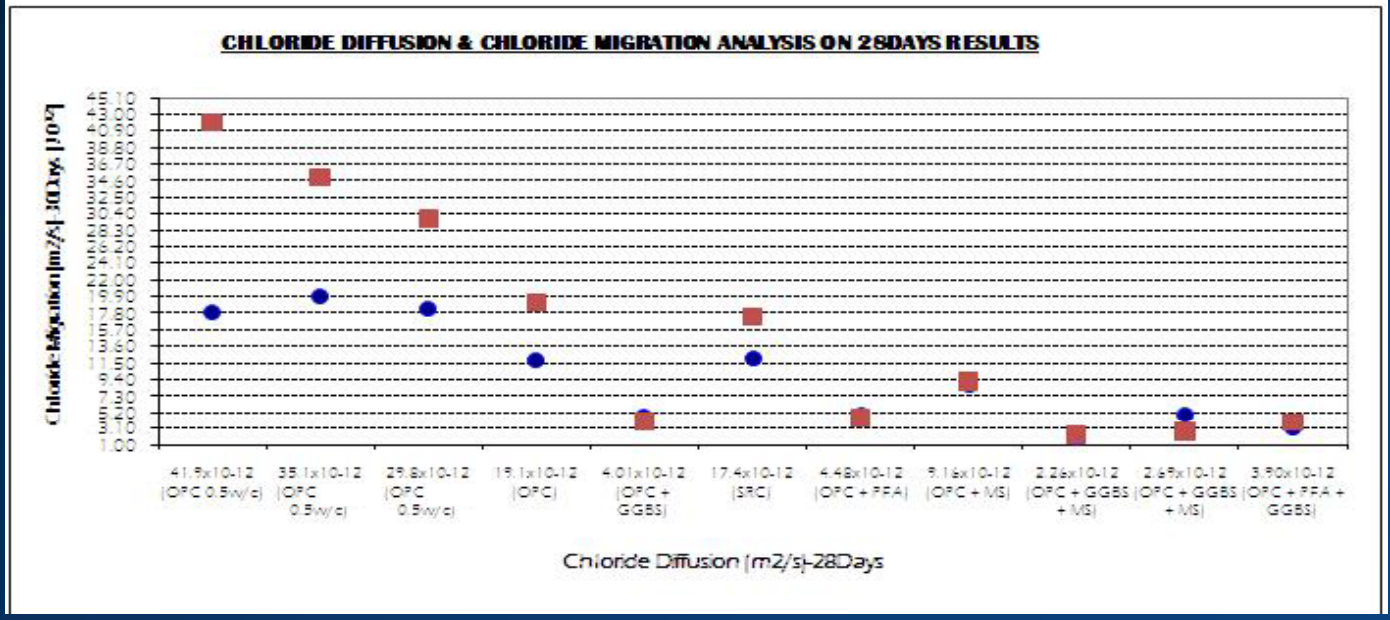
- Chloride Permeability
- Chloride Migration Coefficient-NT Build 492
- Diffusion Coefficient-NT Build 443

RCP Test Results



Migration Coef. Vs. Diffusion Coef.

EVALUATION OF SERVICE LIFE OF REINFORCED CONCRETE IN THE MIDDLE EAST



What Is A Durability Assurance Plan ?

- A management process which gives an Asset Owner confidence that the asset under construction will achieve its design life
- A formal mechanism for all parties in the construction process to maximize delivery of a durable structure

Why Durability Assessment Planning ?

- Match the design with the environmental conditions, service life, construction techniques and maintenance requirements
- Optimise the process of resource distribution (i.e. money, materials & time)
- Provides conduit between design, construction & maintenance during service life

Conclusions

- Arabian Peninsula and Gulf region is most corrosive location in the world
- Corrosion is the main durability factor leads to deterioration of concrete structures
- Use of Quality Concrete and corrosion protection systems such as corrosion inhibitors is the key to achieve the required service life
- MEDRC focuses on assessing and optimizing the service life of RC structures in the Middle East
- This study will provide tools to the construction community in the region to achieve long lasting concrete.

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Thank you

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Questions?