Design for Durability of Concrete Structures

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DURABLE STRUCTURES
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Design for Durability of Concrete Structures

BASIC CONCEPTS

DESIGN MODELS

STRATEGIES FOR DURABILITY

DURABILITY DESIGNS OF NEW STRUCTURES

EXPERIENCE FROM MAJOR REPAIRING WORKS

DURABILITY – BASIC CONCEPTS

DURABILITY

Durability of a structure is its capacity to meet the requirements of serviceability, strength and stability throughout its design working life, without loss of utility or excessive unforeseen maintenance

DURABILITY – BASIC CONCEPTS

PARTICIPANTS AND RESPONSABILITIES

Owner

Specify the service life period, the use, the design basis and performance criteria

Designer

- Identification of exposure conditions
- Conceptual design and design basis
- Choose materials and their specification
- Cover
- Detailing
- Durability design
- Acess for inspection
- Inspection and maintenance manual

Contractor

- Concrete mix, execution and curing
- Control of minimum cover
- Quality of execution

Supervisor

Quality control of execution

User

- Proper use of construction
- Implement maintenance procedures (and inspection)
- Update information

DURABILITY – BASIC CONCEPTS

BIRTH CERTIFICATION

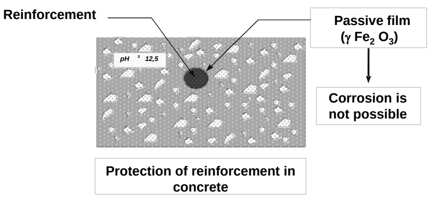
(fib proposal)

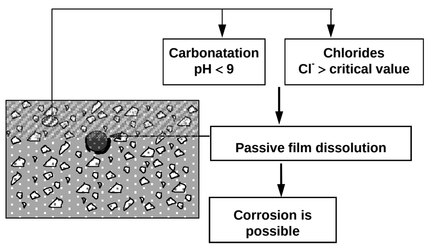
Selected engineering information related to maintenance and durability, continuously updated including the evaluation of the remaining service life

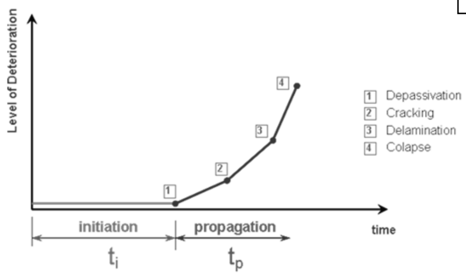
- **General Information**
  Description of the construction, location, environment conditions. Identification of all participants, main dates, …
- **Design Information**
  Design basis and drawings
- **Construction**
  Materials used and suppliers, dates, …
  Concrete mixes and its use in the structure
  Events, nonconformities, …
- **Inspection Plan and Maintenance**
- **Durability Assessment**

DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION





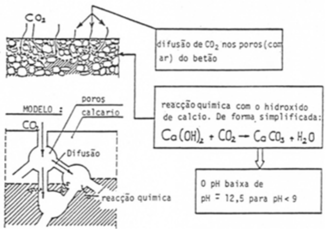


Service Life → $t_L = t_i + t_p$

DURABILITY – BASIC CONCEPTS

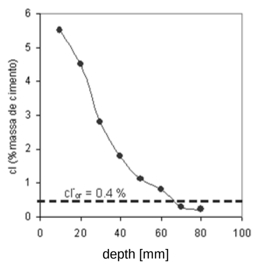
REINFORCEMENT CORROSION – INITIATION PHASE

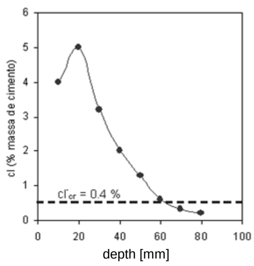
Carbonation of concrete



The purple region represents non carbonated concrete

Chloride Penetration



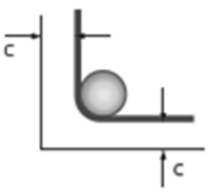


DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – INITIATION PHASE

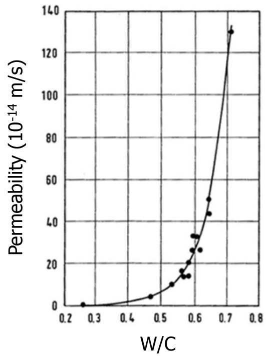
Resistance to penetration of CO_2 and Cl^-

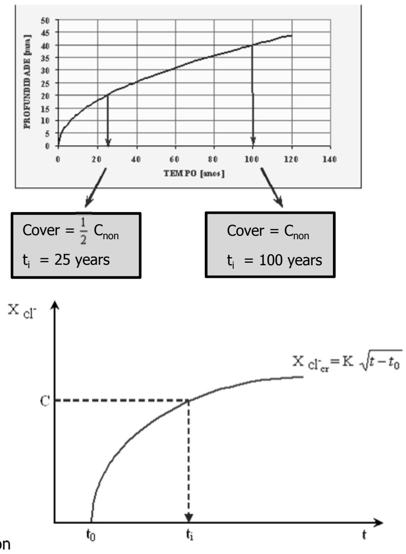
- **Exposure Conditions**
- **Concrete Quality**
  - Concrete mix
    - W/C
    - Type of cement aditions
  - Compaction
  - curing
- **Reinforcement Cover**



DURABILITY – BASIC CONCEPTS

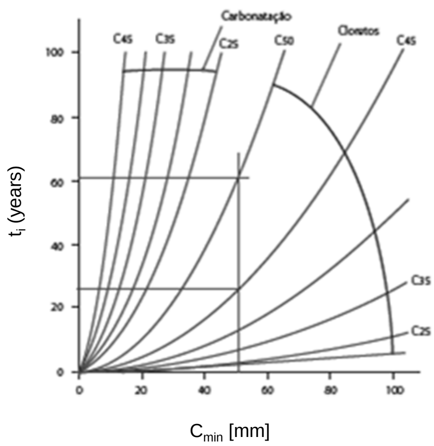
REINFORCEMENT CORROSION – INITIATION PHASE





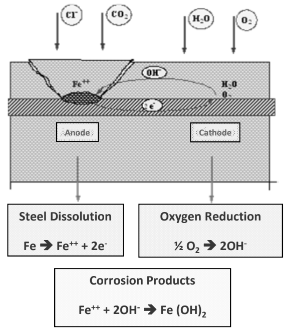
DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – INITIATION PHASE



DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – PROPAGATION PHASE



Exposure of bar in a beam angle due to corrosion

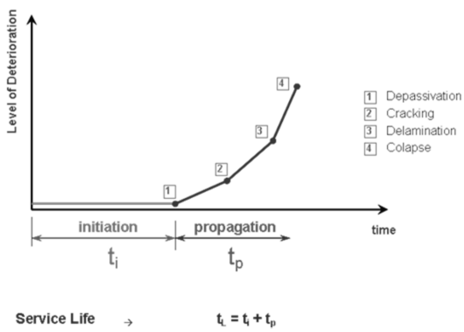
Corrosion process

- Anode - Region of bar depassivation
- Cathod - Region of bar with oxigen acess O_2
- Electric condutor - Bar
- Electrolyte - Concrete

At the anodes irons oxides and hidroxides are developed.

DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – PROPAGATION PHASE

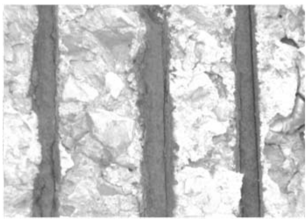


$\phi = \phi_0 - 0{,}023\ I_{corr}\ .\ t\ (\mu m/year)$

Cracking ⇔ loss of 15 to 40 μm

DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – PROPAGATION PHASE

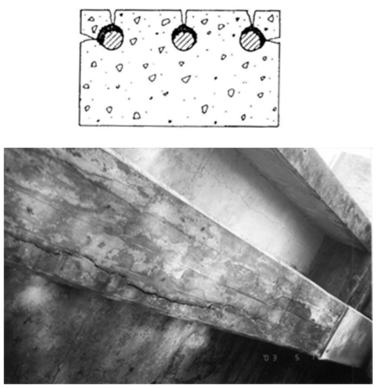


Uniforme Corrosion

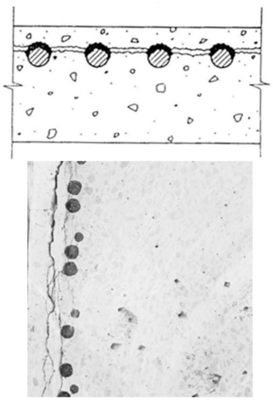
Localized Corrosion

DURABILITY – BASIC CONCEPTS

REINFORCEMENT CORROSION – PROPAGATION PHASE



Cracking parallel to bars



Delamination

(Marine exposure) I_{corr} = 100 μm/year , T_p = 10 years ⇒ Δ_r = 1 mm

$\Delta A_{\phi 10} = 0{,}36\, A_{\phi 10}$

$\Delta A_{\phi 20} = 0{,}19\, A_{\phi 20}$

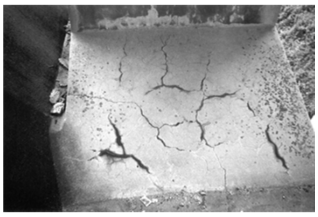
+ Loss of bond + Delamination

DURABILITY – BASIC CONCEPTS

Chemical attack:

Expansion reactions
- Alcalis/Agregates
- Sulphate attack

Destrutive reactions
- Acid attack
- Pure water



DURABILITY – BASIC CONCEPTS

CHEMICAL ATTACK – ALCALIS/AGREGATES REACTIONS

LNEC – E461 – Potential reactive aggregates and prevention of expansive reactions

Reactions
- Alcalinity in concrete pores
- Critical amount of reactive silica
- Water

Relevant control parameters
- Percentage of reactive aggregates
- Control of humidity at concrete pores
- Concrete porosity

DURABILITY – BASIC CONCEPTS

CHEMICAL ATTACK – SULPHATE REACTIONS

Reactions

Presence of aluminates

Presence of sulphates (from inside or outside concrete)

Internal sulphate Reaction

Large concrete masses

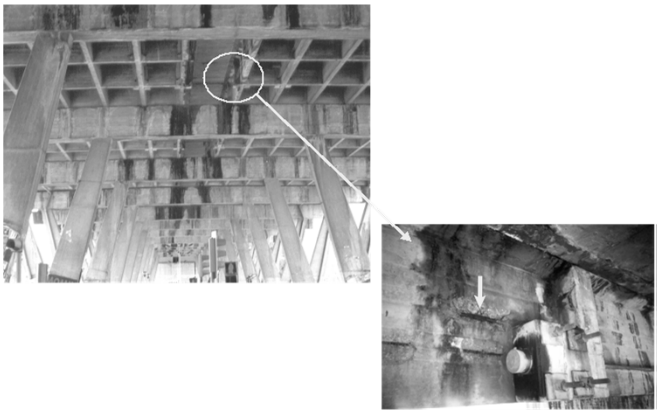
Very rapid hardening with high concrete temperature

DURABILITY – BASIC CONCEPTS

MICROENVIRONMENTS – INTERACTION OF STRUCTURE GEOMETRY WITH ENVIRONMENT

DURABILITY – BASIC CONCEPTS

MICROENVIRONMENTS – INTERACTION OF STRUCTURE GEOMETRY WITH ENVIRONMENT



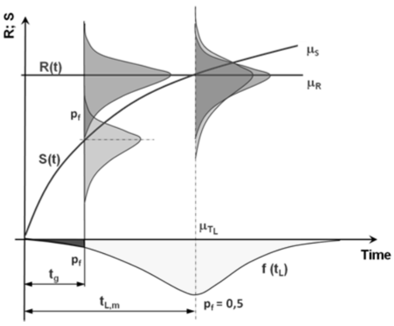
DURABILITY – BASIC CONCEPTS

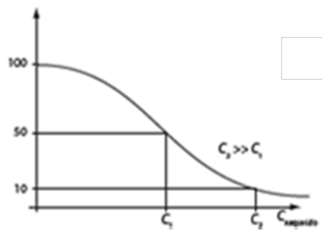
Design Service Life

The design service life is the period during which the structure has a satisfatory performance refering to safety, functionality and economy.

The end of service life occurs when:

- Safety decreases to unaceptable value;
- The maintenance costs and restrictions to use are not acceptable;
- The functionality requirements can not be satisfied.



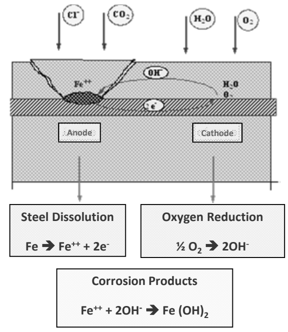


DURABILITY – BASIC CONCEPTS

LIMIT STATES

Service – (β = 1,5 ; P = 10^{-1}) - Depassivation
- Cracking due to corrosion

Ultimate – (β = 3,8 ; P = 10^{-4}) - Rupture



DURABILITY – BASIC CONCEPTS

STRATEGIES FOR DURABILITY DESIGN

Eliminate the deterioration risk

- Surface protection (changes exposure conditions)
- Use of non reactive materials (inox steel, non reactive aggregates)

Surface protection

Surface encapsulation with glass fiber (APE)

DURABILITY – BASIC CONCEPTS

STRATEGIES FOR DURABILITY DESIGN

Selected materials and conceive the structures to resist deterioration during service life

- Adopt the adequate cover
- Adopt the proper concrete mix
- Adopt the proper structure conceptual design

Control the risk of corrosion

- Cathodic prevention

For very aggressive environments adopt a multiple protection strategy.

Access the global construction cost during its service life (initial cost + maintenance)

Cathodic prevention

DURABILITY – DESIGN MODELS – MACRO LEVEL

SERVICE LIFE ASSESSMENT MODELS

Macro level – Semiempirical rules, related to environmental aggressivity and deterioration mechanisms

EN1992-1-1; LNEC E464

Conceptual design (+ drainage)

Crack control

Concrete mix requirements

Minimum cover requirements

Additional protections

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE CLASSES

X0 – No risk of corrosion or attack

XC – Corrosion induced by carbonation

XD – Corrosion induced by chloride

XS – Corrosion induced by chloride from sea water

XF – Freeze/thaw attack

XA – Chemical attack

(Sea water – XA1 ou XA2)

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE CLASSES

XC Corrosion induced by carbonation

Class	**Description of the environment**	**Informative examples where exposure classes may occur**
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE CLASSES

XS Corrosion induced by chlorides from sea water

Class	Description of the environment	Informative examples where exposure classes may occur
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures.

DURABILITY – DESIGN MODELS – MACRO LEVEL

MINIMUM REQUIREMENTS AND NOMINAL COVER

Environmental Requirement for $C_{min,dur}$ (mm)							
Structural Class	**Exposure Class**						
	X0	**XC1**	**XC2/XC3**	**XC4**	**XD1/XS1**	**XD2/XS2**	**XD3/XS3**
S1	10	15	20	25	30	35	40
S2	10	15	25	30	35	40	45
S3	10	20	30	35	40	45	50
S4	10	25	35	40	45	50	55
S5	15	30	40	45	50	55	60
S6	20	35	45	50	55	60	65

tg = 50 years → S4

tg = 100 years → S6

DURABILITY – DESIGN MODELS – MACRO LEVEL

REQUIREMENTS

Minimum Cover for t_g = 50 years (class S4)

	$A_{reinf\ steel}$	Prest. Steel
X0	10	10
XC1	15	25
XC2, XC3	25	35
XC4	30	40
XS1	35	45
XS2	40	50
XS3	45	55

$$c_{nom} = c_{min} + \Delta c_{tol}$$

+ Concrete mix requirements

DURABILITY – DESIGN MODELS – MACRO LEVEL

REQUIREMENTS

Concrete Quality

Type of cement	CEM I (Reference); CEM II/A (1)		CEM II/B(1); CEM III/A(2); CEM IV(2); CEM V/A(2)	
Exposure class	XC1/XC2	XC3/XC4	XC1/XC2	XC3/XC4
Maximum water/cement	**0,65**	**0,60**	**0,65**	**0,55**
Minimum cement content, C (kg/m³)	**240**	**280**	**260**	**300**
Minimum strength class	**C25/30 LC25/28**	**C30/37 LC30/33**	**C25/30 LC25/28**	**C30/37 LC30/33**

Type of cement	CEM IV/A (Reference); CEM IV/B; CEM III/A; CEM III/B; CEM V; CEM II/B (3); CEM II/A-D		CEM I; CEM II/A (3)	
Exposure class	XS1/XD1 XS2/XD2	XS3/XD3	XS1/XD1 XS2/XD2	XS3/XD3
Maximum water/cement	**0,55**	**0,45**	**0,45**	**0,40**
Minimum cement content, C (kg/m³)	**320**	**340**	**360**	**380**
Minimum strength class	**C30/37 LC30/33**	**C35/45 LC35/38**	**C40/50 LC40/44**	**C50/60 LC50/55**

DURABILITY – DESIGN MODELS – MACRO LEVEL

REQUIREMENTS

Concrete Quality

Type of cement	CEM IV/A (Referência); CEM IV/B; CEM III/A; CEM III/B; CEM V; CEM II/B (3); CEM II/A-D			CEM I; CEM II/A (3)		
Exposure class	XA1	XA2 (4)	XA3 (4)	XA1	XA2 (4)	XA3 (4)
Maximum water/cement	**0,55**	**0,50**	**0,45**	**0,50**	**0,45**	**0,45**
Minimum cement content, C (kg/m^3)	**320**	**340**	**360**	**340**	**360**	**380**
Minimum strength class	**C30/37 LC30/33**	**C35/45 LC35/38**	**C35/45 LC35/38**	**C35/45 LC35/38**	**C40/50 LC40/44**	**C40/50 LC40/44**

Water/cement – water/binder

Binder = cement + addition

DURABILITY – DESIGN MODELS – MACRO LEVEL

REQUIREMENTS

Minimum Cover and Concrete Quality

Possible modifications of durability requirements

For 100 years design service life

- For the actions of CO_2 and Cl^-
  - ➢ Change covers increasing the structure classe for S6
- For chemical attack:

  increase cement content by 20 kg/m^3

  increase 2 classes the minimum concrete strength class

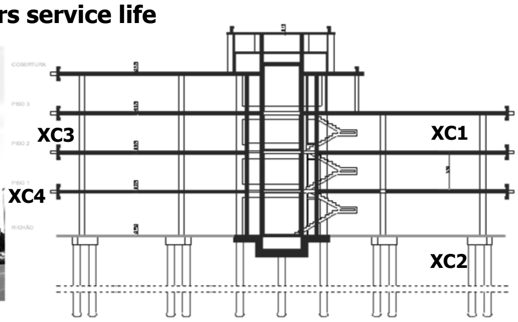
  reduce w/c by 0,05

In special situations C_{min} may be reduced

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE AND REQUIREMENTS CLASSES

Example – Building designed for 50 years service life

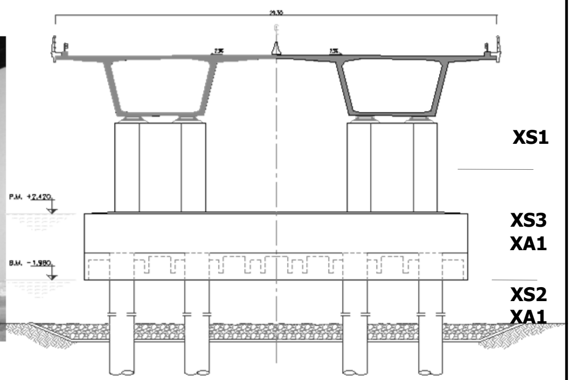


Description	Classification	Preventive measure			
		C_{nom}	$(a/c)_{max}$	C_{min}	f_{ck}^{cub}
Interior	XC1	25	0.65	240	30
Exposed surface	XC4	40	0.60	280	37
Protected surfaces	XC3	35	0.60	280	37
Underground	XC2	35[(5)]	0.65	240	30

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE AND REQUIREMENTS CLASSES

Example – Bridge designed for 100 years service life



DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE AND REQUIREMENTS CLASSES

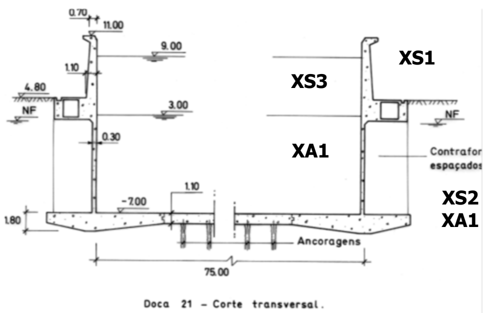
Example – Bridge designed for 100 years service life

Description	Classification	Preventive measure			
		C_{nom}	$(a/c)_{max}$	C_{min}	$(f_{ck})^{cub}$
Atmosferic zone Reinforced corrosion	XS1	55	0.50	320	37
Splash, spray zones Reinforced corrosion	XS3	65	0.40	340	45
Tidal zone Chemical attack Reinforced corrosion	 XA2 XS3	 – 65	 – 0.40	 360 –	 55 –
Submerged zone Chemical attack Biologic attack Reinforced corrosion	 XA1 XS2	 – 60	 0.45 –	 360 –	 55 –

DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE AND REQUIREMENTS CLASSES

Example – Dockyard designed for 50 years service life



DURABILITY – DESIGN MODELS – MACRO LEVEL

EXPOSURE AND REQUIREMENTS CLASSES

Example – Dockyard designed for 50 years service life

Description	Classification	Minimum Design Requirements			
		C_{nom}	$(a/c)_{max}$	C_{min}	f_{ck}^{cube}
Atmospheric zone	XS1	40	0.55	320	37
Zone with frequent contact with water	≅ XS3 XA1	50	0.45	340	45
Zone with unfrequent contact with water	XS3	50	0.45	340	45
Submerged zone	XS2 XA1	45	0.50	340	45

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS

Meso level – Metodology based in physical models

Semiprobabilistic method

$$a_d = a_{min} + \Delta a \geq x_{c,d}(t) = x_{c,k}(t) \cdot \gamma_f$$

a_{min} – minimum cover

Δ_a – tolerance

$x_{c,d}$ (t) – design carbonation depth or Cl^-_{crit} for $t_{service\ life}$ (+ propagation period)

$x_{c,k}$ (t) – Characteristic value

γ_f – Partial safety coefficient

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS

LNEC E465

$$t_{service\ life} = t_i + t_p > t_d = \gamma\ t_g$$

Service life estimated with performance models (initiation and propagation)

Design service life

Safety coefficient

t_i and t_p represents the initiation and propagation periods

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS

Corrosion associated with depassivation by carbonation

t_i – as a function of environment exposure, …

$$R_{c65} = \frac{2\ C_{acel}\ .\ t_1}{x_1^2}$$ (E391)

$C_{acel} = 90 \times 10^3$ Kg/m^3 CO_2

X_1 – Carbonation depth after t_1

Corrosion associated with depassivation by chloride penetration t_i as a function of environment exposure, and material resistance

D_0 (m^2/s) – E463 (Rapid chloride method NT Build 492)

$$D_a = k\ .\left(\frac{t_0}{t}\right)^n .\ D_0$$

$t_p = K\ \phi_0/(1{,}15\ \alpha\ I_{corr})$

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS

E465 Tables for D_0 required for:

- various environmental classes XS1, XS2, XS3
- t_g target service life
- Type of cement, concrete mix
- reliability classes

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS

Probabilistic method

$p_{desp} = p\{a - x_c(t) < 0\} < p_0 \approx 10^{-1}$ ($\beta = 1.3$)

a – cover
x_c (t) – carbonation depth

Ultimate Limit States

$p_{corrosion} = p\{\Delta_{rR} - \Delta_{rs}(t) < 0\} < p_0 \approx 10^{-4}$ a 10^{-6}

($\beta = 3.7$ a 4.4)

Δ_{rR}: loss of bar radius associated with rupture

Δ_{rs}: loss of bar radius due to corrosion

DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS – MESO LEVELS

Exemple

Model for Chloride penetration, as in E 465

Monte Carlo method for the probabilistic analysis

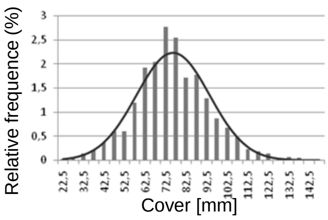
$Z(t) = R(t) - S(t)$

$$S(t) = X(t) = 2\mathrm{erf}^{-1}\left(\frac{C_s - C_{cr}}{C_s}\right)\sqrt{D(t)\,t}$$

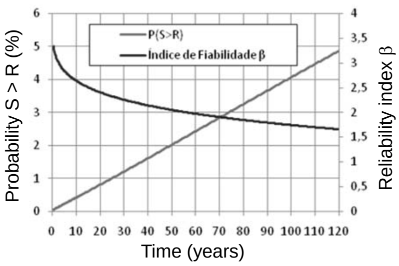
DURABILITY – DESIGN MODELS – MESO LEVEL

SERVICE LIFE ASSESSMENT MODELS – MESO LEVEL

Probabilistic Method



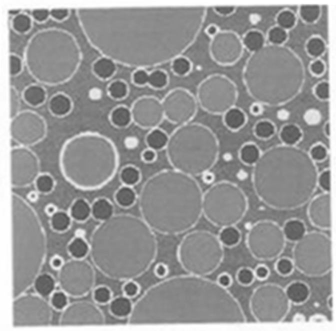
- D (t) from D_0^{med} = 5,39 × 10^{-12} m^2/s (obtained during the execution)



DURABILITY – DESIGN MODELS – MICRO LEVEL

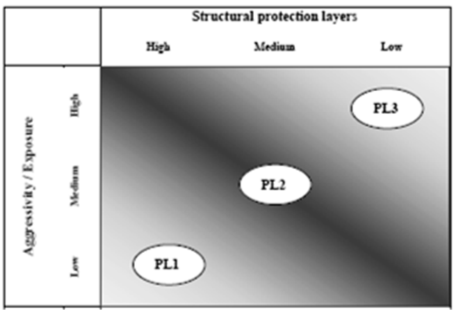
SERVICE LIFE ASSESSMENT MODELS

Micro level – Probabilistic method based in materials science



DURABILITY – POSTENSIONED CABLES

TENDON PROTECTION STRATEGIES (*fib* Bulletin 33 – 2005)



PL1 – A duct with a filling material providing durable corrosion protection

PL2 – PL1 plus an envelope, enclosing the tensile element bundle over its full length

PL3 – PL2 plus integrity of tendon or encapsulation to monitorable or inspectable at any time

DURABILIY – POSTENSIONED CABLES

Aggressivity/Exposure

Low – X0, XC1, XC2
Medium – XC3, XC4
XD1, XD2
XS2, XA1
High – XD3
XS1, XS3
XA2, XA3

Structure Protection Layers

Concrete quality, and cover
Waterproofing and surface protections
Drainage, expansion joints
Cracking control
Constructionn joints treatment
Acess for inspection and maintenance
Quality of construction

DURABILIY – PREVENTION OF EXPANSIVE CONCRETE REACTIONS

LNEC E 461

RAS – Aggregate Classification

Non reactive (class I)

Reactive (classes II and III)
Risk class associated
R1, R2, R3
Exposure conditions
A1, A2, A3
Level of prevention
P1 – No measures required
P2 – One measure required
P3 – Two measures required

Risk cathegory \ Environment exposure	A1	A2	A3
R1	P1	P1	P1
R2	P1	P2	P2
R3	P2 *	P3	P3

* For large masses of concreting level P3 is to be considered

Preventive Measure

- Avoid critical values of reactive silica
- Control alcalinity of concrete pores

DURABILIY – PREVENTION OF EXPANSIVE CONCRETE REACTIONS

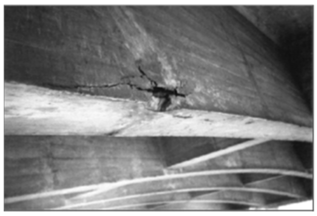
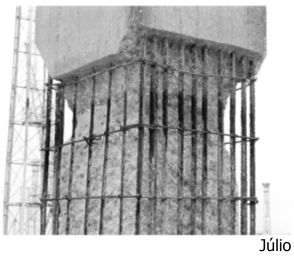
RSI – SIMILAR METHODOLOGY

Preventive Measures

- Avoid high concrete temperatures during hydration
  (T < 65°C)
- Control alcalis, sulphats and aluminates of the cement

DURABILITY – REDUCE EXECUTION DEFFECTS

- Cover control of execution
- Adequate spacers (E 469)
- concrete mix, good compaction and curing
- Treating concreting joints


DURABILITY DESIGN OF NEW STRUCTURE IN AGGRESSIVE ENVIRONMENT

EXAMPLE 1

Maritime Traffic Control Buildings – Build in the year 2000

Offshore 9 storey building constructed in an artificial jetty, 100m from the coast in Lisbon

DURABILITY DESIGN OF NEW STRUCTURE IN AGGRESSIVE ENVIRONMENT

EXAMPLE 1
Maritime Traffic Control Buildings
Durability specifications (1998 – ENV 206/E374)

Concrete mix specifications

HP Concrete	C > 35/45
	w/c ≤ 0,40
	Microsilica ≥ 15 Kg/m^3
	C ≤ 400 Kg/m^3

Concrete performance

Water penetration	< 20 mm (ISO 7031)
	$k < 1 \times 10^{-12}$ m/s
Capilarity absortion	$i = a\sqrt{t}$
	$a < 0,1$ $mm/min^{0,5}$
Porosity	P < 14% (RILEM1980 – COM25 PEM)
Chloride penetration	I < 1000 Coulombs (ASTM C1202 – 94)
	$D < 1 \times 10^{-12}$ m^2/s

DURABILITY DESIGN OF NEW STRUCTURE IN AGGRESSIVE ENVIRONMENT

EXAMPLE 2
Vasco da Gama Bridge – Built 1998

12.3 Km in Tejo Estuary

South Viaduct
Central Viaduct
Main Bridge
(In the estuary)
Expo Viaducts
North Viaducts

DURABILITY DESIGN OF NEW STRUCTURE IN AGGRESSIVE ENVIRONMENT

EXAMPLE 2
Vasco da Gama Bridge – Design Criteria

Design Service Life – 120 Years
ENV206/E378

$D_{cl^-} \leq 2 \times 10^{-12}$ m^2 s^{-1} for 28 days specimens (Method TANG LUPING)
$K_{0_2} < 1 \times 10^{-17}$ m^2 (AFPC – 1997a)

Zones of splash, spray, tidal – ECl_3 (XS3)
EQ2 (XA2)

Land zones in elevation – ECl_1

DURABILITY DESIGN OF NEW STRUCTURE IN AGGRESSIVE ENVIRONMENT

EXAMPLE 2

Vasco da Gama Bridge – Design Criteria

Concrete: $f_{ck}^{cubes} \geq 45$ MPa (in general)
CEM I – Land zones
CEM IV – Estuary zones

No reactive aggregates
w/c = 0,33 - 0,35

Concrete cover: 70 mm – in contact with water
50 mm – pier
40 mm – deck

Detailed inspection and maintenance plan

Preventive measures were introduced when execution deffects were identified

- Surface protection
- APE protection
- Pilot cathodic prevention project

DURABILITY DESIGN OF NEW STRUCTURE WITH LARGE CONCRETE MASS

EXAMPLE 3

Ponte Ocreza – In Construction - 2012

XC

Concreting Large Masses – RSI Prevention

DURABILITY DESIGN OF NEW STRUCTURE WITH LARGE CONCRETE MASS

OCREZA BRIDGE – DESIGN DURABILITY SPECIFICATIONS
Design Service Life – 100 Years

Corrosion Prevention

XC4 Cover 50 mm

Concrete – C35/45 – Foundations
C40/50 – Piers
C50/60 – Deck

Prevention of Internal Chemical Expansive Reactions (E461)

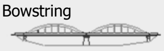
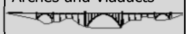
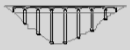
In general – Level P2
Foundations and top pier slabs – Level P3

DURABILITY DESIGN OF NEW STRUCTURE WITH LARGE CONCRETE MASS

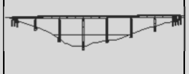
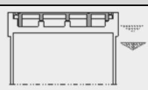
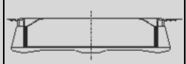
OCREZA BRIDGE – DESIGN DURABILITY SPECIFICATIONS
Design Service Life – 100 Years

Concrete Mix 123 for C50/60
CEM II/A – L – 400 Kg
Fly Ashes – 120 Kg
Sand 1 – 306 Kg
Sand 2 – 307 Kg
Aggregate 1 – 505 Kg
Aggregate 2 – 505 Kg
Water – 169 l
Admixtures – Pozolith – 3.1 l
– Glenium sky 526 - 3,7 l

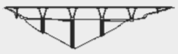
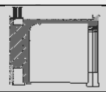
DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS

Name	Type	Dimension	Type of Exposure	Date of Construction	Date of Repairing	Age of repair	Main Cause of Deterioration
P. Chaminé R. Mora	Reinforced Concrete - 3 Arches 	L = 81,6 m l = 27,2 m	XC	1934	1994	60	Cover concrete deffects
P. Arcos R. Sado	Reinforced Concrete – Bowstring 	L = 68 m l = 31,5 m	XC	1944	2008	64	Cover
V. Duarte Pacheco	Reinforced Concrete Arches and Viaducts 	L = 355,1 m l = 90 m	XC (ASR)	1944	2001	57	Cover ASR
P. Sousa R. Sousa		L = 153 m l = 115 m	XC	1952	2009	57	Cover
P. Cávado Caniçada Reservoir	Reinforced Concrete Continuous Girder 	L = 176 m l = 23 m	XC (Albufeira)	1954	2008	54	Cover St cracking
V. Alhandra	Prestressed Concrete precast girder deck 	L = 276 m l = 115 m	XC	1961	2003	42	Cover Drainage

DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS

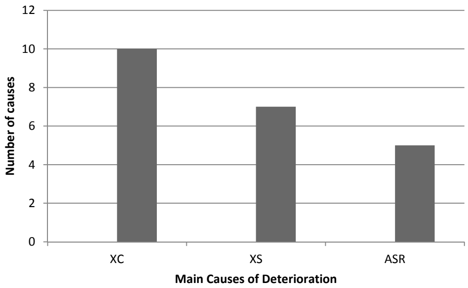
Name	Type	Dimension	Type of Exposure	Date of Construction	Date of Repairing	Age of repair	Main Cause of Deterioration
P. Varela Aveiro		L = 308 m l = 30,8 m	XS	1964	2008	44	Cover
P. Arrábida R. Douro	Reinforced Concrete Arches 	L = 493 m l = 270 m	XS	1965	2002	37	Cover Concrete deffects
P. S.João Areias R.Mondego Aguieira Reservoir		L = 260 m l = 40 m	XC Albufeira (ASR)	1975	2012	37	ASR
Silopor Jetty		L = 254 m	XS	1975	2005	30	Cover
Lisnave Docks		L = 1000 m	XS	1975	2000	25	Conc. quality cracks
Building facade Lisbon		10 Storeys	XC	1976	2006	30	Cover

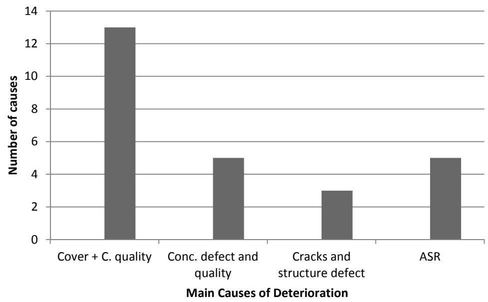
DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS

Name	Type	Dimension	Type of Exposure	Date of Construction	Date of Repairing	Age of repair	Main Cause of Deterioration
P. Pedrogão R.Guadiana P. Reservoir		L = 382 m l = 45 m	XC (ASR)	1978	2005	27	ASR
P. V.Nova Milfontes R. Mira		L = 367 m l = 68 m	XS	1978	2012	34	Cover
V. B. Mondego R.Mondego		L = 295 m l = 27 m	XC (ASR)	1981	2003	22	ASR
P. Figueira da Foz	Cable Stayed Bridge with Steel Deck  Prestressed Concrete Approach Viaducts 	L = 405 m l = 90,5 m L = 225 m l = 45 m	XS (ASR)	1982	2005	23	Concrete deffects Cover ASR
Structure Surounding Mosque Marrocos			XS	1993	2006	13 (Replacement)	Concrete quality Reinf. detailing

DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS

DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS





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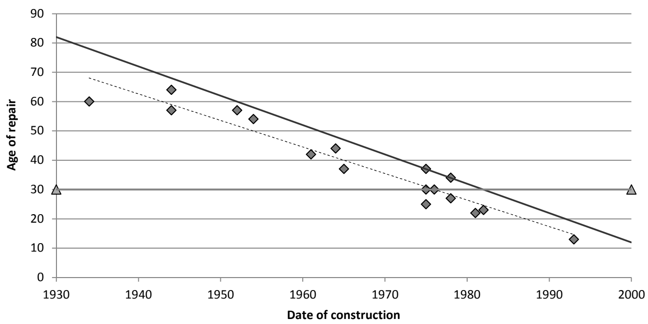
63

DURABILITY – EXPERIENCE FROM MAJOR REPAIRING WORKS



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64

DURABILITY – FINAL CONSIDERATIONS

Need for detailed technical specifications in repairing works

Performance criteria for micro concrete and mortars

Use of self compacted microconcretes, …

Performance criteria for surface protections (thick layers or paints)

Introduction of monitoring for assessment the future behaviour and durability of repairs

The most relevant costs are the required access means and labour costs.

The experience shows that enourmous costs are associated with the unexpected extension of repairing works.

Prevention is a must in new structures

Control of cover in execution

Control of concrete technology quality

Use of surface protection or cathodic prevention or inox steel in most aggressive marine environment regions (XS3)