Raymundo Rivera

International Symposium on Durability of Concrete

Durability Criteria Concepts in the Design of Concrete Structures

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REHABILITAR International Network CYTED

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When Architects and Engineers was recognized by first time in history?

2

Architect Imhotep (physician)

2790 BC

Staggered Pyramid of Djoser

3

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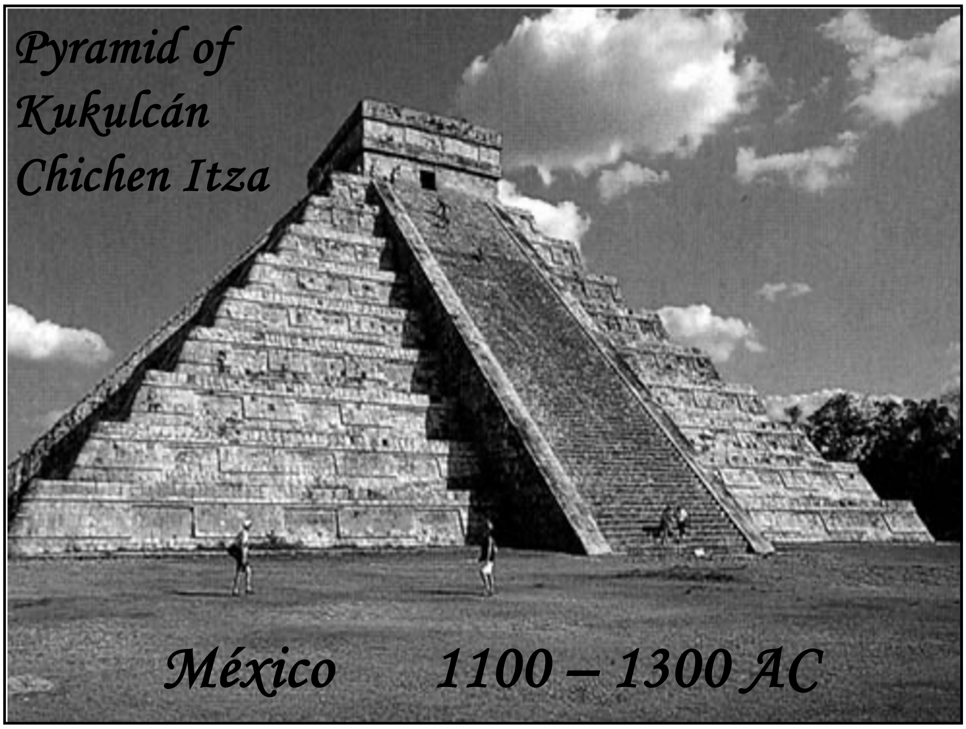

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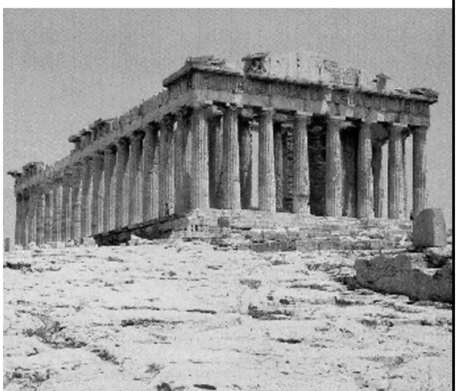
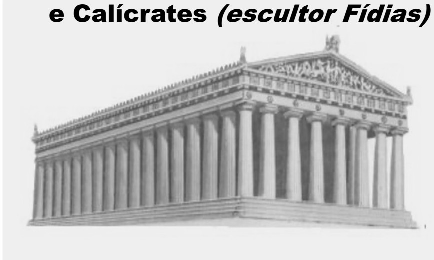
Antiquity

Inherent Willfull Durability Concepts



Arquitetos Ictinos de Mileto e Calícrates *(esculptor Fídias)*



Pártenon, ***440 BC***
“Péricles century”

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When Concrete emerge for first time?

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II Century AC

47m diameter

ROMA

Pantheon

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Century

IV → Byzantine style → Church Santa Sophia, Istanbul

IX → Romanic style → Abbey Cluny, France

XII-XIV → Gothic style → Cathedral Notre Dame, Cologne

XV → Renaissance style

XVII → Baroque style → San Pietro, Bernini

XVII → Neoclassic style → Triumph Arc , Paris

XIX → Steel constructions

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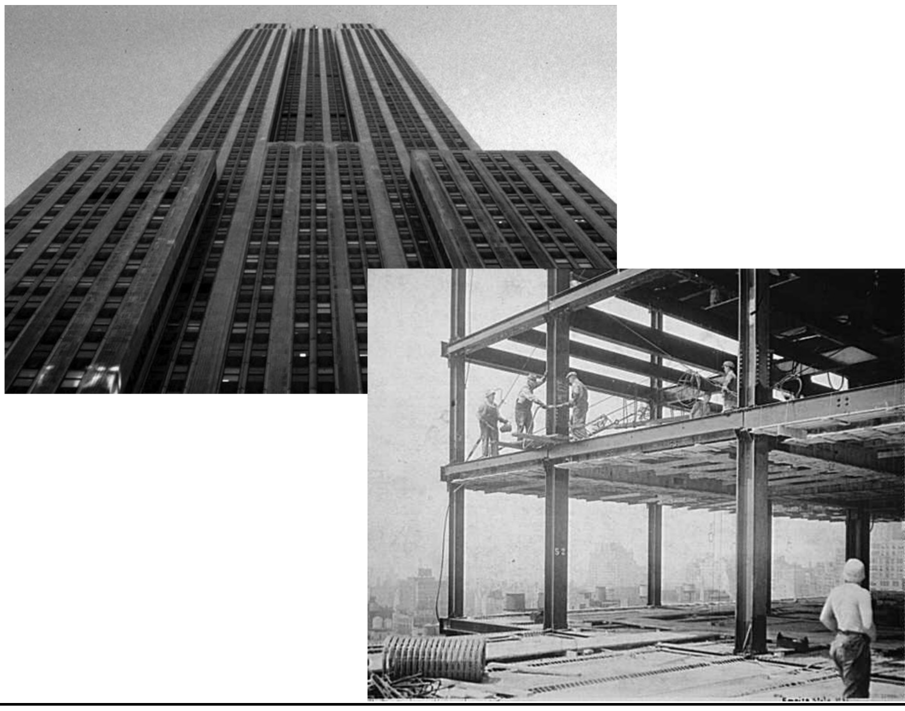

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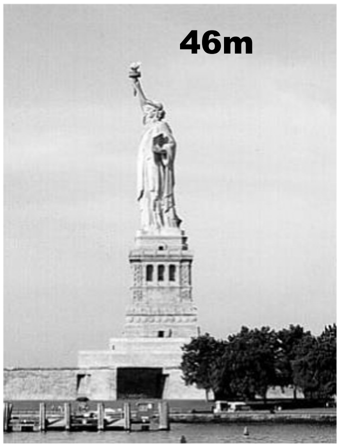
“Gustave Eiffel”
1884 → Statue of Liberty
1889 → Eiffel Tower



(5y+2y)
60t
paint

2004 → 6.230.050 visitors

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XX CENTURY
1900

NEW MATERIAL

Reinforced Concrete

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Salvo Palace
Montevideo

27 stores

Uruguay 1928

103 m

f_{ck} = ?

World record

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Martinelli Tower

São Paulo

1929

30 stores

high 109m

Rua Líbero Badaró

f_{ck} = 13,5 MPa

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Reinforced Concrete = Eternity!!

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MASP Art Museum São Paulo 1968

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Concrete Structures Durability

1. Aging
2. Service Life
3. Aggressiveness
4. Concrete Resistance
5. Prediction Models
6. Design Criteria
7. Materials Selection
8. Construction Procedures
9. Maintenance Procedures

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Aging

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aging

Related to concrete

- leaching (acid, water, liquids)
- expansion (sulfate, alkali aggregrate, freezing and thawing)

Related to reinforcement

- chlorides
- carbonation

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Concrete Structures Durability

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ACI 318

ACI365.1R

service life

ACI 365.1R Chapter 1

Service life is the period of time after concrete placement during which all the properties exceed the minimum acceptable values when routinely maintained.

Three types of service life have been defined;

1. **Technical service life** is the time in service until a defined unacceptable state is reached, such as spalling of concrete;
2. Functional service life is the time in service until the structure needs change in functional requirements;
3. Economic service life is the time in service until replacement of the structure (or part of it) is economically more advantageous than keeping it in service.

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BS 7543, 1992 Guide to

Durability of Buildings and Building Elements, Products and Components

Service Life	Structures
< 10 years	**Exposition**
> 10 years	**Replaceable**
>30 years	**Industrial Buildings**
> 60 years	**Buildings**
>120 years	**Public Buildings**

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End of Service Life?

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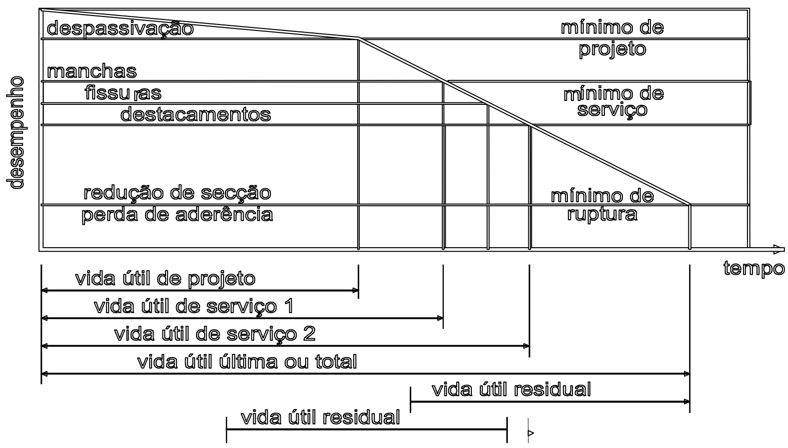
comments

Service Life



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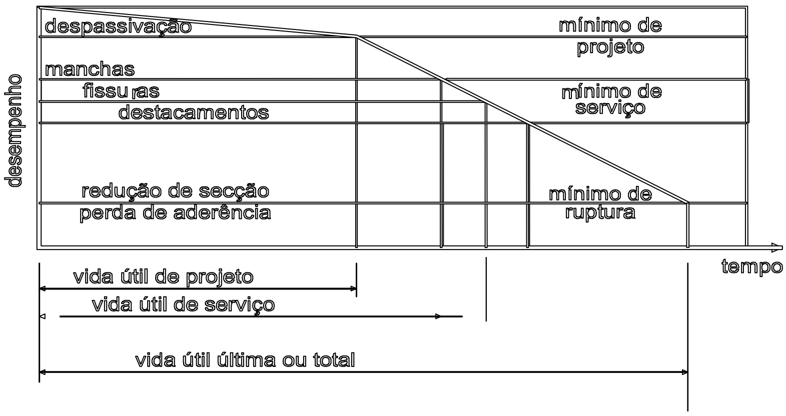
Brazilian ACI 318



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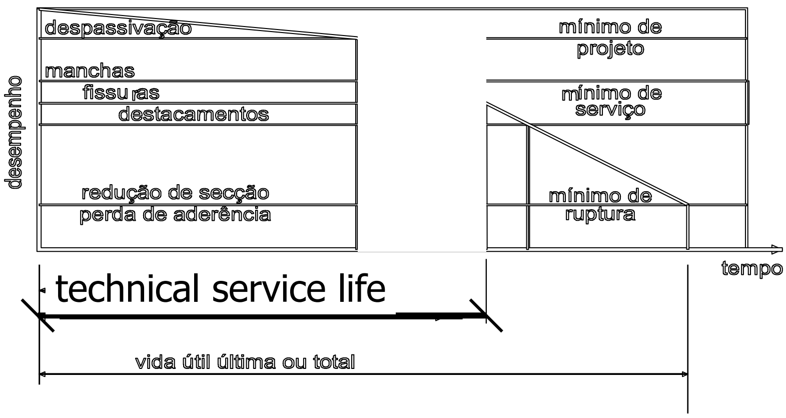
NBR 6118 ACI 318

ACI 365-1R

6 years



t ≥ ??? years

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Concrete Structures Durability

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aggressiveness Chapter 4

SPECIAL EXPOSURE CONDITIONS

Exposure Condition
concrete intended to have low permeability when exposed to water
freezing and thawing or deicing chemicals
corrosion protection of reinforcement – deicing chemicals, salt, salt water, brackish water, seawater or spray from these sources
sulfate exposure

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Brazilian Standard

Aggressiveness approach

macro-clima	micro-clima			
	internal		external	
	dry	wet	dry	wet
rural	I	I	I	II
urban	I	II	I	II
sea shore	II	III	-	III
industry	II	III	II	III
specific	II	III ou IV	III	III ou IV
splash zone	-	-	-	IV
underwater ≥ 3m	-	-	-	I
earth	-	-	I	II, III, IV

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Concrete Structures Durability

1. Aging
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6. Design Criteria
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Service Life Prediction Models

- Empiric or indirect
- Accelerated Tests
- Deterministic Approach

  (Transport Mechanism)
- Stochastic Approach

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Service Life Prediction Models

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First Standards for Concrete Structures

1903	Switzerland
1903	Germany
1906	France
1907	England

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National Association of Cement Users
Philadelphia, USA, Feb.1910

STANDARD BUILDING REGULATIONS for the USE of REINFORCED CONCRETE

"the main reinforcement in column shall be protect by a minimum of two inches (> 5cm) of concrete cover, reinforcement in girders and beams by one and one-half inches (>3,8cm) and floor slabs by one inch (>2,5 cm)."

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Durability Requirements

- **Concrete Cover**
- **Concrete Composition**

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design criteria
concrete cover
sections 7.7.1, 7.7.5

Member	Environmental conditions		
	Not exposed to earth or weather	Exposed to earth or weather	Severe environments
	Nominal concrete cover (mm)		
Slabs	20	40	50
Beams Columns	40	50	60

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ACI 318 design criteria concrete

Table 4.2.2 Requirements for Special Exposure Conditions

Exposure Condition	Maximum w/c	Minimum f'_c (MPa)
Concrete intended to have low permeability when exposed to water	0,50	28
freezing and thawing or deicing chemicals	0.45	31
corrosion protection of reinforcement – deicing chemicals, salt, salt water, brackish water, seawater or spray from these sources	0.50	35

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Service Life Prediction Models

- Empiric or indirect
- **Accelerated Tests**
- Deterministic Approach

  (Transport Mechanism)
- Stochastic Approach

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ASTM E 632, USA 1988

Standard Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials

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Service Life Prediction Models

- Empiric or indirect
- Accelerated Tests
- Deterministic Approach

  (Transport Mechanism)
- Stochastic Approach

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Gas and fluids ingress

- **Permeability**
- **Capillarity**
- **Diffusibility**
- **Migration**

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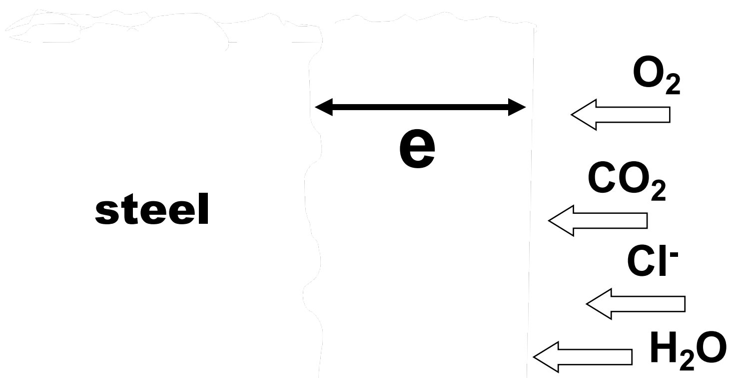
Generalization

$$e = k \bullet \sqrt{t} \quad \text{(cm)}$$



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Carbonation

$$t = \frac{e_{CO2}^2}{k_{CO2}^2} \quad \text{(year)}$$

- e_{co2} → 1 a 5 cm
- k_{co2} → 0.1 a 1.0 cm/year$^{1/2}$

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Carbonation

f_{ck}= 25 MPa

e = 1,0 cm → t = 10 years

e = 2,5 cm → t = 60 years

e = 4,0 cm → t = 160 years

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Carbonation

e = 2,0 cm

f_{ck}= 15 MPa → t = 8 years

f_{ck}= 50 MPa → t = 350 years

f_{ck}= 25 MPa → t = 38 years

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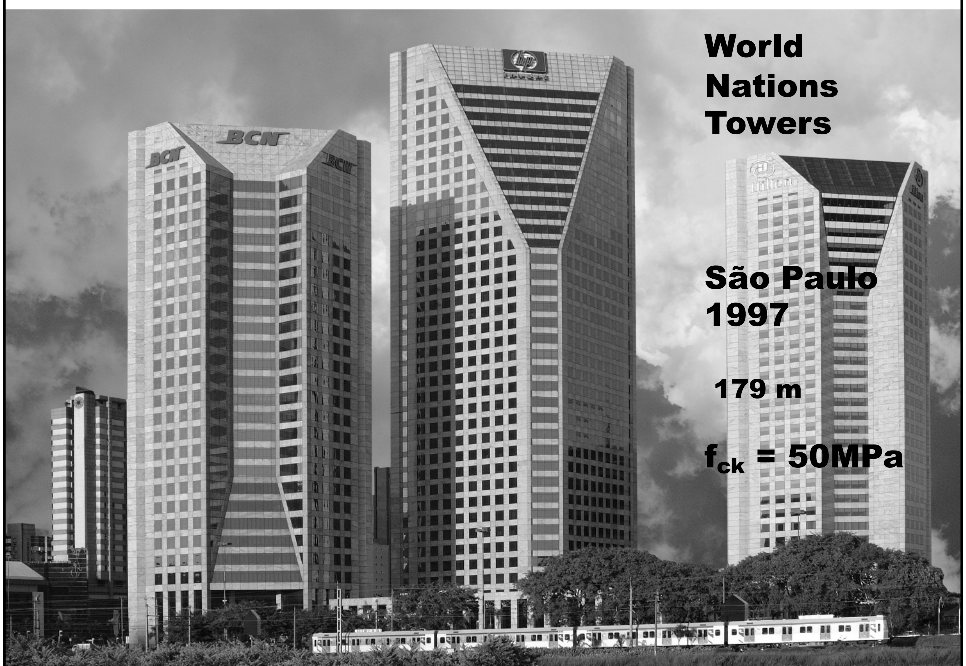

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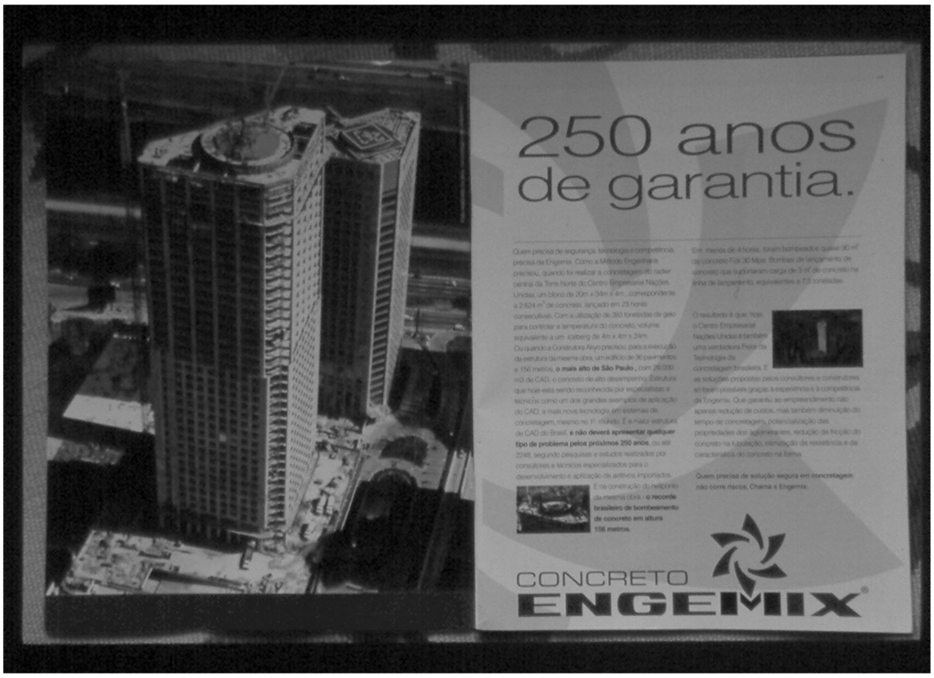

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Chlorides - diffusion

e = 2,0 cm

f_{ck}= 15 MPa → t = 4 years

f_{ck}= 50 MPa → t = 150 years

f_{ck}= 25 MPa → t = 23 years

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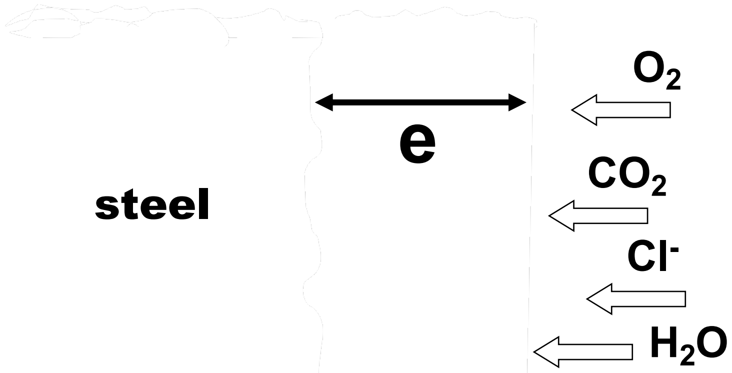
Generalization

$$e = k \bullet \sqrt{t} \quad \text{(cm)}$$



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Chlorides

$$t = \frac{e_{Cl}^{2} \bullet f_{ck}^{2} \bullet A^{0,4}}{7{,}35^{2} \bullet UR^{1,4} \bullet T^{0,2} \bullet Cl^{1,4}} = \frac{e_{Cl}^{2}}{k_{Cl}^{2}} \quad \textbf{(year)}$$

$$k_{Cl} = \frac{7{,}35 \bullet UR^{0,7} \bullet T^{0,1} \bullet Cl^{0,7}}{f_{ck}^{1} \bullet A^{0,2}} \quad \textbf{(cm/year}^{1/2}\textbf{)}$$

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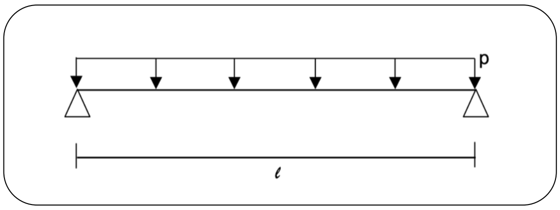
Exemple



SPLASH ZONE

- Permanent load: 5 kN/m (DL)
- Design load: 4,5 kN/m (LL)

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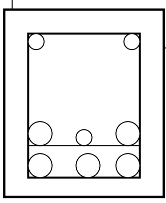
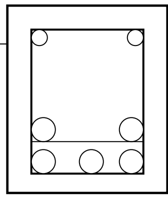
Dimensionamento



Steel = + 12%

C1 = 0%

C2 = - 10%



ACI 318-02

h = 36 cm

reinforcement

5 ϕ 20mm + 1 ϕ 16mm

deflection and creep

NBR 6118/04

h = 36 cm

reinforcement

5 ϕ 20mm

deflection and creep

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Service Life

35 MPa

6 cm

ACI 318

40 MPa

5 cm

NBR 6118

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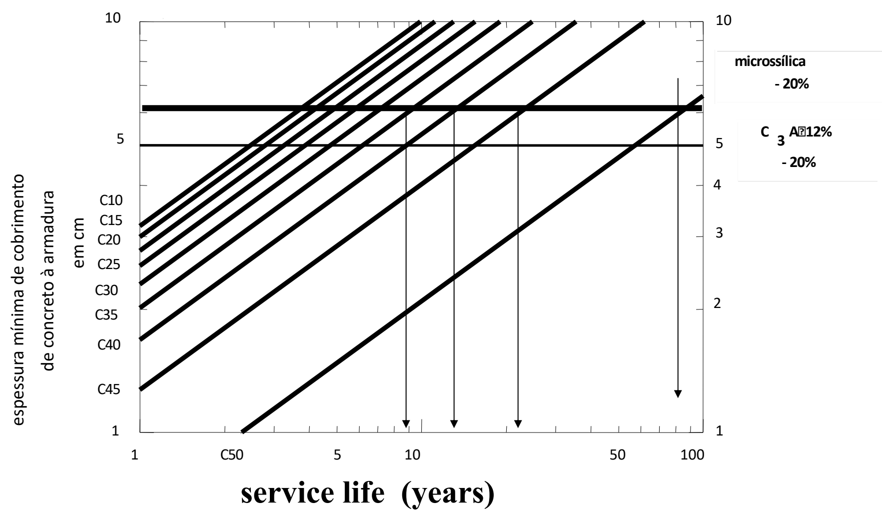
Clohride Diffusion

comments



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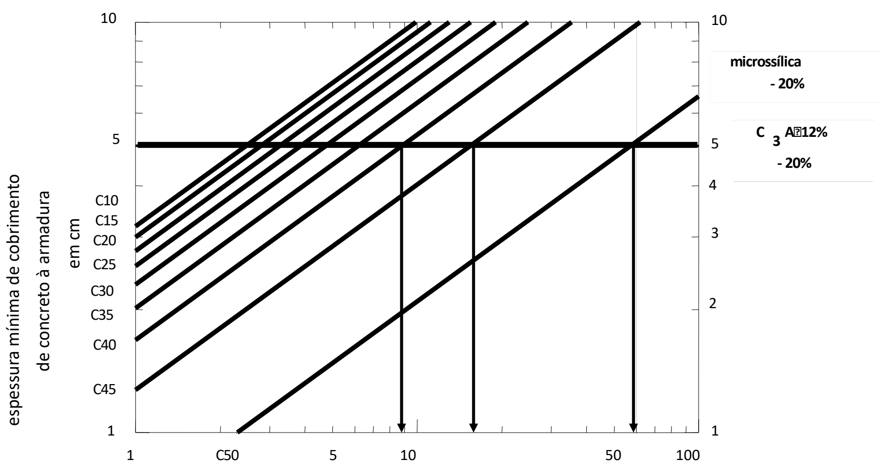
SPLASH ZONE

comments



service life (years)

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Service Life Prediction Models

- Empiric or indirect
- Accelerated Tests
- Deterministic Approach

  (Transport Mechanism)
- Stochastic Approach

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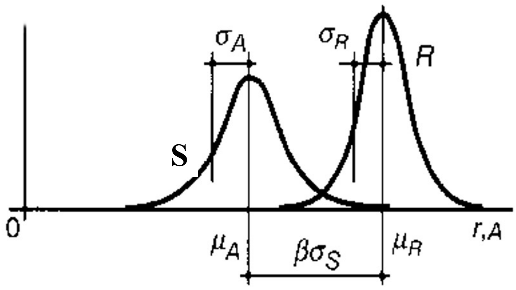
Service Life ~ Structural Approach

Reliability concepts:

$P (S > R) < 10^{-6}$

$\beta = 3.8$



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R → Concrete Cover

μ_{cc} ; σ_{cc}

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R → Concrete Cover

μ_{cc} ; σ_{cc}

S → Carbonation Depth

μ_{CO_2} ; σ_{CO_2}

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Reliability

$$\beta_t = \frac{\mu_{R,t} - \mu_{S,t}}{\sqrt{\sigma_{R,t}^2 + \sigma_{S,t}^2}}$$

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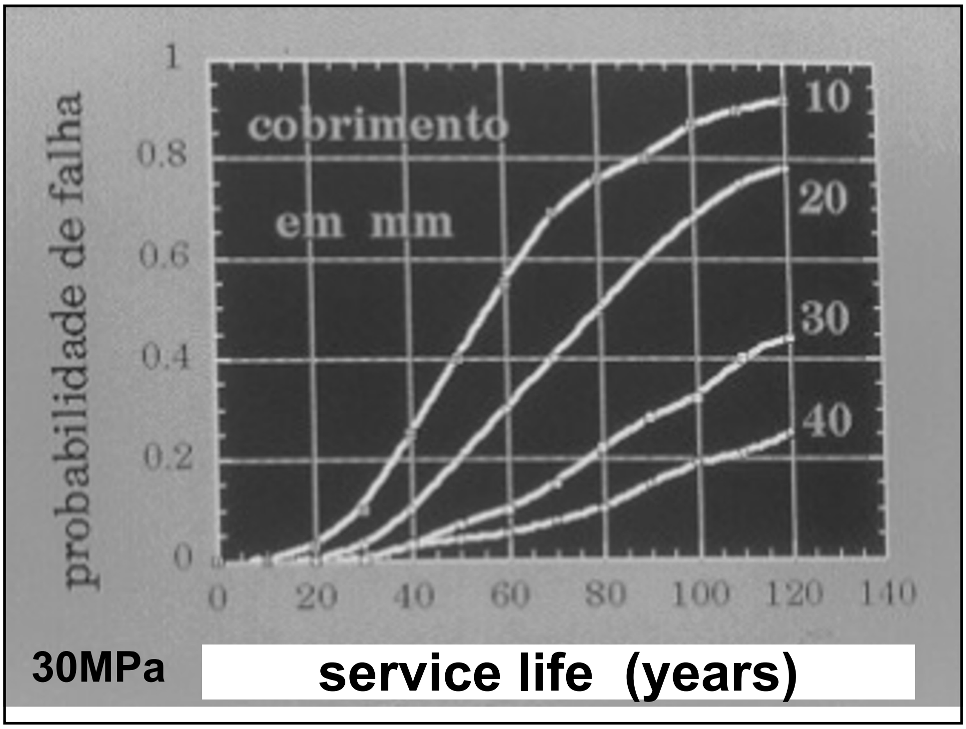

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“How can we increase durability?”

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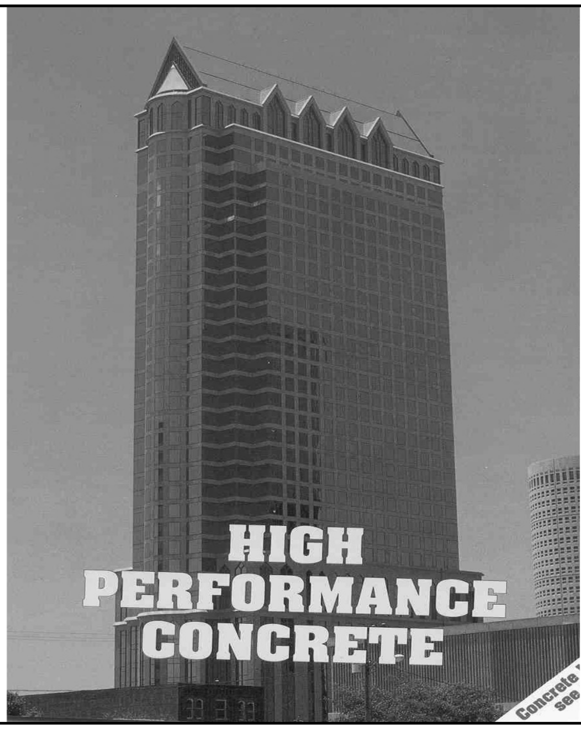

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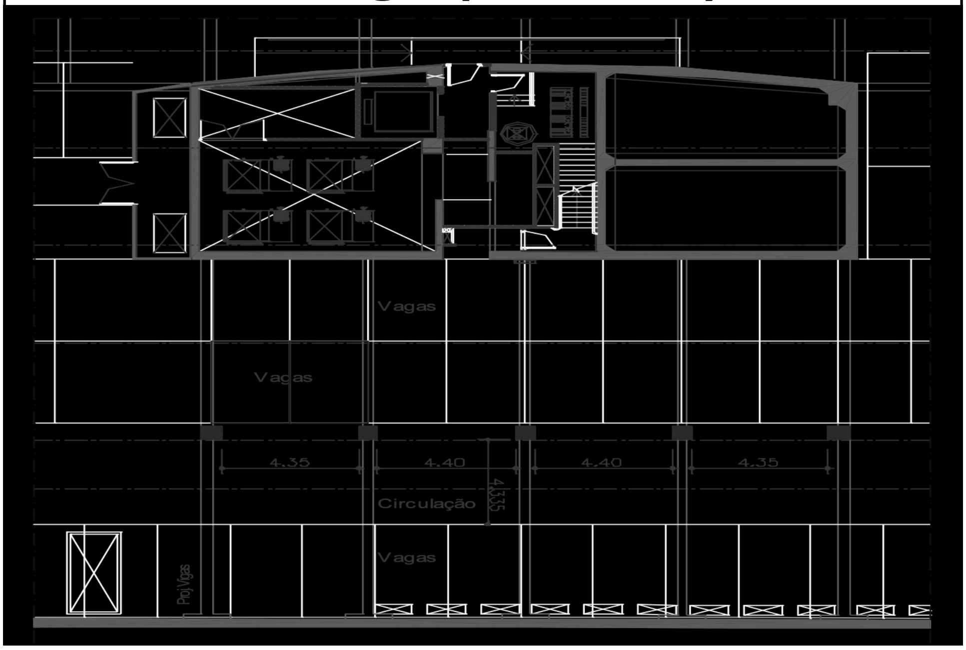
Design *(e-Tower)*



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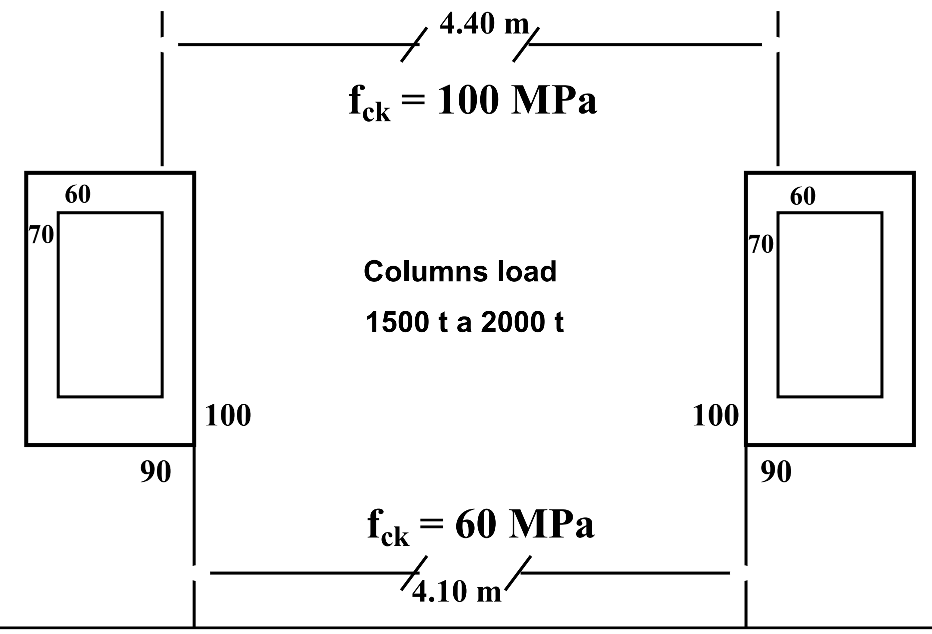
Design *(e-Tower)*



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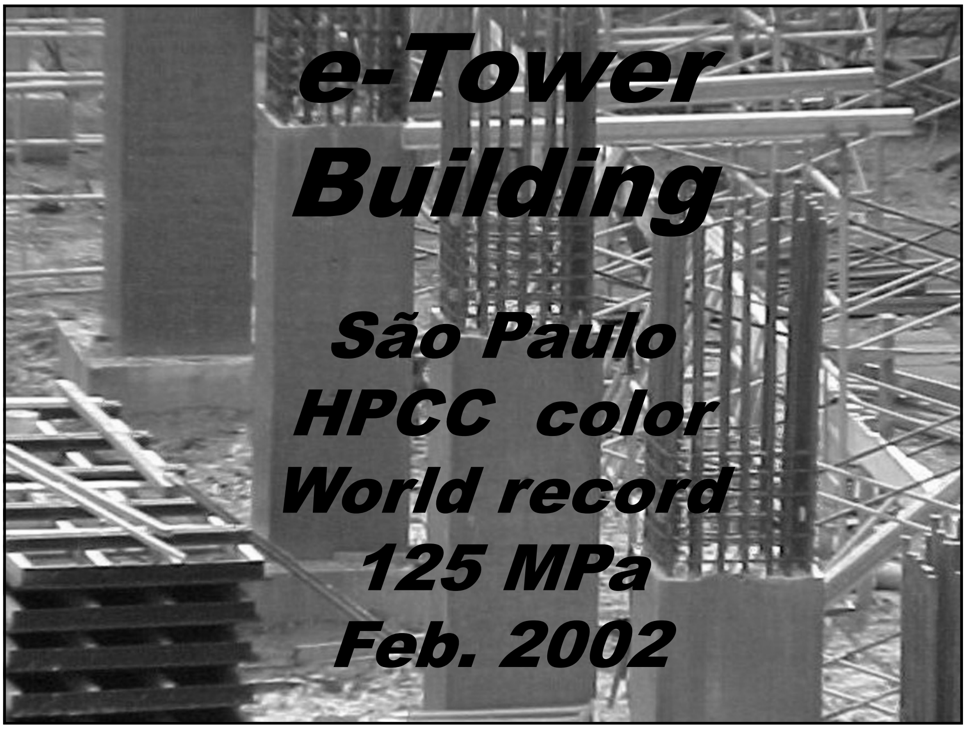

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Service Life
980 years!

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Sustanaible Development

"Increasing service life of concrete structures we can preserve the natural resources.

If we develop the design and construction ability we can get concrete structures with **500 years** service life. Doing this we can multiply by ten our productivity which means preserve the 90% of them"

Kumar Mehta

Reducing the Environmental Impact of Concrete

Concrete International. ACI, v.23, n. 10, Oct. 2001. p.61-66

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The construction must be

- *Firmitas*
- *Utilitas*
- *Venustas*

Marcus Vitruvius

30 BC

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HPC is a great opportunity to increase durability and enhance engineering profession and professionals
2 8 2002

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Thank you!

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