AVECRETO
Venezuela en Concreto

1er Encuentro Internacional
del Concreto Premezclado

Durabilidad y Vida Útil de las Estructuras de Concreto

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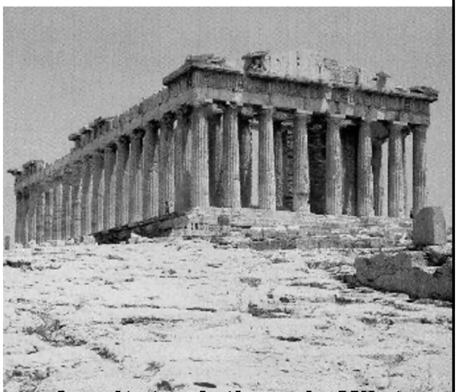
REHABILITAR International Network CYTED

1

Construir con Materiales Resistentes y Durables

2

EL CONCEPTO DE CONSTRUIR CON DURABILIDAD EXISTE EN LAS OBRAS DESDE LA ANTIGUEDAD

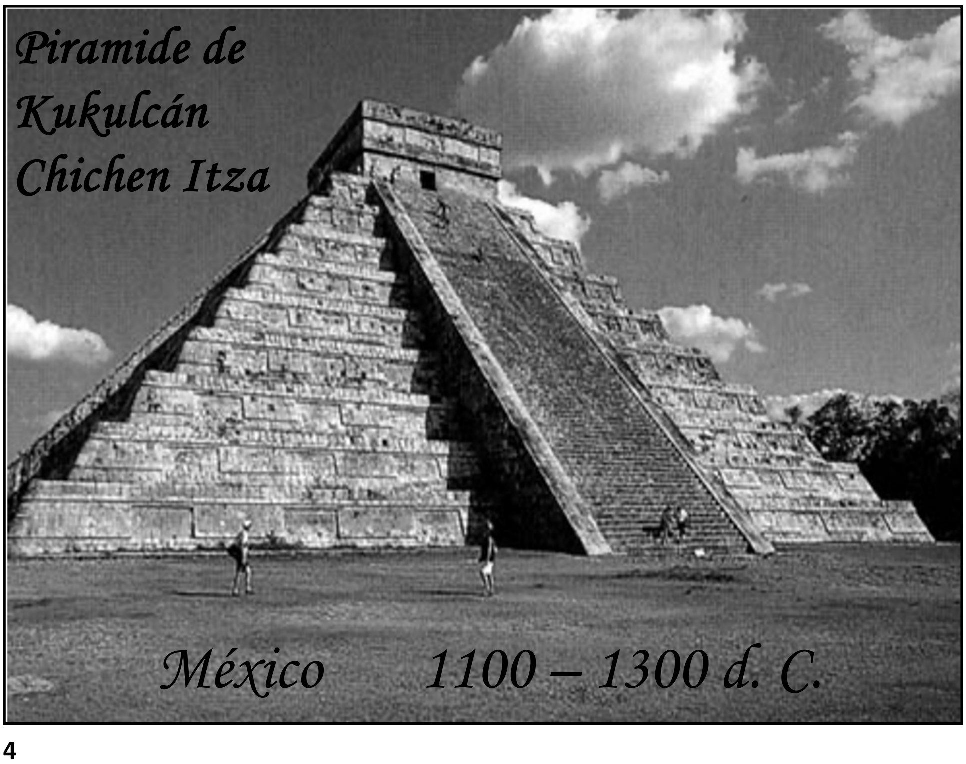


Arquitetos Ictinos de Mileto e Calícrates *(escultor Fídias)*

Pártenon, ***440 aC***

"siglo de Péricles"

3



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QUANDO FUE RECONOCIDA LA PROFESIÓN DE ARQUITECTO e INGENIERO CIVIL POR PRIMERA VEZ ?

6

Arquitecto y médico Imhotep

2790 A C

Pirámide escalonada de Djeser

7

8

QUANDO APARECE EL HORMIGÓN POR PRIMERA VEZ ?

9

Panteón de Roma

10

Domo del Panteón → Siglo II dC

Diámetro de 47m

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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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Catedral de Notre Dame

1163-1330

La bóveda de la nave central → 35 m de altura

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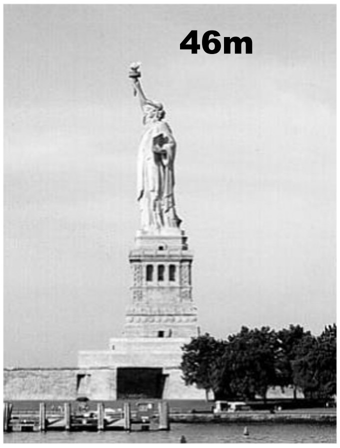
"Gustave Eiffel"
1884 → Estatua de la Libertad
1889 → Torre Eiffel



(5a+2a)
60t
pintura

2204 → 6.230.050 visitantes

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SIGLO XX

1900

APARECE UN NUEVO MATERIAL

Hormigón Armado
Concreto Armado

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Palacio Salvo
Montevideo

27 pisos

Uruguay 1928

Altura 103 m

f_{ck} = ?

record mundial

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Edifício Martinelli

São Paulo

1929

30 pisos

Altura 109m

Rua Líbero Badaró

f_{ck} = 13,5 MPa

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En aquellos tiempos se creía que...

LOS PROBLEMAS DE CORROSIÓN Y DURABILIDAD ESTABAN RESUELTOS DEFINITIVAMENTE PUES EL ACERO SERIA PROTEGIDO “ETERNAMENTE” POR EL HORMIGÓN

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MASP Museo de Arte São Paulo 1968

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“Cómo pueden ser más Durables?”

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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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8. Construction Procedures
9. Maintenance Procedures

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ACI 318 — service life

ACI365.1R — **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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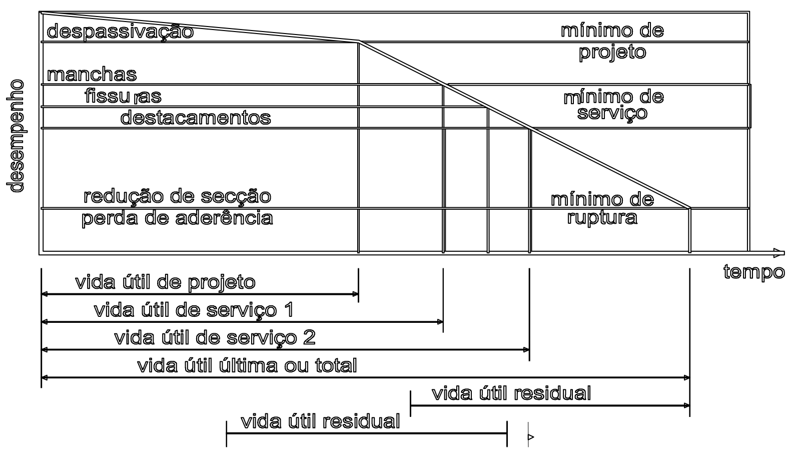
comments

Service Life



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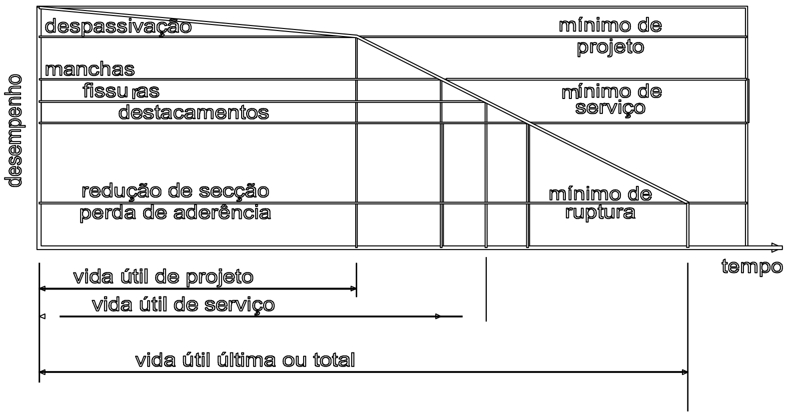
Brazilian

ACI 318



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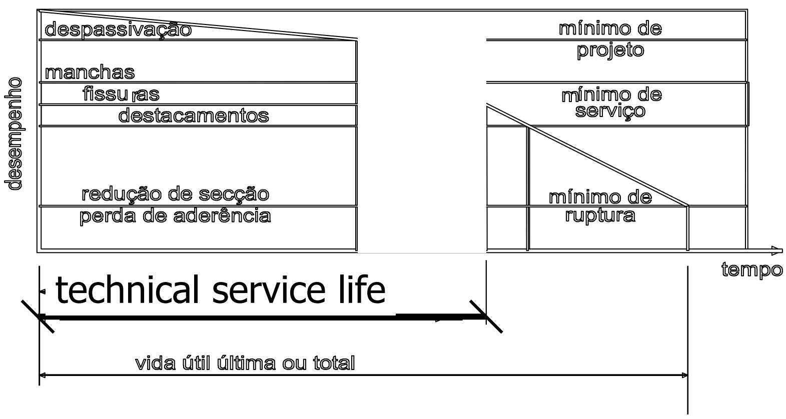
NBR 6118

ACI 318
ACI 365-1R

6 years



t ≥ ??? years

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Concrete Structures Durability

1. Aging
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9. Maintenance Procedures

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ACI 318

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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9. Maintenance Procedures

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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

- Empiric or indirect
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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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ACI 318

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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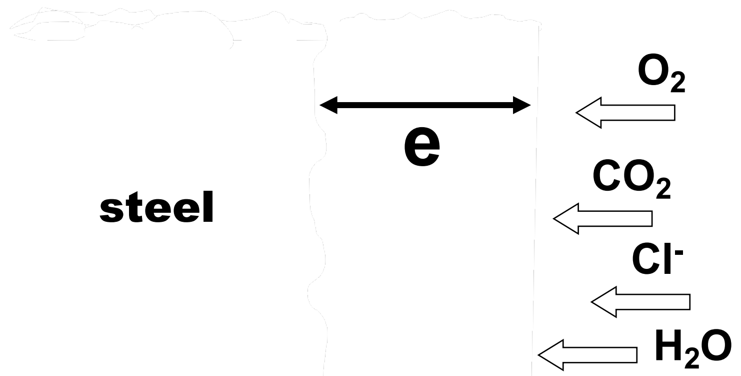
Generalization

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



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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

50

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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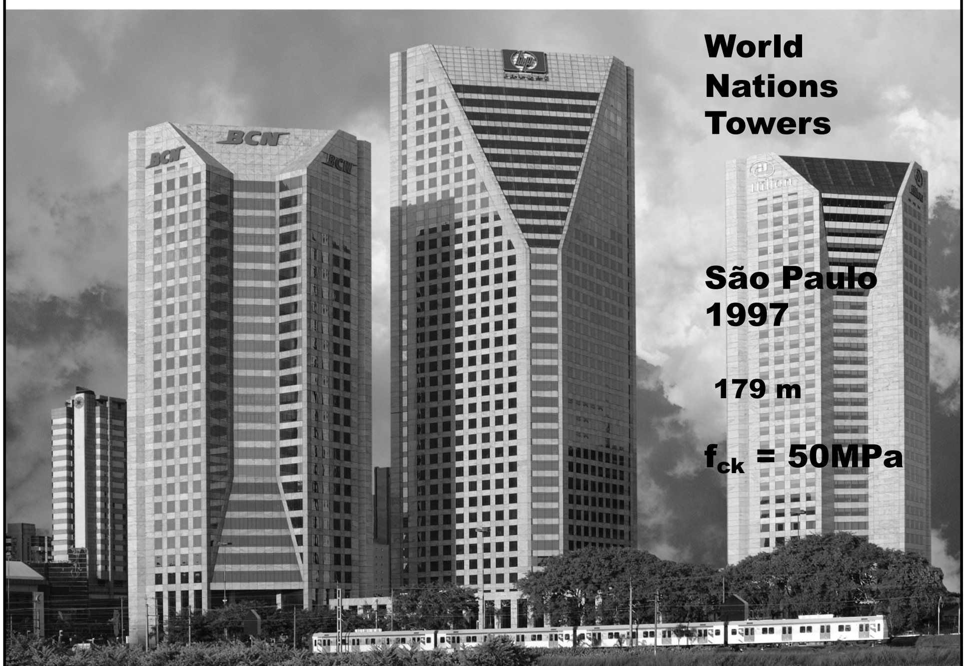

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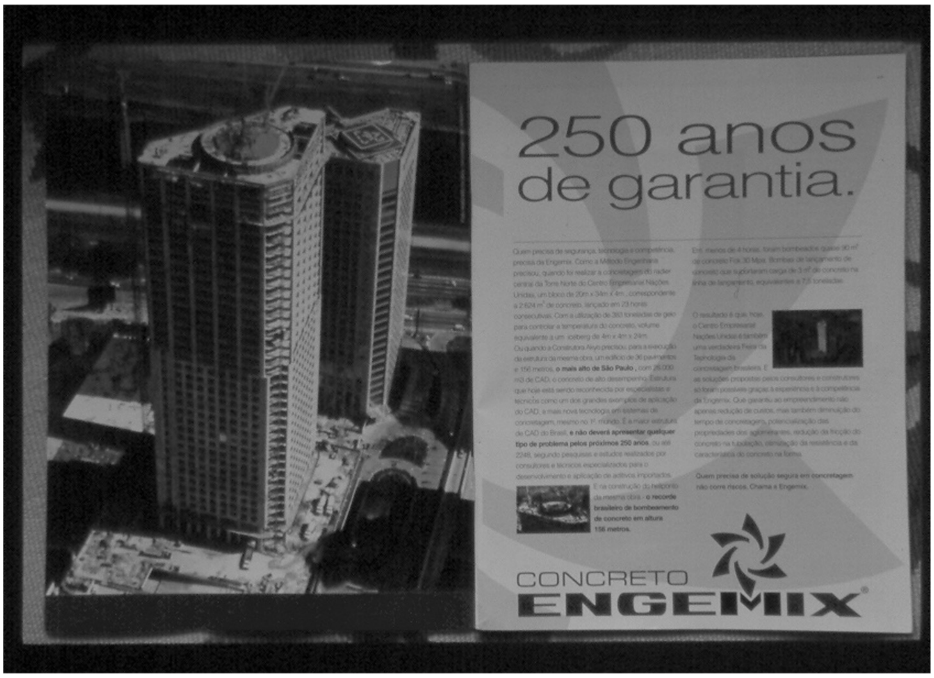

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Chlorides

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

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

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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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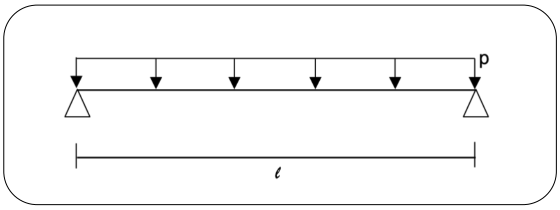
Exemple



SPLASH ZONE

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

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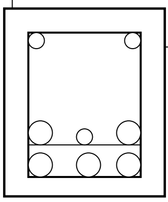
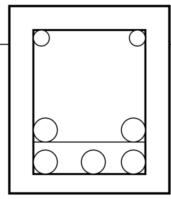
Dimensionamento



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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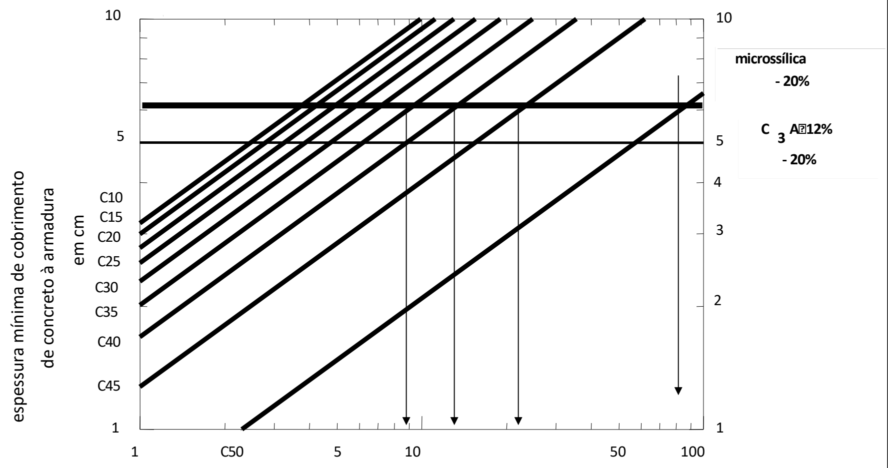
Clohride Diffusion

comments



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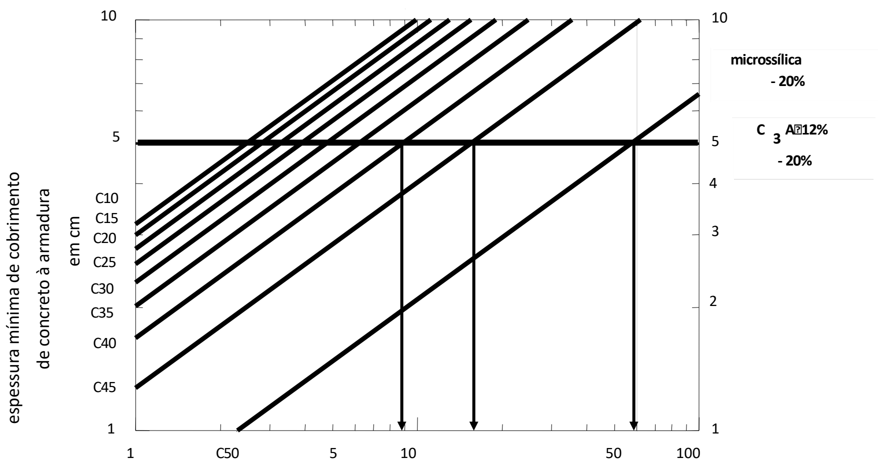
SPLASH ZONE

comments



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Service Life Prediction Models

- Empiric or indirect
- Accelerated Tests
- Deterministic Approach

  (Transport Mechanism)
- Stochastic Approach

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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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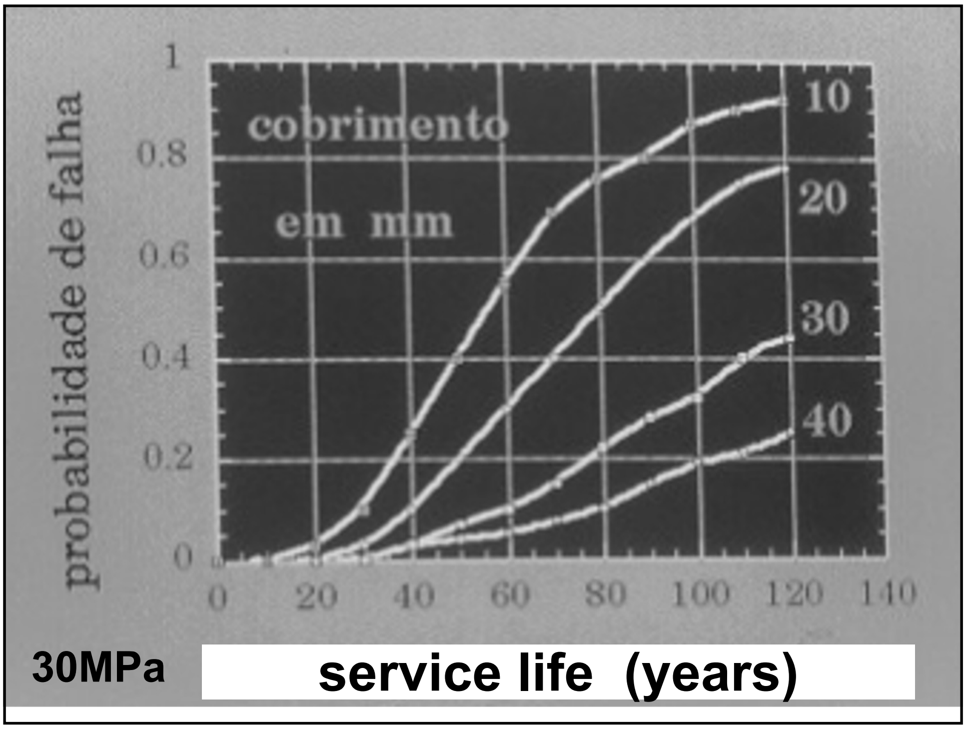

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“How can we increase durability?”

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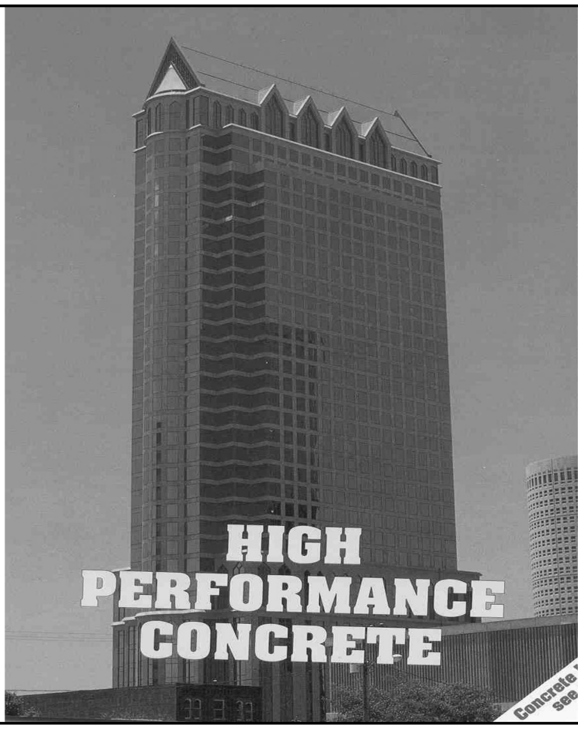

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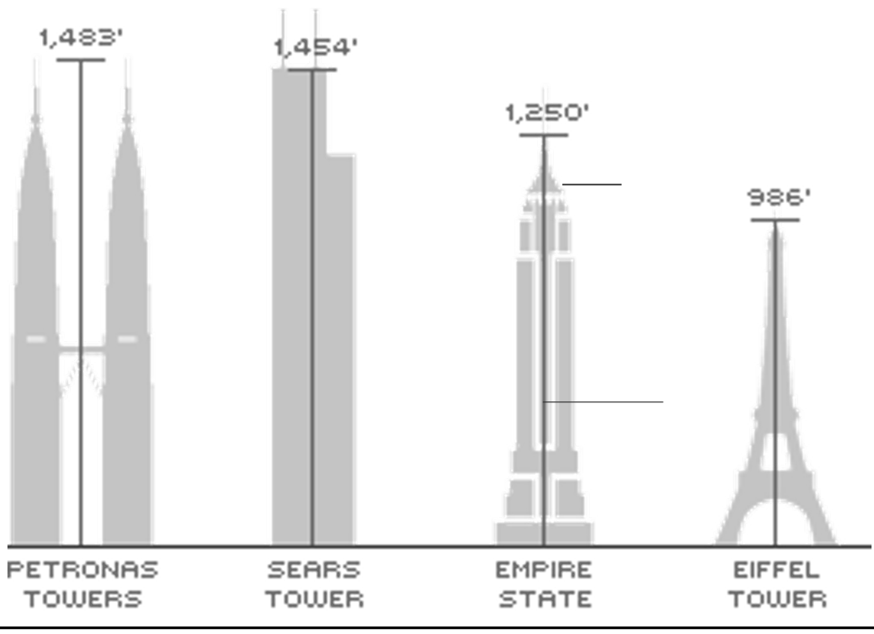
World Highest Towers



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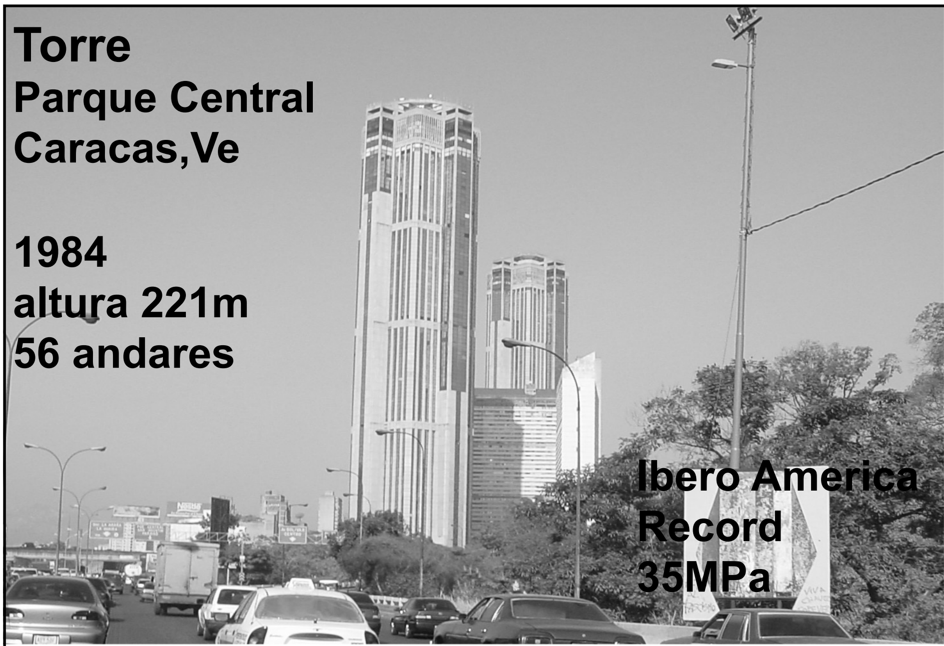

Ings

M. Paparoni & S. Oloma

Arqs

Enrique Siso & Daniel Shaw

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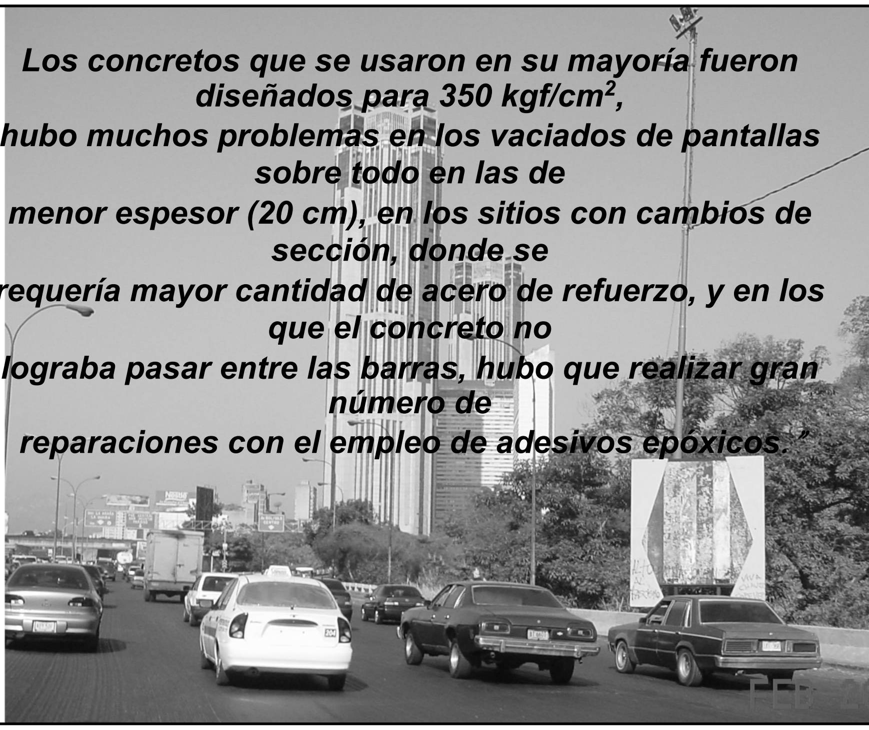

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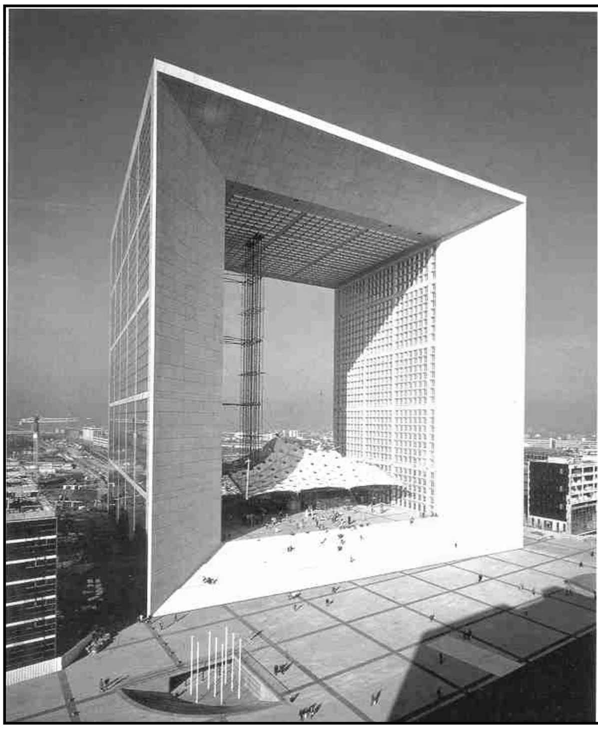

Grand Arch

La Defense

Paris

França 1990

f_{ck} = 60 MPa

“high-tech style”

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Melhoria arquitetônica

Concreto aparente, grandes vãos

Superior Tribunal de Justiça

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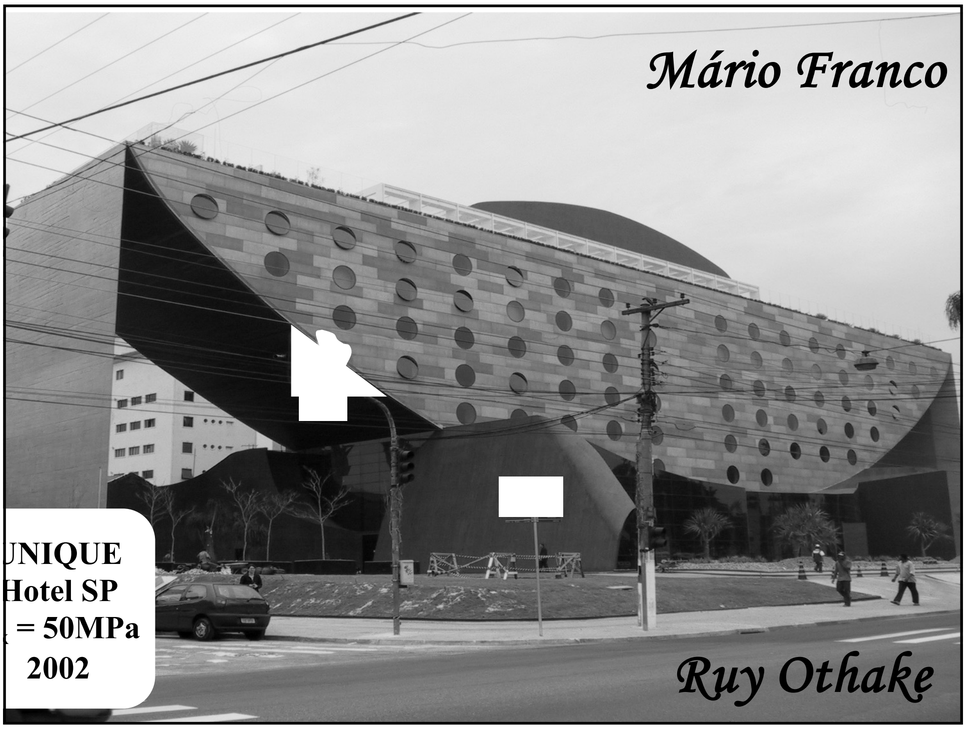

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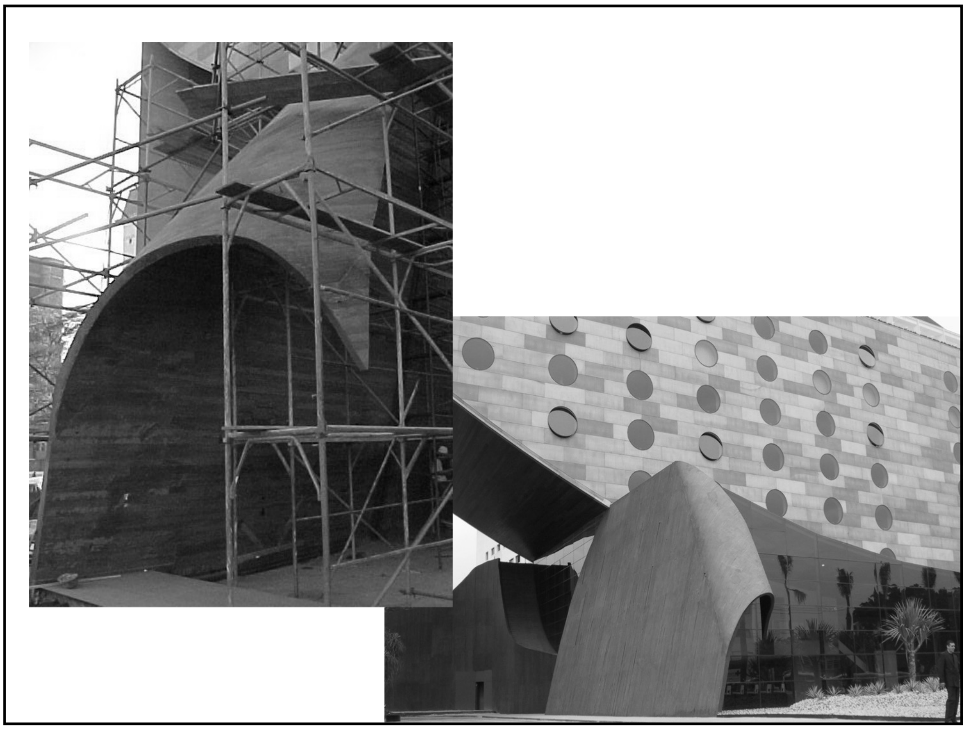

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Considerado

por la prensa

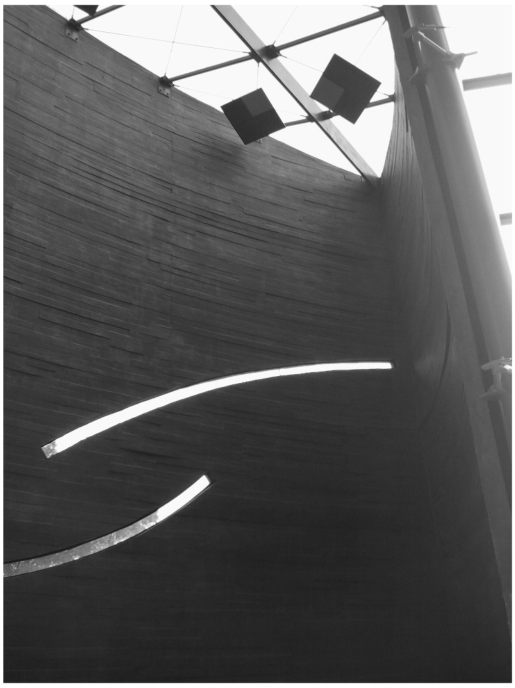
francesa

una de

las 7

maravillas

de 2003



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Vantagens

- Melhor desempenho estrutural
- Melhoria Arquitetônica
- Menor custo da estrutura
- Ganho de área
- Proteção ambiental

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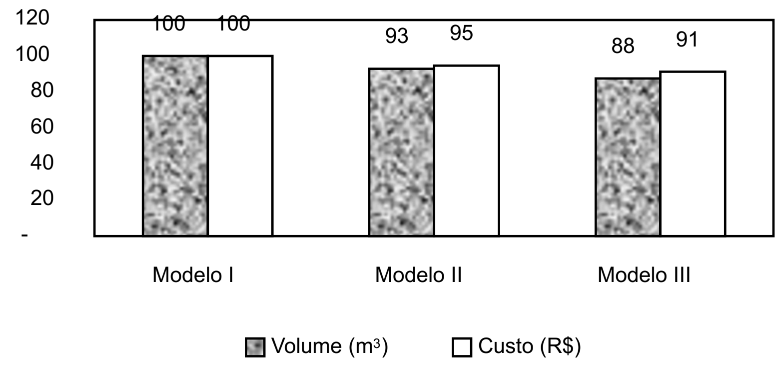
Melhor Desempenho Estrutural



Mod. I - f_{ck} = 30 MPa

Mod. II - pilares f_{ck} var. 30, 45, 60 MPa

Mod. III - pilares e vigas f_{ck} var. 30, 45, 60 MPa

(Engºs Ferreira, Fonte e Athayde Neto, Belém/PA - 2001)

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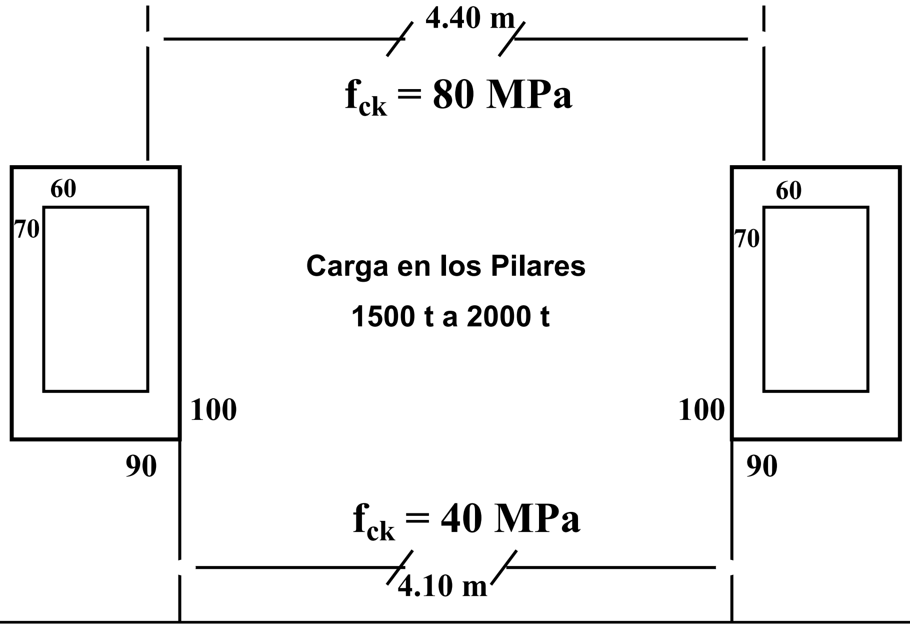
Projecto *(e-Tower)*



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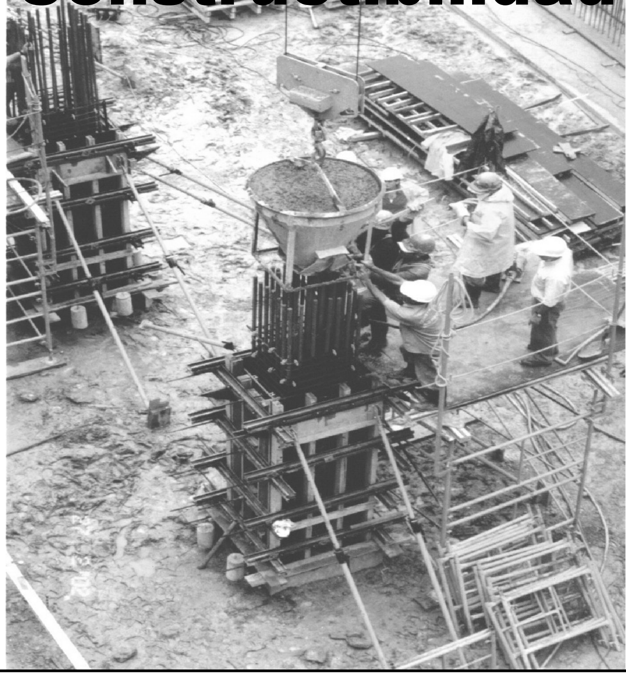
Constructibilidad



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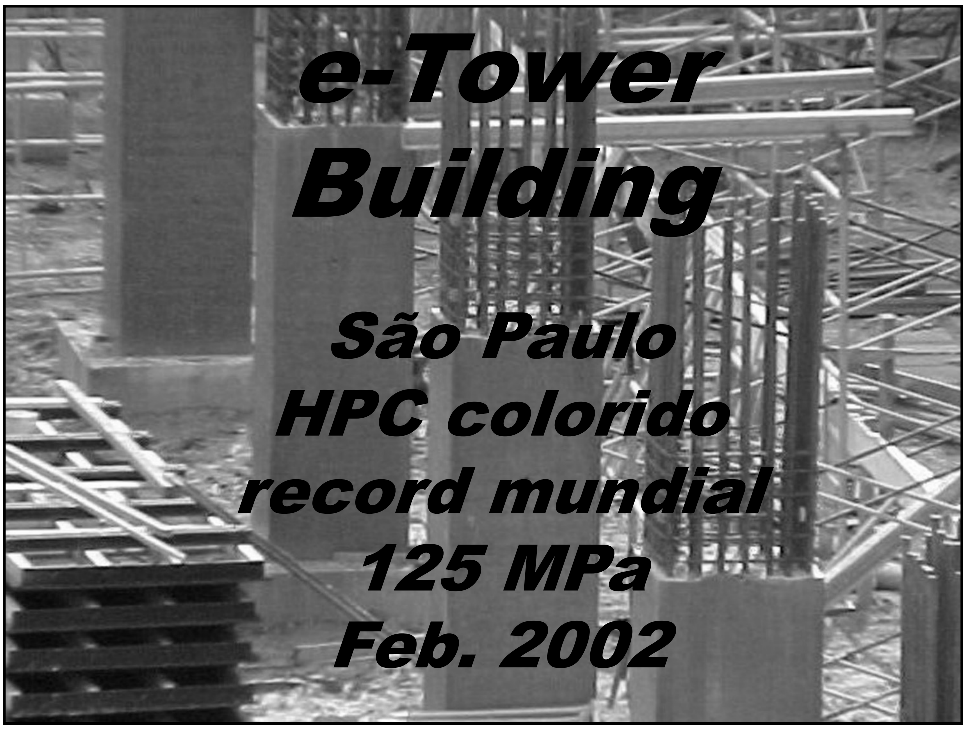
e-Tower
Building
São Paulo
HPC colorido
record mundial
125 MPa
Feb. 2002

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Vida Útil de 980 años!

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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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Los Arquitectos y los Ingenieros construyen los marcos de pujanza, de grandeza, de desarrollo y de poder de las civilizaciones.

Traduzen su historia, sus sueños e ideales en majestuosas y durables obras que elevan la autoestima de su gente.

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"…Alli va una pequeña parte de una importante OBRA de este gran PAÍS"
2005/04/26

85


Muchas Gracias!

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