1

Prof. Jefferson Libório → HSC early ages
Universidade de São Paulo SP
Escola de Engenharia de São Carlos

Prof. Geraldo Isaia → HPC HVFA
Universidade Federal de Santa Maria RS

Prof. Ivan Ramalho Almeida → HPC MS
Universidade Federal Fluminense RJ

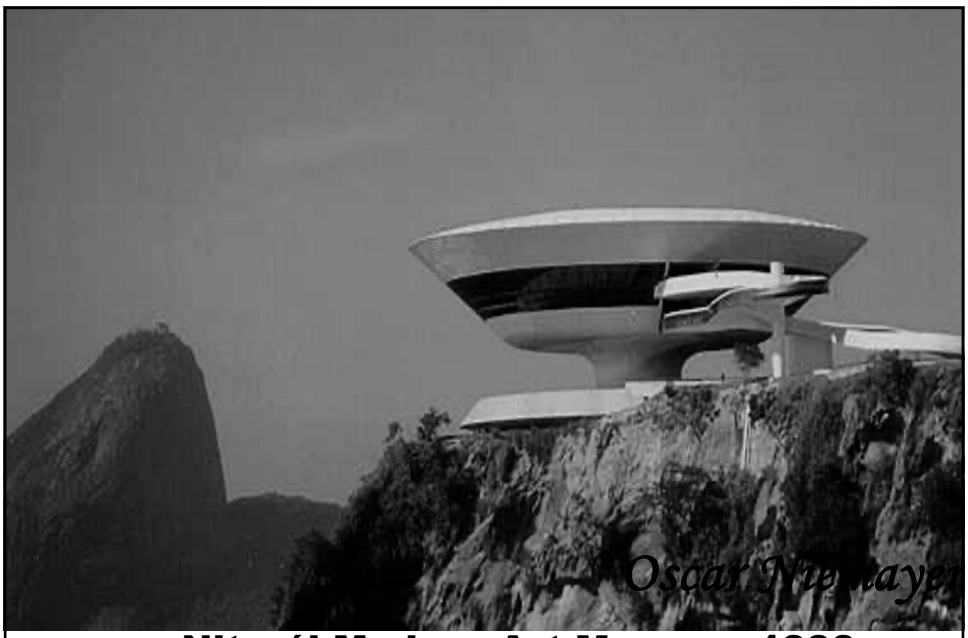
Profa. Denise Dal Molin → HPC MS
Universidade Federal do Rio Grande do Sul RS

Prof. Tibério Cescon → HSC
Universidade de Pernambuco PE

2

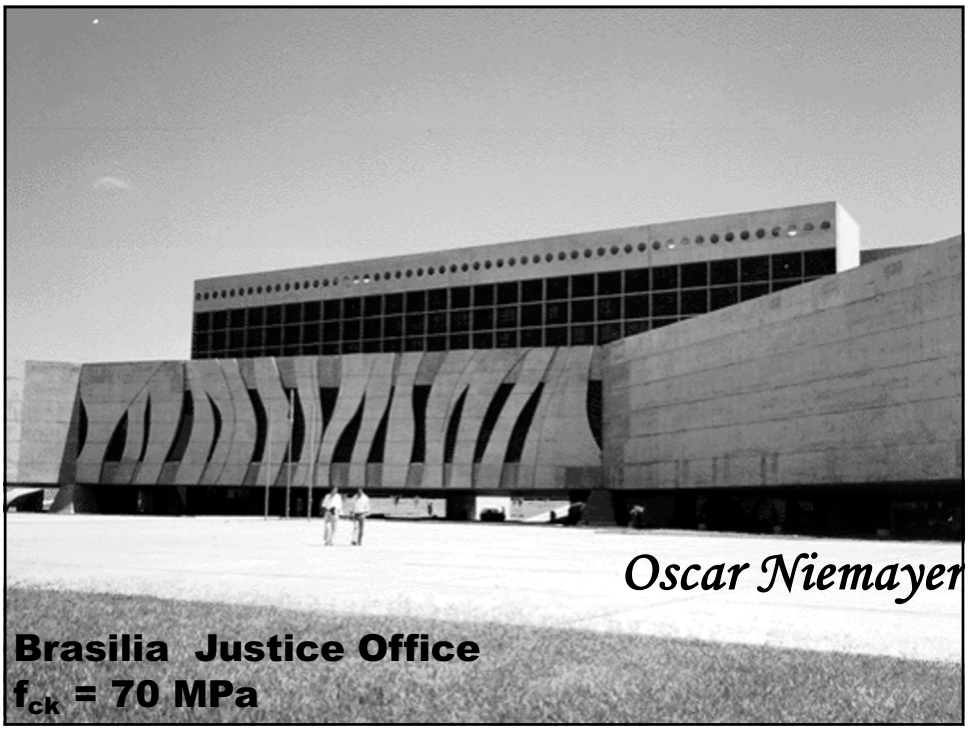
São Paulo Art Museum 1968
f_{ck} = 45 MPa

3

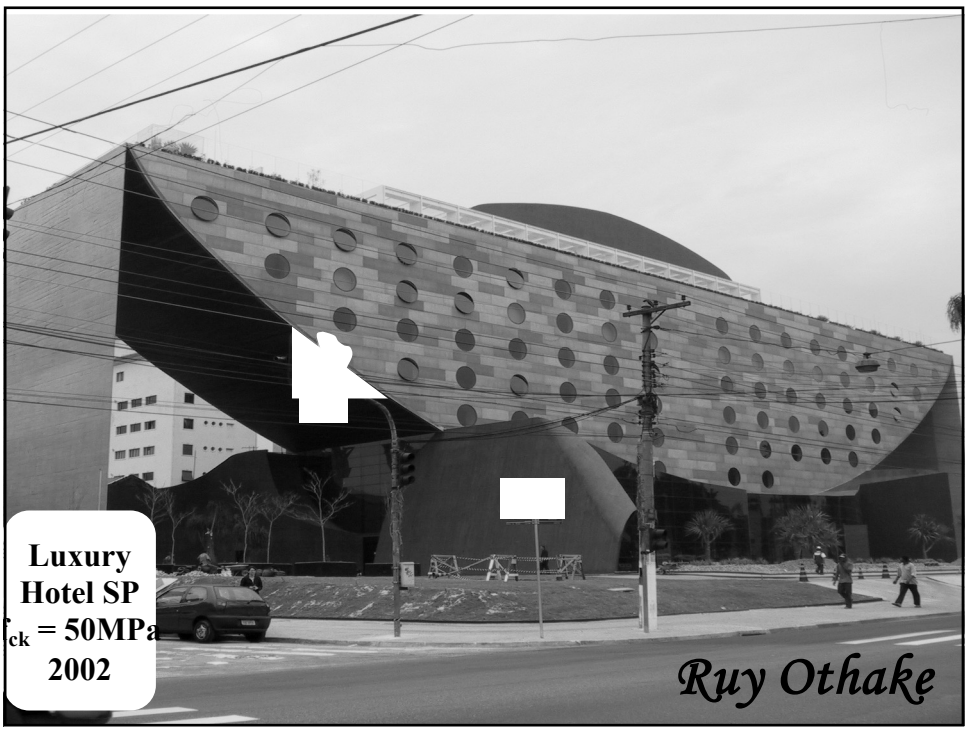


Niterói Modern Art Museum 1999
f_{ck} = 50 MPa

4

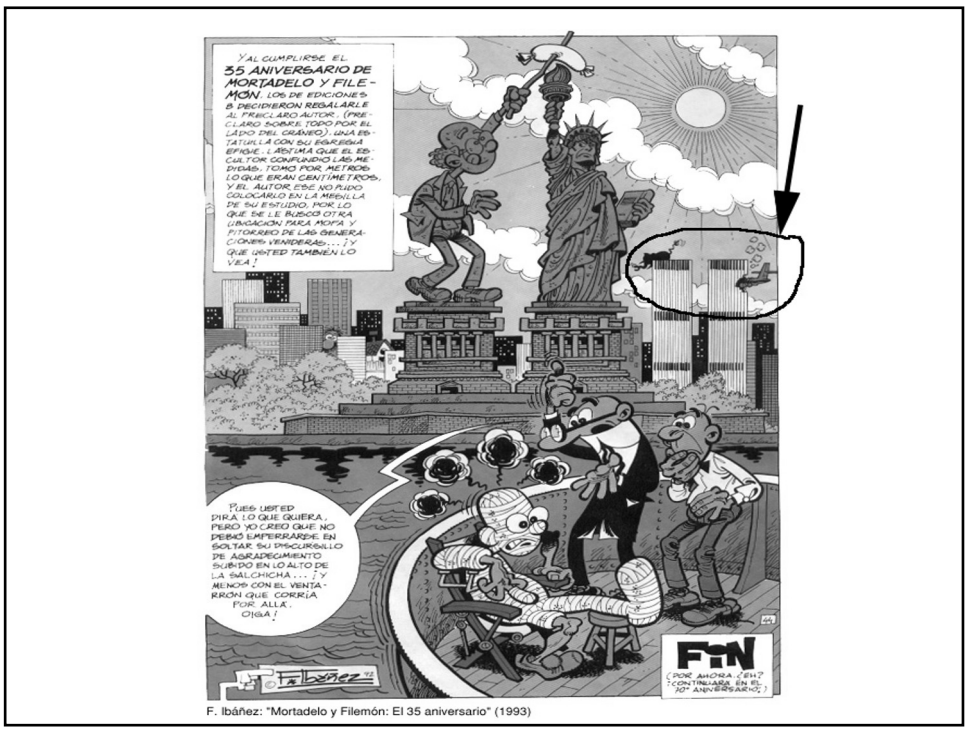

Oscar Niemayer
Brasilia Justice Office
f_{ck} = 70 MPa

5


Luxury
Hotel SP
f_{ck} = 50MPa
2002
Ruy Othake

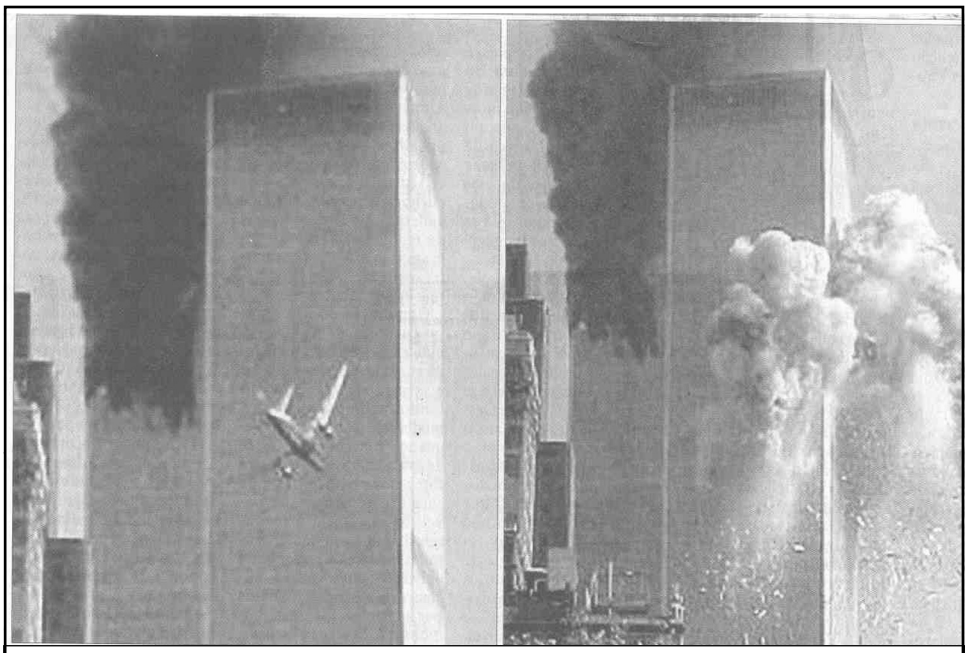
6

7

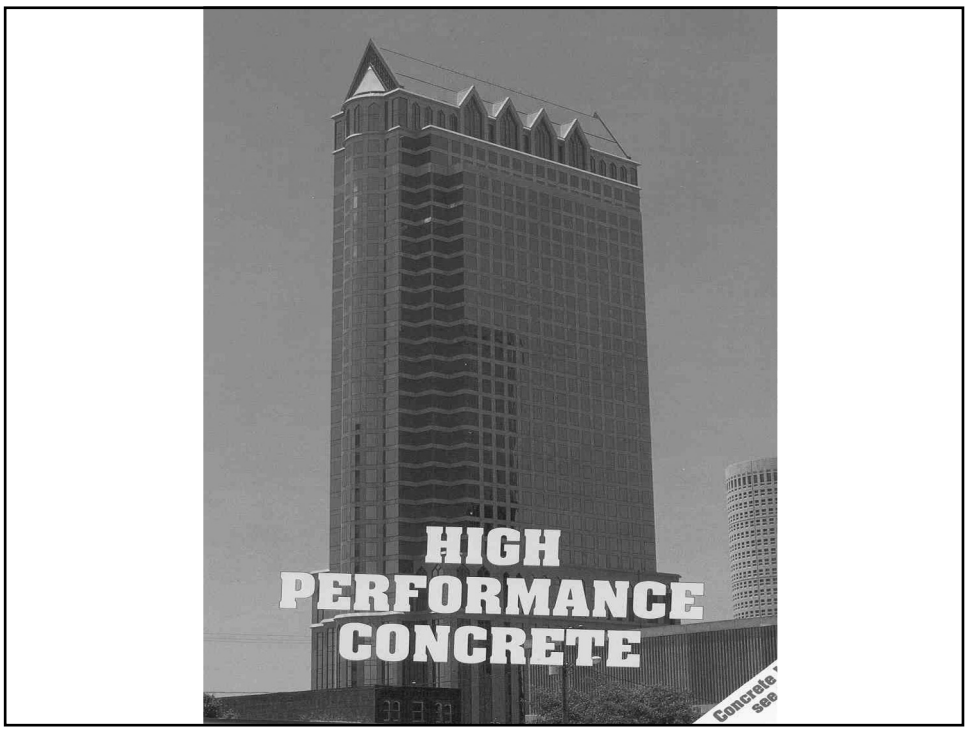


F. Ibáñez: "Mortadelo y Filemón: El 35 aniversario" (1993)

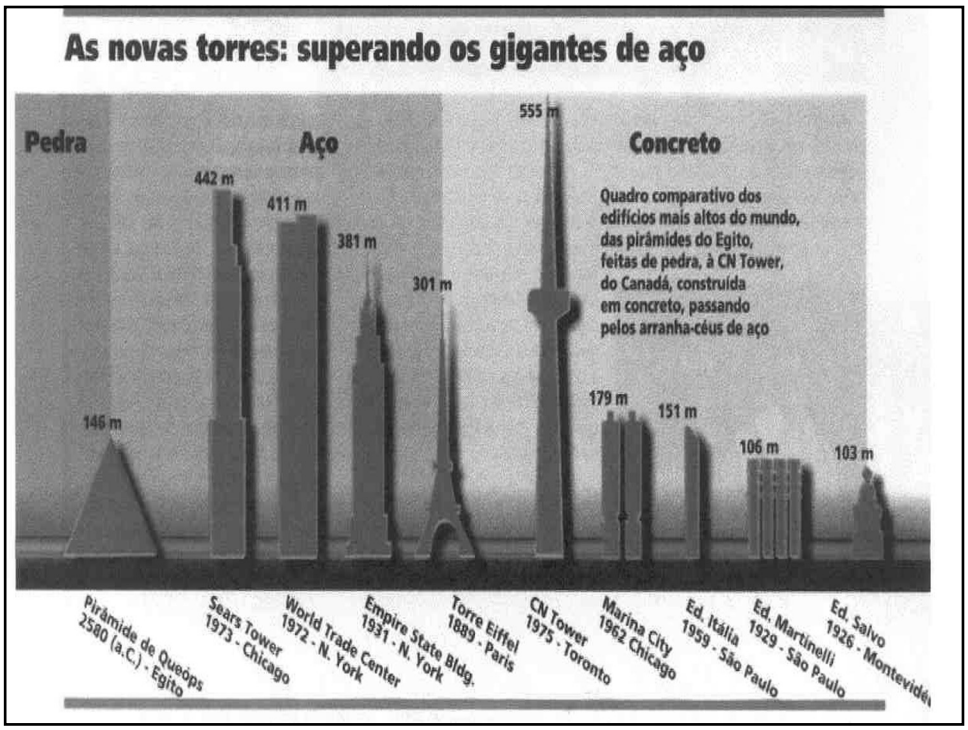
9



10



11



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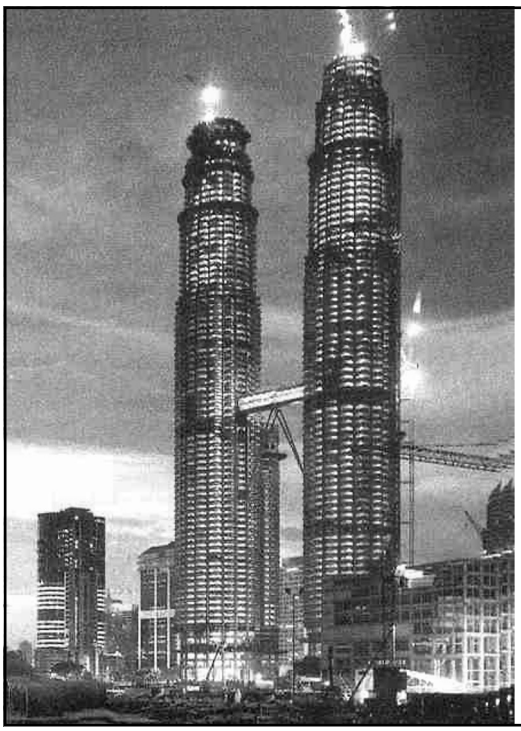


Petronas Towers

Kuala Lumpur

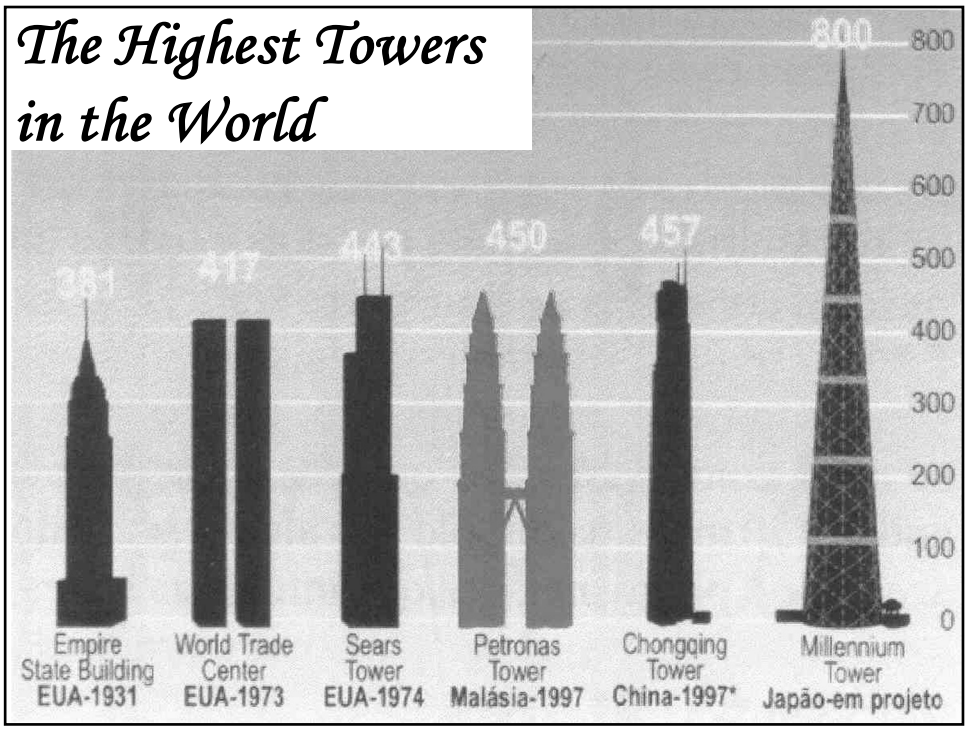
Malásia 1998

Height 452 m

f_{ck} = 65 (80) MPa

f'_c = 9,500 psi
cylinder

13



14

Petronas Towers

Kuala Lumpur

Malásia 1998

Height 452 m

f_{ck} = 65 (80) MPa

f'_c = 9,500 psi

cylinder

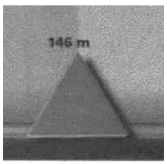
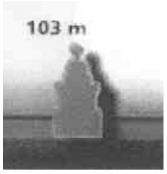
15

Genesis, 11.4

The God People said:

“ Let us built a City and a Tower whose top may reach unto heaven, and let us stamp our name in history lest we be scattered abroad upon the face of the whole earth.”

16

	**Pyramid of Queóps Egypt**	**2580 b.C.** **high 146 m**	**Exist**
	**Alexandria Lighthouse Egypt**	**280 b.C.** **high 134 m**	**Destroyed by earthquake** **XIV Century**
	**Salvio Tower Montevideo**	**1926** **high 103 m**	**Exist**

17

Martinelli Building SP

Torre Norte SP

18

Martinelli Building

São Paulo

1925

25 floors

Height 106 m

Líbero Badaró street

f_{ck} = 13.5 MPa

f'_c = 2,000 psi

19

Itália Building

São Paulo

1959

45 floors

Height 156 m

f_{ck} = 18 MPa

f'_c = 3,000 psi

20

spiritual satisfaction but also achieve the actual needs

- **Adequate Structural Safety**
- **Long Service Life**
- **Enhanced Constructibility**
- **Reduced Cost**
- **Sustanaible Development**

21

Service Life

- Carbonation
- Chlorides
- Acid ashes
- Bacteria
- Leaching
- Shrinkage
- Sulfates

- << pH
- Corrosion
- Cracks
- Spalling

22

Chlorides - diffusion

$$t = \frac{c^2_{Cl}}{4 \cdot z^2 \cdot D^{½}_{ef,Cl}} \text{ (year)}$$

c_{Cl} → 1 a 5 cm

$D_{ef,Cl}$ → 0,15 a 2,7 cm²/year

23

Chlorides - diffusion

e = 2,0 cm

f'_c= 15 MPa → t = 4 years

f'_c= 50 MPa → t = 150 years

f'_c= 25 MPa → t = 23 years

24

Carbonation

$$t = \frac{e^2_{co2}}{k^2_{co2}} \text{ (year)}$$

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

25

Carbonation

e = 2,0 cm

f'_c= 15 MPa → t = 8 years

f'_c= 50 MPa → t = 350 years

f'_c= 25 MPa → t = 38 years

26

27

United Nations Business Center

North Tower

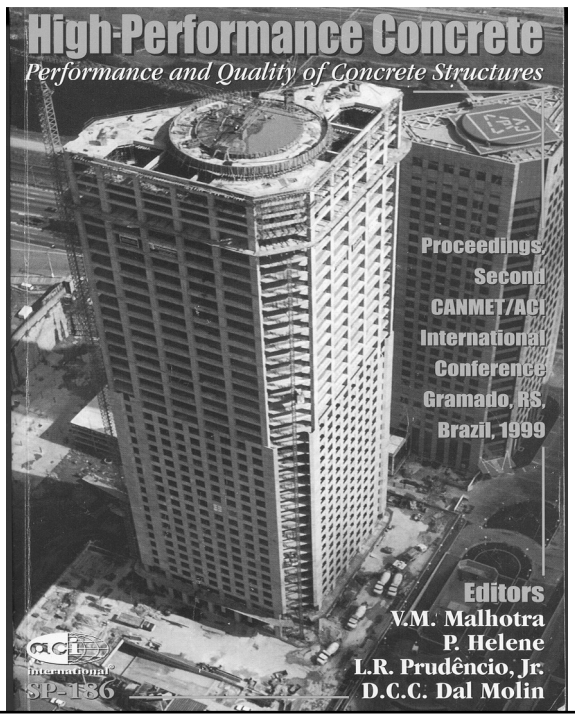
São Paulo 1998

Height 189 m

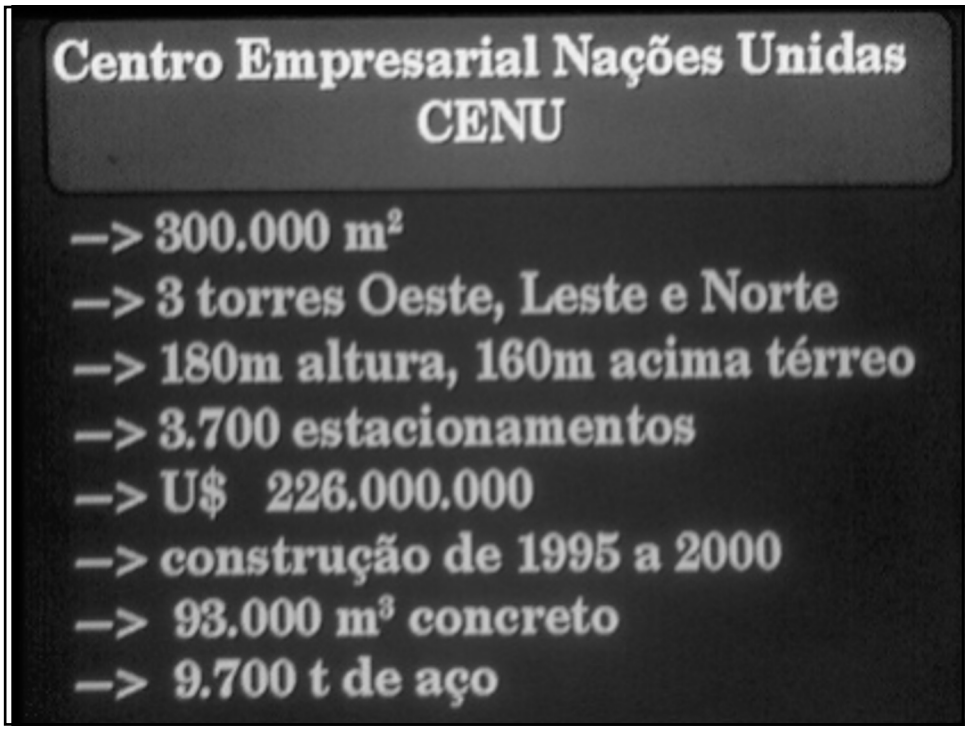
f_{ck} = 50MPa

f'_c = 7,300 psi

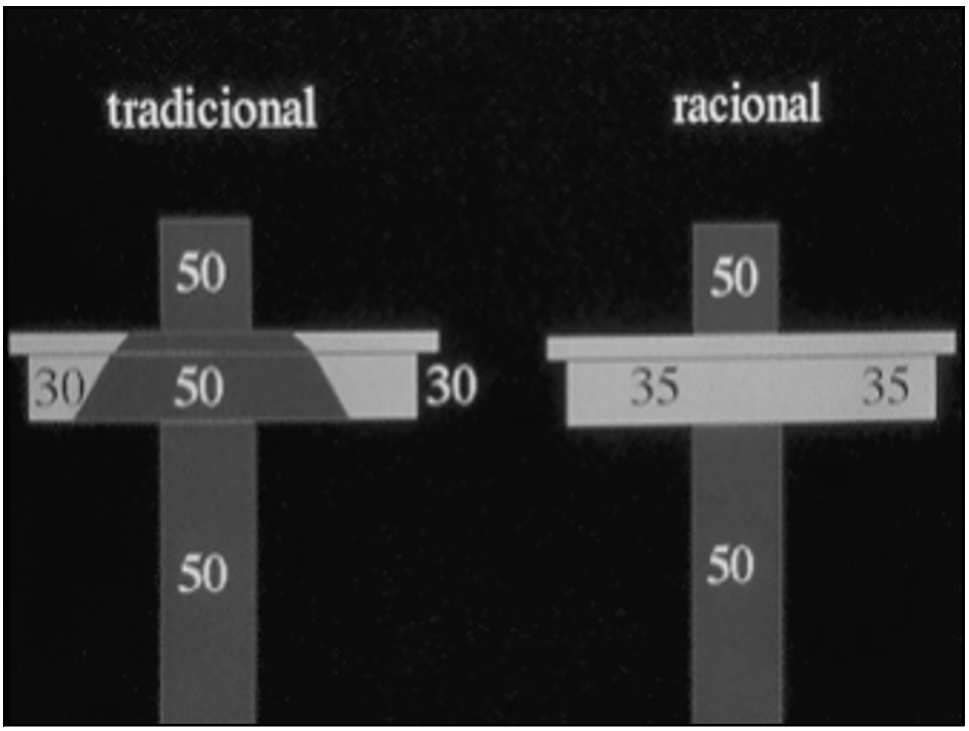
28



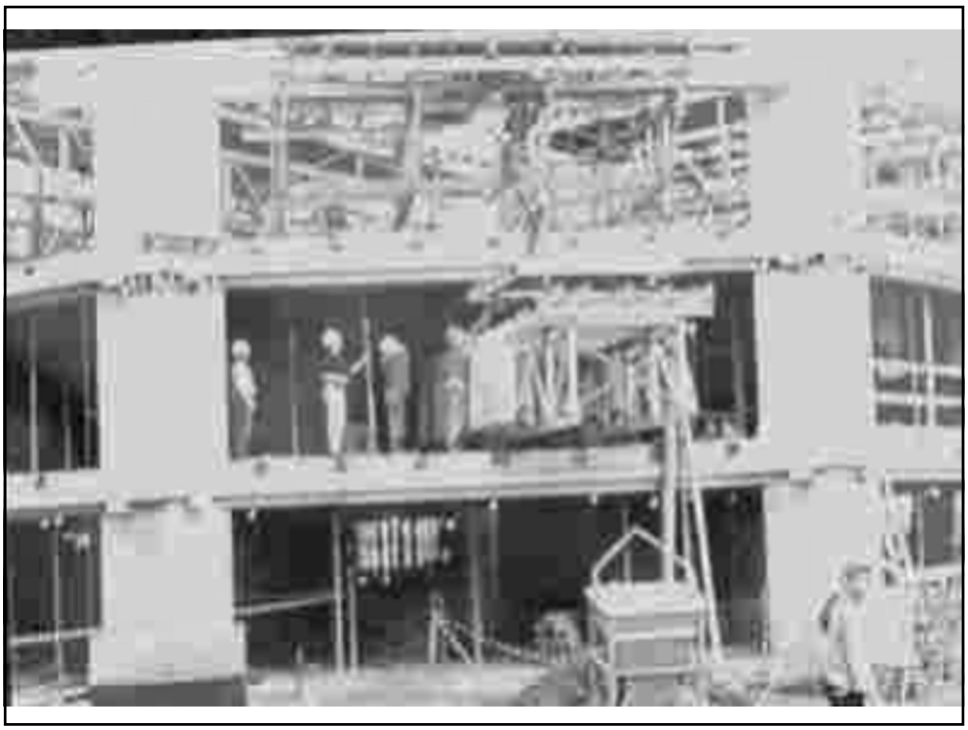
29


Centro Empresarial Nações Unidas
CENU
–> 300.000 m²
–> 3 torres Oeste, Leste e Norte
–> 180m altura, 160m acima térreo
–> 3.700 estacionamentos
–> U$ 226.000.000
–> construção de 1995 a 2000
–> 93.000 m³ concreto
–> 9.700 t de aço

30

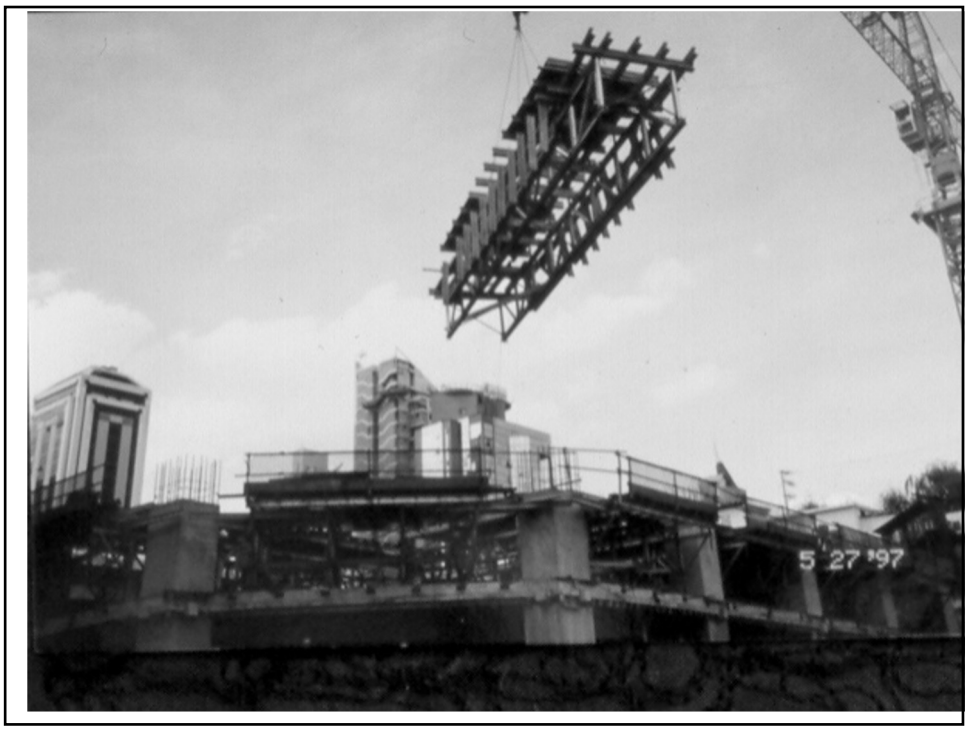

tradicional
racional
50
50
30
50
30
35
35
50
50

31



32

33



34

35

36

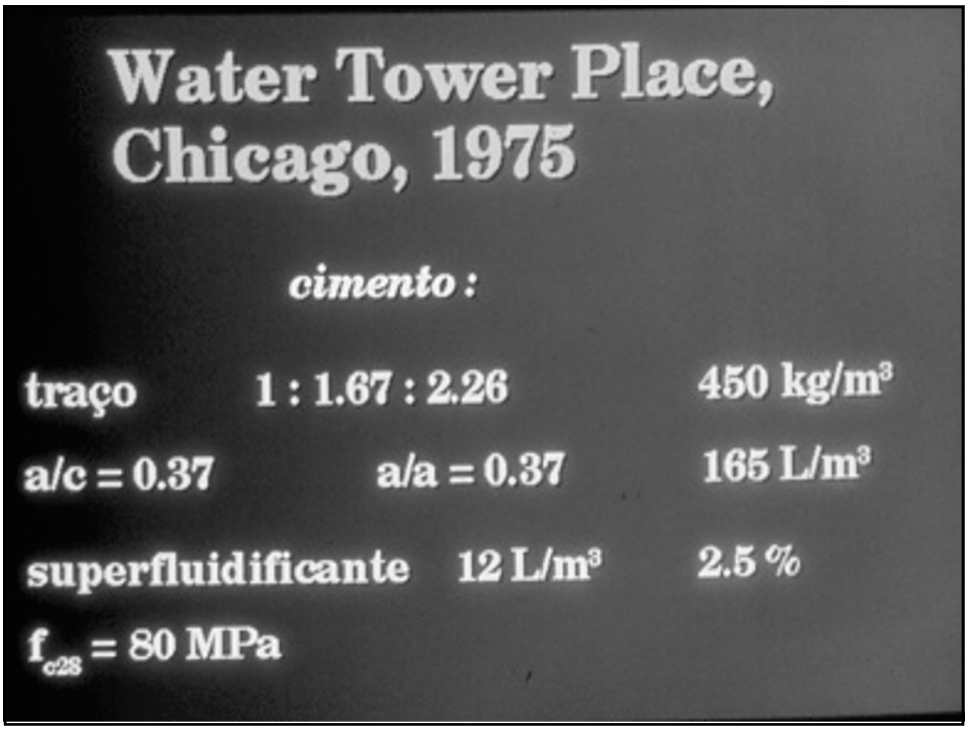
37

38

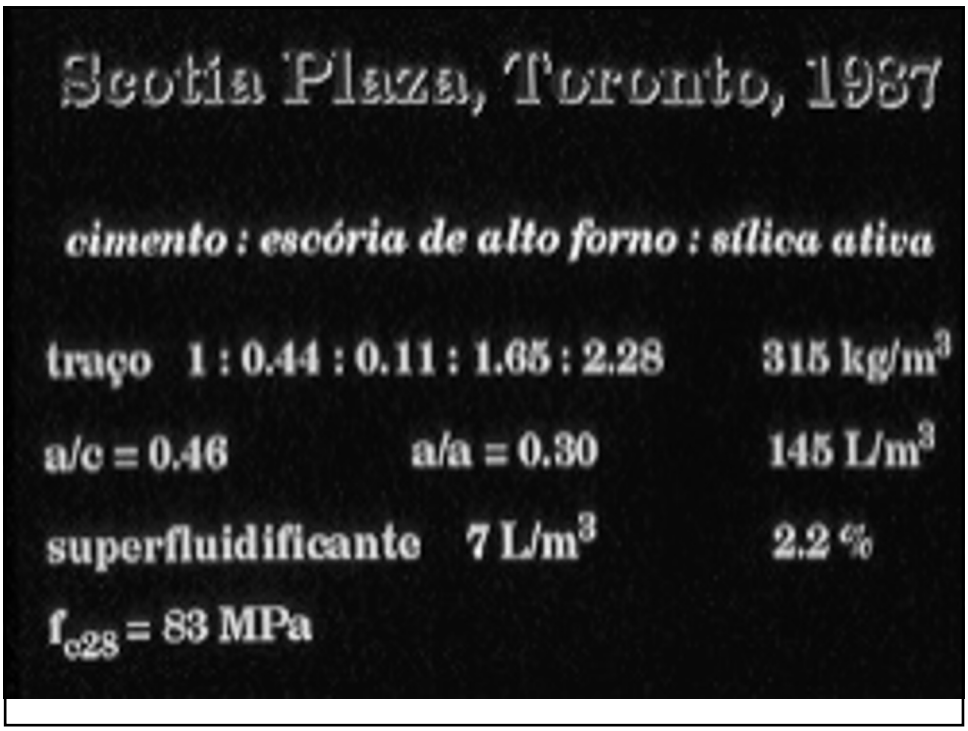
Concreto f_{ck} 35 MPa p/ lajes

	Feb 98	May 97
cimento	460	420
areia	950	858
brita 1	790	920
água	196	182
plastificante	0.3%	0.3%
bombeante	0.8%	—
slump	150±20	100±20
pavimento	≥ 34°	< 10°

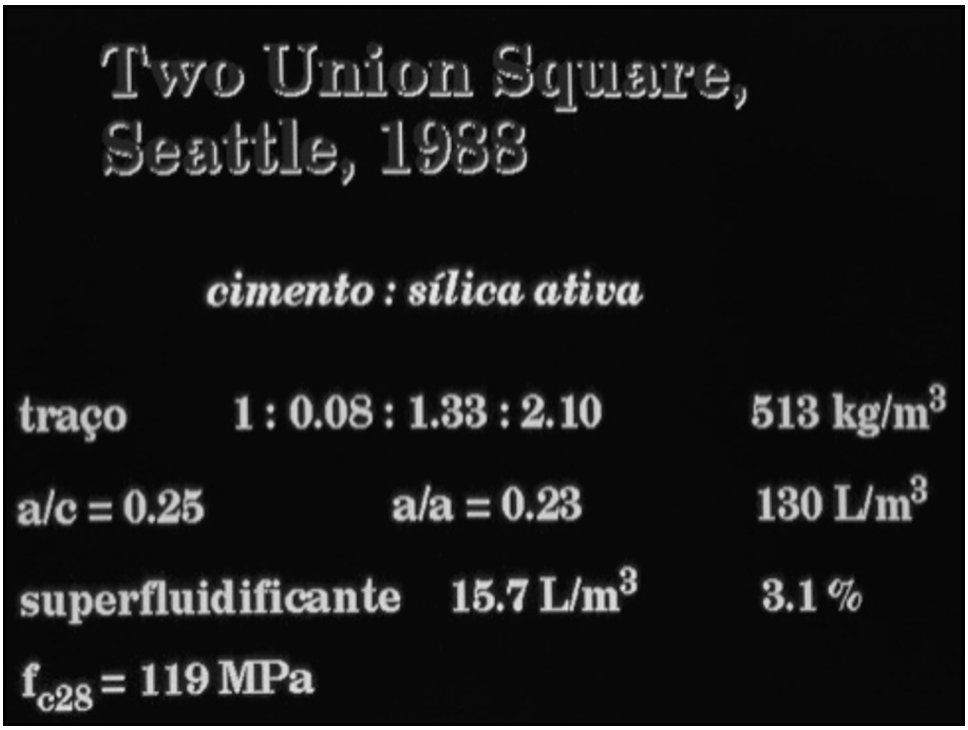
39


Water Tower Place,
Chicago, 1975
cimento :
traço 1 : 1.67 : 2.26 450 kg/m³
a/c = 0.37 a/a = 0.37 165 L/m³
superfluidificante 12 L/m³ 2.5 %
f c28 = 80 MPa

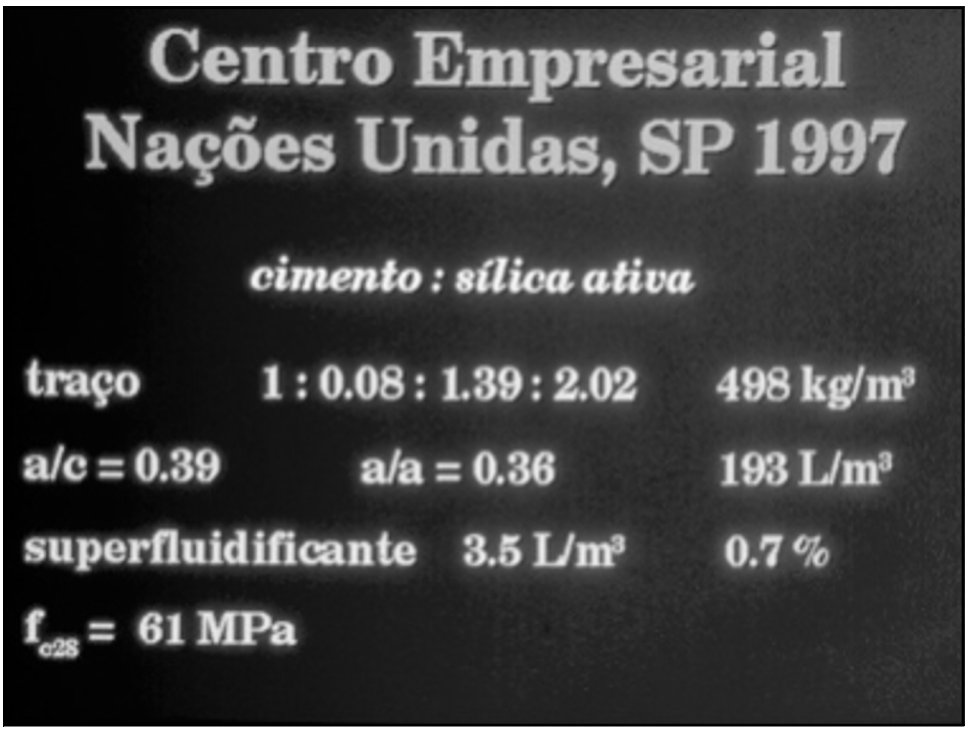
40


Scotia Plaza, Toronto, 1987
cimento : escória de alto forno : sílica ativa
traço 1 : 0.44 : 0.11 : 1.65 : 2.28 315 kg/m³
a/c = 0.46 a/a = 0.30 145 L/m³
superfluidificante 7 L/m³ 2.2 %
f c28 = 83 MPa

41


Two Union Square,
Seattle, 1988
cimento : sílica ativa
traço 1 : 0.08 : 1.33 : 2.10 513 kg/m3
a/c = 0.25 a/a = 0.23 130 L/m3
superfluidificante 15.7 L/m3 3.1 %
fc28 = 119 MPa

42

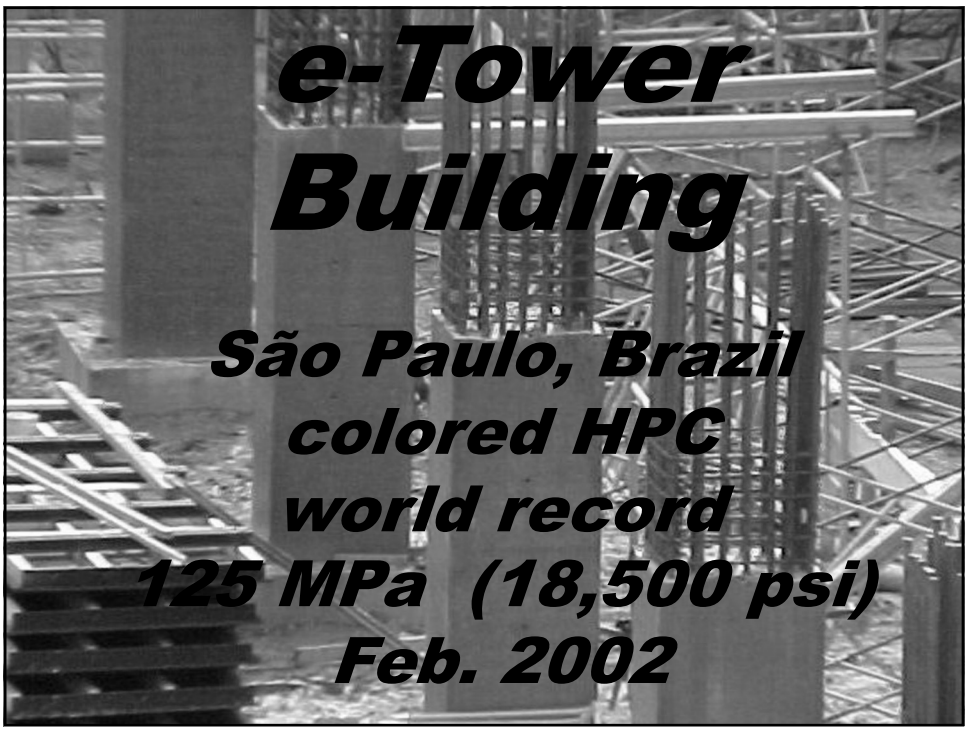

Centro Empresarial
Nações Unidas, SP 1997
cimento : sílica ativa
traço 1 : 0.08 : 1.39 : 2.02 498 kg/m3
a/c = 0.39 a/a = 0.36 193 L/m3
superfluidificante 3.5 L/m3 0.7 %
fc28 = 61 MPa

43

Concreto f_{ck} 50 MPa pilares

cimento	498	550
sílica ativa	40	—
areia	692	737
brita 1	1002	968
água	193	193
plastificante	0.3%	0.3%
superplast.	0.7%	—
a/(c+s)	0.36	0.35
α	55%	57%
slump	70±10	70±10

44



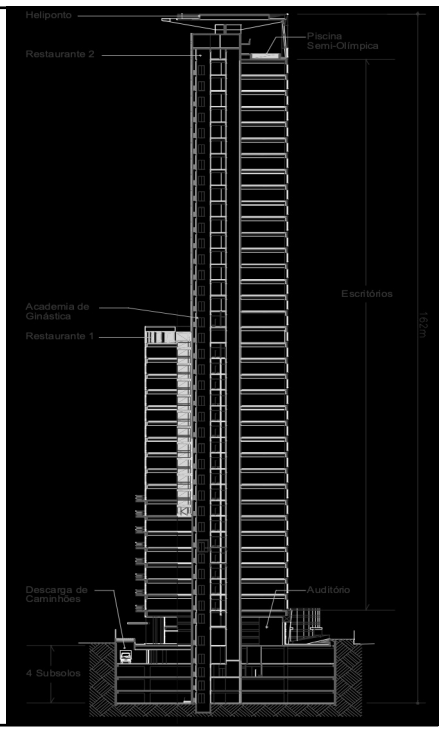
45

46

e-Tower

São Paulo

- 52.000 m² surface constructed
- 42 floors (04 underground)
- 800 car parking
- 02 restaurants
- Fitness center (19º floor)
- Olympic swimming pool (37º floor)



47

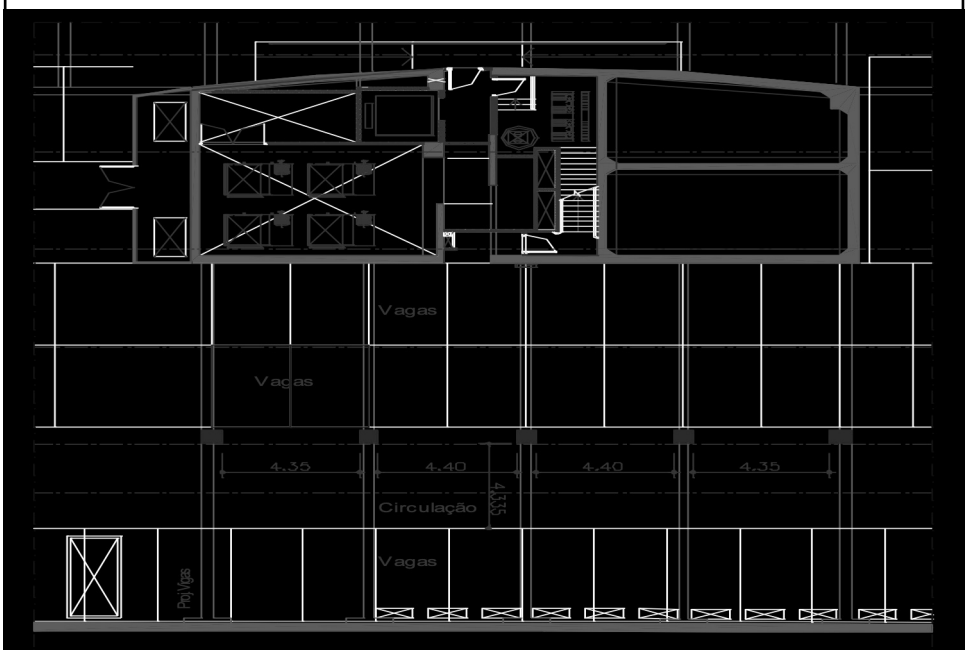
48

Designing *(e-Tower)*

- **Strict modular coordination – axis each 1,25 m**
- **Columns each 5 m at north face**
- **Parking two cars requires 4,20 m free space between columns**
- **Straight faces with corridor to facilitate transit in car parking**

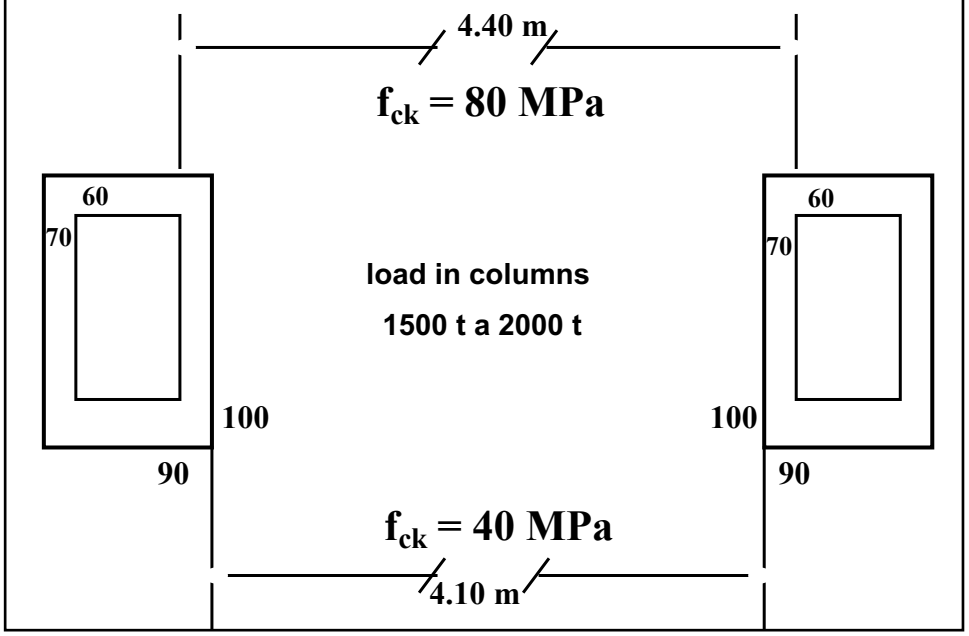
49

Designing *(e-Tower)*



50

Designing *(e-Tower)*



51

Designing *(e-Tower)*

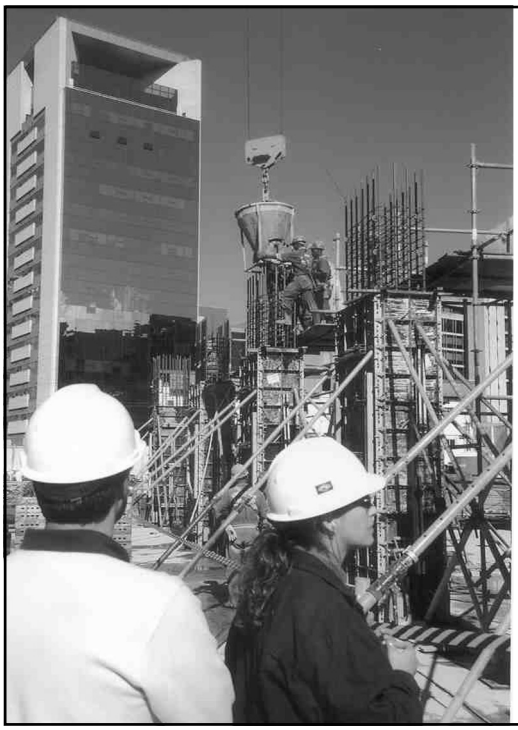
- Gain 4 additional car park by floor
- 4 x 4 floor = 16 new car park
- US $ 5,000 each car park
- earn US $ 80,000

52

Designing *(e-Tower)*

- initial cross section = 90 x 100 = 0.9 m^2
- final cross section = 60 x 70 = 0.42 m^2
- save = 0.9 – 0.42 = 0.48 m^2
- 53% less concrete volume
- cost C80 = 45% over price C40
- save 8% in concrete cost

53



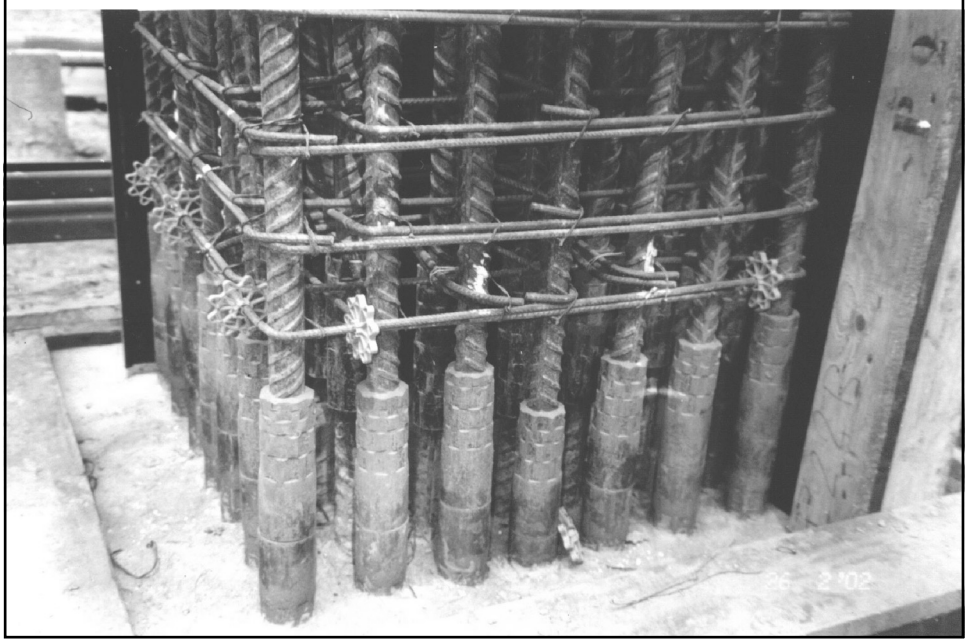
formwork

single columns

save formworks

54

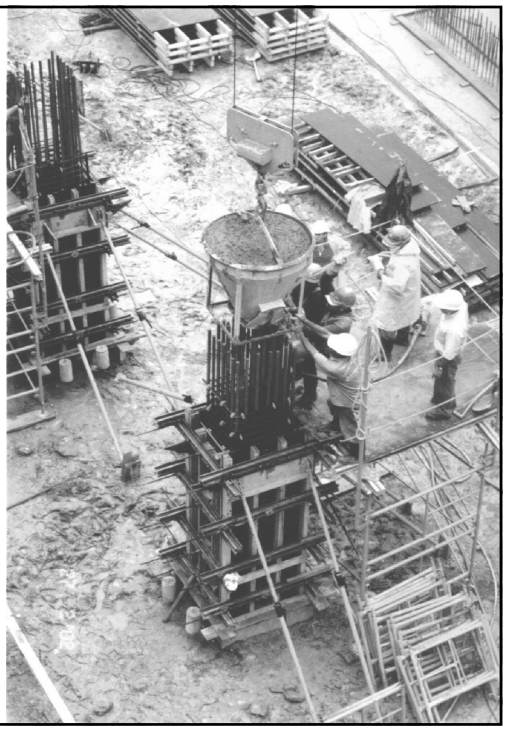
Reinforced Steel



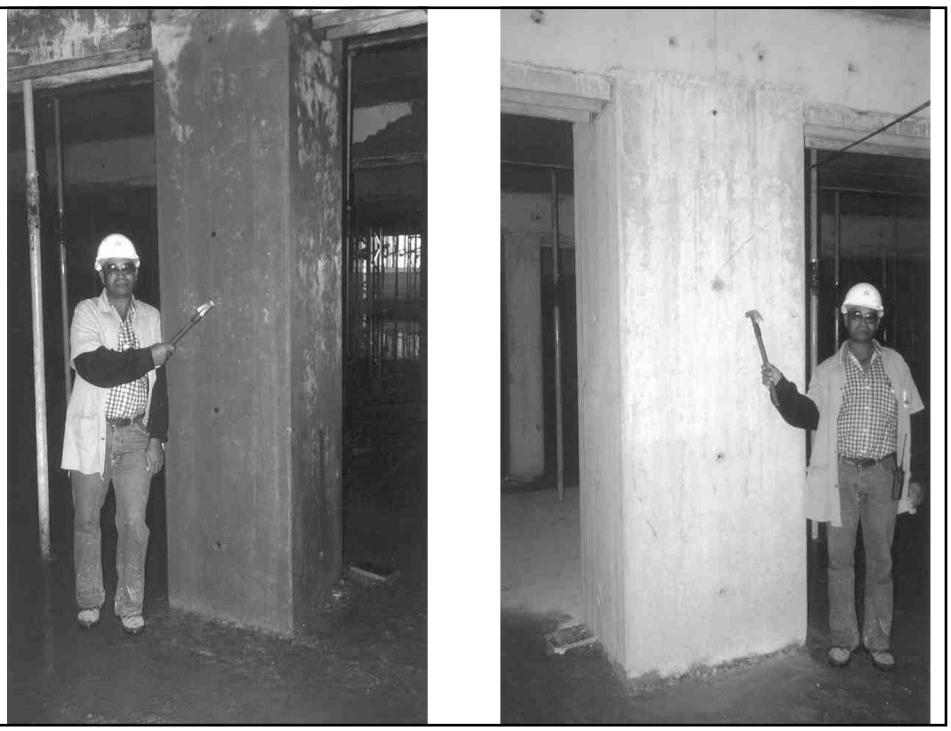
55

placement

- ✓ 5.5 m over reinforced steel
- ✓ no honey combs
- ✓ increasing productivity



56



57

Mix Design Research

3 months

lab tests

⇩

potentials mix proportions

⇩

mixing concrete in trucks

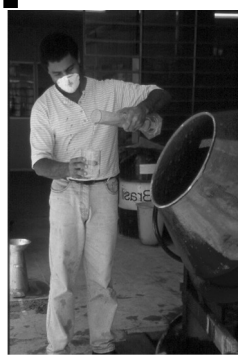
⇩

complete field test in aux columns

58

Experiment

Engemix, Ready Mix Plant, And University of São Paulo Research and Development Center In Concrete



59

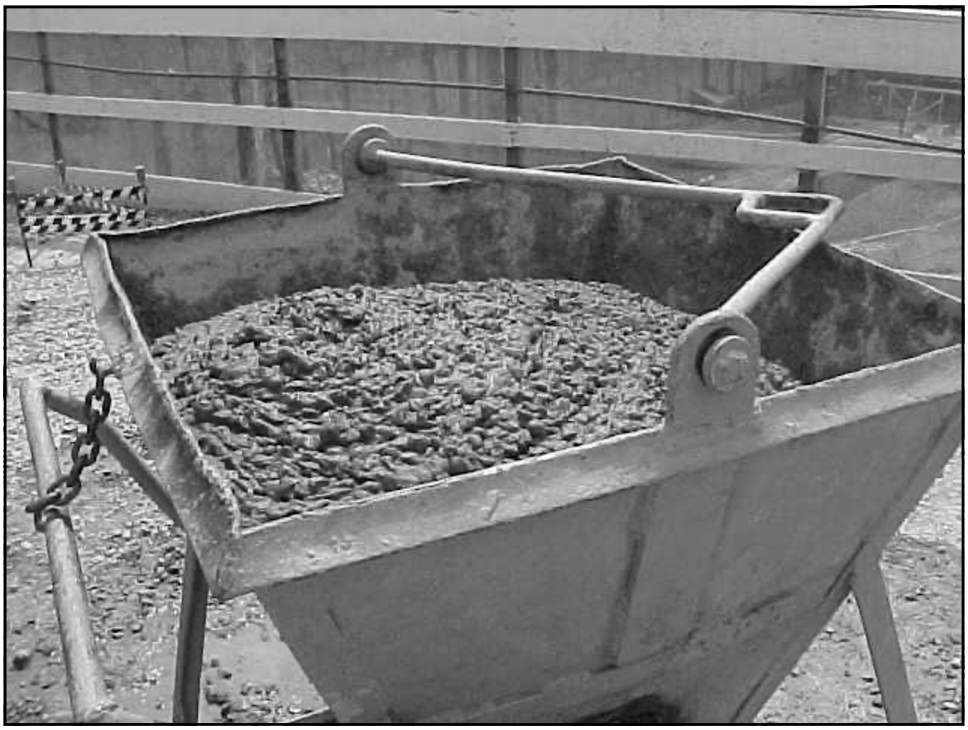
Control of Materials

60

complete field test

Parking Columns
no ice and no pigment concrete
slump: 190 mm
severe test conditions
Concrete temperature 37º C
Ambient temperature 32º C

61



62

63

64

65

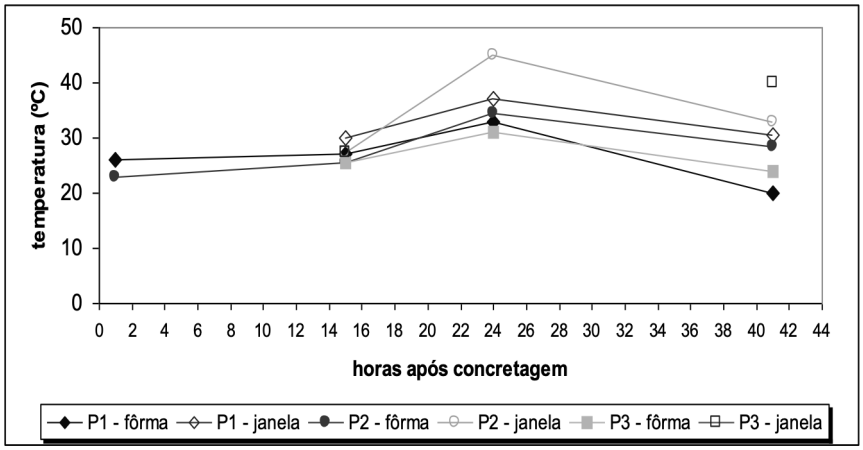
66

Temperature and Times

Controle de tempo	
Horário de início da mistura	12:55
Horário da saída da central	13:35
Horário chegada obra	14:30
Horário término da concretagem	16:00
Temperatura concreto na chegada na obra	
37,5 ºC	

67

Concrete Columns Temperature

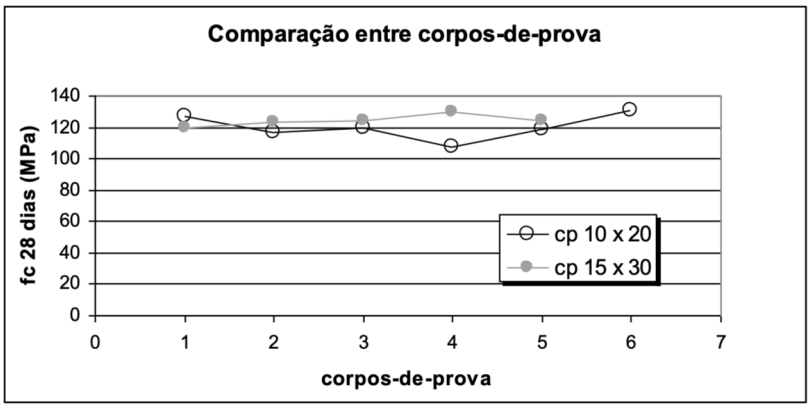


P1 = 133 P2 = 134 P3 = 135

68

69

Compression Strenght



70

Columns

Concrete slump

14 to 20 cm

4 m³ by mixing truck

71

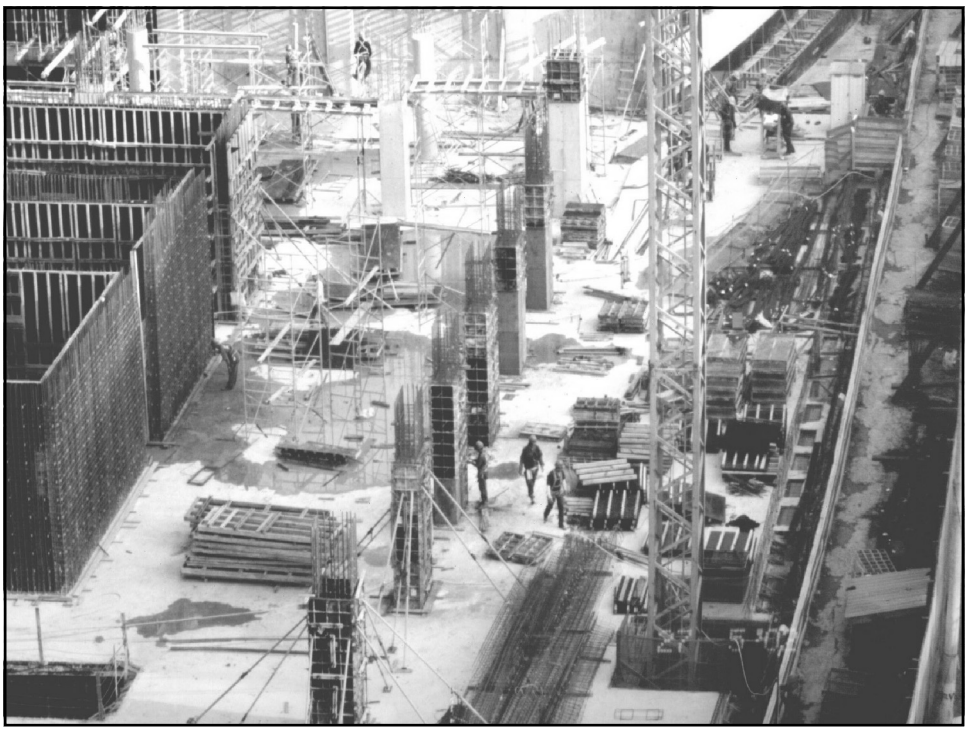
Columns Concreting

- 4 parking floors, ground floor and 2 more floors
- ice and pigment concrete
- slump: 190 mm
- concrete temperature 21° C
- ambient temperature 22 to 30° C

72

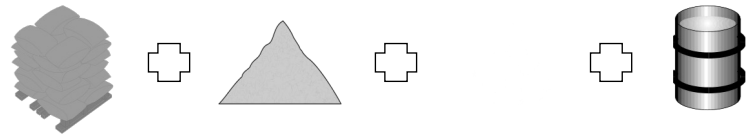
73

74



75

HPC composition



Portland cement | Fine aggregate | Coarse aggregate | water

Concreto comum

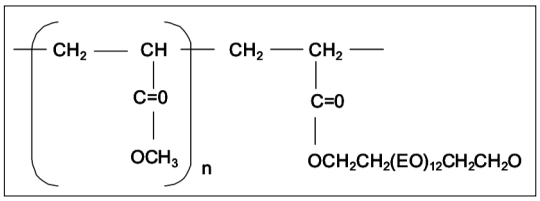
Admixtures

Additions

HPC

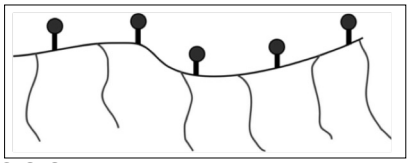
76

POLICARBOXILATO



(a) Monômero de um policarboxilato

- Conhecidos comercialmente como de 3ª geração;
- Redução de até 40% de água da mistura
- Possuem grupos carboxílicos COOH;
- Cadeia lateral longa.



(b) Esquematização da molécula

77

superplasticizer

Cimento Portland + Água

⇩

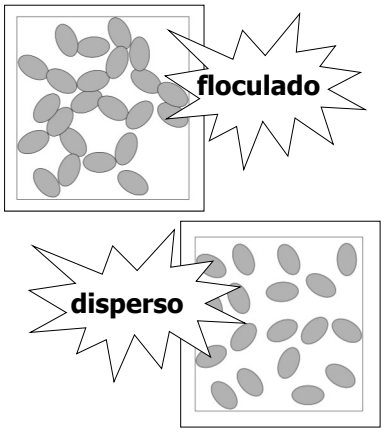
Floculação

⇩

aprisonamento de água entre os grãos de cimento

⇩

redução da fluidez e da área específica disponível para hidratação



78

superplasticizer

Cimento Portland + Água

⇩

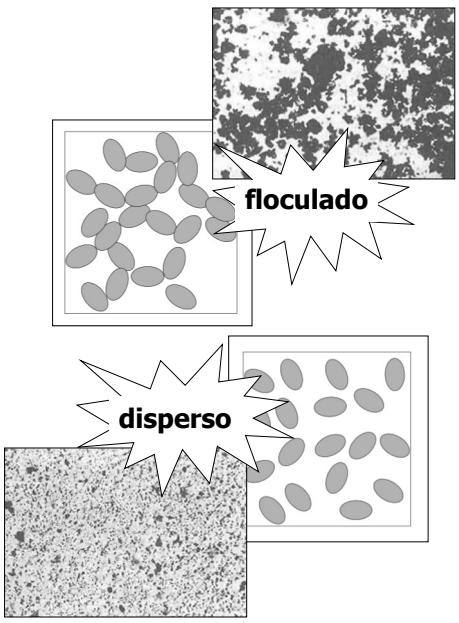
Floculação

⇩

aprisonamento de água entre os grãos de cimento

⇩

redução da fluidez e da área específica disponível para hidratação



79

Mineral Additions

Para obter maior compacidade e maior resistência mecânica

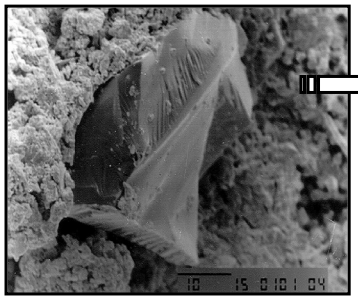
adição de minerais ativos

Metakaolim and silica fume

- **estrutura mais compacta**
- **reagem com a cal livre melhorando a resistência e durabilidade.**

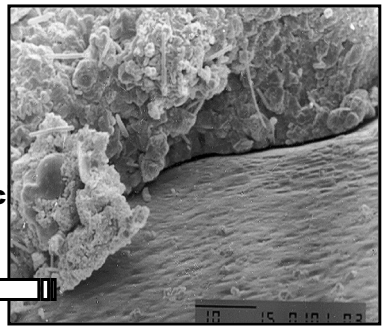
80

MINERAL ADDITIONS



Aumento 1500x

Conventional Concrete



Aumento 1500x

Concrete with

Metakaolin

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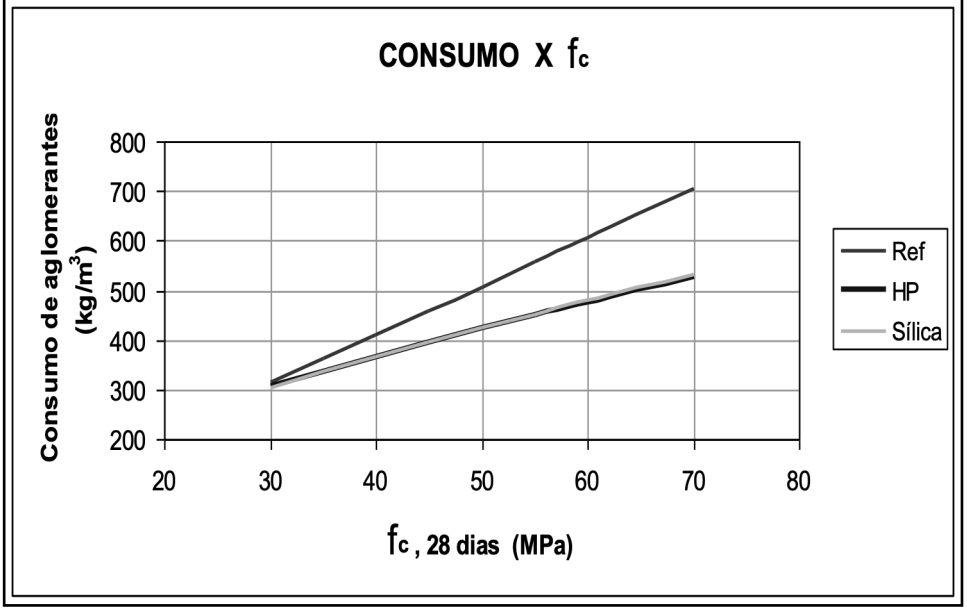
MINERAL ADDITIONS



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MINERAL ADDITIONS

f_{ck} em MPa	referência cimento kg/m³	silica ativa aglomerantes kg/m³	*MetacaulimHP aglomerantes kg/m³*	*MetacaulimHP cimento kg/m³*	*MetacaulimHP adição 8% kg/m³*
30	314	304	**305**	**281**	**24**
35	361	336	**336**	**309**	**27**
40	409	366	**366**	**337**	**29**
45	458	395	**395**	**363**	**32**
50	506	424	**423**	**389**	**34**
60	605	479	**477**	**439**	**38**
70	704	532	**529**	**487**	**42**

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RED PIGMENT

- ✓ **Iron oxide Fe_2O_3 > 98%**
- ✓ **grau 8 de solidez a luz solar**
- ✓ **0,5% de sais solúveis**
- ✓ **99,95% diâmetro de particula < 0,045mm (#325) 0,05% de retenção**
- ✓ **Densidade 4.500 kg/m^3**
- ✓ **Formato Partícula: Esférica**
- ✓ **EN 12878 y ASTM C 979**

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Concrete Mix Proportion

materials	ratio	amount	obs
blended cement	1,00	623 kg/m^3	(460 + 163 slag) CPV
addition	0,15	93 kg/m^3	silica & metakaolin
coarse aggregate	1,65	1.027 kg/m^3	basaltic, 19mm, MF 6,9, 3.020 kg/m^3
fine aggregate	0,88	550 kg/m^3	quartz, 2,4mm, MF 2,0, 2.670 kg/m^3
pigment	0,04	25 kg/m^3	Iron oxide
superplasticizer	0,01	6,2 kg/m^3	policarboxilato
retarder	0,0058	3,6 kg/m^3	acido hydrocarboxálico
water	0,19	135 kg/m^3	A / C = 0,19

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FRESH CONCRETE TEMPERATURE CONTROL

Problemas	Aceitável	Ideal	Aceitável	Problemas

5° 10° 15° 20° 25° 30°

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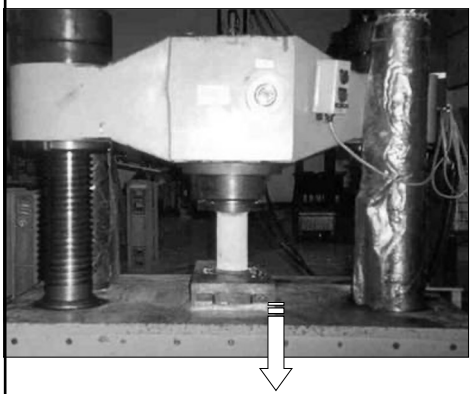
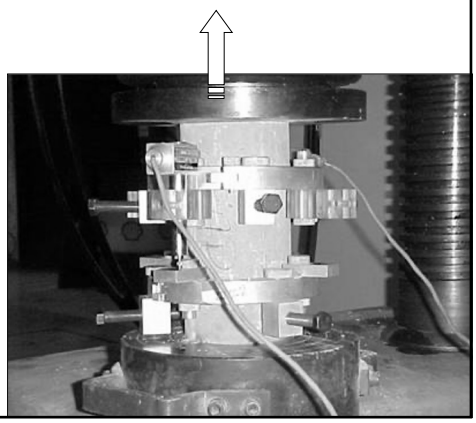
Routine Properties Control



Compression Strenght

Modulus of Elasticity



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Compression Strenght

Traço	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Amostra	amostra 1	amostra 2	amostra 3	amostra 4	amostra 5	amostra 6	amostra 7	amostra 8	amostra 9	amostra 10
Data moldagem	10/10/2002	17/10/2002	21/11/2001	15/2/2002	27/2/2002	16/3/2002	25/3/2002	5/4/2002	11/4/2002	11/4/2002
CP 1	134.3	119.7	120.2	113.1	133.0	114.9	121.8	115.6	119.0	116.2
CP 2	131.2	123.0	124.7	121.8	144.3	105.6	127.4	114.9	129.9	126.2
CP 3	127.4	124.1	120.8	125.6	149.9	115.6	133.7	111.2	123.7	126.8
CP 4	129.9	129,6	115.8	118.7	143.0	112.4	124.9	123.1		
$f_{c\,máx}$	134.3	129.6	115.8	133.1	149.9	115.6	133.7	123.1	129.9	126.8
$f_{c\,min}$	127.4	119.7	124.7	105.6	133.0	105.6	121.8	111.2	119.0	116.2
f_{cm}	130.7	122.3	120.4	127.3	142.6	119.1	127.0	116.2	124.2	123.1
Desvio padrão	2.9	2.3	3.6	3.0	3.0	2.6	2.0	3.0	2.5	3.0
Coef. Variação	2.2	1.9	3.0	8.2	2.9	3.1	3.0	3.3	3.4	3.8

f_{cm} 124.6

$f_{c\,min}$ 116.6

$f_{c\,máx}$ 149.9

28 days

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Modulus of Elasticity

	T7	T8	T9	T11
CP 1	41.6	47.1	42.8	51.7
CP 2	42.2	48.4	47.2	55.2
CP 3	41.7	45.8	45.7	51.2
CP 4		48.2	50.8	
Average	41.8	47.4	46.6	52.7
Stand. Dev.	0.3	1.3	2.2	2.2
Variab.	0.8	2.7	4.8	4.1
Average			47.1	
Maximum			55.2	
Minimum			41.6	

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Mechanical Properties

		❑f_{ck} = 115 MPa	❑f_{ck} = 25 MPa
		❑f'_c = 17,000 psi	❑f'_c = 3,600 psi
f_c	7 days	111	18
f_c	28 days	125	32
f_c	63 days	139	37
f_c	91 days	155	39
E_{ci}	28 days	50	30
f_{ct}	28 days	10	3,1
Ultra-sound	m/s	4950	3250
Hammer test		52	23

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Durability Properties

	❑f_{ck} = 115 MPa	❑f_{ck} = 25 MPa
	❑f'_c = 17,000 psi	❑f'_c = 3,600 psi
Carbonation 28+63d 25ºC 65% 5%	zero	29mm
Absorption H_2O	0,40%	7,5%
Volumn Pores	1%	17,5%
Density	2530 kg/m³	2310 kg/m³
Capilar absorption	0,1 g/cm²	2,7 g/cm²
Capilar ascenption	0 cm	30 cm
Chlorides	43 C	8.400 C
Abrasion cm³/cm²	0,019	0,051

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Service Life using second Fick's law for carbonation agressiveness 980 years!!!!

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Sostenaible 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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Os Arquitetos e os Engenheiros Constroem os marcos de pujança de uma civilização.

Traduzem sua história, seus sonhos, seus ideais em obras imponentes e duráveis que elevam a auto estima de seu povo.

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O Concreto de Elevado Desempenho é uma das grandes oportunidades atuais de resgatar essa importância e vocação da arquitetura e da engenharia de nossos países

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