Sixth International Conference
CONCRETE UNDER SEVERE CONDITIONS
Environment and Loading

June 7-9, 2010, Mérida Yucatán, México

HSCRC

HIGH STRENGTH COLORED REINFORCED CONCRETE UNDER STANDARD FIRE EXPOSURE

Paulo Helene
PhD Engineering President
Member of PREVENIR Network
President of ALCONPAT International
Brazilian Concrete Institute IBRACON Director
MSc, PhD, Full Professor at University of São Paulo
*Member of **fib**(CEB-FIP) Model Code for Service Life Design*

1

ANDRAUS Building
São Paulo
Brazil
1972

2

ANDRAUS Building
Reinforced Concrete Structure

32 office floors

Construction: 1962

Fire: 24th February 1972

fire time: 4h 240min

perfect conditions nothing collapsed

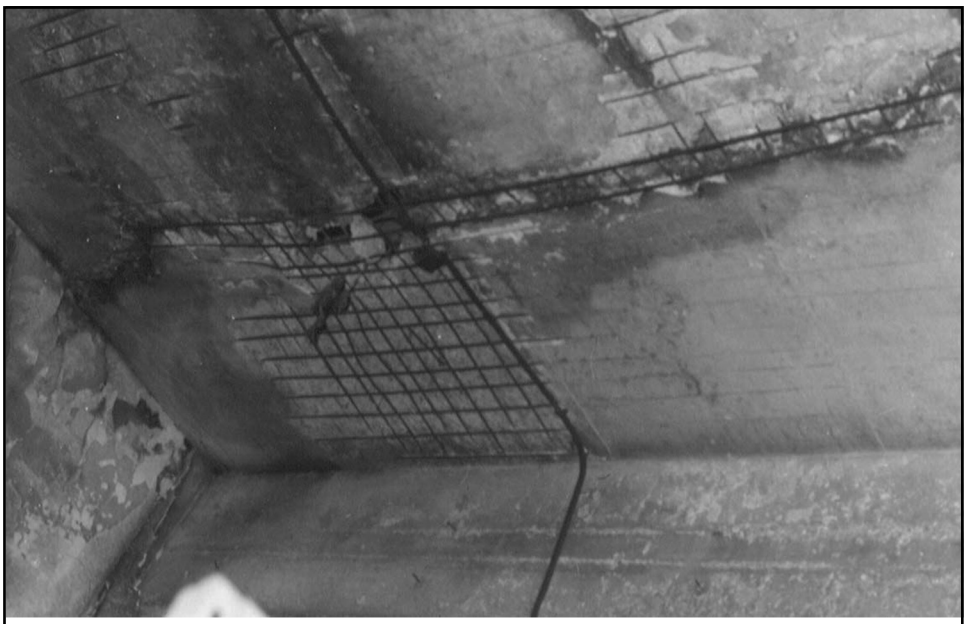
3

typical columns remaining aspect

4

typical beams aspect

5



typical slabs aspect

6

JOELMA Building
São Paulo
Brazil
1974

7

JOELMA Building
Reinforced Concrete Structure

26 stories
10 parking garages
+ 15 offices floors

Construction: 1971

Fire: 1st February 1974

fire time: 6h30min
390min

perfect conditions
nothing collapsed

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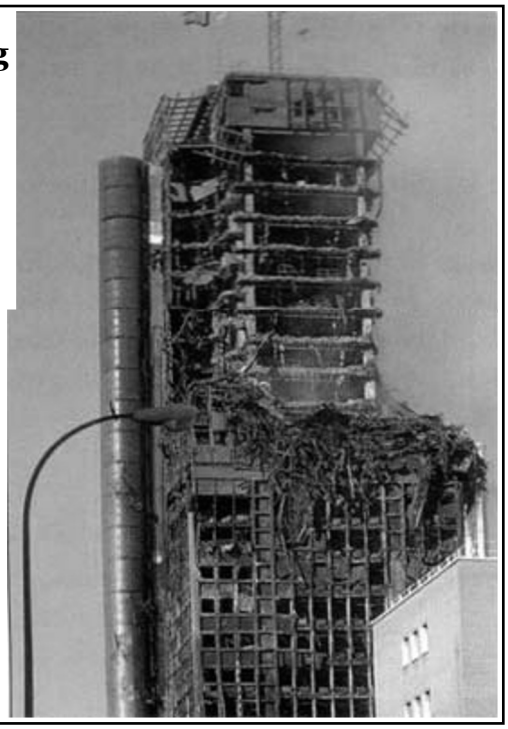
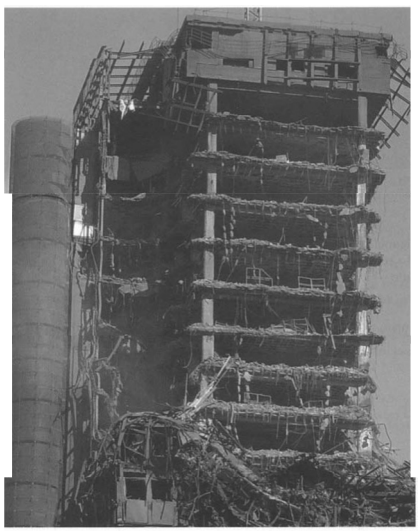
WINDSOR Building
Madrid
Spain
2005



9



WINDSOR Building
Steel-Concrete Structure

37 stories
5 basement parking garages
+ 32 offices floors

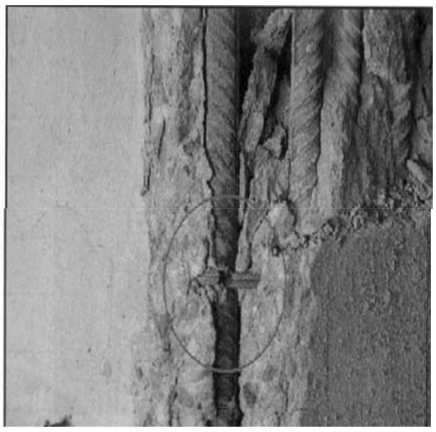
Construction: 1991

Fire: 12nd February 2005

Fire time: 16h
960min

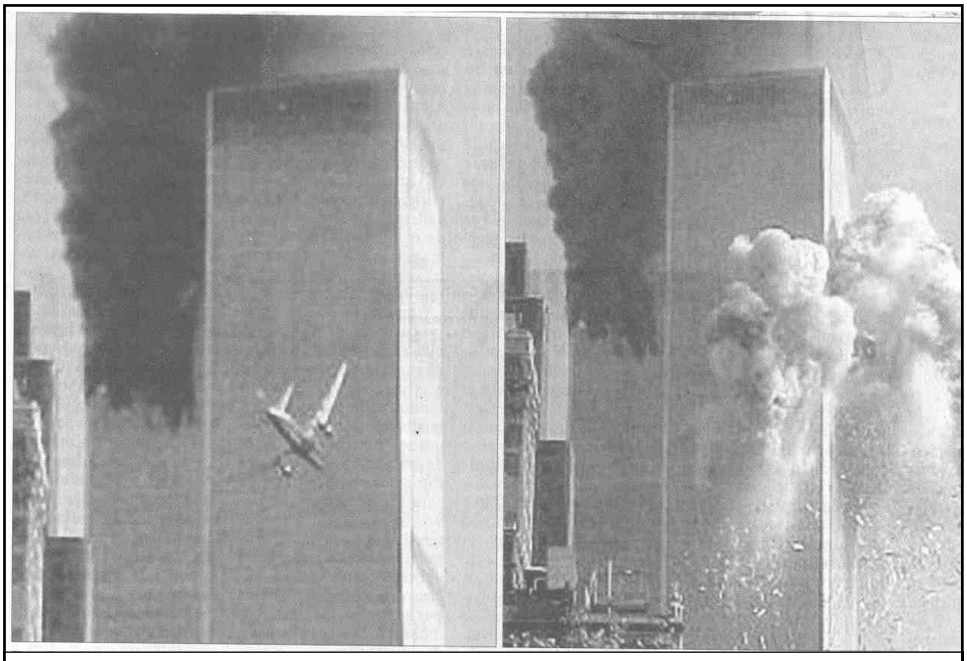
only steel parts collapsed
totally demolished

10



" the reinforced concrete structure, columns, beams and slabs under 16h severe fire condition , could perform well and no collapse"

11



September 11, 2001

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Concrete in fire

✓ site conditions
✓ lab conditions

❖ concrete reduce strength
❖ concrete can have spalling
❖ concrete can have explosive spalling

➢ HSC can have heavy explosive spalling !!!???

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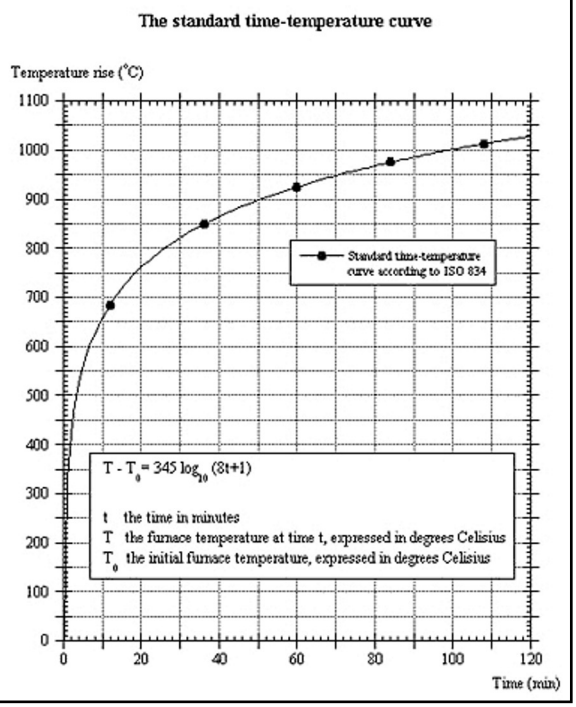
Time-Temperature Curve

Standard Fire

ASTM E 119

ISO 834



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Concrete under Fire
research tests options

cylinders or cubic SPECIMENS
5cm to 15cm diameter, 5cm to 20cm cubic,
diferent aggregates

STRUCTURAL isolated COMPONENTS
columns, beams and slabs
different concrete cover, dimension,
reinforcement, concrete strength, aggregates
...

STRUCTURE

15

Carino & Phan. NISTIR 6726. National Institute of Standards and Technology

HSC water-cement ratio 0.22 to 0.57, 51 to 93 MPa

1. High-strength mixtures made with very low w/cm (0.22) showed less strength loss than with 0.33 w/cm.

2. Explosive spalling was observed when the temperature of the specimen center was in the range of 200 ^{o}C and 325 ^{o}C.

16

HSC water-cement ratio 0.22 to 0.57, 51 to 93 MPa

3. Preload seems to have a mitigating effect on the development of explosive spalling.

4. For concrete samples casted with 0.22 w/cm, tested under restrained conditions, explosive spalling never occurred. Only occurred with some samples casted with 0.33 w/cm.

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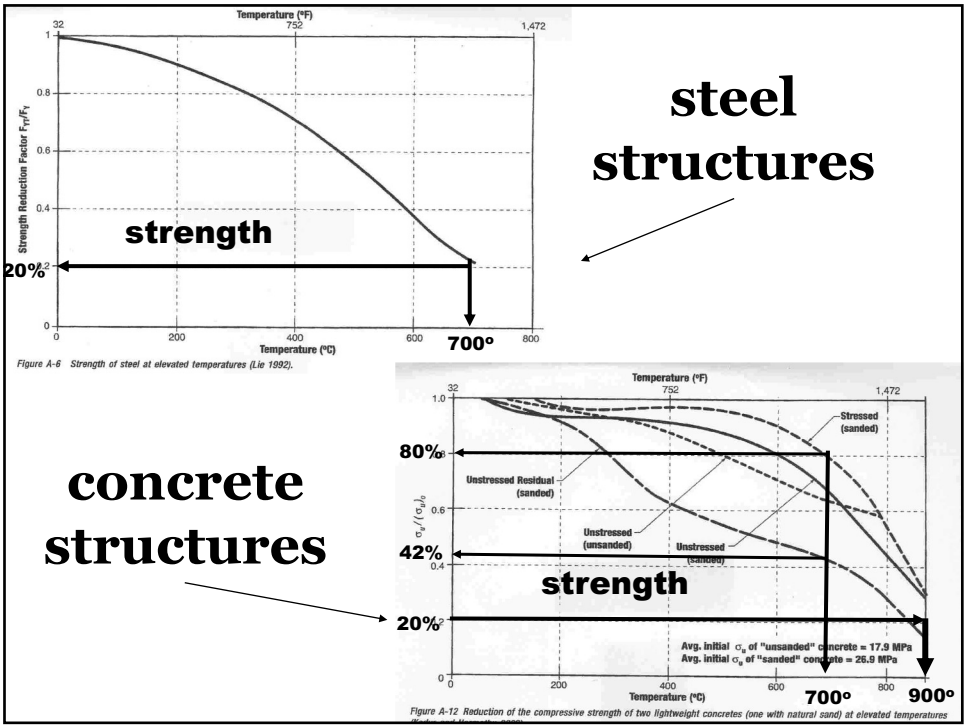

Figure A-6 Strength of steel at elevated temperatures (Lie 1992).

Figure A-12 Reduction of the compressive strength of two lightweight concretes (one with natural sand) at elevated temperatures

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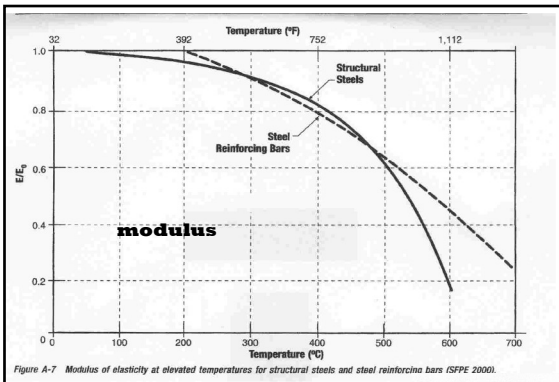
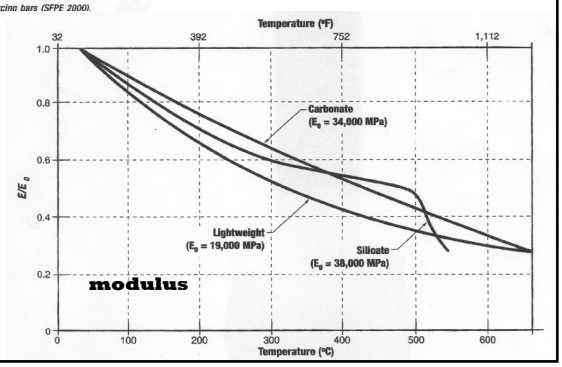


Figure A-7 Modulus of elasticity at elevated temperatures for structural steels and steel reinforcing bars (SFPE 2000).

steel structures

concrete structures



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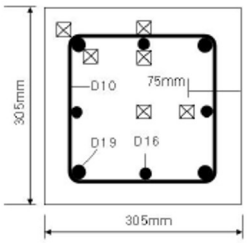
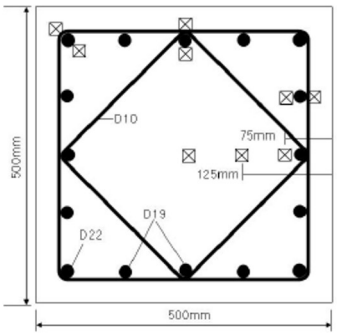
cross section dimension influence



30,5cm x 30,5cm x 3,4m



50cm x 50cm x 3,4m

120MPa HSRC

Park et al, 2007

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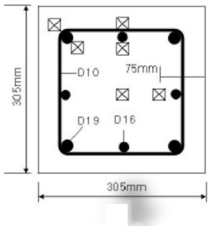
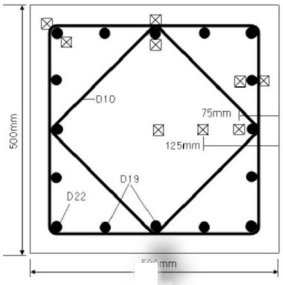
cross section dimension influence

30,5cm x 30,5cm x 3,4m



- ✓ *spalling*: 13mm
- ✓ fire → 176min.
- ✓ collapsed

50cm x 50cm x 3,4m



- ✓ *spalling*: 0mm to 5mm
- ✓ fire: 240min.
- ✓ no collapse

Park et al, 2007

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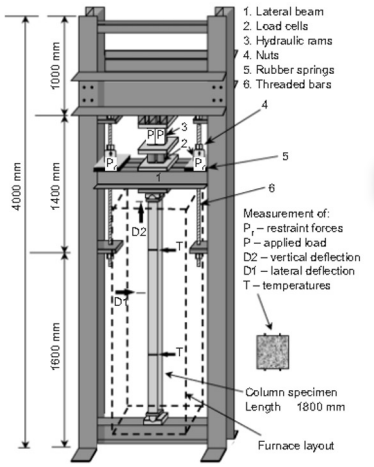
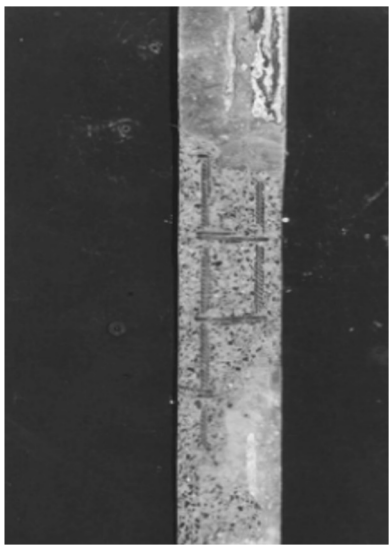
column 1.8m high !!??

> 60cm





cross section 12,5cm x 12,5cm

Benmarce &Guenfoud, 2005

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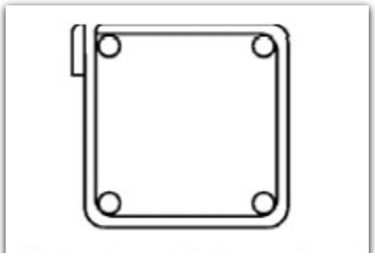
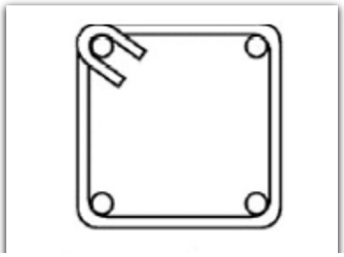
reinforcing details

stirrups in columns



incorrect



correct

Kodur, 2005

23

incorrect

Configuração Convencional de Estribos

correct

Configuração Modificada de Estribos

Kodur, 2005

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concrete cover

40mm

- ✓ spalling: 13mm to 18mm
- ✓ fire: 4 h
- ✓ no colapse
- ✓ 500ºC → after 2h

70mm

- ✓ spalling: 15mm to 30mm
- ✓ fire: 4 h
- ✓ no colapse
- ✓ 500ºC → after 3h

Park & Lee (2008)

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concrete strength

			Concreto normal (43MPa)		Concreto de alta resistência (106MPa)	
Referência	Amostra	Grau de restrição	Tipo de *spalling*	Grau de *spalling*	Tipo de *spalling*	Grau de *spalling*
1	A	0	secundário	16%	severo	39%
2	B		severo	34%	principal	11%
3	C		nenhum	0%	severo	26%
4	A	0,1	severo	27%	principal	1%
5	B		nenhum	0%	principal	1%
6	C		principal	18%	principal	2%
7	A	0,2	severo	35%	nenhum	0%
8	B		principal	29%	principal	4%
9	C		secundário	5%	nenhum	0%

Ali, 2002

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concrete structure fire test

The Cardington Fire Test
By Pal Chana and Bill Price, British Cement Association
Jul 15, 2003, 09:00

- ✓ **7 stories**
- ✓ **25m high**
- ✓ **slab → 15cm f_{ck} = 37MPa**
- ✓ **beam → 2cm f_{ck} = 74MPa**
- ✓ **column → 4cm f_{ck} = 100MPa**
- ✓ **calcário and granite**
- ✓ **RH > 80%**

Cardington Concrete Building Frame

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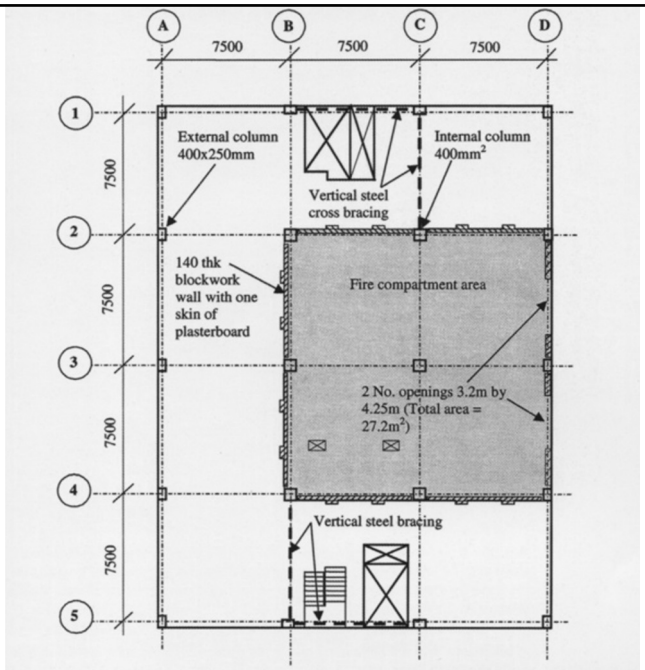

plan of building showing location of fire compartment.

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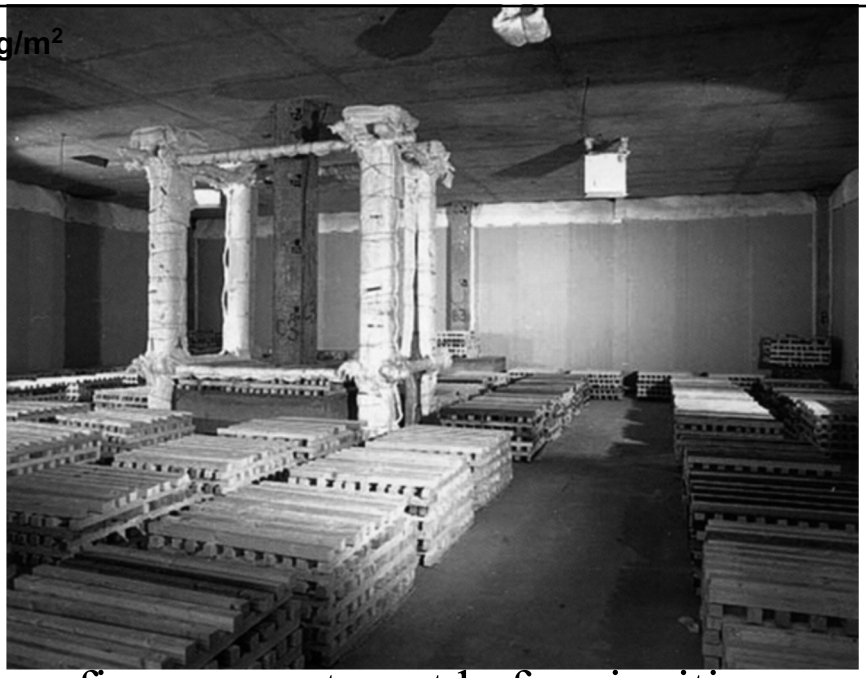
40kg/m^2



fire compartment before ignition.

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after 120min

30

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Cardigan conclusion:

1. The concrete structure survived an intensive fire without collapse;

2. The building satisfied the relevant performance criteria of load bearing function (R), insulation (I) and integrity (E), when subjected to a realistic fire;

3. Extensive spalling of the first floor slab was observed but did not compromise the structural integrity of the floors under the imposed loads;

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4. The maximum horizontal displacements of the floor slab was 6cm;

5. The high strength concrete columns (103MPa), which contained polypropylene fibers, performed very well;

6. The slab was able to carry the imposed loads with residual vertical displacements (7cm).

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RESEARCH
at University of São Paulo
BRAZIL
2002 → 2010

PhD student: Carlos Britez
Supervisor: Paulo Helene

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concrete under very severe condition

HSCRC
High Strength Colored Reinforced Concrete Column

8 years old
kept in natural environmental conditions
125MPa → 8 years ago
now → 140MPa from cores

natural inorganic steel oxide as red pigment

3h (180min) standard fire in lab environment

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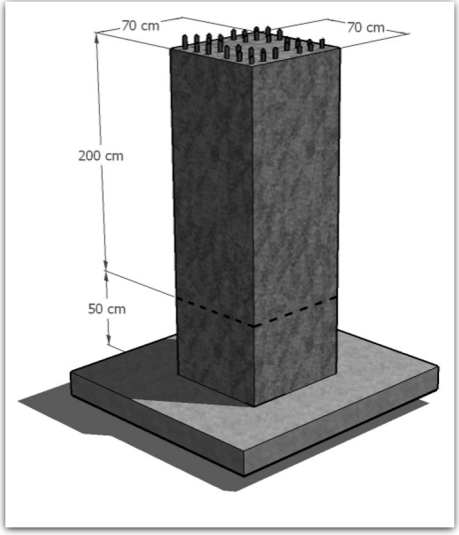
Tested Column



- ✓ **70cm x 70cm**
- ✓ **high: 2m**
- ✓ **weigth: 2500kg**
- ✓ **age: 8 years**
- ✓ f_c **= 140MPa**
- ✓ **cover: 25mm**

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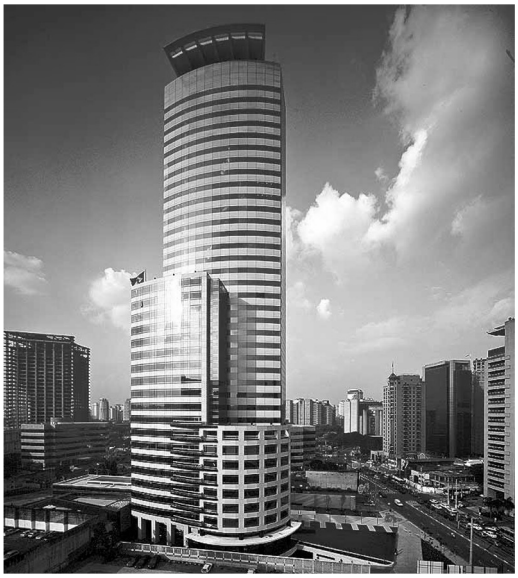
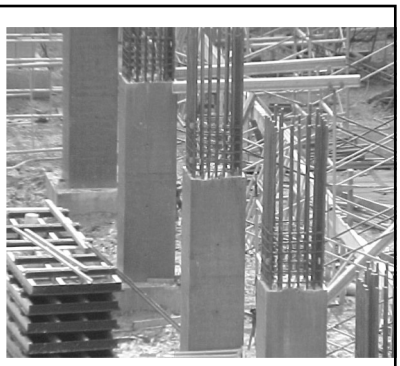
antecedents





e-Tower building

São Paulo Brazil

2002

f_c = 125MPa

world record

6 columns in 7 floors

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“ HPCC in Brazilian Office Tower”

Concrete International. ACI, American Concrete Institute, v. 25, n. 12, p. 64-68, 2003

HELENE, Paulo &
HARTMANN, Carine

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lab column at natural environmental exposure during 8 years

40

research significance

- ✓ aggregate petrography type (basalt)
- ✓ age and natural aging
- ✓ colored (pigmented) concrete
- ✓ very high strength

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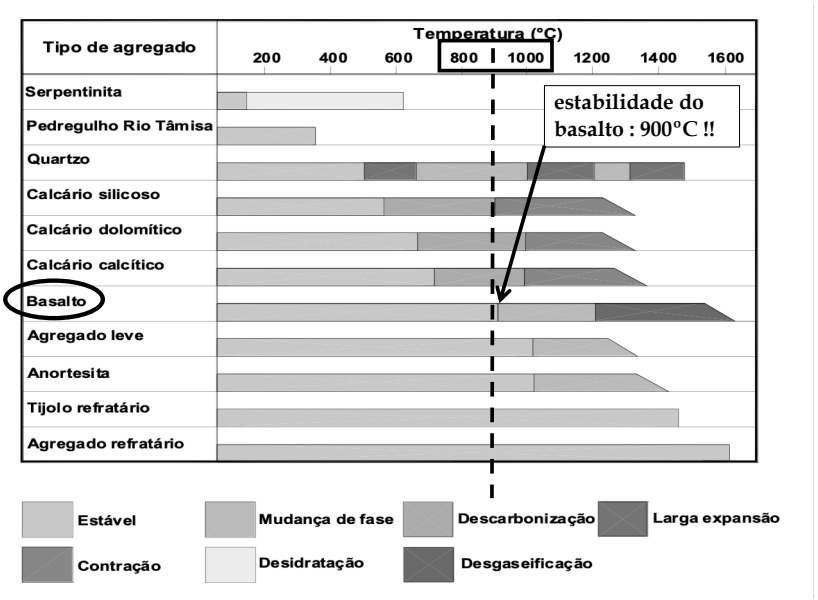
Aggregate (*fib* bulletin 38, 2007)



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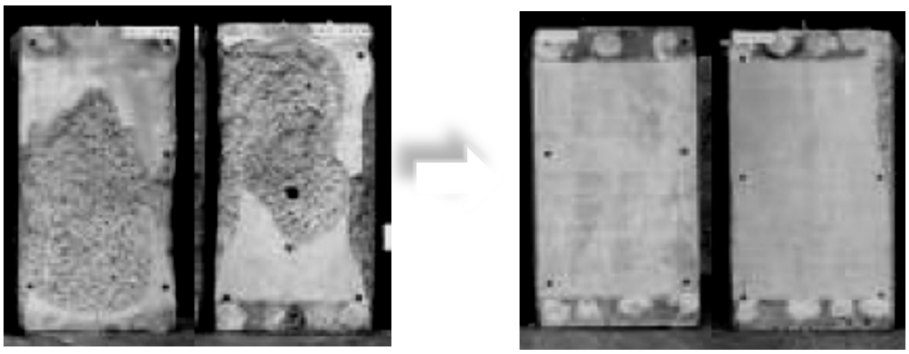
old age ...



2 months

1 year

Morita et al, 2002

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colored (pigmented) concrete

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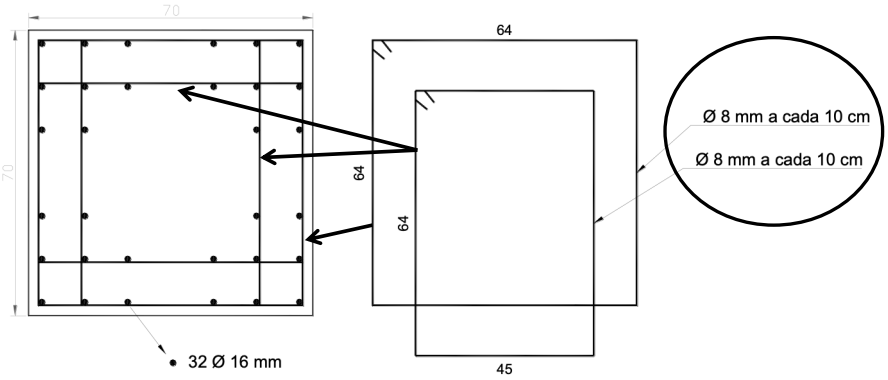
cross section



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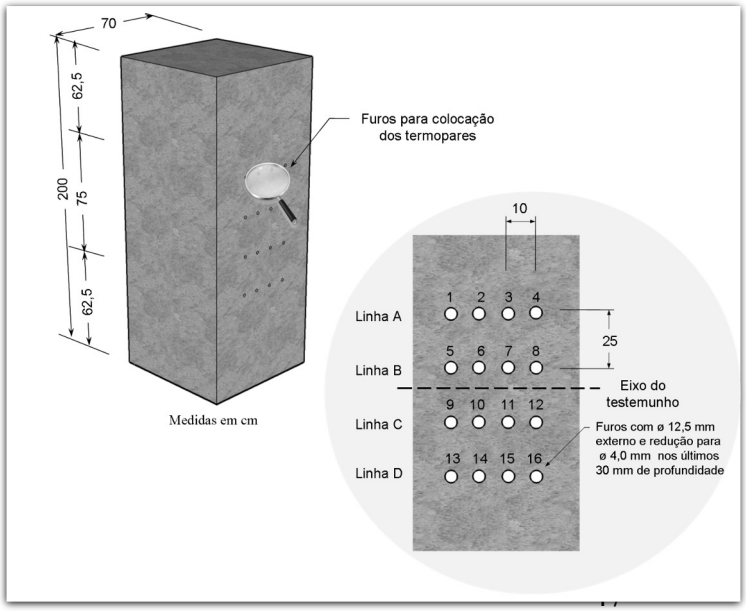
termopares



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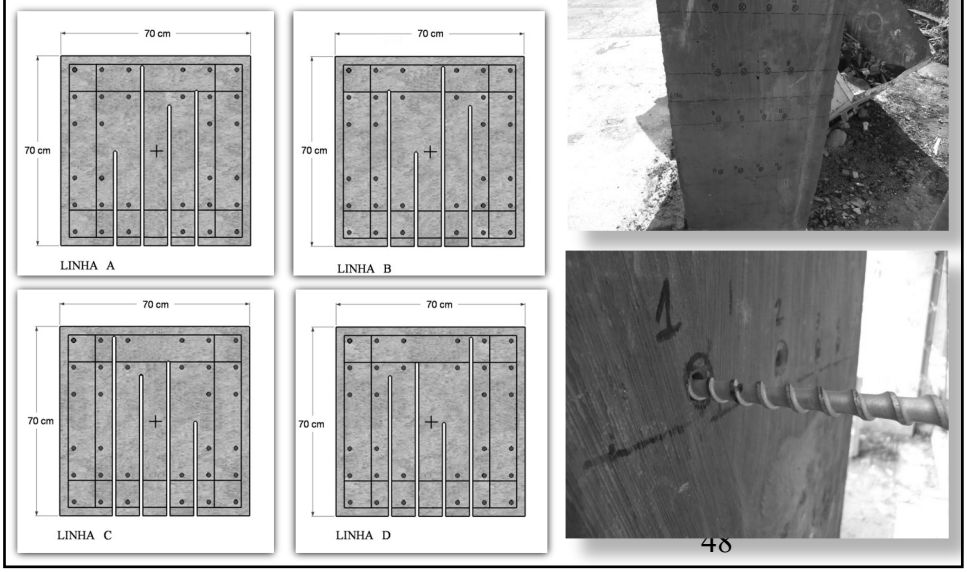
insering termopares



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cores extraction

140 MPa

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column → cut and transport

diamond wire

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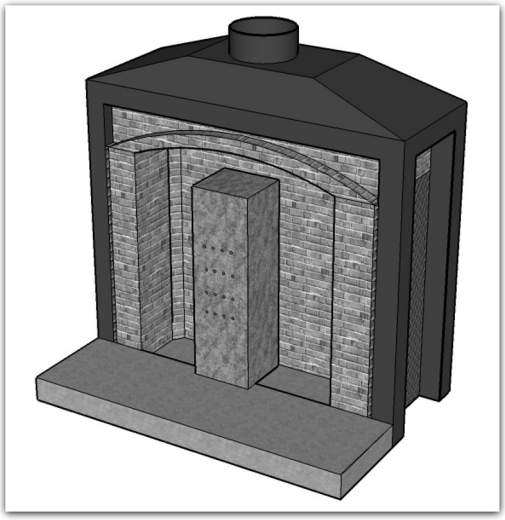
Lab Test



- ✓ unloaded
- ✓ 3 sides
- ✓ISO 834
- ✓ 180 min

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Top protection with ceramics fiber

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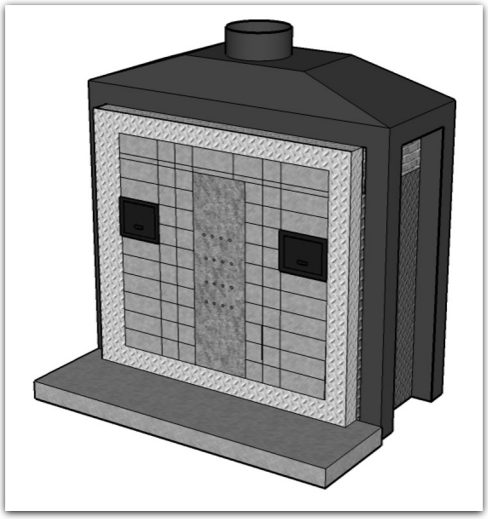
Lab Test



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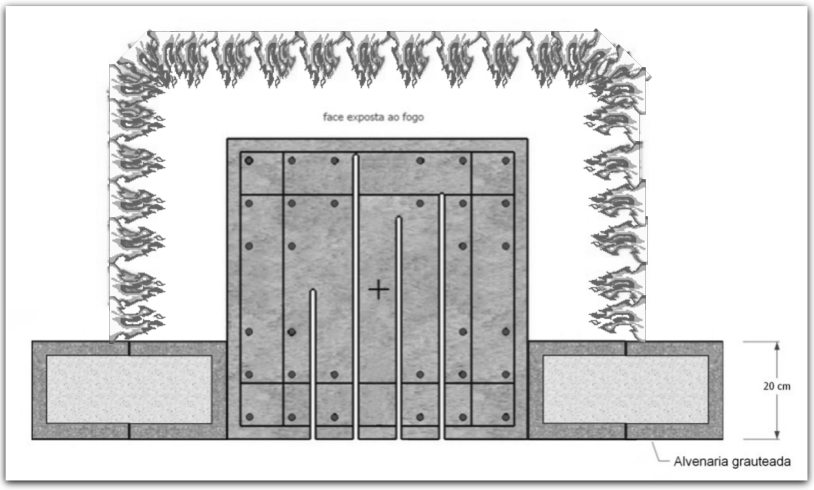
Heat Conditions (3 sides)



ISO 834 standard fire

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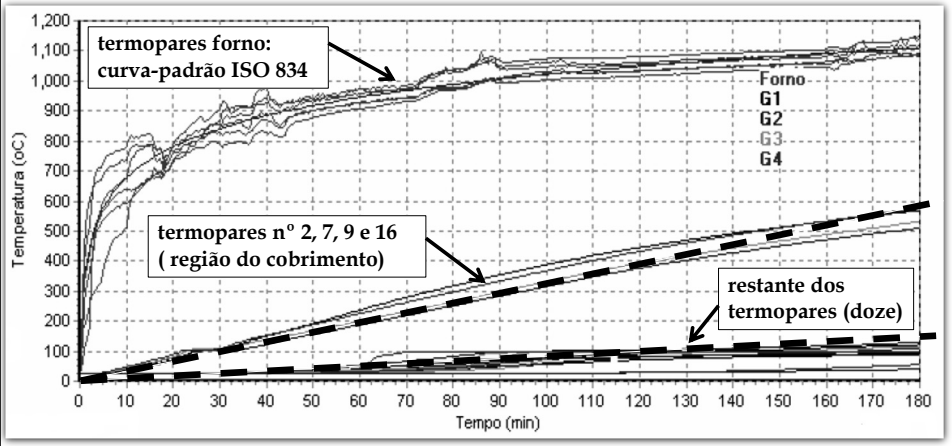
temperature evolution



55

55

After Lab Test
180min fire + 3 days

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Integrity

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Integrity after 180min

- ✓ ***spalling*** **no explosive**
- ✓ **pop corn sounds < 36min**
- ✓ **uniform distribution**
- ✓ **< 48mm (deep)**

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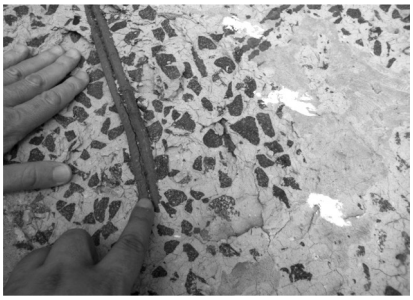
Integrity



exposed steel
< 5%

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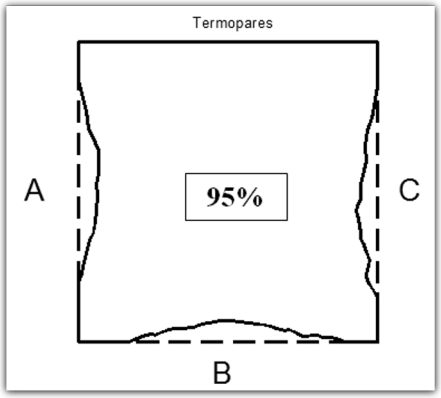
Integrity

60

Integrity



spalling **measured in 450 points (150 each side)**

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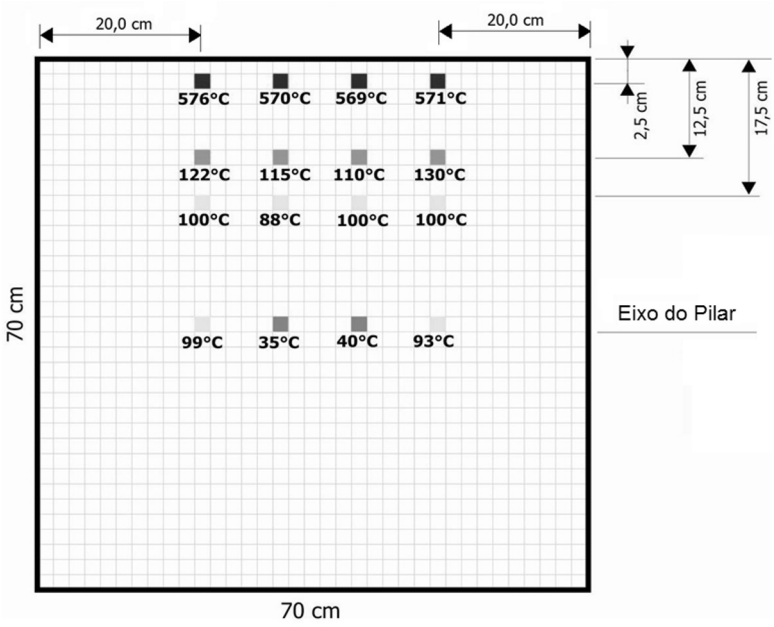
temperatures after 180 min



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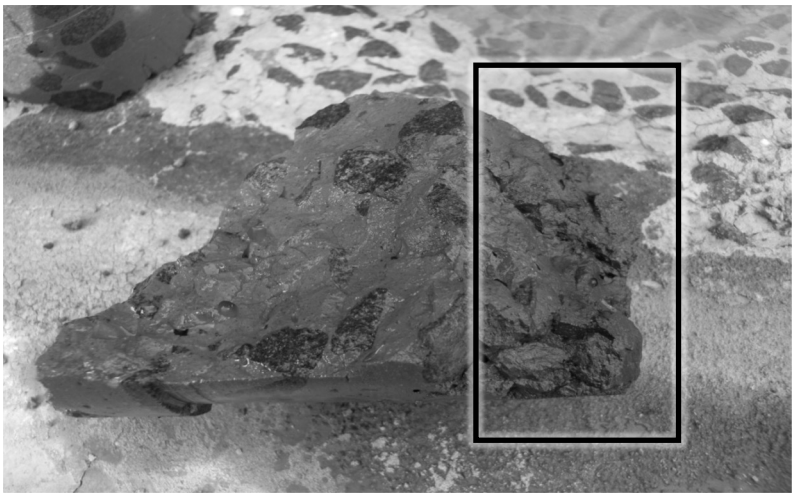
"pigment as natural thermometer"



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"natural thermometer"

- ✓ red pigment
- ✓ deep ≈55mm
- ✓ Fe_2O_3 em Fe_3O_4
- ✓ hematite to magnetite

about 600ºC

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numerical analysis of the residual load capacity according to EUROCODE II

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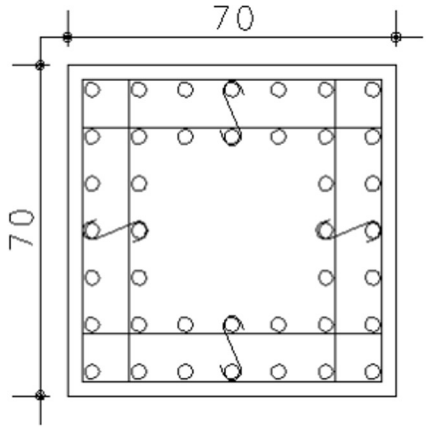
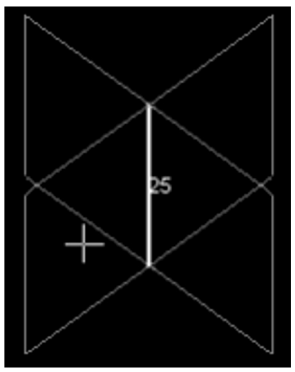
Initial Condition

cross section = 70x70cm
Ac = 4578,32cm²
As = 40 Ø 32mm = 321,68cm²
ρ =7,03%

Hipótese de Cálculo (Contraventamentos)





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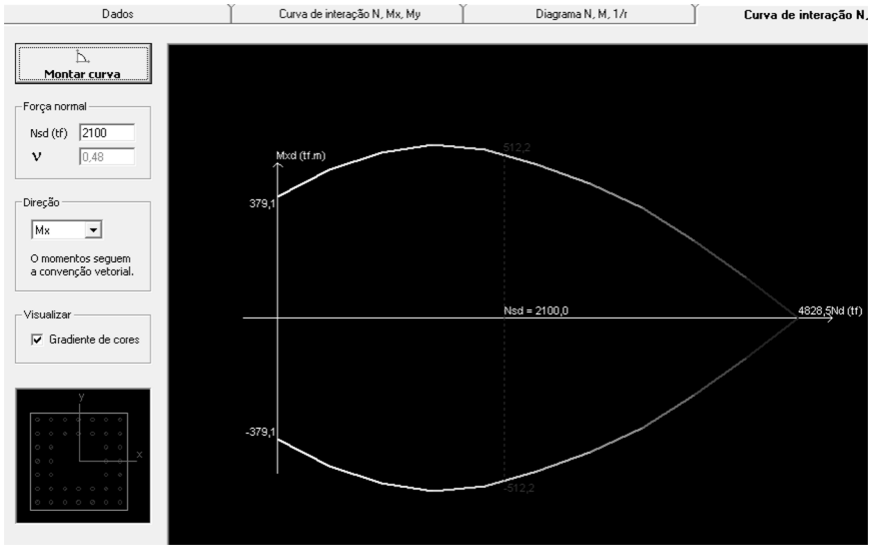
cross section 70x70
Interação Nd, Mx = My



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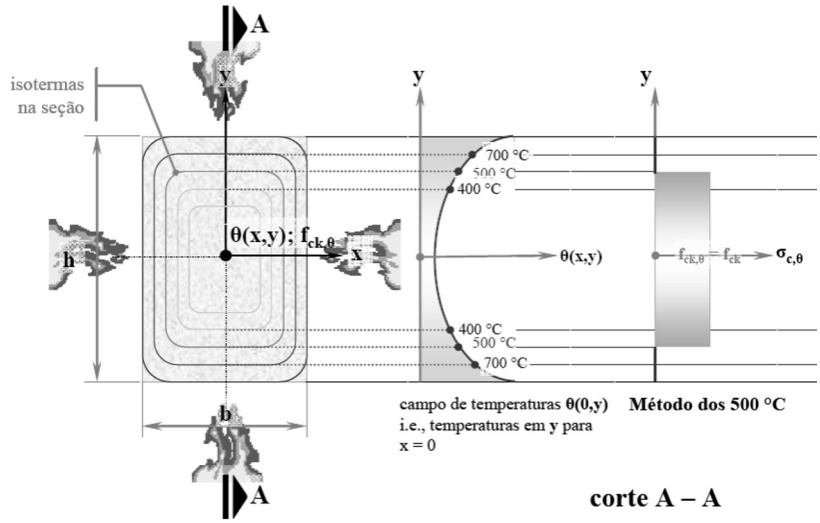
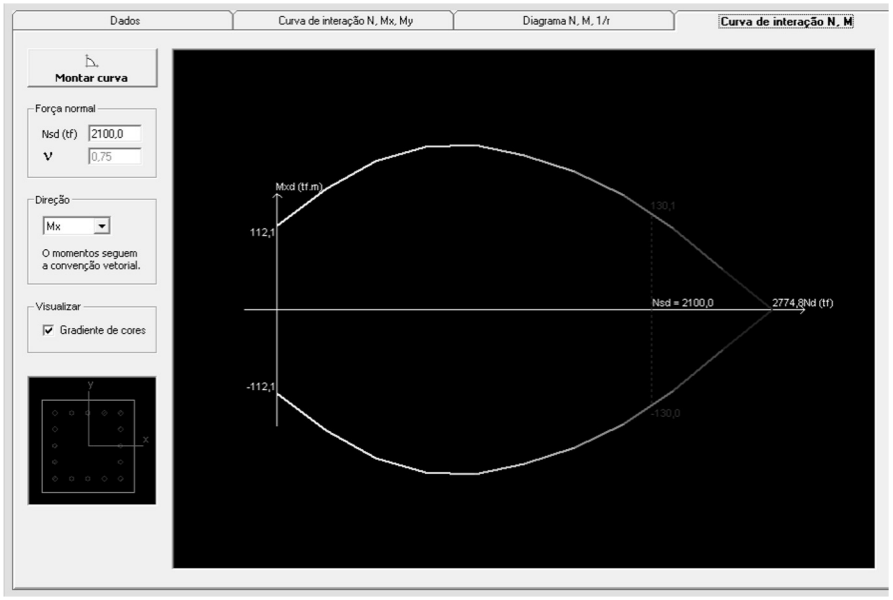
500°C Isotherm Method . EN 1992-1-2-2004 (EUROCODE II)



(Costa,2008)

70

cross section 56x56
Interação Nd, Mx = My



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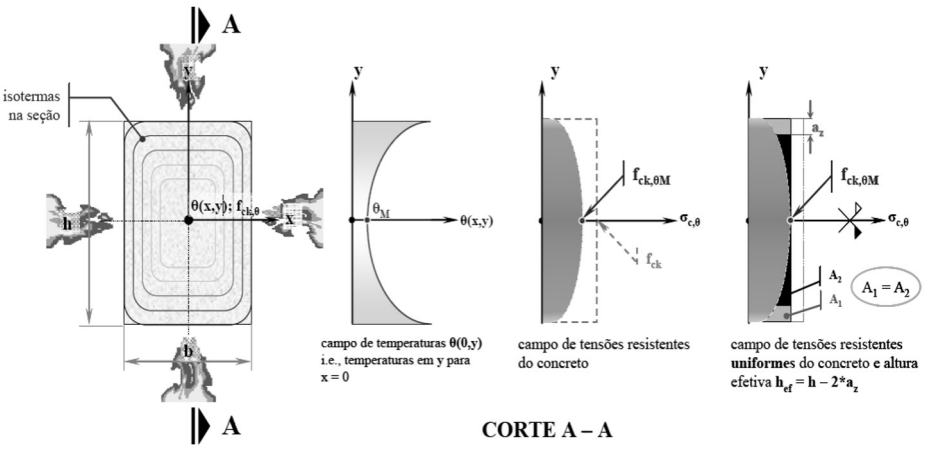
Zone Method . EN 1992-1-2-2004
EUROCODE II



(Costa,2008)

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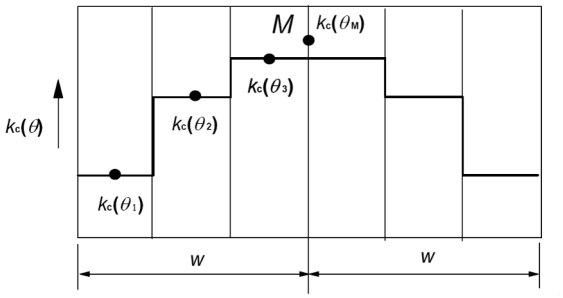
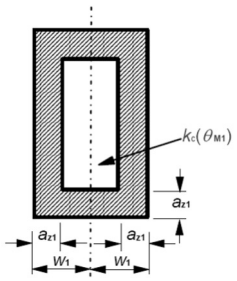
Zone Method . EN 1992-1-2-2004
EUROCODE II





$$a_z = \begin{cases} w \cdot \left(1 - \dfrac{\kappa_{c,m}}{\kappa_{c,\theta_M}}\right) & \rightarrow \text{ lajes e vigas;} \\ w \cdot \left[1 - \left(\dfrac{\kappa_{c,m}}{\kappa_{c,\theta_M}}\right)^{1,3}\right] & \rightarrow \text{ pilares e pilares – parede.} \end{cases}$$

$$\kappa_{c,m} = \frac{\left(1 - \dfrac{0,2}{n}\right)}{n} \cdot \sum_{i=1}^{n} \kappa_{c,\theta i}$$

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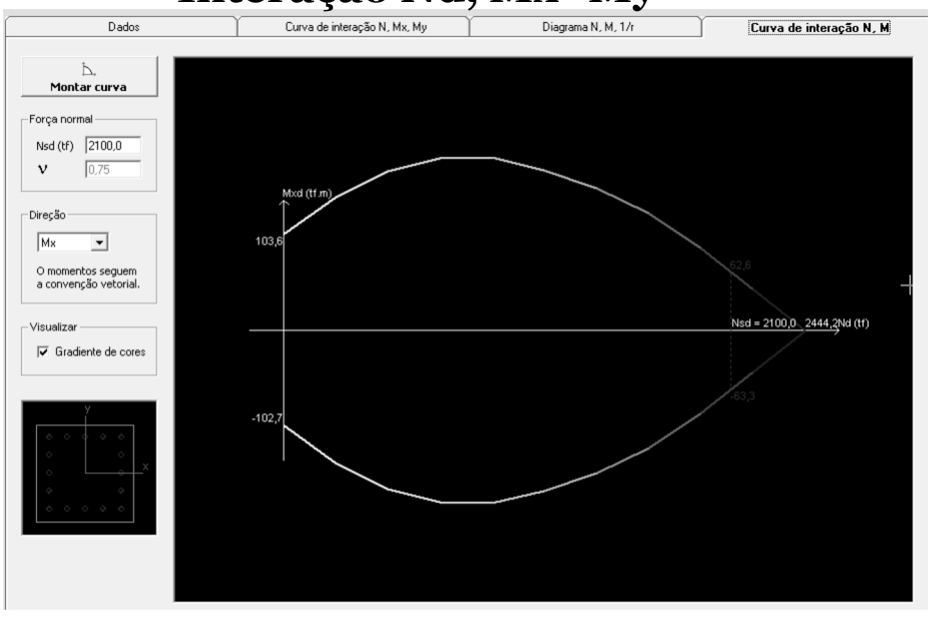
cross section 52x52
Interação Nd, Mx=My



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summary for Mx = My = zero

initial condition
cross section → 70x70
N_{dmax} = 4828 tf *(100%)*

500°C Isotherm Method
cross section → 56x56
N_{dmax} = 2774 tf *(57%)*

Zone Method
cross section → 52x52
N_{dmax} = 2444 tf *(50%)*

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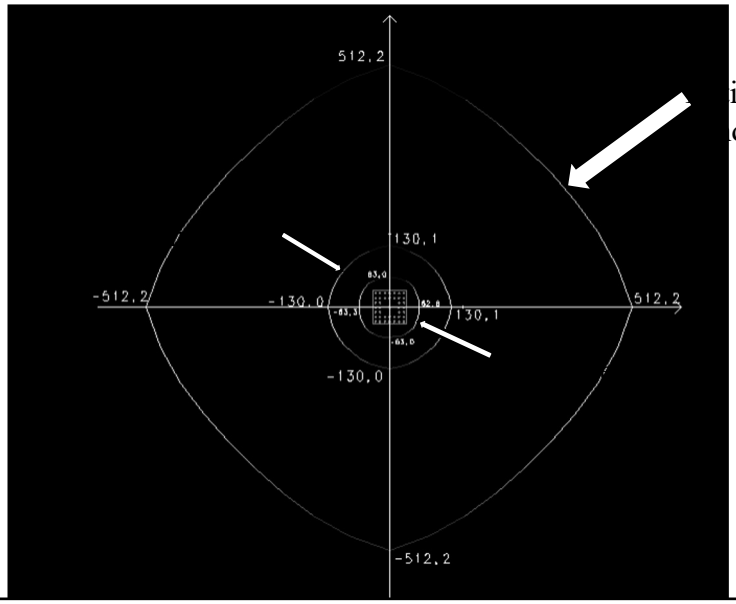
Comparação das Curvas de Interação Mx e My para N_d = 2100tf



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WINDSOR Building
Steel-Concrete Structure

Madrid
Spain
2005

" the behavior of reinforced concrete structure under severe fire condition was extremely positive and much better than standard (EUROCODE) prediction under fire conditions"

Jose Calavera Ruiz
Ingeniería Estructural. AIE n.37, 2006

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Conclusion

1. A materials-based approach is not sufficient on its own to explain the performance of a real concrete structure in a fire.

2. Additional factors, such as elements dimensions, steel distribution, cover deep, concrete age, and others of the concrete structure as a whole, are also significant.

3. The best way can be allow a performance-based approach to be used in design; taking

4. Taking into account actual fire-loading scenarios, physical material parameters, and analysis of the whole structure.

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