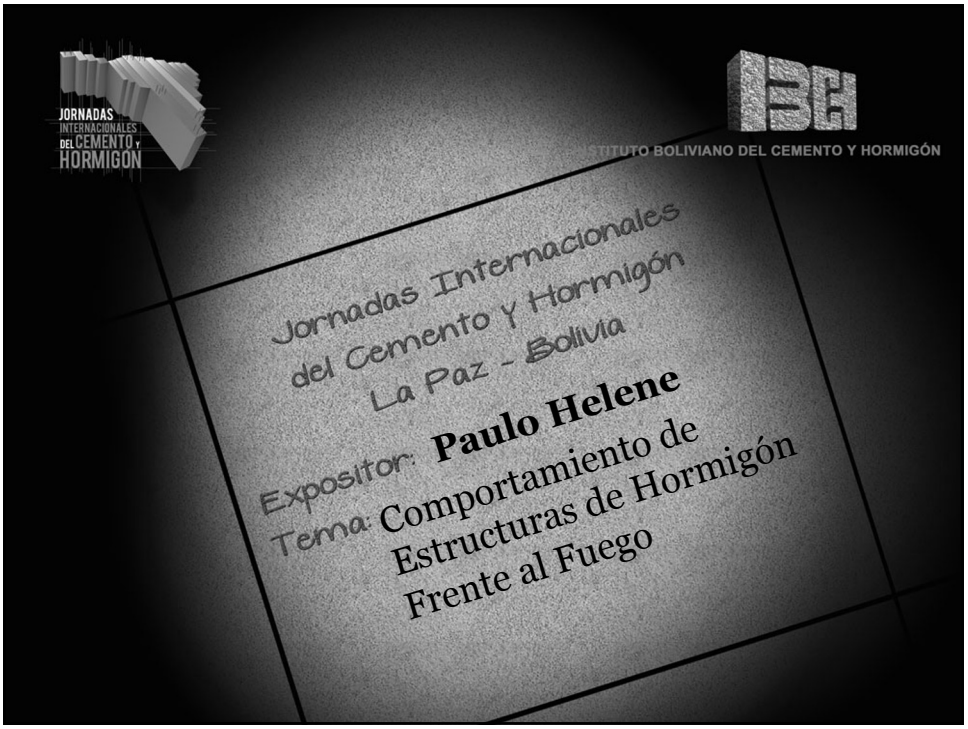


1

Comprehensive fire protection and safety with concrete

BCA · BRITISH PRECAST · BRITISH READY-MIXED CONCRETE ASSOCIATION · the Sign of Quality

European Concrete Platform

April 2007

European Concrete Platform ASB

2

Pavimentos de hormigón en túneles
su influencia en la seguridad frente al fuego

Carlos Jofré
Joaquín Romero
Rafael Rueda

IECA INSTITUTO ESPAÑOL DEL CEMENTO Y SUS APLICACIONES

Editado por:
IECA
José Abascal, 53
28003 MADRID
2010

3

"La Federación de Bomberos de Francia opina que "la simple lógica debería imponer la sustitución de las mezclas bituminosas por un material totalmente neutro como es el hormigón" .

"Por su parte, el Comité Técnico Internacional para la Prevención y Extinción de Incendios (CTIF) [1], una organización que representa a cinco millones de bomberos y que es la más importante a nivel mundial, indica que "los firmes de las carreteras deberían ser incombustibles, no emitir humos tóxicos y ser claros, lo que mejora la visibilidad. Por ello el hormigón debería preferirse a las mezclas bituminosas".

4

HSCRC

HIGH STRENGTH COLORED REINFORCED CONCRETE UNDER STANDARD FIRE EXPOSURE

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

5

ANDRAUS Building
São Paulo
Brazil
1972

6

ANDRAUS Building
Reinforced Concrete Structure

32 office floors

Construction: 1962

Fire: 24th February 1972

fire time: 4h 240min

perfect conditions
nothing collapsed

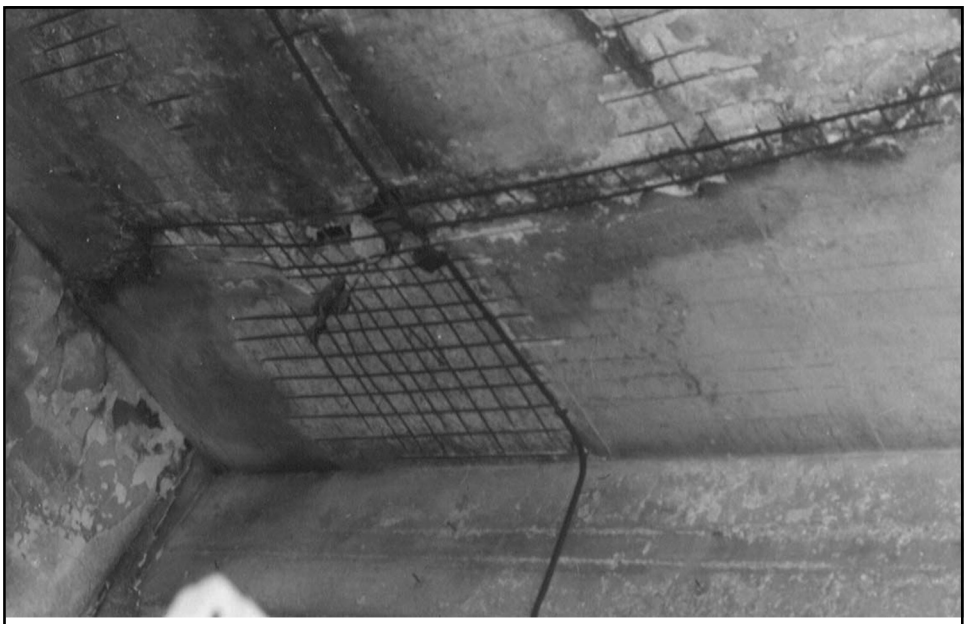
7

typical columns remaining aspect

8

typical beams aspect

9



typical slabs aspect

10

JOELMA Building
São Paulo
Brazil
1974

11

JOELMA Building
Reinforced Concrete Structure

26 stories
10 parking garages
+ 15 offices floors

Construction: 1971

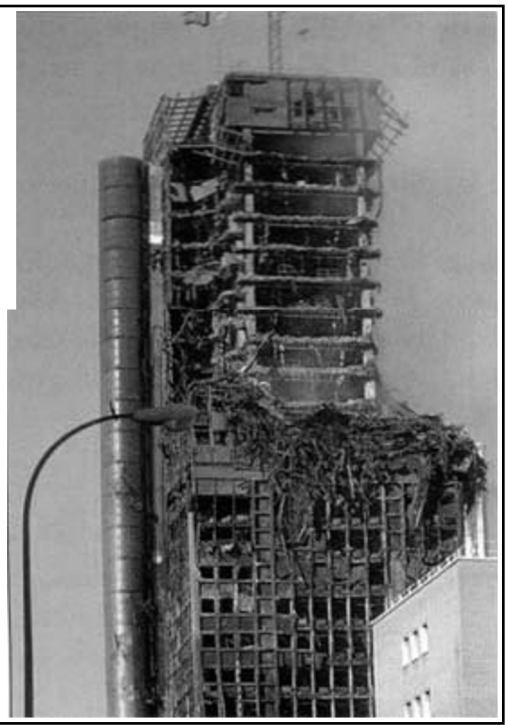
Fire: 1st February 1974

fire time: 6h30min
390min

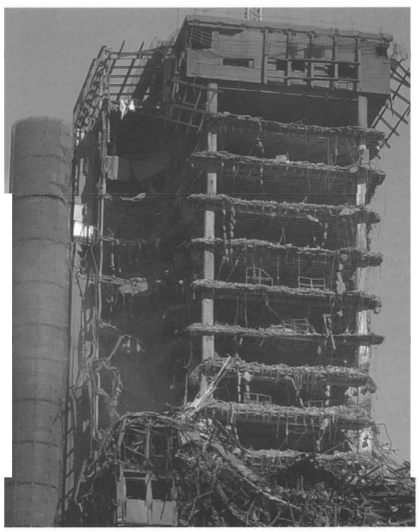
perfect conditions
nothing collapsed

12

WINDSOR Building
Madrid
Spain
2005



13



WINDSOR Building
Steel-Concrete Structure

37 stories
5 basement parking garages
+ 32 offices floors

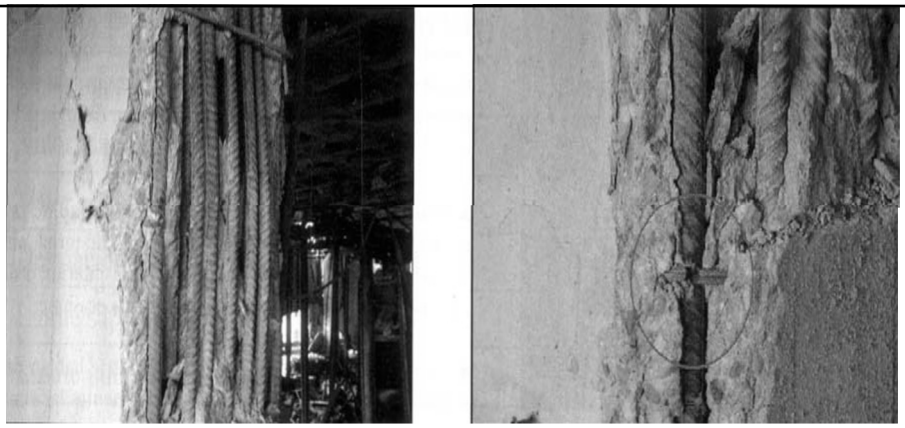
Construction: 1991

Fire: 12 February 2005

Fire time: 16h
960min

only steel parts collapsed
totally demolished

14

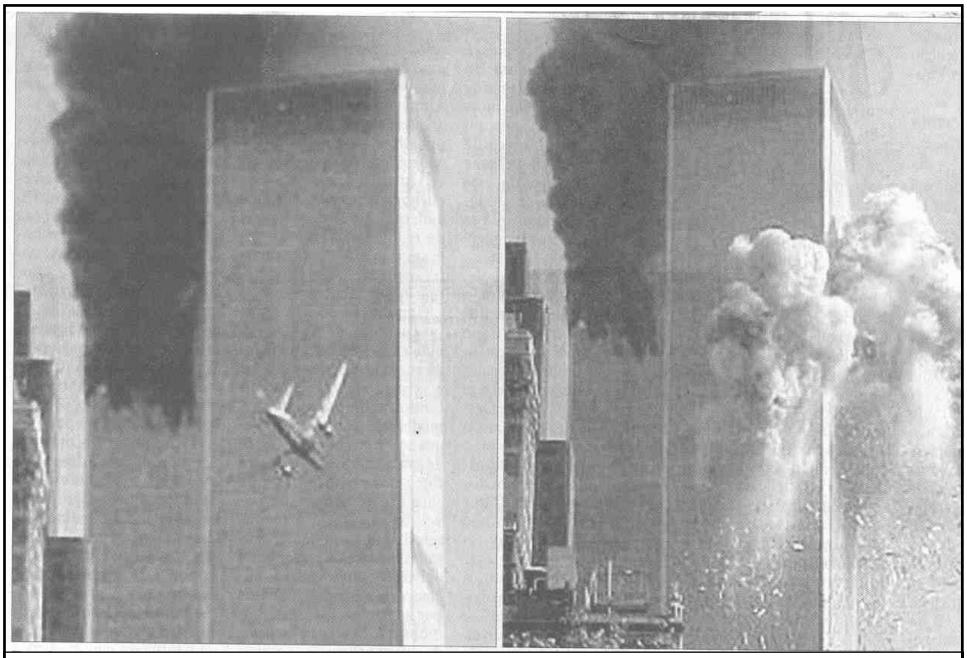


" the reinforced concrete structure, columns, beams and slabs under 16h severe fire condition , could perform well and no collapse"

... "the penetration of the damaged, is heterogeneous and vary from 1.5cm in 19 floor to 3 cm in 12 floor... "

Dra. Cruz Alonso. IET.

15



September 11, 2001

17

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

Is it true?

18

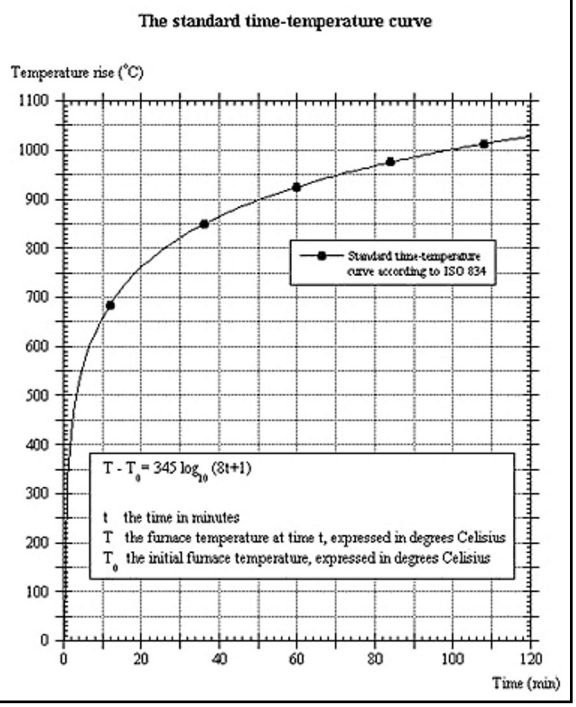
Time-Temperature

Curve

Standard Fire

ASTM E 119

ISO 834



19

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

20

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.

21

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.

22

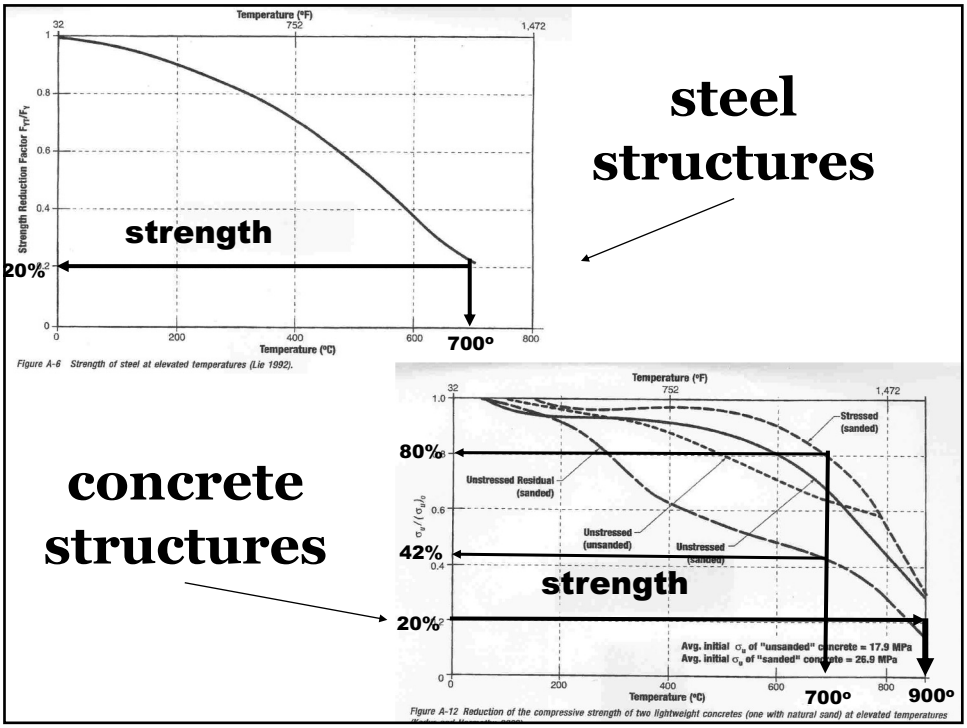


Figure A-6 Strength of steel at elevated temperatures (Lie 1992).

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

23

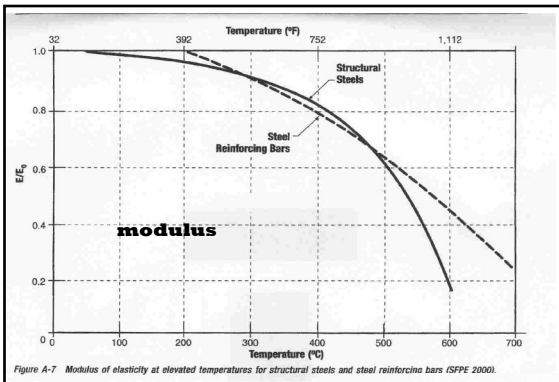
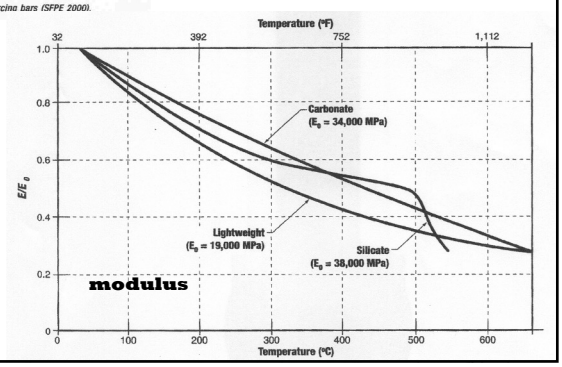


Figure A-7 Modulus of elasticity at elevated temperatures for structural steels and steel reinforcing bars (SFPE 2000).

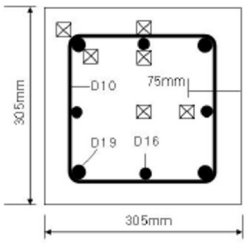
steel structures

concrete structures

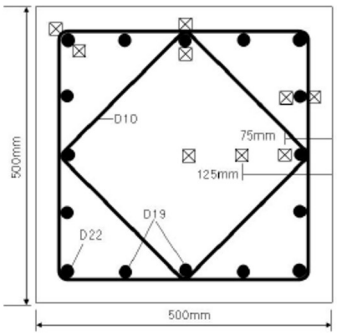


24

cross section dimension influence



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



50cm x 50cm x 3,4m

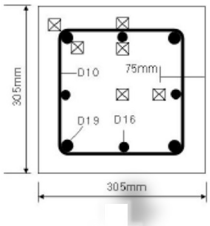
120MPa HSRC

Park et al, 2007

25

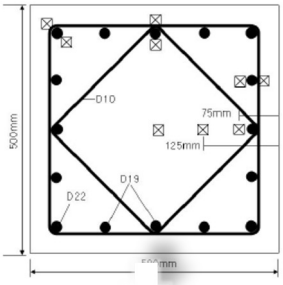
cross section dimension influence

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



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

50cm x 50cm x 3,4m



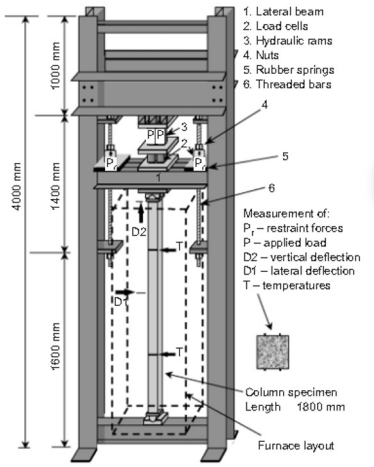
- ✓ *spalling*: 0mm to 5mm
- ✓ fire: 240min.
- ✓ no collapse

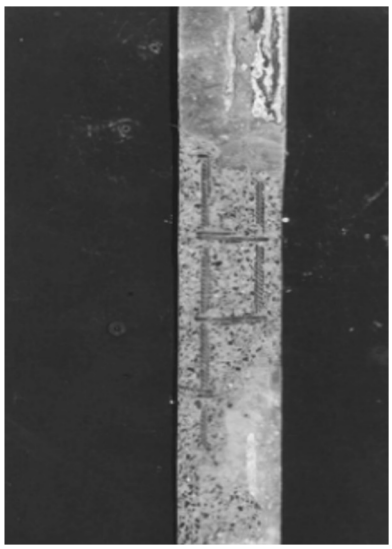
Park et al, 2007

26

column 1.8m high !!??

> 60cm





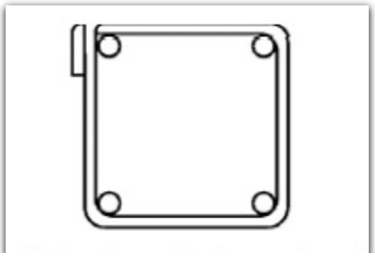
cross section 12,5cm x 12,5cm

Benmarce &Guenfoud, 2005

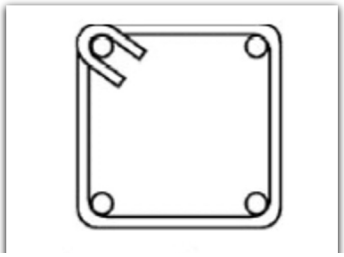
27

reinforcing details

stirrups in columns



incorrect



correct

Kodur, 2005

28

incorrect

Configuração Convencional de Estribos

correct

Configuração Modificada de Estribos

Kodur, 2005

29

concrete cover

40mm	70mm
✓ spalling: 13mm to 18mm	✓ spalling: 15mm to 30mm
✓ fire: 4 h	✓ fire: 4 h
✓ no colapse	✓ no colapse
✓ 500ºC → after 2h	✓ 500ºC → after 3h

Park & Lee (2008)

30

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

31

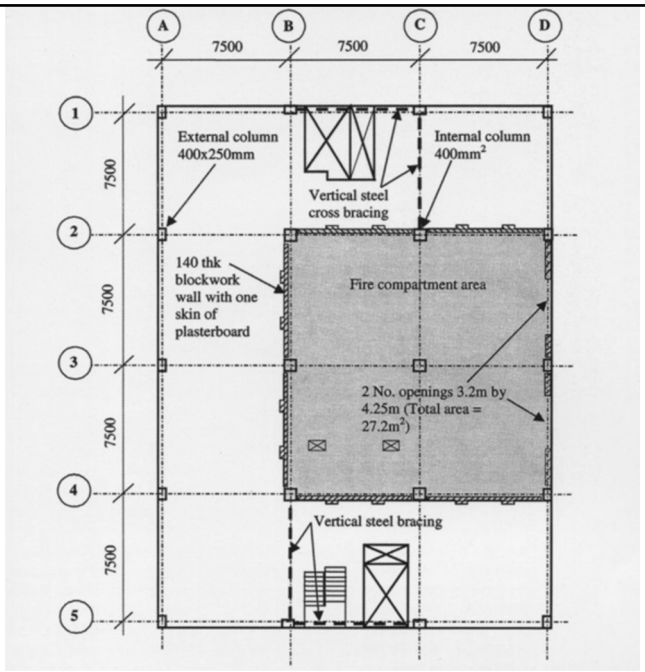
concrete structure fire test

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

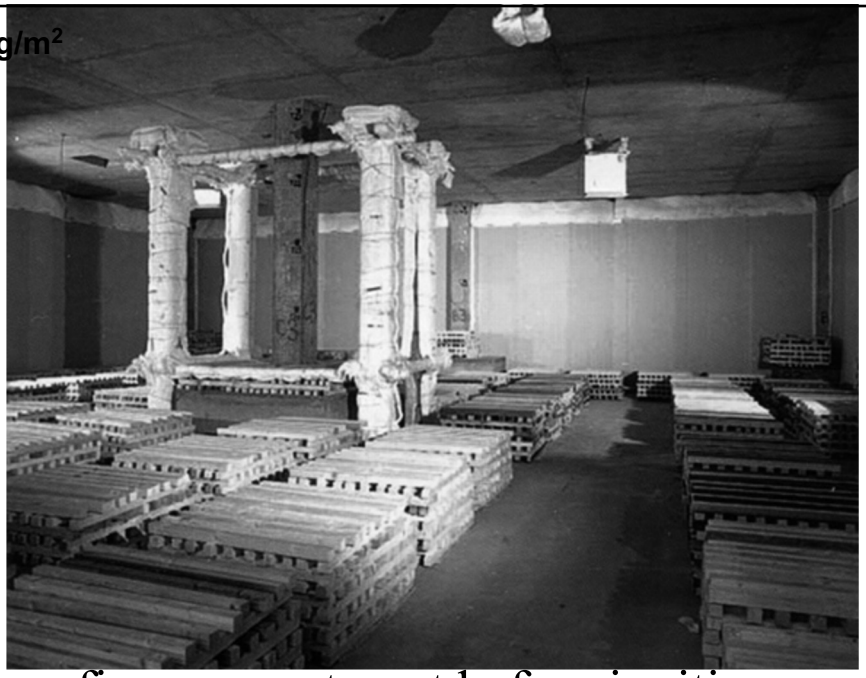
32



plan of building showing location of fire compartment.

33

40kg/m^2



fire compartment before ignition.

34

after 120min

35

36

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;

37

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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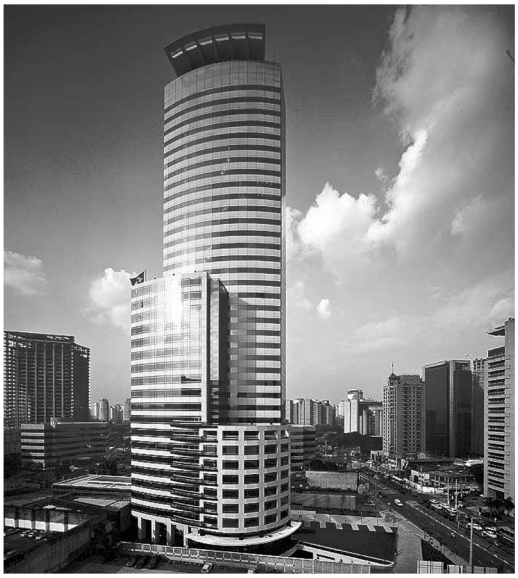
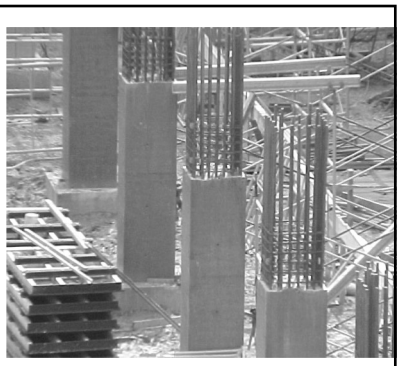
past history





e-Tower building

São Paulo Brazil

2002

f_c = 125MPa

world record

6 columns in 7 floors

40

concrete

41

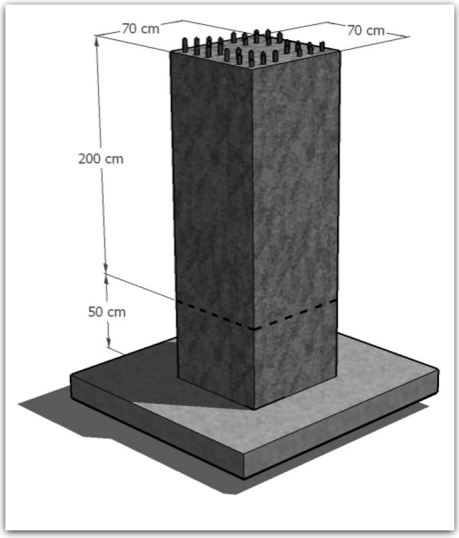
“ HPCC in Brazilian Office Tower”

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

HELENE, Paulo &
HARTMANN, Carine

42

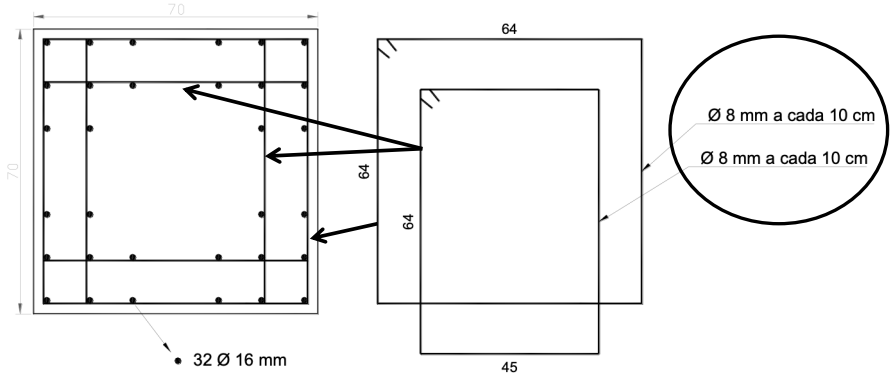
Tested Column



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

43

cross section



44

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 iron oxide as red pigment

3h (180min) standard fire in lab environment

45

similar lab column kept at natural environmental exposure

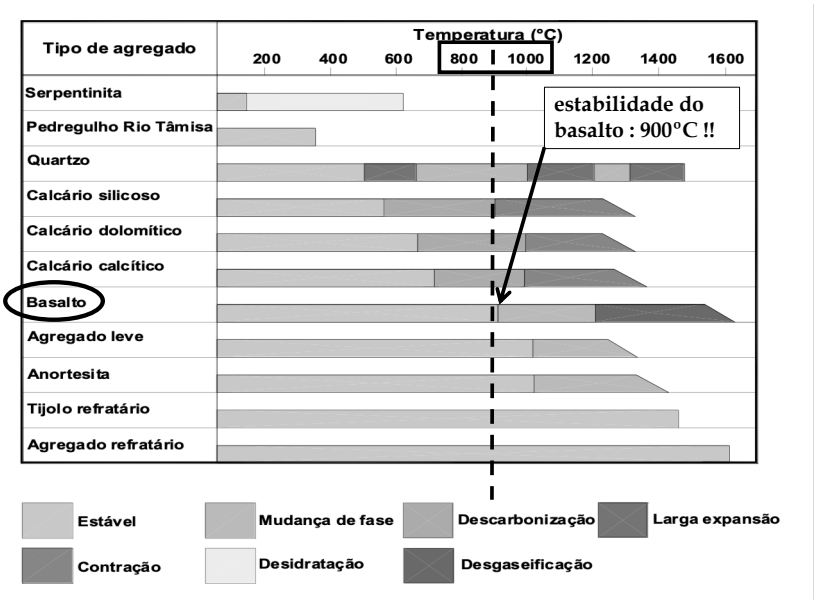
46

research significance

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

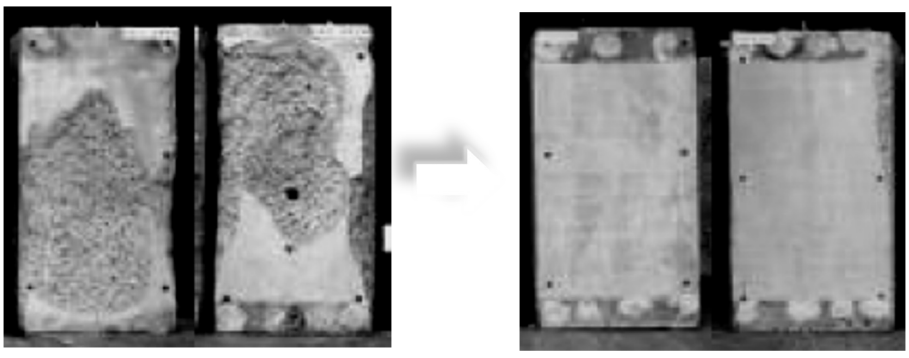
47

Aggregate (*fib* bulletin 38, 2007)



48

old age ...



2 months **1 year**

Morita et al, 2002

49

colored (pigmented) concrete

50

column → cut and transport

diamond wire

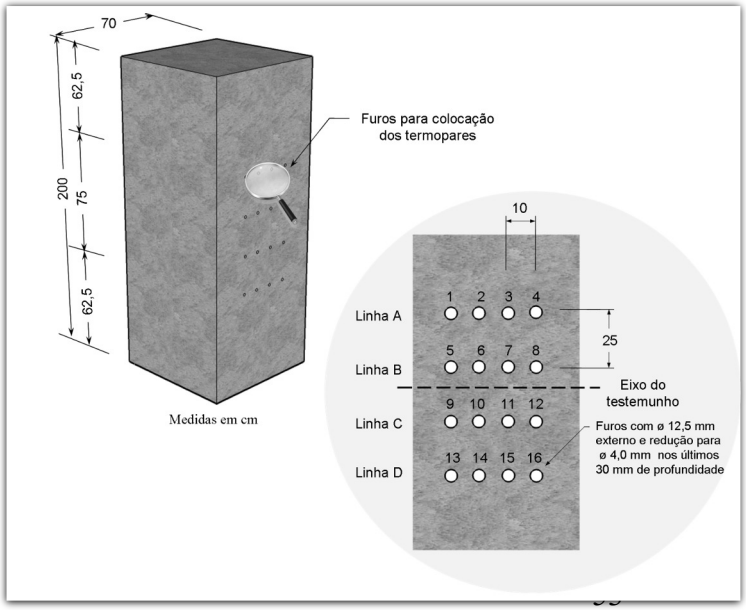
51

drilled cores

140 MPa

52

16 thermocouples



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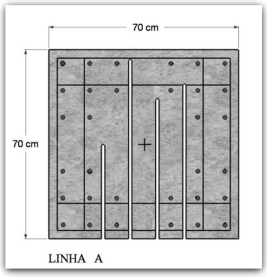
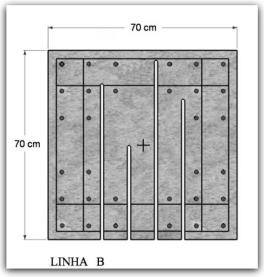
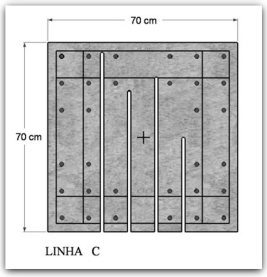
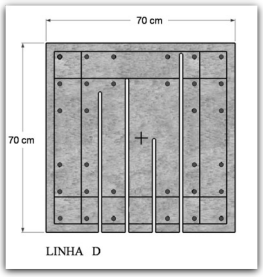
inserting thermocouple









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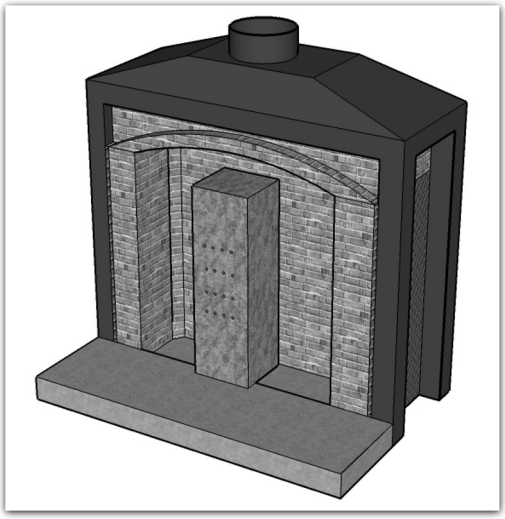
Lab Test



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

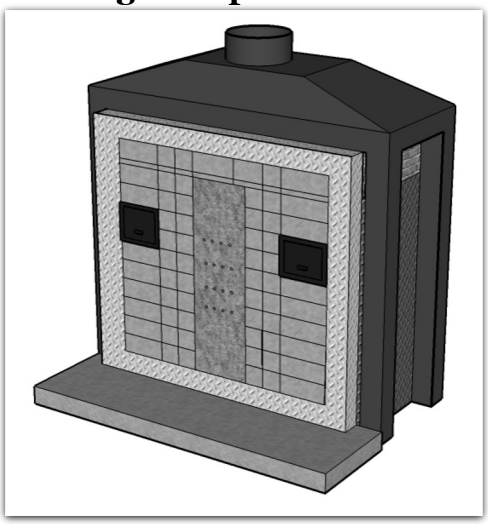
55

top protection with ceramics fiber

56

Lab Test

high temperature oven



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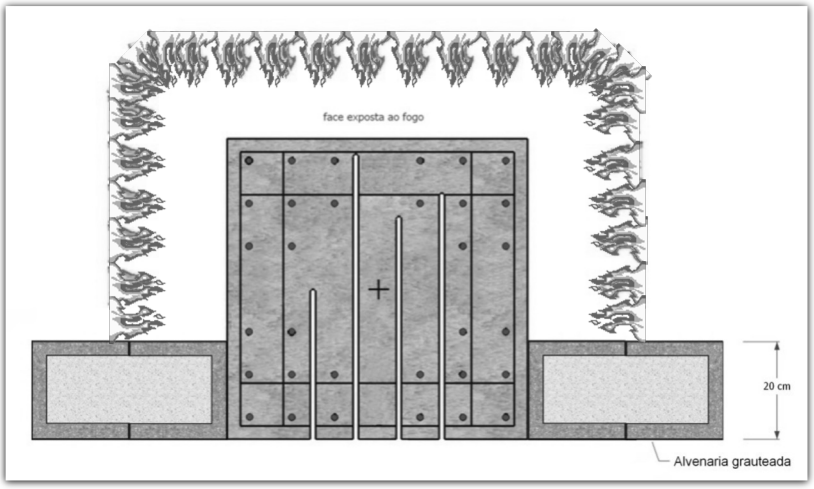
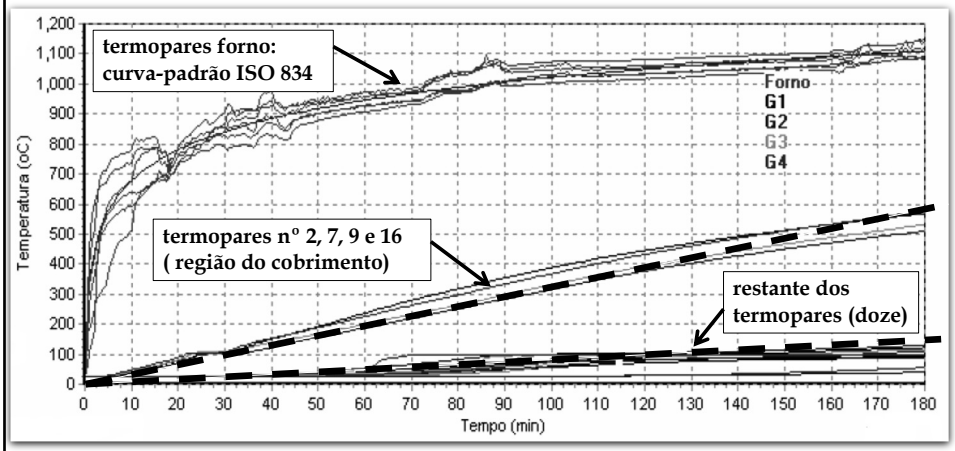
Heat Conditions (3 sides)



ISO 834 standard fire

58

temperature evolution



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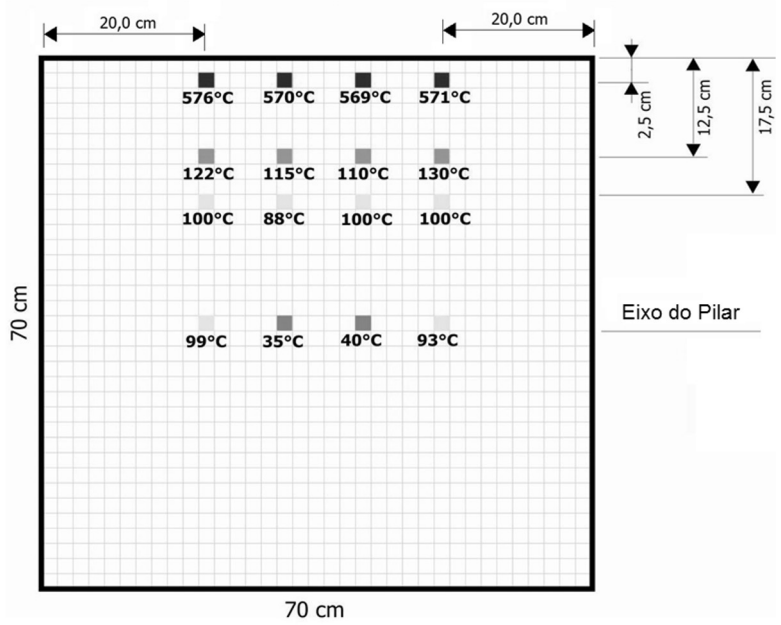
temperatures after 180 min



60

After Lab Test
180min fire + 3 days

61

Integrity

perfect corners

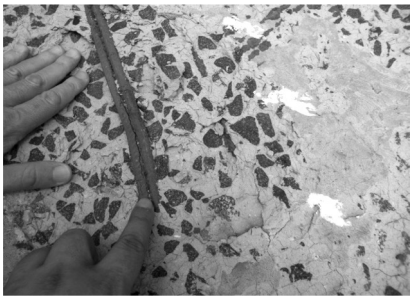
62

Integrity after 180min

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

63

Integrity



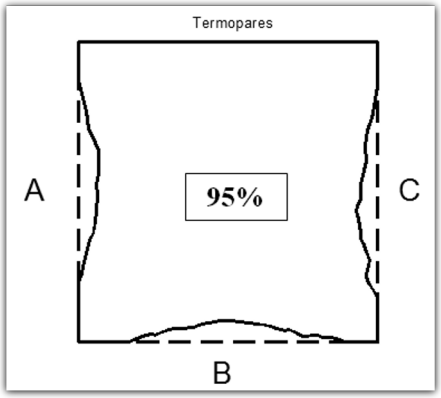
exposed steel
< 5%

64

Integrity

65

Integrity

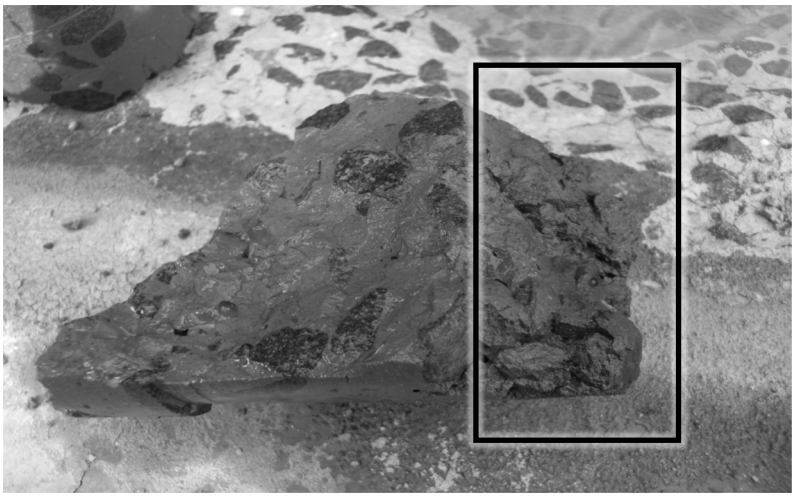


spalling **measured in 450 points (150 each side)**

66

67

"pigment as natural thermometer"



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"natural thermometer"

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

about 600°C

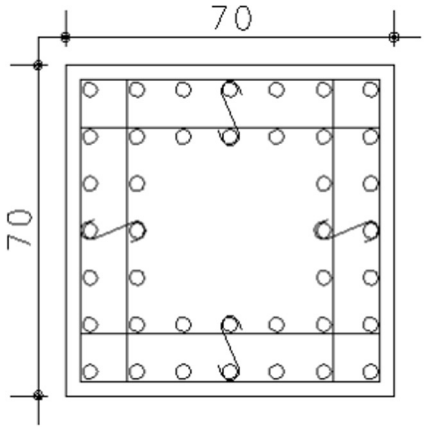
69

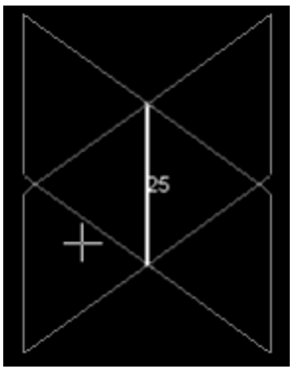
numerical analysis of the residual load capacity according to EUROCODE II

70

Initial Condition

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





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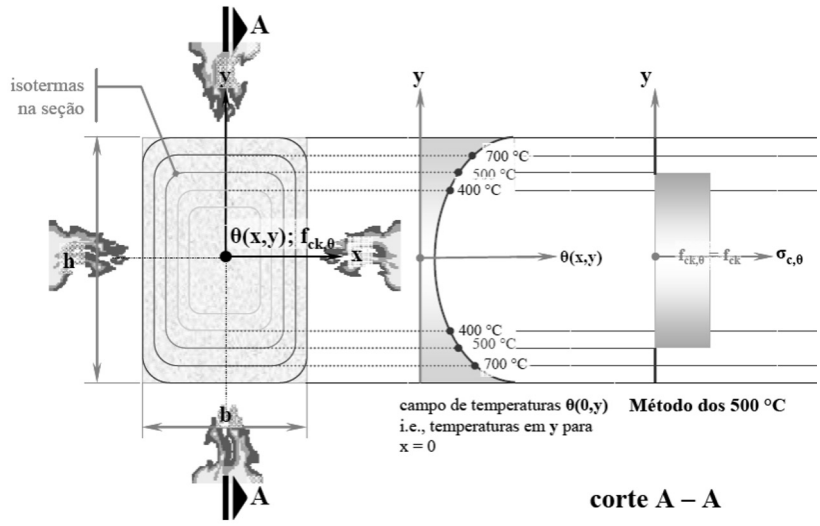
500°C Isotherm Method . EN 1992-1-2-2004 (EUROCODE II)



(Costa,2008)

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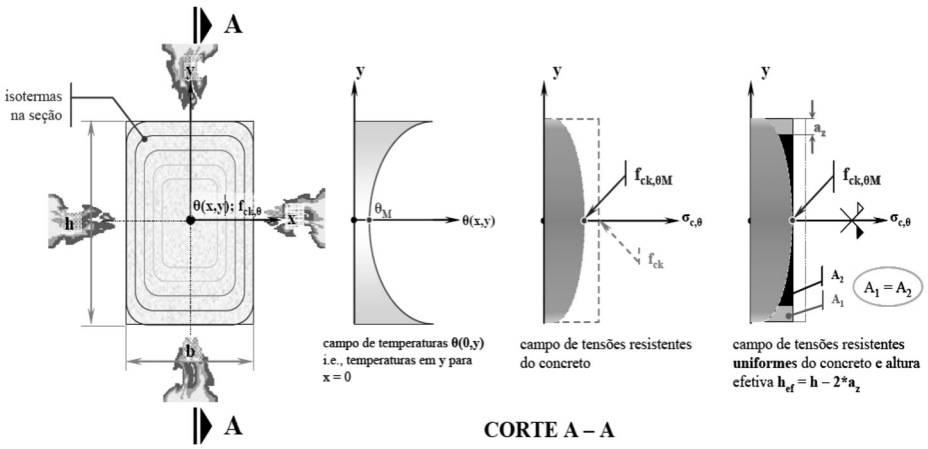
Zone Method . EN 1992-1-2-2004 EUROCODE II



(Costa,2008)

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summary for Mx = My = 0

initial condition
cross section → 70x70
P_{max} = 4.828 tf *(100%)*

500°C Isotherm Method
cross section → 56x56
P_{max} = 2.774 tf *(57%)*

Zone Method
cross section → 52x52
P_{max} = 2.444 tf *(50%)*

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Real Research Condition

initial condition
cross section → 70x70
P_{max} = 4.828 tf *(100%)*

real condition after fire
ambient temperature
cross section → 59x59
P_{max} = 3.429 tf *(71%)*

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summary for Mx = My = 0

initial condition
P_{max} = 4.828 tf *(100%)*

500°C Isotherm Method
P_{max} = 2.774 tf *(57%)*

Zone Method
P_{max} = 2.444 tf *(50%)*

After Fire
P_{max} = 3.429 tf (71%)

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WINDSOR Building
Steel-Concrete Structure

Madrid
Spain
2005

" the behavior of reinforced concrete structure under severe fire condition, 16h, 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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Conclusión

1. Investigación basada solamente en él comportamiento de los materiales, no es suficiente para explicar el efectivo comportamiento de las estructuras bajo fuego

2. Otros factores como dimensiones de los elementos, distribución de los aceros, espesor de recubrimiento, edad del concreto, son muy significantes

3. El ideal es adoptar un enfoque basado en prestaciones para lograr un buen diseño, tomando en cuenta los scenarios de fuego y cargas, los parâmetros de los materiais, e una buen análisis de toda la estructura

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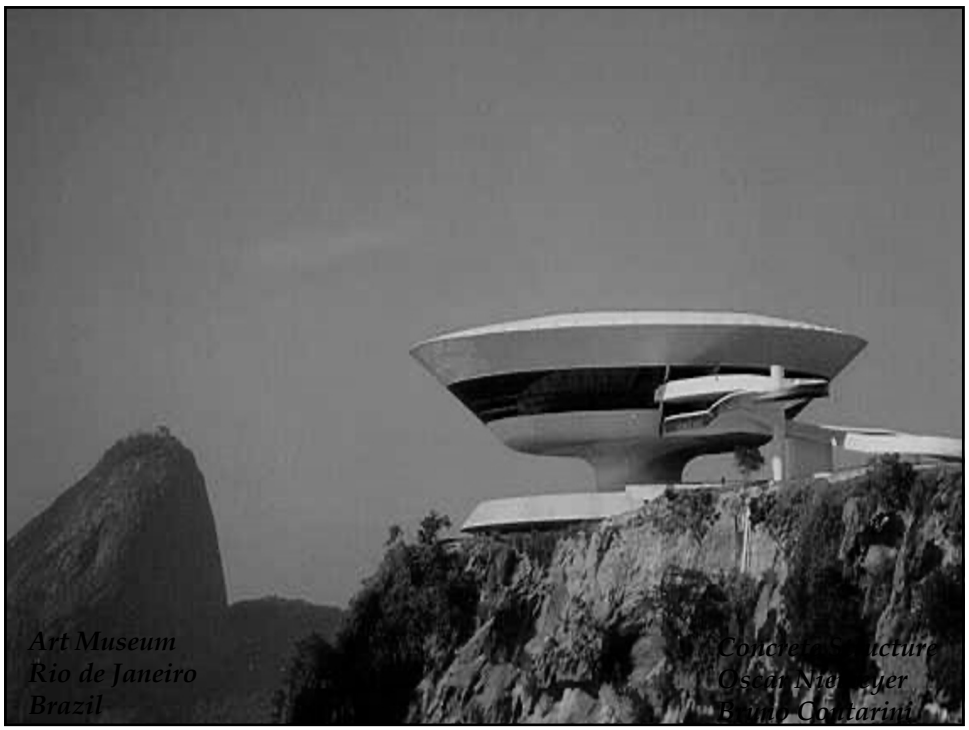

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