Fire and Collapse of the Wilton Paes de Almeida Building
Lessons Learned

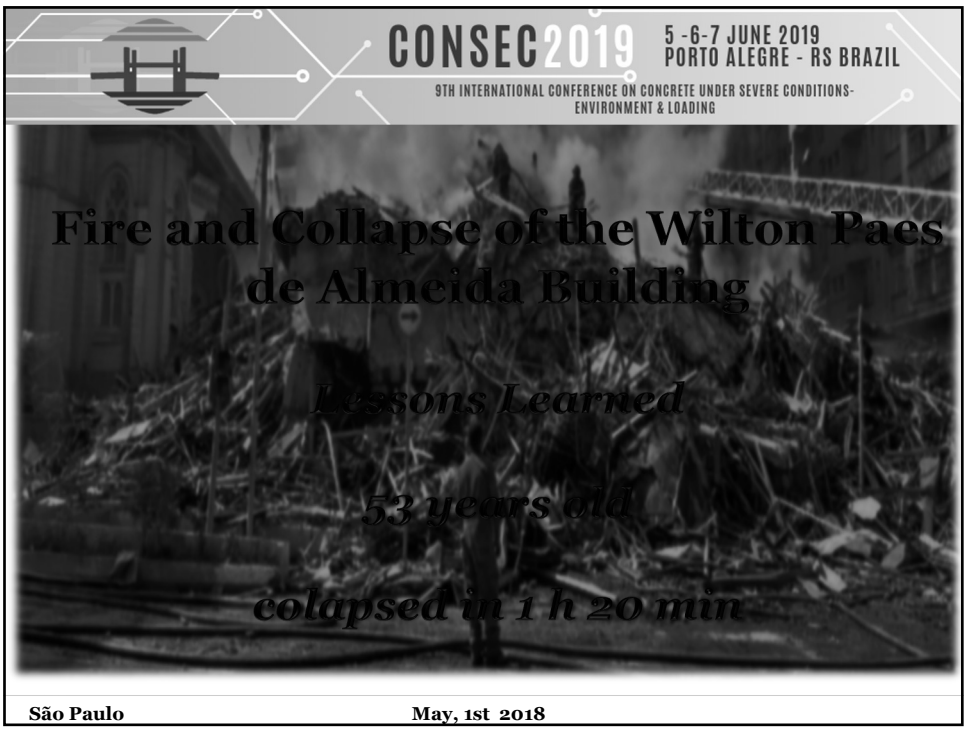
Paulo Helene
PhD Engenharia Director
IBRACON Technical Director
Prof. Universidade de São Paulo
ALCONPAT Internacional, past President
*Member **fib**(CEB-FIP) Model Code for Service Life Design*

CONSEC 2019

IBRACON

PhD Engenharia

1



São Paulo **May, 1st 2018**

2

Site view on Google Earth

Google Earth Pro / by Marcos Carnaúba

3

Site view on Google Earth

Google Earth Pro / by Marcos Carnaúba

4

Site view on Google Earth

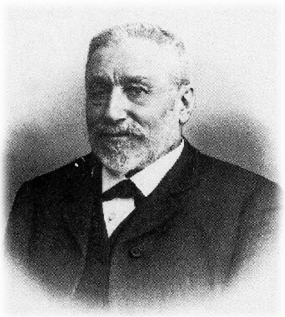
Google Earth Pro / by Marcos Carnaúba

5

Reinforced Concrete

patent in Belgium

August 8th, 1892



François Hennebique

Il développe le *Système Hennebique* de béton armé.
Installe son entreprise avec le slogan:

« plus d'incendies désastreux »

The end of disastrous fires

6

Système Hennebique

Paris, Rue Danton

7 floors
France 1900
30 m (98,4 feet)

f_{ck} = ?
119 *years old!*

The oldest reinforced concrete building in the world.

7

8

Martinelli Building

São Paulo

1929

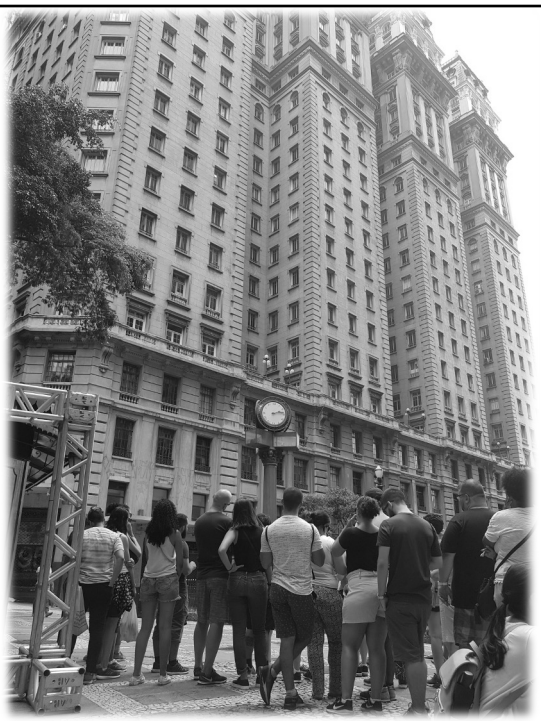
Reinforced concrete.

The tallest concrete building in the world in its inauguration

30 floors - 106 m (350 feet) high

90 years old

The oldest skycraper in Brazil



9

ANDRAUS Building

São Paulo, Brazil

32 storey office building
115 m (377,3 feet)

Construction: 1957-1962

Fire: 24 Fev. 1972

Duration: 4 h
240 minutes

Nowadays: in use
Not colapsed!

10

11

Nowadays: in use

Not colapsed!

12

JOELMA Building

São Paulo, Brazil

26 floors
10 parking garage floors
+ 15 office storey

Construction: 1969-1971

Fire: 1 Fev. 1974

Duration: 6,5 h
390 minutes

In use
Not colapsed!

13

14

Ribbed slab with band beams

15

https://pt.slideshare.net/macielshirlene/incndios-top-10

16

WINDSOR Building

Madrid, Spain
2005
steel-concrete structure

37 floors
5 parking garage floors
+ 31 office storey

Construction: 1991

Fire: 12 Fev. 2005

Duration: 16 h
960 minutes

Partial damage (steel)
implosion

17

18

19


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

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

Dra. Cruz Alonso. IET, 2006.

20

Park Central Tower
East Tower

Caracas, Venezuela

221 m, 56 floors

Construction: 1979

Fire: 17.10.2004

Duration: 20 h
seismic zone: IV

concrete not collapsed
Recovered and in use today

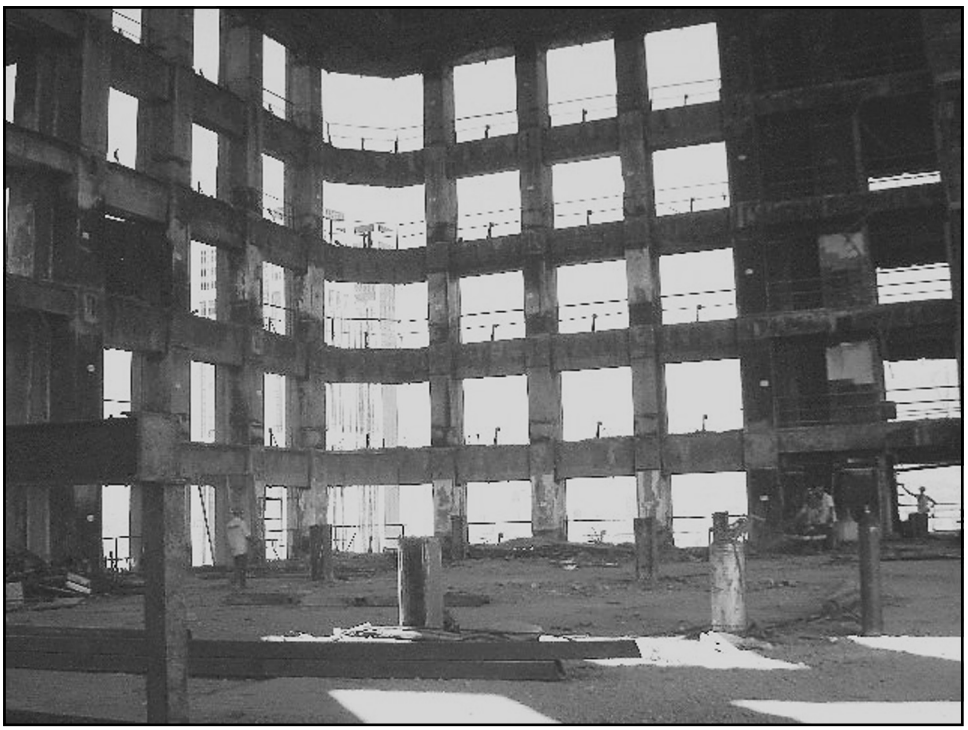
21

22

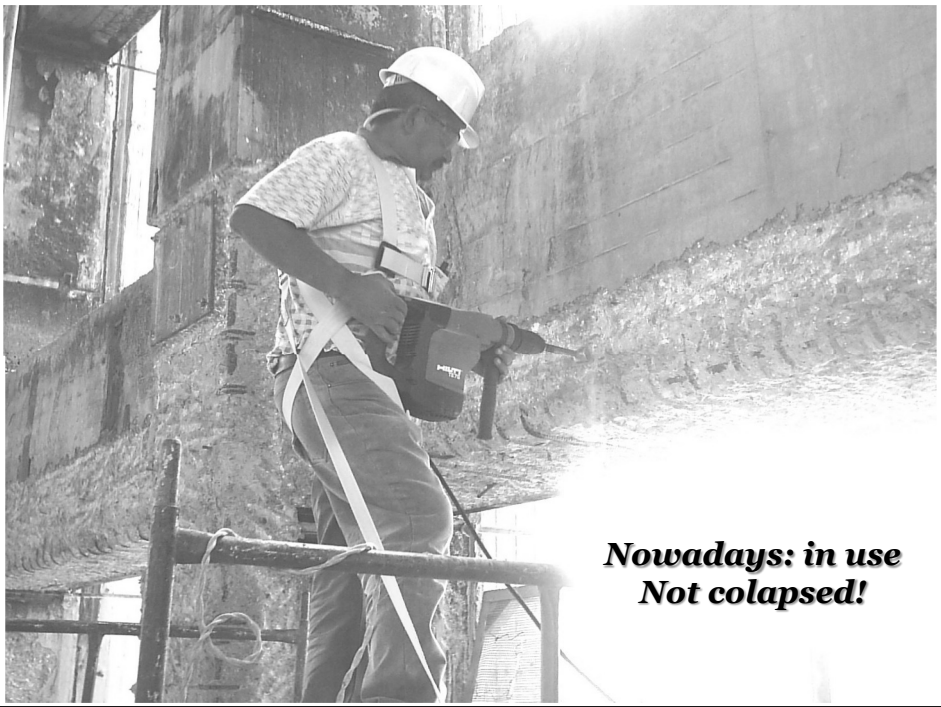
23

24

25



26



27

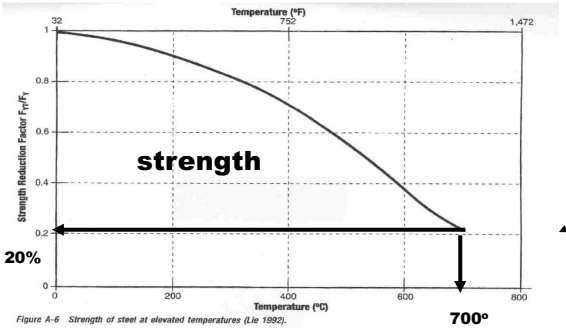


Figure A-6 Strength of steel at elevated temperatures (Lie 1992).

structural steel f_{yk}

concrete f_{ck}

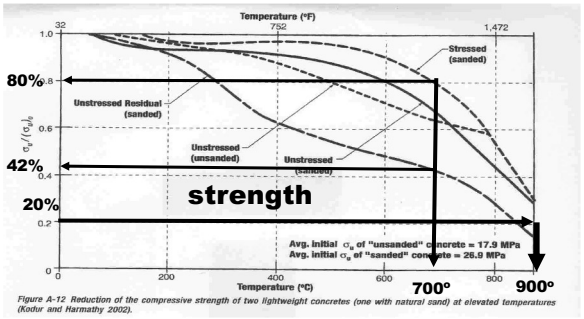


Figure A-12 Reduction of the compressive strength of two lightweight concretes (one with natural sand) at elevated temperatures (Kodur and Harmathy 2002).

28

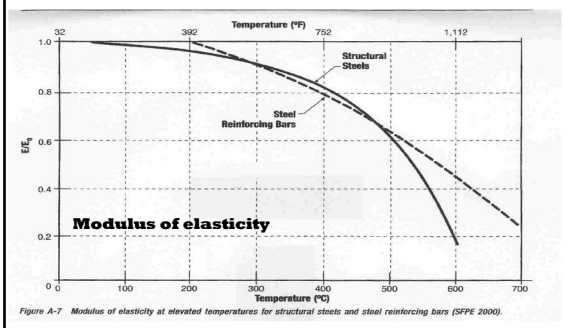
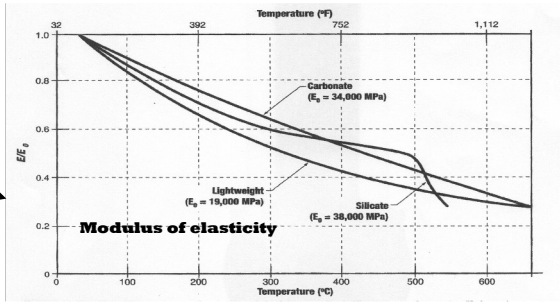


Figure A-7 Modulus of elasticity at elevated temperatures for structural steels and steel reinforcing bars (SFPE 2000).

structural steel E_s

concrete E_{cs}



29

Steel temperature rise fast due fire exposure for unprotected steel column

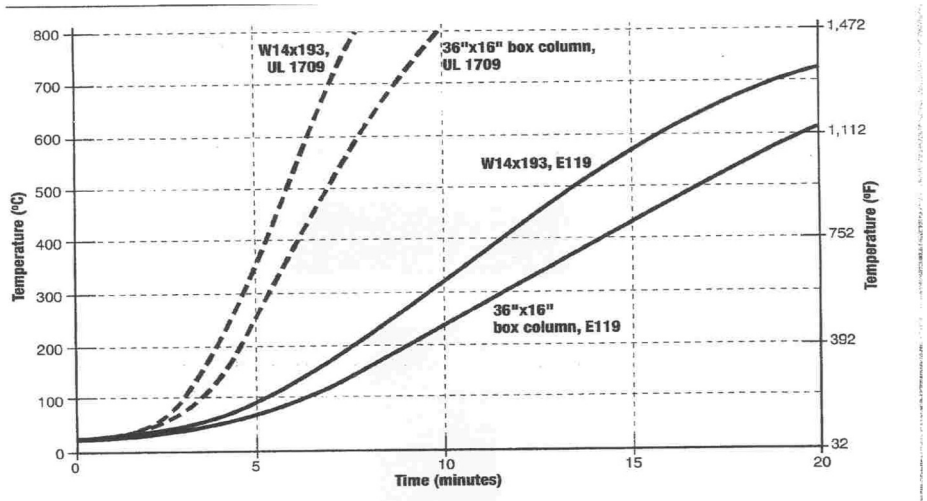


Figure A-9 Steel temperature rise due to fire exposure for unprotected steel column.

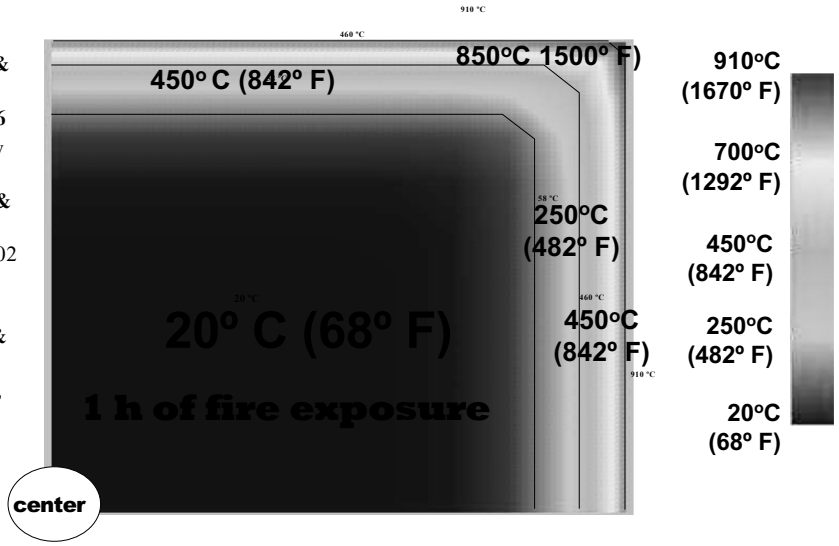
30

Temperature rise for a 50 x 50 cm (20 x 20 inches) concrete column

Polivka & Wilson
UC, 1976
Berkeley

Calmon & Claudio
UFES, 2002
Vitória

Bazant & Kaplan
Logman, 1996



31

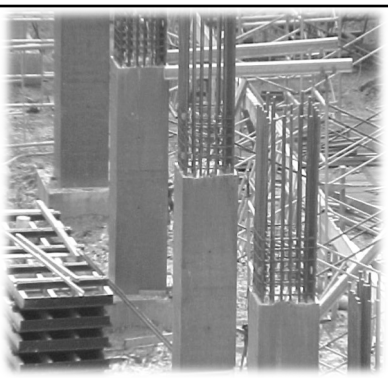
Research
University of São Paulo

Brazil
2002 → 2010

PhD student: Carlos Britez
Supervisor: Prof. Paulo Helene

32

Background



e-Tower Building

São Paulo, Brazil

f_{cm} = 125 MPa (18,000 psi)

HPCC world record

6 columns in 7 floors

2 months

Jan/Feb 2002

33

American Concrete Institute ACI

Concrete International magazine

December 2003

HPCC in Brazilian Office Tower

High-performance colored concrete offers strength, thinner columns, more usable space, and aesthetics

BY PAULO HELENE AND CARINE HARTMANN

Fig. 1: Architectural rendering of the e-Tower

Currently nearing completion, the e-Tower in São Paulo, Brazil, employs high-performance (high-strength) colored concrete (HPCC) having an f'_c = 125 MPa. Employed within five columns for the first seven floors of the structure, the HPCC was batched in a normal commercial concrete plant, mixed by truck on the way to the site through heavy urban traffic, and placed 40 to 60 min after leaving the plant.

The experience represents a first-time use in Brazil of such a special concrete straight out of the research laboratory, with the objective of maximizing occupancy space, easing concrete placement, and thereby increasing productivity. At the same time, the coloring of the concrete columns achieves desired architectural effects in occupied portions of the structure and in its parking garage area.

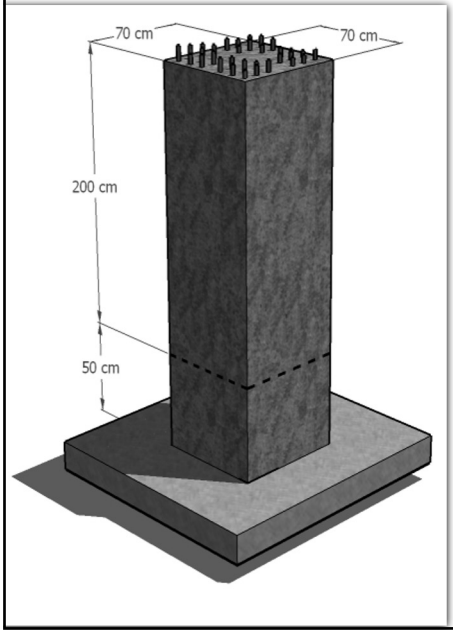
At completion, e-Tower will be a modern office building (Fig. 1) offering 800 parking garage spaces, two excellent restaurants, a convention and business center, a semi-Olympic-sized swimming pool and fitness center, and a rooftop helicopter landing pad. It will also have an "intelligent" air conditioning system and provisions for energy and water system savings. Floor area for the completed 162-m-high, 42-story tower will be 52,000 m^2. Among the five tallest buildings in Brazil, the e-Tower can be considered a high-rise structure, or "skyscraper," under the international classification adopted by the Council on Tall Buildings and Urban Habitat.

BRAZILIAN CONCRETE BACKGROUND

Brazil is one of the most advanced nations in concrete technology in South America, having a tradition of constructing tall buildings over 100 m high. It is a long tradition. Seventy-four years ago, in 1929, Brazilian engineers designed the Martinelli Building, reputed to be the highest concrete tower in the world at the time with its height of 106 m above the streets of São Paulo. In 1960, they inaugurated the Palacio Zarzur Kogan concrete tower, the

34

Column Mockup (Lab POLI.USP)



- ✓ **70 cm x 70 cm** ***(28 in x 28 in)***
- ✓ **height: 2 m** ***(6,5 feet)***
- ✓ **mass: 2.500kg** ***(5500 lb)***
- ✓ **age: 8 years old**
- ✓ $f_{ck,est}$ **= 112 MPa** ***(16,000 psi)***
- ✓ f_{cm} **= 125 Mpa** ***(18,000 psi)***
- ✓ **concrete cover: 25 mm** ***(1 in)***
- ✓ **w/c ratio = 0,19**

35

Mockup: cut, lifting and transport

Diamond wire

36

cores withdrawal

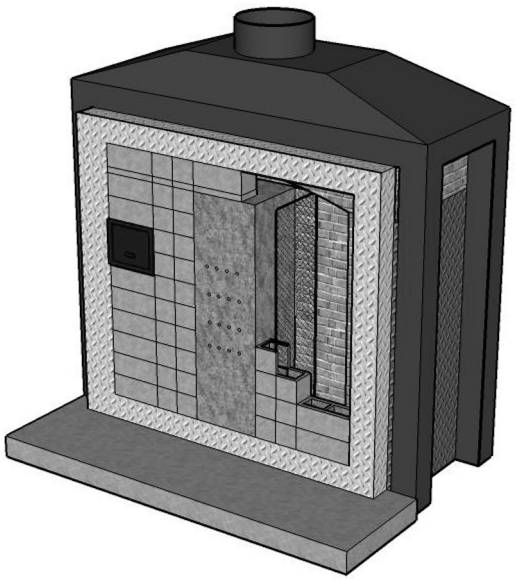
after 8 years

140 MPa ***(20,000 psi)***

cylinder specimen

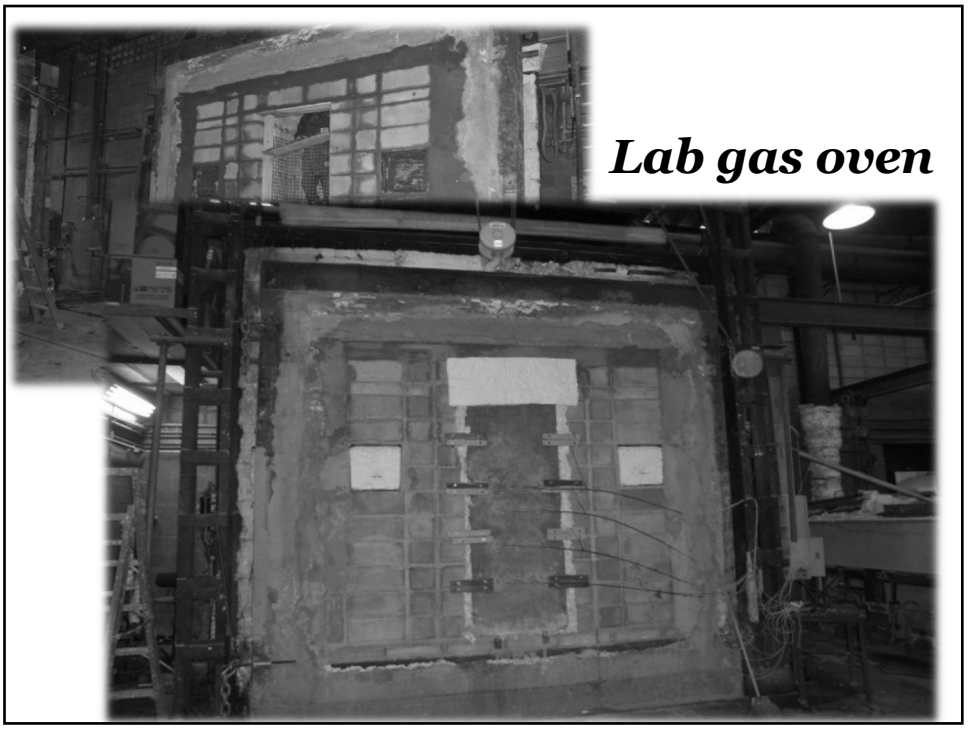
37

Lab gas oven



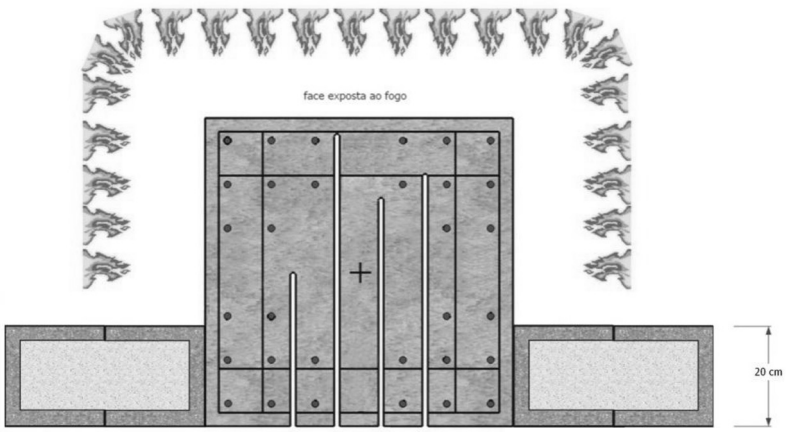
✓ masonry closure (refractory)

38



39

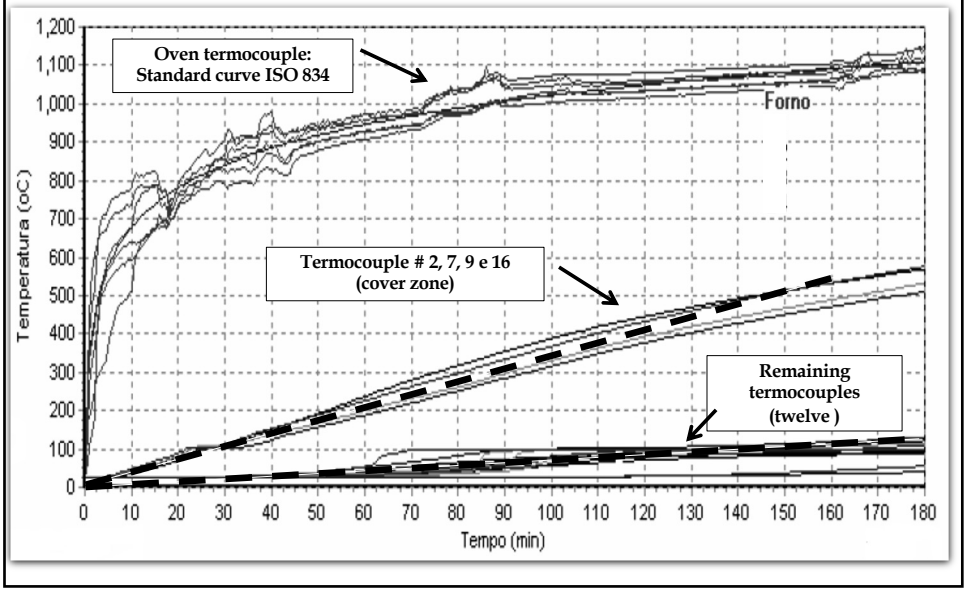
Simulation draft (plan view)



Grouted masonry

40

Temperature rising



41

Mockup integrity after 180 minutes

- ✓ only sallow spalling observed;
- ✓ start: 36 minutes (initial);
- ✓ "popping" sound, then it stops;
- ✓ intact edges;
- ✓ depth: from 0 to 48 mm ***(0 to 2 in)***
- ✓ average spalling: 9,3 mm (***3/8 in***)

42

43

Prof. Dr.
Venkatesh
Kodur
& Brazilian
Researcher Engineer
IPT, 2010

Prof. Dr.
Venkatesh
Kodur
& Dr. Carlos
Britez
IPT, 2010

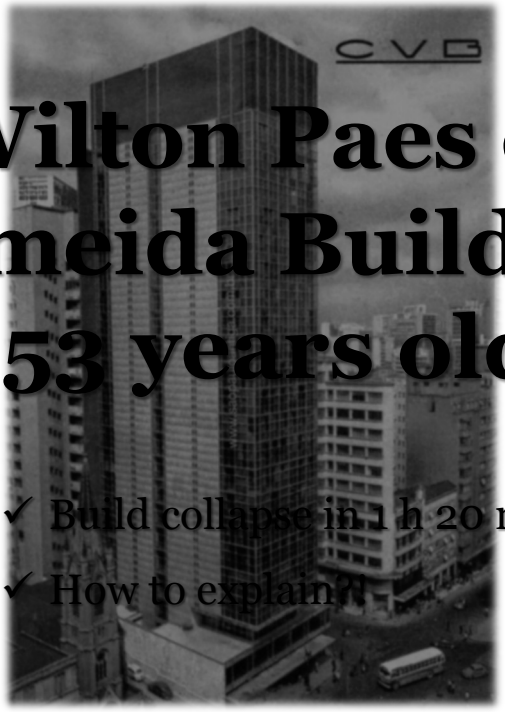
44

Conclusions

- ✓ Concrete is a bad heat conductor;
- ✓ Concrete resists well to high temperatures
- ✓ Up to 3h, 4h, 6h, 12h, 20h…

45

Wilton Paes de Almeida Building 53 years old



- ✓ Build collapse in 1 h 20 min
- ✓ How to explain?

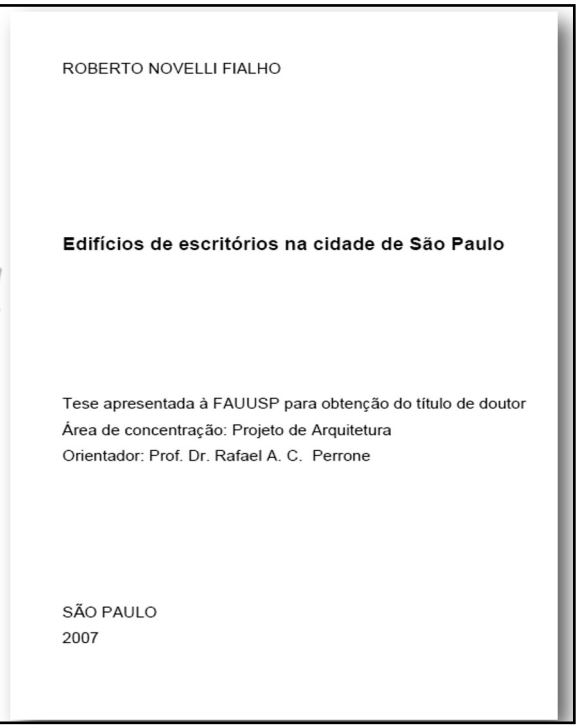
46

data

- Architect: Roger Zmekhol (died)
- Contractor: Morse & Bierrenbach (closed, 2001)
- **Structural design: *not found, yet***
- Construction: 1961 - 1965
- Floors: 24
- Building area: 12.000 m² **(130,000 sq ft)**
- Collapse: May 1st, 2018

47

background research



ROBERTO NOVELLI FIALHO

Edifícios de escritórios na cidade de São Paulo

Tese apresentada à FAUUSP para obtenção do título de doutor
Área de concentração: Projeto de Arquitetura
Orientador: Prof. Dr. Rafael A. C. Perrone

SÃO PAULO
2007

48

Structure: Steel columns with concrete slabs

49

background *research*

Structure: Steel columns with concrete slabs

REFERENCES:

O Estado de S. Paulo – Feb/28th, 1961
O Estado de S. Paulo – Jul/03rd, 1965
O Estado de S. Paulo – May/12th, 1979

https://pt.aleteia.org/2018/05/02/a-trajetoria-do-predio-que-desabou-no-centro-de-sao-paulo/

50

May 1st, 2018 at 4:00 PM

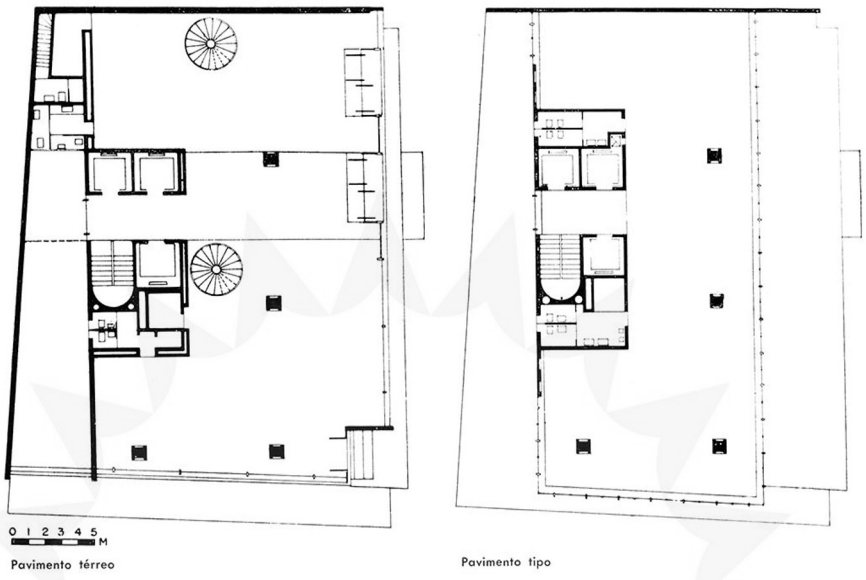
51

background *research*

Revista Acrópole Número 323 Ano 27 Novembro 1965

52

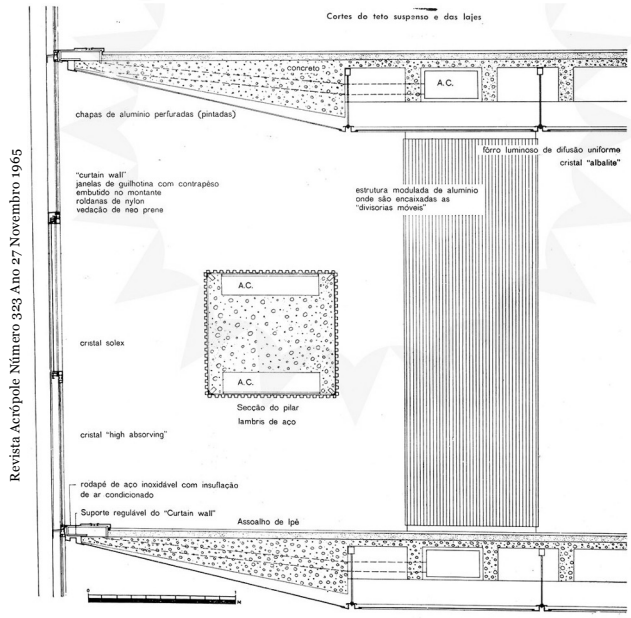
background *research*



Revista Acrópole Número 323 Ano 27 Novembro 1965

53

background *research*



54

55

56

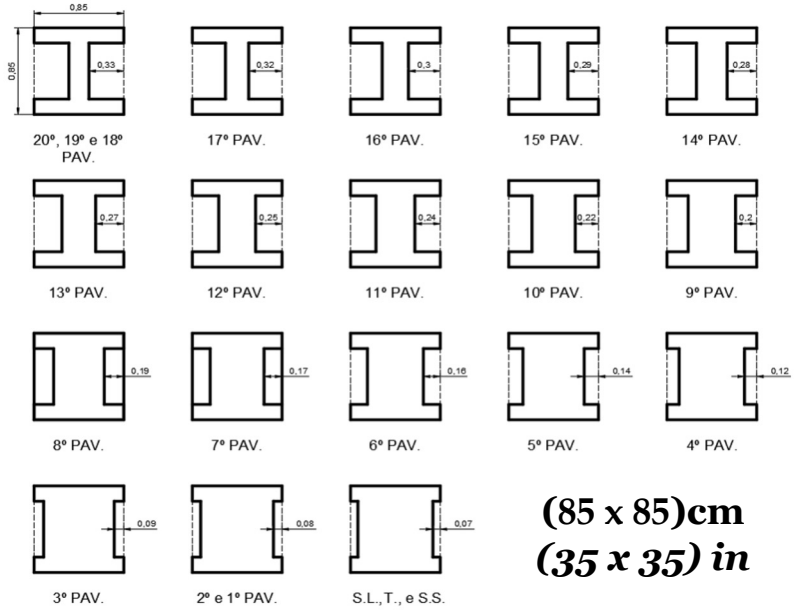
57

58

Columns geometry

59

Cross section of columns in each floor



(85 x 85)cm
(35 x 35) in

60

Fire

Dawn of May 1st, 2018, at 1:30 AM, fire starts in the 5th floor and propagate to the other floors (underground floors to 10th floor + penultimate)

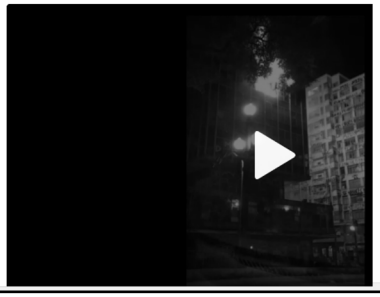
61

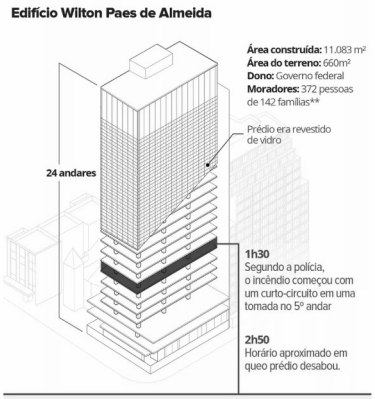
SÃO PAULO

Incêndio em prédio de SP foi causado por curto-circuito em tomada no 5º andar, diz secretário

Em depoimento, moradora disse que fogo começou em tomada onde estavam ligados TV, micro-ondas e geladeira.

Por César Galvão, TV Globo, São Paulo
03/05/2018 16h27 · Atualizado 03/05/2018 21h33





62

fire start at 1:30 AM (video)

63

Collapse at 2:50 AM (video)

64

65

66

After collapse...

http://oglobo.oglobo.com.br/brasil/moradores-de-predio-que-caiu-denunciam-achaques/

67

After collapse...

68

Análise dos escombros

Diretor-técnico do Instituto Brasileiro do Concreto, Helene diz ter obtido autorização da prefeitura para colher materiais nos escombros. Os itens serão analisados em laboratório para que se elabore um diagnóstico sobre as causas da queda. Ele estima que a análise possa levar até um mês.

"Estamos falando de uma estrutura da década de 60 sobre a qual se tem pouca informação até agora. Queremos medir, por exemplo, a resistência e a porosidade do concreto, características que são importantes para conhecermos melhor o projeto e podermos chegar a alguma conclusão".

Term of technical and scientific cooperation between São Paulo City Hall, SPObras, Urban Infrastructure Secretary and IBRACON (Brazilian Concrete Institute)

May 2018

69

Colecting samples to test

70

Investigation and test plan

- As built survey in slabs, beams and columns;
- Rebar tests: tension, bending, stretching and ductility yield, chemical composition and metallography;
- Mineralogical characterization of aggregates;
- Obtaining concrete cores to strength and modulus tests;
- Rebar scanning;
- Ultrasound and dynamic modulus tests;
- Water absorption, permeable void index and specific mass;
- Mineralogical characterization by X ray diffractometry and thermal analysis by ATD-TG;
- Mix reconstitution of concrete and cement content;
- Carbonation depth;
- Granular material analysis
- Structural Check ("assumption")

71

Sample preparing

- ✓ Rebar cut with acetylene torch
- ✓ Concrete cut with diamond wire

Mackenzie University

72

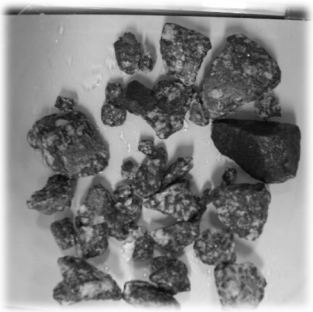
Cores withdrawal

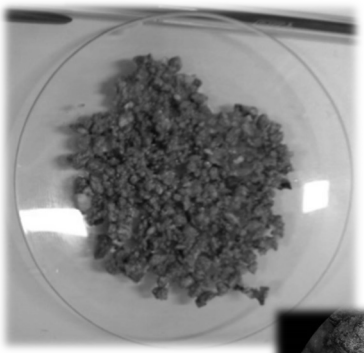
Mackenzie University

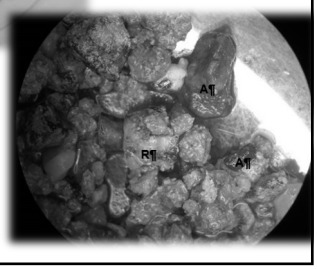
73

Petrographyc analysis

by Prof. Cláudio Sbrighi Neto







74

Petrographyc analysis

by Prof. Cláudio Sbrighi Neto

- Crushed granite : igneous rock, D_{max} = 25 mm
- Coarse sand washed from river
- Quartz was preserved: concrete shall have been exposed to temperatures under to 573 º C.
- Aggregates were not cracked or chipped.

calcined thickness obtained by thermogravimetric analysis and x-ray diffraction
< 1,0 cm

75

Mix design reconstitution

Table 1 - Mix reconstitution in parts of mass

Sample Id.	Composition	
	Cement	Aggregates
Column	1	5.9
Structure	1	6.2

76

Table 2 - Determinaton of absorption, void index and specific mass

Test	Sample	
	Column	Structure
Absorption after plunge and boiling (%)	6.52	6.68
Void index after saturation and boiling (%)	14.75	15.21
Specific Mass of dry sample (g/cm³)	**2.26**	**2.28**

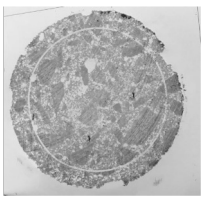
→ cement content **309 kg/m³**

77

Compressive strength

✓ Average strength: 21,8 MPa (3,200 psi)

f_{ck} = 15 MPa (2,200 psi)



78

Tensile strength

✓ Average strength: 2,1 MPa (300 psi)

79

Ultrasonic and Modulus of elasticity

Average value of Dynamic Modulus of Elasticity: **27 GPa**

Static Modulus $E_{ci\ 0,3\ fc}$ = 24GPa

Ultrassom (m/s)
3663
3788
3669

80

Carbonation depht

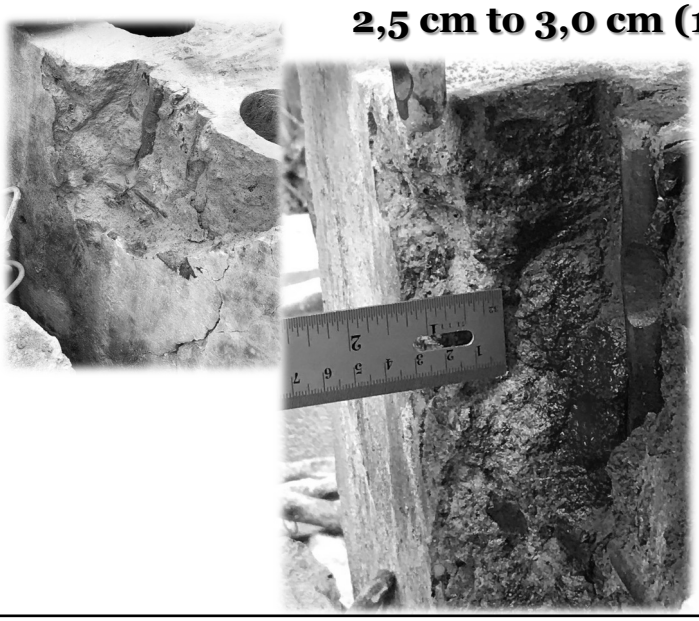
2,5 cm to 3,0 cm

1 to 1 1/2 in

81

Carbonation depht

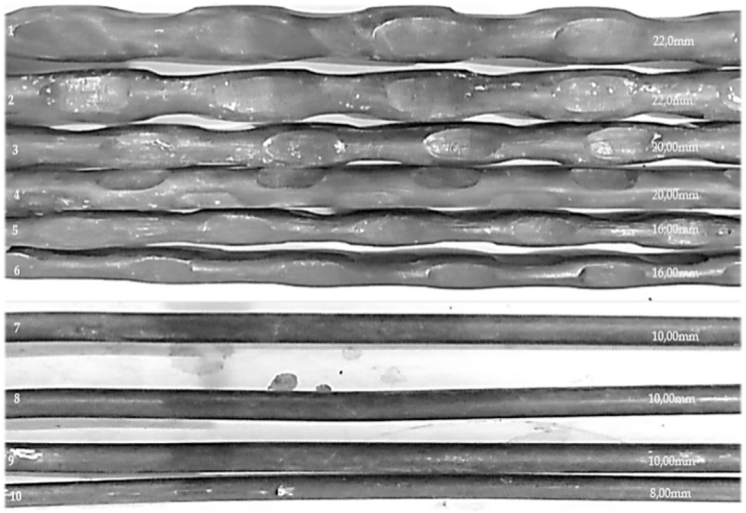
2,5 cm to 3,0 cm (1 to 1 1/2 in)



82

Rebar

Notched rebars with diameters of 22, 20 e 16 mm (1, 3/4 and 5/8 in) CA 60
Stirrups with diameters of 8 e 10 mm (5/16 and 3/8 in) CA 37



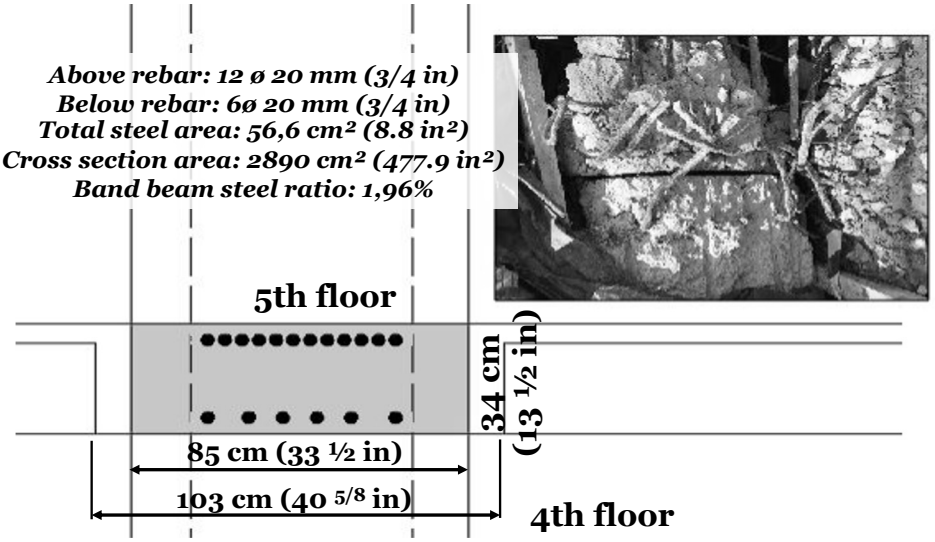
ArcelorMittal Labs.

83

reconstitution of cross section of band beam and column

84

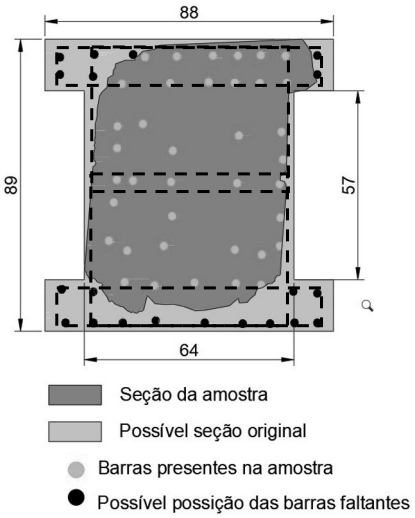
Above rebar: 12 ø 20 mm (3/4 in)
Below rebar: 6ø 20 mm (3/4 in)
Total steel area: 56,6 cm² (8.8 in²)
Cross section area: 2890 cm² (477.9 in²)
Band beam steel ratio: 1,96%



reconstitution of band beam

85

Reconstitution of column cross section



Concrete cover = 0,5 cm to 4,0 cm (13/64 in to 1 ½ in)

4th floor to 5th floor columns stretch

86

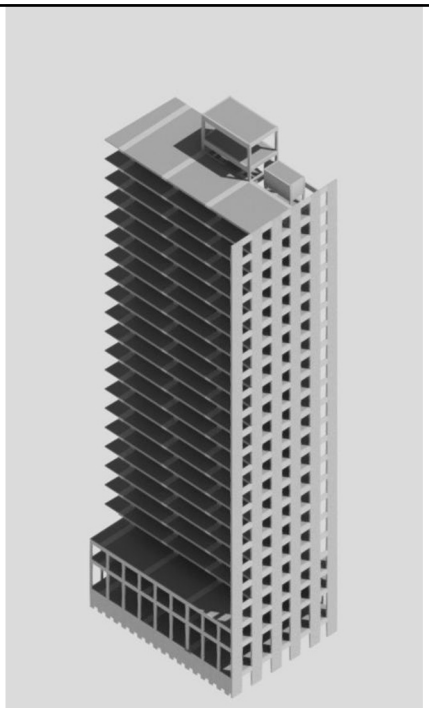
modelling
reinforced
concrete
structure

floors

87

modelling
reinforced
concrete
structure

compartmentation
fire wall



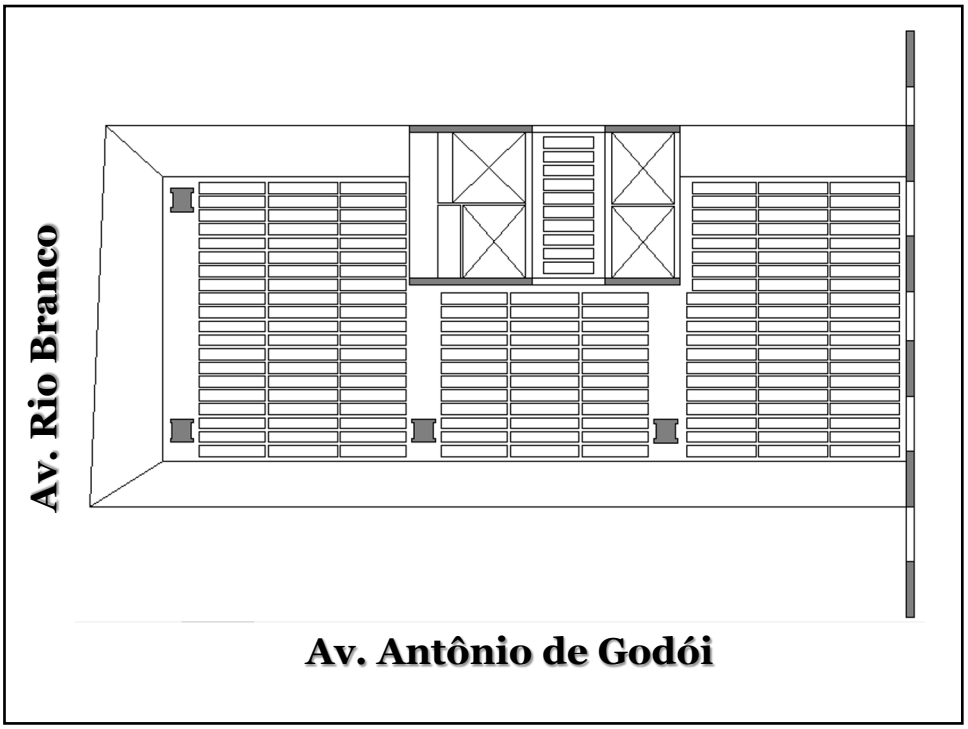
88

modelling reinforced concrete structure

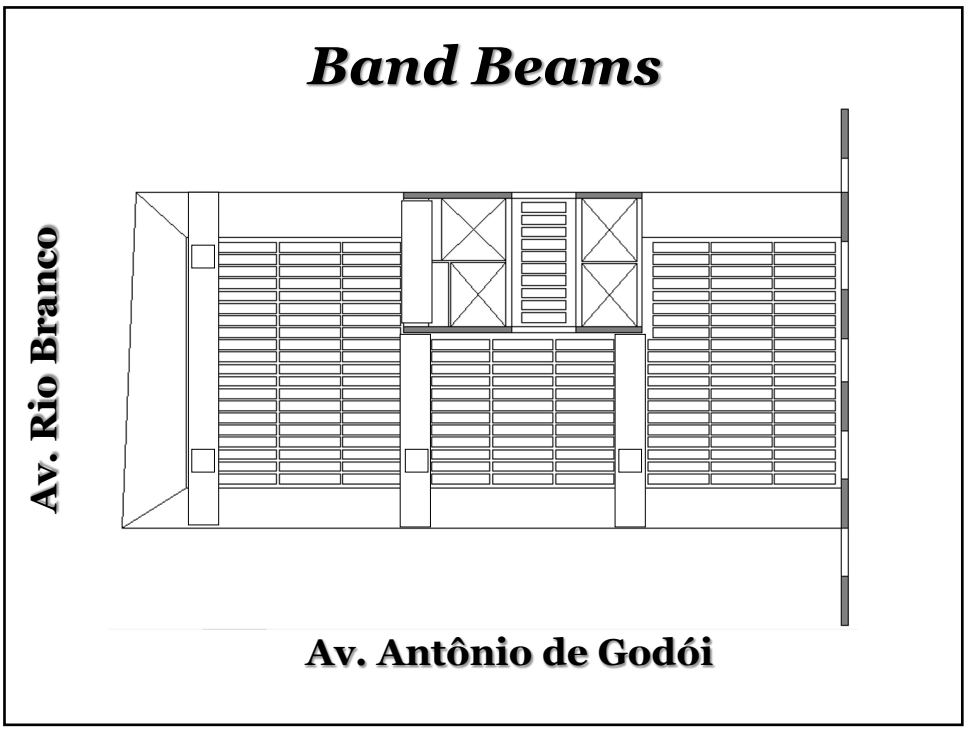
ascensour and stairs

89

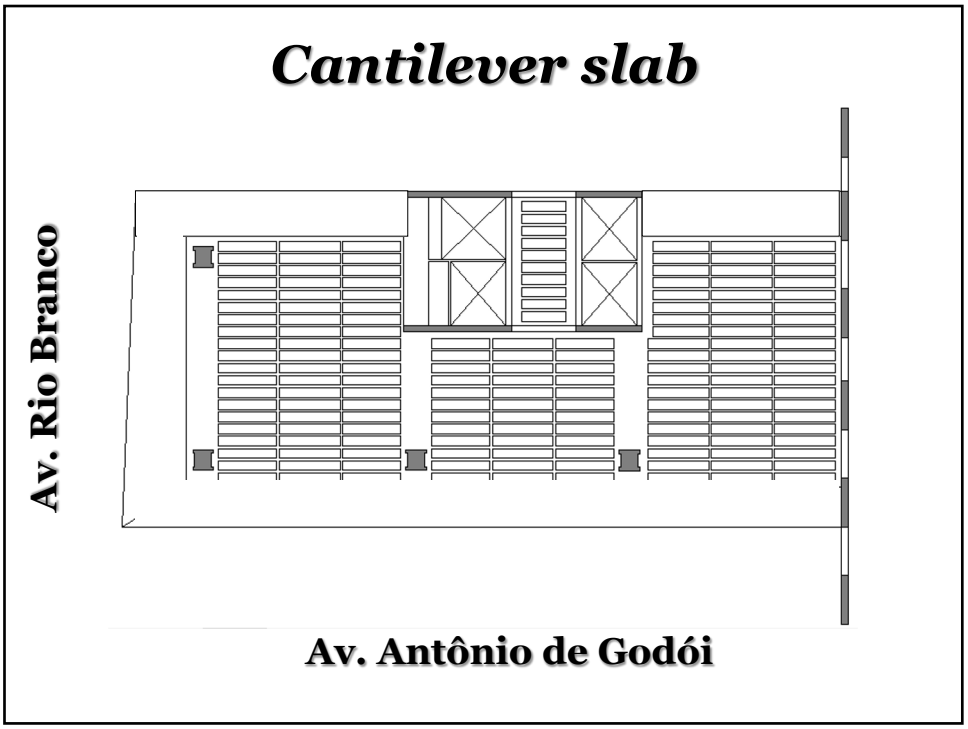
90


Av. Rio Branco
Av. Antônio de Godói

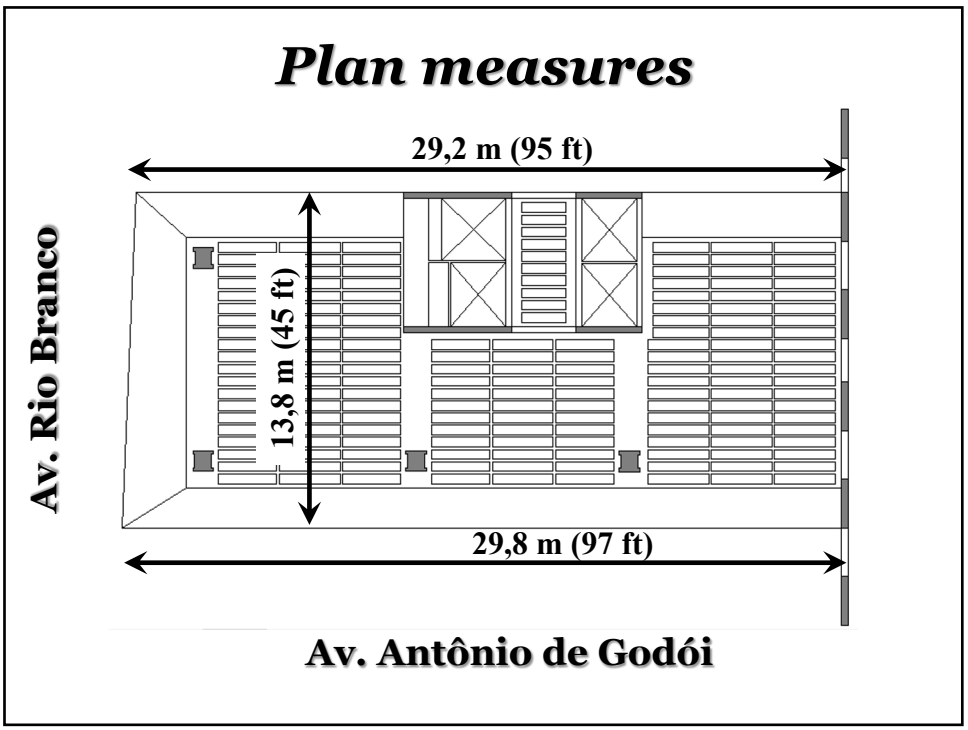
91


Band Beams
Av. Rio Branco
Av. Antônio de Godói

92

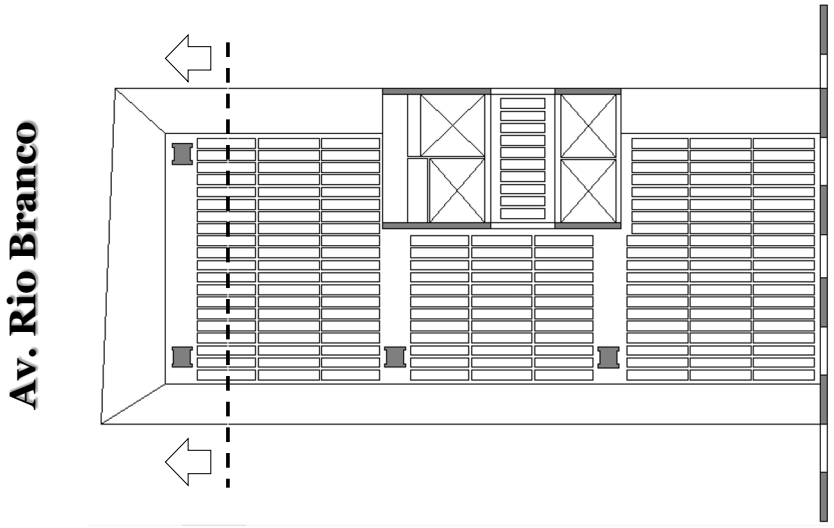

Cantilever slab
Av. Rio Branco
Av. Antônio de Godói

93


Plan measures
29,2 m (95 ft)
13,8 m (45 ft)
29,8 m (97 ft)
Av. Rio Branco
Av. Antônio de Godói

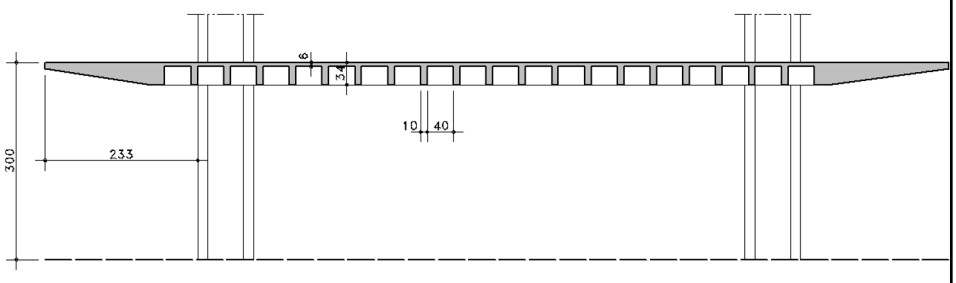
94

Cross section of ribbed slab



95

Cross section of ribbed slab

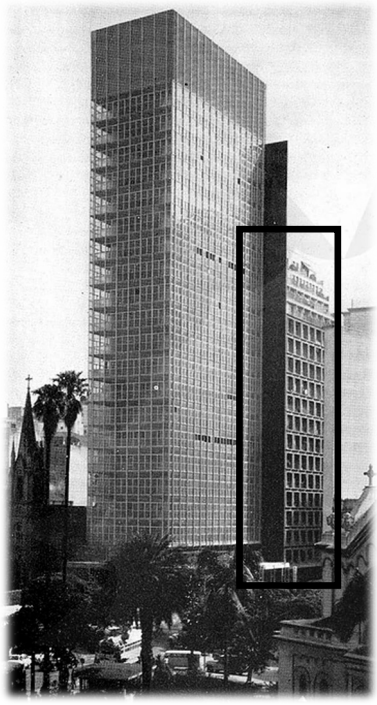


96

ULTIMATE DISPLACEMENTS

ULS Model with thermal variation and wind speed of May 1st 2018

97



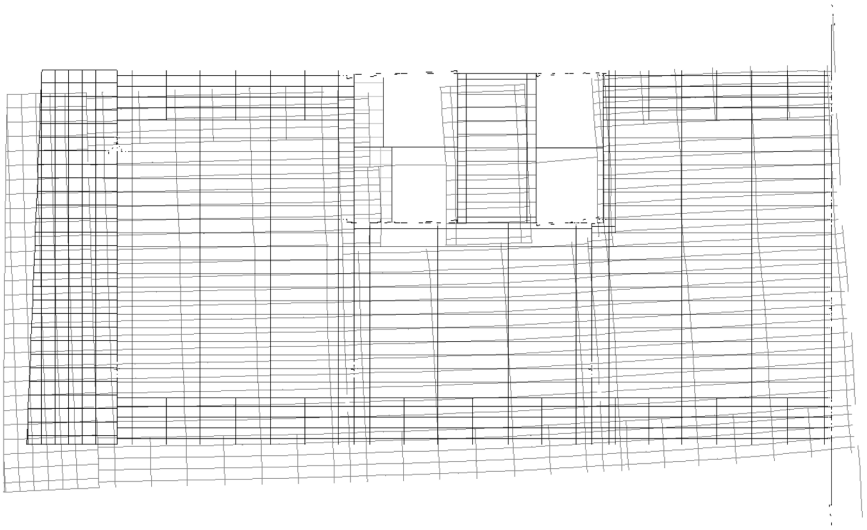
http://www.arquivo.arq.br/edificio-wilton-paes-de-almeida

Caracu Building attached to the back façade

→ rotation constraint

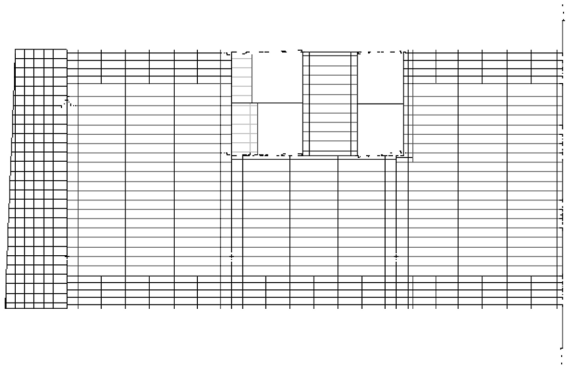
98

Torsion due the vertical load, thermal load and wind of the day of collapse.



99

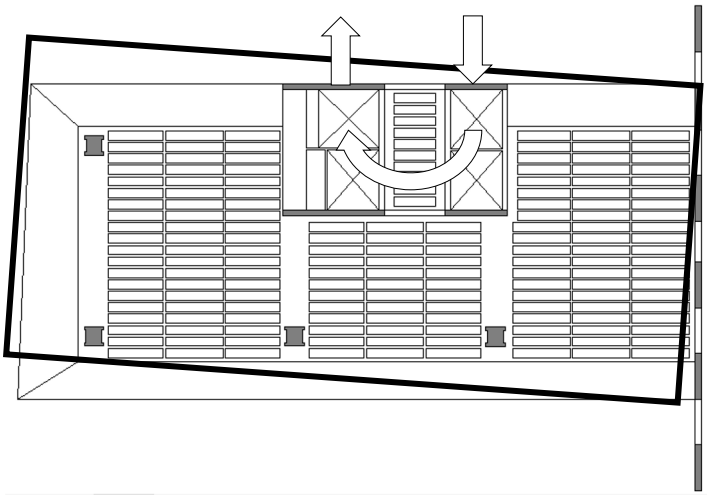
Constraint of building attached



Caracu Building

100

Assumption of collapse mechanism



101

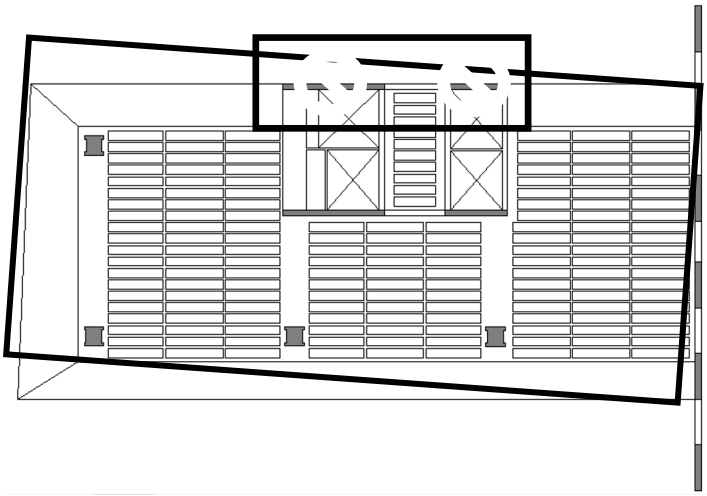
Variation of 200º C:
SLS combinations → 21 cm (8 ¼ in)
ULS combinations → 28 cm (11 in)

Variation of 500º C:
SLS combinations → 36 cm (14 ¼ in)
ULS combinations → 58 cm (22 ¾ in)

temperature → increasing of more than 10 times to the bending moments on elevator region columns when compared with results from just vertical loads.

102

Assumption of collapse mechanism



103

104

Neighbor Building at Av. Rio Branco in front of church: Glass Windows Façade

105

FOLHA DE S.PAULO

DESDE 1921 ★★★ UM JORNAL A SERVIÇO DO BRASIL

DIRETOR DE REDAÇÃO: OTAVIO FRIAS FILHO — SEXTA-FEIRA, 11 DE MAIO DE 2018 — EDIÇÃO SP/DF • CONCLUÍDA À 0H24 • R$ 4,00

Geisel avalizou execuções na ditadura, diz documento

Documento de 1974 liberado pelo governo americano mostra que, segundo relato do chefe da CIA, o ex-presidente Ernesto Geisel (1974-1979) aprovou a continuidade de uma política de execuções sumárias de adversários da ditadura militar no Brasil. Os papéis, públicos desde 2015, foram divulgados pelo colunista da **Folha** Matias Spektor. Poder A4

Sócio da Dolly é preso sob suspeita de fraude fiscal

Um dos sócios da empresa de refrigerantes Dolly, Laerte Codonho foi preso preventivamente em São Paulo. Ele é acusado de liderar esquema de fraude que acumulou R$ 4 bilhões em impostos não pagos. Sua defesa considerou a prisão injusta e afirmou que recorrerá. Mercado A20

Governador de SP acelera medidas visando eleições

Vereadores fecharam, de 2006, Márcio França (PSB) encurtou caminho para a transferência de recursos do estado a municípios. França, que substituiu Geraldo Alckmin (PSDB), tenta crescer nas pesquisas eleitorais para governador —no Datafolha de abril, teve 8%. Poder A8

Guia p.6
Vinte lugares na cidade para comer com os seus filhos ou levar a sua mãe

Saúde B7
Criado por brasileiro, método para medir pressão no cérebro chega a hospitais

Laerte Codonho, sócio da Dolly, segura cartaz alusivo à concorrente Coca-Cola, que disse não comentar processos em que não esteja envolvida

TRUMP E KIM SE REUNIRÃO EM 12 DE JUNHO

O presidente dos Estados Unidos aplaude três presos americanos libertados pelo ditador norte-coreano Kim Jong-un ontem; reunião entre os líderes ocorrerá em Cingapura Mundo A10

SP tem 25 mil edifícios fora de regra mais dura antifogo

47% dos prédios da capital paulista foram construídos antes de incêndio no Joelma (1974), que levou a mudança nas normas

De todos os prédios de São Paulo, 47% foram construídos quando precisavam ter pouco mais que extintores e hidrantes como itens de prevenção e combate a incêndios, de acordo com dados tabulados pela **Folha**.

Segundo informações do IPTU de 2017, a capital tem 33 mil prédios. Destes, 14,7 mil foram construídos antes de 1974, quando incêndio no edifício Joelma, no centro, deixou 189 mortos.

A tragédia se seguiram amplas alterações nas normas de prevenção. Até então, o mesmo era regulado pelo Código de Obras de 1929.

Uma semana após o caso, a prefeitura anunciou conjunto mais extenso de normas, que incluíam, entre outros, quanto tempo paredes precisam resistir ao fogo.

Hoje, mesmo edifícios antigos precisam de extintores, sinalização e saídas de emergência. Medidas que envolvem mudança estrutural, porém, dependem de ampliação ou reforma. É o caso de sistemas de compartimentação, que evitam que incêndios se alastrem.

O prédio que desabou no largo do Paissandu, matando cinco, era de 1961 — anterior às normas. Cotidiano B1

106

cotidiano

FOLHA DE S.PAULO

Quase metade dos prédios de SP são de antes das regras duras contra incêndio

Dos 53 mil edifícios da cidade, 24,7 mil foram construídos em período anterior à tragédia do Joelma, em 1974

107

CONSEC2019 5 -6-7 JUNE 2019 PORTO ALEGRE - RS BRAZIL

9TH INTERNATIONAL CONFERENCE ON CONCRETE UNDER SEVERE CONDITIONS- ENVIRONMENT & LOADING

conclusion: Lessons Learned *(actions)*

1. Architectural Final Project (City department records);
2. Check of structural project to thermal loads (due fire) and peer review;
3. Redundancy & Robustness in design;
4. Structural final project or as built filed on City department records to obtain the license to use *(clouds)*;
5. Periodic Surveys

108

conclusion: Lessons Learned *(actions)*

1. Architectural Final Project (City department records);
2. **Check of structural project to thermal loads (due fire) and peer review;**
3. Redundancy & Robustness in design;
4. Structural final project or as built filed on City department records to obtain the license to use *(clouds)*;
5. Periodic Surveys

109

Acknowledgements!

Prof. Alfonso Pappalardo Júnior
Eng. Alio Ernesto Kimura
Geol[a]. MSc. Ana Lívia Silveira
Dr. Antonio Fernando Berto
Sr. Antonio Paulo Pereira
Geol. Arnaldo Forti Battagin
Prof. Bernardo Tutikian
Eng. Carlos Augusto Nonato da Silva
Dr. Carlos Britez
Sr. Cesar Augusto dos Santos
Eng. M.Sc. Douglas Couto
Perito Edgar Rezende Marques
Sr. Eduardo Antônio Franca
Prof. Eduardo Thomaz
Prof. Enio Pazini Figueiredo
Sr. Francisco Pereira Souza
Sr. Gustavo de Andrade Silva
Eng. Jefferson Dias de Souza Junior
Eng[a]. Jéssika Pacheco
Sr. José Luiz de Morais Andrade
Eng. José Luiz Varela
Eng. Júlio Timerman
Sr. Lázaro de Castro
Eng. Leandro Coelho
Sr. Luiz Adauto Moraes Mazarin
Eng. Luiz Aurélio Fortes da Silva
Prof[a]. Magda Salgueiro Duro
Sr. Matheus Moreira
Sr. Mauricio Brun Bucker
Perita Mônica Bernardi Urias
Sr. Nelson Candido Rosa
Major Oscar Samuel Crespo
Prof. Oswaldo Cascudo
Eng. Me. Pedro Bilesky
Dr. Rogério Cattelan de Lima
Sr. Ronald M. Nascimento
Prof. Sérgio Lex
Prof. Simão Priszkulnik
Sra. Thamyris Torsani Pimentel
Prof. Valdir Pignatta e Silva
Prof. Vitor Levy Castex Aly
Sr. Waldir Aparecido dos Santos
Sr. Waldir Aparecido dos Santos Filho

110