EP-USP

PEF2602
Estruturas na Arquitetura I I - Sistemas Reticulados

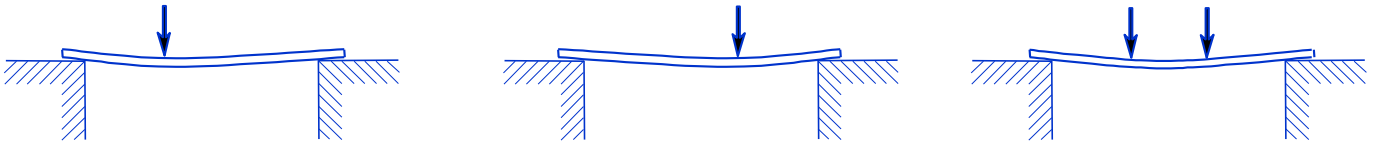
FAU-USP

Arcos, Cabos, Estais

24/09/2018

Ruy Marcelo de Oliveira Pauletti
Leila Meneghetti Valverdes
Luís Antônio Bitencourt Jr.

Estruturas flexíveis



(a) uma **estrutura rígida**, como uma viga, não muda drasticamente de forma, ao variar do carregamento

(b) uma **estrutura flexível**, como um cabo, muda drasticamente de forma, ao variar do carregamento

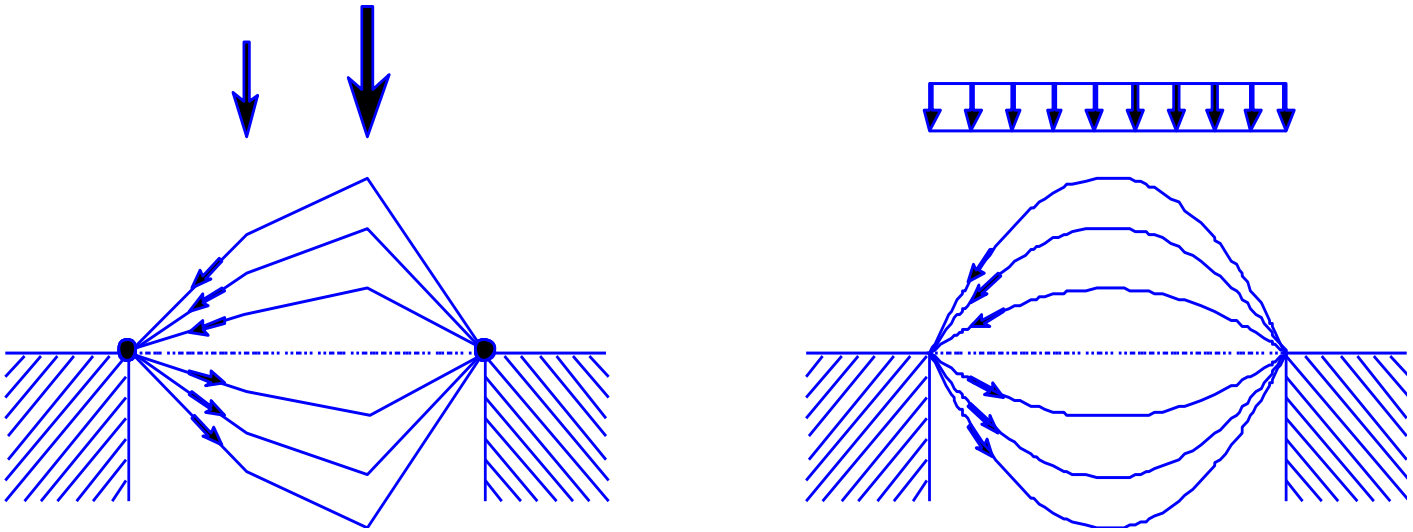
Passarela semi-destruída em Mardan, Paquistão – agosto 2006

Estruturas flexíveis devem se conformar às

formas funiculares:

Aquelas que equilibram um conjunto de cargas, sem o surgimento de esforços de flexão.

* Cabos e arcos:



To fill the vacancy of the enſuing page, I have here added a *decimate* of the *centeſme* of the Inventions I intend to publiſh, though poſſibly not in the ſame order, but as I can get opportunity and leaſure; moſt of which, I hope, will be as uſeful to Mankind, as they are yet unknown and new.

1. *A way of Regulating all ſorts of* Watches *or* Time-keepers, *ſo as to make any way to equalize, if not exceed the* Pendulum-Clocks *now uſed.*

2. ***The true Mathematical and Mechanichal form of all manner of*** **Arches** ***for Building, with the true butment neceſſary to each of them.*** A Problem which no *Architectonick* Writer hath ever yet attempted, much leſs performed. abccc ddeeeee f gg iiiiiiii llmmmmnnnnnooprr sssttttttuuuuuuuux.

3. *The true Theory of* Elaſticity *or* Springineſs, *and a particular Explication thereof in ſeveral Subjects in which it is to be found: And the way of computing the velocity of Bodies moved by them.* ceiiinosssttuu.

4. *A very plain and practical way of counterpoiſing Liquors, of great uſe in* Hydraulicks. Diſcovered.

5. *A new ſort of Object-Glaſſes for* Teleſcopes *and* Microſcopes, *much outdoing any yet uſed.* Diſcovered.

[Hooke's anagram for the "law of the arch"](#) **, from Hooke, Robert (1635-1703),** ***Lectiones Cutlerianæ, or A collection of lectures: physical, mechanical, geographical, & astronomical.*** **London: Printed for John Martyn, 1679.**

abcccddeeeeefggiiiiiiiiill
mmmmmnnmnooprrsssttttttt
uuuuuuvx

ut pendet continuum flexile,
sic stabit contigum rigidum inversum

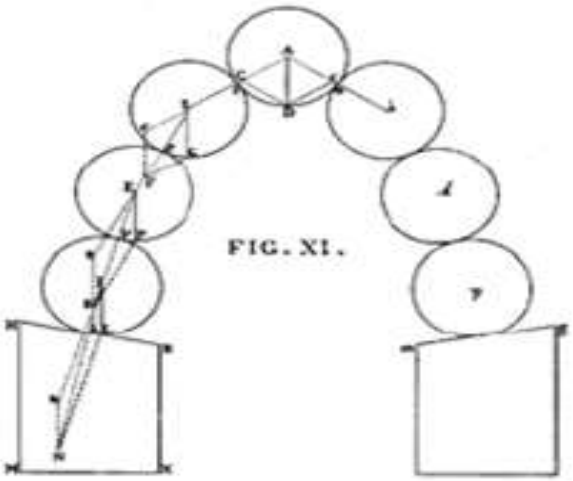


FIG. XI.

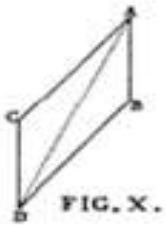


FIG. X.

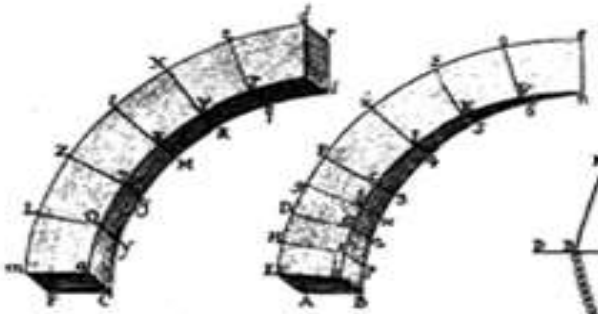


FIG. XIII.

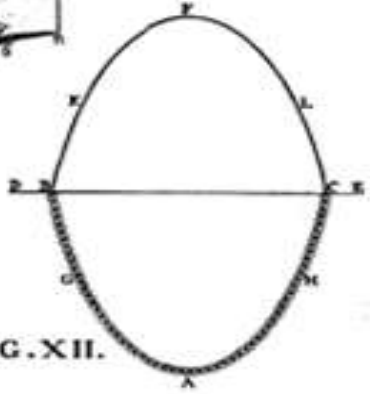
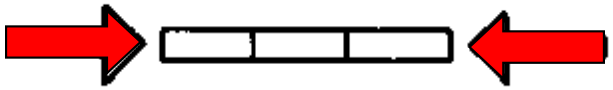


FIG. XII.

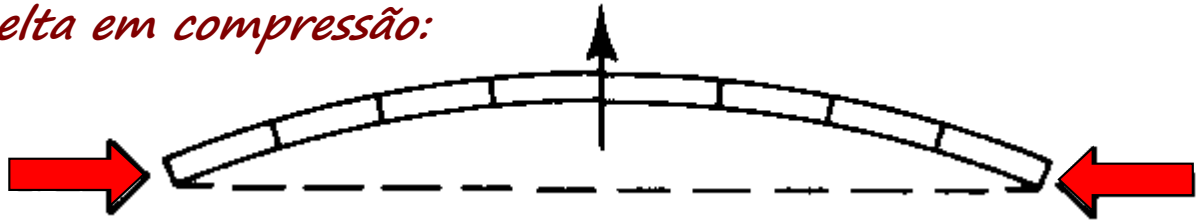
Poleni 1748

Estados de Solicitação Interna

- Barra curta em compressão:

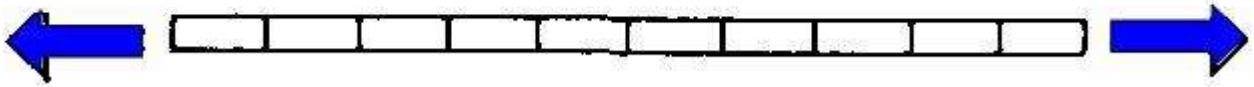


- Barra esbelta em compressão:

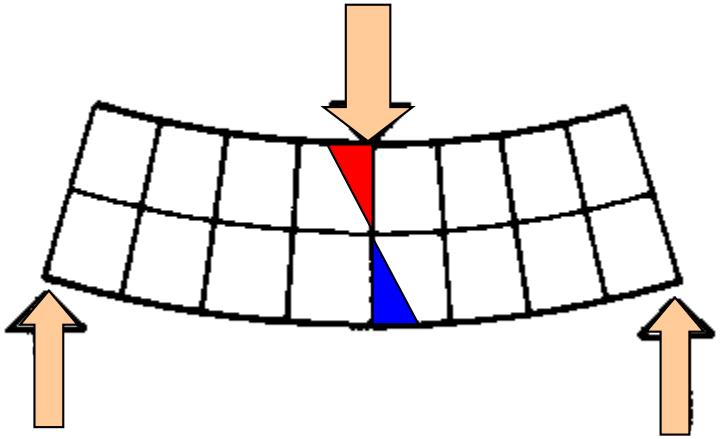


Flambagem!

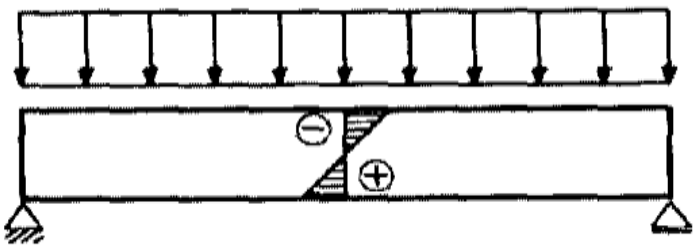
- Barra esbelta em tração:



- Barra sujeita à flexão:

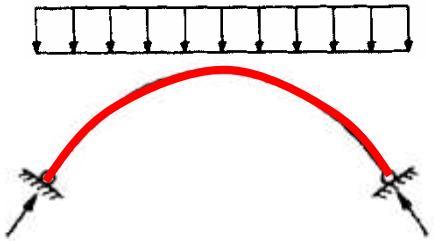


Flexão

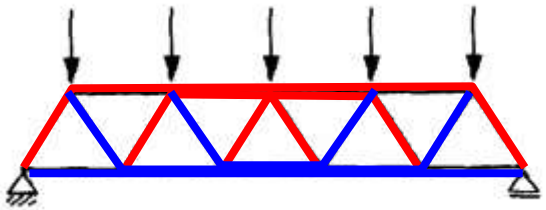


Compressão / Tração

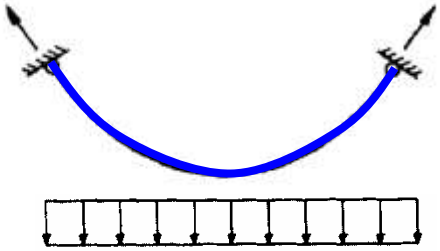
Compressão:
Arcos



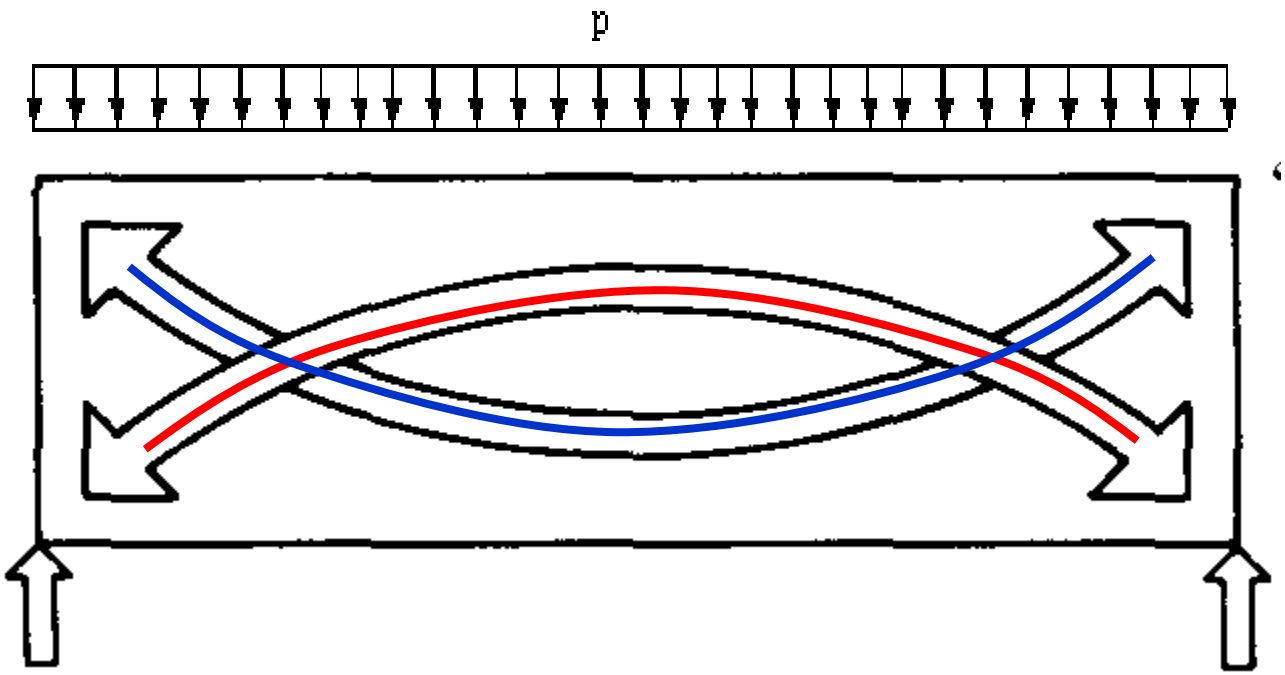
Tração + Compressão = Flexão
Vigas



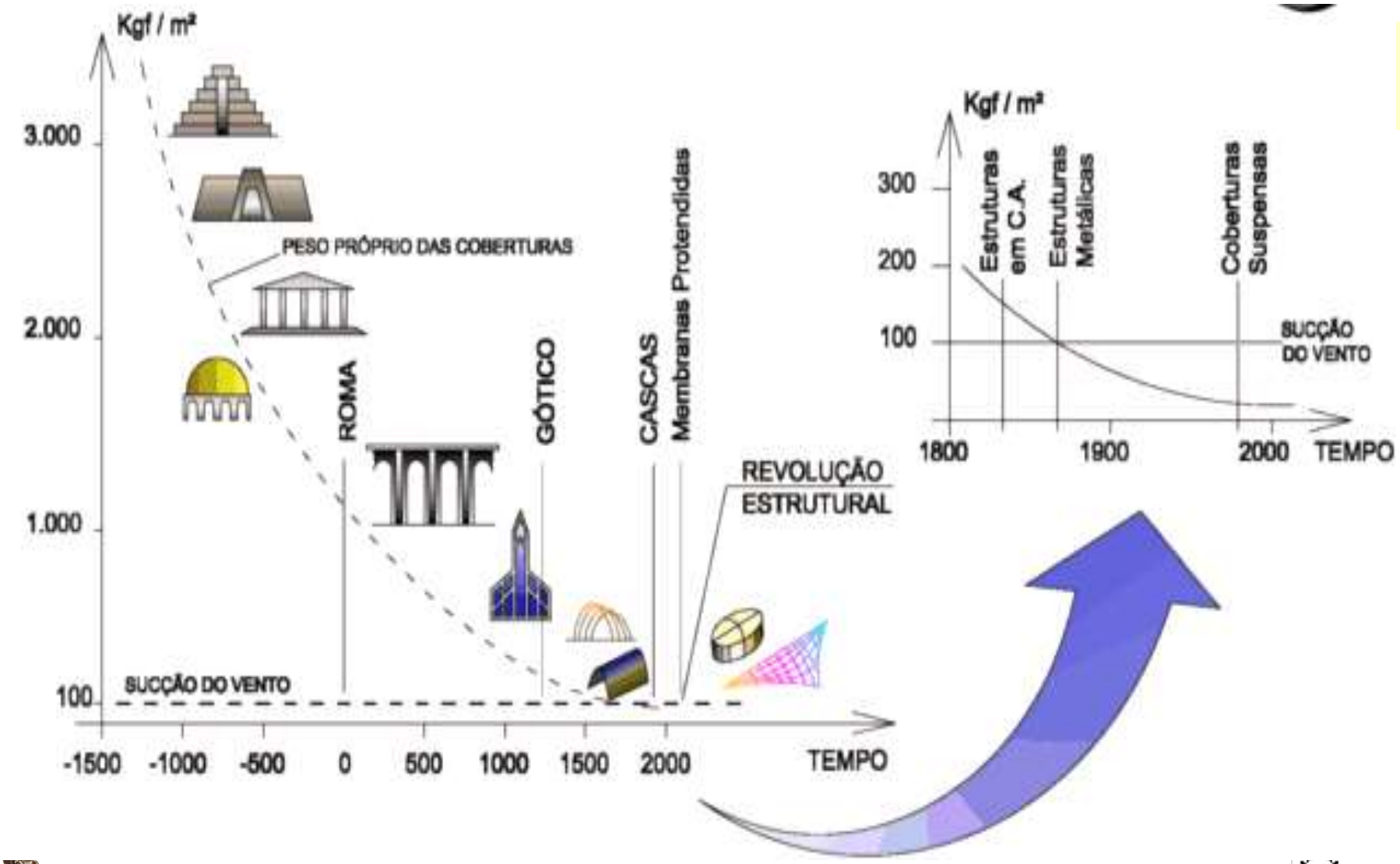
Tração:
Cabos

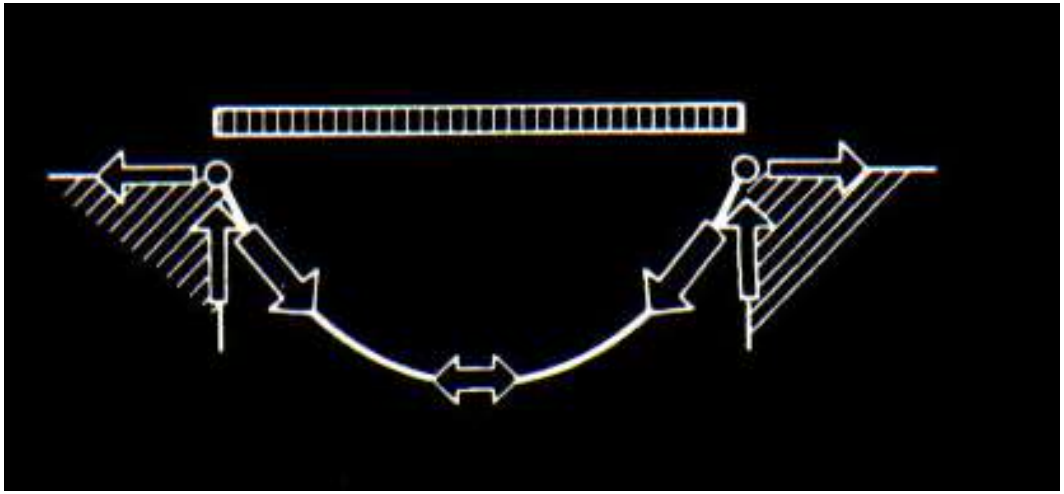


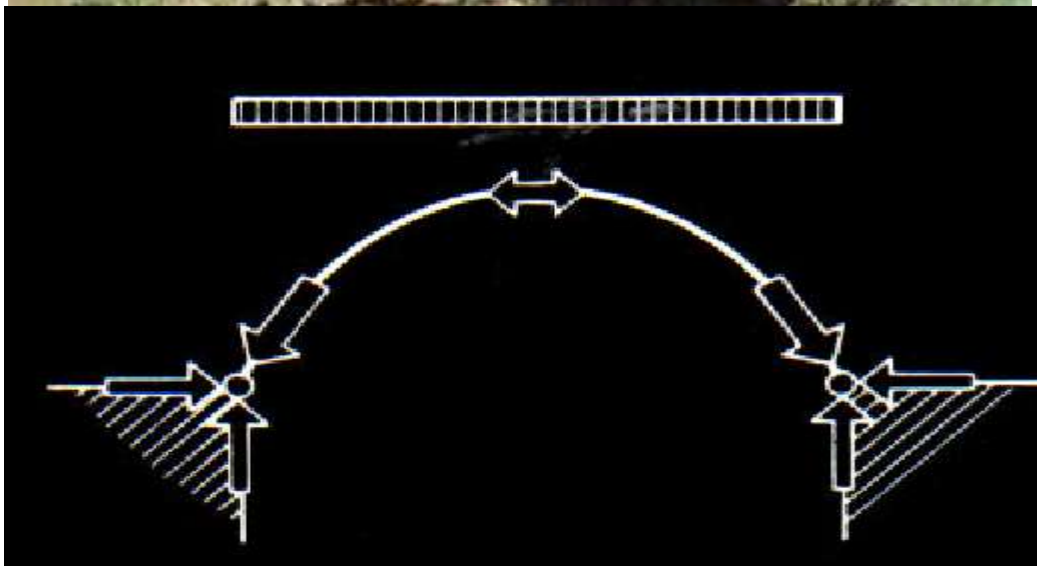
Flexão : 'Efeito Arco' x 'Efeito Cabo'



Estruturas Leves

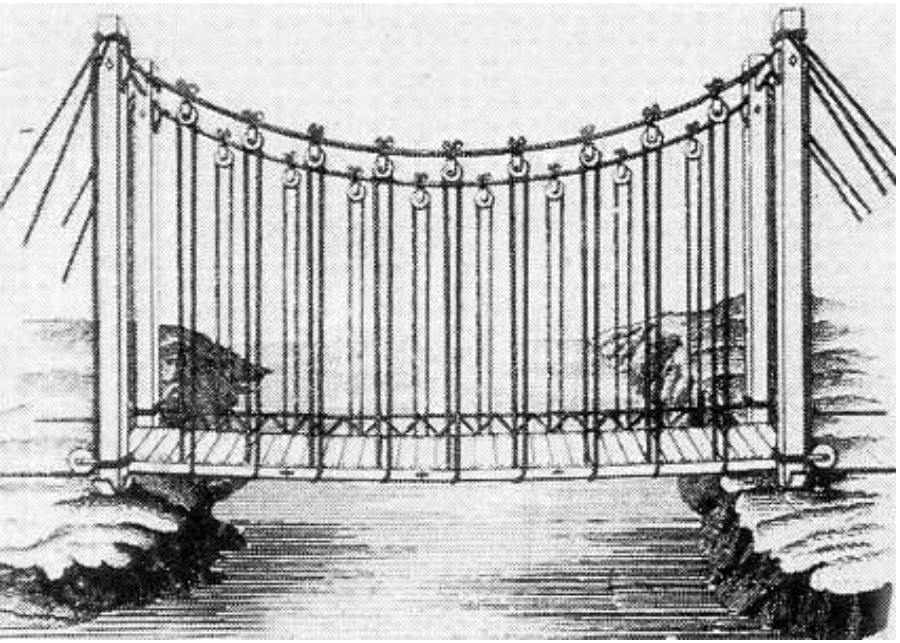


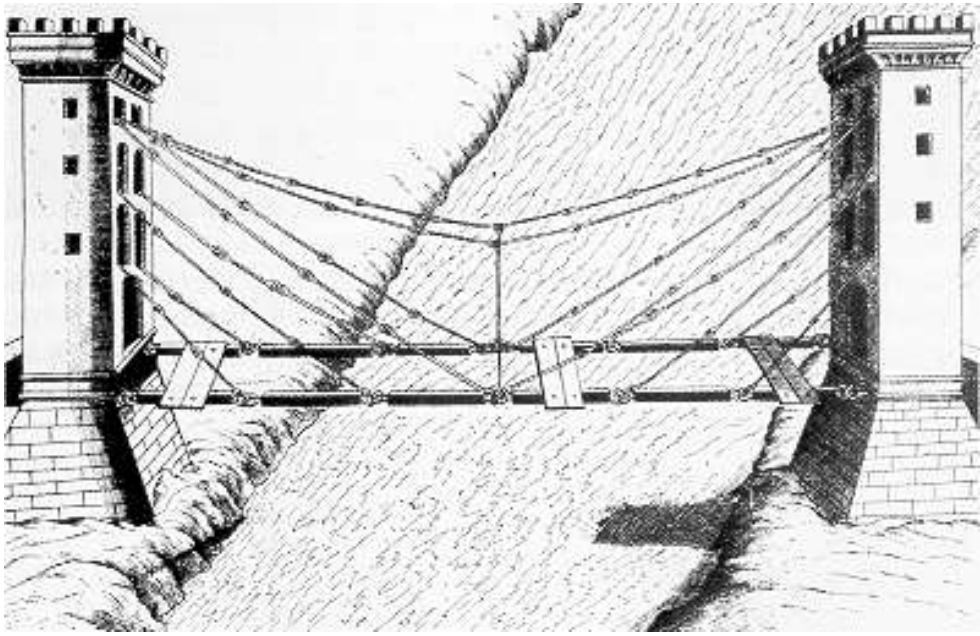




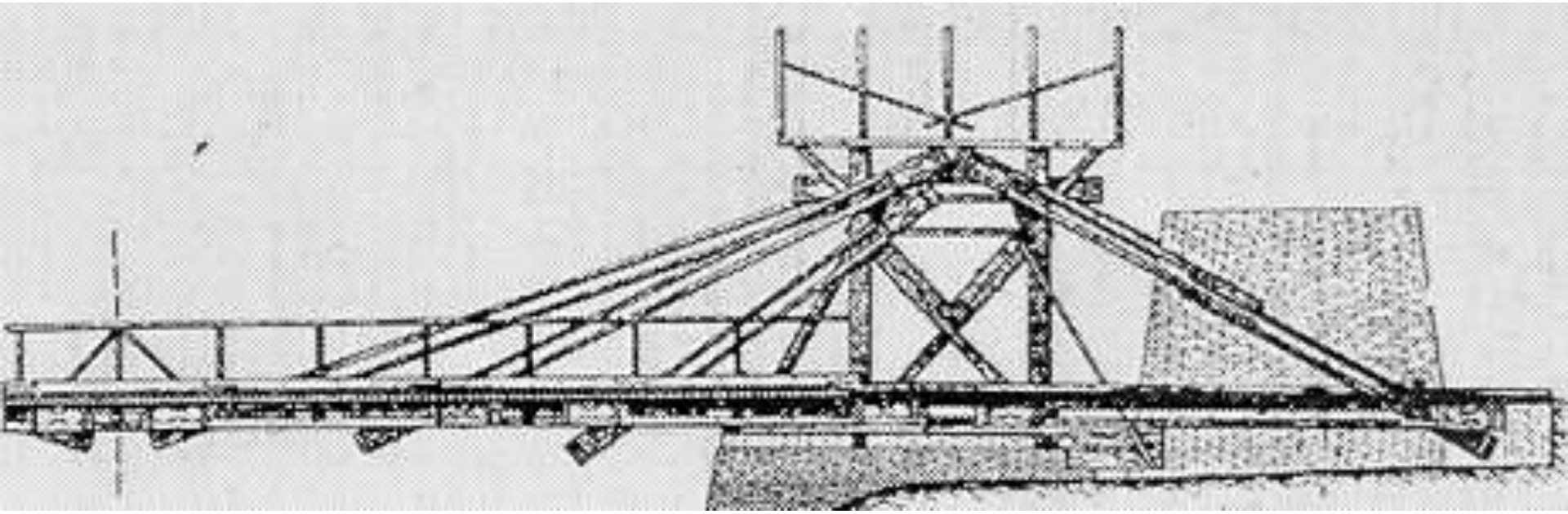

Ponte sobre o rio Mekong
Vão 74m, circa 1470

Esquemas de Faustus Verantius para pontes suspensas e estaiadas (1617)





Esquema de Immanuel Loscher, para uma ponte estaiada de madeira (1784)

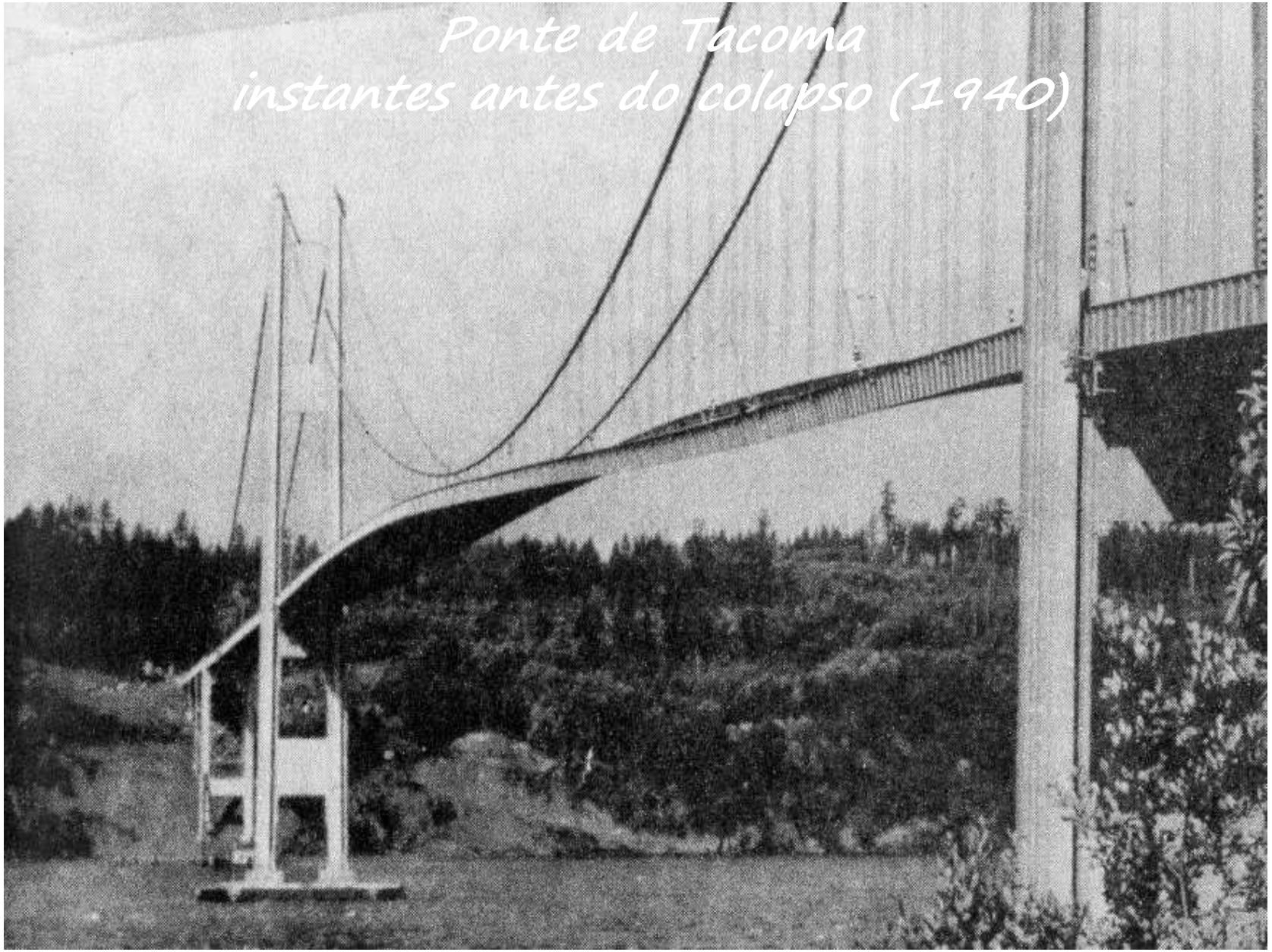



Ponte sobre o estreito de Menai
(1826, vão livre 177m)

Ponte do Brooklyn
(Nova Iorque, 1883, vão livre 486m)

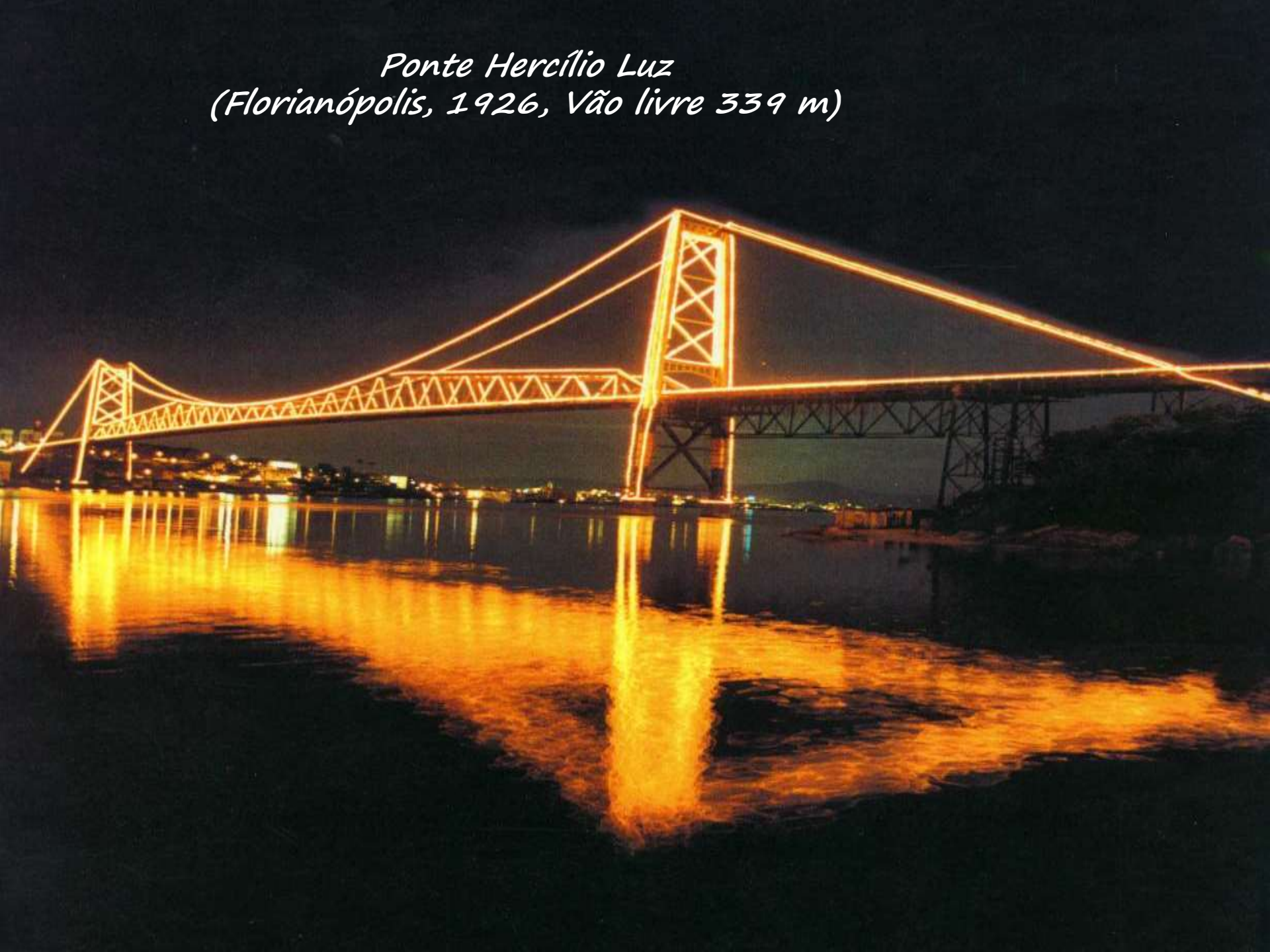
Ponte Golden Gate
(São Francisco, 1936, vão livre 1281m)

Ponte de Tacoma
instantes antes do colapso (1940)

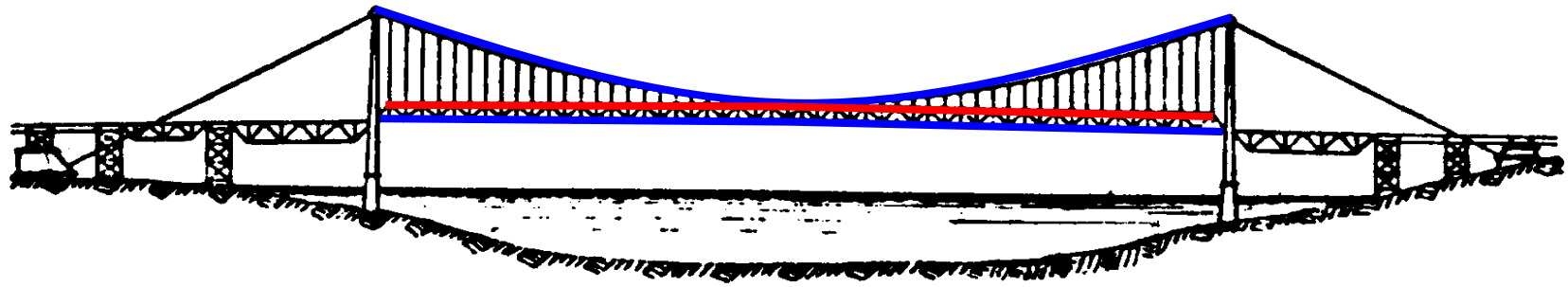



Ponte Akashi-Kaikyo
(Japão, 1998, vão livre 1990 m)

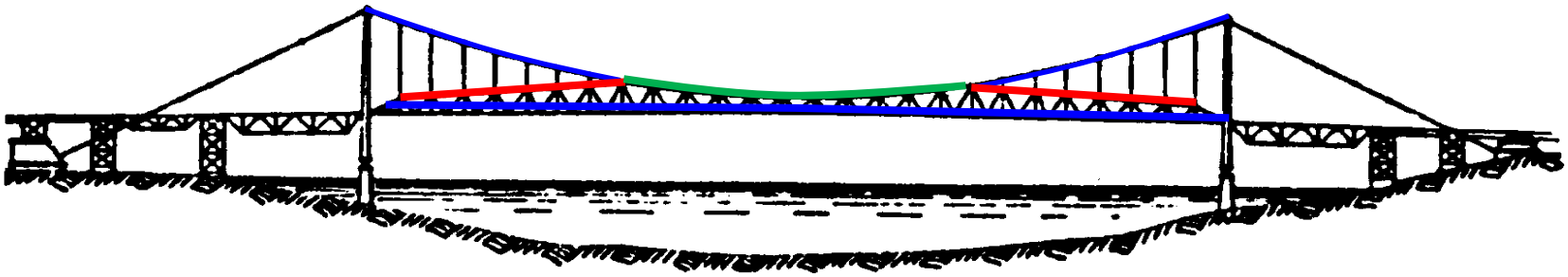
Ponte de São Vicente (1914). Vão livre 180m


Ponte Hercílio Luz
(Florianópolis, 1926, Vão livre 339 m)

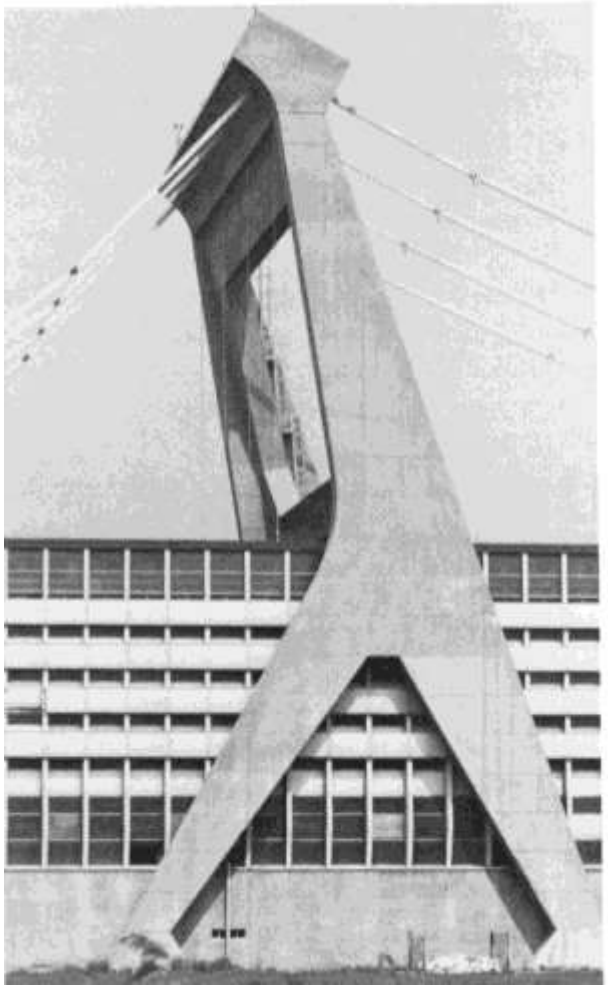
Ponte Hercílio Luz
Esquemas original e executado

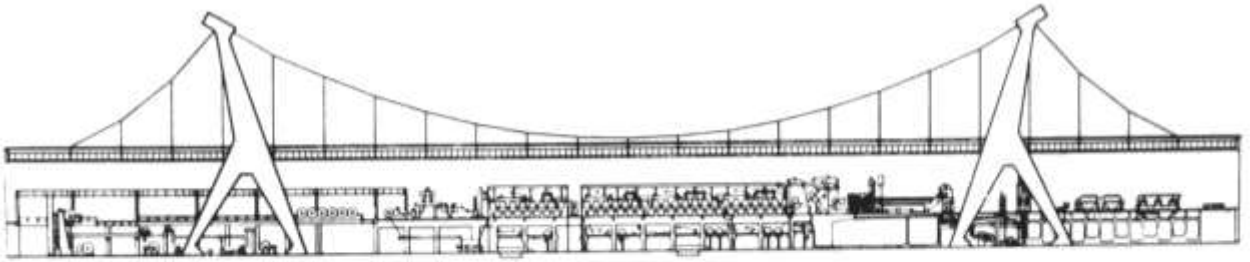


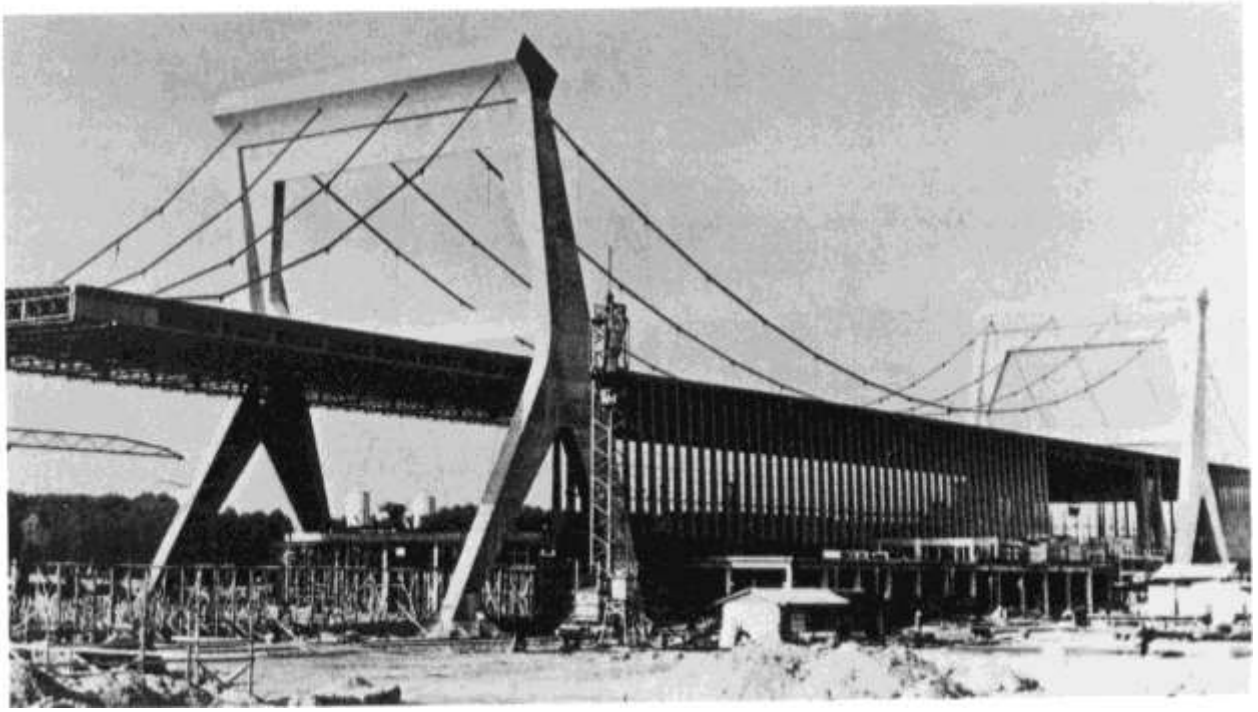
Projeto Original



Projeto Executado



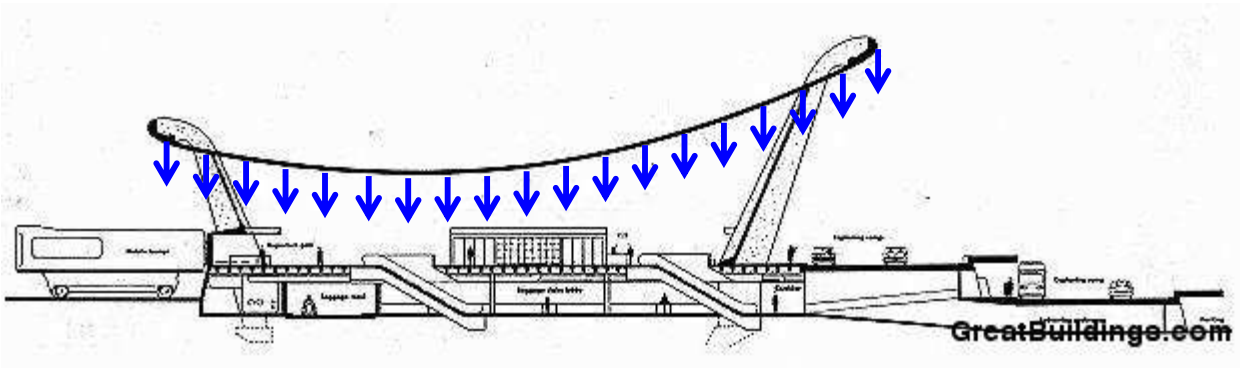




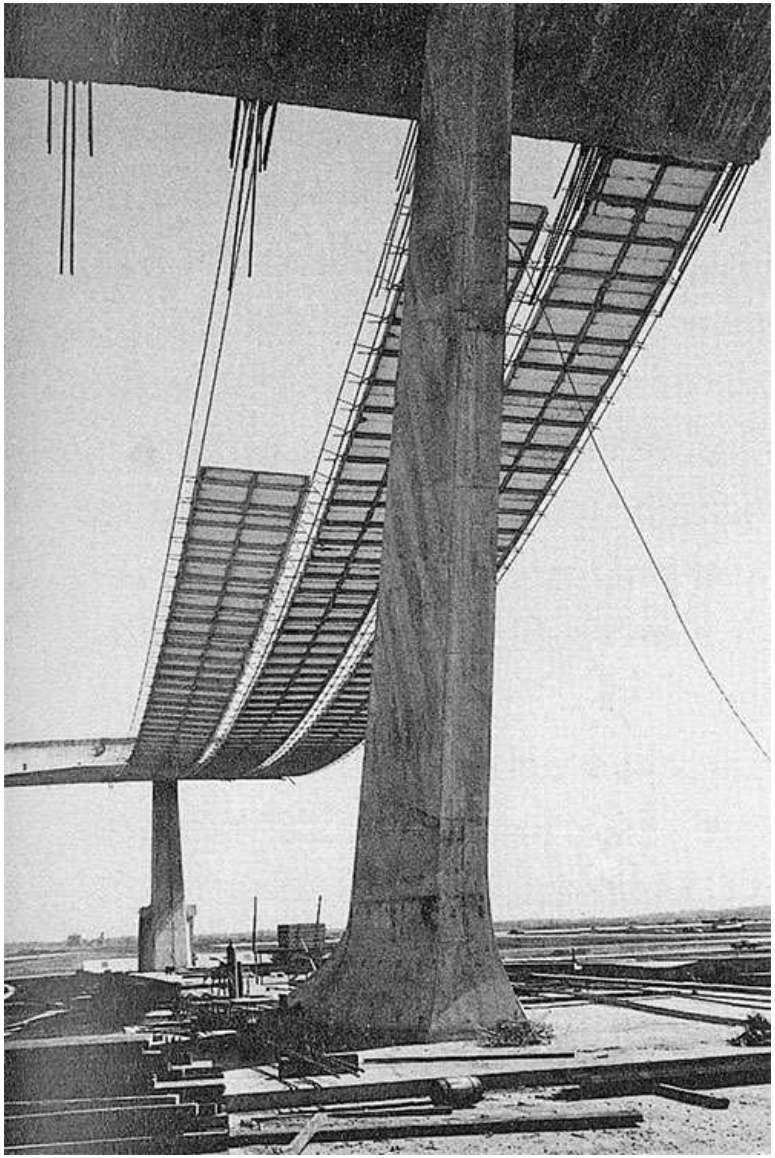
Fábrica de papel em Mântua (P. Nervi, 1963)

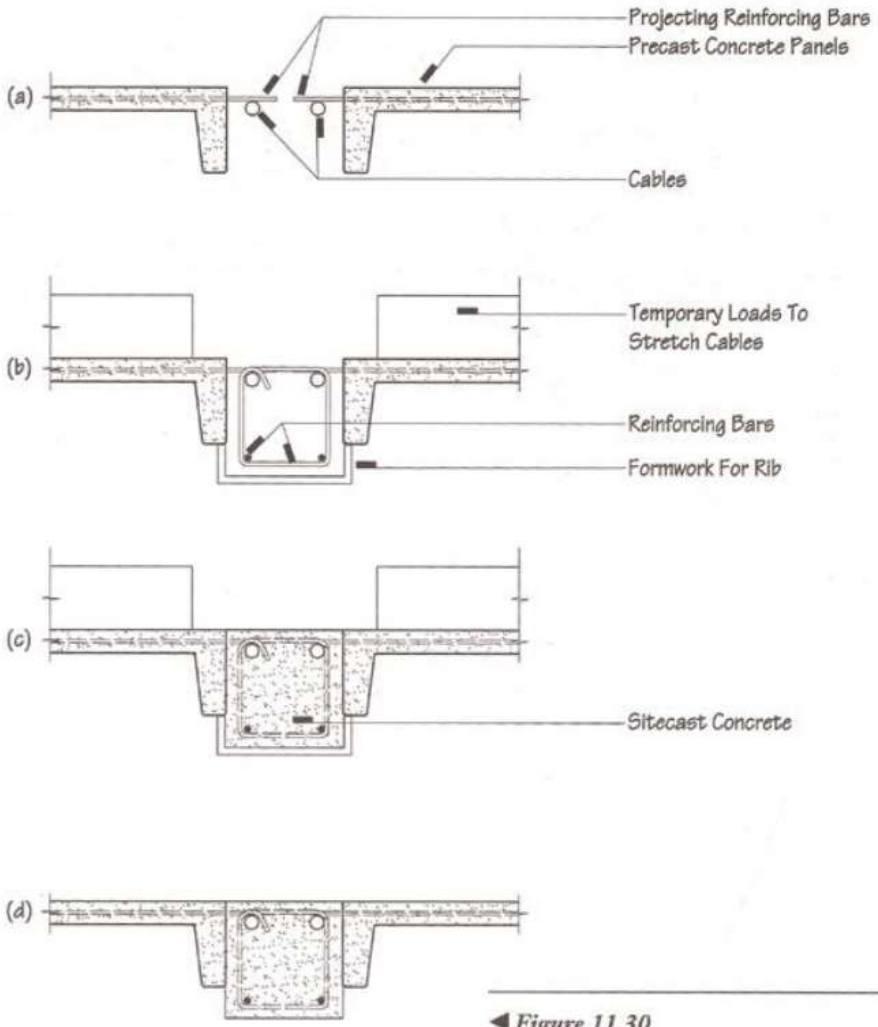
Aeroporto Dulles, Washington (1958)

Atual "Ronald Reagan Washington National Airport"




AMERICAN
AMERICAN
AMERICA

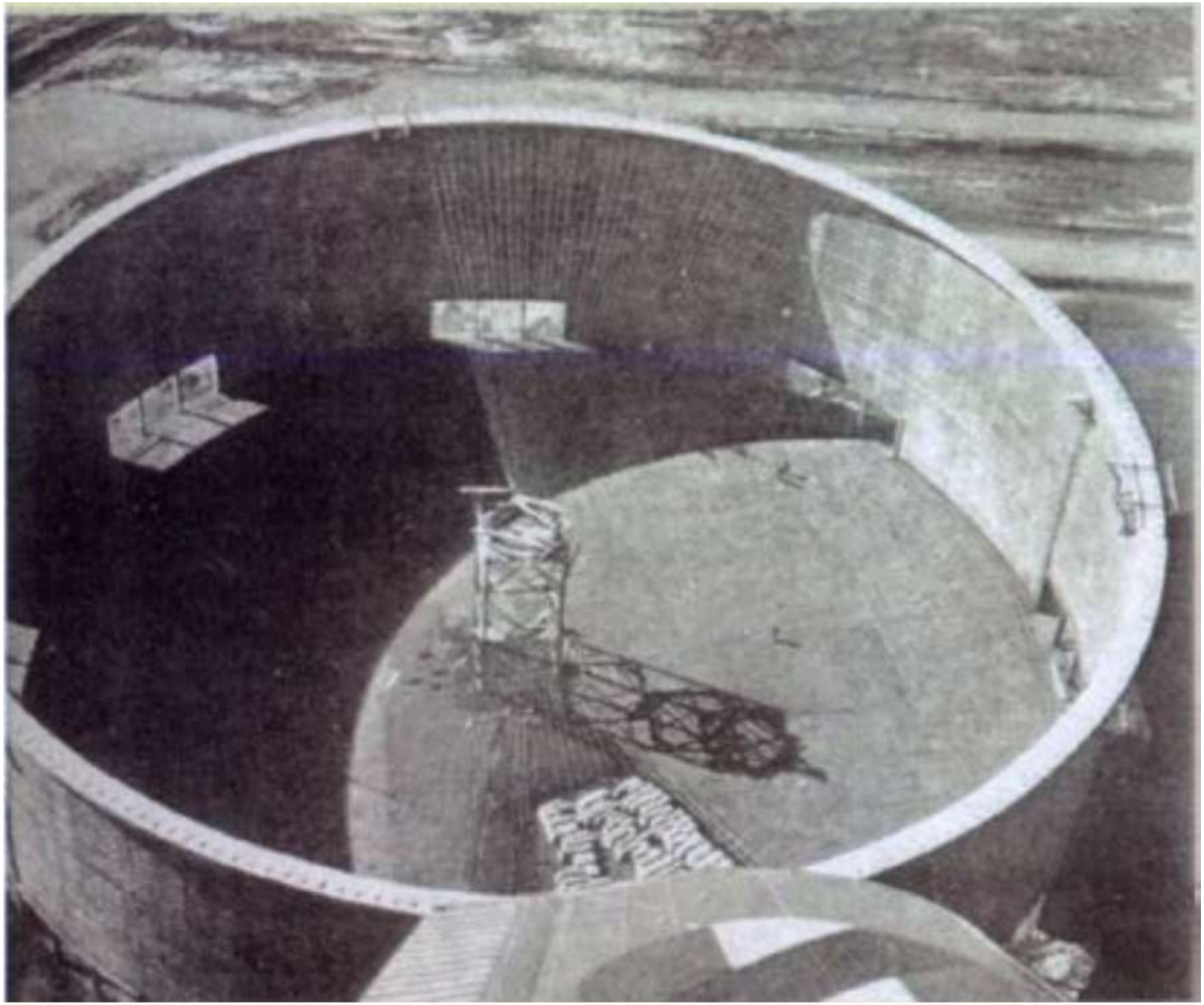


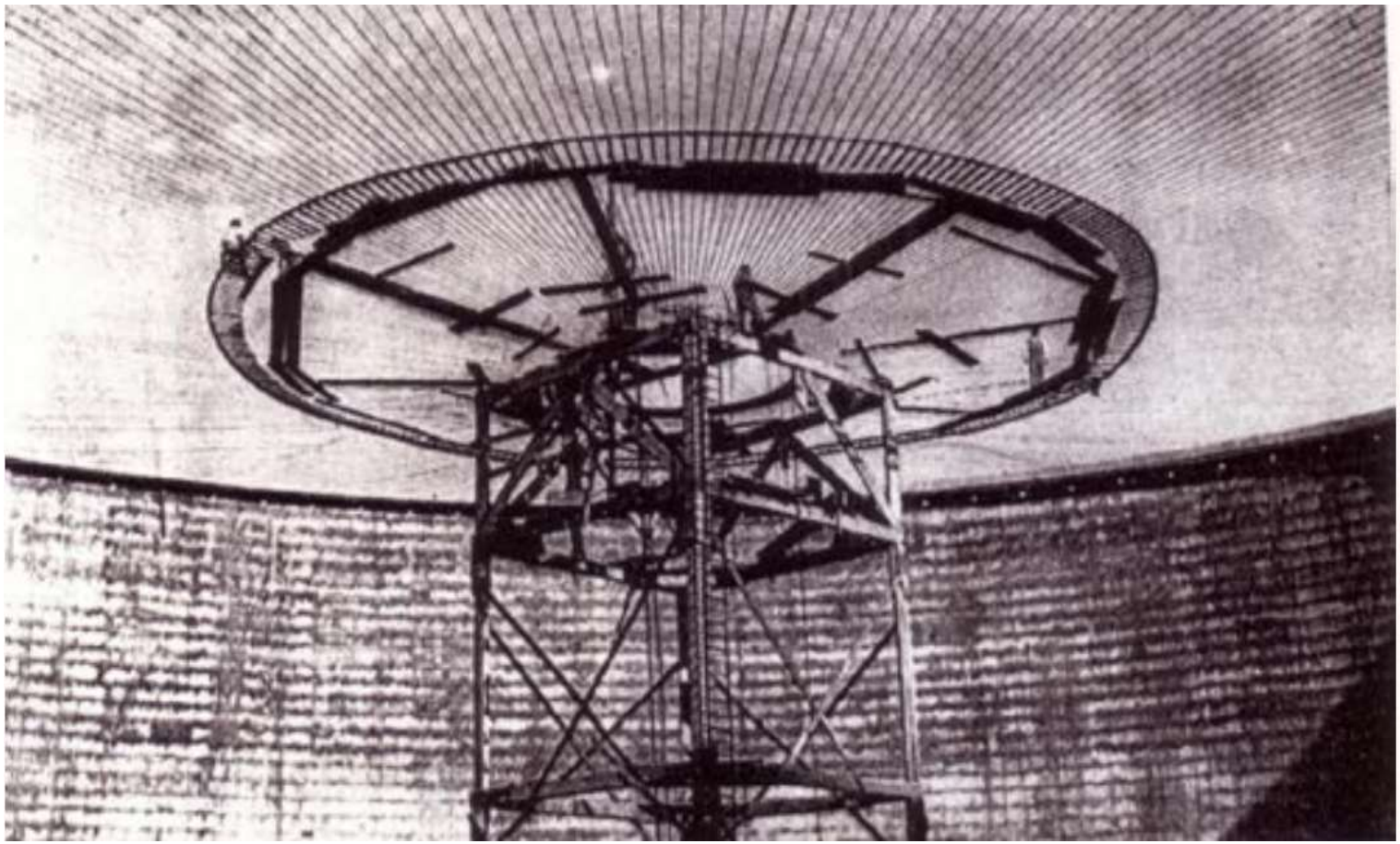


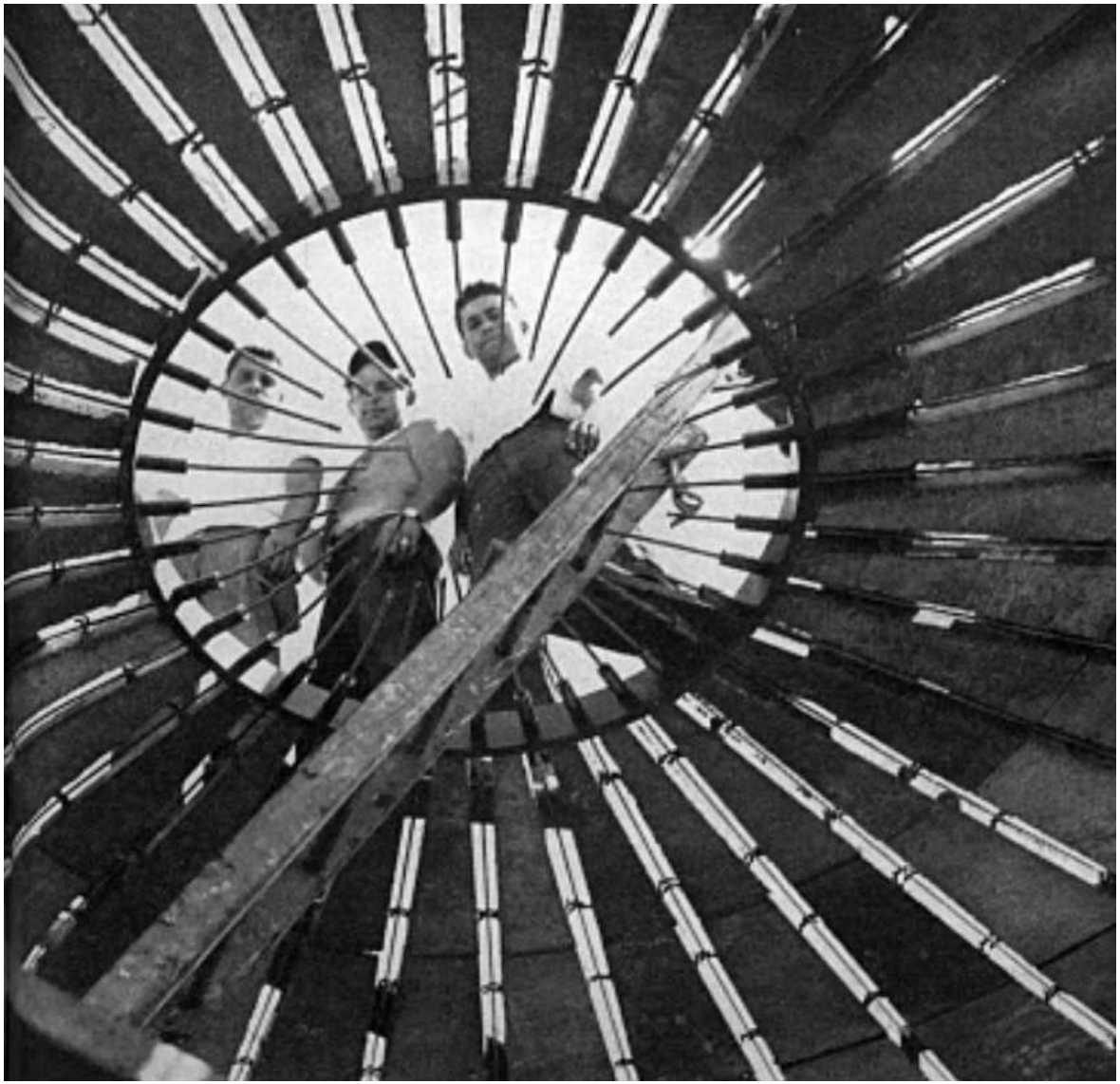
◀ *Figure 11.30*
How the deck was attached to the Dulles roof.

‘Cilindro Municipal’, Montevideo, Uruguay

Arq. Leonel Viera e Luis A. Mondino (1956). Incendiado em 2010, demolido em 2014.
Diâmetro do anel externo: 95 m, diâmetro do anel interno 5,5m. Capacidade 18.000 espectadores



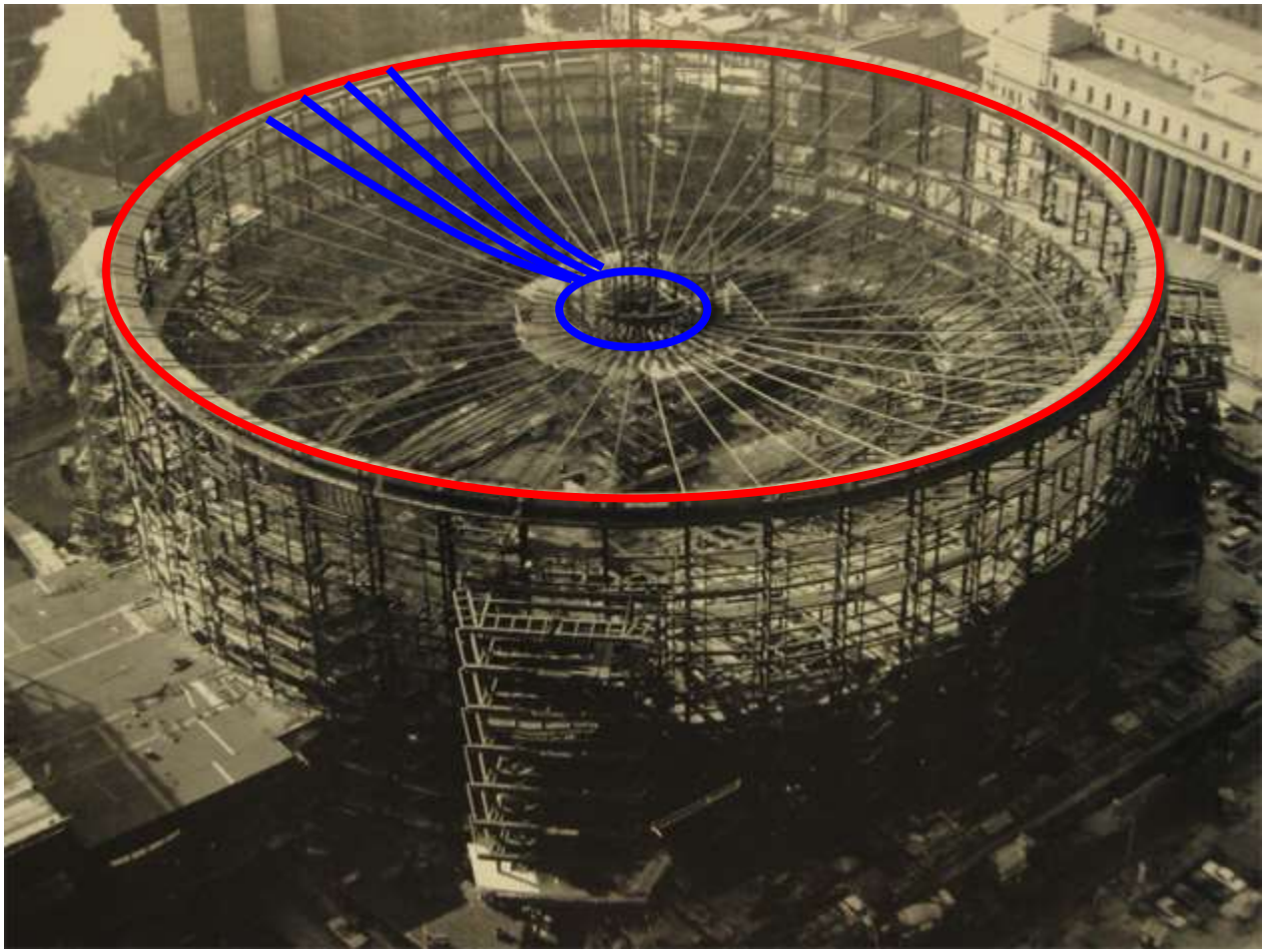




'Cilindro Municipal', Montevideo, Uruguay

Danificado por um incendio em 21/10/2010, demolido em 12/05/2014

Madison Square Garden's, New York (1968)

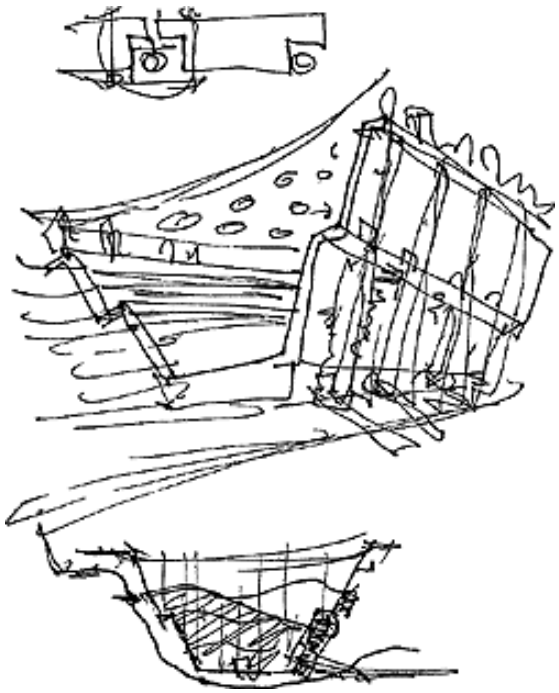


Pavilhão de Portugal para EXPO 98 (Lisboa)

Arq. Eduardo Souto de Moura

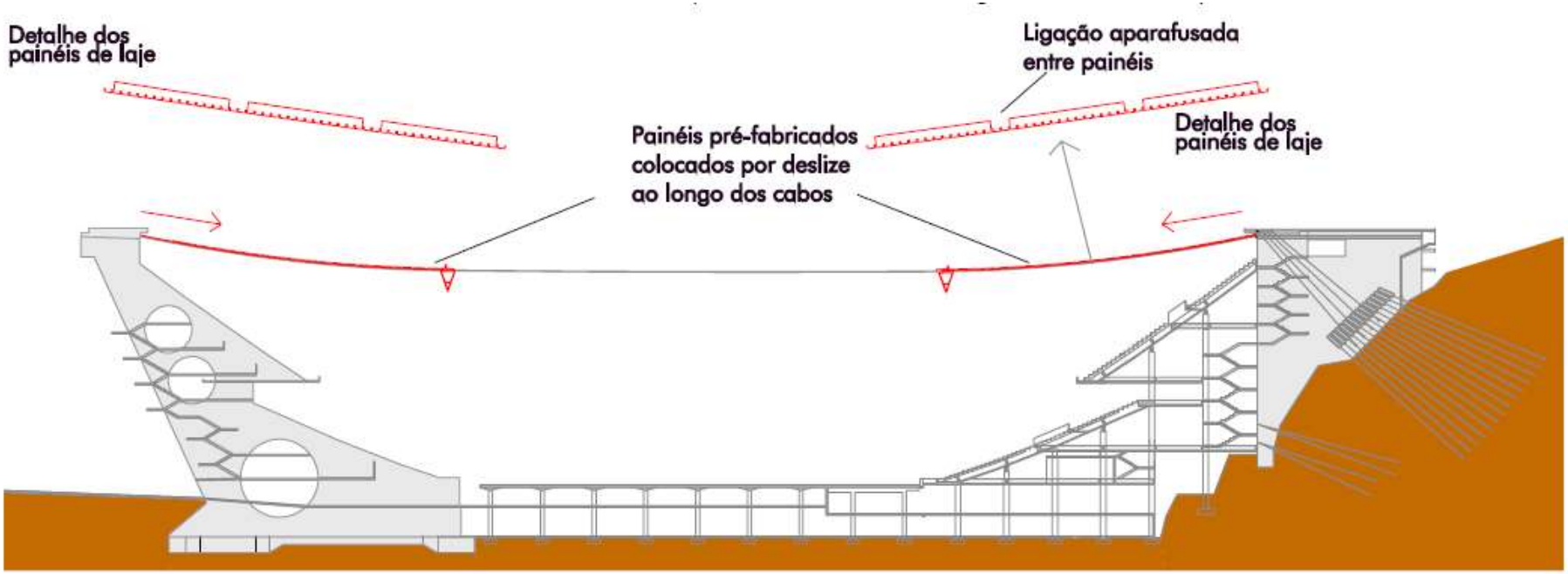
Pavilhão de Portugal para EXPO 98 (Lisboa)

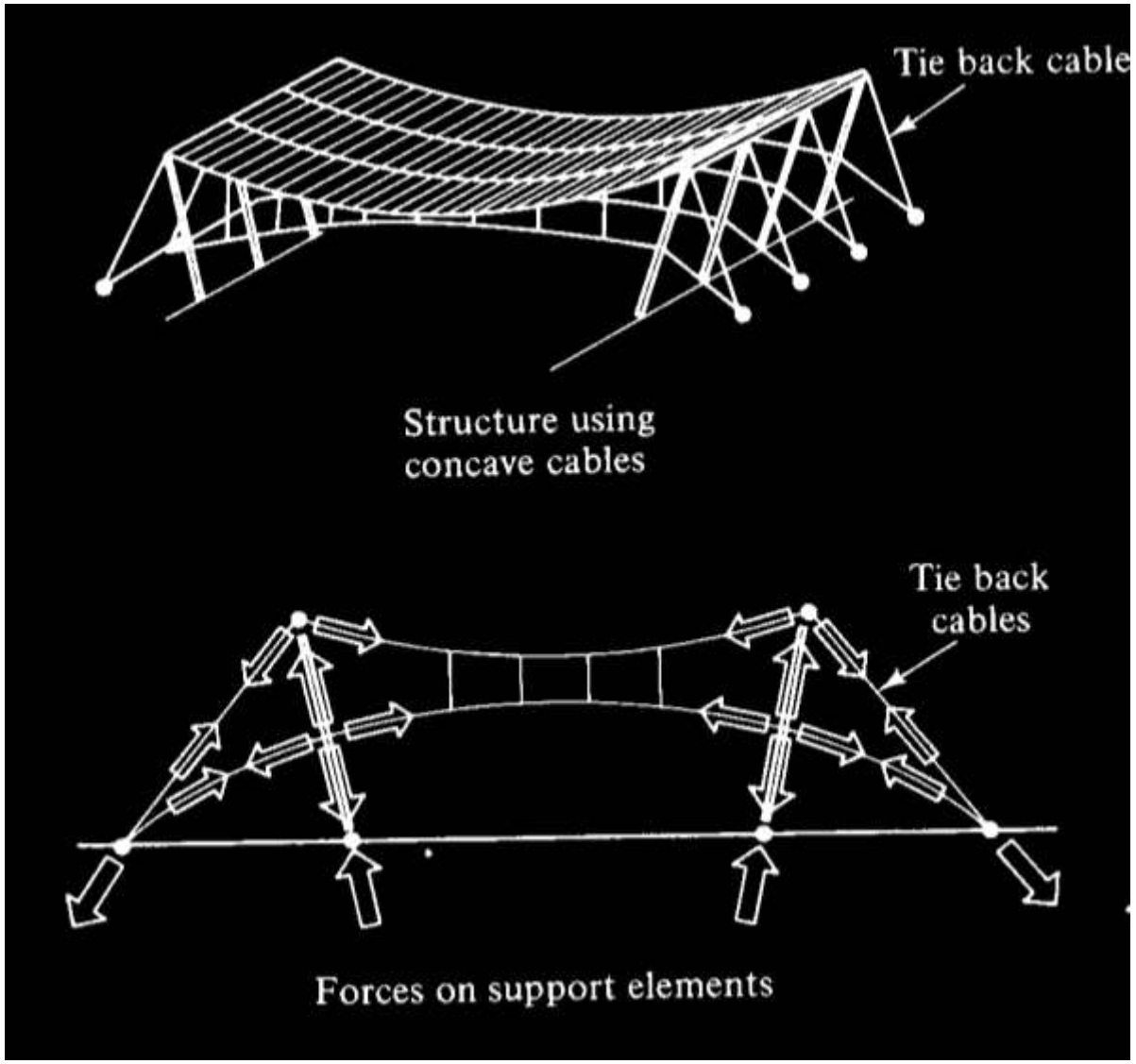
Arq. Eduardo Souto de Moura



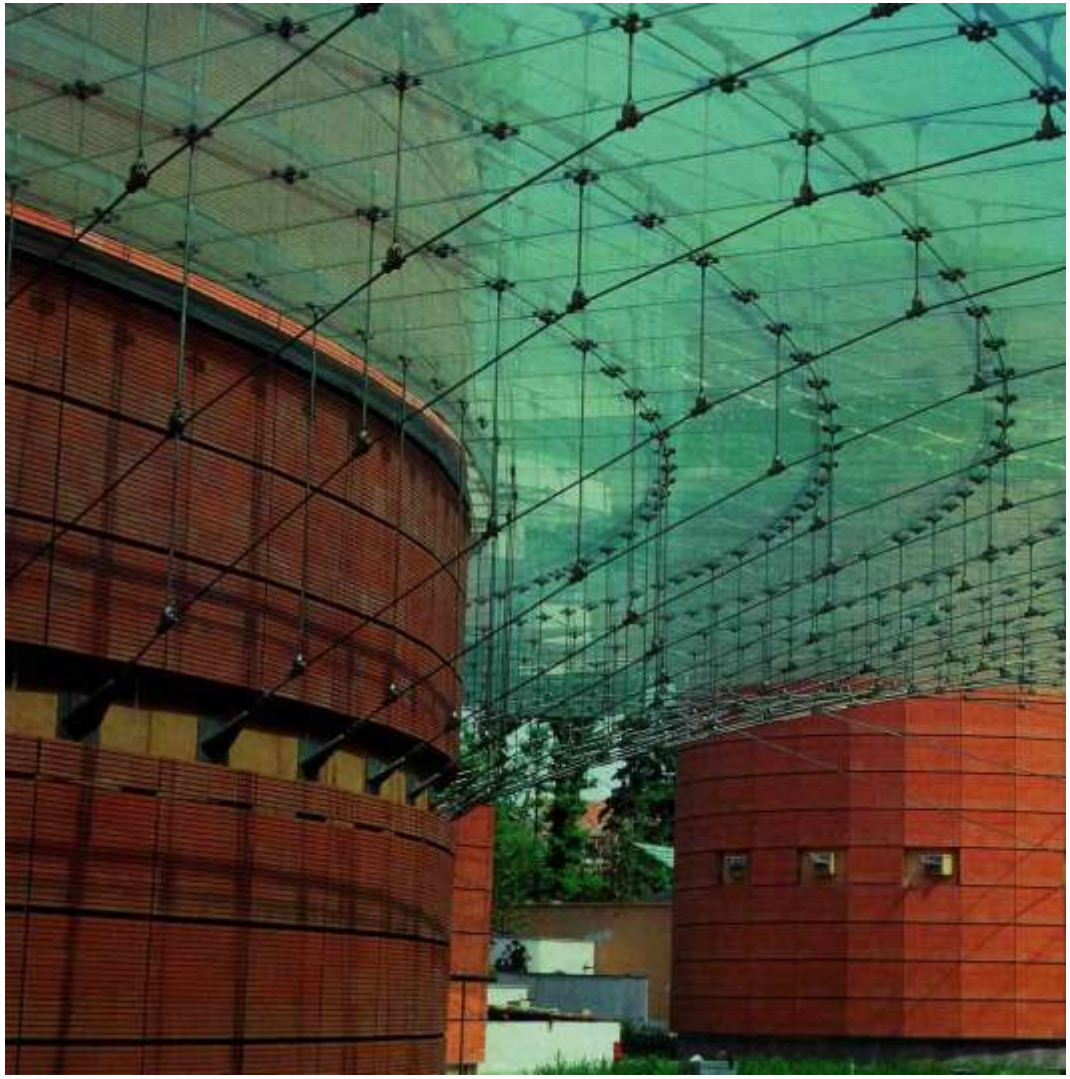
Estádio Municipal de Braga – Braga, Portugal, 2004

Arq. Eduardo Souto de Moura & Eng. Rui Furtado


Detalhe dos painéis de laje
Ligação aparafusada entre painéis
Painéis pré-fabricados colocados por deslize ao longo dos cabos
Detalhe dos painéis de laje

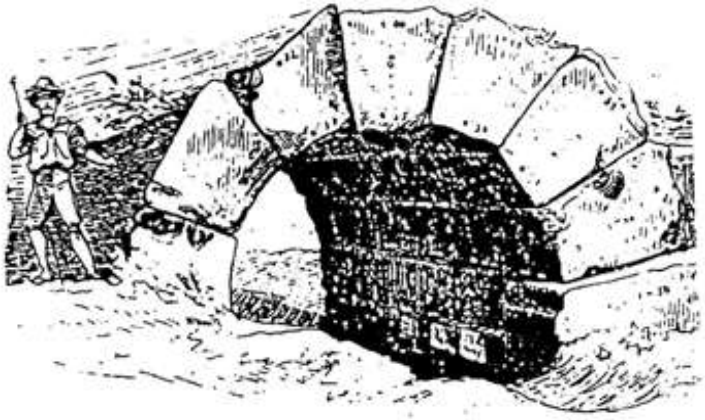

Tie back cable
Structure using
concave cables
Tie back
cables
Forces on support elements

Cobertura de vidro em Lodi (1999)



Cobertura de vidro em Lodi (1999)

Federal Reserve Building, Minnesota



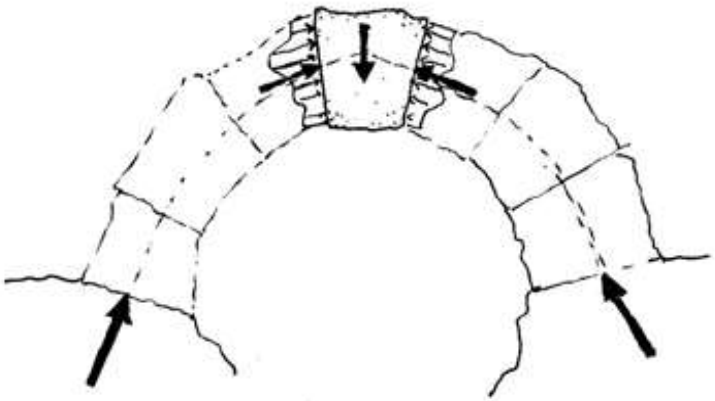
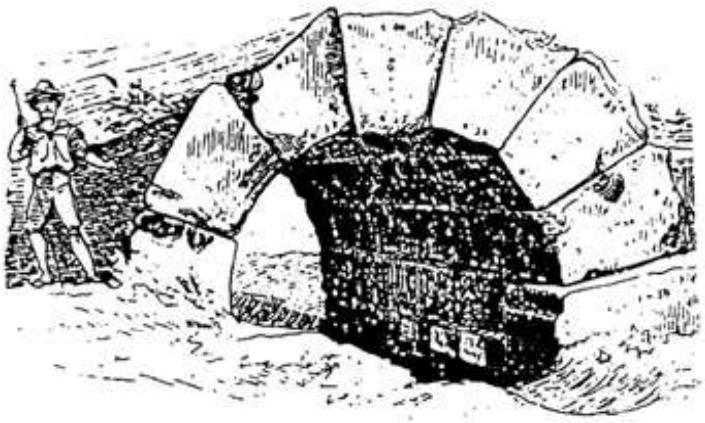


Figure 2 : Etruscan voussoir arch (Durm, 1885)



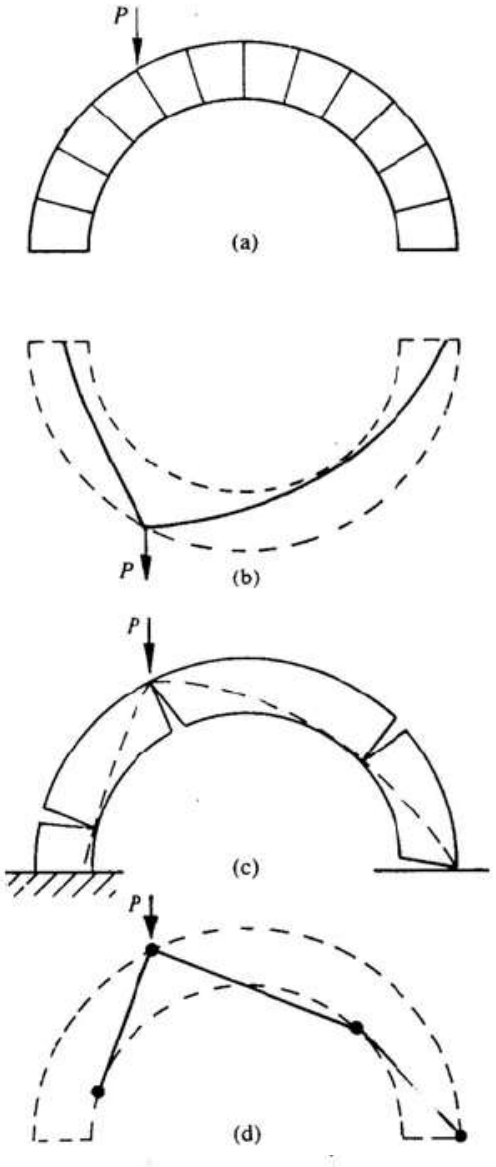


Figure 11 : Collapse of a semicircular masonry arch under a point load (Heyman 1995)

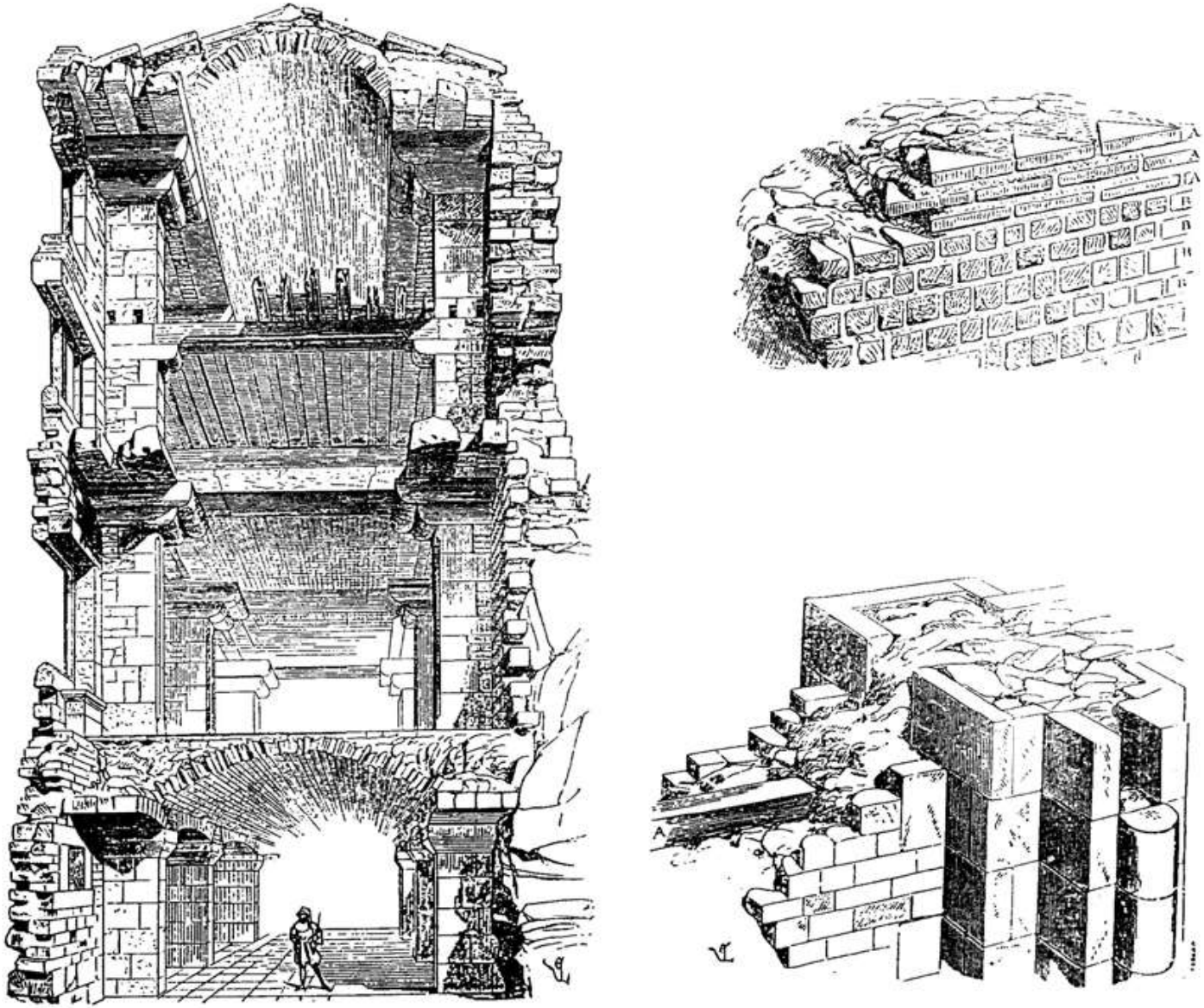


Figure 1 : Constructive section through a medieval building. Details of the construction of roman and medieval walls (Viollet-le-Duc 1858)

Arachtos Bridge, século XIII, recontruída 1603
Rion-Antirrion / Grécia

Catedral de Notre Dame, Paris, 1160 – 1345.

Catedral de Amiens, 1220 – 1266.

King´s College Chapel, Cambridge, 1446-1515

King's College Chapel, Cambridge, 1446-1515

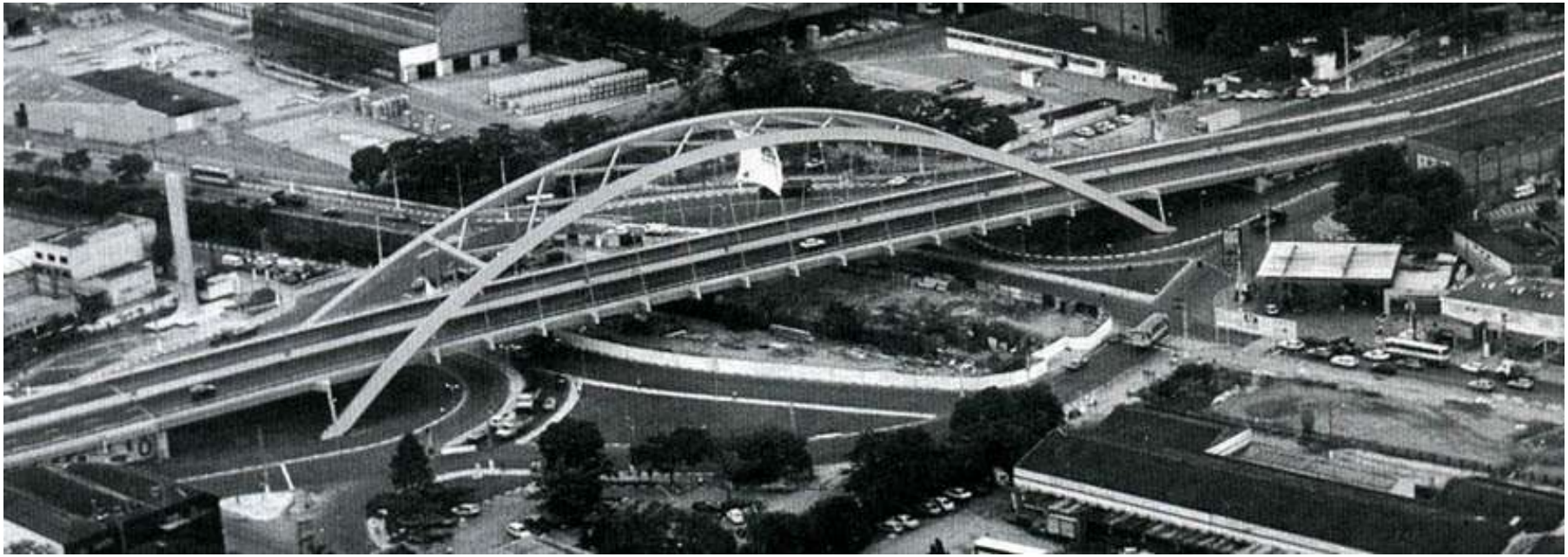
Ponte Salginatobel, Suíça
Robert Maillart, 1929
(total length 133 metres, longest span 90 metres)

Ponte Salginatobel, Suíça
Robert Maillart, 1929
(total length 133 metres, longest span 90 metres)

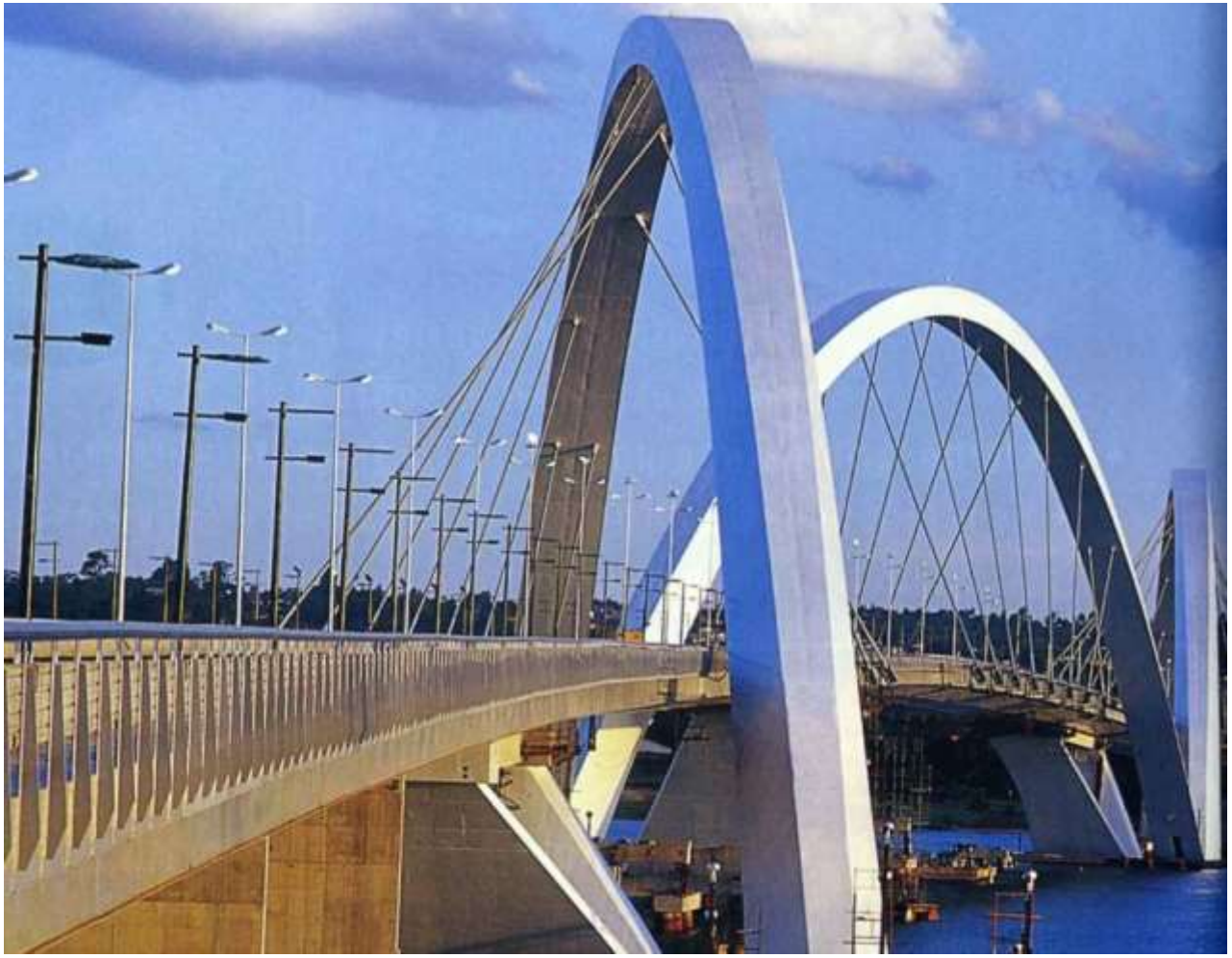
Viaducto del Ulla, 2011. 630 metros de comprimento, altura máxima 117m, vão principal 168m.

Viaducto del Ulla, 2011

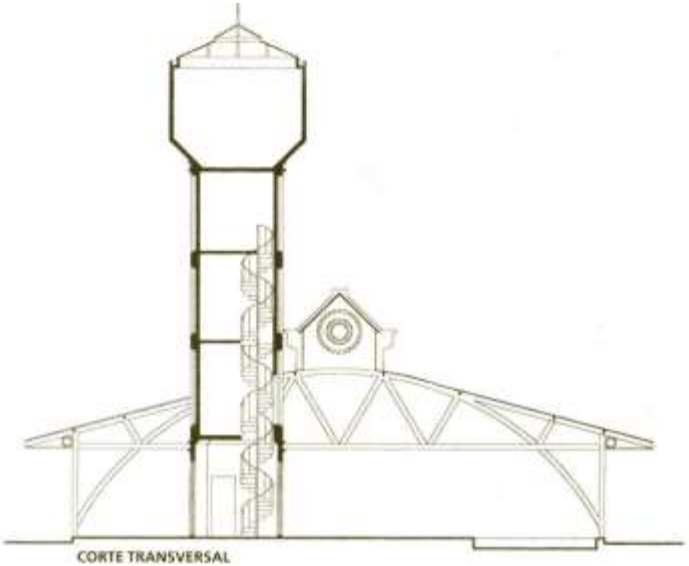
Viaducto del Ulla, 2011



Ponte de Osasco
Autoria – Usiminas Mecânica e Escritório de Engenharia
RMG – Belo Horizonte
Concepção estrutural – Tabuleiro de aço com 150m de vão livre suspenso por tirantes em dois arcos metálicos



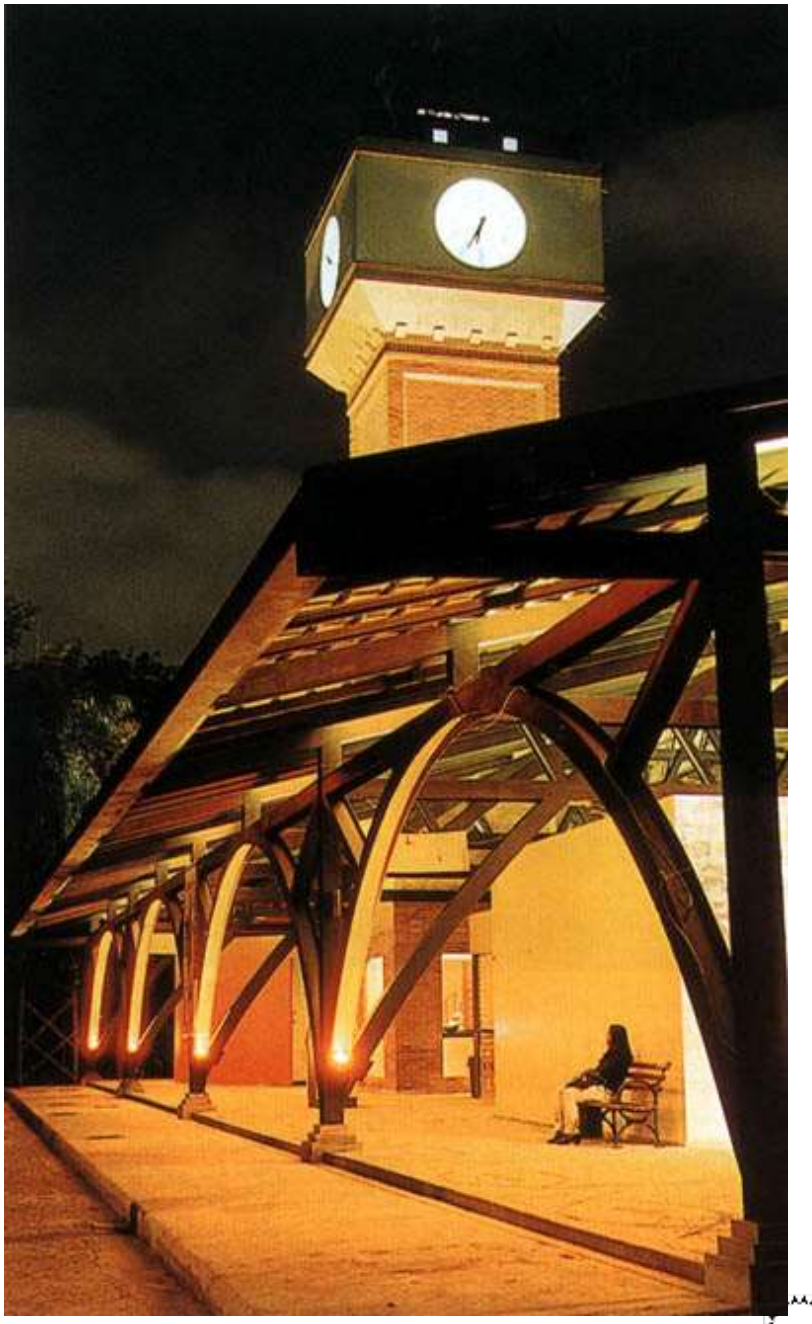
Centro de recepção do museu da vida
Rio de Janeiro
Autoria: Arqto Benedito Tadeu e Renato da Gama
Concepção estrutural: estrutura metálica recoberta de telhas cerâmicas em forma de arcos treliçados



CORTE TRANSVERSAL

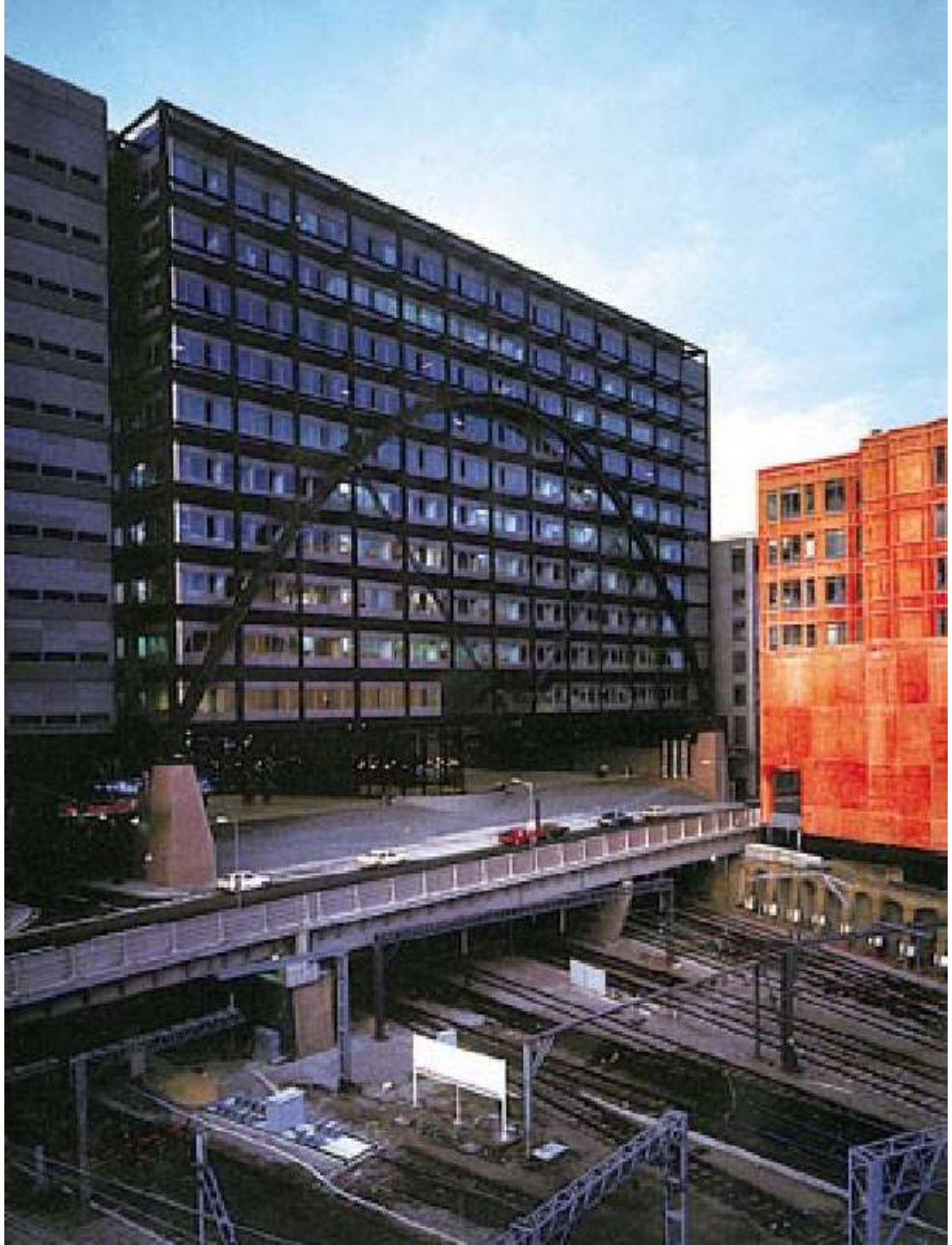
PLANTA BAIXA

1. Anfiteatro / 2. Sala de vídeo / 3. Loja / 4. Lanchonete
5. Informações/administração / 6. Espera / 7. Multimídia
8. Acesso de ônibus / 9. Acesso de trem / 10. Jardim



Broadgate Exchange House, Liverpool, Londres, S.O.M., 1990

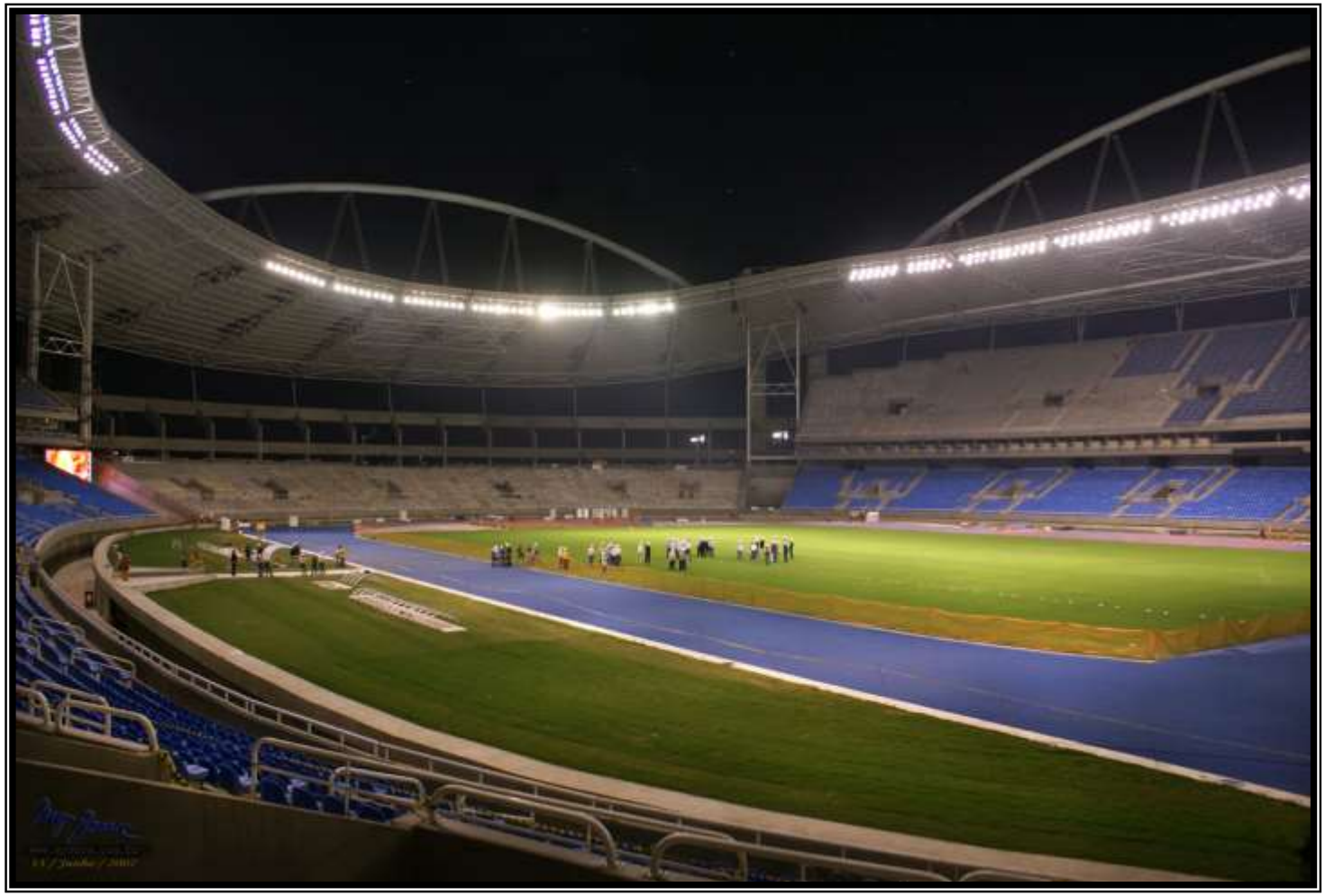
Broadgate Exchange House, Liverpool, Londres, S.O.M., 1990

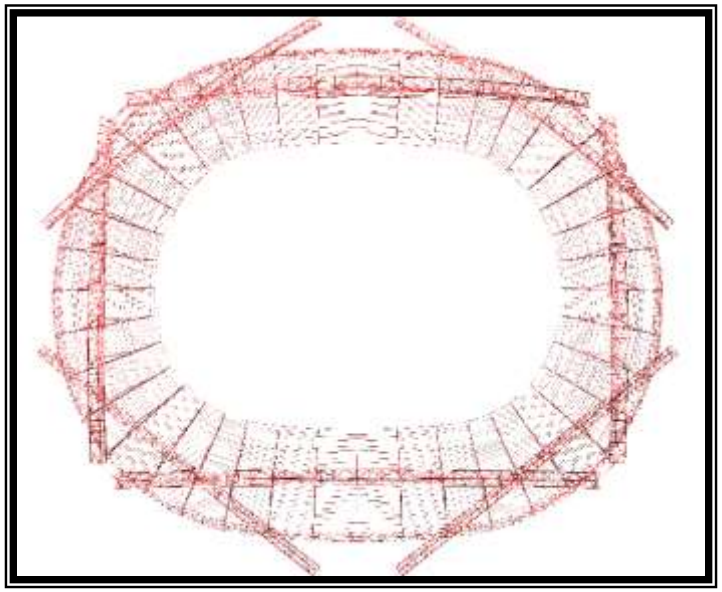


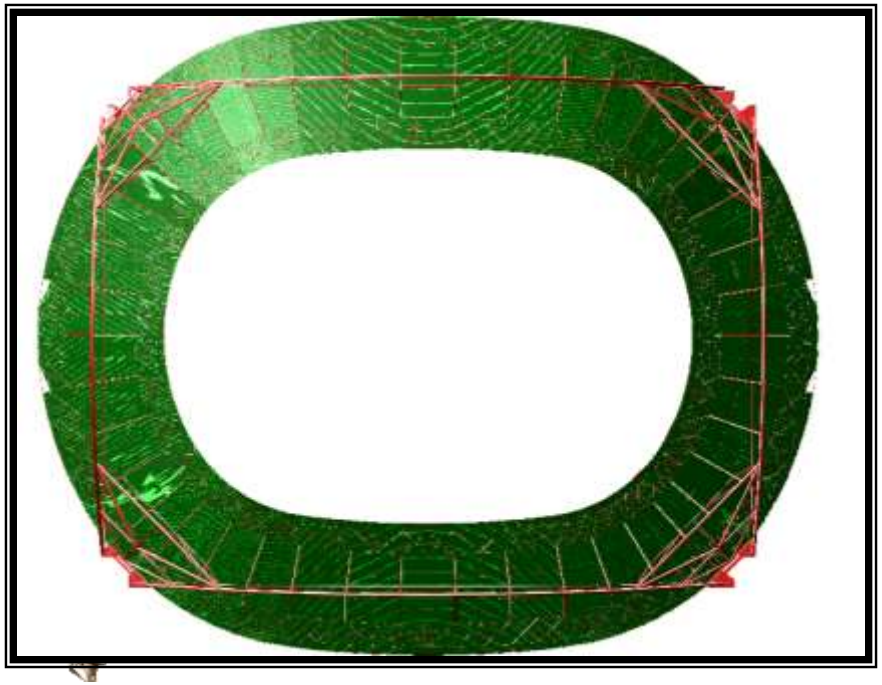
ESTÁDIO OLÍMPICO JOÃO HAVELANGE

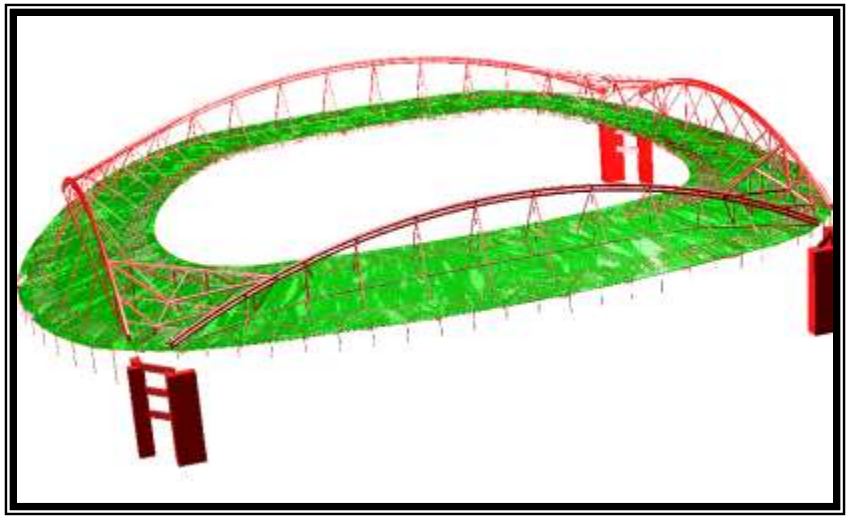
Jogos Panamericanos 2007

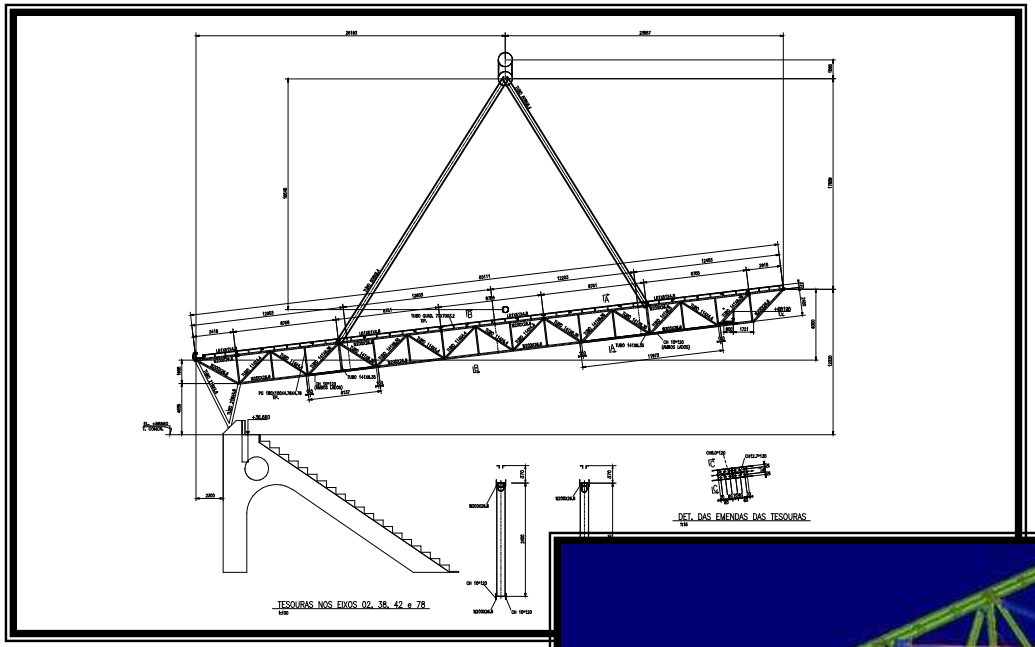
Arquitetura: CARLOS PORTO e GILSON RAMOS DOS SANTOS
***PROJETO ESTRUTURAL DA COBERTURA:* FLAVIO D ALAMBERT**

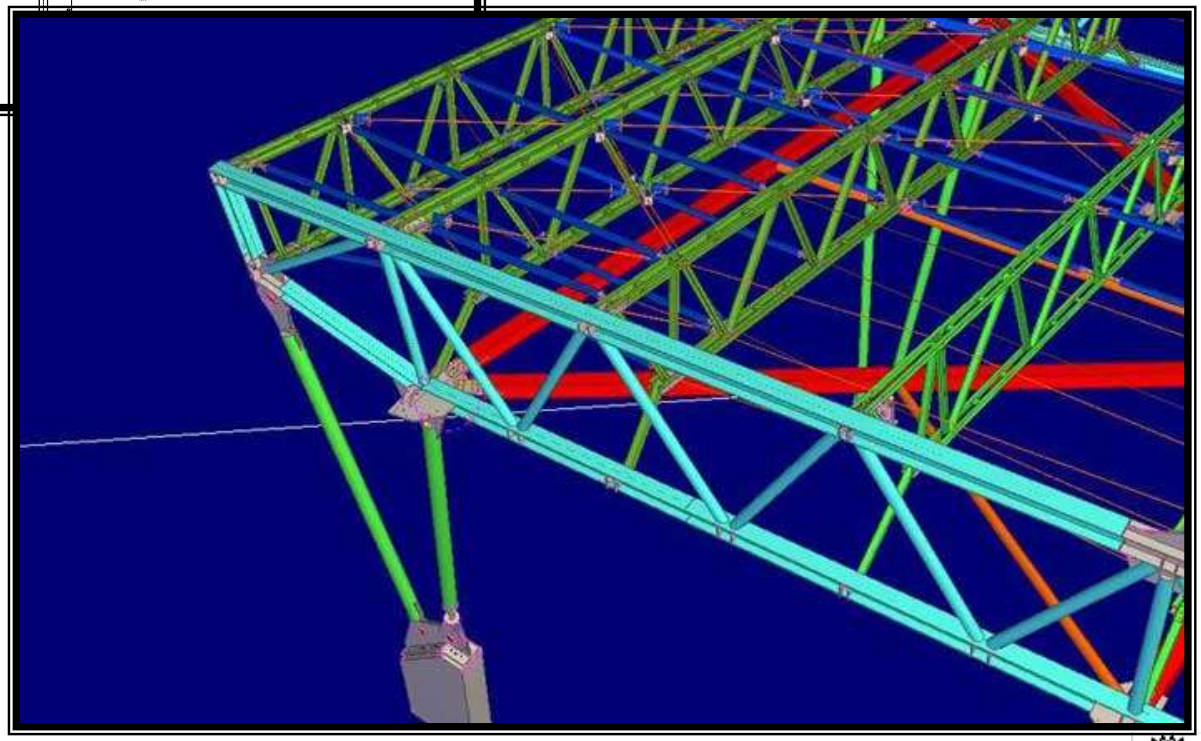


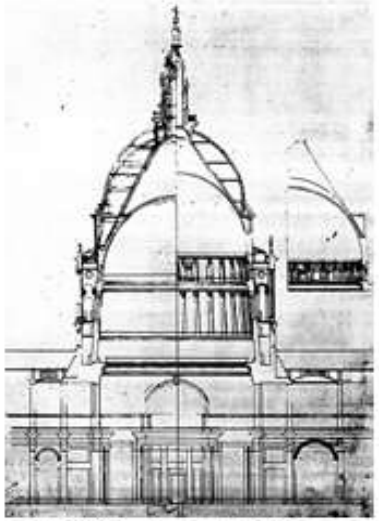




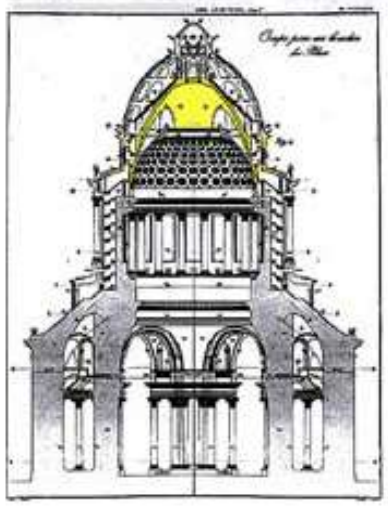



TESOURAS NOS EIXOS 02, 38, 42 e 78
DET. DAS EMENDAS DAS TESOURAS





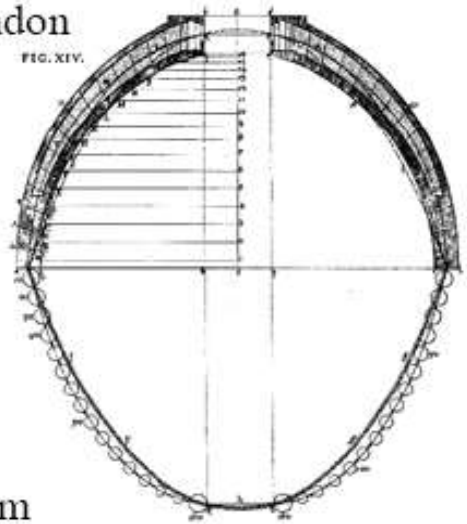
C. Wren ~1700
St. Paul, London



Rondelet 1790
Pantheon, Paris

Frei Otto 1958
St. Louis

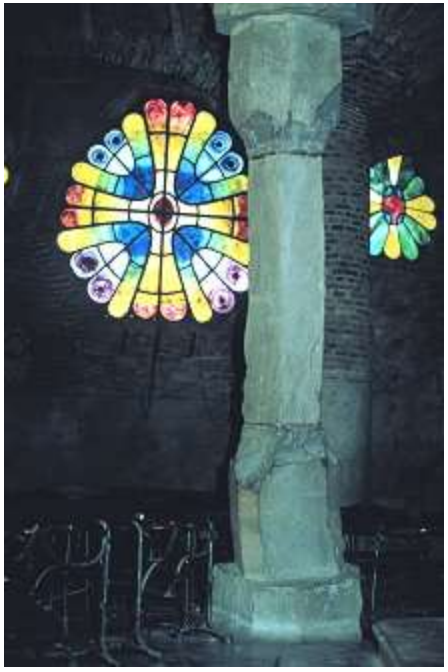
Gaudi 1899
Colonia Güell

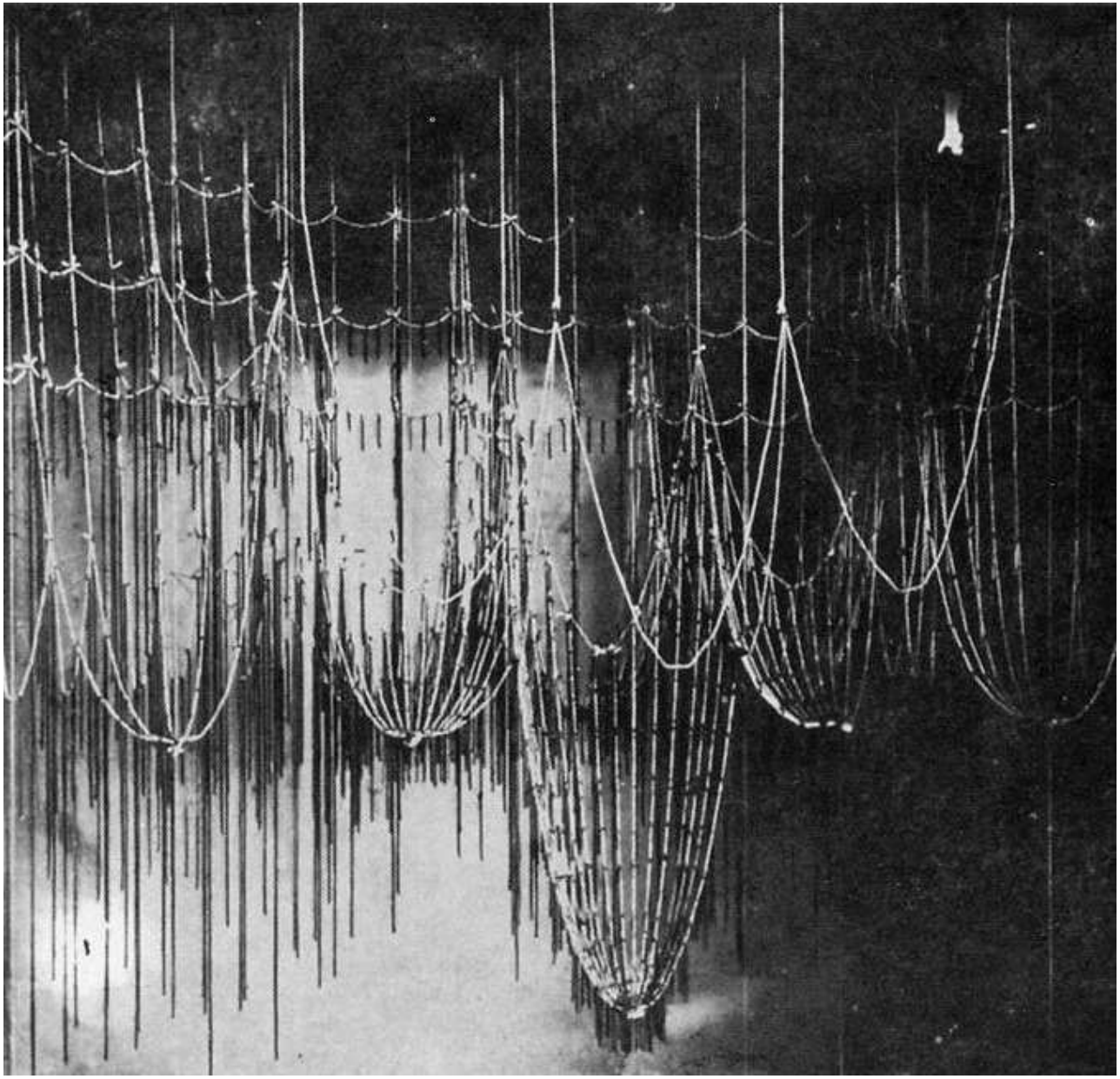


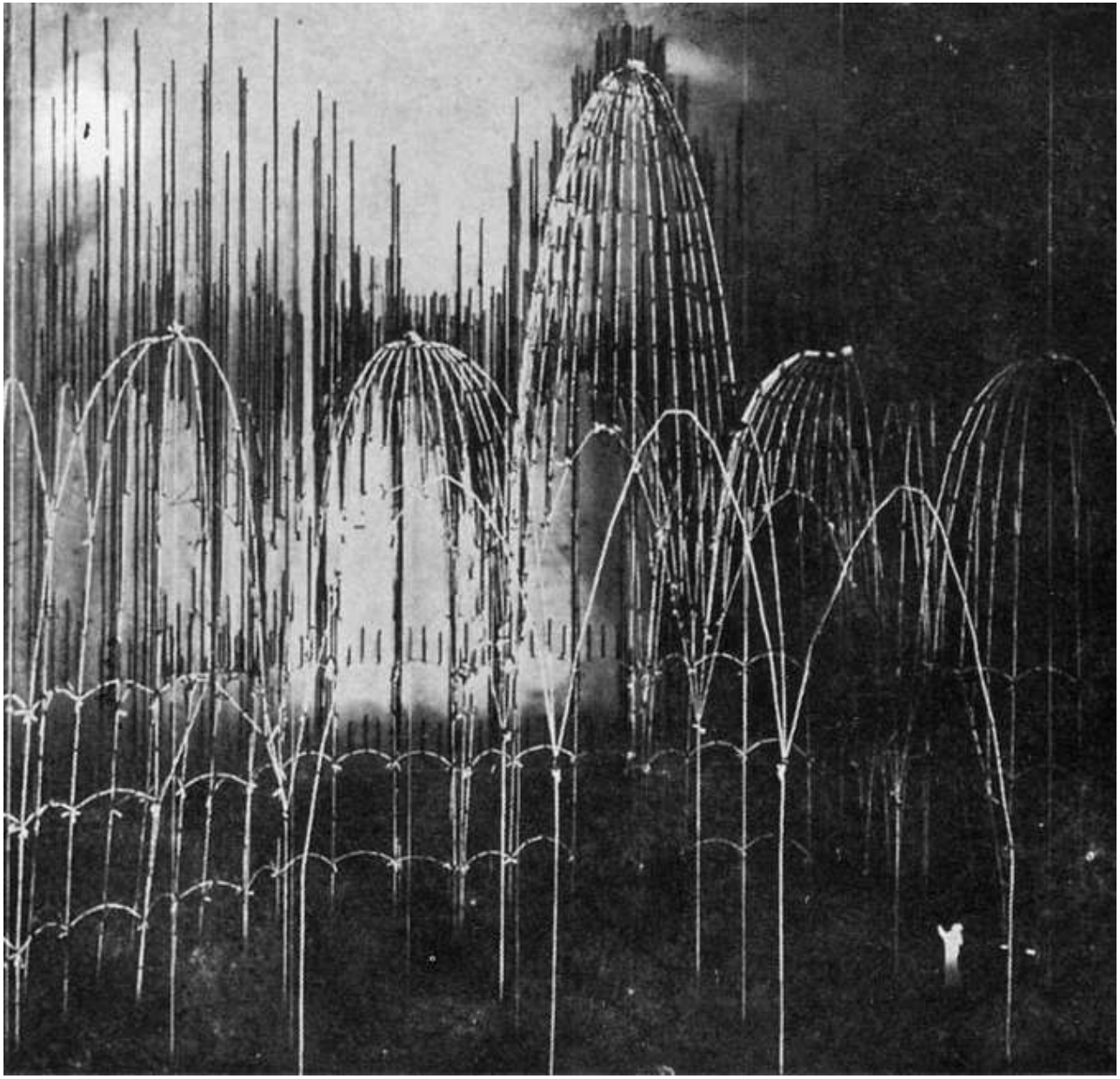
Poleni 1748
St. Peter, Rom

Isler ~1970,
Switzerland

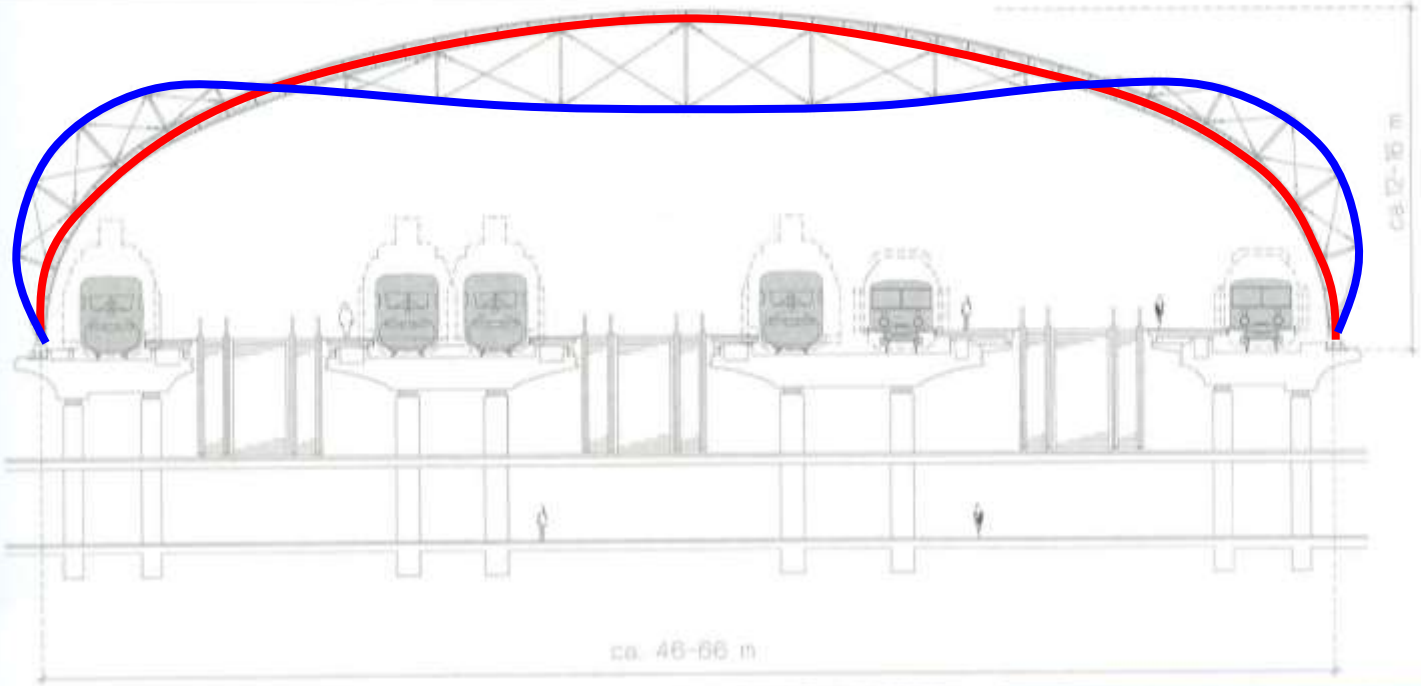
Figure 15. Application of hanging model principle (hanging models shown upside down)

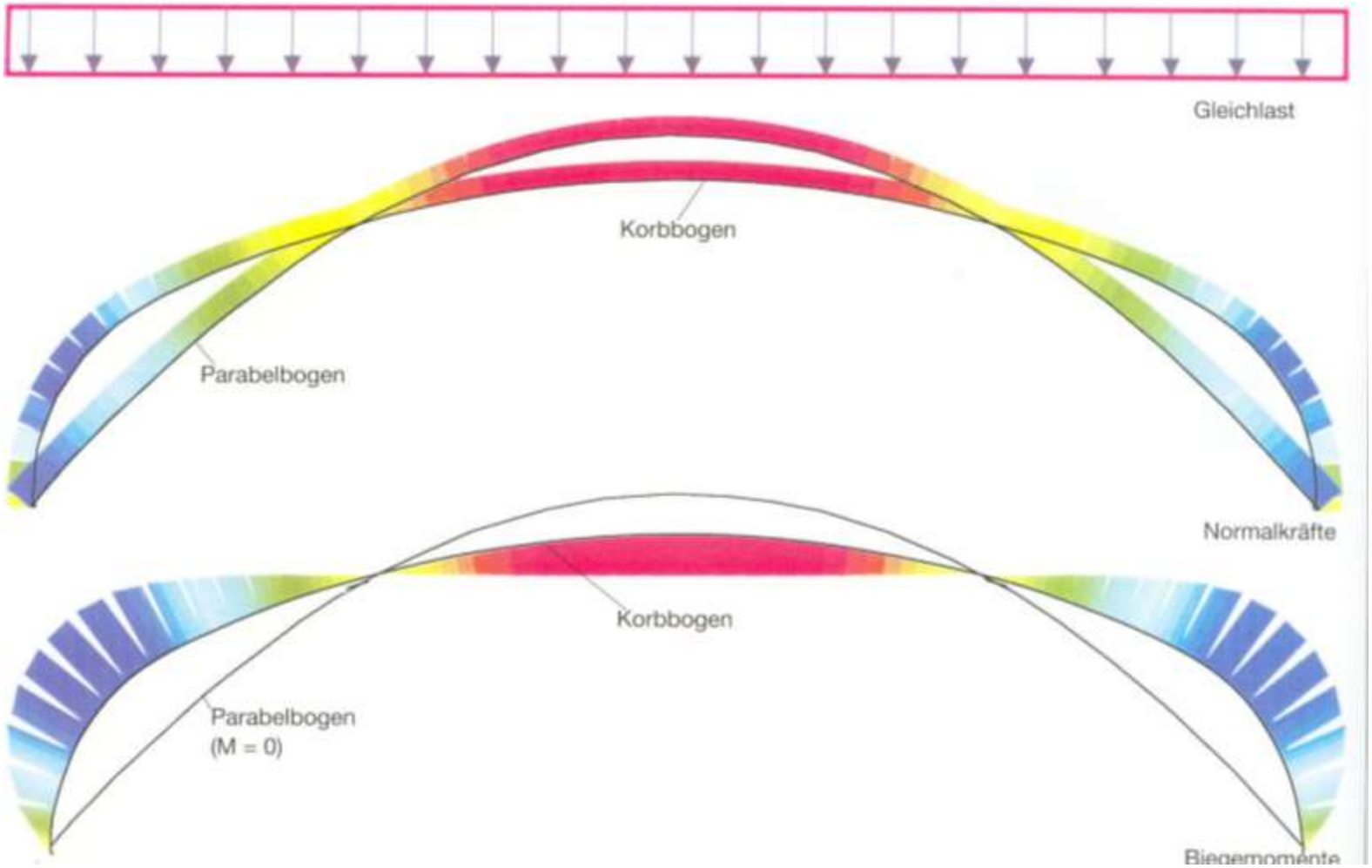




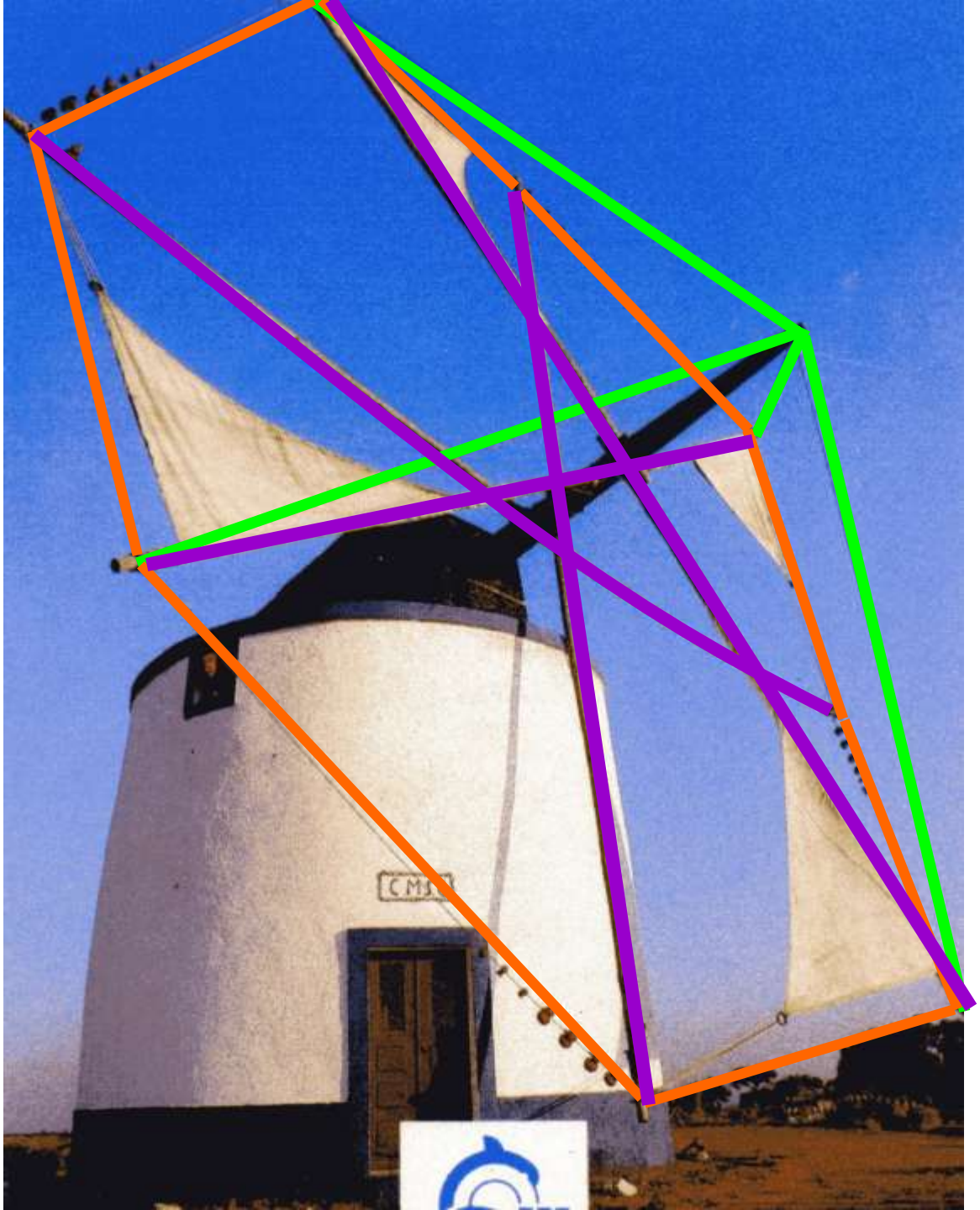


Estação de Trens Lehrter, Berlim

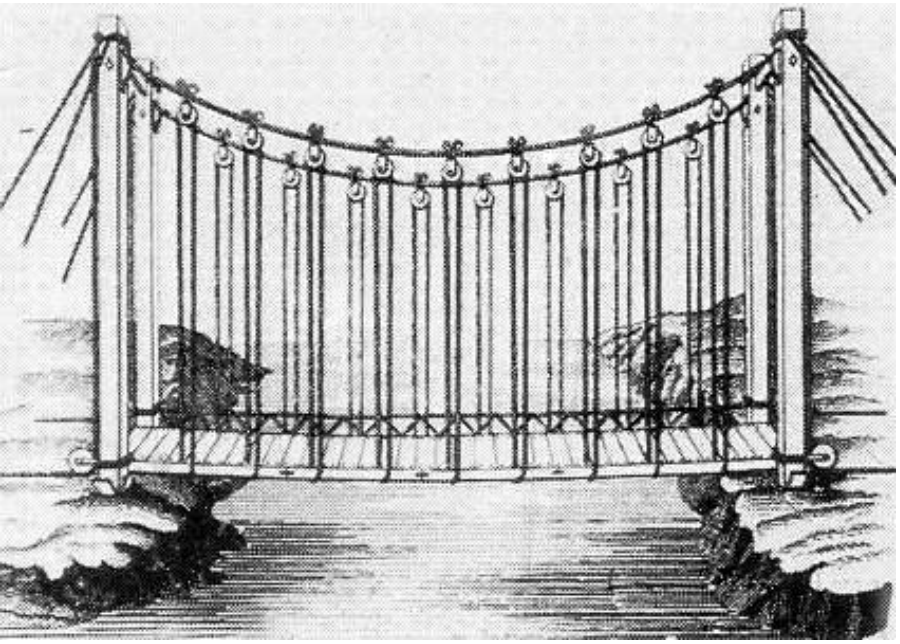

ca. 12-16 m
ca. 46-66 m

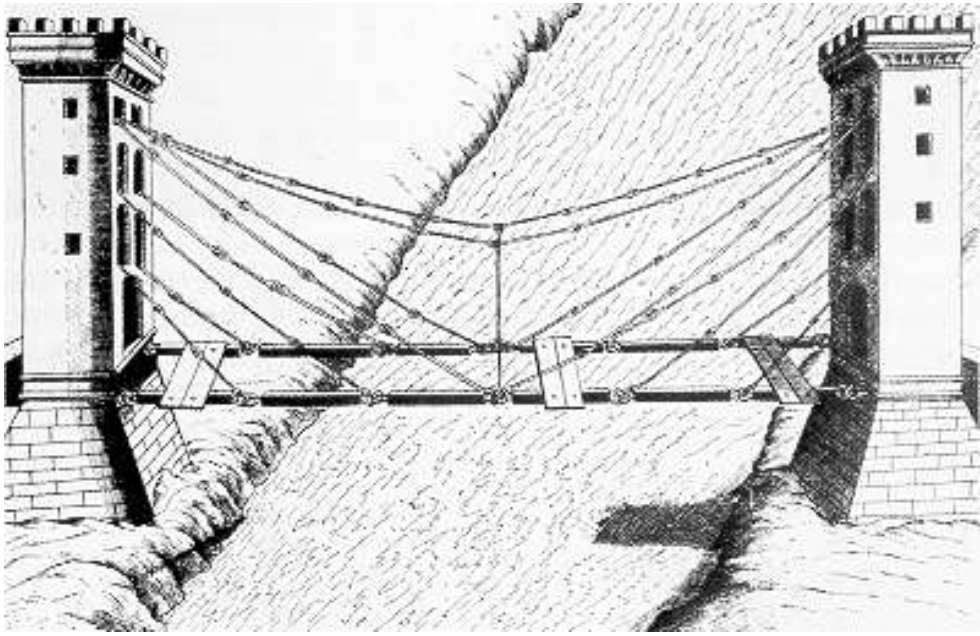

Gleichlast
Korbbogen
Parabelbogen
Normalkräfte
Korbbogen
Parabelbogen
(M = 0)
Biegemomente


CMSC

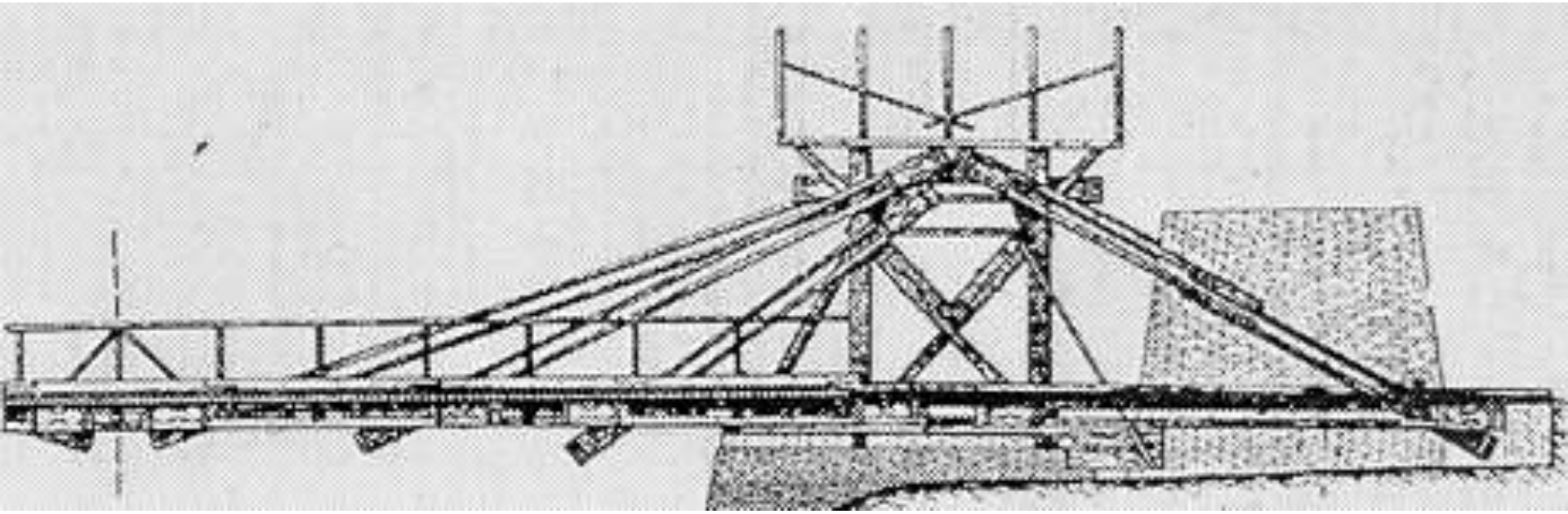


Esquemas de Fausto Verranzio para pontes suspensas e estaiadas (1617)





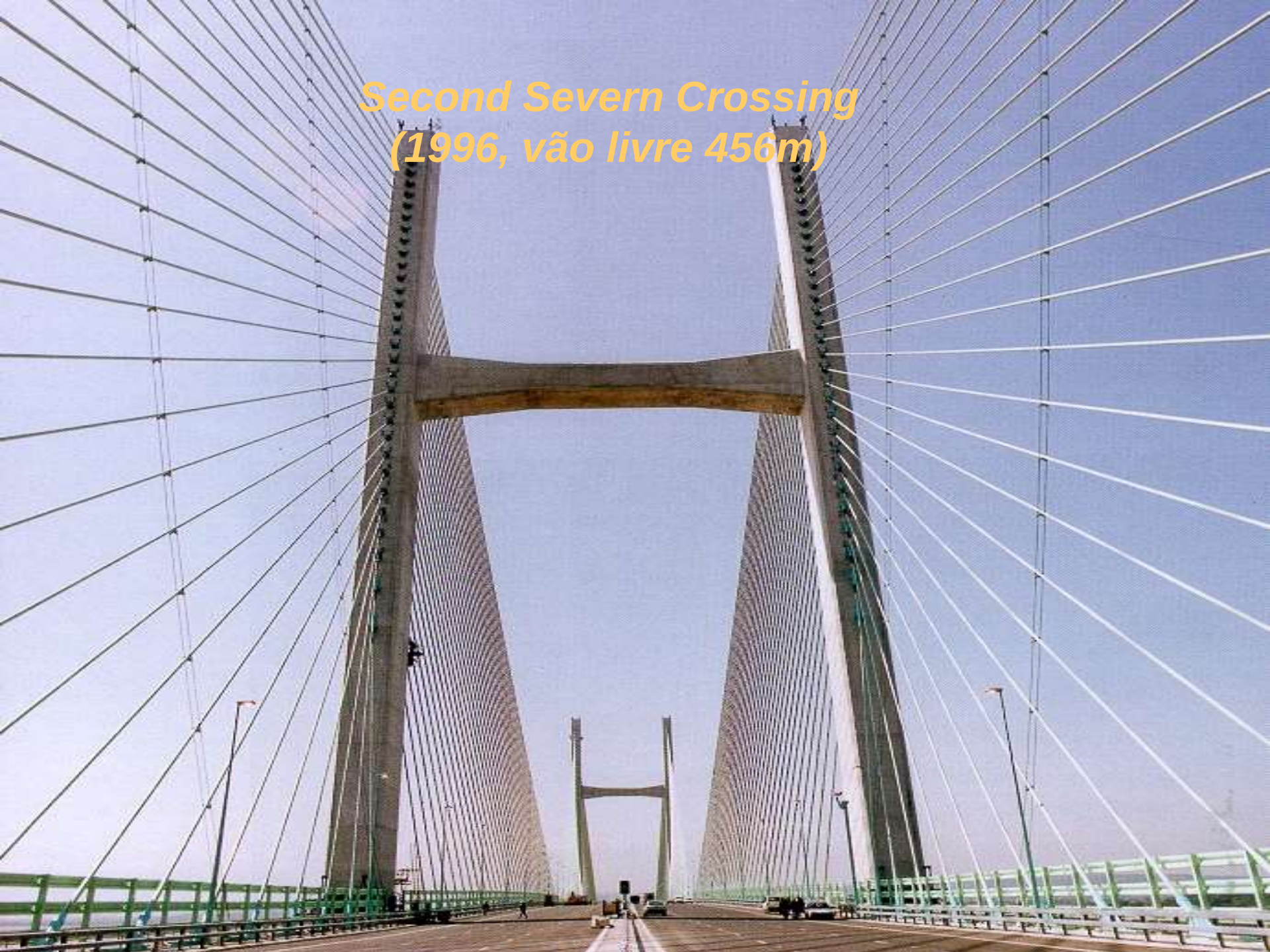
Esquema de Immanuel Loscher, para uma ponte estaiada de madeira (1784)



Albert Bridge, sobre o Tâmisa
(1873, vão livre 122m)

Ponte do Brooklyn
(Nova Iorque, 1883, vão livre 486m)

Second Severn Crossing
(1996, vão livre 456m)


Second Severn Crossing
(1996, vão livre 456m)


Ponte da Normandia
(1995, vão livre 856m)


Puente del Alamillo, Sevilha
(Santiago Calatrava, 1992)

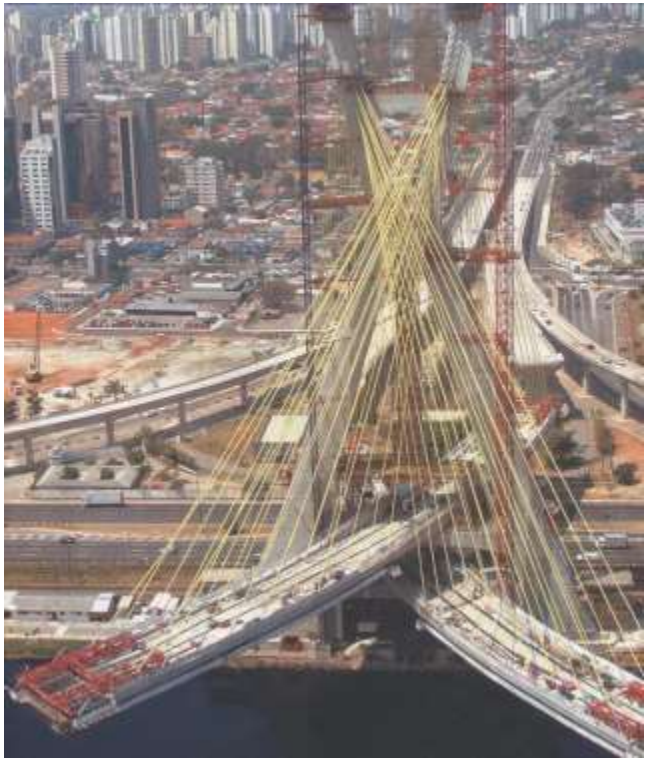

Erasmus Bridge, Rotterdam
(Ben van Berkel, 1996)


Russky Bridge (Vladivostok, 2012)
(vão principal 1104m)


Sutong Bridge (China, 2008)
(vão principal 1088m)

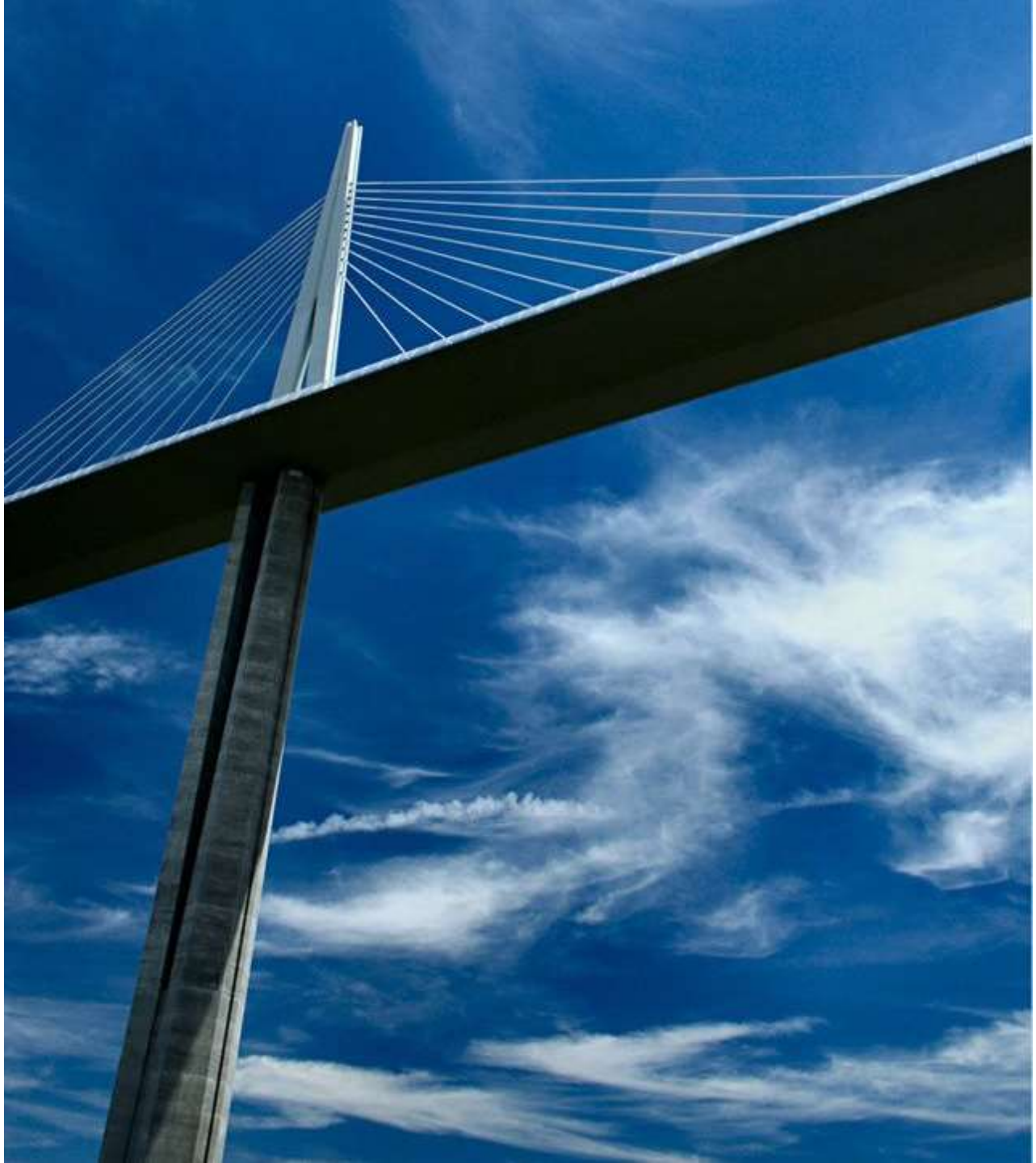

Stonecutters Bridge (China, 2009)
(vão principal 1018m)

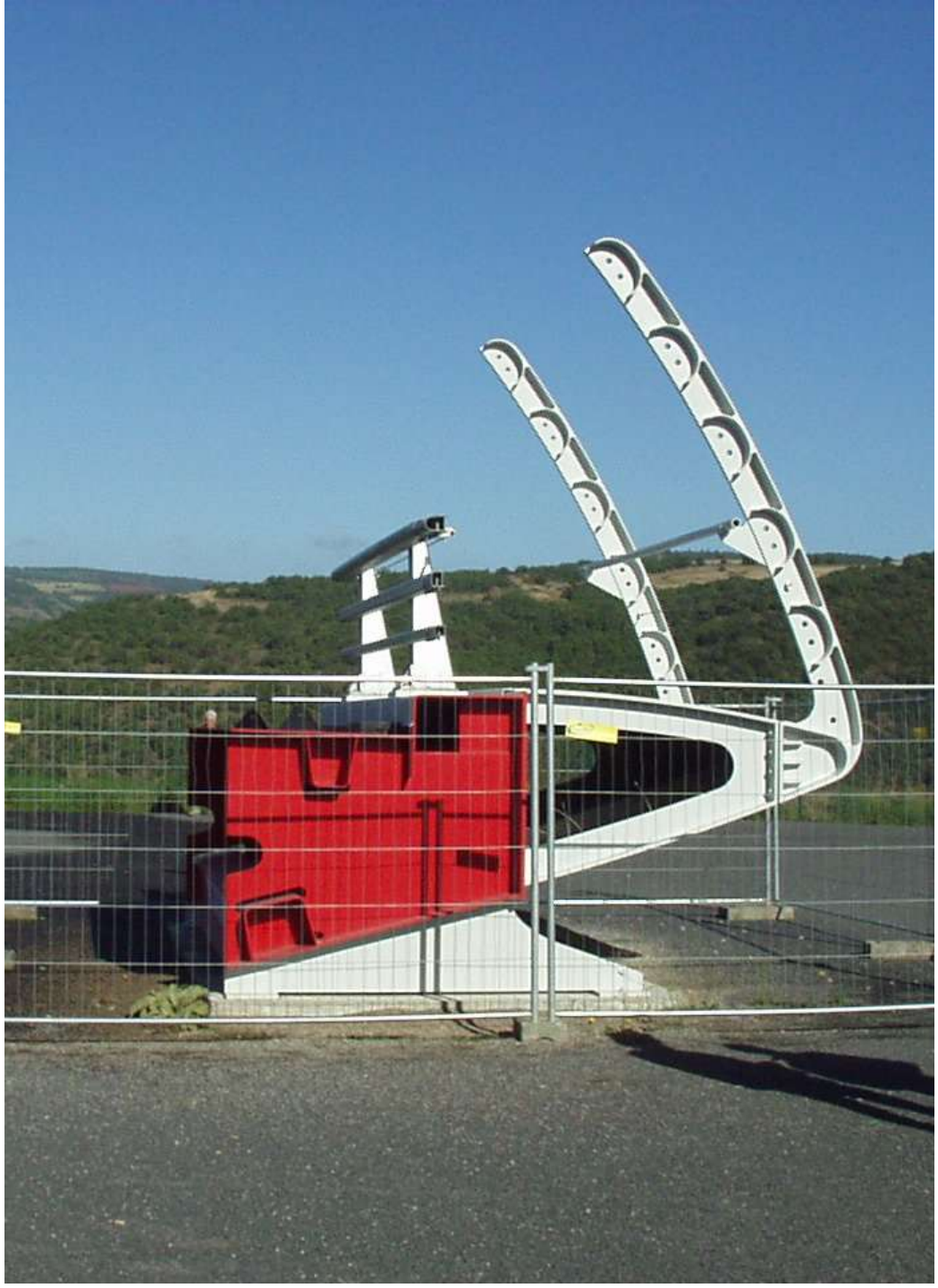

Ponte sobre o Rio Pinheiros (1999)
(Extensão 233m, vão central de 122m)



Viaduto de Millau

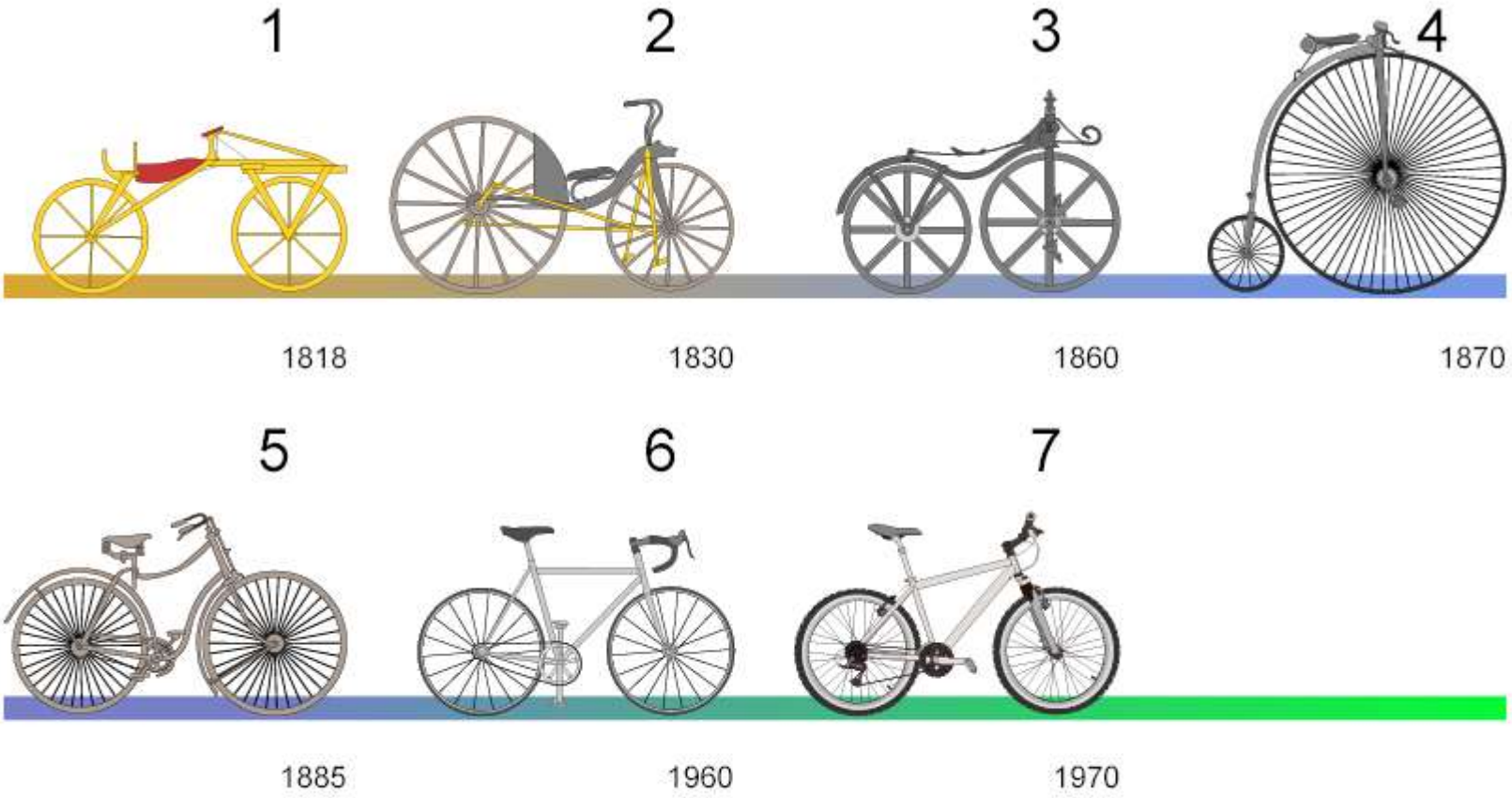
(Norman Foster , Michel Virlogeux, 2004)



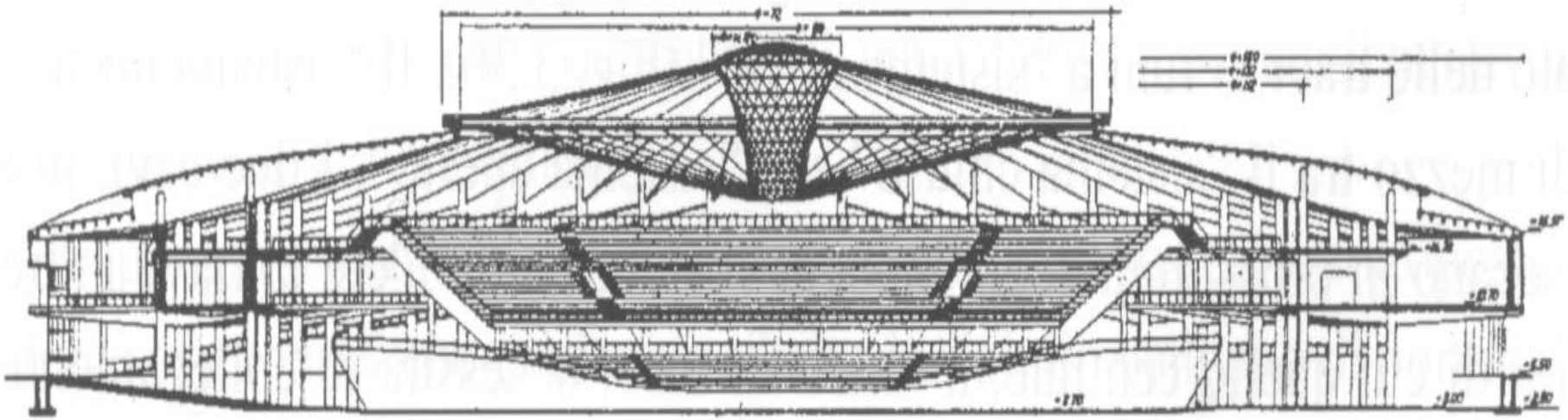


Roda raiada, ~2000 AC
Museu Nacional do Irã

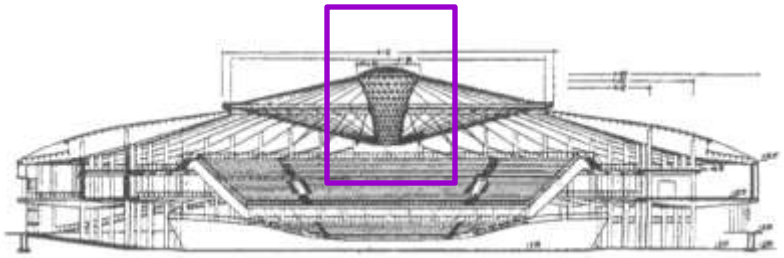
Bicycle Wheel, Marcel Duchamp, 1913

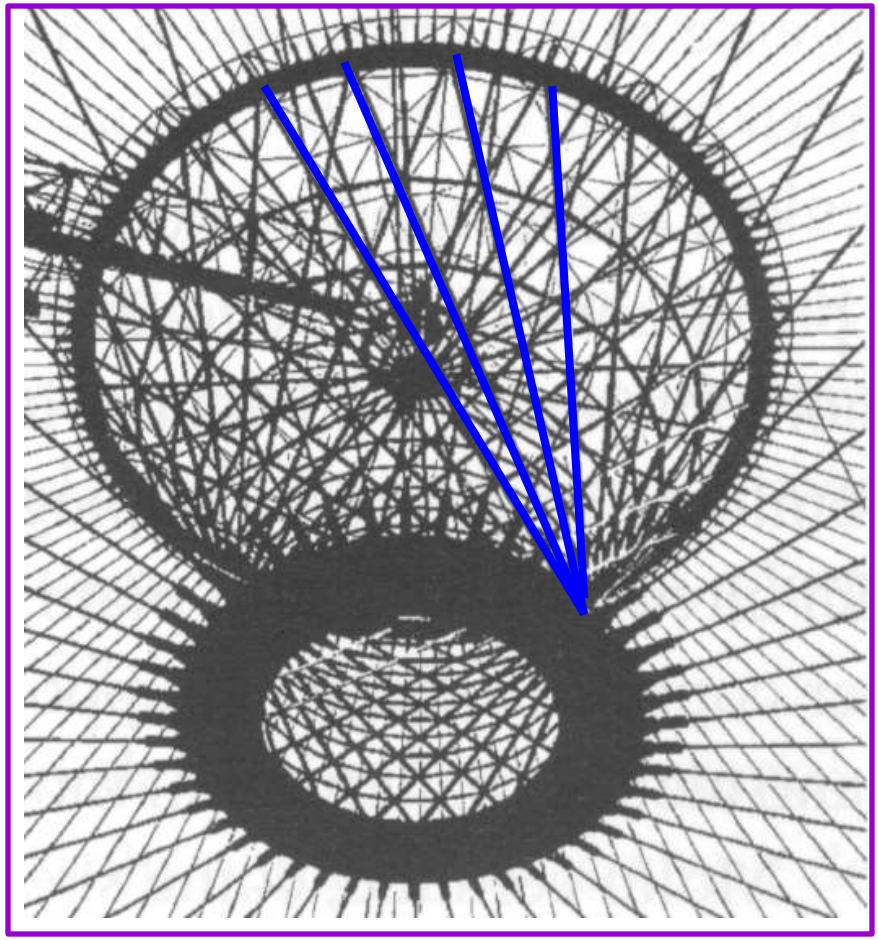

1
2
3
4
1818
1830
1860
1870
5
6
7
1885
1960
1970

Palácio dos Esportes de Gênova, Itália (1963). Detalhe da parte central da cobertura e Elevação.

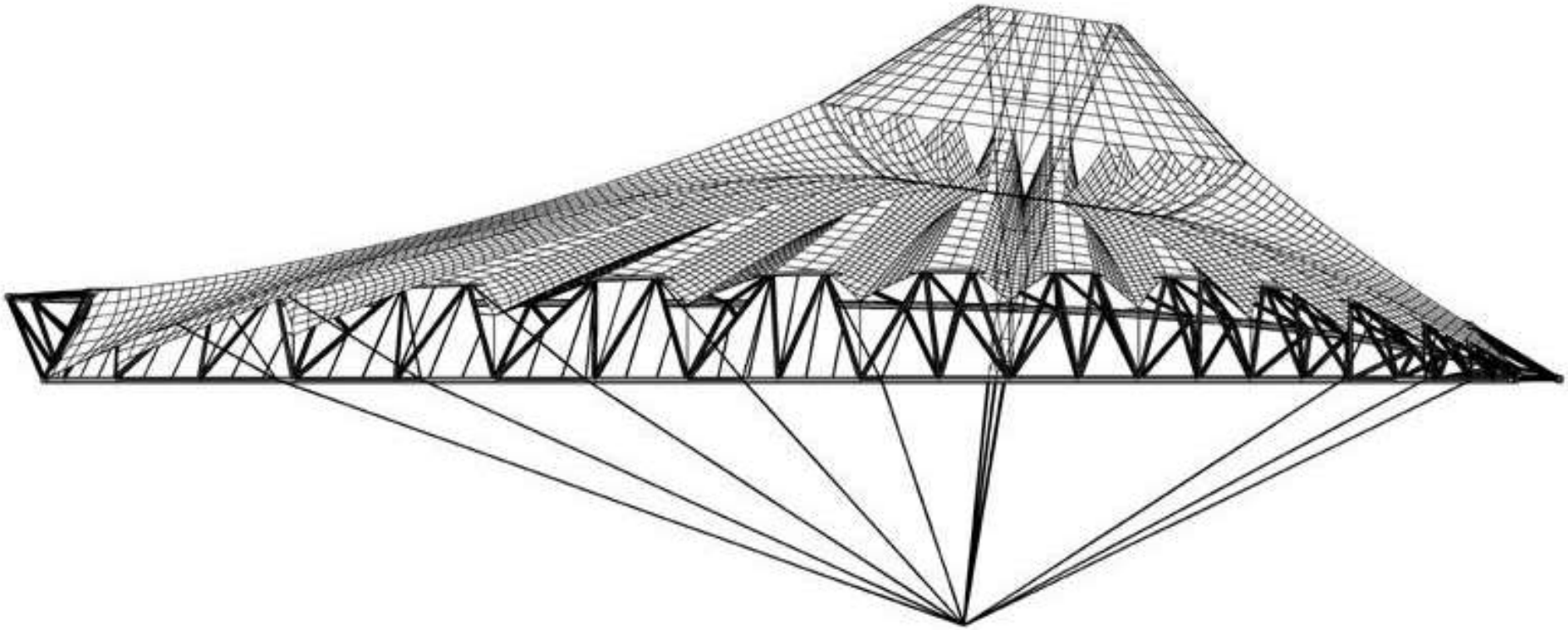


Palácio dos Esportes de Gênova, Itália (1963). Detalhe da parte central da cobertura e Elevação.



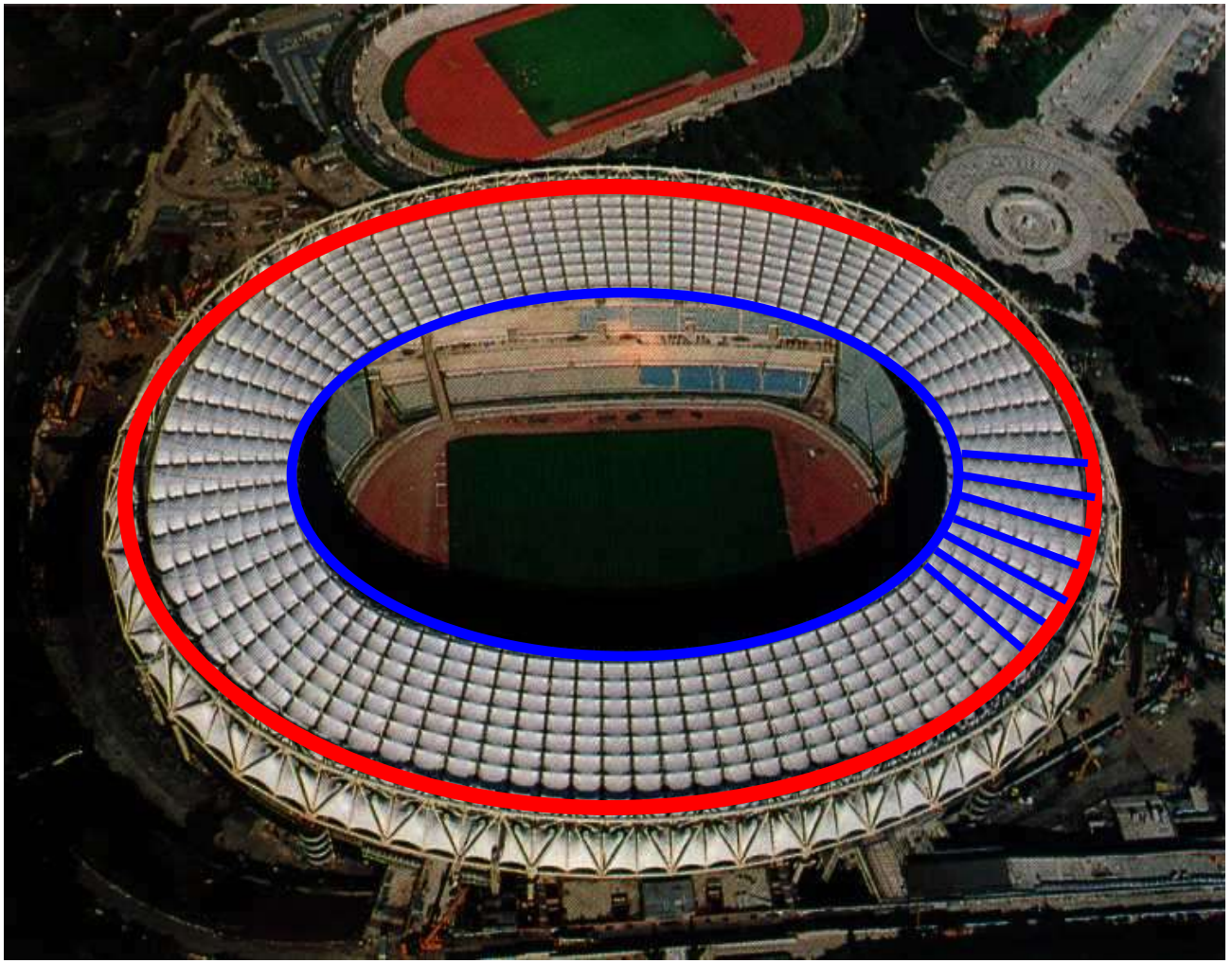


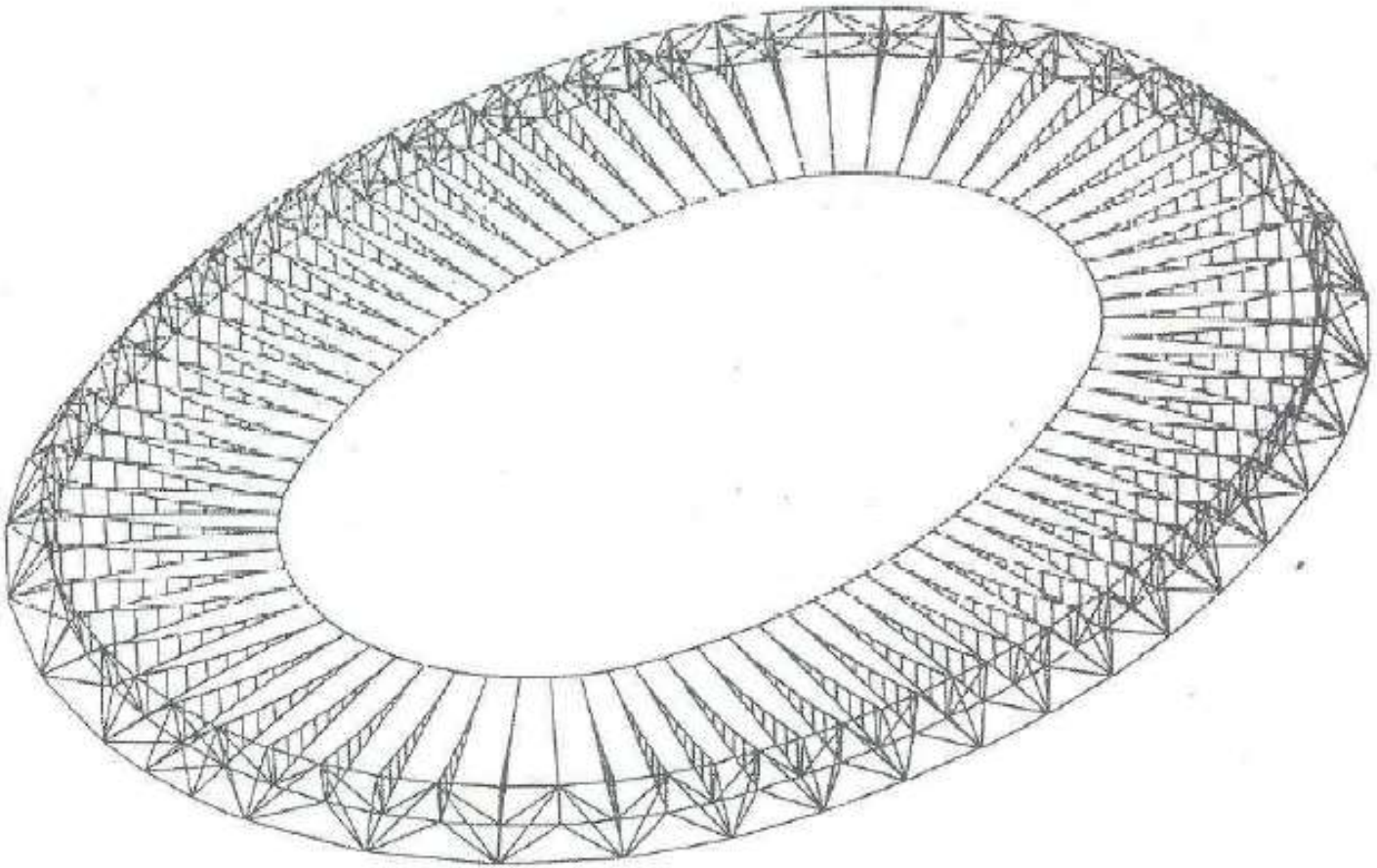
Sony Center
Potsdamer Platz - Berlim



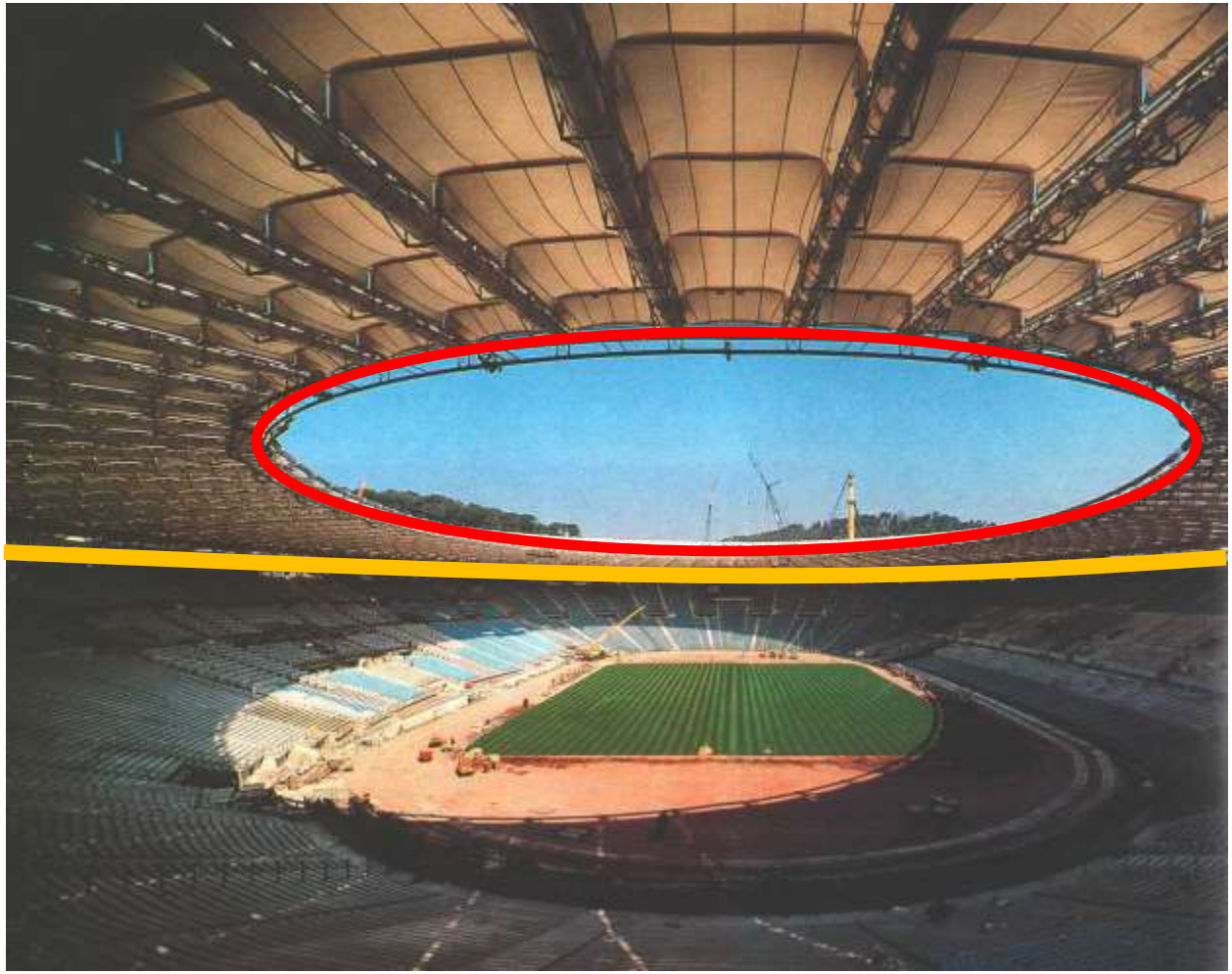
- Mastro cônico, inclinado de 8 graus; abertura superior com 10 m de diâmetro;
- a viga de borda é uma treliça formada por três tubos com altura variando entre 4,5 a 7,0 m

Estádio Olímpico de Roma (coberto em 1990) Vistas aérea.

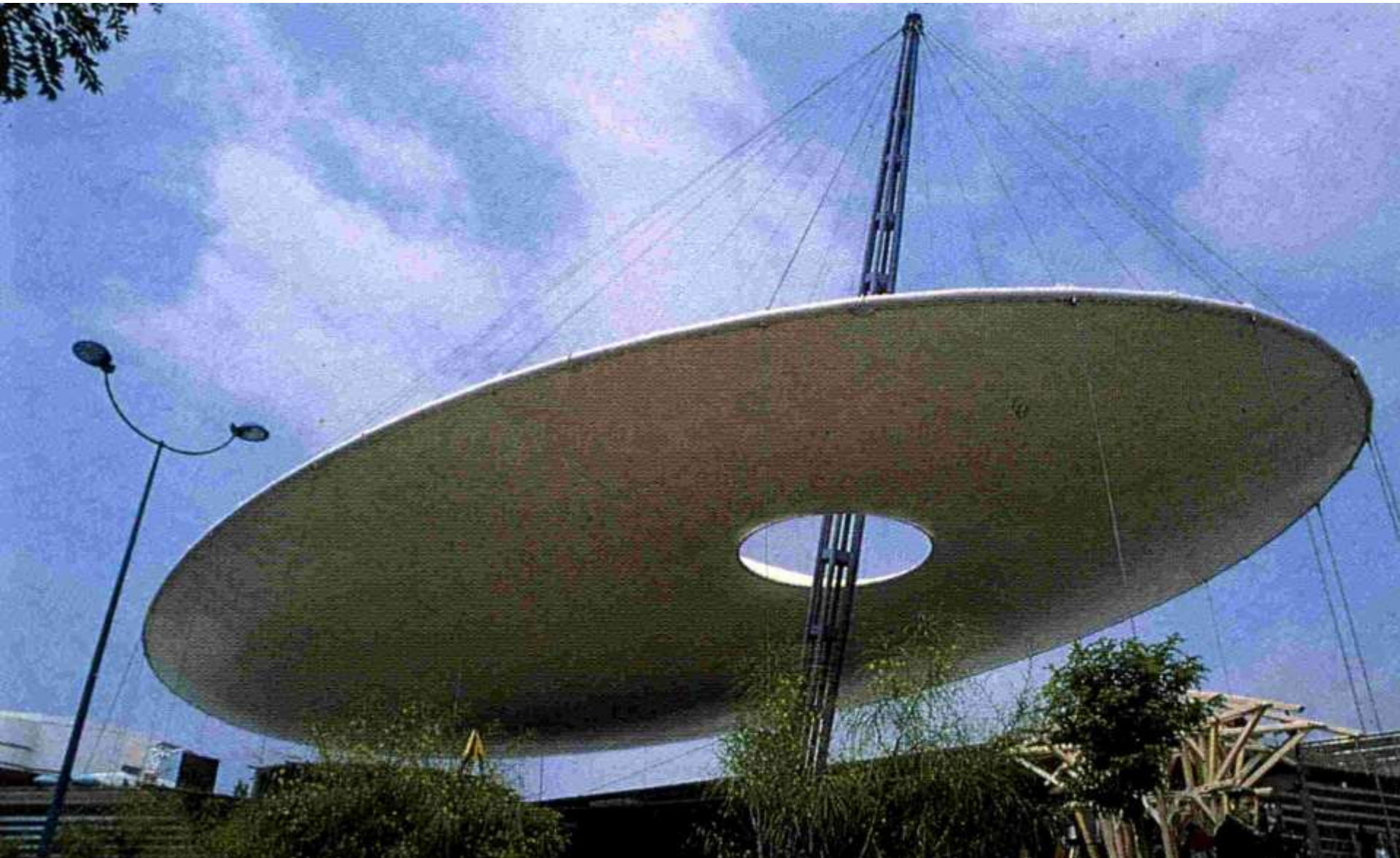




Estádio Olímpico de Roma (coberto em 1990) Vista interna.



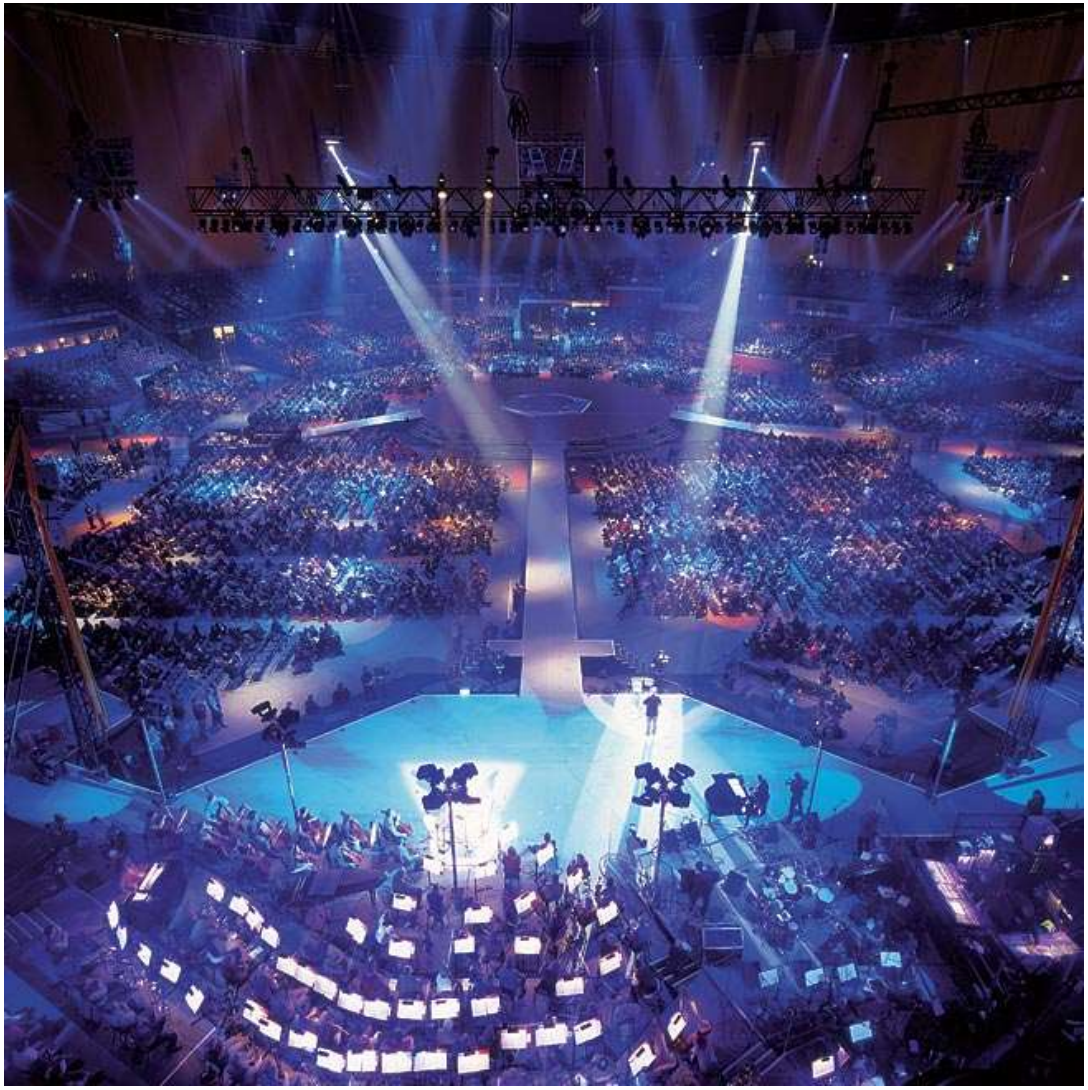
Lente pneumática de cobertura
Do Pavilhão Alemão na EXPO92



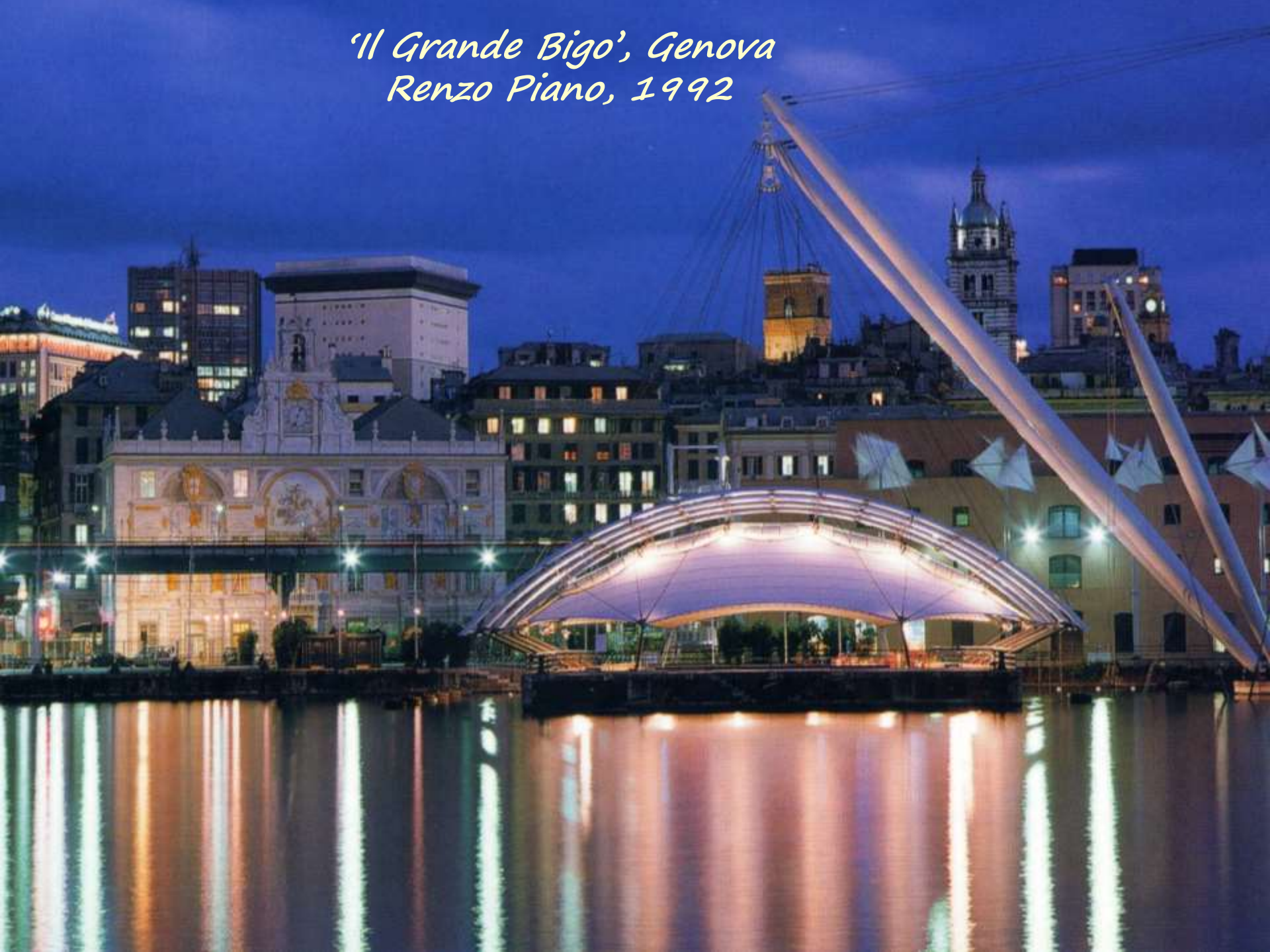
Domo do Milênio
– Londres, 2000

Domo do Milênio: sistema de cabos.


WARNING



'Il Grande Bigo', Genova
Renzo Piano, 1992


'Il Grande Bigo', Genova
Renzo Piano, 1992

Stade de France, Paris, 1998

Michel Macary, Aymeric Zublena, Michel Regembal, Claude Constantini

Stade de France, Paris, 1998

Michel Macary, Aymeric Zublena, Michel Regembal, Claude Constantini

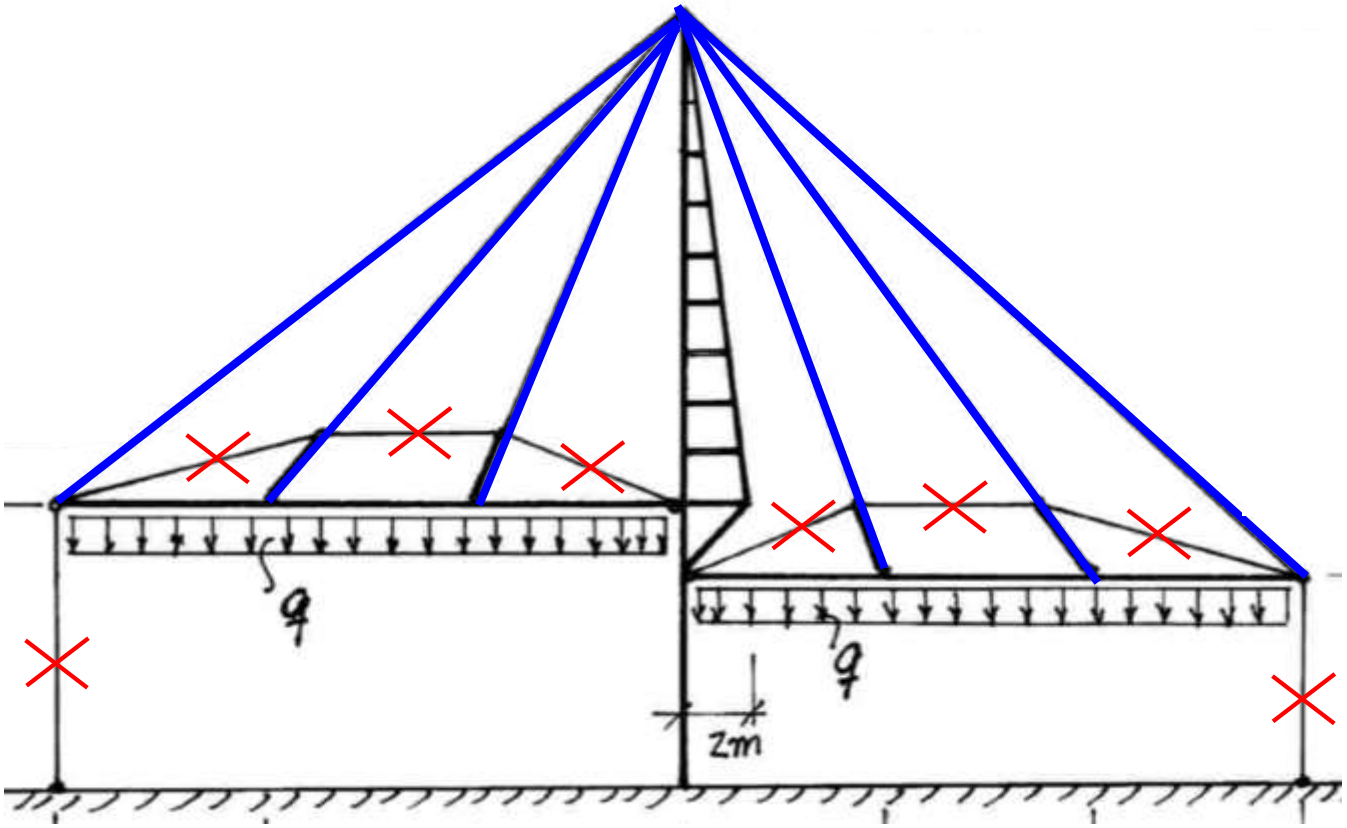
Stade de France, Paris, 1998

Michel Macary, Aymeric Zublena, Michel Regembal, Claude Constantini

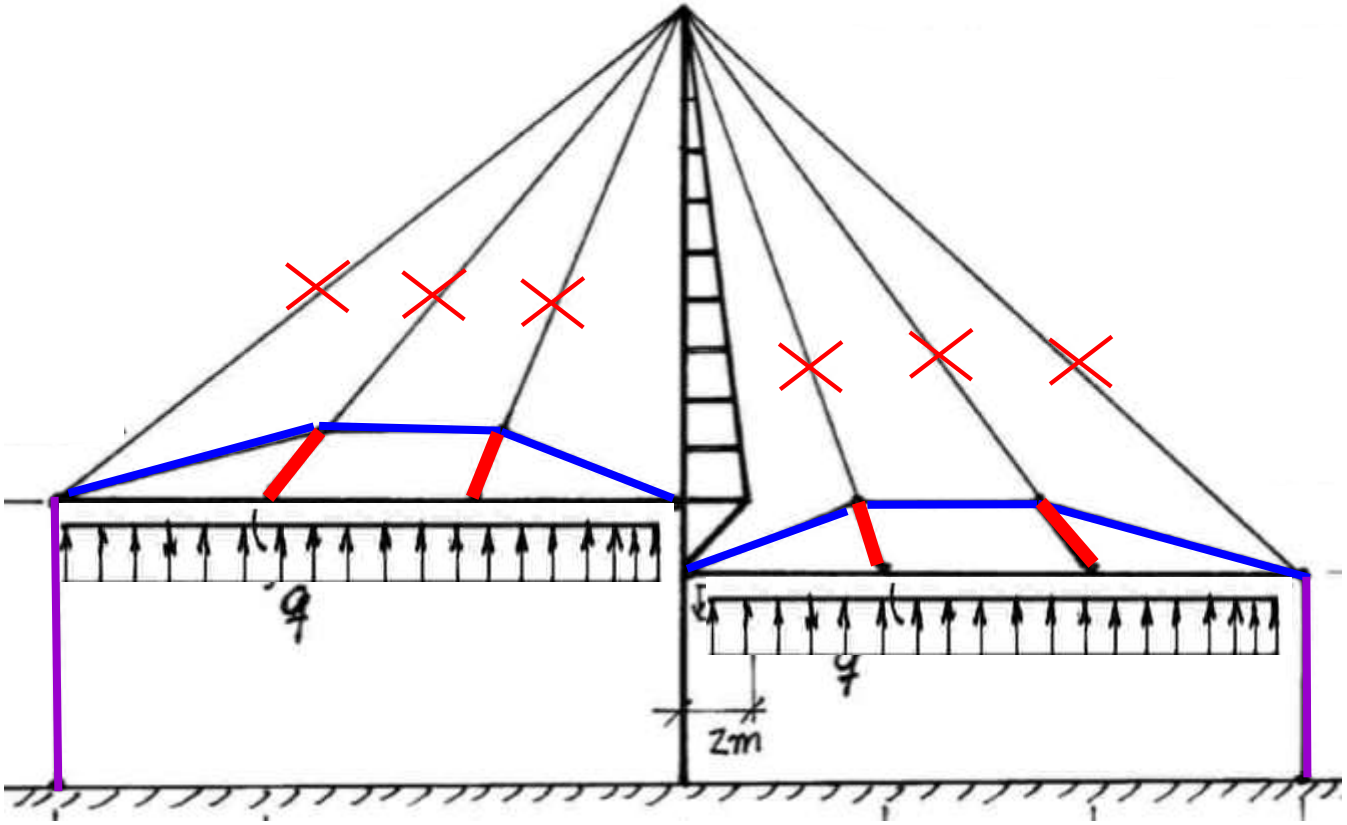
Estação de Saint Denis, Paris

Estação de Saint Denis, Paris

Estação de Saint Denis
Funcionamento para cargas descendentes

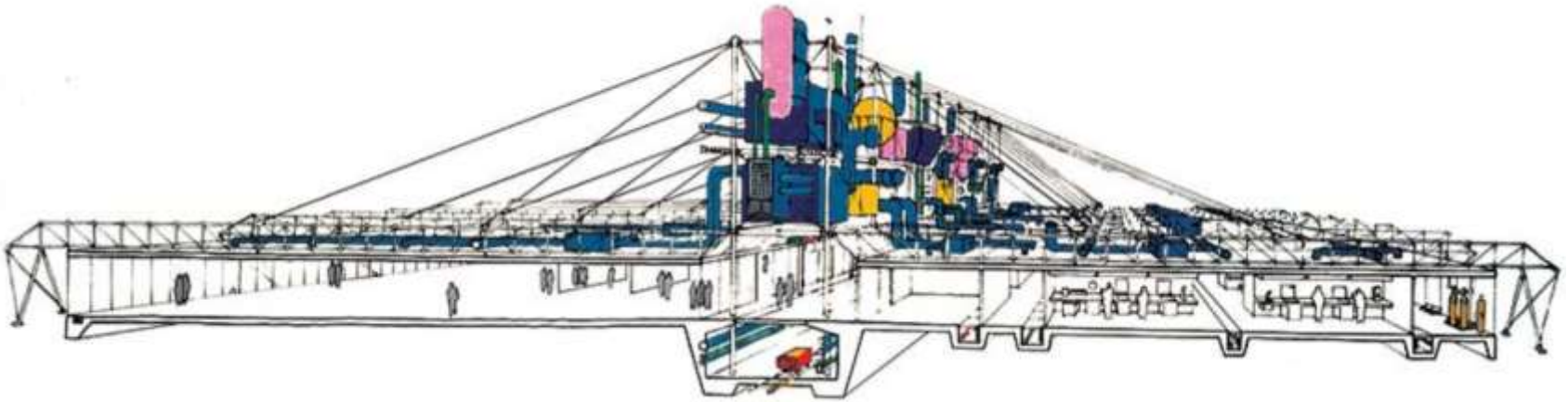


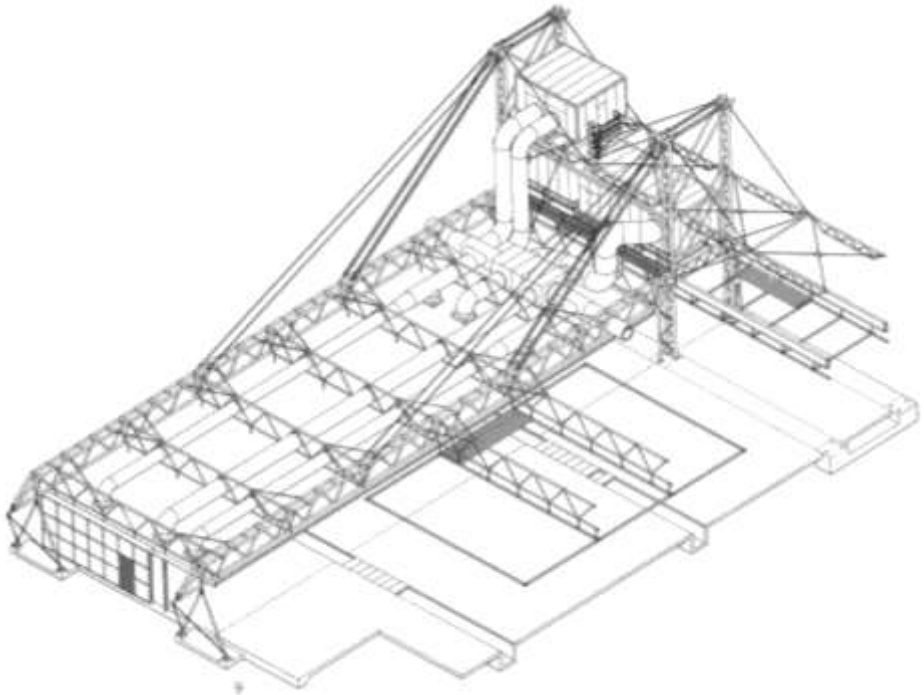
Estação de Saint Denis
Funcionamento para cargas ascendentes



Inmos Factory

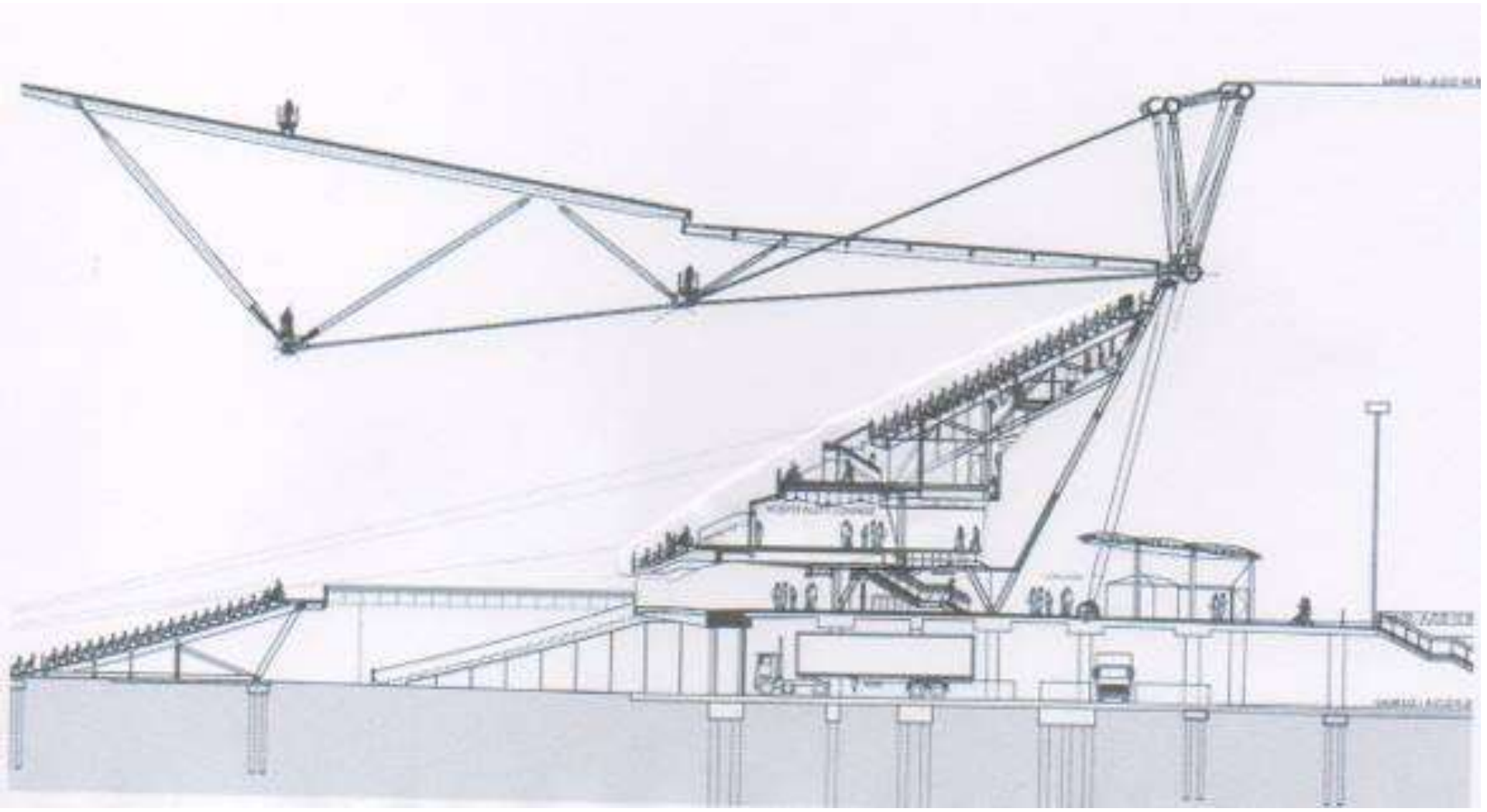
Arq. Richard Rogers, 1980/1982

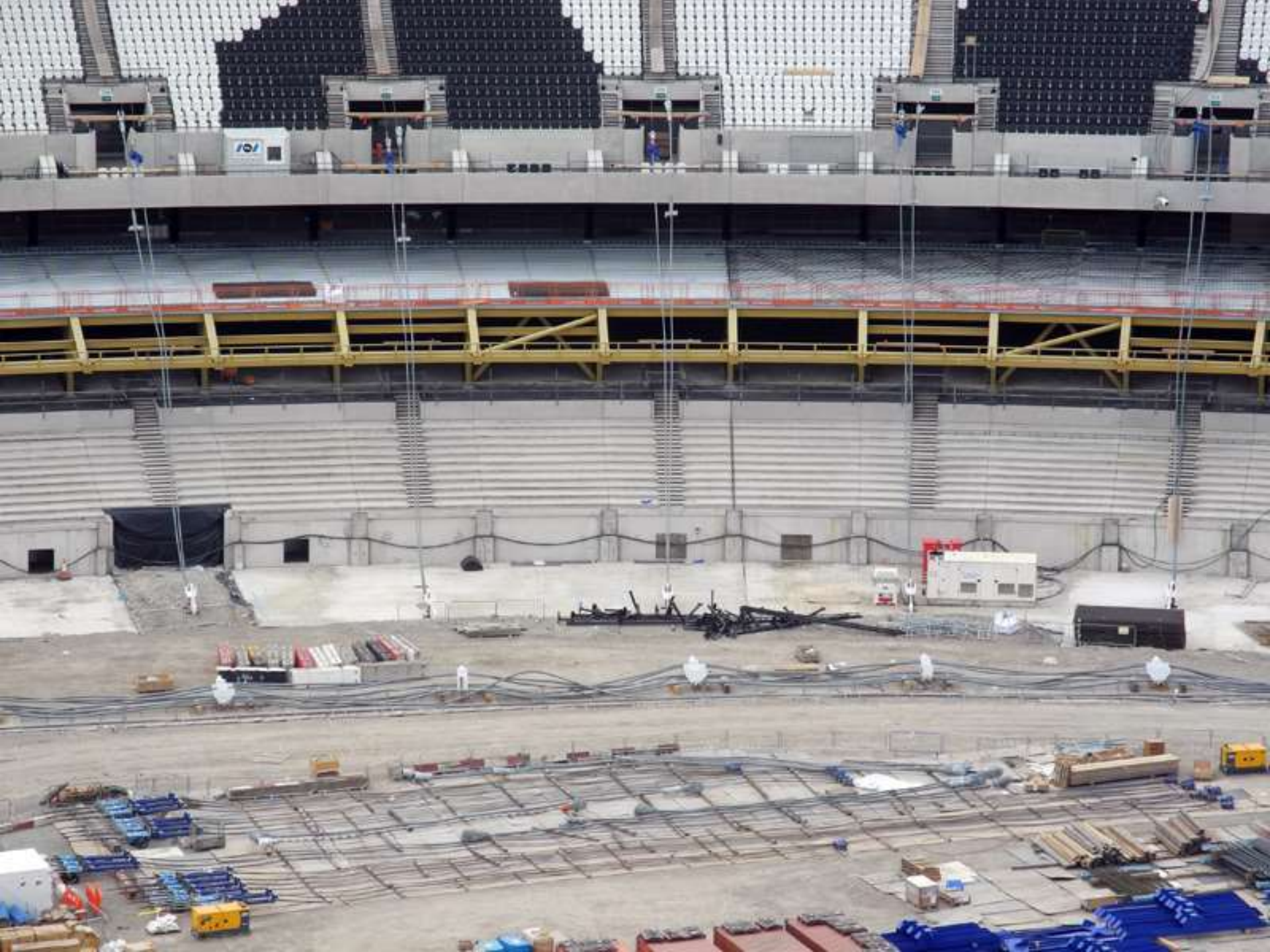




Estádio Olímpico de Londres, 2012

Figure 2. Typical stadium section showing permanent seating in lower concrete bowl, upper steel-framed temporary seating tier and external spectator facilities on podium






WELDEX