Course overview

Structural design I

1. Introduction
2. Equilibrium and graphic static
3. + 4. Cables
5. Cable-net and membrane structures
6. Materials and dimensioning
7. Arches
8. + 9. Vaults, domes and shells
10. Arch-cable-structures
11. Spatial arch-cable-structures

Structural design II

12. + 13. Trusses
14. Spatial trusses
15. + 16. Beams and frames
17. Spatial beams
18. Bending
19. Columns
Cable-net and membrane structures

- Static behavior of cable-net and membrane structures
- Frei Otto’s physical form-finding experiments
- Types of tensioned roof systems
- Construction detailing
- Retractable membrane structures
- Pneumatic membrane structures
- Membrane materials
Tensile tree tent
Static behavior of cable-net and membrane structures
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prestressed state
Static behavior of cable-net and membrane structures
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Anatole Kopp, R. Sager: Stade de Saint-Ouen, Nanterre, 1971
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Cable-net and membrane structures

Static behavior of cable-net and membrane structures

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Frei Otto’s physical form-finding experiments

Frei Otto, Pritzker Prize Winner 2015
Frei Otto’s physical form-finding experiments
Frei Otto’s physical form-finding experiments

Frei Otto: Study „Membraneforms“, Germany, 1986
Frei Otto’s physical form-finding experiments

Frei Otto: Study „Membraneforms“, Germany, 1986
Frei Otto’s physical form-finding experiments
Frei Otto’s physical form-finding experiments
Frei Otto’s physical form-finding experiments

Frei Otto: Soap film machine
Frei Otto’s physical form-finding experiments

Frei Otto: Model, soap film
Frei Otto’s physical form-finding experiments

Frei Otto: Humped tent, Aberdeen and Hyde Park, 1975
Cable-net and membrane structures

Static behavior of cable-net and membrane structures
Frei Otto’s physical form-finding experiments
• Types of tensioned roof systems
  Construction detailing
  Retractable membrane structures
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Types of tensioned roof systems
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Foster + Partners, Arup: Bishop Square, London, 2005
Types of tensioned roof systems

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Types of tensioned roof systems
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Günter Behnisch, Frei Otto: Olympic stadium, Munich, 1972
Types of tensioned roof systems

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Types of tensioned roof systems
Ackermann and Partner, Schlaich Bergermann and Partner: Ice rink, Munich, 1983
Types of tensioned roof systems

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Types of tensioned roof systems
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Circus tent, Taupo
Frei Otto: Model for Institute for Lightweight Structures, Stuttgart, 1966
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Types of tensioned roof systems

Frei Otto: Montreal Pavilion, Montreal, 1967
Types of tensioned roof systems

SOM: Hajj-Terminal, Jeddah, 1981
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Cable-net and membrane structures

Static behavior of cable-net and membrane structures
Frei Otto’s physical form-finding experiments
Types of tensioned roof systems
- Construction detailing
  Retractable membrane structures
  Pneumatic membrane structures
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Ackermann and Partner, Schlaich Bergermann and Partner: Waste management, Munich, 1999
Construction detailing
Connection of membranes

- Welded membrane
- Locking chain link carabiner
- Integral edge cables
- Concealed snaps
- Lower membrane gutter tapers and slopes to drain
Detail of membrane
Construction detailing
Construction detailing
Construction detailing
Construction detailing
Ackermann and Partner, Schlaich Bergermann and Partner: Waste management, Munich, 1999
Construction detailing

Flat panels

Assembled
Ackermann and Partner, Schlaich Bergermann and Partner: Waste management, Munich, 1999
Curtis Fentress, Horst Berger: Denver International Airport, Denver, 1995
Construction detailing

CAD model formfinder
Construction detailing

Günter Behnisch, Frei Otto: Olympia Park, Munich, 1972
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Cable-net and membrane structures

Static behavior of cable-net and membrane structures
Frei Otto’s physical form-finding experiments
Types of tensioned roof systems
Construction detailing
• Retractable membrane structures
Pneumatic membrane structures
Membrane materials
Frei Otto: Prototype Umbrella, Red Sea Coast, 1987
Frei Otto: Prototype Umbrella, Red Sea Coast, 1987
Bodo Rasch, Frei Otto: Project study, multimedia stadium for Farbwerke Hoechst, Germany, 1971
Frei Otto: Open-air theater, Bad Hersfeld, Germany, 1969
Retractable membrane structures

Frei Otto: Open-air theater, Bad Hersfeld, Germany, 1969
Retractable membrane structures

Bodo Rasch: Quba Mosque, roof over courtyard, Madhina, 1987
Retractable membrane structures

Bodo Rasch, BuroHappold: Prophet’s Holy Mosque, Medina, 1992
Retractable membrane structures

Fig. 19

Fig. 20

Fig. 21

Fig. 22

Bodo Rasch: foldable umbrella, 2003
Retractable membrane structures

University of Stuttgart, Bending active membrane roofing, marrakech itke, 2011
Cable-net and membrane structures

Static behavior of cable-net and membrane structures
Frei Otto’s physical form-finding experiments
Types of tensioned roof systems
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Retractable membrane structures
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Air hall
Pneumatic membrane structures

\[ P_1 = p \cdot b \]
\[ P_2 = p \cdot l \]
\[ P_3 = p \cdot b \]
\[ P_4 = p \cdot l \]
Earth station, Raisting, Germany, 1964
Pneumatic membrane structures
Studio Philips Barrett: BC Place Stadium, Vancouver, 1983
Fuji-Pavilion at world exposition in Osaka, 1970, Arch. Y. Murata, Ing. M. Kawaguchi
Pneumatic membrane structures

Herzog & de Meuron, ARUP: Allianz Arena, Munich, 2005
Pneumatic membrane structures

PTW, ARUP: Swimming Centre, Peking, 2008
Sir Nicholas Grimshaw, Anthony Hunt: Eden Project, Cornwall, 2001
Pneumatic membrane structures
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• Membrane materials
Membrane materials

Polyvinylchlorid / PVC
- less buckling sensitive
- hardly inflammable
- cheaper

Glas fibre / PTFE
- buckling sensitive
- non flammable
- more durable