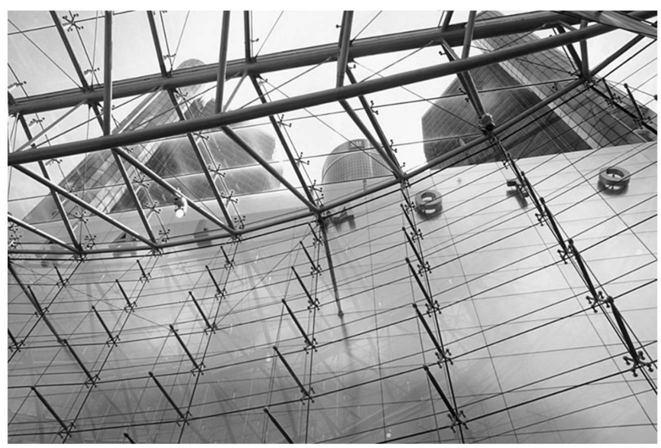
Architecture 324
Structures II

Pre- and Post-Tensioning

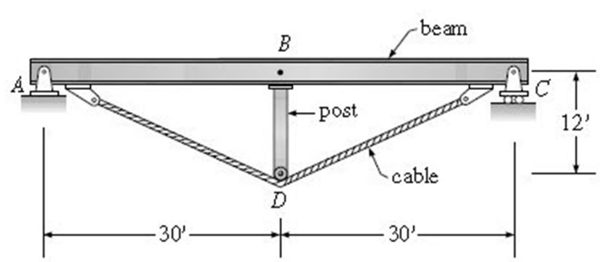
- Cable Trusses
- Concrete Beams
- Stressed Membranes

Cable Trusses



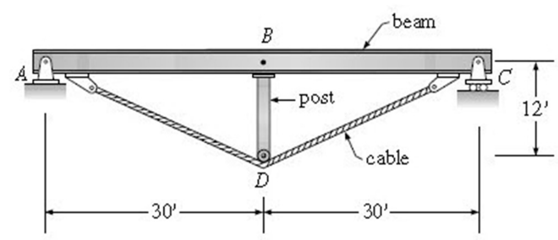
- Reduce flexure stress
- Reduce deflection
- Produces stiffer section with less material
- Lighter weight
- Longer spans possible
- Analysis by combined stress

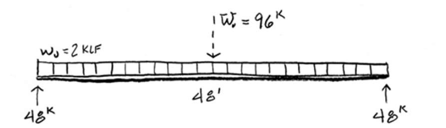
$$f = -\frac{P}{A} \pm \frac{M}{S} \pm \left[\frac{Pe}{S}\right]$$

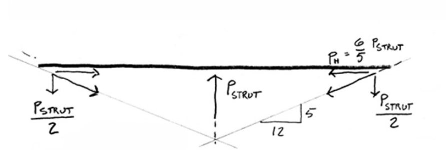


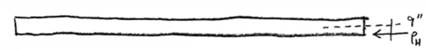
Cable Truss – stress analysis
determine cable prestress

1. Break beam load into 3 FBDs.
   1. applied load
   2. cable + strut
   3. eccentric load (if any)
2. Solve moment for beam at C.L. for applied load
3. Solve C.L. moments for other 2 FBDs in terms of strut force, Ps
4. Equate the moments from the three moment equations to cancel at the CL
5. Solve for the strut and cable forces.
6. Construct moment diagram for the beam with all loadings combined: applied load + cable at ends + struts.
7. Solve combined stress in beam using interaction equation.







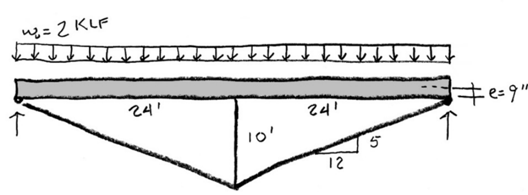


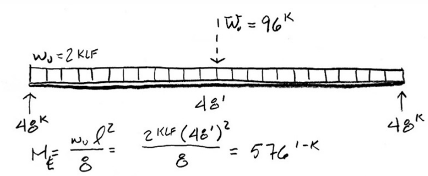
Cable Truss Analysis
Example

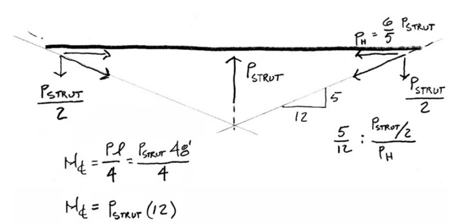
Given: truss configuration with applied load

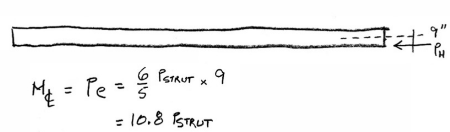
Required: force in the cable which will result in zero moment at the center line, C.L.

1. Divide the truss into 3 Free Body Diagrams:
   1. applied load
   2. cable + strut
   3. eccentric load (if any)



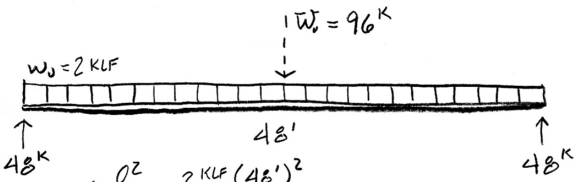






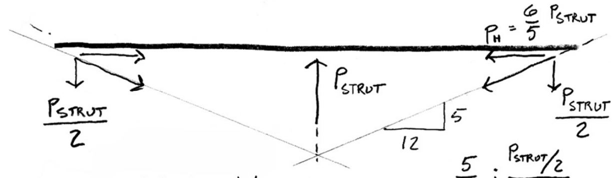
Cable Truss Analysis

2. Find the C.L. moment based on applied load alone.



$$M_{℄} = \frac{w_u \ell^2}{8} = \frac{2^{KLF}(48')^2}{8} = 576^{\,1\text{-}K}$$

3. Find the C.L. moment for the cable and strut in terms of the strut force, P_{strut}. Write the components of the cable force in terms of P_{strut}



$$\frac{5}{12} : \frac{P_{STRUT}/2}{P_H}$$

$$M_{℄} = \frac{P\ell}{4} = \frac{P_{STRUT}\,48'}{4}$$

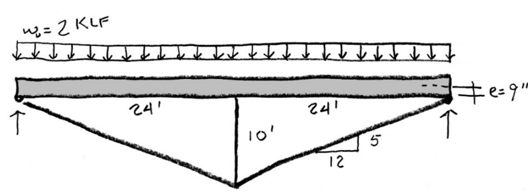
$$M_{℄} = P_{STRUT}(12)$$

4. Find the C.L. moment for the eccentric cable load in terms of P_{strut}

$$M_{℄} = Pe = \frac{6}{5} P_{STRUT} \times 9$$

$$= 10.8\, P_{STRUT}$$

Cable Truss Analysis



5. Set the sum of the C.L. moments equal to zero and solve for the strut force, P_{strut}

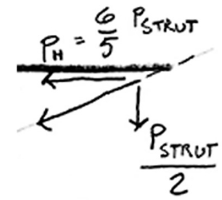
$$+M_U - M_{STRUT} - M_e = 0$$

$$576 - 12\,P_{STRUT} - 10.8\,P_{STRUT} = 0$$

$$22.8\,P_{STRUT} = -576 \text{ K-FT}$$

$$P_{STRUT} = 25.26^K$$

6. Sum the cable components to find the total cable force.

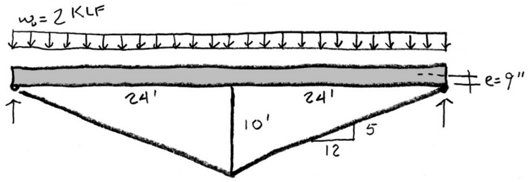


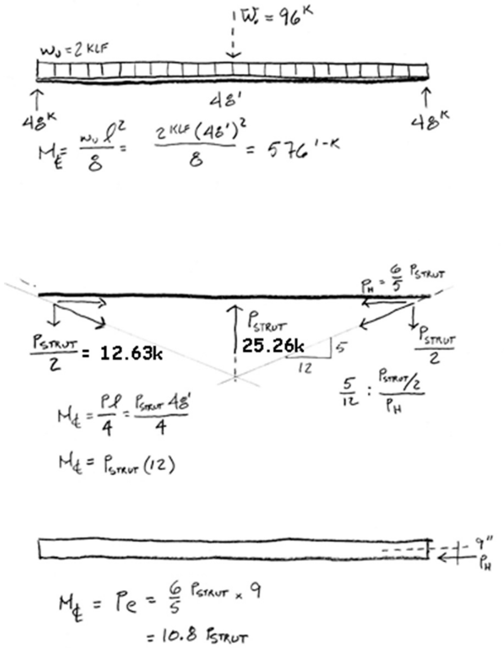
CABLE FORCE

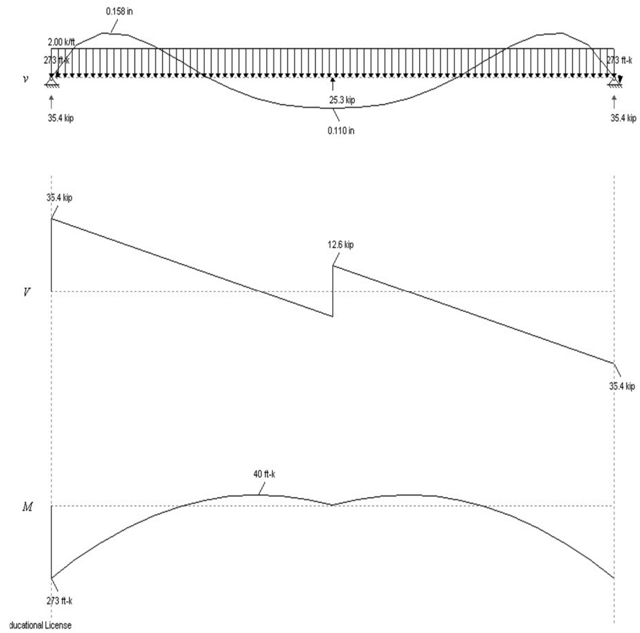
$$\sqrt{\left(\frac{6}{5}(P_{STRUT})\right)^2 + \left(\frac{P_{STRUT}}{2}\right)^2} = 32.84^K$$

Cable Truss Analysis

7.find end reactions and calculate shear & moment



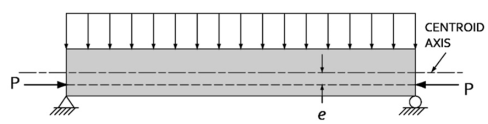


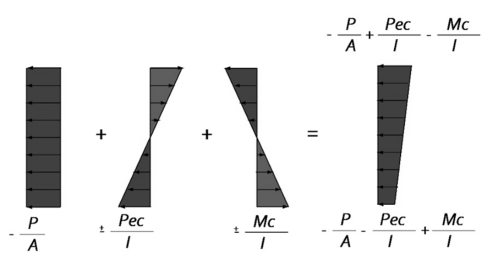


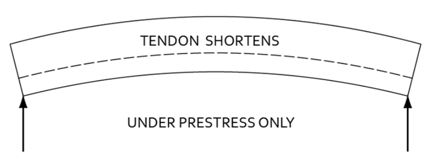
Pre-stressed Concrete

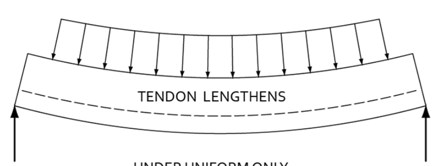
- More concrete active in resisting moment
- Produces stiffer section with less material
- Lighter weight
- Longer spans possible
- Analysis by combined stress

$$f = -\frac{P}{A} \pm \frac{Pec}{I} \pm \frac{Mc}{I}$$



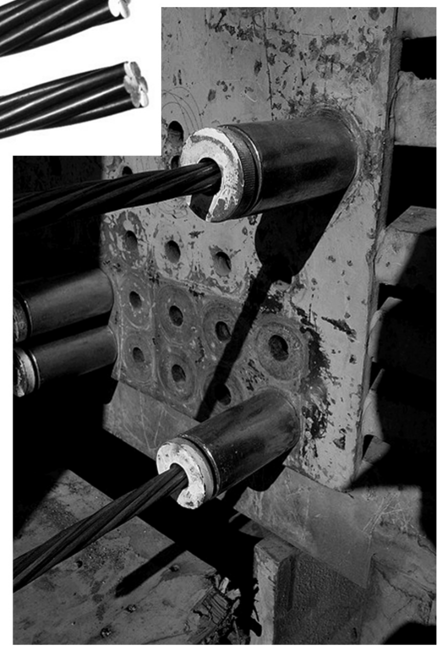






Pre-stressed Concrete

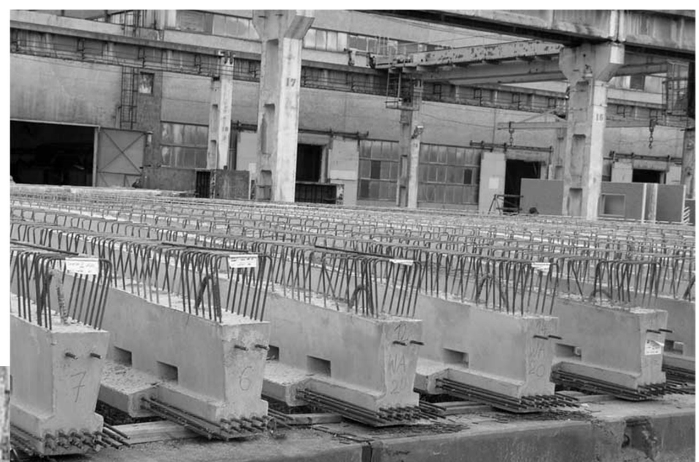
Steel:
- high strength wires 250 or 270 ksi
- wire diameter 0.105 – 0.276
- used in strands of bundled wire
- most common is 7 wire strand



Concrete:
- higher strength 5 – 10 ksi
- to reduce creep and strain
- reduced cracking
- stiffer sections

Photo by Angelo Marasco

Pre-stressed Concrete



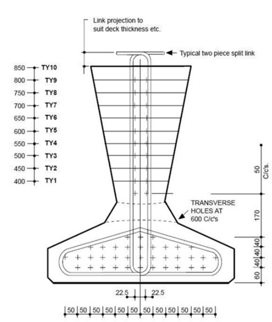
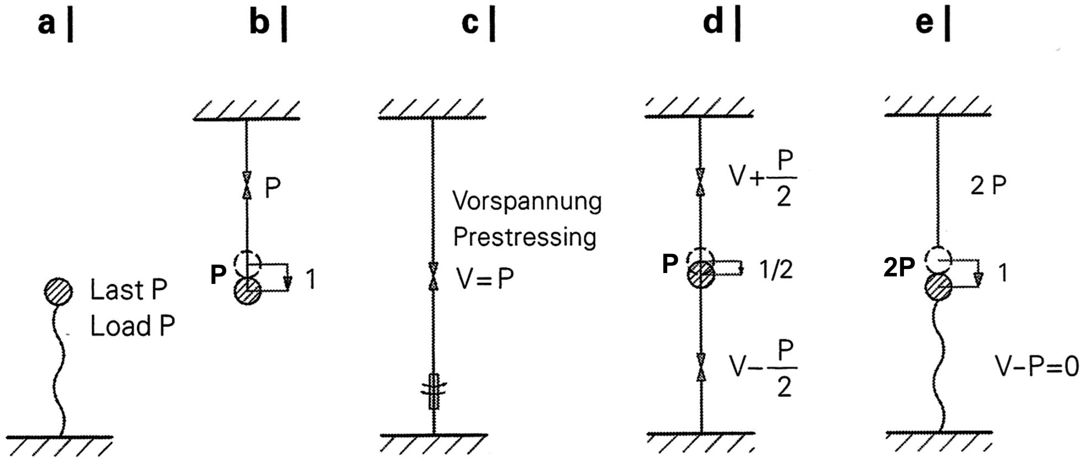


Photo by MACRETE

Pre-stressing

Reducing deformation

(b) carries P and deflects 1
(e) carries 2P and deflects 1
what makes the difference?



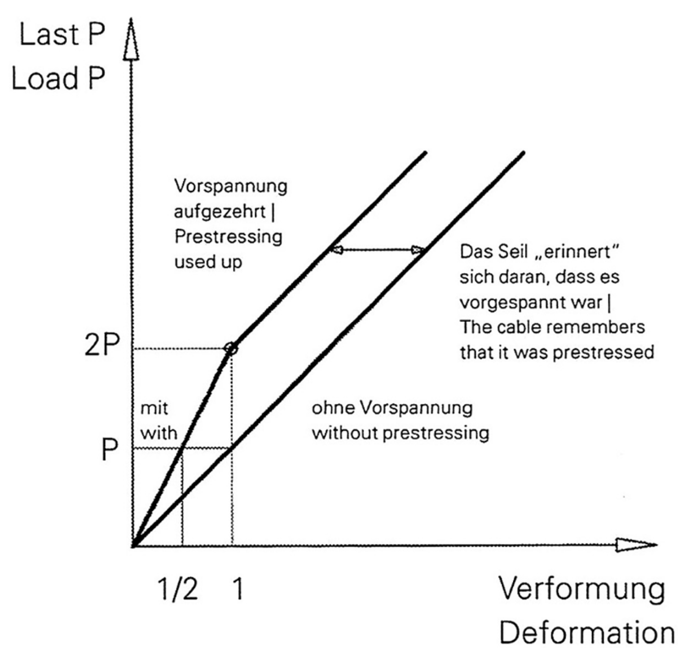
Jörg Schlaich, *Light Structures*

Pre-stressing

increasing stiffness

and

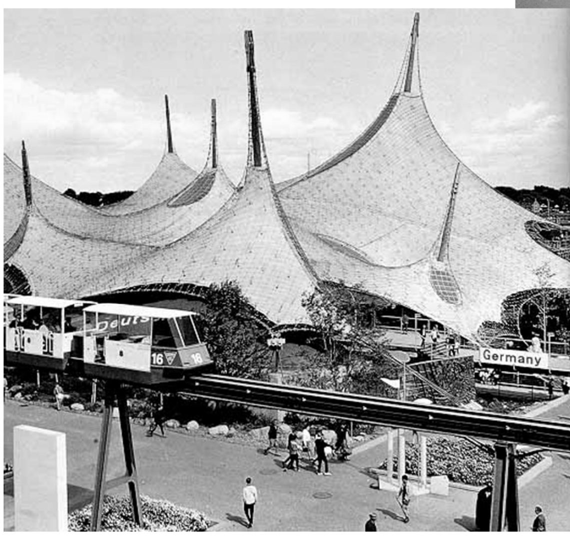
reducing deformation

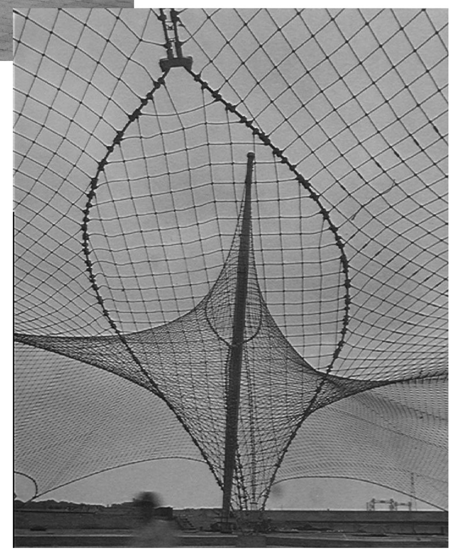


Jörg Schlaich, *Light Structures*

Expo ’67, Montreal

Frei Otto
German Pavilion





Institute for Lightweight Structures – IL (now ILEK)

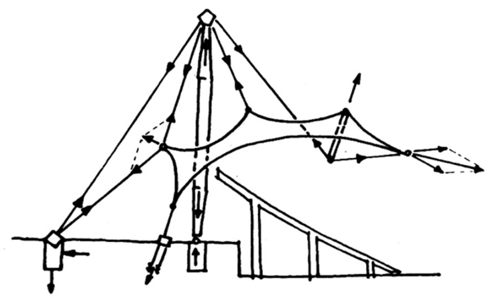
University of Stuttgart

Frei Otto, IL building, University of Stuttgart

Stressed Membrane

Olympic Buildings, Munich 1972
Eng. Otto, Leonhardt, Schlaich
Arch: Behnisch

- Opposing curvature
- Stressed by anchors and masts

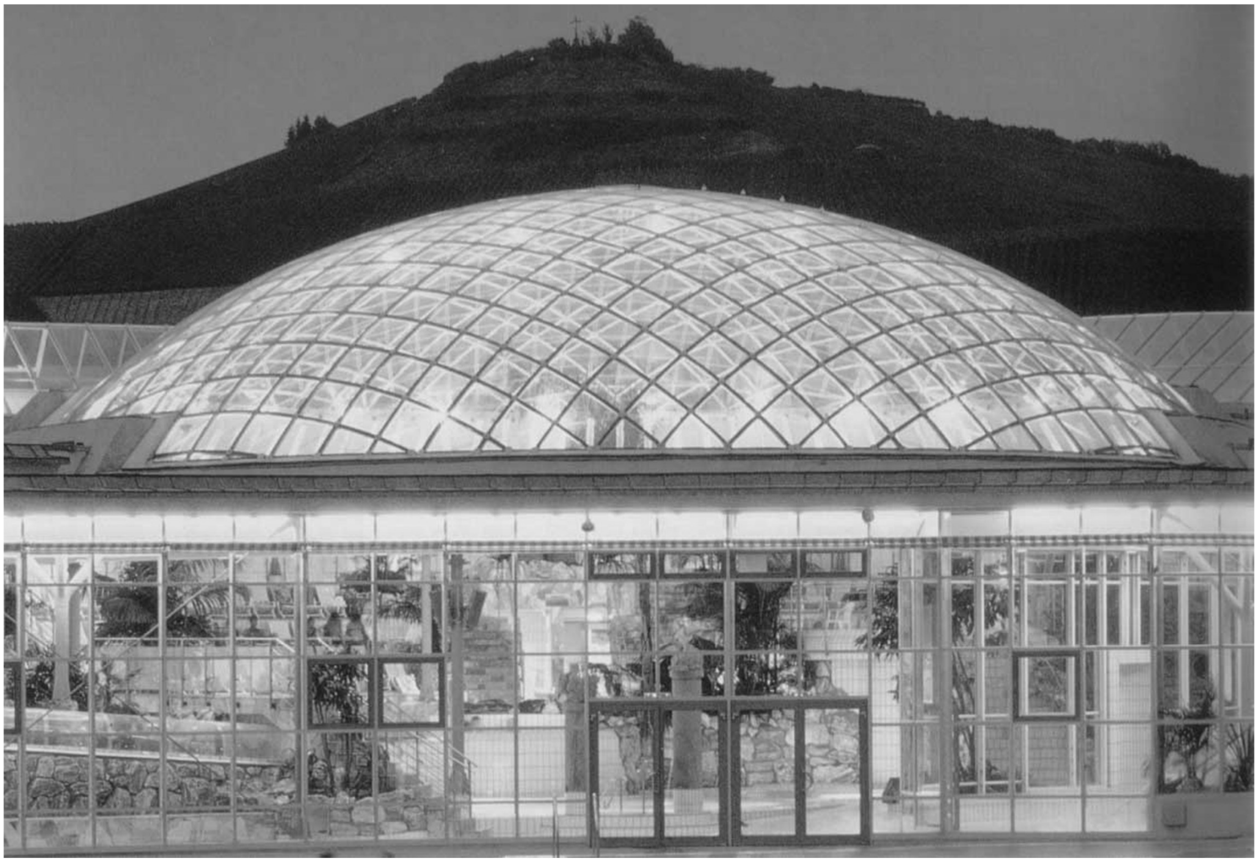


Frei Otto, Munich Soccer Stadium (from back)

Stressed Membrane Olympic Stadium, Munich 1972

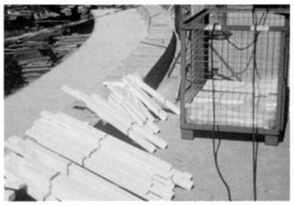
Bundesgartenschau Köln
Frei Otto

Schlaich Bergermann & Partners – Neckarsulm Swimming Pool

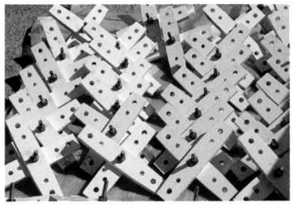


Schlaich Bergermann & Partners

Neckarsulm, 1989

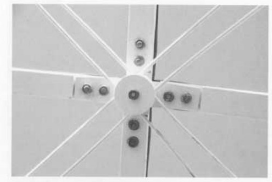


6.14
The slats

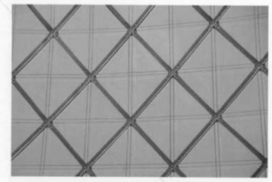


6.15
The rotatable joints

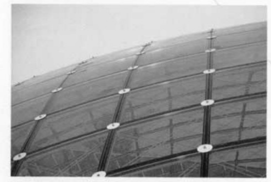
6.16
Assembly of the grid elements



6.17
Close-up of the joint assembly
with diagonal cables installed



6.18
A segment of the grid showing the double
pattern formed by the slats and cables



6.19
A segment of the completed roof
with the spherically-curved glass panes

6.20
Water barrels representing
partial snow load

Schlaich Bergermann & Partners

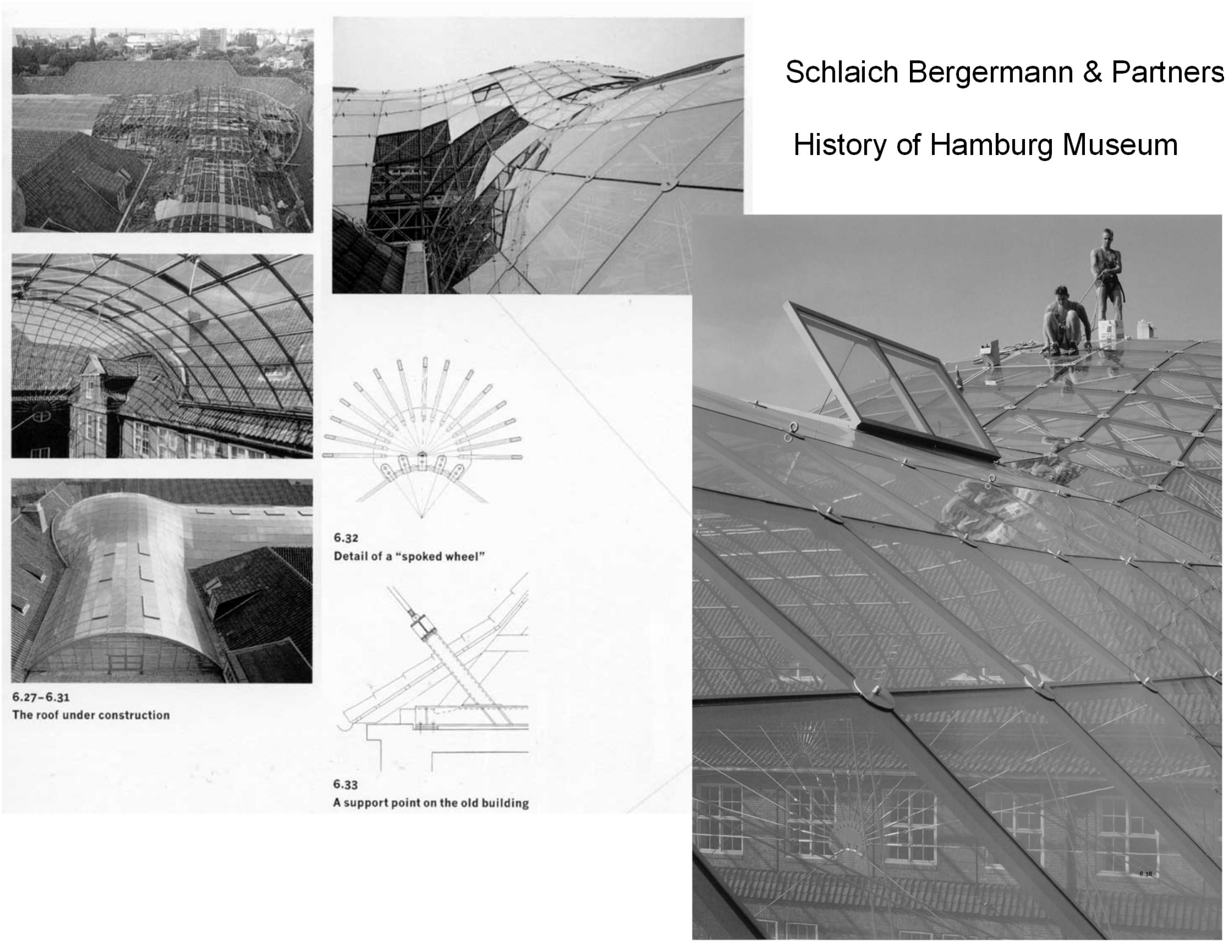
Neckarsulm Pool

Schlaich Bergermann & Partners

History of Hamburg Museum

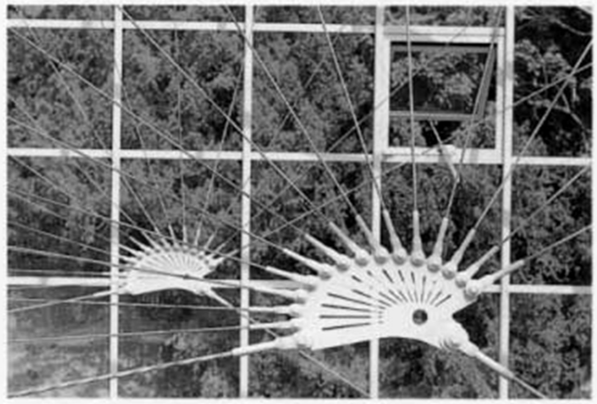
Schlaich Bergermann & Partners

History of Hamburg Museum



Schlaich Bergermann & Partners – Pool cover for mineral spa, Bad Cannstatt

Schlaich Bergermann & Partners – Stuttgart – Bad Cannstatt, 1993



6.40
The hub connections (see the dra-wing on the cover of this book)

6.41
Connections of the pretensioned cable "spokes" to the "rim"

Stressed Membrane

Bosch-Areals, Stuttgart 2001
Eng. Schlaich Bergermann + Parteners

- Opposing curvature
- Stressed by cable spokes

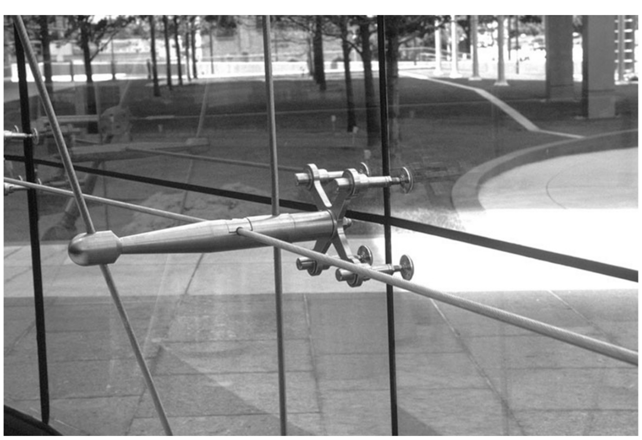
Stressed Membrane

Renaissance Center
Entrance Pavilion
Detroit 2004
SOM

- Point supported glass
- “fish belly” cable truss bacing

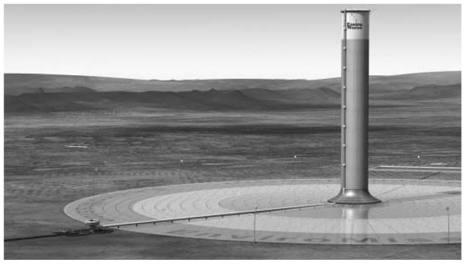
Stressed Membrane

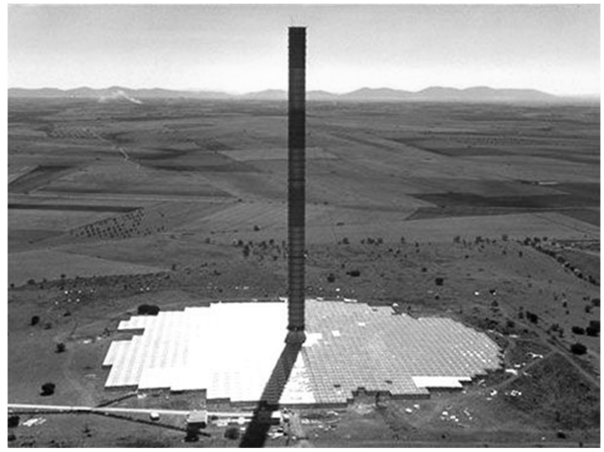
Renaissance Center
Entrance Pavilion
Detroit 2004
SOM

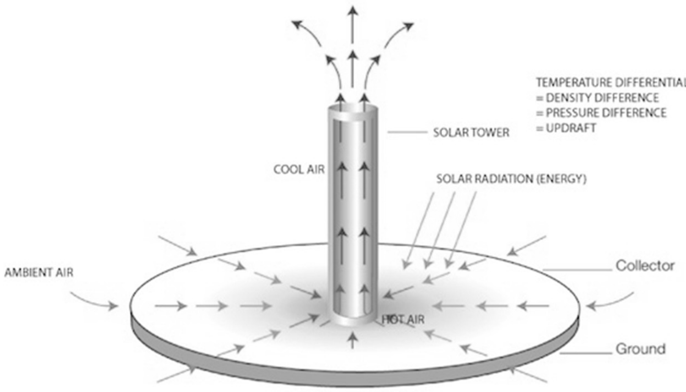


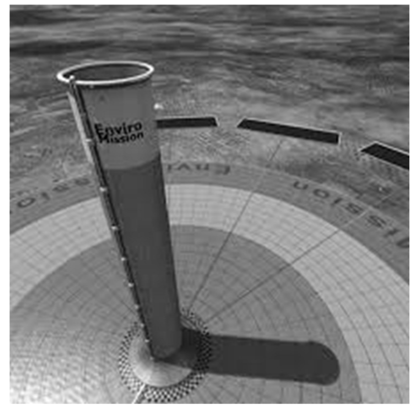
Solar Towers

Enviro Mission









Solar Towers

Jörg Schlaich, Updraft Solar Chimneys