APPLIED ARCHITECTURAL STRUCTURES:
STRUCTURAL ANALYSIS AND SYSTEMS
ARCH 631
DR. ANNE NICHOLS
FALL 2013

lecture
thirteen

Denver Airport – Birdair.com

membrane, net & shell structures

Membrane and Net Structures

- *form follows pressure or tension*

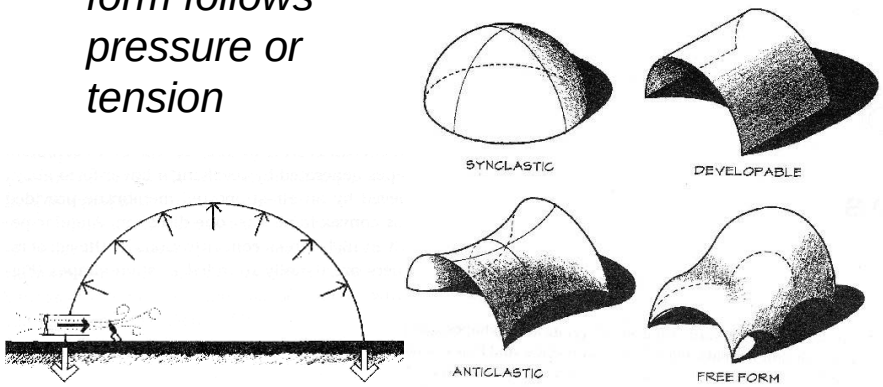
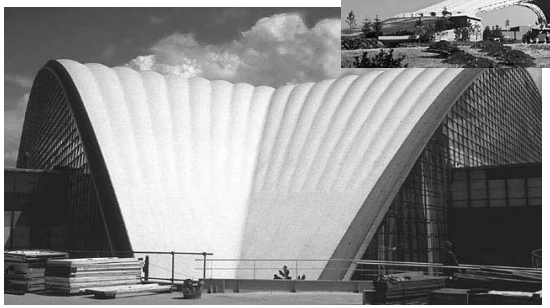


Figure 15.1: Shell shapes.

Membrane and Net Structures

- *types*
  - *fabric*
  - *cables*

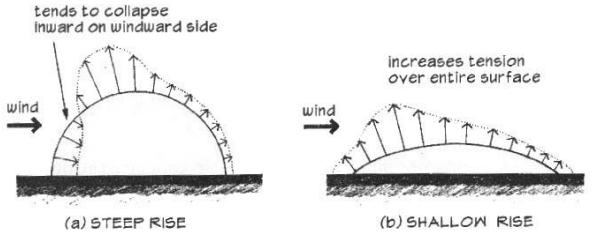
http://nisee.berkeley.edu/godden



  - *pneumatic*
  - *inflated*

Membrane and Net Structures

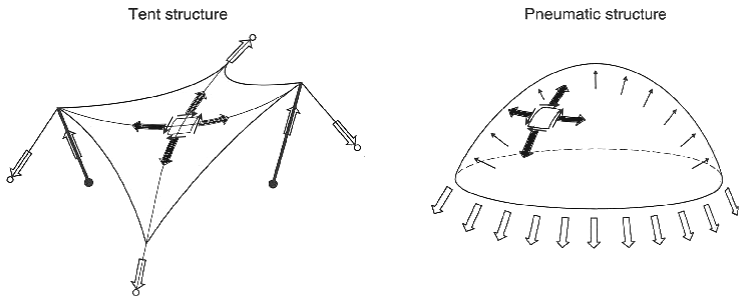
- *sensitive to aerodynamic effects of wind*
  - *fluttering*



- *stabilization*
  - *rigid supporting framework*
  - *prestressing of surface*

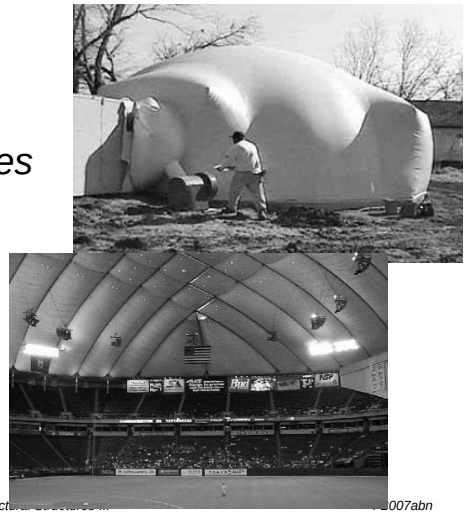
Membrane and Net Structures

- *tensile stress <u>and</u> tangential shear stresses occur*



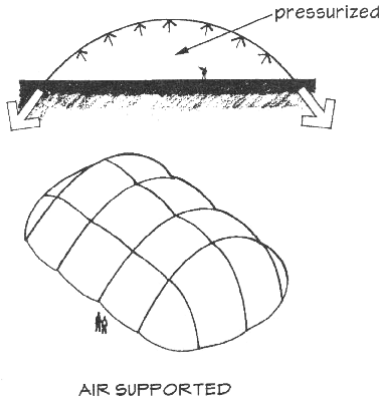
Pneumatic Structures

- *internal pressure*
  - *– air-supported: entire volume*
  - *– air-inflated: cavities*
    - *ribs*
    - *dual walls*



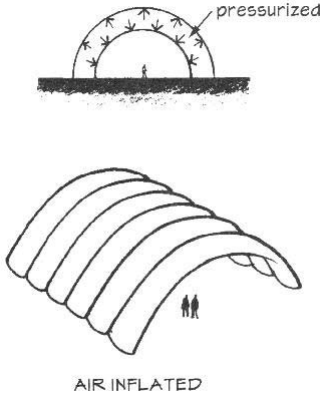
Air-Supported Structures

- *pressure slightly higher than atmospheric*
- *light loads*
- *greater spans than air-inflated*



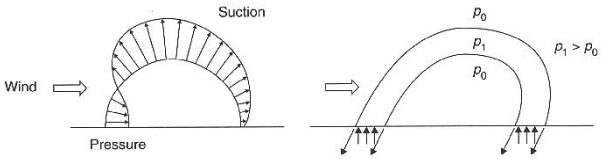
Air-Inflated Structures

- *higher degree of pressurization*
- *pressure doesn't directly balance loads*
- *buckling or folding results in collapse*
- *flexibility in space*



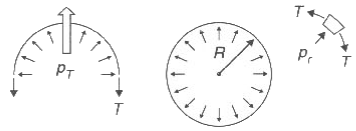
Loads & Behavior

- *snow accumulation*
  - *shape*
  - *heat loss*
- *avoid large concentrated loads*
- *wind loads*
  - *suction*
  - *tension*
  - *"buckling"*

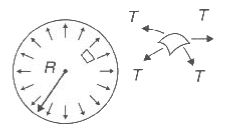


Membrane Stresses

- *pressure is constantly applied stress*



(a) Circular membrane of unit width carrying an internal pressure p_r. Tension forces in membrane: $T = p_r R$.



(b) Spherical membrane carrying an internal pressure of p_r.

General relationship:
$p_r = T_1/R_1 + T_2/R_2$

For a sphere:
$R_1 = R_2 = R$
$T_1 = T_2 = p_r R/2$

Membrane Stresses

- *enough pressure to prevent folding*
- *large radius, large stress*

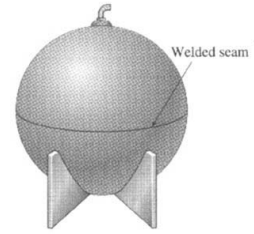


FIG. 8-1 Spherical pressure vessel

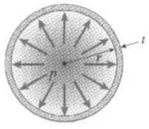
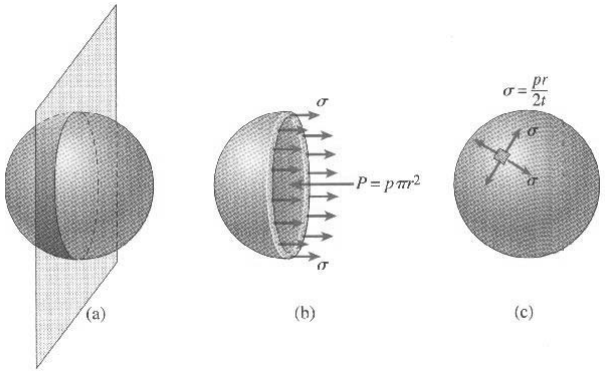
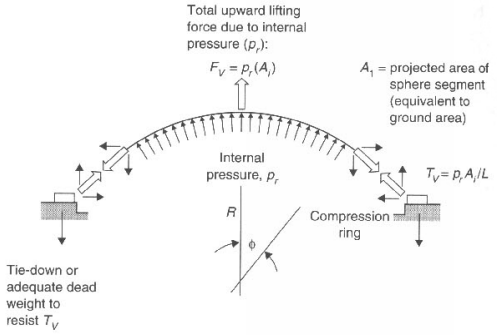


FIG. 8-2 Cross section of spherical pressure vessel showing inner radius r, wall thickness t, and internal pressure p



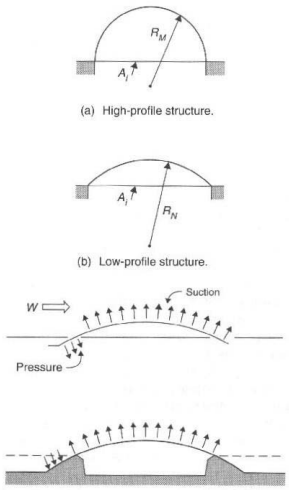
Supports

- *air-supported*
  - *need airtight seal*
  - *resists uplift and thrust*
  - *"inverted" arch*
  - *containment rings*



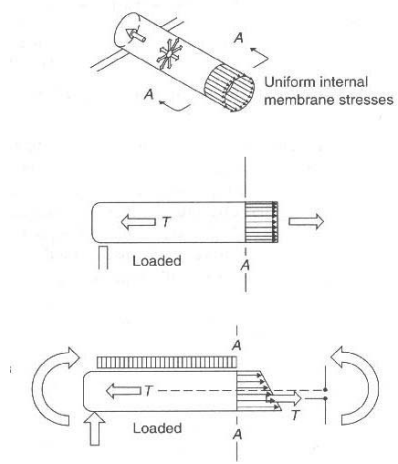
Profile Selection

- *lower profile*
  - *higher stresses*
  - *lower air volume*
  - *can be used to avoid wind pressure effects*



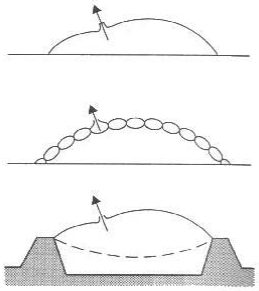
Air-Inflated Members

- *prestressed in tension*
- *structural stresses added*
- *increase in tension*



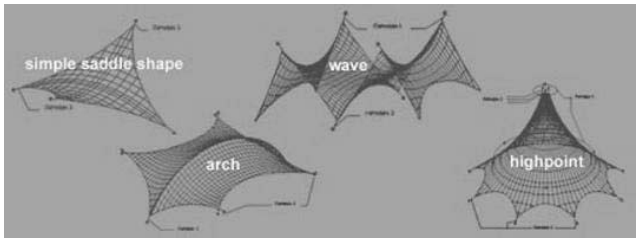
Punctures

- *fracture or rip from redistribution of stresses*
- *air-supported*
  - *low pressure*
  - *gradual deflation*
- *air-inflated*
  - *isolated cells deflate*
- *design in suspension*



Net and Tent Structures

- *low curvatures, high stress (big radius)*
- *avoid flat areas*
- *carefully place high & low points*



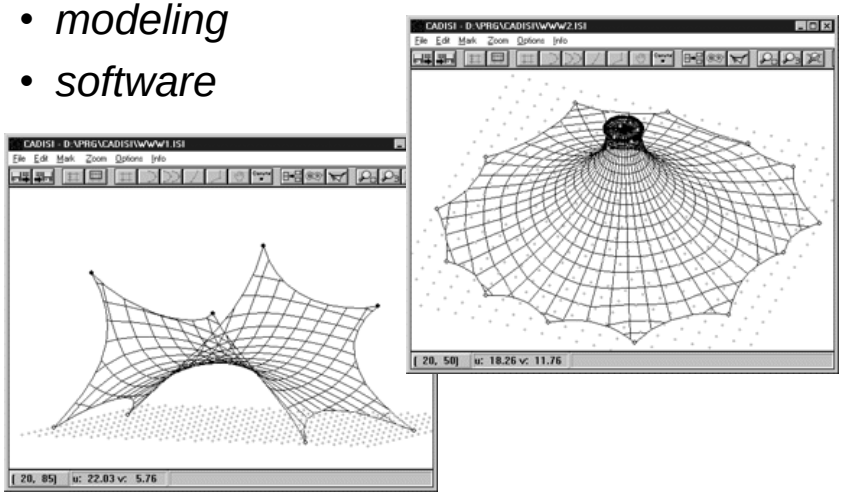
Basic Types of Tensile Structures (© Tentech)

Support Conditions

- *compression masts*
- *uplift at ground*
- *free edges can be stiffened with cables*
- *stress reduction at high points by a cable ring*

Form Development

- *modeling*
- *software*



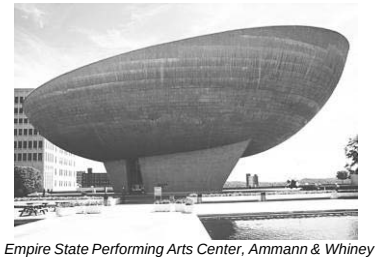
Materials

- *strength*
  - *tear resistant*
  - *bi-directional*
- *durability*
  - *ultraviolet effects*
  - *creep*
  - *corrosion in metals*

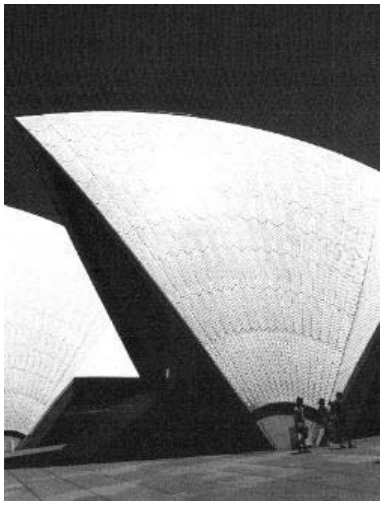
Shells

- *similar to membranes, domes & vaults*
- *THIN*
- *rigid*

Shells

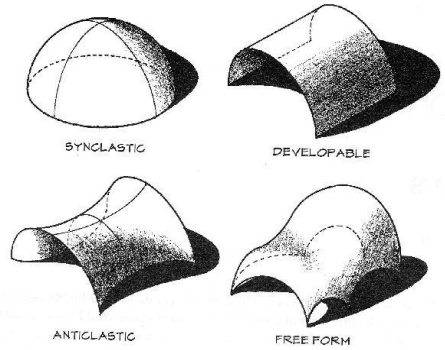


Empire State Performing Arts Center, Ammann & Whiney



Shell Types

- *shape classifications*
  - *developable:*
    - *singly curved (vault)*
  - *synclastic*
    - *doubly curved*
    - *same direction*
  - *anticlastic:*
    - *doubly curved*
    - *opposite curvature*
  - *free form*



Synclastic

- *surface of revolutions*

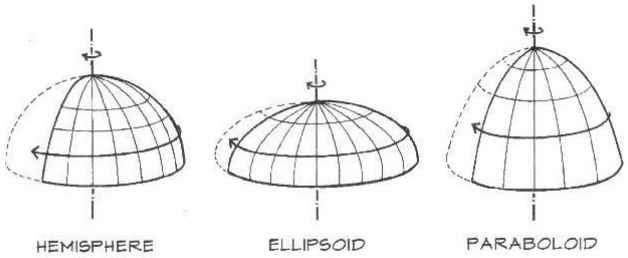
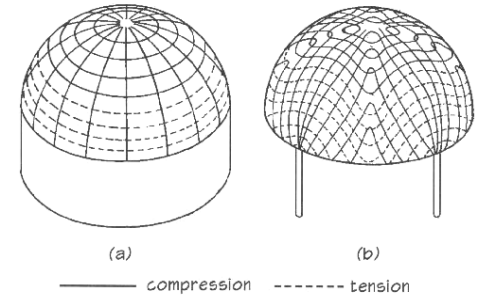


Figure 15.2: Rotational surfaces.

Shell Stresses

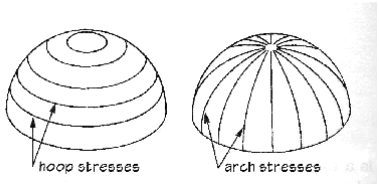
- *in-plane*
  - *tension*
  - *compression*
  - *shear*
- *insignificant bending*

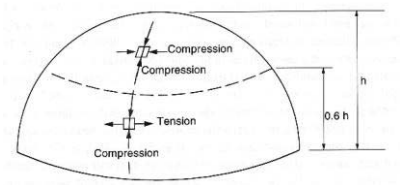


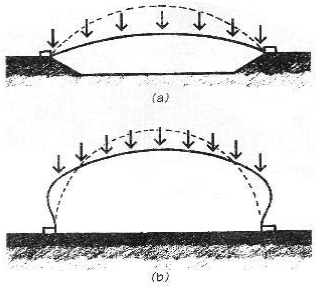
- *suitable for distributed loads*
- *can't handle concentrated loads well*

Spherical Shells

- *arch of revolution*
- *compression*
- *some tension*
  - *"bow"*

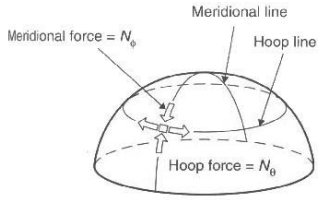


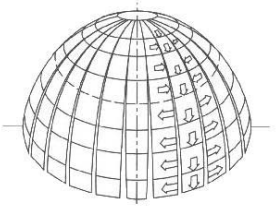




Forces in Spherical Shells

- *similar to plates*
  - *two directions of forces*
  - *shear*
  - *maintain curvatures*
- *meridional– arch direction*
- *hoop – radial direction*
  - *can see tension*
- *holes redistribute stresses*
  - *edges need reinforcement*





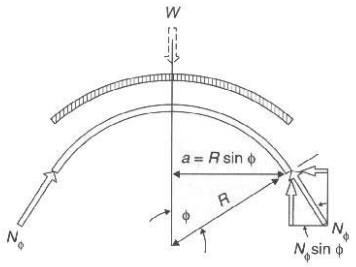
Meridional and Hoop Forces

- *meridional force per unit length:*

$$N_\phi = \frac{W}{2\pi R \sin^2 \phi}$$

- *hoop force per unit length:*

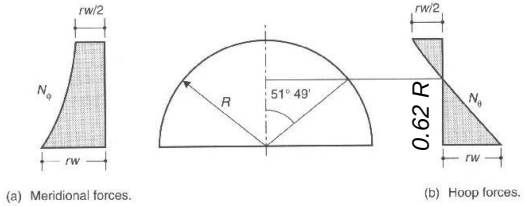
$$N_\theta = Rw\left(-\frac{1}{1+\cos\phi} + \cos\phi\right)$$



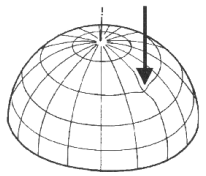
Distribution and Concentrated Forces

- *size distributions*

$$\cos(51°49')R = 0.62R$$

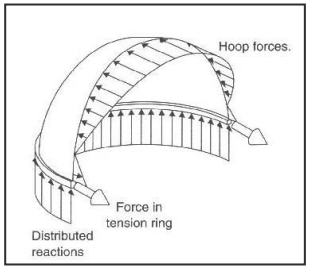


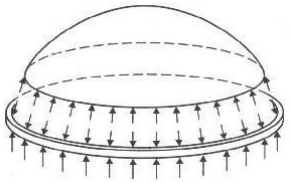
- *concentrated force causes* $N_\phi \to \infty$



Support Conditions

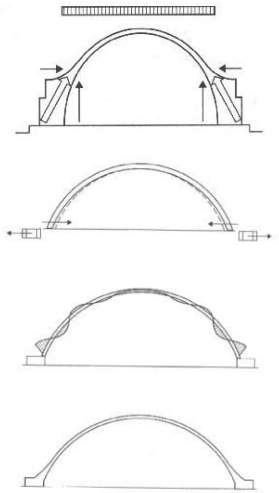
- *absorb horizontal thrust*
  - *tension ring*
  - *being pushed out*
  - *need to be continuous*
  - *can be used as foundation*
- *top (crown) rings*
  - *in compression*





Support Conditions

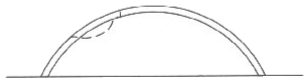
- *buttresses*
- *edge restraint effects*
  - *deformations different*
  - *fixed edges*
    - *bending stress*
    - *deep section*
  - *pinned edges*
    - *still induces bending*
  - *post-tensioning helps stiffen*



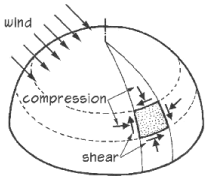
Buckling & Lateral Loading

- *instability*
  - *compression*
  - *moment of inertia*
  - *low stress levels*
- *local*
- *snap-through*
- *lateral loading*
  - *shear*

(a) Snap-through buckling.



(b) Local buckling.



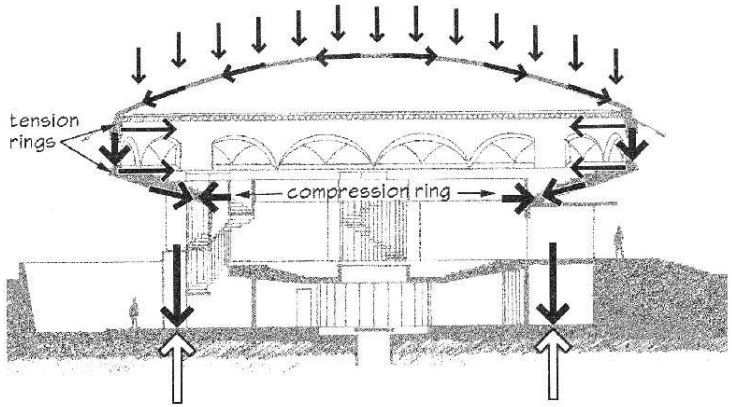
Annunciation Greek Orthodox Church

- *Wright, 1956*

http://www.bluffton.edu

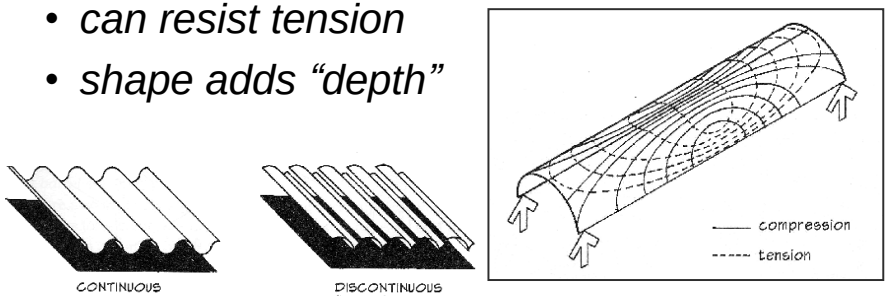
Annunciation Greek Orthodox Church

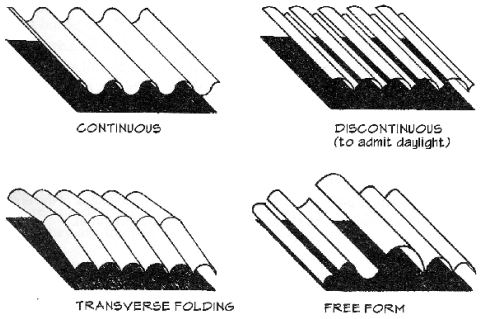
- *Wright, 1956*



Cylindrical Shells

- *can resist tension*
- *shape adds "depth"*



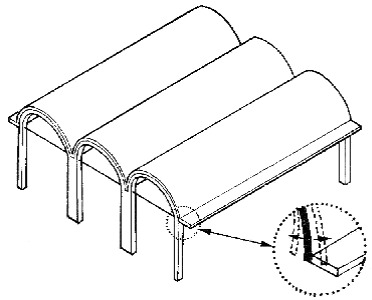


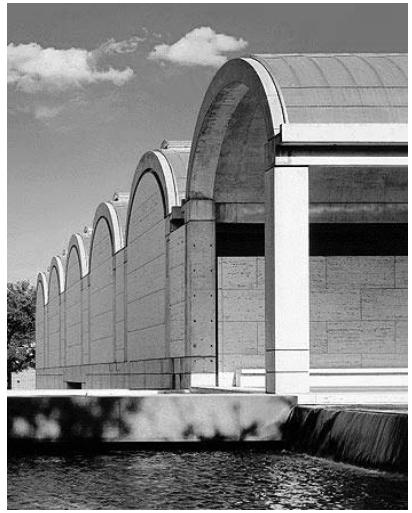
- *not vaults*
- *barrel shells*

Kimball Museum, Kahn 1972

Kimball Museum, Kahn 1972

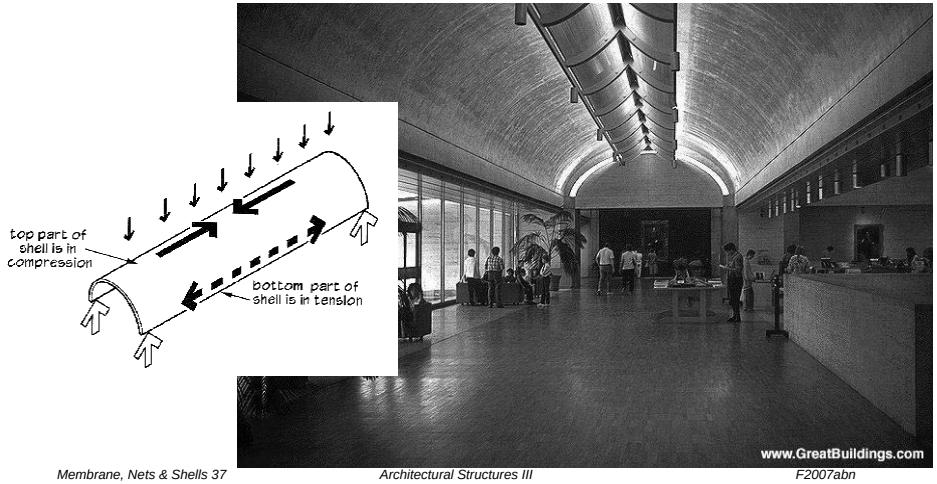
- *outer shell edges*





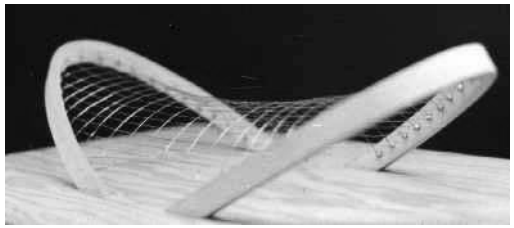
Kimball Museum, Kahn 1972

- *skylights at peak*



Anticlastic Shells (Hyperbolic Paraboloid)

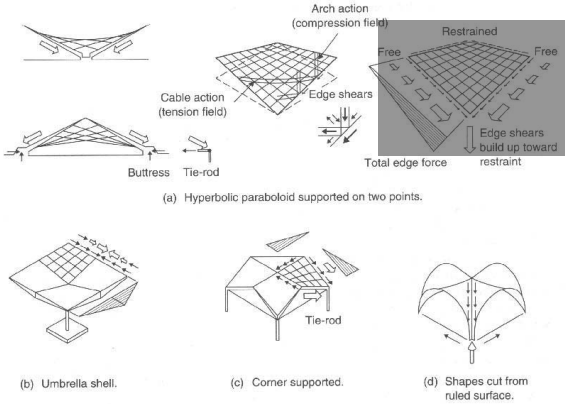
- *saddle or "ruled" shapes*
- *surface generated with straight lines*



- *tension follows "cable drape"*
- *compression follows "arch"*

Anticlastic Shell Behavior

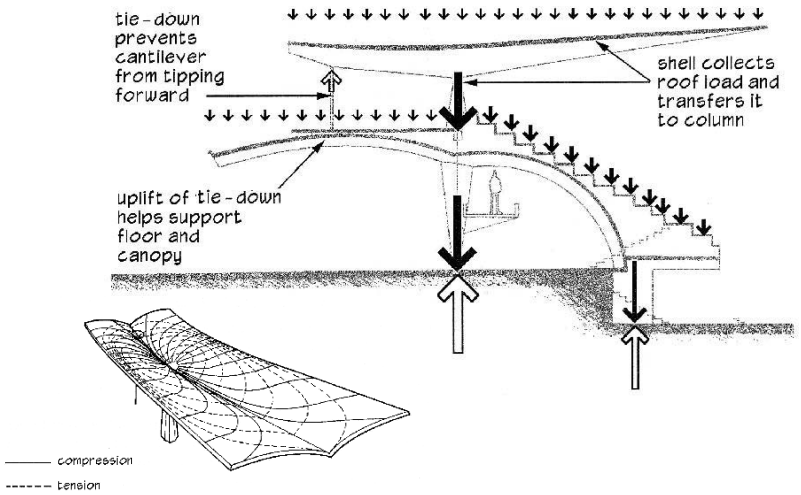
- *edge conditions offer restraint*
  - *tie rods useful*
  - *shears*



Zarzuela Hippodrome, Torroja 1935

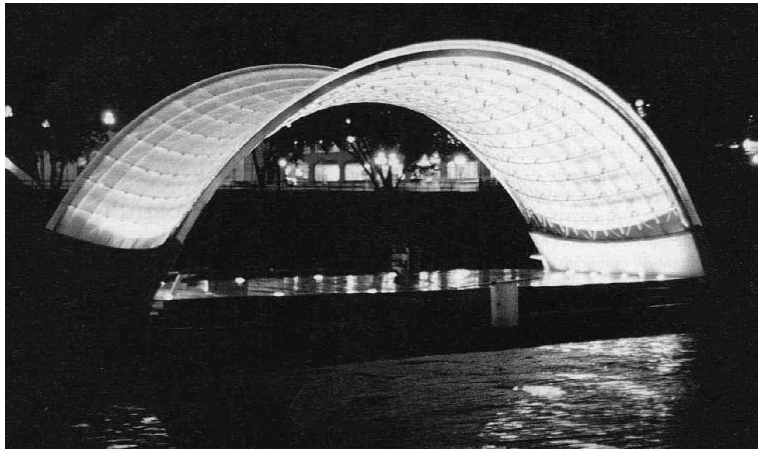
http://www.arch.mcgill.ca

Zarzuela Hippodrome, Torroja 1935



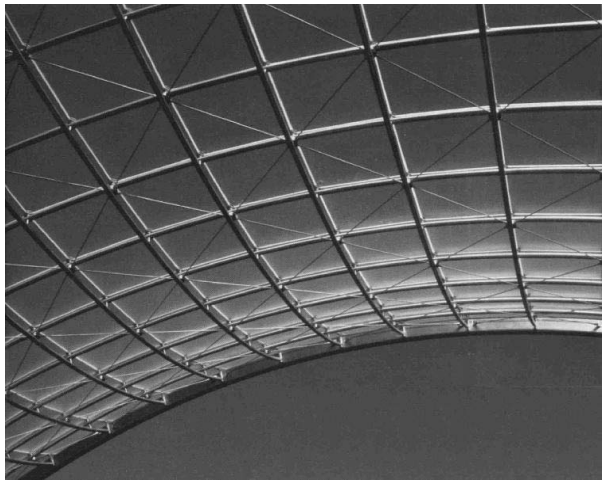
Heilmajer Memorial Bandstand

- *Kramer, 2002*



Heilmajer Memorial Bandstand

- *Kramer, 2002*



Heilmajer Memorial Bandstand

- *Kramer, 2002*