Applied Architectural Structures: STRUCTURAL ANALYSIS AND SYSTEMS

ARCH 631 DR. ANNE NICHOLS **F**ALL 2013

lecture



Denver Airport - Birdair.com

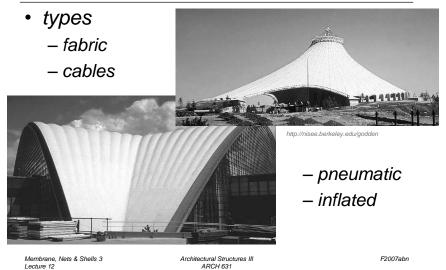
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membrane, net & shell structures

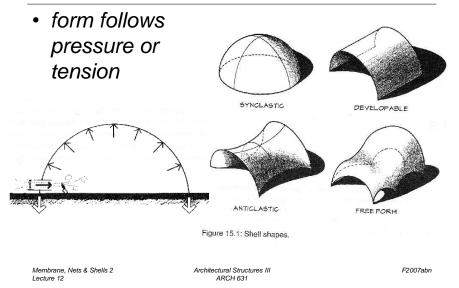
Membrane, Nets & Shells 1 Lecture 13

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Applied Architectural Structures
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Membrane and Net Structures



Membrane and Net Structures

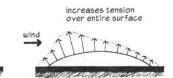


Membrane and Net Structures

- · sensitive to aerodynamic effects of wind
 - fluttering

wind

tends to collapse inward on windward side



(a) STEEP RISE

- stabilization
 - rigid supporting framework - prestressing of surface

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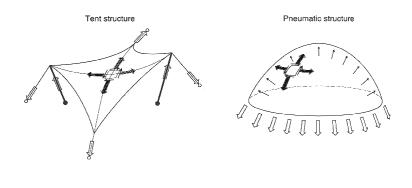


(b) SHALLOW RISE

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Membrane and Net Structures

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



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Air-Supported Structures

• pressure slightly higher than atmospheric

• greater spans than

• light loads

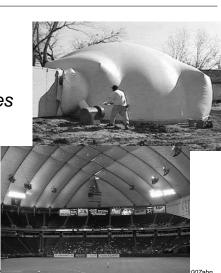
air-inflated

AIR SUPPORTED

Pneumatic Structures

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





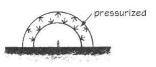
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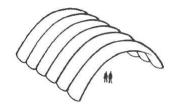
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Air-Inflated Structures

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





AIR INFLATED

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pressurized

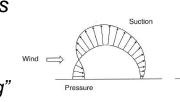
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Loads & Behavior

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



 p_0

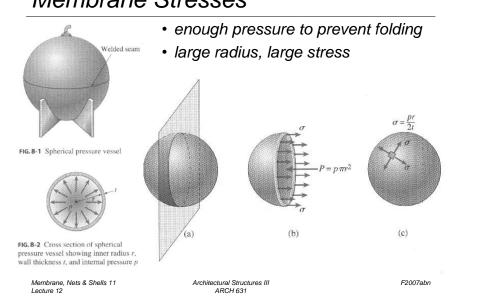
 p_1

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 $p_1 > p_0$

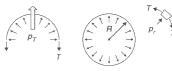
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Membrane Stresses



Membrane Stresses

pressure is constantly applied stress





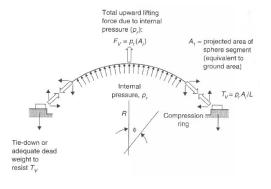
General relationship: $p_r = T_1/R_1 + T_2/R_2$ For a sphere: $R_1 = R_2 = R$ $T_1 = T_2 = p_r R/2$

- (a) Circular membrane of unit width carrying an internal pressure p_i . Tension forces in membrane: $T = p_r R$.
- (b) Spherical membrane carrying an internal pressure of $\rho_r.$

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Supports

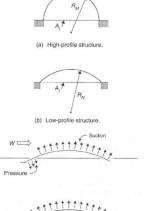
- air-supported
 - need airtight seal
 - resists uplift and thrust
 - "inverted" arch
 - containment rings



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Profile Selection

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



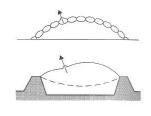
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Punctures

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

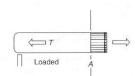


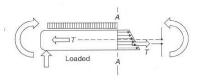


Air-Inflated Members

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





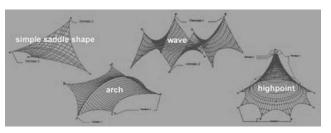


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Net and Tent Structures

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



Basic Types of Tensile Structures (© Tentech)

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Support Conditions

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



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Materials

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



Form Development

<complex-block>

Shells

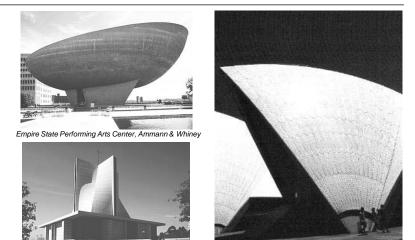
- similar to membranes, domes & vaults
- THIN
- rigid



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Shells



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Synclastic

surface of revolutions

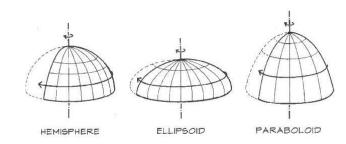


Figure 15.2: Rotational surfaces.

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Shell Types

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

SYNCLASTIC DEVELOPABLE ANTICLASTIC FREE FORM

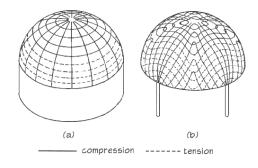
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Shell Stresses

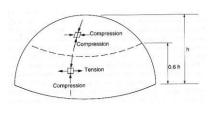
- in-plane
 - tension
 - compression
 - shear
- insignificant bending

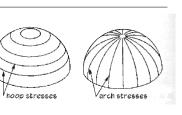


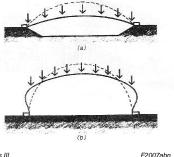
- suitable for distributed loads
- can't handle concentrated loads well

Spherical Shells

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



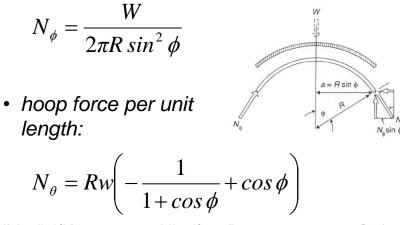




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Meridional and Hoop Forces

• meridional force per unit length:

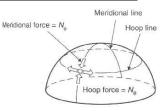


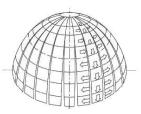
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Forces in Spherical Shells

- 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

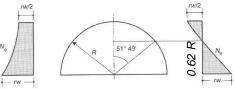




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Distribution and Concentrated Forces

- size distributions
- $cos(51^{\circ}49')R = 0.62R$



(a) Meridional forces.



• concentrated force causes $N_{\phi} \rightarrow \infty$

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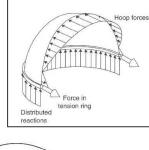


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Support Conditions

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



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Buckling & Lateral Loading

- instability
 - compression



- moment of inertia
- (a) Snap-through buckling.
- low stress levels
- local
- snap-through
- lateral loading
 shear

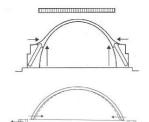
(b) Local buckling.

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Support Conditions

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





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Annunciation Greek Orthodox Church

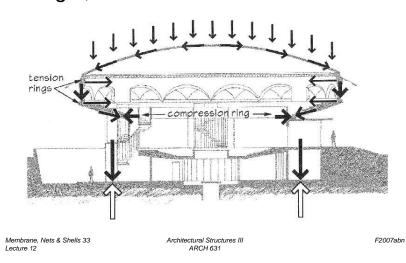
• Wright, 1956



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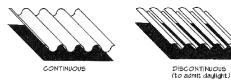
Annunciation Greek Orthodox Church

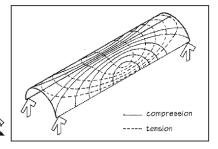
• Wright, 1956



Cylindrical Shells

- can resist tension
- shape adds "depth"





not vaults barrel shells

TRANSVERSE FOLDING

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Kimball Museum, Kahn 1972

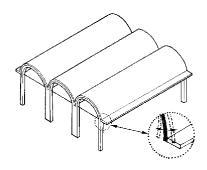


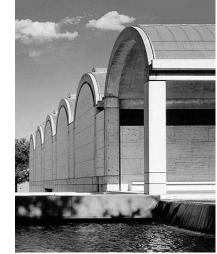
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Kimball Museum, Kahn 1972

FREE FORM

• outer shell edges





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Kimball Museum, Kahn 1972

• skylights at peak i i i L top part of shell is in compression ottom part of www.GreatBuildings Membrane, Nets & Shells 37 Architectural Structures II. F2007abr

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Anticlastic Shells (Hyperbolic Paraboloid)

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



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

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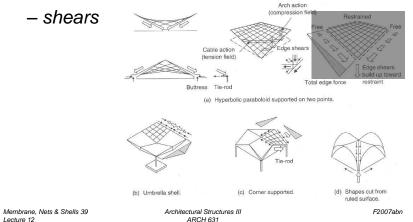
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Anticlastic Shell Behavior

- edge conditions offer restraint
 - tie rods useful

Lecture 12

Lecture 12



Zarzuela Hippodrome, Torroja 1935



http://www.arch.mcgill.ca

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Zarzuela Hippodrome, Torroja 1935 tie-down prevents cantilever shell collects from tipping roof load and forward transfers it to column *** uplift of tie-down helps support floor and canopy name and send that Service Less and compression ----- tension Membrane, Nets & Shells 41 Architectural Structures III F2007abn ARCH 631 Lecture 12

Heilmajer Memorial Bandstand

• Kramer, 2002

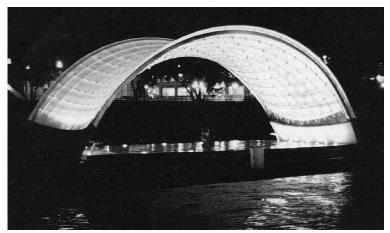


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Heilmajer Memorial Bandstand

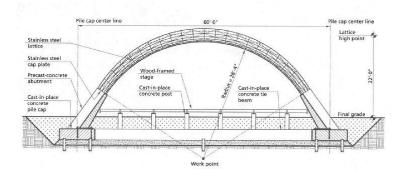
• Kramer, 2002



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Heilmajer Memorial Bandstand

• Kramer, 2002



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