MID- and LARGE-SPAN STRUCTURES

Bekir Özer Ay

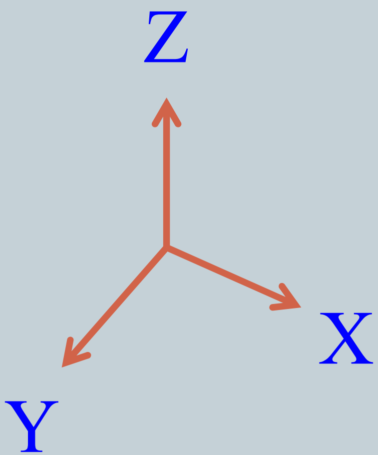
MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ARCHITECTURE

Structures & Dimensions

Ordinary systems

$X \approx Y \approx Z$



One-way spanning

$X >> Y \ \& \ Z$

High-rise

$Z >> X \ \& \ Y$

Two-way spanning

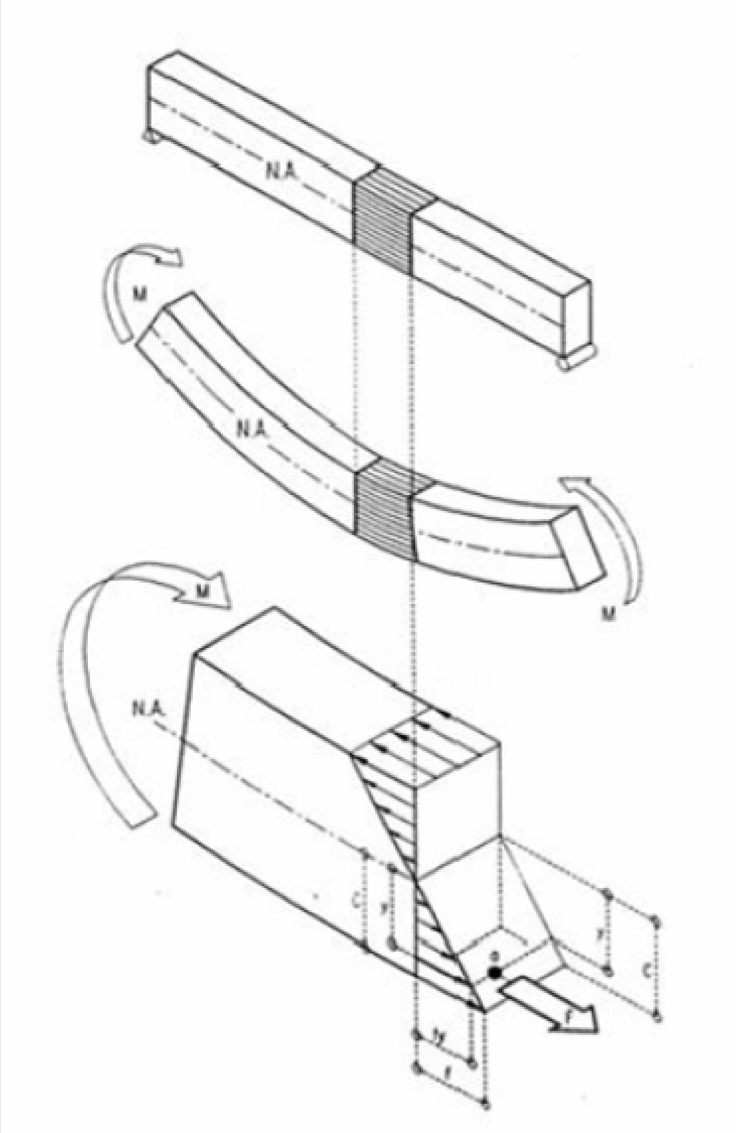
$X \approx Y >> Z$

Spanning Systems - Orthogonal frames

Linear elements forming frames with orthogonal rigid joints

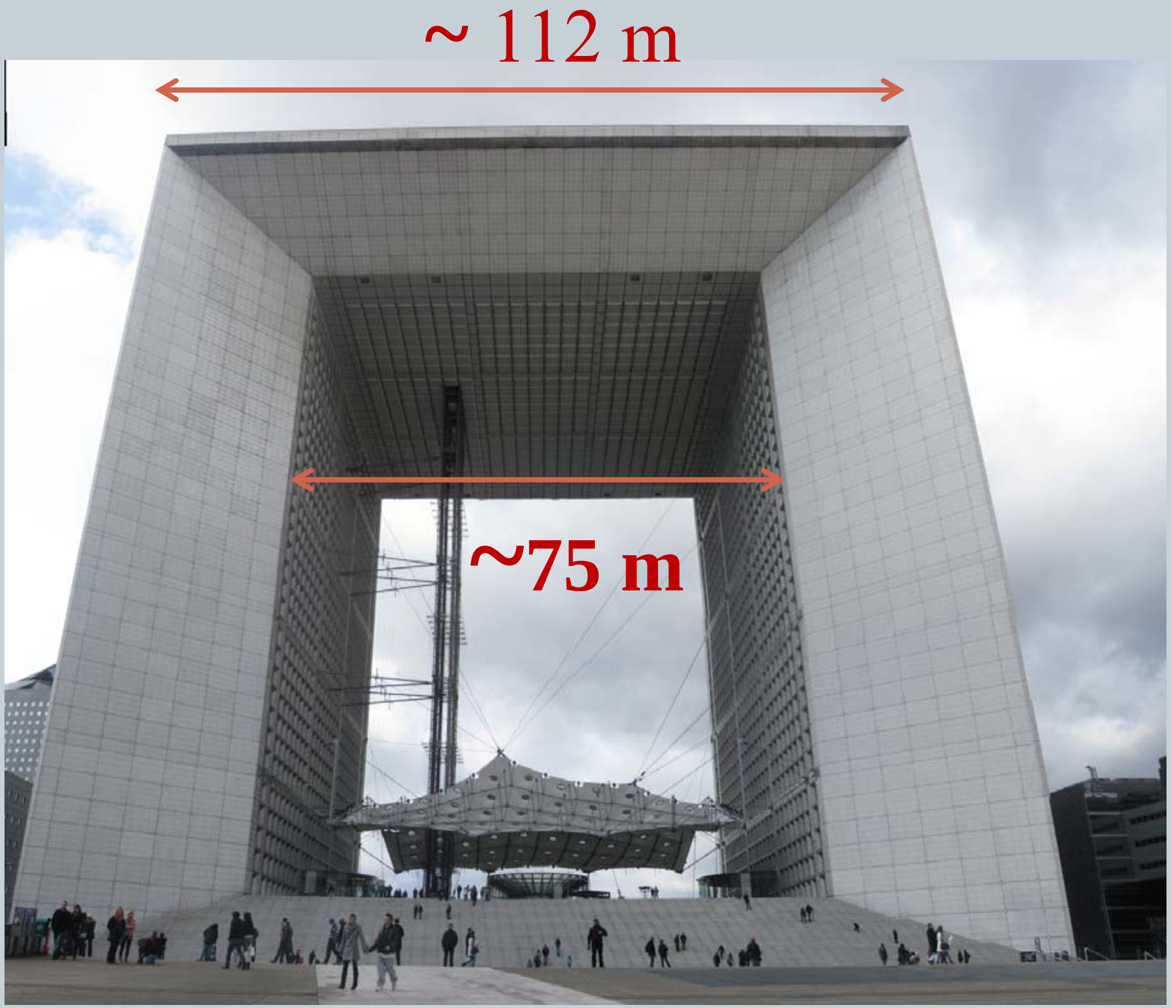
- **Vertical members** (columns) subjected to axial load (compression & tension)
- **Horizontal members** (beams) subjected to flexure (moment)

Bending elements are **less efficient for large spans** because they use **only half of the material** (bending stress varies from compression to tension with zero stress at the neutral axis)

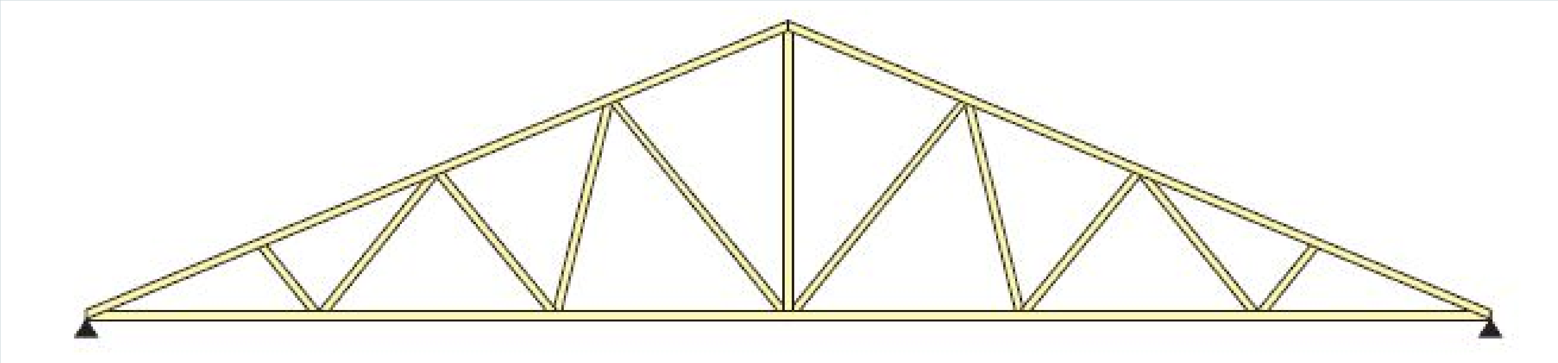


Spanning Systems - Orthogonal frames

La Grande Arche (1989) by Johann Otto von Spreckelsen

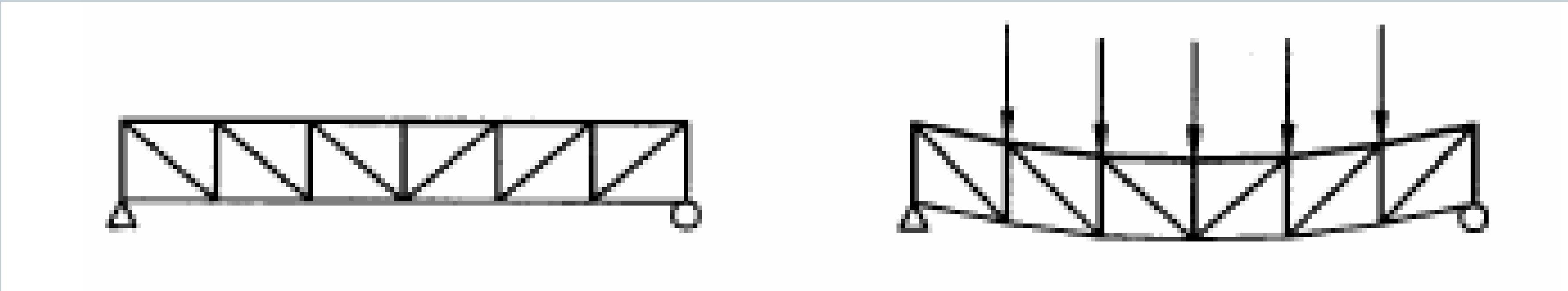


Spanning Systems - Trusses

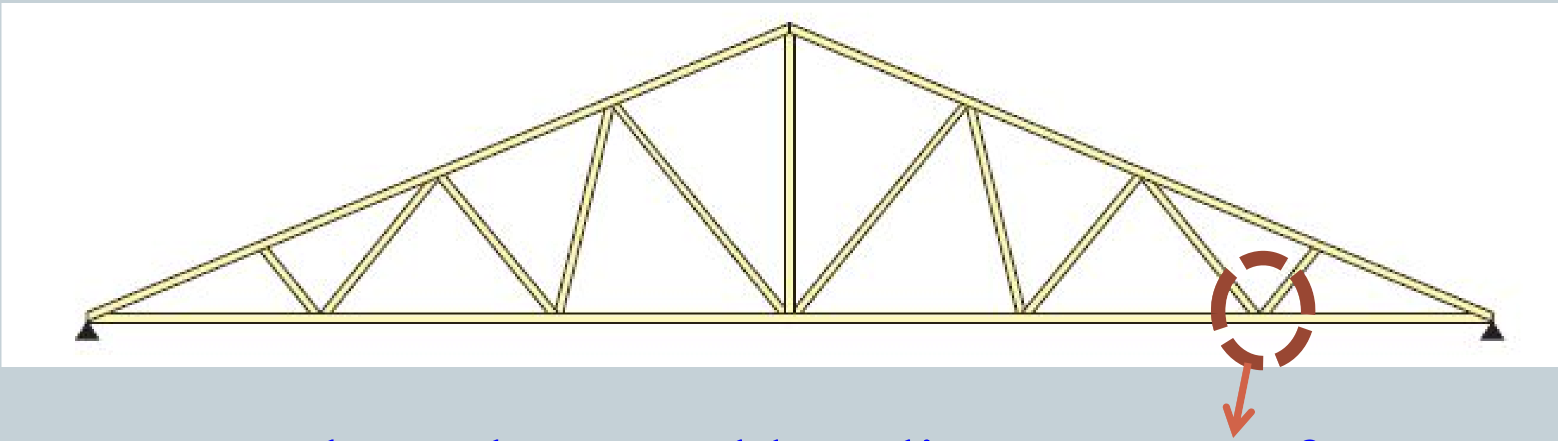


A truss is a structural frame based on the geometric rigidity of the triangle. Linear members are subjected only to axial tension and compression.

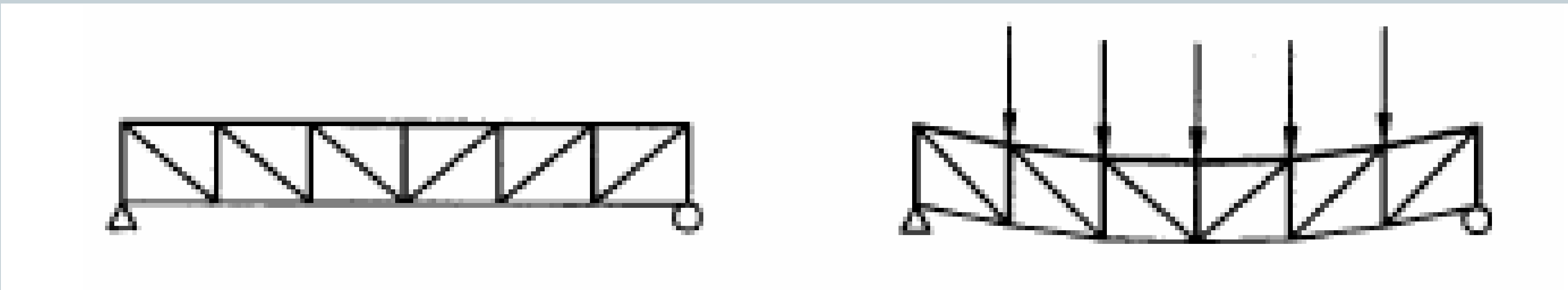
They support load much like beams but for larger spans.



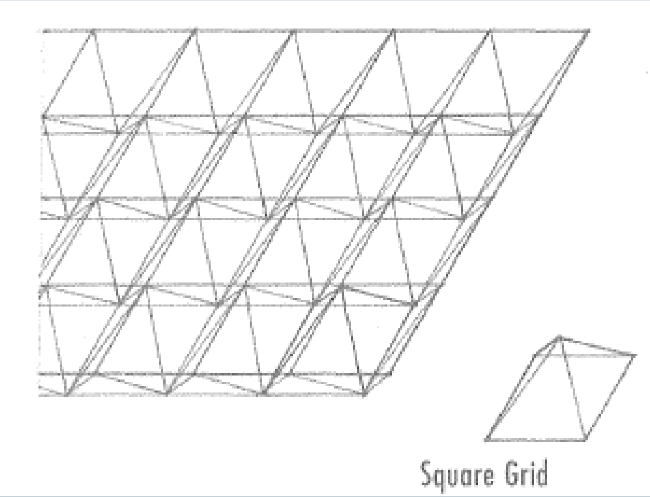
Spanning Systems - Trusses

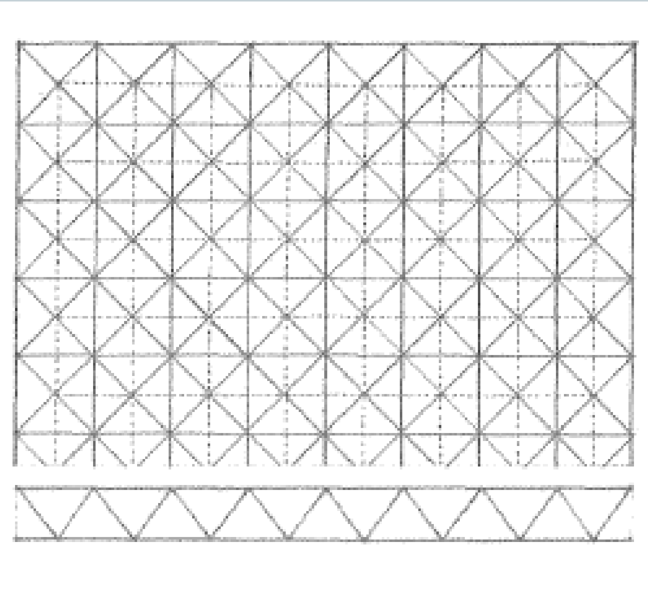


To prevent secondary shear and bending stresses from developing, **the centroidal axes of the truss members** and **the load at a joint** should pass through **a common point**



Spanning Systems - Space Trusses

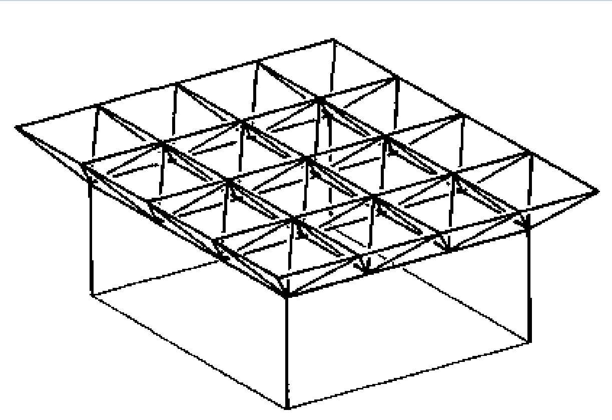


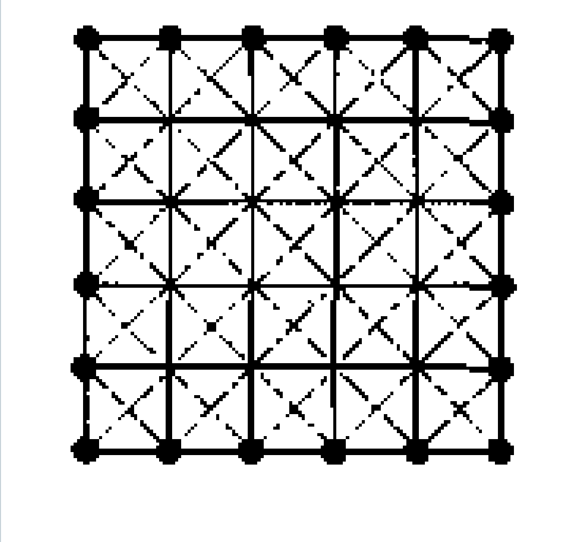


A space truss is
a long-spanning three-dimensional plate
structure based on the rigidity of the
triangle.

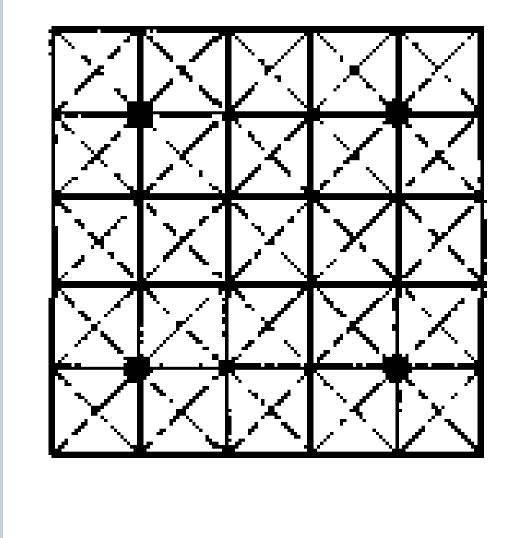
Two-way space trusses are most effective
if the spans in the principle directions are
almost equal.

Spanning Systems - Space Trusses





Support around perimeter



Minimal Support

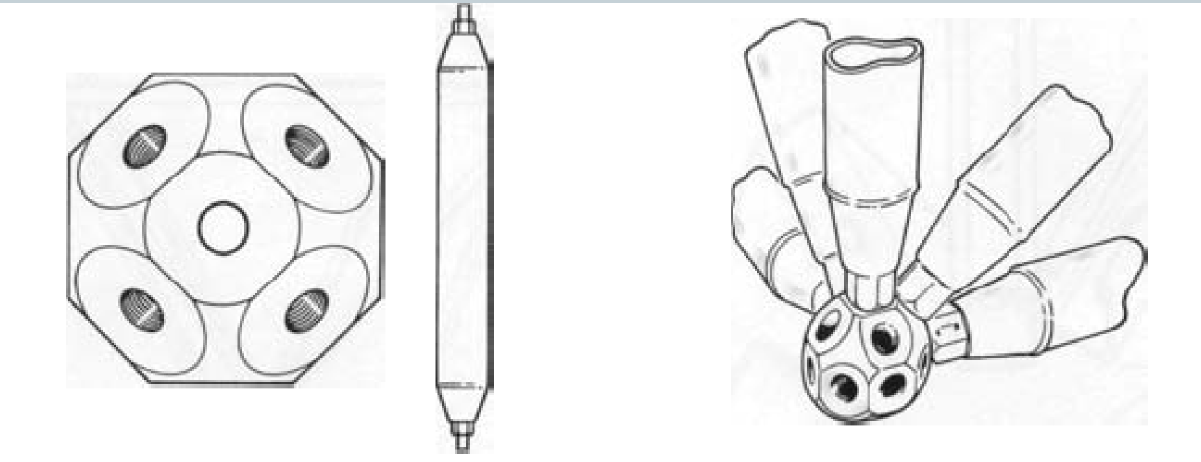
The most suitable overall plan-form is a square in which the frame is supported around its perimeter on columns or walls

Span/Depth = 20 (Approximately)

Spanning Systems - Space Trusses

Table 3.8 Approximate depths and span ranges for the Mero space framework

Span (m)	*Frame depth* (m)
up to 15	up to 1.5
15 to 27.5	1.5 to 2.1
27.5 to 36	2.1 to 2.5
36 to 50	2.5 to 4.0

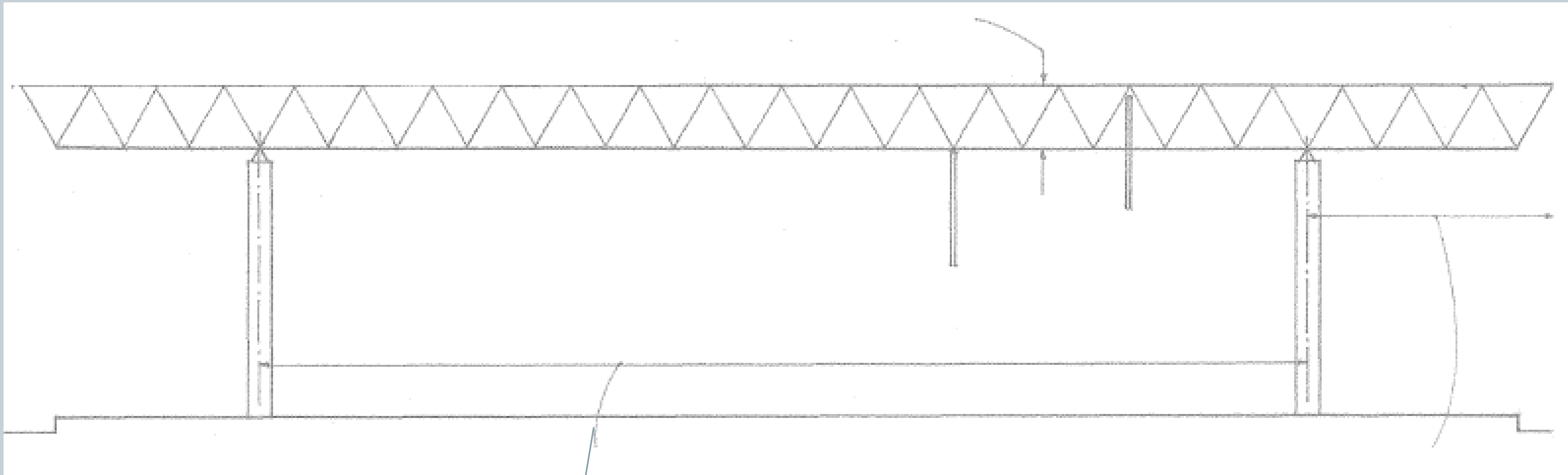


It is complicate to design and construct the space frames, therefore they are more expensive than the plane-truss systems.

Space frames are economically competitive at spans **greater than 20 m**

Spanning Systems - Space Trusses

Depth range: **span/12 to span/20**



Overhangs: **15% to 30% of span**

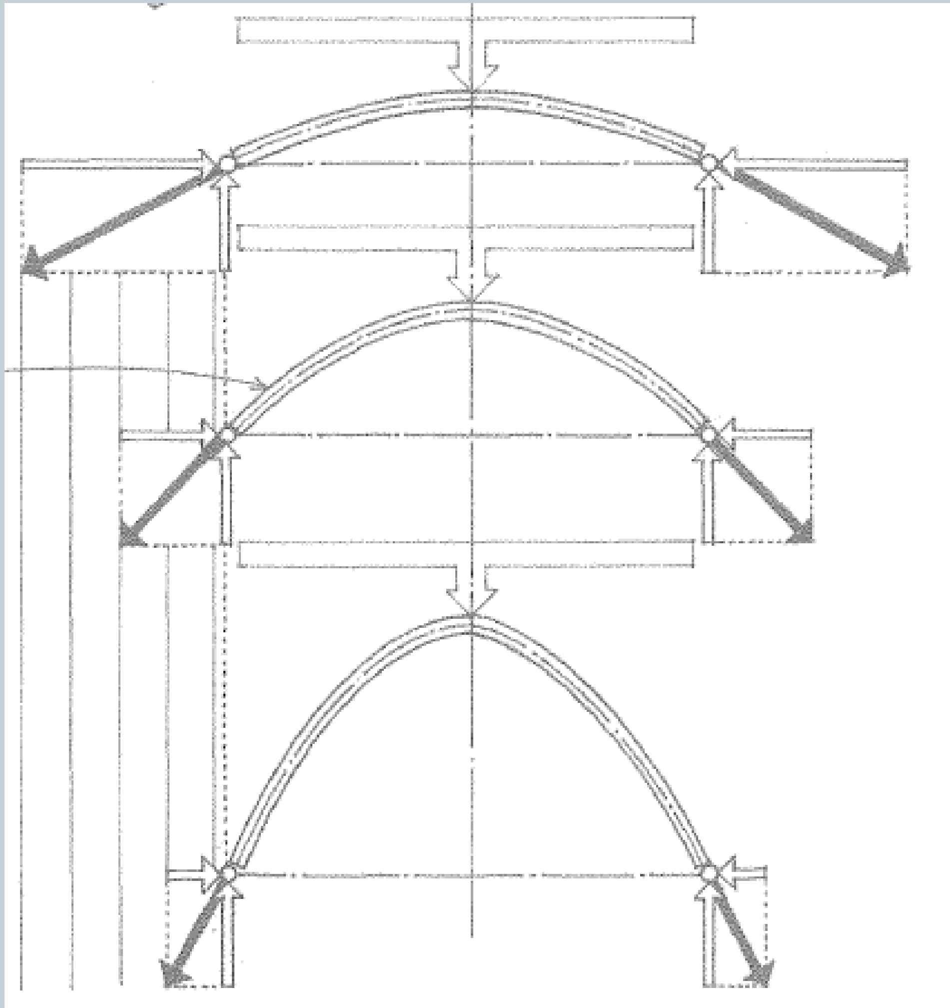
Span range for column-supported: **9 to 24 m**

Span range for wall-supported : **9 to 39 m**

Spanning Systems - Arch

Arch is an efficient spanning system through its shape and geometry (**structural form**).

- Arches are curved structures designated **to support a vertical load primarily by axial compression.**
- The thrust of an arch on its support is **proportional to the span and inversely proportional to its rise.**



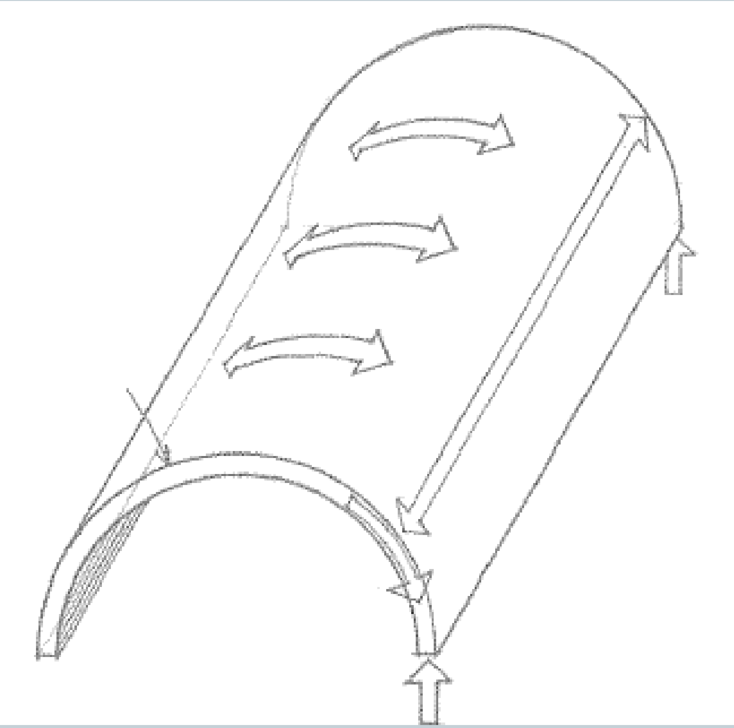
Spanning Systems - Arch

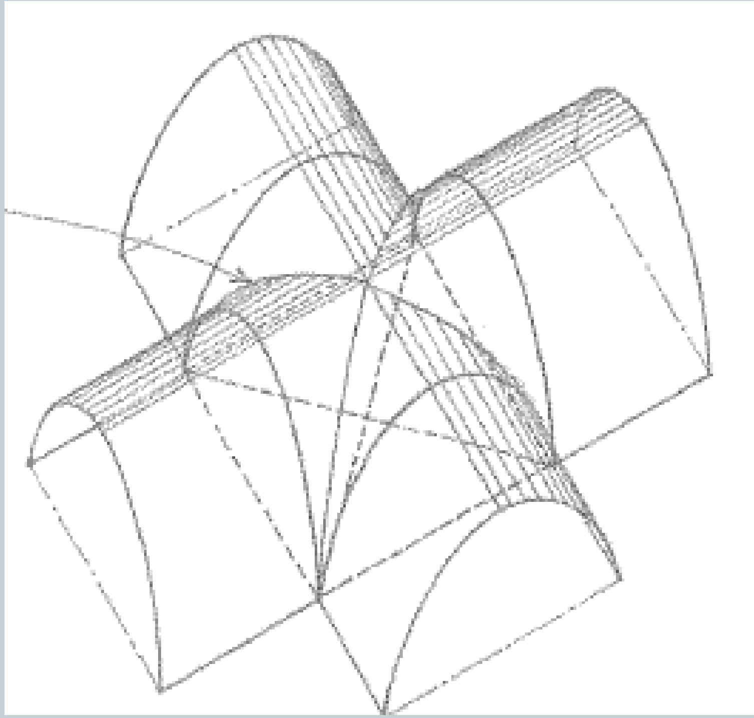
Skating Rink, (104m) (Munich, 1983) by Ackermann

Oriente Station (Lisbon) by Calatrava

Spanning Systems - Vault

- Vaults are arched structures forming a ceiling or roof over an area

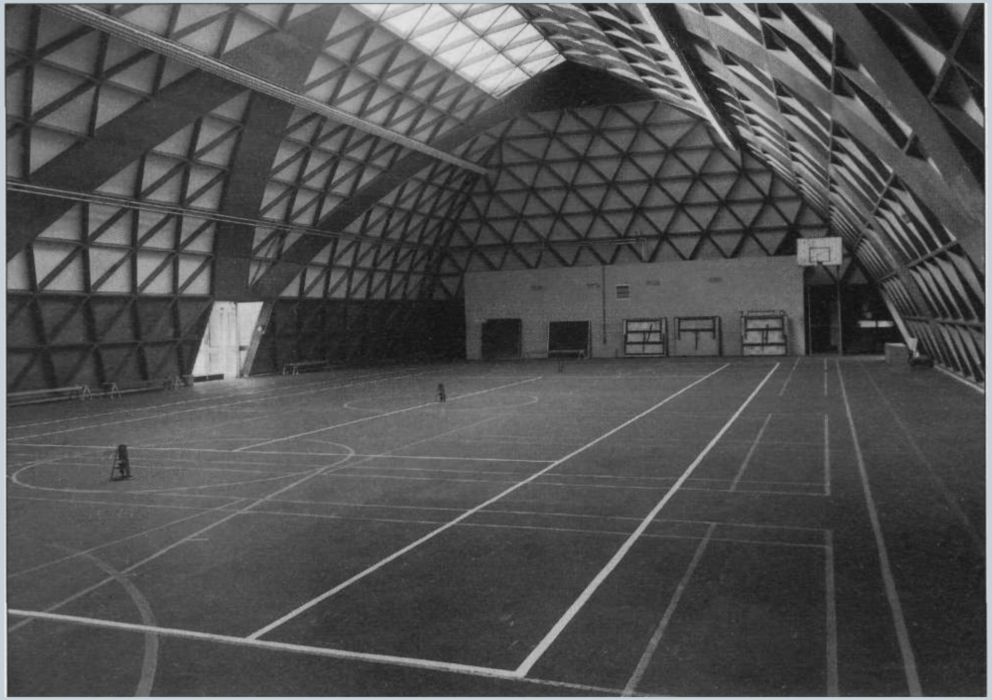




- Because a vault behaves as an arch extended in a third dimension, **the longitudinal supporting members must be strengthen for the outward thrust of the arching action**.

Spanning Systems - Vault

- The lamella vault is a system which allows large interiors to be created.

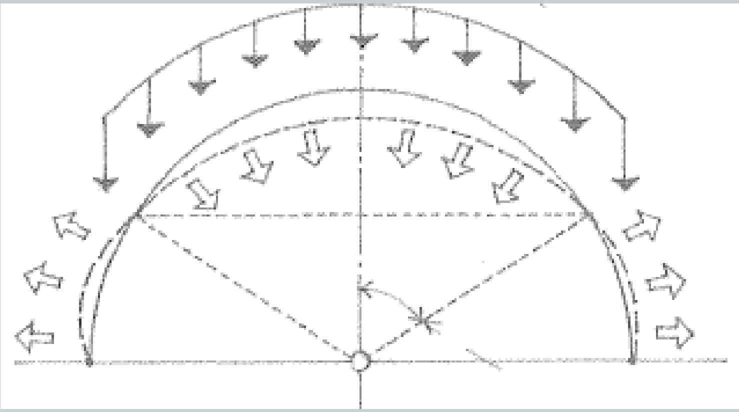


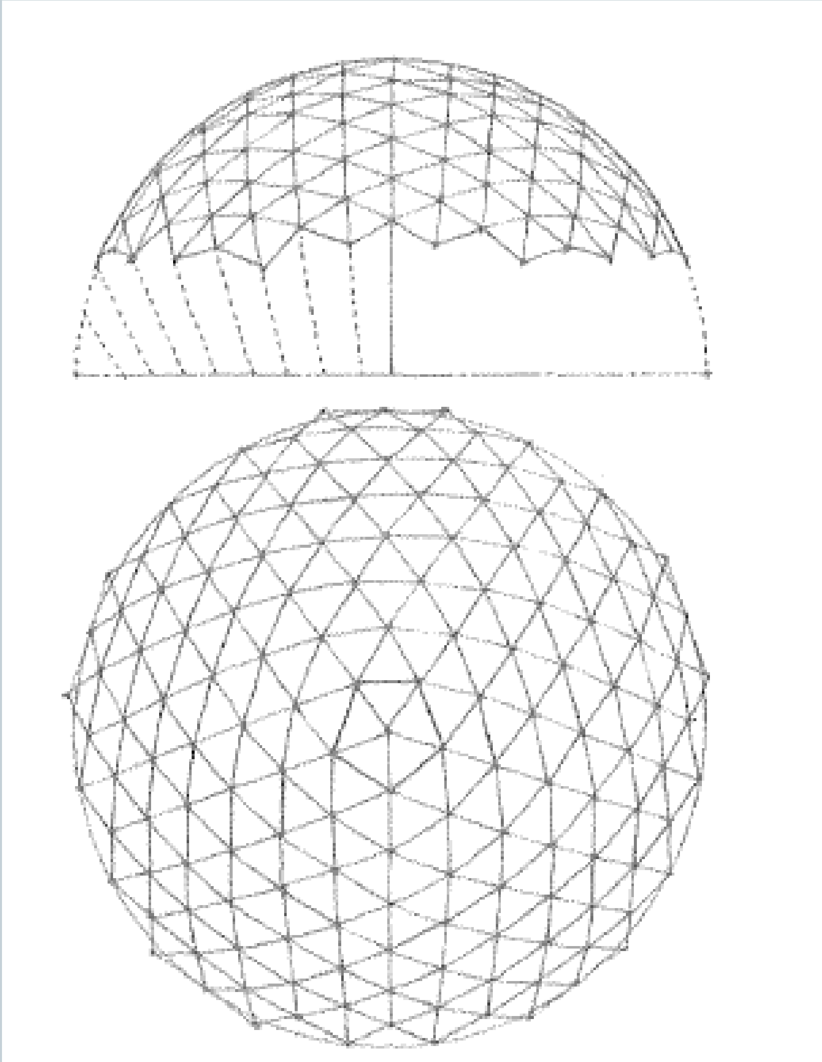
- Casa Mila, Gaudi

Spanning Systems - Dome

A dome is a spherical surface structure having a circular plan.

A dome is similar to a rotated arch except that circumferential forces are developed that are compression near the crown and tensile in the lower portion.



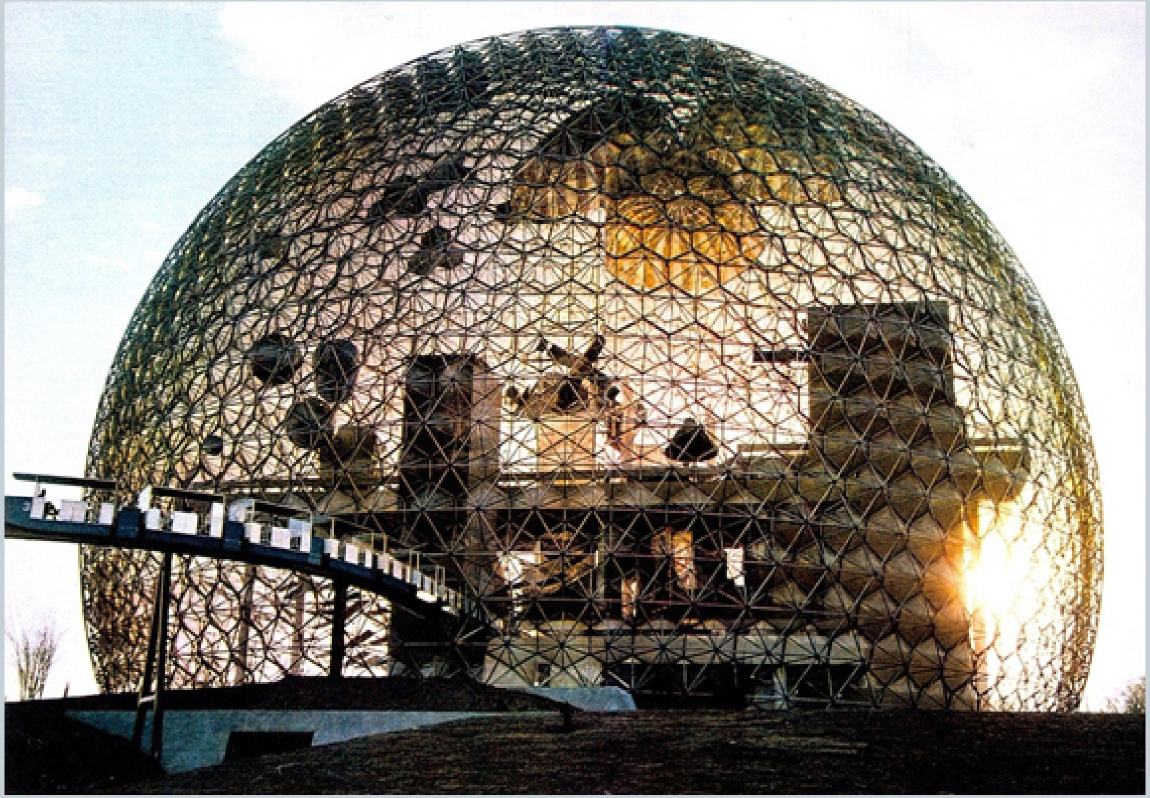


Spanning Systems - Dome

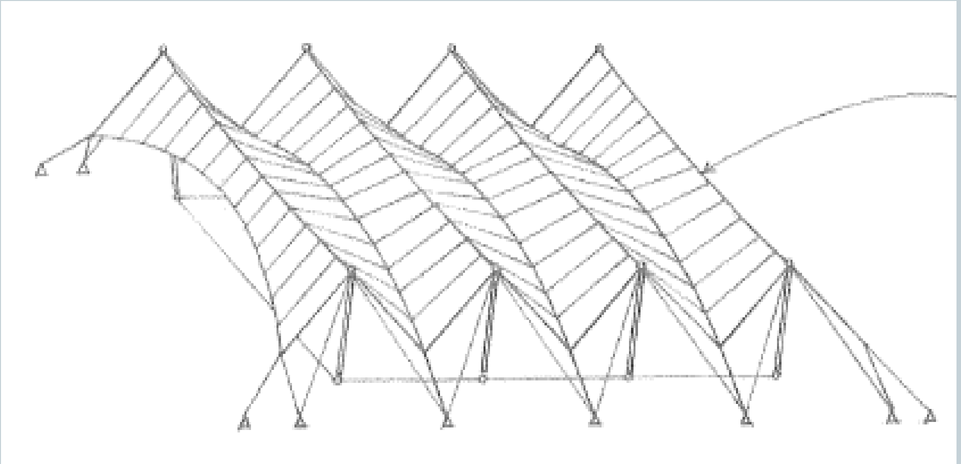
The dome of Selimiye Mosque by Great Sinan

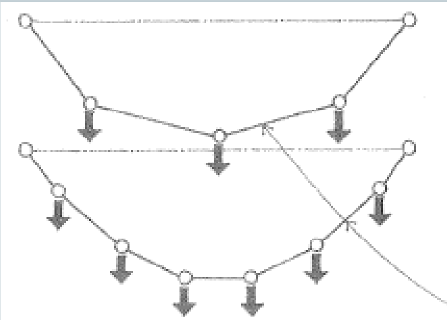
Spanning Systems - Dome

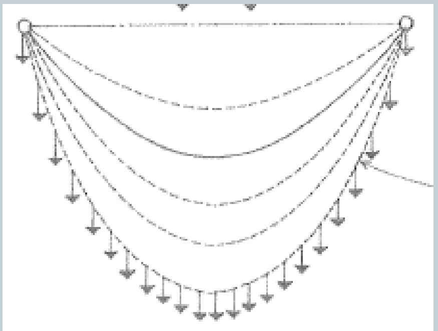
The Geodesic Dome (with a diameter of 80m)
US Pavillion in Montreal, 1967 by R. Buckminster Fuller



Spanning Systems - Cable Structures



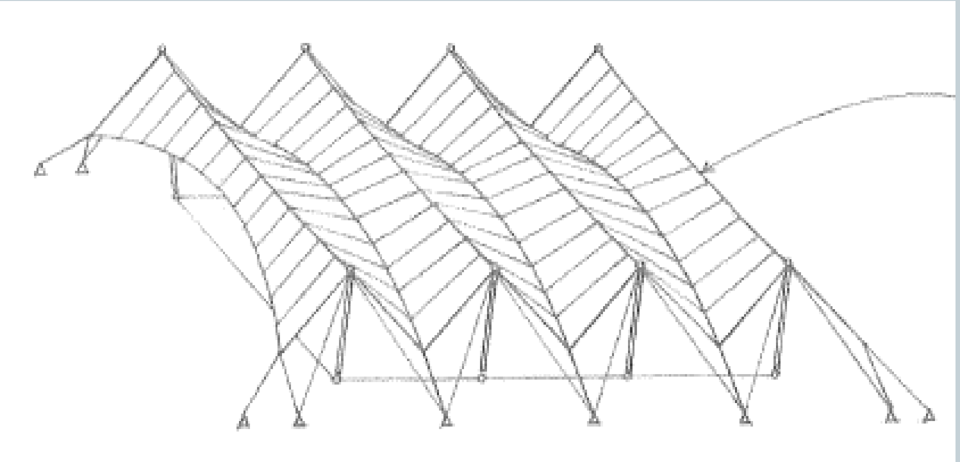


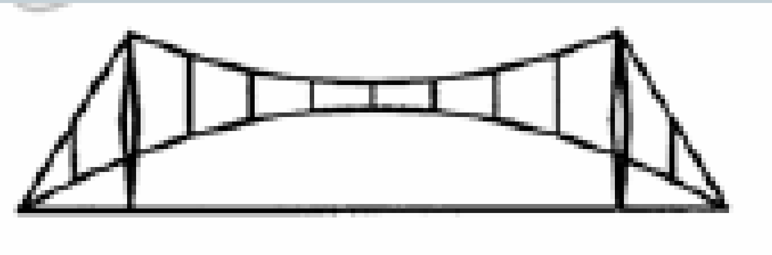


- Cable structures utilize the cable as the principle means of support. Because cables have high tensile strength but offer no resistance to compression or bending ,they must be used purely in tension.

- When subjected to concentrated loads, the shape of a cable consists of straight line segments.
- Under a uniformly distributed load, it will take on the shape of an inverted arch.

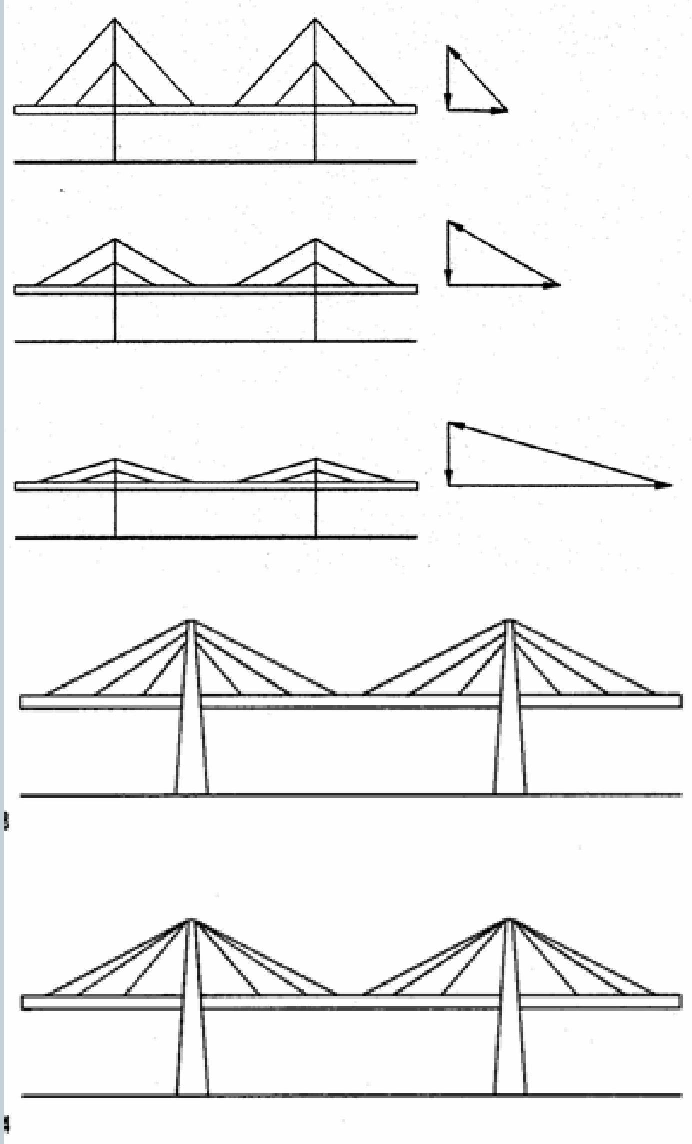
Spanning Systems - Cable Structures

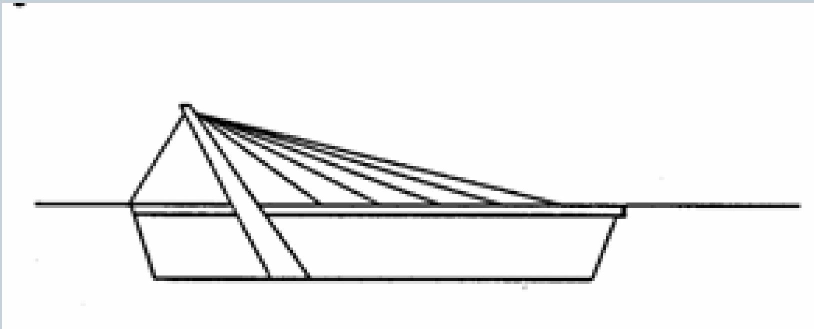




- They are effective if the curvature is compatible with spatial design objectives, and the thrust is resisted by a compression ring or grandstand.
- They are unstable under wind uplift and uneven loads
- Under wind uplift suspended cables tent to flutter. Stabilizing cables and ballast weight are used agains flutter

Spanning Systems - Cable Structures



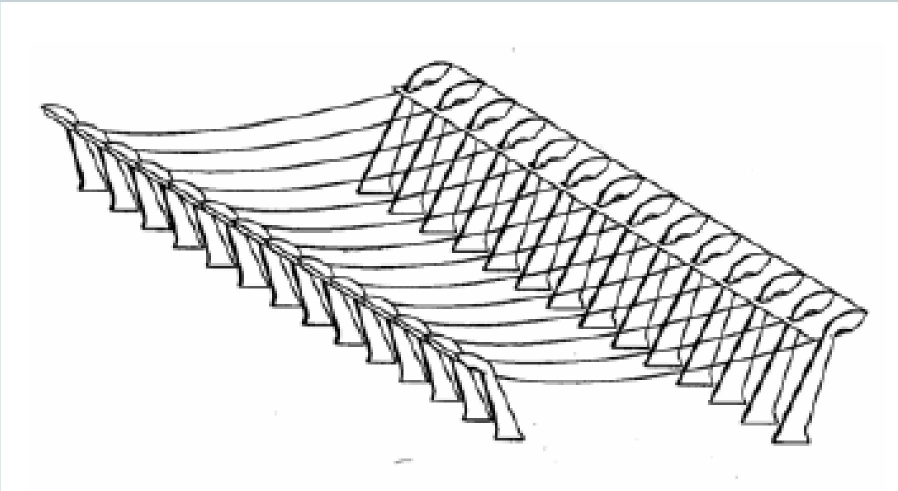


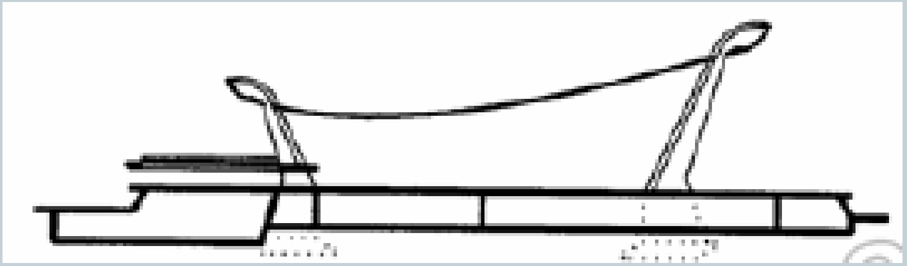
- Stay slope of 25° to 30° is usually optimal.
- Steep stay slope causes small forces but high masts.
- Shallow stay slope causes high forces but low masts.
- Span/depth ratio of about 10 to 15 is optimal.

Spanning Systems - Cable Structures

Dulles Airport by Saarinen

A cable (span=49m) roof supported by concrete **outward leaning** columns (span= 46m, a 46x183 m structure) and concrete edge beams.





The concrete dead weight resists wind uplift and minimizes the roof deformations.

Spanning Systems - Cable Structures

1998 Portugal Pavilion by Alvaro Siza

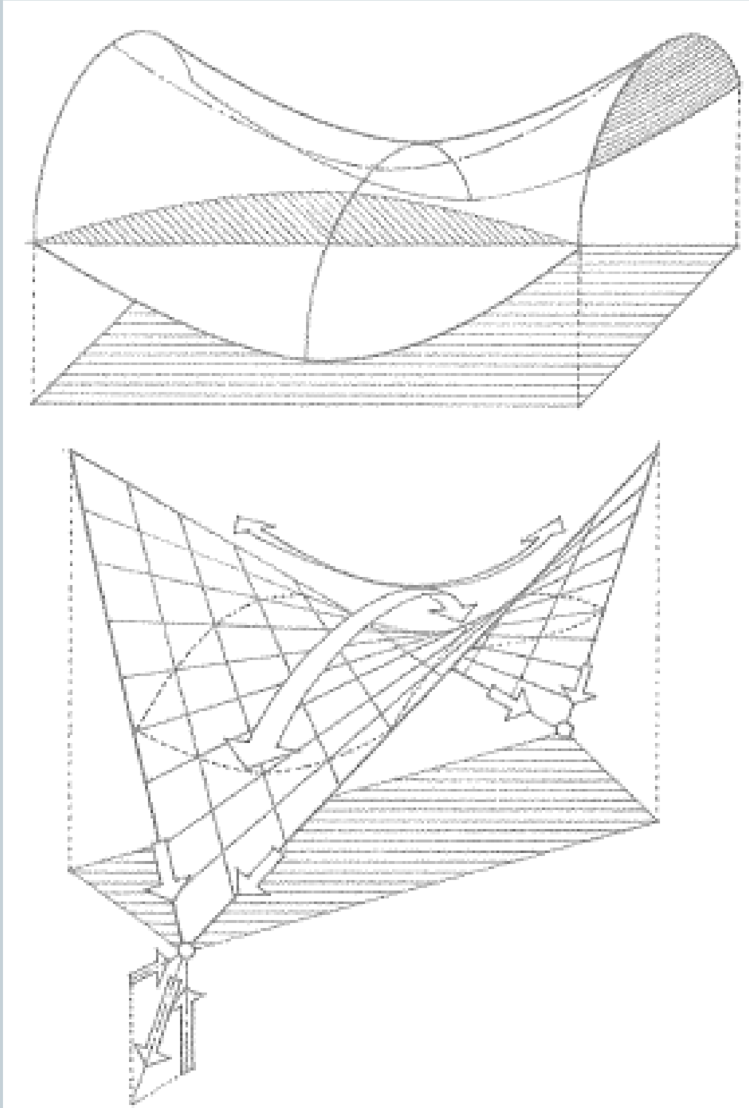
The Portuguese National Pavilion is a prestigious landmark building designed by Alvaro Siza to host Expo 98. The pavilion consists of two exhibition areas, one housing main exhibitions, the second providing a large outdoor space for national displays.

- The most iconic feature of the pavilion is a thin, curved concrete sail which creates a canopy over the ceremonial plaza.
- Cables supporting the canopy require enormous tension, provided by a series of 14m high fin-like walls which form porticos on either side of the plaza.

Spanning Systems - Shell Structures

•Shells are thin, curved plate structures typically constructed of reinforced concrete.

•A shell can sustain relatively large forces if uniformly applied. Because of its thinness, however, a shell has little bending resistance and is unstable for concentrated loads.



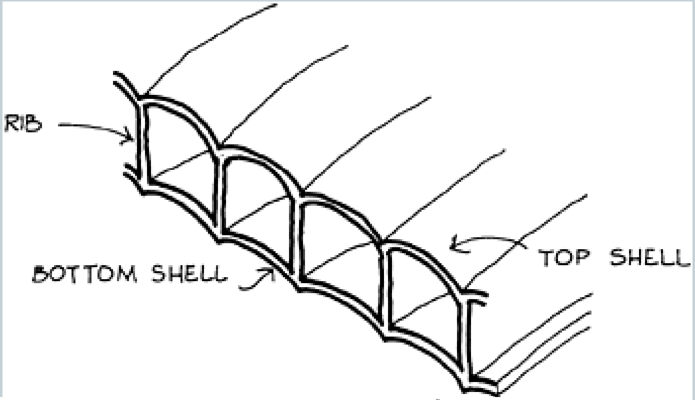
Spanning Systems - Shell Structures

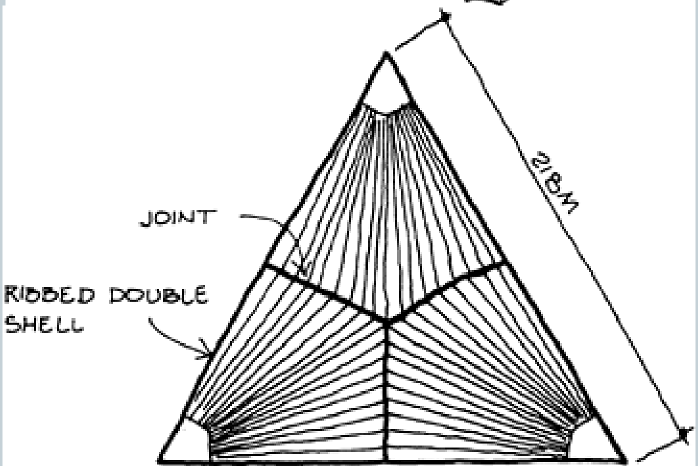
CNIT by Camelot, De Mailly and Zehrfuss (Architects) and Prouve, Esquilan (Engineers)

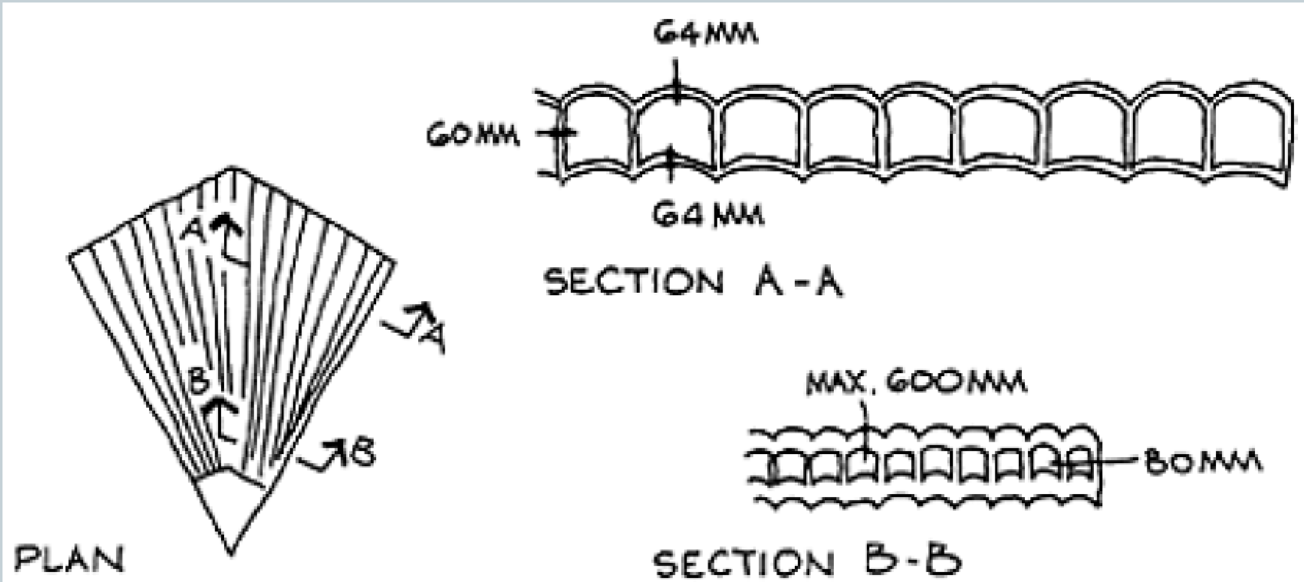
CNIT : the largest unsupported concrete (post-tens.) span (two hundred and eighteen meters wide and forty six meters high)

Spanning Systems - Shell Structures

structure	location, year, architect	geometry	dimensions	radius *a*	thickness *t*	ratio *a* / *t*
CNIT	Paris 1957 Esquilan	intersection of 3 cylinders on 3 supports	219 m between supports	89.9–420.0 m	1.91–2.74 m total 0.06 – 0.12 m outer layers	47–153







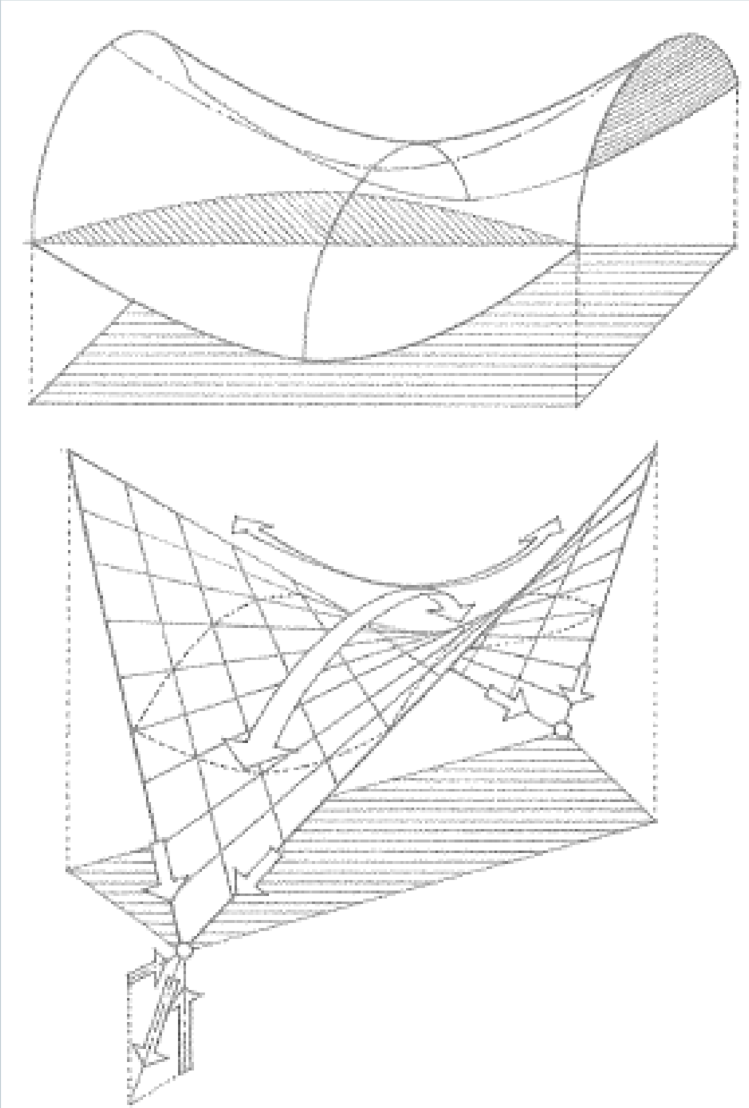
References:

- Building structures : from concepts to calculations/ Malcolm Millais, New York : Spon Press, 2005.
- CT4143 Shell Analysis Class Notes, Delft University of Technology

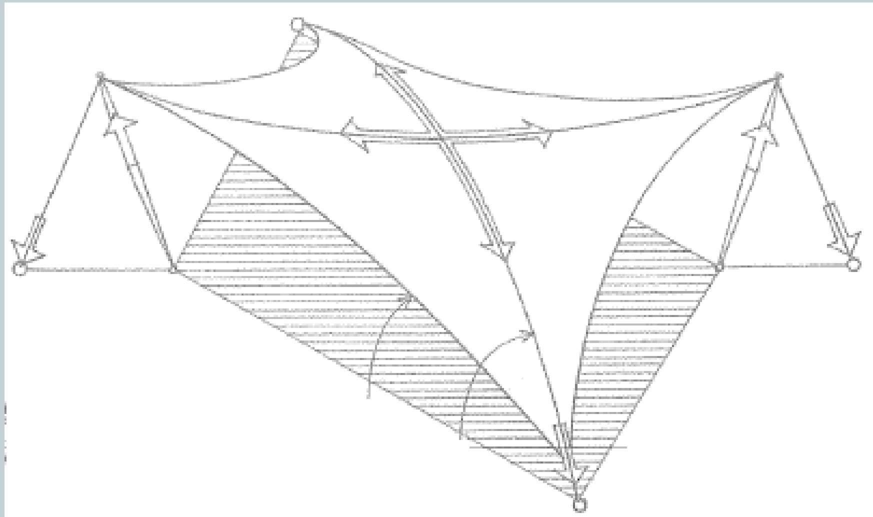
Spanning Systems - Shell Structures

Table 4.5 Typical thicknesses of hyperbolic paraboloid shells in reinforced concrete

Span (m)	*Shell thickness (mm)* *At crown*	*At edges*
10	40	50
20	40	75
30	40	100
40	75	130



Spanning Systems - Membrane Structures



- Membranes are thin, flexible surfaces that carry loads primarily through the development of tensile stresses.

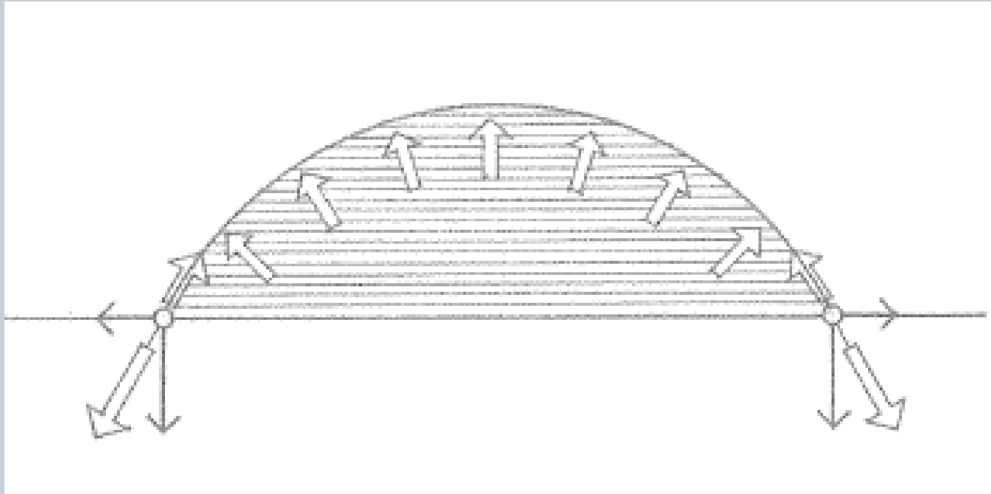
- They may be suspended (German pavilion by Otto, expo 67)

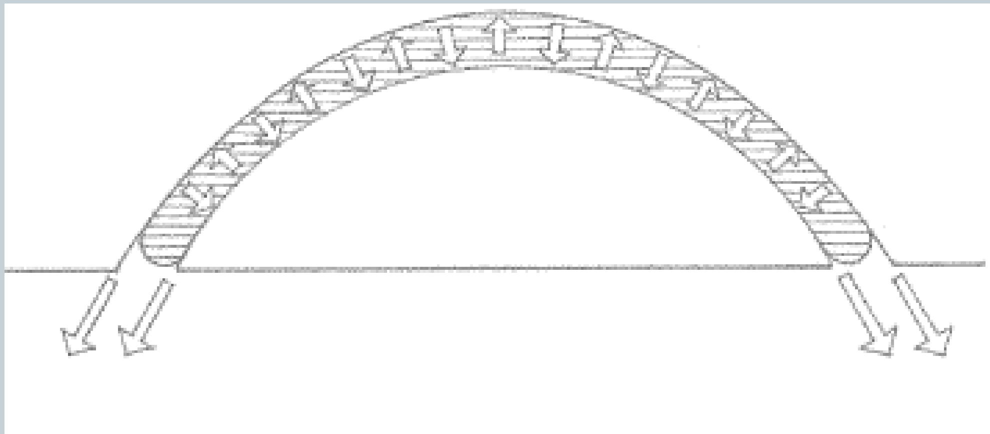
Spanning Systems - Membrane Structures

- or stretched between posts

- or be supported by air pressure (Pneumatic structures, Tokyo Dome ≈ 185m x 185m)

Spanning Systems - Membrane Structures





Pneumatic structures

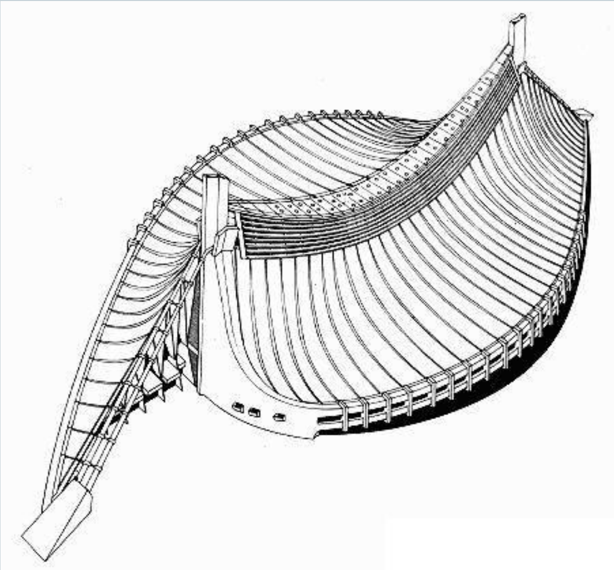
- Air-supported structures consists of a single membrane supported by an internal air pressure slightly higher than normal atmospheric pressure (i.e., 0.3% in Tokyo Dome)

- Air-inflated structures are supported by pressurized air within inflated building elements

Spanning Systems - Membrane Structures

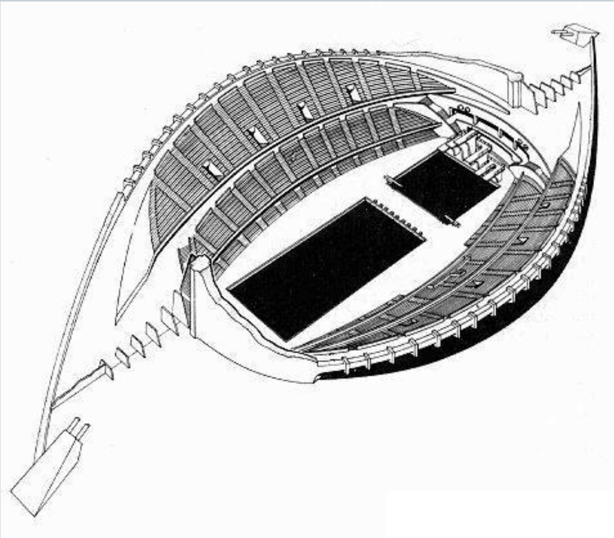
Olympic Pool Tokyo (1964) by Tange

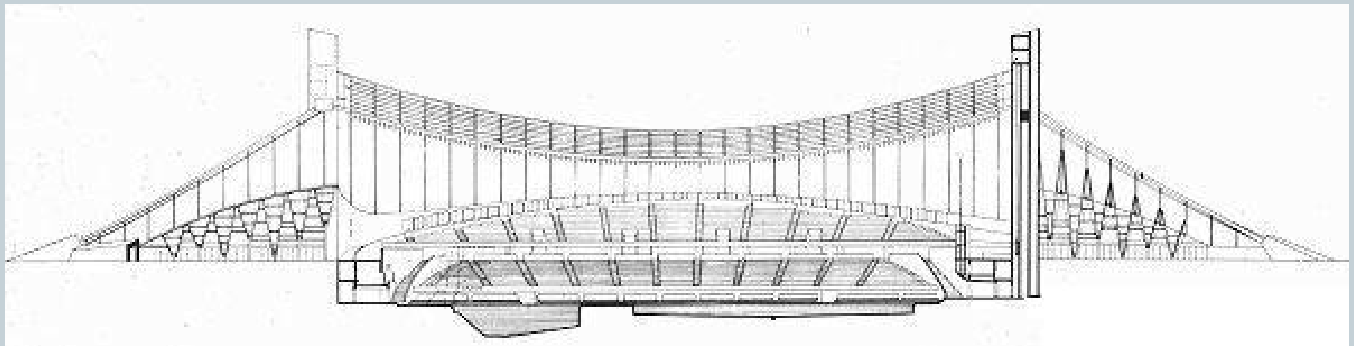
Spanning Systems - Membrane Structures



Olympic Pool Tokyo (1964) by Tange

•Two anticlastic saddles supported by two cables draped over two concrete columns.





Spanning Systems - Membrane Structures

Olympic Roof, Munich (1972) by Behnisch and Otto

A spider web hovering over the landscape