

THEORY & DESIGN OF STRUCTURES IV



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UNIT – III

Tensile Frames

TENSILE FRAME





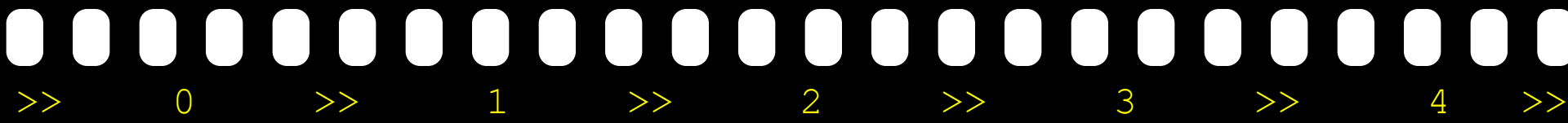
TENSILE FRAMES

➤ DEFINITION

- Members of tensile structures are subjects to pure tension under the action of external loads. Because the tensile stress is uniformly distributed over the cross-sectional area of members, the material of such a structure is utilized in the most efficient manner.

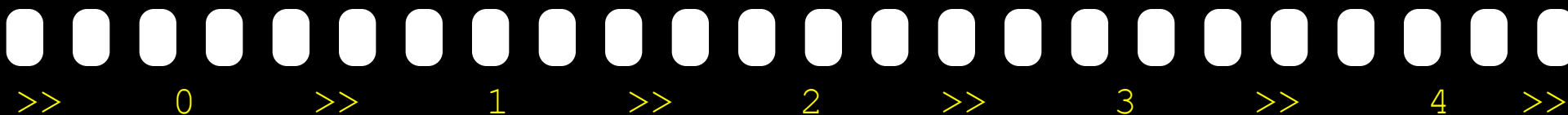
TENSILE FRAMES

- A **tensile structure** is a construction of elements carrying only tension and no compression or bending. The term tensile should not be confused with tensegrity, which is a structural form with both tension and compression elements. Tensile structures are the most common type of thin-shell structures.
- Most tensile structures are supported by some form of compression or bending elements, such as masts (as in The O₂, formerly the Millennium Dome), compression rings or beams.
- A **tensile membrane structure** is most often used as a roof, as they can economically and attractively span large distances



The briefest of histories

- Tensile fabric structures have been with us since the Mongolians swept down from the plains, with their yurts as their transportable overnight accommodation. The Bedouins have done the same for untold years. And there's evidence that the Romans even covered the Colosseum with massive canopies, hoisted by an intricate system of pulleys, to protect the audience from the elements.



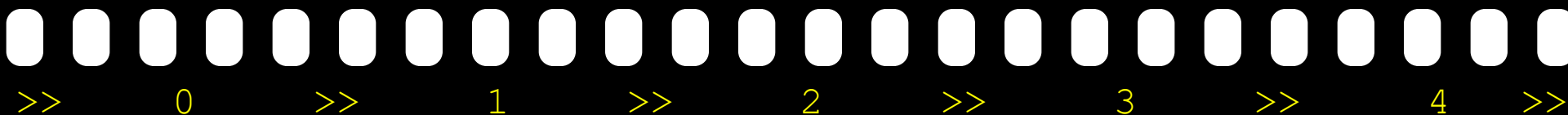
The briefest of histories

- But they really came into their own in the last half of the 20th century, when designs like this by Germany's Frei Otto opened everyone's eyes to what could be created with a little imagination... and a deeper understanding of fabric and cable engineering.



The briefest of histories

- The ability of fabric to form double curvature surfaces and its inherent translucency has always been attractive for designers. But with the advent of computer form finding and the development of reliable structural fabrics the world of tensile structures took a giant leap forward.



Frei Otto Olympic Stadium

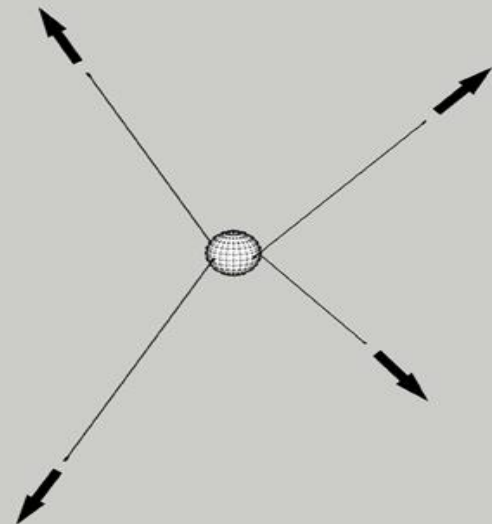
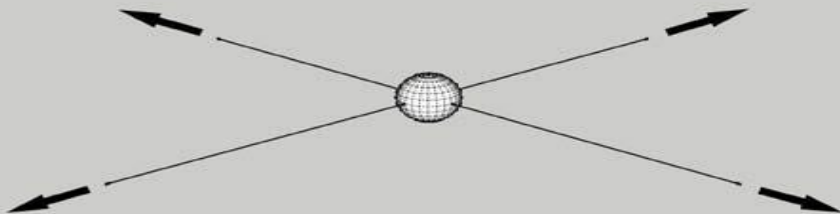


Colosseum roof



Why tensiles are the shape they are

- Large flat pieces of fabric are very poor at resisting loads*. Imagine four of you each pulling on the strings laced through a tennis ball.
- Fig 1. A fifth person pushing down on the ball can deflect it easily. Imagine a flappy marquee roof. Try lifting two opposite strings and lowering the other two.
- Fig 2. The ball is now locked in space. Apply this principle to fabric and you have created 'anticlastic' double curvature**. Sounds grand but actually is simply derived from one of three fabric shapes; the hypar, the cone and the barrel.



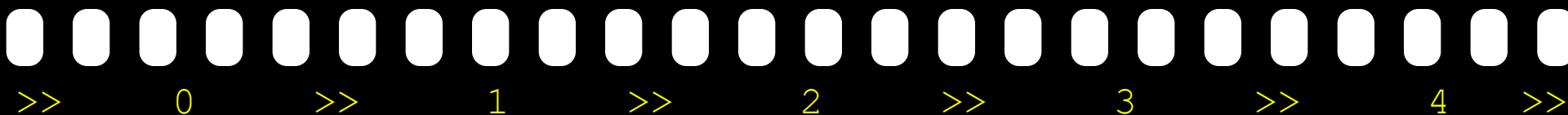
Why tensiles are the shape they are

- Flat fabric panels can be used to create larger structures – The O2 dome in Greenwich is a cable net with lots of flat panels inbetween.
- Inflatables have synclastic curvature where the fabric is curved the same way in two axis.



Loading Mechanism

- The high tensile strength of steel, combined with the efficiency of simple tension, makes a steel cable the ideal structural element to span large distances.
- Cables are flexible because of their large small lateral dimensions in relation to their lengths. As uneven stresses due to bending are prevented by flexibility the tensile load is evenly divided among the cable strands.
- In order to understand the mechanism by means of which a cable supports vertical loads, one may first consider a cable suspended between two fixed points, located at the same level and carrying a single load at mid span. Under the action of the load the cable assumes a symmetrical triangular shape and half the load is carried to each support by simple tension along the two halves of the cable.



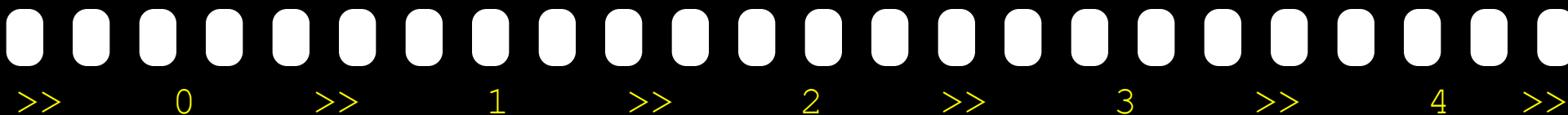
Where do the loads go?

- In the image below you can see that all the tensile loads are contained within the steel frame. This solution is particularly appealing where you don't want to apply 'pull out' loads to an existing building.



Where do the loads go?

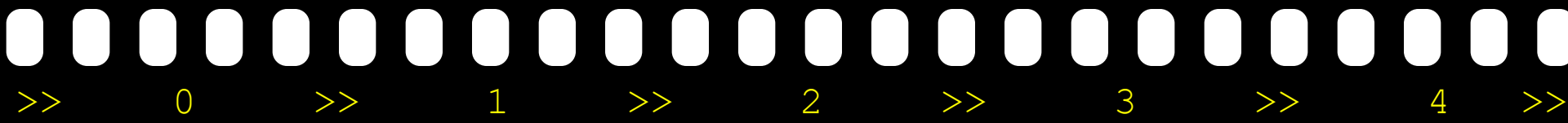
- With the classic tensile fabric structure there is no frame and the tensile loads are transferred directly into the surrounding building or foundations via masts and tie rods. So while the structure itself will look lighter and airier, it will probably require larger foundations – not unlike a suspension bridge.
- There are some complex maths involved in deriving loads, all of it meat and drink to a computer, and we can advise on this.



Things you should know

- **Insulation**

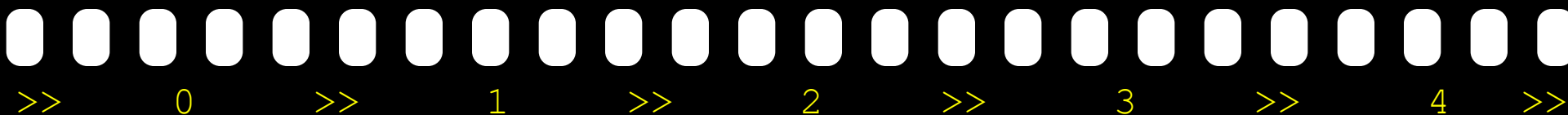
Although fabric structures are generally used to cover unheated spaces it is possible to have a multi layer construction consisting of an inner and outer fabric skin with an interlayer of insulation. One disadvantage is the loss of translucency, although there are now translucent products such as Nanogel that could be used if the budget permits. A double skin construction can be used to reduce the risk of condensation if this cannot be designed out by other means.



Things you should know

- **Fire safety**

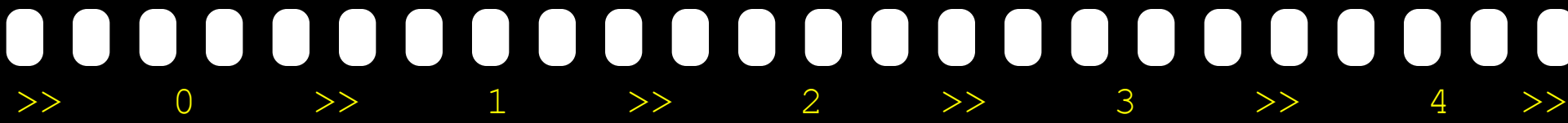
All structural fabrics are fire rated although some behave differently than others in a fire. Pvc coated polyesters will melt back from a heat source which is useful for venting the flames & smoke. Coated glass fibre based fabrics will tend to produce less smoke and stay intact longer until the seams fail at very high temperatures. Any fabric producing burning droplets is totally unsuitable. The European fire coding system measures flammability, smoke production and burning droplets.



Things you should know

- **Acoustics**

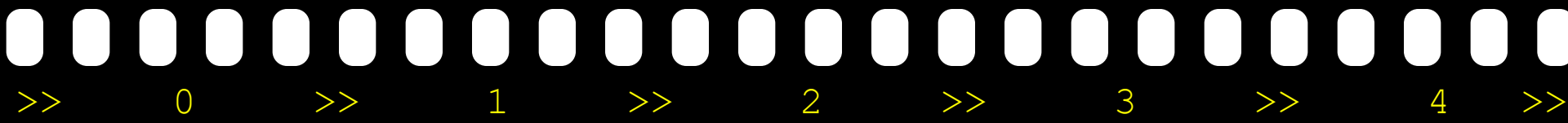
To achieve an effective sound absorption you need plenty of mass, which is not one of fabric's strong points. What fabric is useful for is reducing reverberation times in interiors with a lot of hard surfaces. The best combination is a mesh fabric with an acoustic quilt behind. One technical fabric by Mermet has been engineered to reduce mid to high frequency sound whilst still being translucent to light.



Things you should know

- **Environmental**

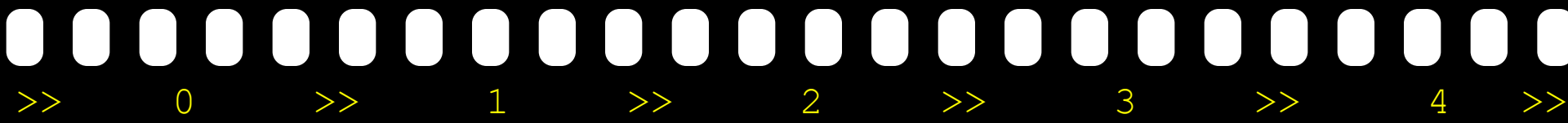
Many (but not all) of the fabrics now in popular use can be recycled. If this is a major concern for you or your client, the fabric matrix gives an indication of this and we can give more detailed advice. The amount of embodied carbon can also be calculated for your project.





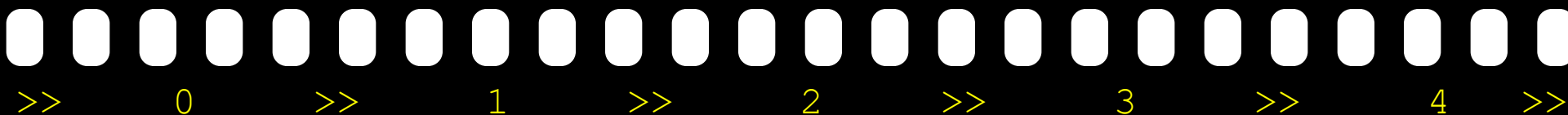
Types Of Tensile Structures

- Stayed
- Suspended
- Anticlastic
- Pneumatic
- Cable Truss

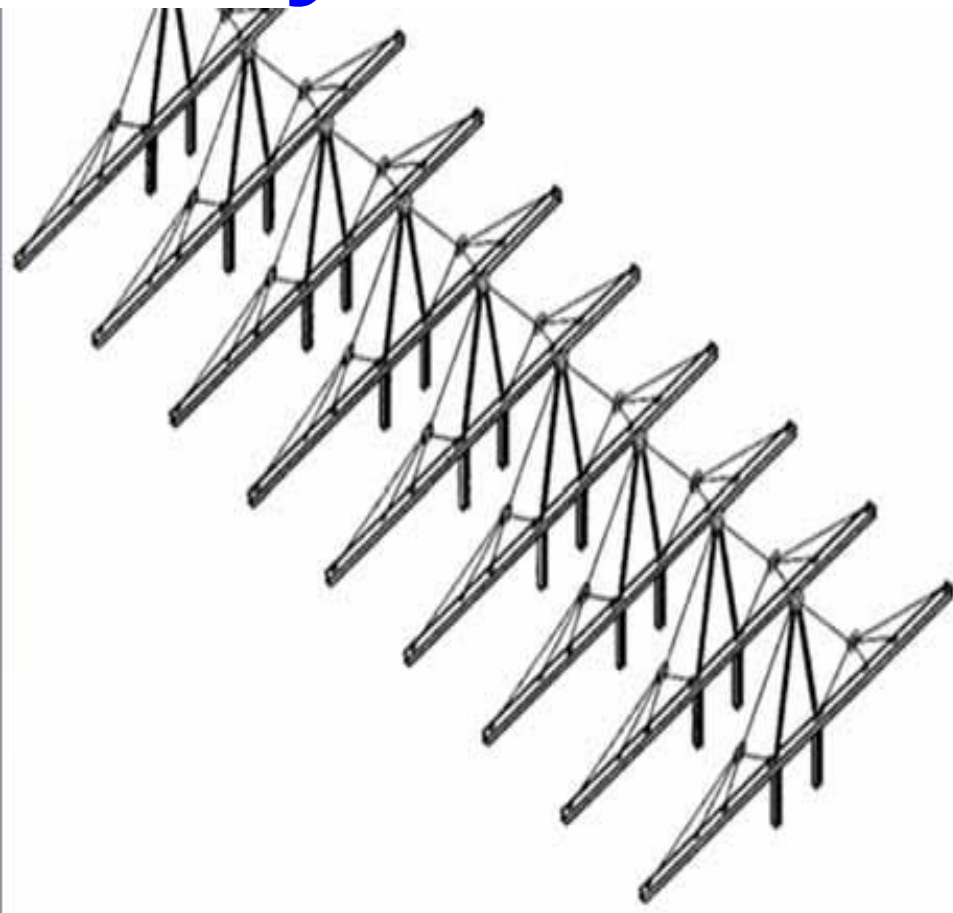


Stayed

- To span railroad trucks underneath, the truss roof is suspended by stay cables from concrete pylons.
- 1 Axon
- 2 Section
- 3 Center joint
- 4 Exterior joint
- A Pylon top
- B Stay cable
- C Truss web bar
- D Stay bracket
- E Edge stay, resists wind uplift



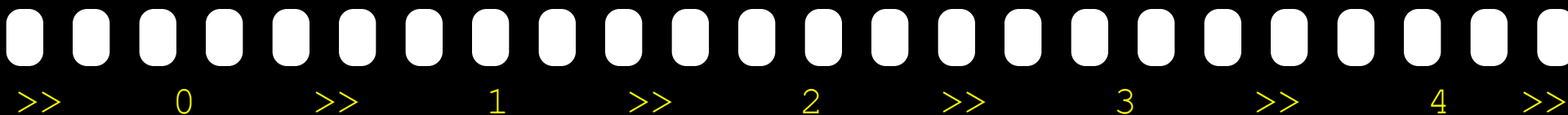
Stayed Tensile Structures



Suspended

Suspension span/sag ratios:

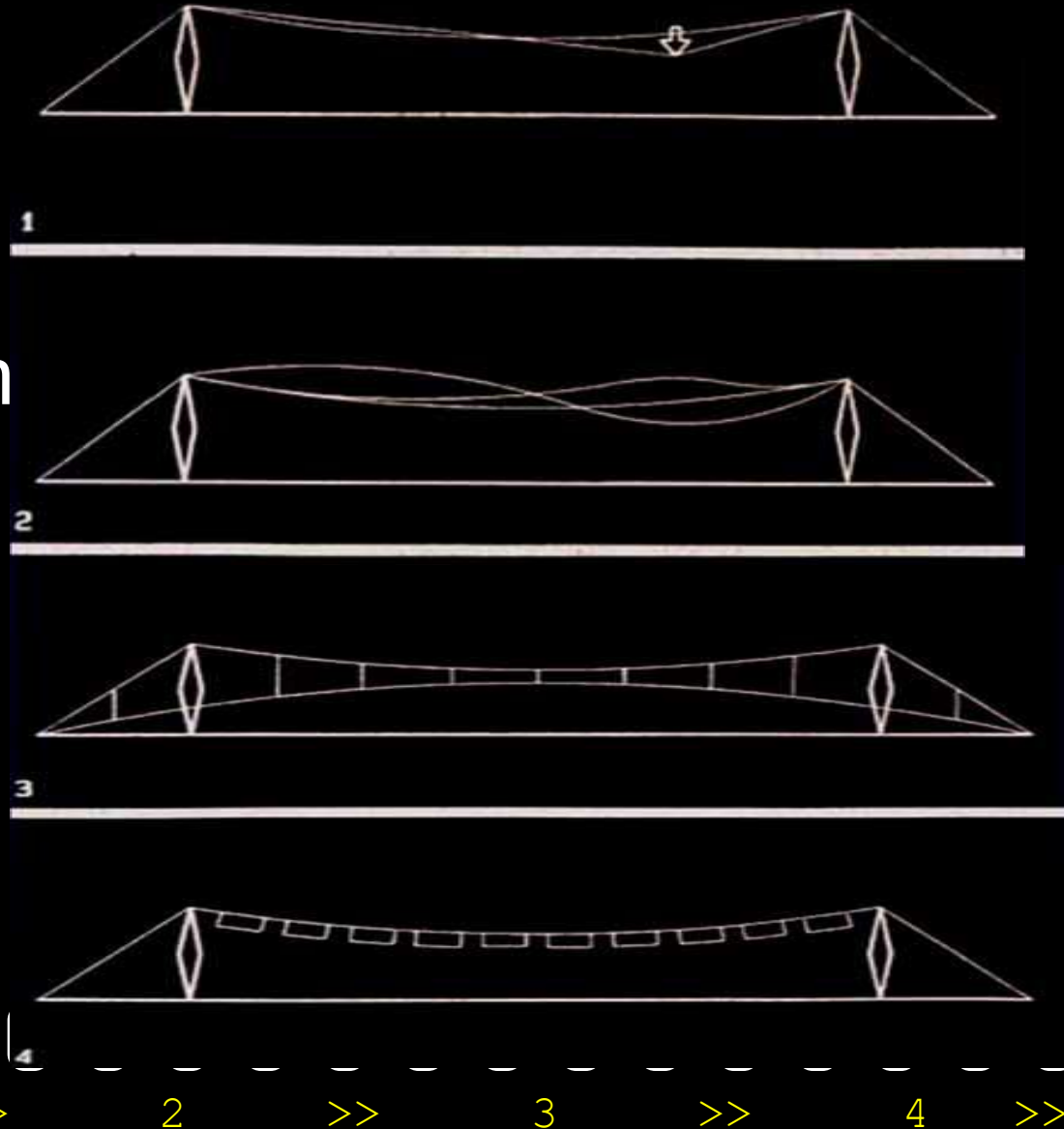
- Small sag = large stress
- Large sag = small stress but tall supports
- Optimal span/sag ratio = 10



Suspended

Stability issues:

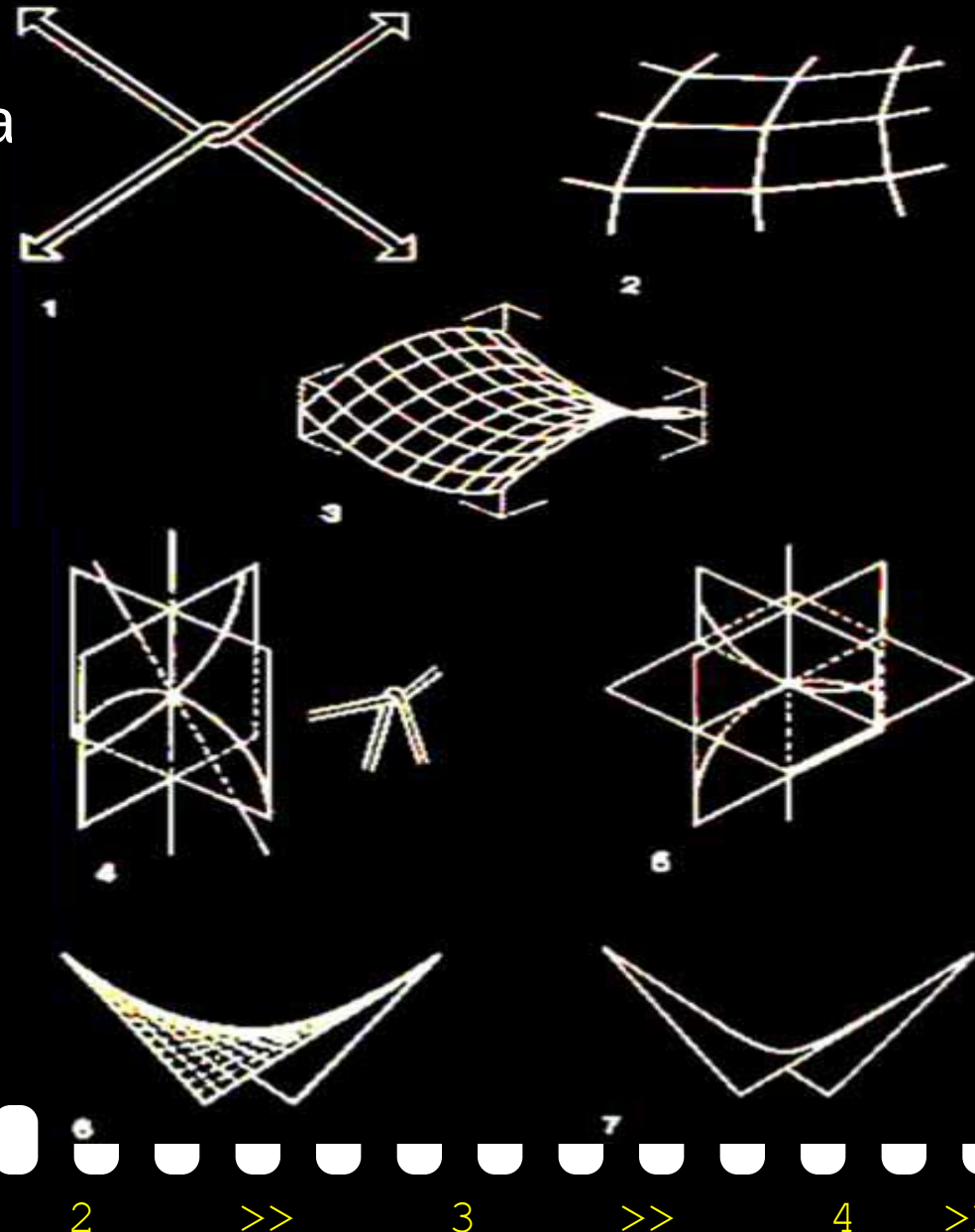
- 1 Point load deformation
- 2 Wind deformation
- 3 Stabilizing cable to resist wind uplift
- 4 Dead load to resist wind uplift



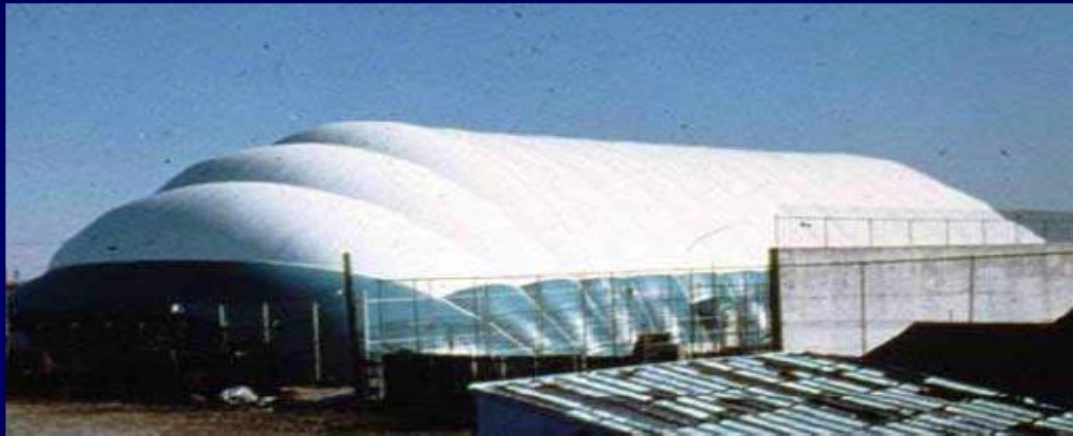
Anticlastic

Anticlastic Surface

- 1 Opposing strings stabilize a point in space
- 2 Several opposing strings stabilize several points
- 3 Anticlastic curvature stabilizes a membrane
- 4 Membrane shear causes wrinkles in fabric
- 5 Stress without wrinkles
- 6 HP-surface Quadratic equation
- 7 Minimal surface



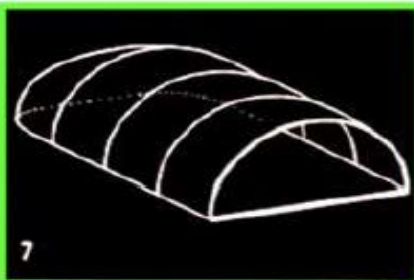
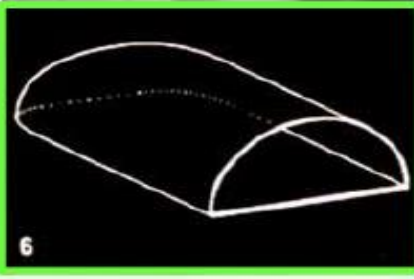
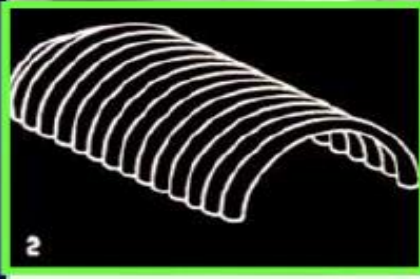
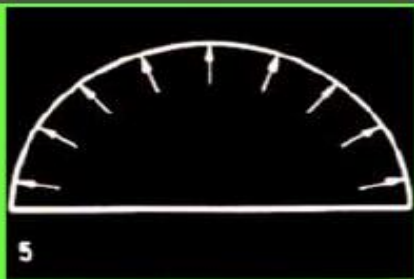
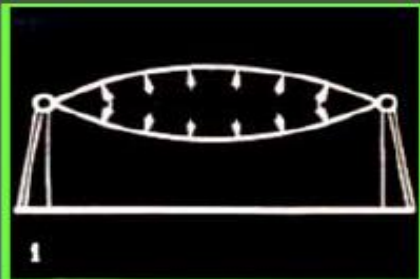
Pneumatic



Air Supported



Air Inflated
Fuji pavilion Osaka Expo 1970



Pneumatic structure types:

Left: Air inflated

Right: Air supported

1 Air inflated cushion

2 Air inflated vault

3 Air inflated dome

4 Air inflated dome grid

5 Air supported dome

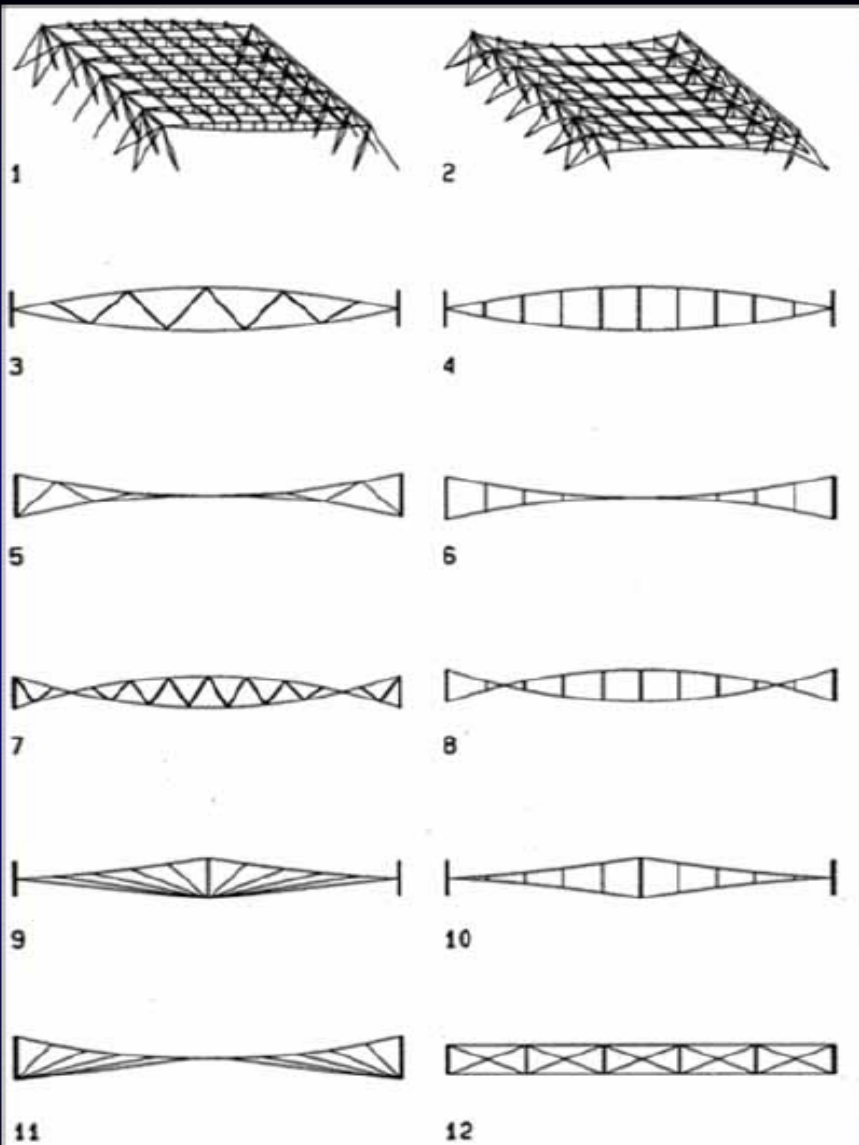
6 Air supported vault

7 Air supported vault with cables

8 Air supported dome grid

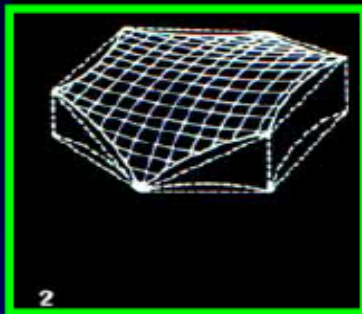
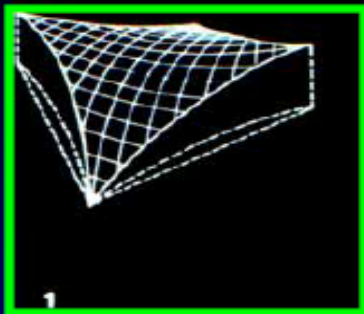
Cable Truss





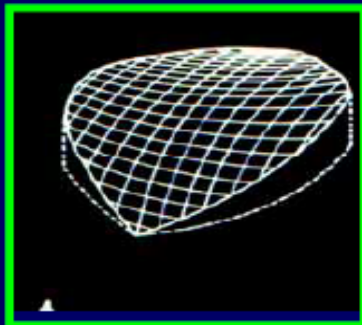
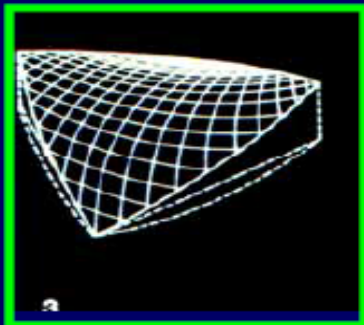
Cable trusses

- 1 Lintel trusses
- 2 Concave trusses
- 3 Lintel truss with compression braces
- 4 Lintel truss with compression struts
- 5 Concave truss with tension braces
- 6 Concave truss with tension struts
- 7 Concave/lintel truss with braces
- 8 Concave/lintel truss with struts
- 9 Gable truss with radial strut
- 10 Gable truss with center compression struts
- 11 Radial brace truss
- 12 Flat chord truss with compression struts

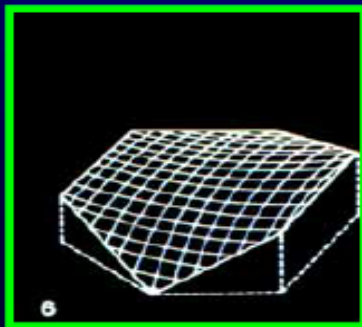
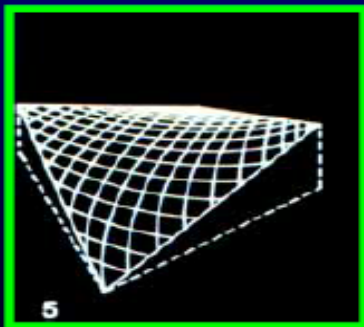


Edge Conditions

1, 2 Edge Cable



3, 4 Edge Arch



5, 6 Edge Frame



Edge Cable





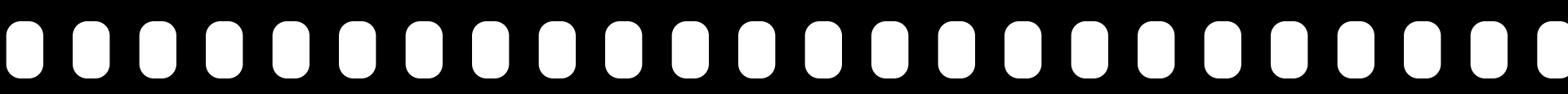
Edge Arch



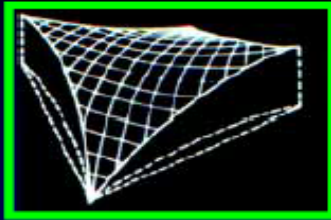


Edge Frame





Surface Conditions



Surface Conditions

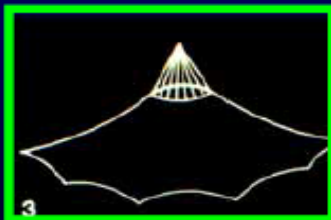
- Saddle shapes



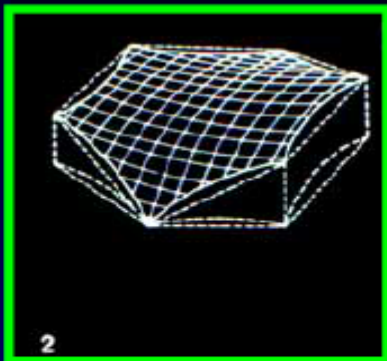
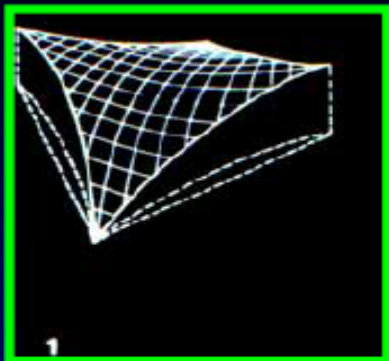
- Arch shapes



- Wave shapes



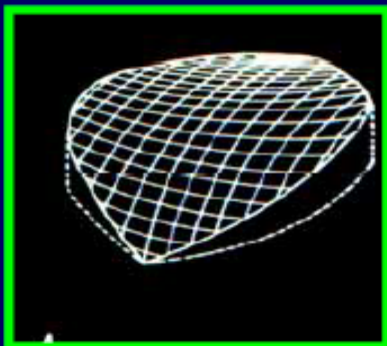
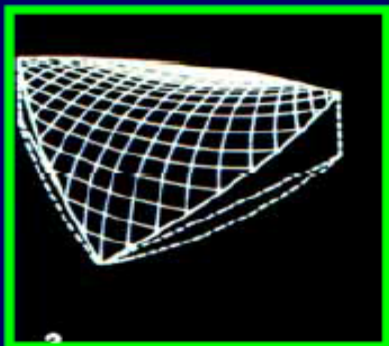
- Point shapes



Saddle Shapes

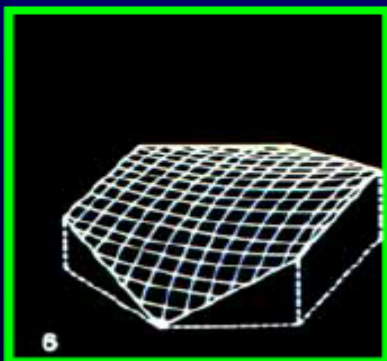
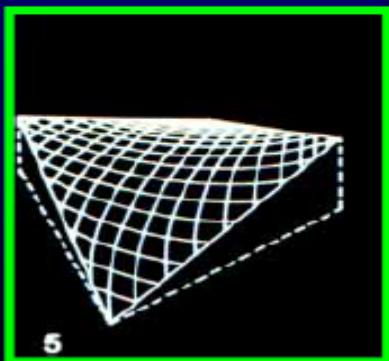
1 Square / cable edge

2 Hexagon / cable edge



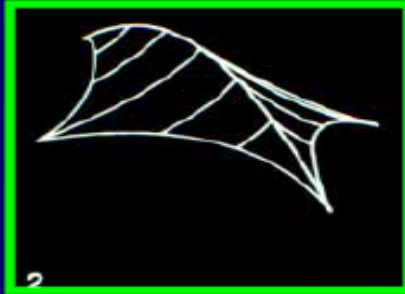
3 Square / arch edge

4 Oval / arch edge



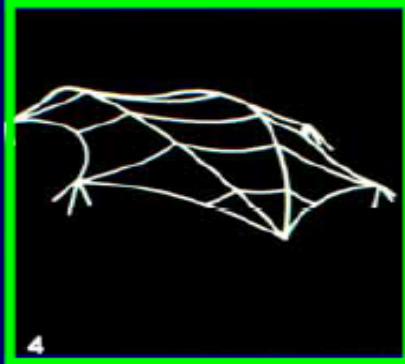
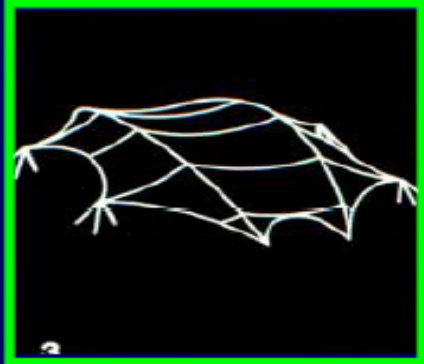
5 Square / beam edge

6 Hexagon / beam edge

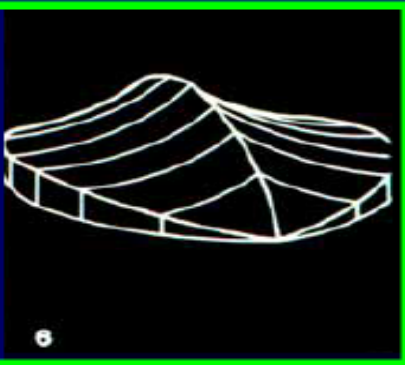
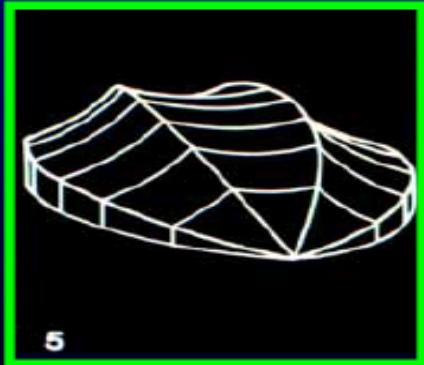


Arch Shapes

1, 2 Single arch / edge cable

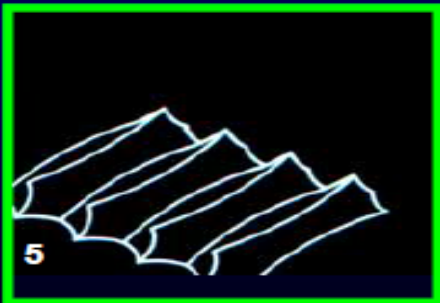
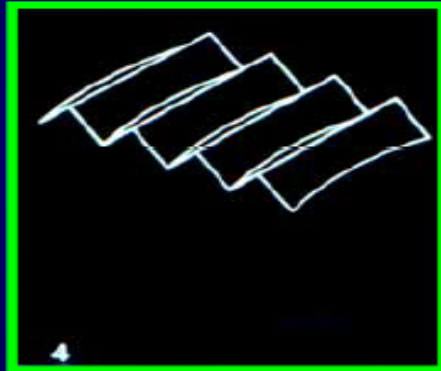
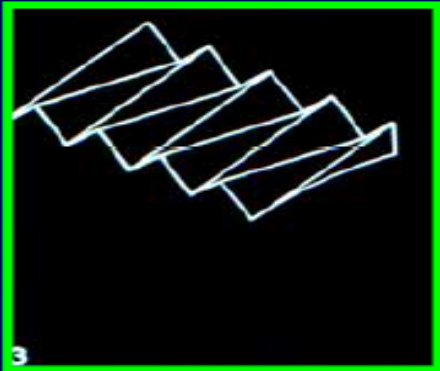
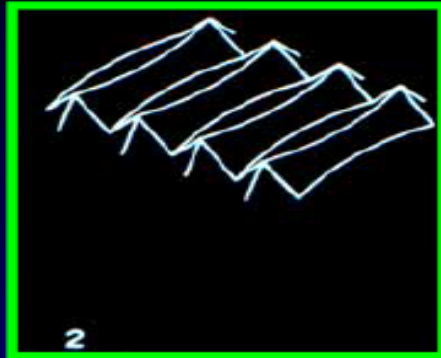
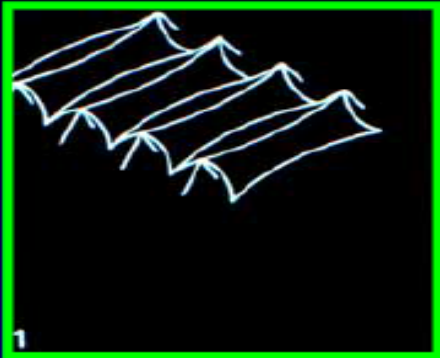


3, 4 Twin arch / edge cable



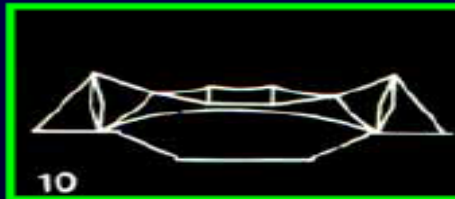
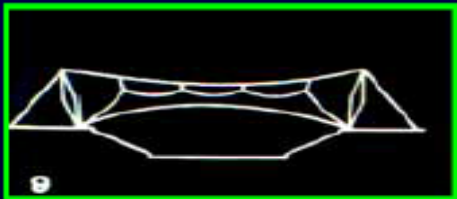
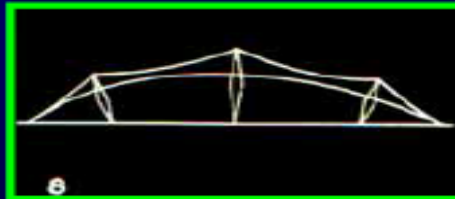
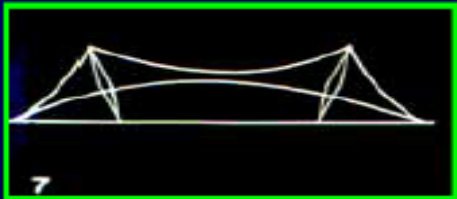
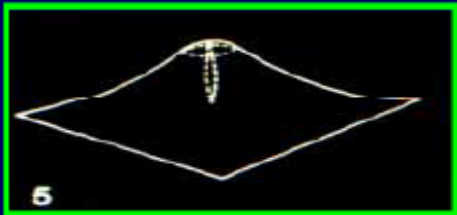
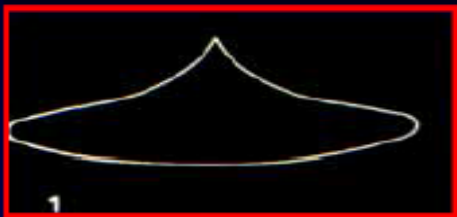
5 Twin arch / edge arch

6 Single arch / edge arch



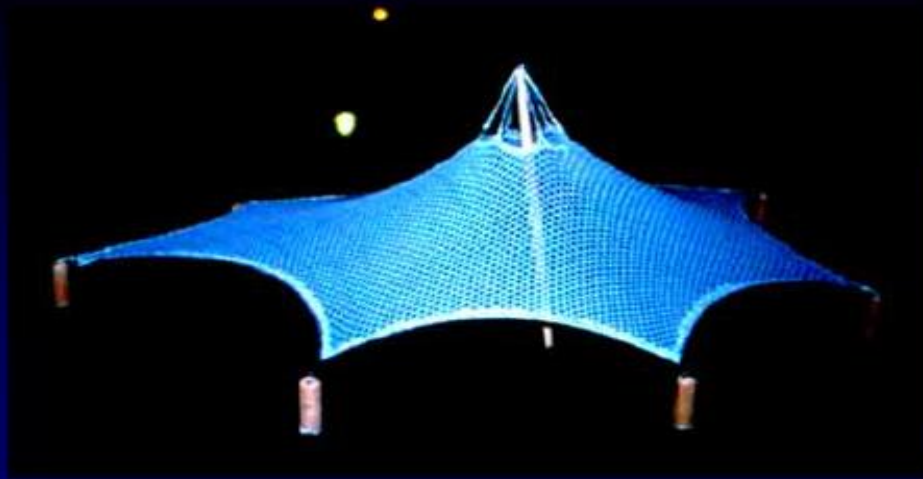
Wave Shapes

- 1 Ridge/valley cables, cable edge
- 2 Ridge/valley cables, beam edge
- 3 Ridge/valley beams, beam edge
- 4 Ridge beam/valley cable beam edge
- 5 Ridge/valley cables, closed end
- 6 Ridge/valley cables, circular plan



Point Shapes

- 1 Mast punctures fabric
- 2 Radial cables
- 3 Ring with radial cables
- 4 Loop cable
- 5 Dish top
- 6 Eye cable
- 7 Twin mast rows
- 8 Three mast rows
- 9 Suspension cables
- 10 Supporting cables



Design Process

Stretch fabric models



Design Process computer models Cutting patterns by triangulation

