2.1 Introduction

These are systems of flexible, non-rigid matter, in which the redirection of forces is
effected by particular form design and characteristic form stabilization. Examples are:

- Cable structures
- Tent structures
- Pneumatic (inflatable) structures
- Arch structures.

Form-active structures are normally used only in circumstances where a special structural
requirement to achieve a high degree of structural efficiency exists, either because the span
involved is very large or because a structure of exceptionally light weight is required. They
have geometries which are more complicated than post-and-beam types and they produce
buildings which have distinctive shapes (Macdonald, 2001). Form-active structures are
almost invariably statically indeterminate and this, together with the fact that they are
difficult to construct, makes them very expensive in the present age, despite the fact that
they make an efficient use of structural material.

2.2 Cable structures

Cable structures are a type of tensile structures. A tensile structure is a construction of
elements carrying only tension and no compression or bending. Tensile structures can be
linear, three dimensional or surface stressed. Tensile structures comprise of cables,
membranes or both cables and membranes.

Common cable structures include:
- Suspension bridges
- Draped cables
- Cable-stayed beams or trusses
- Cable trusses
- Straight tensioned cables
- 3D cable trusses

2.3 **Structural concept of cable structures.**

High strength steel cables have been used extensively over the past twenty-five years for space roof structures. There are two different possibilities when using steel cables in roof structures. The first possibility, consists of using the cables only for suspension of the main roof structure, which can be either conventional, e.g. beams, cantilevers, etc., or a space frame. In this case, the main roof structure, instead of being supported, is actually suspended from steel cables above the roof, which transmit the tensile forces to appropriate anchorages. They are cable-stayed roofs.

Use of cables to suspend main structure

In this type of construction, the cables behave as simple suspension elements, while the roof structure itself behaves like a normal load resisting unit, subject to moments, shears, and other kinds of action effect. It is expected that the suspending elements remain in tension, even under wind uplift, due to the dead weight of the roof.

The second possibility is represented by those roof structures where the steel cables are effective members of the roof structure itself, and not just conveyors of forces from the
structure to the anchorages. In this type of construction (tension structures), the cables themselves resist the various external loads. Their particular behaviour has deeply influenced the structural forms used and has imposed new methods of execution. Tension structures may be categorized as:

- Single-layer cable systems
- Double-layer prestressed cable truss systems
- Prestressed tensile membrane systems
Prestressed tensile membrane system (an anticlastic cable net)

Single cable structures are characterized by their flexibility. They require stiffening to prevent a change of shape with each variation in load and to make them capable of resisting uplift due to wind. Gusty winds can produce oscillations, unless damping is provided to the structure. The principal methods of providing stability are the following:

1. Additional permanent load supported on, or suspended from, the roof, sufficient to neutralize the effects of asymmetrical variable actions or uplift. This arrangement has the drawback that it eliminates the lightweight nature of the structure, adding significant cost to the entire structure.

2. Rigid members acting as beams, where permanent load may not be adequate to counteract uplift forces completely, but where there is sufficient flexural rigidity to deal with the net uplift forces, whilst availing of cables to help resist effects of gravity loading.
3. Rigid surfaces behaving as inverted shells or vaults, where uplift forces are countered by the in-plane compressive rigidity of the structure.

4. Secondary cables prestressing the main cables so that these remain in tension under all conditions of load. Such prestressing can take a variety of forms:
   - a stayed (guyed) arrangement, wherein the main cable is stayed to other elements or to the ground, as in the case of guyed trusses
   - A planar arrangement of suspension and stabilising cables, with opposite curvatures cables. This structure reacts elastically to all changes of shape provoked by the externally applied loads. This principle can be extended to permit creation of space trusses, or structures of revolution.
   - An orthogonal or diagonal arrangement of suspension and stabilising cables, with opposite curvatures, forming an anticlastic (saddle-shaped) surface.
Cable stability: additional staying

Cable stability: prestressing with cable of opposite curvature

Cable stability: staying with transverse cables to ground or to another part of the structure

This can also be applied to cable truss systems. A cable truss system has a triangulated structural form which increases stiffness, particularly under non-symmetric loading.
Cable stability: cable trusses

(a) Cable trusses with diagonal struts

(b) Cable trusses with diagonal ties

Cable stability: cable trusses
2.4 Examples of cable structures.


Cable structure. National stadium, Abuja.
2.5 **Tent structures**

A tent is membrane structure pre-stressed by externally applied forces so that it is held completely taut under all anticipated load conditions. The purpose of a tent structure is to provide a means of shelter that is lightweight, portable, and quick to install.

A Membrane is a thin, flexible surface that carries loads primarily through the development of tension forces. Net structures are conceptually similar; expect that their surfaces are made from cable net meshes.

![Typical tent structure](image)

2.6 **Structural concept of tent structures.**

There are several ways of stabilizing a membrane or net surface:
• An inner rigid supporting framework.
• Prestressing the surface by:
  – external force (Tents)
  – internal pressurization (Pneumatic structure).

2.7 Examples of tent structures.

Hajj Terminal, Jeddah, Saudi Arabia. Skidmore, Ownings and Merrill.

Tent structure. National stadium, Abuja
2.8 Pneumatic (inflatable) structures

A pneumatic structure is a membrane structure that is stabilized by the pressure of compressed air. These structures are the most cost effective type of building for long spans. The word pneumatic is derived from the Greek word “pneuma”, meaning breath of air, as members get mainly supported by air. Although this kind of lightweight structures has been used been known for thousands of years, it was introduced to the building technology only a few decades ago.

**General characteristics**

- Lightweight: there is no maximum span as determined by strength, elasticity, specific weight as with other materials, thus allowing for great lengths.

- Safety: while the plastics used by the pneumatics can fire quickly and totally, their light weight prevents accidents, making them safer than other materials. Also the human body can resist the pressure needed to sustain pneumatic structures; therefore, no health concerns are presented.

- Benefits: this type of structures is very easy to fabricate erect and dismantle, as well a very economical, making them a choice material for temporary constructions.

Pneumatic structures are usually curved, often domes or cylinders, or some other form compatible with pressurized construction.
Types of pneumatic structures.

- **Air inflated (air supported structures)**: pressurized air is supplied and contained in the volume.

- Air supported structures: a single member supported by a small internal pressure difference. Internal air must be supplied constantly and kept at a pressure higher than atmospheric. This type of structures can be further divided into positive pressure difference which makes the structure curve outward or negative pressure, where the membrane curves inwards.

1.0 **Materials**

**Isotropic materials**

These show the same strength and stretch in all directions.

- Plastic films: these are primarily produced from PVC, poly ethylene, polyester, polyamide, etc.
- Fabrics: these may be made of glass fibres or synthetic fibres which are coated in PVC, polyester or polyurethane film.
- Rubber membrane: they are the lightest and most flexible.
- Metal foils: they possess very high gas diffusion resistance and high tensile strength. One of the major problems in the use of metal foils is the need to produce very exact cutting patterns.

**Anisotropic materials:**

These do not show the same strength and stretch ability in all directions. They have direction oriented properties. These include:

- Woven fabrics: they have two main direction of weave. They can be made of Organic fibres (wool, cotton or silk), mineral fibres (glass fibres), metal fibres (thin steel wires) and synthetic fibres (polyamide, polyester and polyvinyl).
- Gridded fabric: these are coarse-weave made of organic mineral or synthetic fibres or metallic networks. They are particularly used where maximum light transmission and high strength is required.
- Synthetic rubbers: combination of plastic and rubber. They can take better wear and tear. They are the latest and are more resistant to elongation.
- Plastics: like woven fabrics. Their advantage is that they have more of tensile strength than normally manufactured plastic sheets.

2.9 **Structural concept of pneumatic (inflatable) structures.**

- Round in shape because it creates greatest volume for least amount of material.
• The whole envelope has to be evenly pressurized for best stability.

• Pre stressing of membrane can be done either by applying external force or by internal pressurizing.

**Principles**

• Use of relatively thin membrane supported by pressure difference.

• Dead weight increases by increasing the internal pressure and the membrane is stressed so that no asymmetrical loading occurs.

• Membrane can support both tension and compression and thus withstand bending moment.

**Components of pneumatic structures**

• Envelope
• Cable system
• Pumping equipment
• Entrance doors
• Foundation

**Loading of pneumatic structures**

• Wind and Snow loads are the primary loads that are acting on pneumatic structures.

• They are anchored very tight to the ground, so no horizontal forces are exerted to the envelope.

• As pneumatic structures are tensile, the envelope has the ability to gain stiffness in order to withstand the loads acting on them

• Wind loads produce a lateral force on the structures and snow load causes downward forces on envelope.

• Pneumatic structures are designed to withstand wind load of 120 mph and a snow load of 40 pounds/yard.
Forces acting on a pneumatic structure
2.10 Examples of pneumatic (inflatable) structures.

Pneumatic structures. Eden Project, Cornwall, England, United Kingdom. Inside the two biomes are plants that are collected from many diverse climates and environments.
Pneumatic structures. Eden Project, Cornwall, England, United Kingdom.
2.11 Arch structures

An arch is a structure, forming the curved, pointed, or flat upper edge of an open space and supporting the weight above it, as in a bridge or doorway. The main advantage of an arch is that it can be supported without any tension. By using the arch configuration, significant spans can be achieved. This is because all the compressive forces hold it together in a state of equilibrium.
2.12 Structural concept of arch structures.

In stone arches, the last stone to be placed at the top is called the keystone. It provides a structure which eliminates tensile stresses in spanning a great amount of open space. All the forces are resolved into compressive stresses.

Materials

The materials used in constructing arches are:
- Iron (wrought iron, cast iron, steel, stainless steel)
- Concrete (reinforced concrete, prestressed concrete)
- Aluminium
- Composite materials
- Alloys
- Masonry
- Timber

2.13 Examples of arch structures.
Example of arch. St. Louis, USA. Note the height above the city. Source: Photograph by Ogunsote.

Example of arch. St. Louis, USA. Note the segments. Source: Photograph by Ogunsote.
Example of arch. St. Louis, USA. Note the massive size of the base. Source: Photograph by Ogunsote.

Example of arch. St. Louis, USA. This model in the Arch Museum shows the structural elements. Source: Photograph by Ogunsote.
Example of arch. St. Louis, USA. This model in the Arch Museum shows the assembly of the segments. Source: Photograph by Ogunsoye.

Use of arches at the Taj Mahal, Agra, India. Photograph by Ogunsoye.
Use of arches at one of the entrances to the Taj Mahal, Agra, India. Photograph by Ogunsote.

Detail of arches in one of the buildings at the Taj Mahal, Agra, India. Photograph by Ogunsote.
Use of arches at the Taj Mahal, Agra, India.
2.14 References

The Constructor (2016). Cable and Tension Structures. Retrieved from


https://designontopic.wordpress.com/2014/01/18/pneumatic-structures/