Afzir Tensile Structures

(Design manufacturing erection)

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Introduction

Afzir Co. was found in April 2009 to design, engineering and fabricating light cover and beautiful structures.

Why a Fabric Structures?

Tensile Membrane Structures are a striking and exciting new-age method of construction. The fabric possesses a unique ability to allow curvature, translucency and the capability to light both, internal as well as external spaces stunningly. Tensile Membrane Structures are characterized by having a rather small mass relative to the applied load, which is determined through an optimization process. Tensile structures generate live loads instead of the static loads of conventional roof materials and modern architectural fabrics offer increased stability and longevity of over 20 years.

Advantages of Tensile Fabric Structures

- ✓ Flexible Design Aesthetics

  Virtually unlimited designs of distinctive elegant forms can be realized because of the unique flexible characteristics of architectural membrane. Also, fewer support columns create more functional, aesthetically pleasing spaces.

- ✓ Outstanding Translucency

  In daylight, the membrane's translucency offers soft diffused naturally lit spaces reducing interior lighting costs. At night, the artificial lighting creates an ambient exterior luminescence.

- ✓ Shortened Construction Schedules

  Incorporating the most modern construction techniques, large fabricated membrane panels can be installed quickly to shorten installation schedules. Likewise, fabric removal can be accomplished easily.

- ✓ Cost Benefits

  Lightweight structures can be a more cost effective solution than traditional building materials offering building owners reduced costs. Materials, such as photo-catalytic membranes, can help prevent temperature rise as well as reduce maintenance costs due to their self-cleaning properties.

- ✓ Long Span Structure

  Lightweight membrane is a cost-effective solution that requires less structural steel to support the roof, enabling long spans of column-free space.

- ✓ Earthquake Resistant

  Lightweight tensile membrane structures bear less building load than traditional roofing materials and the membrane's elasticity offers further earthquake resistance.

Applications

- ✓ Stadium
- ✓ Toll Plaza Canopies
- ✓ Car Parks
- ✓ Atrium Roofs
- ✓ Art and Sculpture
- ✓ Icon Buildings
- ✓ Commercial Retail Centers
- ✓ Malls
- ✓ Walkways
- ✓ Tents
- ✓ Events and Exhibitions
- ✓ Amphitheaters
- ✓ Entrance Canopies

Main uses for internal tensile are:

- ✓ Sculptural features
- ✓ Reduce solar glare and heat gain in atria
- ✓ Internal ceilings to mask unsightly roofs
- ✓ Internal screens and partitioning
- ✓ Tensile for luminaries and lighting schemes
- ✓ Signage and branding

Technical Information

This section aims to explain simply our design process of these exciting free-form structures.

Membrane materials

Materials and knowledge of their behavior is crucial in understanding how these structures perform. Other than ETFE foils (PTFE-coated fibreglass and PVC-coated polyester), structural fabrics have a woven base cloth and are coated to protect the fibers and provide a durable weather, UV resistant and soiling resistant surface. They come in many types and strengths and the designer should be aware of their qualities in relation to the environment and use they are to be put. Strengths are designated by type from I up to VIII. The larger the number the greater the tensile strength. Type I fabrics tend to be used in either small permanent or larger demountable / re-locatable structures. Type II, III & IV fabrics are used in the vast majority of permanent structures although heavier (stronger) fabrics are available. Their structural performance is influenced largely by the woven base fabric and the interaction between warp and weft (fill) fibers. The materials used in these structures are highly nonlinear (i.e. the rate of increase in deformation or membrane stress is not always in proportion to the rate of increase in applied load), so it is important to understand this nonlinearity in relation

to how the tensile fabric structure will perform. Understanding the bi-axial properties are also crucial in being able to correctly prepare compensated patterns (see Patterning). Almost every fabric types, as well as batches from different production runs, have differing strength and extension characteristics. Testing of the fabric, therefore, is an important and integral part of the design process and is undertaken in specially designed rigs by specialist test houses, fabric manufacturers or fabricators.

Apart from the structural characteristics of these fabrics, other properties are an important aspect of why these materials are chosen. The following table shows typical material properties of a number of generic fabrics.

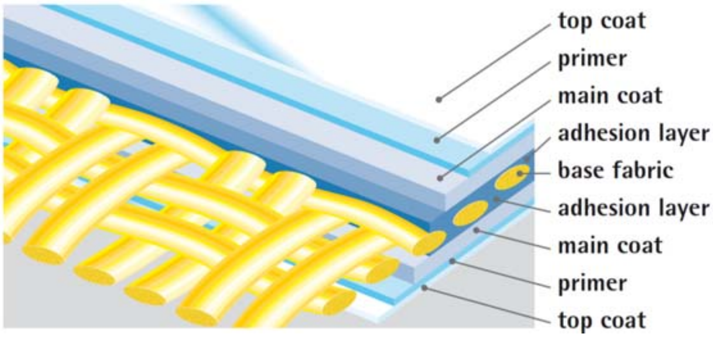


Fig 1.Typical section of Mehler coated PVC-Polyester fabric

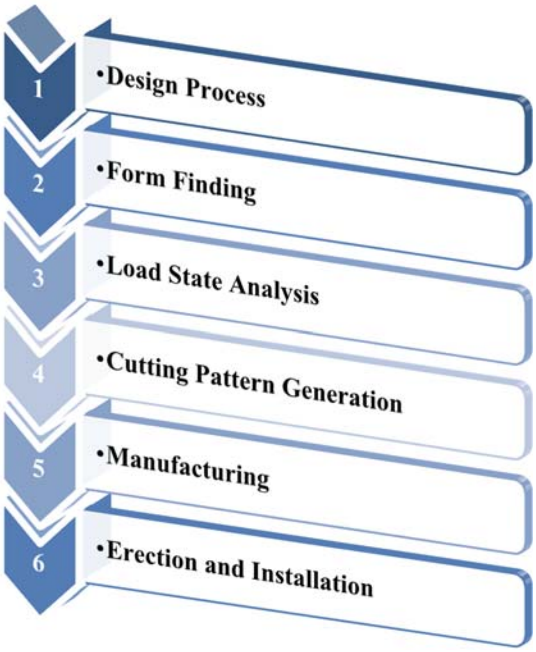
Table 1. Material Characteristics

Property	PVC/Polyester	Silicone/fiber glass	PTFE/fiber glass
Life expectancy	10-15 years	+30 years	+30 years
Burning Characteristics	Polyester combustible PVC – flame retardant	glass non-combustible silicon – inherently flame retardant	glass non-combustible PTFE – inherently flame retardant
Toxicity during Combustion	CO/CO^{2} Halogens, traces of Dioxin Oxides of N	CO/CO^{2} only non toxic	above 290˚ C HF, fluorine compounds
FDA (Food Approval)	None	certain grades DA, BgW approved	approved
Light Transmission	up to 20%	up to 30%	up to 20%
UV light transmission Allows photosynthesis	No	Yes UV-B and UV-C filtered mainly UV-A transmitted	No
Bleaching	n/a	not necessary	tan, until bleached with time
Cost	low-medium	medium-high	high
Soiling Behavior	medium	very good	excellent
Chemical resistance	good	very good	excellent
Capillary Rise	< 20 mm	< 2 mm	no data yet
Temperature Range	-30 to 70˚ C	-55 to 200˚ C Stiff below -20˚ C	-20 to 260˚ C
Tensile strength	medium	high	high
Tear strength	medium	high	high
Dimensional stability	medium	high	high
Flexibility	high	excellent	low
Reusability	possible	yes	with difficulty
Joining Techniques	Welding	Stitching/Sewing with Tenara glass thread or bonding with silicon adhesives	Thermal splicing with aid of FEP tapes
Recycling	Yes	Yes	n/a

It can be seen that the material choices are numerous and it is sometimes necessary to decide which characteristics are important in the overall design. For example, if higher light transmission is required this generally suggests the use of lighter fabrics. This will probably affect the type and configuration of the supporting structure, so early consultation is encouraged to determine the overall feasibility.

Fabrication Process of Tensile Membrane Structures

There are six steps in the Fabrication Process of Customized Tensile Membrane Structures



1. Design Process

The Design Process is considerably more complex than for conventional structures since one has to take into account so many more issues at an early stage. The structure is its shape and so will determine, limit or drive the available forms which are influenced by the span, loading and Architectural requirements. However, beyond the shape and fundamental structural constraints, there are further issues to consider such as load transfer, water control and disposal, shade, light transmission, coverage, constructability, safety, erection, maintenance and sustainability. Once these constraints have been ascertained and their influence embodied within the concept, the engineering design process can start with the formfinding.

2. Form Finding

Form Finding is the process of determining a minimal surface for, in most cases, an anticlastic (doubly curved) shape subject to pre-stressing. The most common mathematical (numerical) systems used to determine the optimum shape are the Dynamic Relaxation (DR) and Force Density (FD) methods.

The behavior of structures which depend upon prestress to attain their strength is non-linear, so anything other than a very simple cable has, until the 1990s, been very difficult to design. The most common way to design doubly curved fabric structures was to construct scale models of the final buildings in order to understand their behavior and to conduct form-finding exercises. Such scale models often employed stocking material or tights, or soap film, as they behave in a very similar way to structural fabrics (they cannot carry shear).

Soap films have uniform stress in every direction and require a closed boundary to form. They naturally form a minimal surface—the form with minimal area and embodying minimal energy. They are however very difficult to measure. For large films the self-weight of the film can seriously and adversely affect the form.

For a membrane with curvature in two directions, the basic equation of equilibrium is:

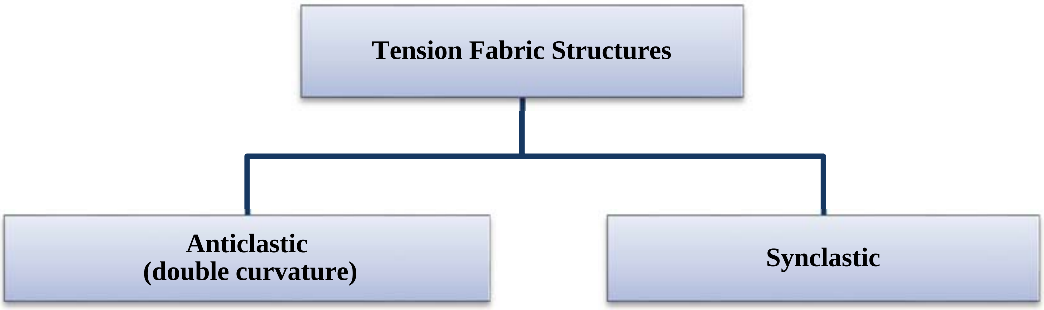
$$w = \frac{t_1}{R_1} + \frac{t_2}{R_2} \tag{1}$$

Where: R_1 and R_2 are the principal radii of curvature for soap films or the directions of the warp and weft for fabrics, t_1 and t_2 are the tensions in the relevant directions, w is the load per square meter

Lines of principal curvature have no twist and intersect other lines of principal curvature at right angles. A geodesic or geodetic line is usually the shortest line between two points on the surface. These lines are typically used when defining the cutting pattern seam-lines. This is due to their relative straightness after the planar cloths have been generated, resulting in lower cloth wastage and closer alignment with the fabric weave.

In a pre-stressed but unloaded surface $w = 0$, so. $\frac{t_1}{R_1} = -\frac{t_2}{R_2}$. In a soap film surface tensions are uniform in both directions, so $R_1 = -R_2$. It is now possible to use powerful non-linear numerical analysis programs (or finite element analysis) to formfind and design fabric and cable structures. The programs must allow for large deflections.

There are two shapes evident in tension fabric structures.



Anticlastic Structures

Anticlastic structures are pure tensile fabric surfaces having a curvature at a given point and in a particular direction, which is of the opposite sign to the curvature at that point in a perpendicular direction. There are 3 basic forms of a tensile structure which incorporate double curvature to create the strength and organic design. These are available in many free tension fabric forms and shapes such as:

Cones: Single cone, multiples cones, fixed edges, catenaries edges, cables edges, height variations, inverted cones etc.

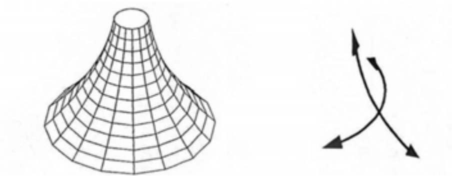


Fig (2): Single cone form

Arched Vault (Barrel vault form): Parallel arches and crossed arches

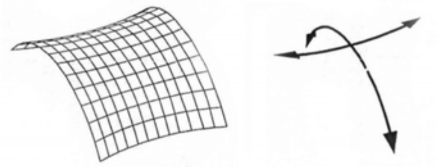


Fig (3): Barrel vault form

Hypar: Two opposing high points and two opposing low points.

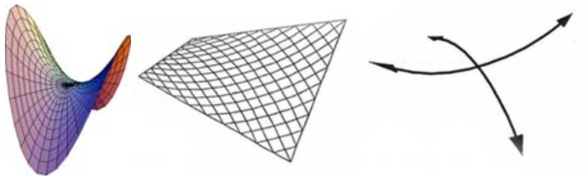


Fig (4): Hypar Form

Synclastic Structures

Synclastic structures are air-supported surfaces having a curvature at a given point and in a particular direction that is of the same sign as the curvature at that point in the perpendicular direction. For such air-supported structures, the fabric envelope is supported by pressurized air but most of the fabrics derive their strength from their double curved shape.

Once the initial geometry is set, preliminary form-finding can begin and the agreed shape used as the basis for subsequent structural analyses and patterning.

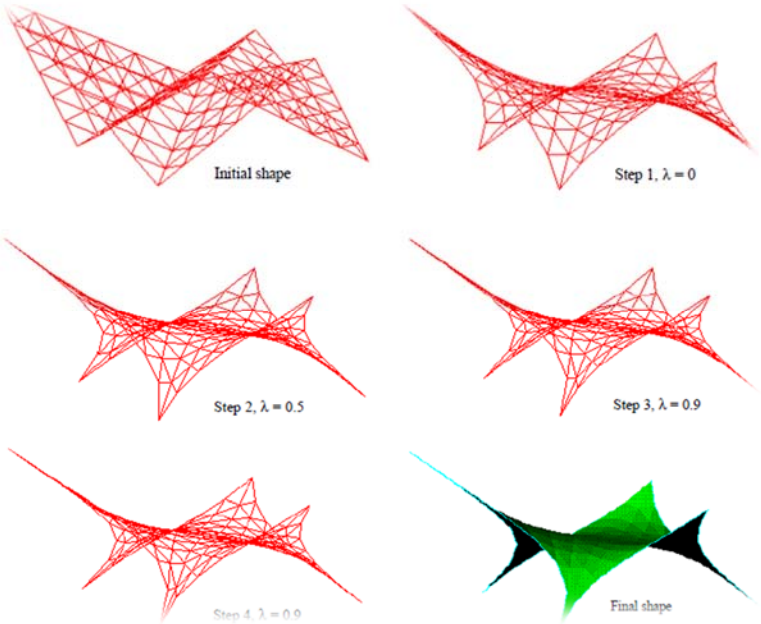


Fig (5): Setting out defined & Form found shape

3. Load State Analysis

Due to the large state deflections to which membrane structure is inherently subjected, geometrically non-linear analysis needs to be performed. Additionally, given the large amount of data required to model membrane structures, the graphical representation of the deformation, force and stress results must be easily controllable to highlight relevant data.

Loading can be particularly difficult to calculate given the quite extreme shapes that can be formed. The predominant load is nearly always from wind and the variations in pressures over the surface can be extremely complex. The correct determination of snow loading, however, can be critical in ensuring that a ponding situation is avoided. The elimination of ponding is, perhaps, the most important serviceability criteria and is an area that should be investigated thoroughly. Where there is even the slightest possibility of snow accumulation, an accurate assessment of loading should be made and the deformed surface checked to ensure no depressions occur. If this happens, the process is nearly always irreversible and the fabric can easily be stretched beyond its design limits. Developed software's which assist in these processes and these links into analysis programs to ensure both consistency and accuracy.

Analysis & Design

Analysis of this type of structures is a specialist area and one that should be entrusted to chartered engineers experienced in their design. Although the basic algorithms are fairly simple, the highly iterative process required to ascertain a deflected form (and stresses) in balance with externally applied loads lends itself to the use of computer based methods. As with all computer based analysis and design tools, it is important that the designer has a 'feel' for what is correct. This comes with experience and properly using the correct material characteristics. It should be noted that since there are numerous choices for cables and fabrics it is important that the final analyses are undertaken using material proper ties that are consistent with those that will be used in the actual structure. For example, using different (size or stiffness) cables or fabrics than those defined in the analytical model can result in subtle changes to forces within the structure or reactions at the structural supports. It can also subtly alter the structural performance which may be critical if deformation under load is incorrectly assessed. Once analyzed, fabric membrane stresses, cable loads and frame forces (when included) are output and used in the substantiation of the individual structural elements.

Substantiation for both cables and fabric is simply a process of checking their tensile loads against their design capacities ensuring that an adequate factor of safety is maintained. The industry accepted factors of safety used are generally 5.0 for fabric and 2.5 for cables. Where local membrane stresses exceed permissible values, it is not uncommon to provide reinforcement patches. Other supporting structures in steel, timber or aluminum and their membrane fixtures and fittings are designed in accordance with normal standards.

4. Cutting Pattern Generation

Patterning follows after the identifying the final positions of the supporting structure fixed points, otherwise known as Fabric System Points (or Lines). For most structures, this can only be achieved once the supporting structure is fully detailed. The connected edges of individual fabric panels (seam lines) are set out. These seam lines are usually geodesic, i.e. they follow the shortest path across a curved surface and their setting out is normally a function of i) aesthetics, ii) the available width of the fabric and, iii) sometimes to create stiffer lines for structural or serviceability reasons (i.e. to create a more pronounced ridge if local ponding issues were identified but could not de designed out).

The patterning process starts with the flattening of the usually doubly curved panels. Once flattened, the panels are compensated to introduce the desired level of pre-stress and, in places, de-compensated to ensure fixed lengths remain consistent with those of the supporting structure.

Compensation is the act of reducing the fabric panel size (before manufacture into the full membrane) so that once installed and ‘pulled’ into position the extension of the fabric induces the requisite pre-stress. De-compensation is either a full or partial reversal of the compensation process that is undertaken to ensure dimensional compatibility with the supporting structure. Compensating the fabric panels correctly is critical in ensuring that the membrane is wrinkle free and the accuracy of the material bi-axial testing is paramount in achieving this.

Panels are usually joined by over-lapping and welding. Weld widths are 50mm wide for the majority of structures. Wider welds are used for heavier fabrics (where higher stresses occur) or where the structure is subject to high in-service temperatures. PVC-coated polyester fabrics are high frequency (HF) welded, glass cloth fabrics are heat (& pressure) welded.

Cable pockets, kedered edges and other elements such as patch reinforcement, joints and flaps are added in the fabrication shop.

Modeling of these structures is an integral part of the design process. They allow the designer to check and confirm the geometric consistency of the membrane and supporting frame and portray an accurate representation of the completed structure. These models also serve to highlight possible clashes between the membrane and structure.

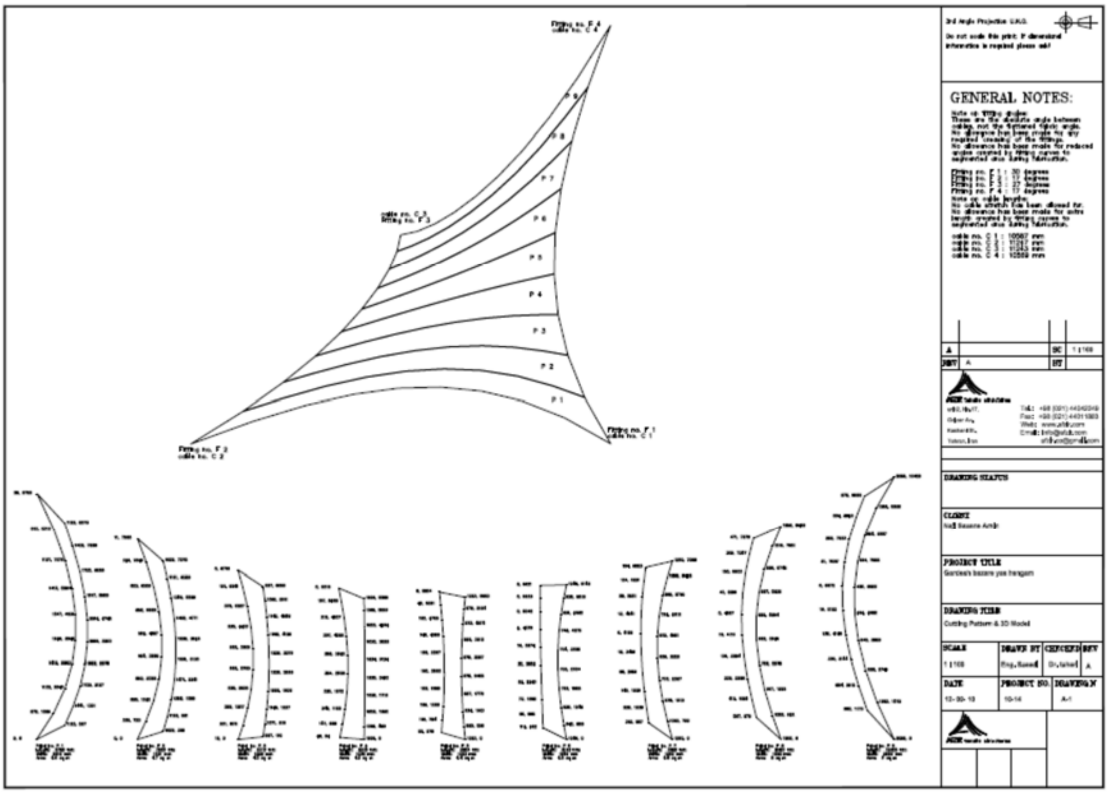


Fig.6 Example of Cutting Pattern

Detailing of tensile fabric structures is perhaps the most challenging of the design process as the essence of these forms rely very much upon the visible nature of the support system. Although many components are standard items, it is their accurate geometric arrangement which is important. To this end, many of our drawn details are taken direct from our 3-D models.

5. Manufacturing

Subsequent to analysis and patterning, the fabric is cut on precision clutter plotters and fabricated with welding machines.

Fabric fixing can be achieved in numerous ways but by far the most common is by keder (polypropylene core) edges slid into keder (luff) tracks.

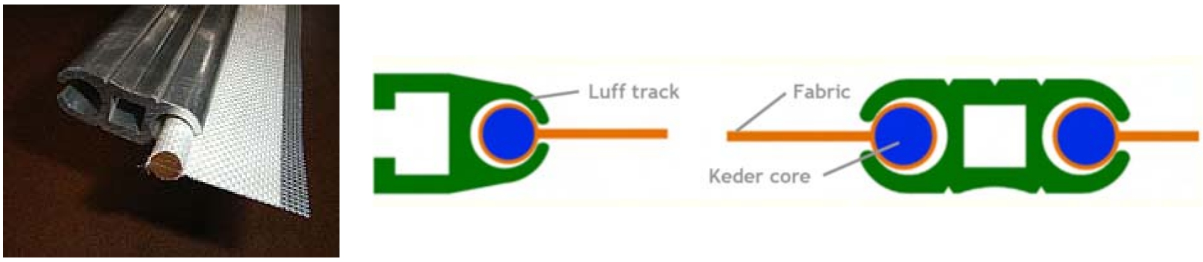


Fig.7 Typical single and double aluminum luff tracks

This system originated and was developed from sailing technology and the tracks are invariably made from extruded aluminum. They can be straight, segmented or rolled to a radius. Double ('shotgun') tracks are usually bolted or (self drill) screwed to supporting frameworks. Single tracks are fixed by inserting bolt heads into the purpose designed rear slot.

Clamping fabric is another widely used method to fix the membrane to the supporting structure. It is also used at head-rings and sometimes to join different regions (parts) of a larger sub-divided membrane by over-lapping kedered edges and bolting clamp plates above and below the fabric.

Fig.8 Fabric joined by clamping

Cables

Cables are used extensively in tensile fabric structures both as stays or ties as part of the structural support system and within the fabric membrane itself to create curved boundaries. Cables are generally stainless steel or galvanized and they sit within fabric pockets which are welded to the fabric edges. Where PTFE coated glass cloths are used, the cables sometimes sit outside of and are clamped to the fabric membrane (Fig.7). Cable ends and the fabric are usually connected to membrane plates which serve to collect and distribute the loads into the supporting structure.

Fig.9 External boundary cable

Membrane plates

Membrane plates are important structural, visual and practical elements which perform a number of functions. They collect and distribute cable loads, clamp the fabric in place and can incorporate water collection and disposal details. As they are designed and detailed to perform varying functions and since the geometry is invariably unique, they become bespoke items. Although there are common elements in these items, it is the overall arrangement of the component parts which become visually important.

Fig.10 Membrane plate on boss with water collection, with edge belt & Drainage

Masts

Masts are found in many forms of tensile fabric structures either as a primary support to the membrane itself or as part of the supporting structure.

Within conic membrane structures they generally have a dual function, i) to provide fabric support and, ii) usually to provide a means of tensioning the membrane. The fabric support is usually affected by clamping the membrane into a purpose made circular head ring, although it is possible to achieve other shapes. Tensioning of conic shaped membranes is generally undertaken by the jacking up of a telescopic mast and locked into position once the desired pre-stress is achieved.

Fig.11 a) Mast, b) Flying mast & jacking system, c) Fixed mast & head ring clamping

Drainage

Drainage of tensile membranes should be considered early in the design process given that the forms can be quite extreme. There are numerous details and devices that can be incorporated to control run-off or water collection and disposal. The most common drainage system involves the addition of an upstand along a cable boundary (Fig.12) which directs water to a membrane plate (Fig.10) from which a flexible hose connects to the RW system.

Fig.12 Boundary cable *upstand* plate

Erection

Erection should always be considered as part of the design since installation methods can influence the detailing. Larger membranes may need to be broken down into smaller regions, additional tensioning devices may need to be added or component parts limited in size if weight or size restrictions are identified.

The installation sequence should also be understood so if temporary works are required they can be incorporated into the final design.

Erection of the membrane has to be undertaken with utmost care to ensure no damage is caused to the membrane. Care has to be taken keeping the wind speeds and rain in mind unlike the conventional erection of heavy structures.

Fig.13 Erection of fabric structure

Project Management

The successful manufacture and installation of bespoke tensile fabric structures requires great attention to detail and a firm grasp of the overall program for each project.

Management and quality control of the separate manufacturing facilities we entrust our projects to is of paramount importance to us. We use top specification fabrics, cables and rigging hardware, and the best in manufacturing expertise to provide our customers with exceptionally high quality canopies designed and built for maximum durability.

We also recognize the value and importance of close co-operation with the client construction team and can readily advise typical lead in times. Many of our clients however require a more flexible approach from us in order to manage the overall site works as smoothly as possible, and we are always happy to be able to help in this regard.

Maintenance

Maintenance is an essential process for any tensile membrane structure and periodic cleaning and inspections will extend the serviceable life.

Longevity

Longevity depends on a number of factors including the efficacy of the overall design, the appropriateness of the details and continued maintenance. With advances made in material technology together with high standards of manufacture, these structures are now a real and economic alternative to more traditional forms.

Examples of Completed Fabric Structure