


Membrane Structures

LSAA

LIGHTWEIGHT STRUCTURES ASSOCIATION OF AUSTRALASIA INC.

website: www.lsaa.org

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Background

In the 1950's new materials, techniques and processes gave impetus to developing novel construction forms. Long span bridge technology inspired a new generation of architects and engineers who pursued a geometrical vision under this influence.

One of the streams of this phenomena of lightweight structures is membrane structures. Notable pioneers Fred Severud, Frei Otto and Walter Bird have passed on their pioneering zeal to establish main stream design companies and so the new becomes the norm.

Membrane structures are a new colour on the architects palette. While their share of overall construction is small, today their highly aesthetic forms are a dominant feature in the building landscape.

For many people these structures are typified by world class sports stadia roofs, temporary exposition structures as well as applications in shopping centres, corporate headquarters, leisure centres and more recently in council playgrounds and schools.

Design

Having arisen from the time honoured craft of tent making the industry now utilises highly contemporary techniques for design and construction.

Computers predominate in engineering design and graphic imaging and the manner in which we communicate.

Complex surfaces are resolved swiftly using powerful programs and new generation hardware. Design skills have refined through the first challenging decades of work in the field. Nowadays competent and experienced design teams approach the most complex works with confidence and the proliferation of built structures increases exponentially.

The opposite side of the equation is a fabrication and construction industry which has experienced dramatic development in the specialised processes involved in assembling structures into finished project work. The works speak for themselves.

Structural Materials

In this century science fiction writers and future scientists proposed force fields as structure.

Nowhere has this dream been closer to fulfilment than with membrane structures.

The surface is held under a constantly applied prestress force presenting a film thickness division between inside and outside environments.

Materials development has rapidly paralleled design technology improvement to make available truly engineered fabrics designed for specific purposes.

High strength durable synthetic materials are marketed for selection by designers in accordance with specific requirements and building regulations.

The Association

The Lightweight Structures Association of Australasia (LSAA) is a multi disciplinary group of companies and individuals working directly or peripherally in the field of lightweight membrane structures.

Membership is comprised of architects and engineers, academics, artisans and fabricators, materials and service companies and construction groups. It marries pure theory with practical building know how in a coherent organisation in support of this developing sector of architecture, engineering and construction.

Through its publications, conferences and funded research projects, educational activity, specification writing and promotional works it provides a unique service to members and the public.

History of Fabric Architecture

Exploited by nomadic tribes almost from the dawn of civilisation, the use of fabric to provide mankind with shelter from the natural elements of sun, rain, wind and snow is an architectural design strategy whose origins are lost in antiquity.

However, the tactical elements for its fuller exploitation relative to other engineering options have only recently been explored, refined and commercially resolved.

These elements are as new as the discovery of high performance polymers, methods for their incorporation into advanced composites and the development of a computerized methodology for the analysis of their non-linear, time dependent viscoelastic behaviour. These elements have finally come together over the past twenty years to lend credibility to the concept of permanent fabric architecture.

What are Membrane Structures?

Membrane structures are those structures which employ a thin, flexible surface material, such as coated fabrics, as their main structural and cladding element. The membrane is usually stressed between its support system and its anchorages.

Typical membrane structures are tension structures supported by frames, cables or masts and those which are supported by (internal) air pressure - "air supported structures."

The fanciful shapes and festive colours of membrane structures make them a perfect choice for many recreational facilities.

They also have very practical advantages. They provide wide, clear span areas without large supporting members. Foundation requirements range from simple footings for the mast or masts and solid anchorages for cable connections at perimeter points where significant uplift or horizontal loads may be present.

As shelters for performance stages they can provide a proscenium-like setting without the heavy structure required with other materials. Their ability to provide vast clear span space assures clear sight lines for the audience with minimum of supporting posts. These attributes enable a designer to use his imagination to the fullest.

The versatility of tensioned membrane structures makes them useful is a wide range of applications; outdoor dining areas, eye-catching entrance gateways, walkway coverings, shelter for building courtyards, atria roofs for commercial and recreational building, even weather protection for transportation terminals.

What is a tensioned membrane structure?

It may seem to be merely a tent or dome, but in reality a tensioned membrane structure is something far more sophisticated. It is a very special structure which obtains its strength from a combination of its geometric shape - its "structural form" - and the properties of the material from which it is manufactured.

With a 'tent' the fabric is simply a covering for a structural frame, only incidentally contributing to the tent's structural integrity. In a tensioned membrane structure, the fabric provides a structural membrane. The combination of the membrane and steel cable or arch elements achieves stability so that the smooth curvilinear forms remain stable even under high wind uplift loads or down loads from snow, wind or hail.

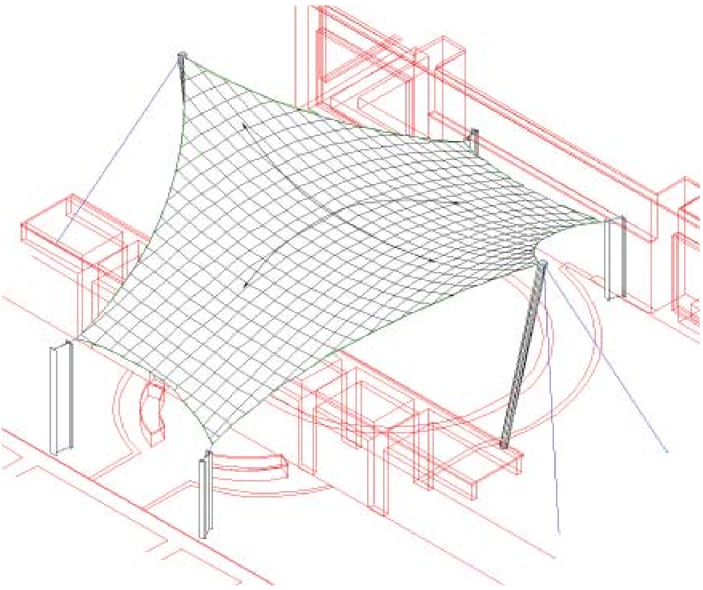
When the requirements call for large scale exhibition buildings, membrane structures can be an exposition designer's best resource. They allow a design freedom not possible with other building materials; shapes which cannot be achieved any other way become possible. Tensioned membrane structures are uniquely suited to the needs of expositions and fairs for exciting, attractive pavilions, exhibition halls and entertainment theatres.

A membrane structure is a flexible surface (skin, fabric) which is only capable of transmitting tensile stress. It relies on double curvature to achieve its stability in the prestress condition, when no external loads such as wind are present.

The double curvature and prestress are essential as well when wind or other external loads in either direction are acting.

Membranes can be sub-divided into two major groups:

- Prestressed membranes such as tension membranes or air-supported structures. Tension membrane structures assume double negative (anticlastic) curvature. This is also termed a "saddle shape". Air supported structures assume a double positive (synclastic) curvature.



- Non prestressed membranes such as tents, sails and air (or other medium) filled structures, which are originally slack in the unloaded condition and assume shapes of either single or double curvature when loaded.

Materials

Several membrane materials are available for permanent structures; coated, woven synthetic fabrics are by far the most widely used.

Due to their low durability (2-3 years), fabrics from natural fibres have been almost completely replaced by the more durable and dimensionally stable synthetic or mineral fibres.

Preferred fibres for woven fabrics are polyester or glass fibre. PVC coatings and thin outer layers are applied to polyester fabrics (PVC/PES). Teflon (PTFE) or Silicon is applied to glass fibre fabric.

Recent advances include transparent foils which are often used in the form of inflated bubbles are rapidly increasing in popularity (ETFE). Each class of material has its particular attributes in terms of durability, thermal and optical performance and cost. Glass fibre membranes must be handled with care to avoid folding and kinks.

High Inherent Strength

Membrane tensile strength values are as high as the strength of high tensile steel, yet the membrane material is 5-6 times lighter. The materials are therefore well suited for large clear spans.

Resistance to Environmental Pollution

Most modern fabrics have natural dirt shedding capabilities or are specially treated to achieve a high level of cleanability.

’Self cleaning’ properties of PVC coated fabrics are enhanced by the addition of an external film of Tedlar (PVF).

Service Life

A minimum service life of 10-15 years can be expected from a good quality PVC coated fabric with appropriate surface protection. Teflon coated fibreglass has an anticipated minimum life of 25 years.

Fire Safety

PVC coated polyester and Teflon coated fibreglass are ’fire safe’ and meet the requirements of local authorities in most applications.

Thermal Properties of Membranes

In general terms uninsulated membrane structures are energy efficient in warmer climates typical of Australia and New Zealand but due to their low thermal mass are relatively ineffective in very cold climates.

Thermal insulation may be increased by a variety of measures. In the case of tension membrane and air supported structures secondary liners may be used.

A higher thermal insulation can be achieved by the use of multi-layered membranes. Stratification and venting can be used to advantage.

The understanding of the properties of individual materials, the effect of form and shape by the project mechanical consultant is important to the success of a fabric structure design.

Acoustics

The acoustical performance of a membrane structure can be regarded as a function of the shape of the membrane and of the finishes beneath the membrane. In air supported structures it is necessary to address the affect of reverberation time created by the concave surfaces. The industry provides acoustical treatment such as liners or suspended panels with Noise Reduction Coefficients as low as 0.61.

Lighting

One of the attractions of choosing a membrane structure is their high degree of translucency.

In daytime the light penetrating the membrane provides a unique natural environment. The light quality which will be influenced by the fabric selection is colour. The light will be balanced, shadowless and diffuse. At night the fabric surface provides the opportunity to obtain diffuse radiant lighting effects internally, while at the same time a gentle glow penetrates the membrane creating a landmark.

Colour Fastness

Materials are available in a range of colour fast pigmentations. However consideration should be given to the effect on transmitted light and additional heat load into the space below when darker coloured fabrics are used.

Special Shading Materials

Shading materials developed for use in tropical climates allow controlled transmission of sun, dew and rain and protection from frost and hail for use in horticultural applications. Hail and shade protection applications have included large car yards, school and council playgrounds as well as domestic situations.

With recent concerns of skin cancer, it is important to be able to predict shade patterns at different times of the day throughout the year. This includes the effects of overlapping panels with curved edges as illustrated below.

Design Considerations

Shape Determination and Structural Analysis

Several computer programs for form finding and structural analysis of membrane structures are available. Form finding and analysis of complex shapes and large structures requires a degree of program sophistication. Structural analysis of membrane structures involves non-linear large displacement static as well as dynamic analysis.

Without these computer programmes it would not be possible to achieve the degree of precision required for the design and fabrication of a fabric structure. The use of models to help establish initial shapes is still a useful tool.

In Australia the main design loadings are the initial prestress conditions generated during the erection and initial tensioning of the membrane surface. The other loads are from wind which may produce uplift or downward loads on the system. Wind tunnel testing may be warranted.

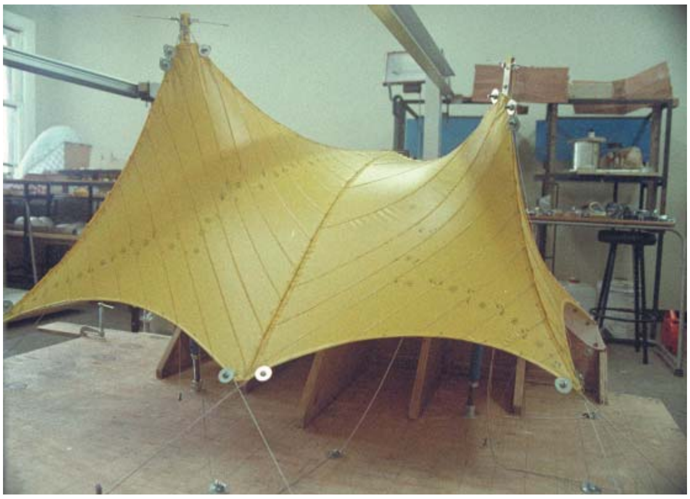
An important load case is from heavy rain which may cause ponding on relatively flat portions of membranes. Hail loads and snow which collect on the surface can also lead to large localized loadings. Inadequate consideration of water ponding or from hail or snow has caused partial or full collapse of several structures.

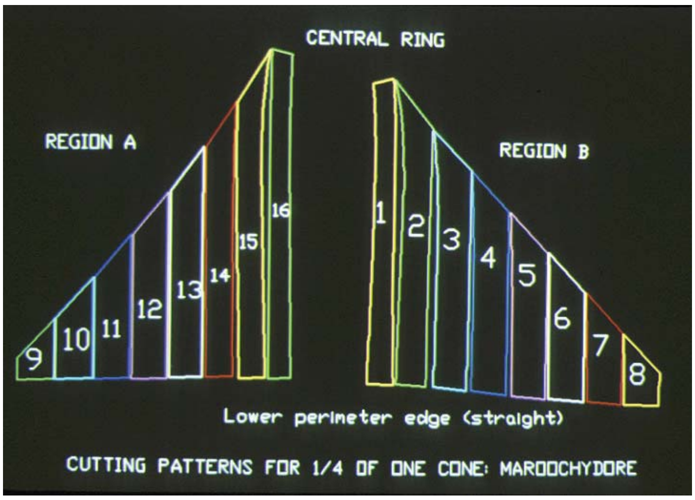
Cutting Patterns

An accurate scale model may be constructed and cutting patterns obtained from it by laying paper strips across.

Alternatively, computer programmes are available to undertake the patterning of certain materials. The edges of the strips can be defined using geodesic lines. The flattened strip must be altered in size so that it is cut whilst unstressed but assumes a stretched size when installed. The differences are terms compensations and are determined by biaxial testing of the fabric material.

The complexity in the overall design process from concept to cutting pattern has led to the development and fabrication of several standard types and shapes for membrane structures.





Design Guidelines

The market and the number of firms involved in the fabrication of membrane structures in Australia is increasing. As the industry has developed the level of Quality Assurance has also increased.

Documented guidelines and Australian standards for construction are presently lacking, due to the diverse nature of design, however the fundamental design principles can be readily learned.

Costs

The cost of membrane structures vary dependent upon materials selection, scale of project, complexity and degree of symmetry and construction requirements. To obtain the most cost effective solution it is essential that architectural, structural and mechanical disciplines co-ordinate their design in consultation with specialist fabricators and materials suppliers from the outset.

Environmental Issues

The environmental 'footprint' of membrane structures is intrinsically low, because in practical terms the self-weight of the membrane is negligible. Hence, the ratio of applied load to self weight, an inherent measure of the efficiency of material usage, is many times larger than for conventional buildings.

The majority of membrane structures are fabricated from PVC coated polyester. Despite well publicized claims to the contrary, the CSIRO concluded in a detailed study that in an environmental context, PVC performs as well or better than alternative materials.

If one defines sustainable as "meeting the needs of the present, while ensuring that future generations have the same opportunities"; then PVC is a sustainable product. It is intrinsically recyclable, energy and resource efficient to manufacture, and being derived from the most basic of hydrocarbons and salt, is a low consumer of non-renewable resources.

Given its expected life of between fifteen and twenty-five years, proven by field usage, PVC coated polyester scores highly in a life cycle analysis. It is safe to handle, fabricate, and in a building context, has too little mass available to contribute to the fuel load of a fire. It has excellent UV and heat absorption characteristics.

The technology is presently available to separate the constituents of PVC coated polyester, but unfortunately not yet in Australia. The practicality of cost effective and environmentally logical recycling ultimately depends on the logistics of collection, transport and re-processing.

Special Construction Features

Some features specific to membrane structures should be noted. These result from the special material properties of the membranes.

Membranes can span large distances without supporting structures used in conventional buildings, yet these membrane structures must always be tensioned not in one direction but in two to achieve their essential stability. Flat planar surfaces should be avoided.

The membrane must be kept tensioned biaxially to obtain stability and a long service life. Certain classes of materials have higher creep properties than others and in these cases provision for re-tensioning at a later date may be required.

Roof structures are built with spans exceeding 150m. They can be designed to bear the same loads as their conventional counterparts.

Stability can be fully warranted even under extreme wind loads. Structures built on this principle have withstood cyclones with wind velocities of 200km/hour.

It is important for all membrane structures that point loading be avoided. Surface slopes must be steep enough to eliminate ponding under heavy rain or snow buildup.

Example Applications

The Lightweight Structures Association of Australasia (LSAA)

The Association is an autonomous, inter-disciplinary group of interested parties involved in the field of lightweight structures and has a major focus on membrane structures. The object of the Association is in promoting the proper application of lightweight structures - their design, fabrication, construction and the further development of these and other aspects of lightweight and membrane structures technology.

LSAA Pursues the following aims:

- To establish guidelines for the design, analysis, fabrication and construction of lightweight structures and the development of industry standards.
- To collect and disseminate information to its members and encourage the exchange of information between members and interested parties through the organisation of meetings, workshops, seminars, conferences and publications.
- To promote the services and products of the Members.
- To encourage research and development in the field of membrane and lightweight structures.
- To keep abreast of international developments by contact with or affiliation to similar bodies or institutions overseas.

Organisation

The business of the Association is conducted by the Executive comprising the President, Vice-President, Secretary and Treasurer. The Executive is assisted by an elected Committee and a part time Executive Officer.

Activities include:

- Publicity, Education, Organisation of Meetings, Seminars etc.
- Design, Analysis, Materials, Fabrication, Safety, Development of Design and Performance Guidelines and Standards, Co-ordination with Government Regulation, Codes etc., and Other Activities as required.
- Research and Development and Other Activities as required.
- Maintain an up to date, informative website which also promotes the profiles and achievements of its members. (www.lsaa.org)