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STRUCTURAL USE OF COATED FABRIC FOR LONG SPAN ROOFS - AN OVERVIEW

by

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ABSTRACT

One of the more visible developments in civil engineering in the past decade has been the utilization of coated fabrics as a major structural component for roofs of large spans. Fabric roofs can now be found throughout the world covering various types of structures such as sports stadia, ice rinks, swimming pools, leisure centres and other applications. Coated fabrics are now being used extensively in hot countries to create shades. The decision to use a fabric structure can be for one of three reasons: image, cost or some special property of the material, such as translucency or radio transparency. It is intended that this paper will provide an introductory overview of the technology of modern lightweight fabric structures by means of brief description and illustration of some technical aspects of such systems.

INTRODUCTION

Membrane structures are ones in which the main load-carrying members transmit loads to the foundation or support system by tensile stresses with no compression or flexure allowed. They are refered to as load-adaptive due to the fact that the members re-shaping the geometry in order to accomodate any change in load rather than increasing the stress level.

Membrane structures can be divided into three subclasses[1]:

i. Air-supported structures in which an enclosing membrane is supported by a small differential air pressure (Figure 1).

ii. Prestressed membranes in which fabric is stretched over rigid frameworks and columns to form enclosures (Figure 2).

iii. Hybrid systems in which fabrics panels are spanned between primary load-carrying members such as prestressed cables and rigid members (Figure 3).

Membrane materials should have high tensile strength and should be flexible and light in weight. They should have good dimensional stability, be highly resistant to the propagation of minor accidental damage, and be easily and cheaply seamed or jointed in a reliable manner. Equally important, the materials should also be resistant to the enviromental degredation and fire resistant.

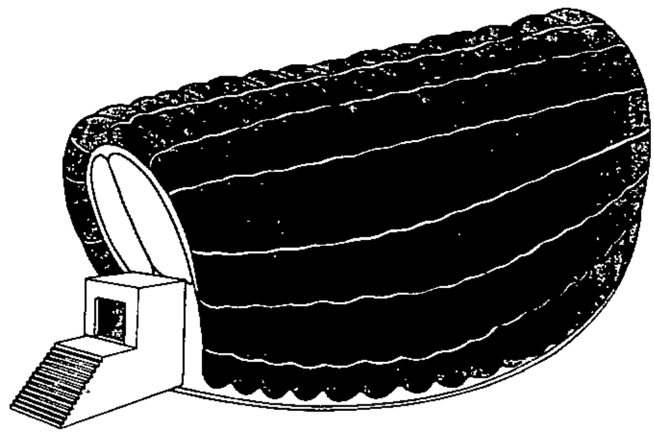


Figure 1:
Air supported structure

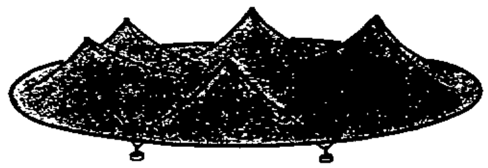


Figure 2: Prestressed membrane

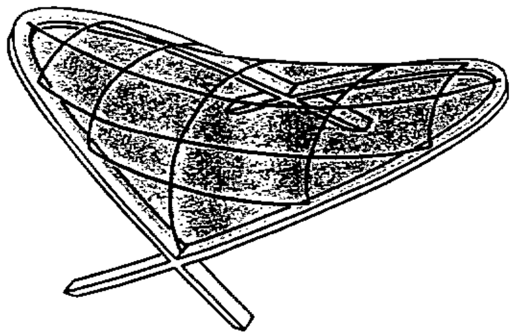


Figure 3: Cable net roof

Various materials can be used in the fabrication of membrane structures such as hyperelastic (rubberlike) materials, fabrics, composites, etc. Hyperelastic materials are highly nonlinear in nature and can sustain large strains. However, the applications of these materials are limited due to their low stiffeness and low strength properties. Fabrics, on the other hand possess high tensile strength, but give relatively low resistance to tearing, cyclic folding and wrinkling.

It is not possible at present to satisfy simultaneously all requirements in a single material. The best solution is a composite in which each of the components is selected to fulfill a particular set of conditions, and the final material is much better than the sum of the components.

COATED FABRICS

Coated fabrics consist of plain-weave fabrics processed with a coating material to produce a flexible, fibre-reinforced composite. The general properties that are important in a building application are listed in Figure 4 which shows the relative dependence of these properties upon the coating and the fabric.
Table 1 gives several types of coated fabric materials along with their characteristics. The two materials that so far have found success in building are PVC coated Polyester and PTFE coated glass.

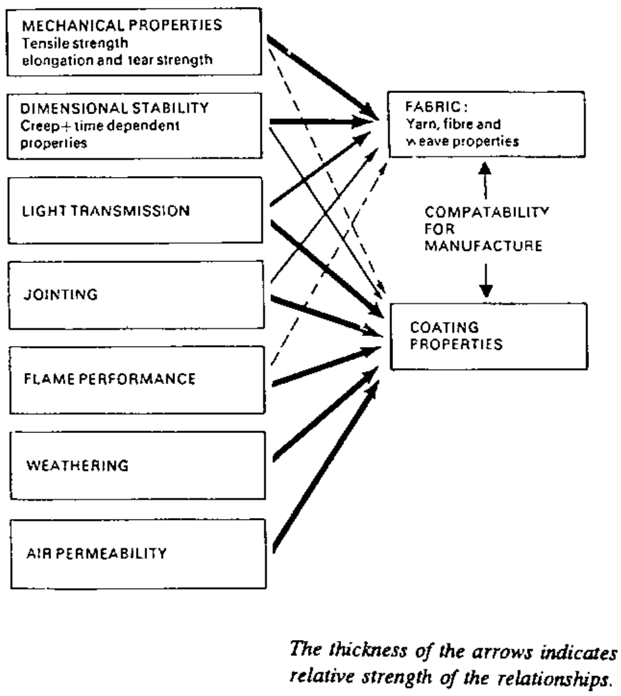


Figure 4: Material properties
Source: Ref.[5]

Table 1 : Commonly Used Coated Fabric

Source: Ref.[6]

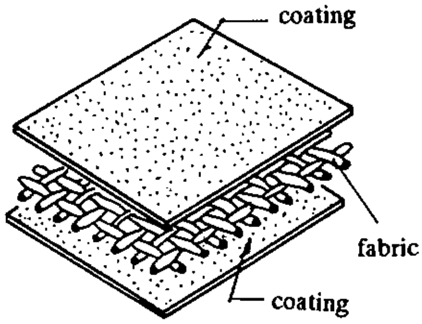
Materials	Cost/m ^ 2	Tensile Strength (kN/m)	Elongation	Durability	Translucency	Fire Resistance	Colour Ranges	Application
1. PVC coated Polyester Cloth with Acrylic Lacquer	RM8 – RM28	20 – 200	16 %	D	8 – 30 %	B	All	Widely used for air–house and fabric structures. Can be coloured opaque etc. High translucent materials are less durable. PVC laquer is now available to give a more durable surface.
2. PVC Coated Nyalon	RM8 – RM28	20 – 200	20 %	D	8 – 30 %	B	All	As above but less popular because of poor dimensional stability and creep.
3. PVC Coated Kevlar	?	100 – 400	5 %	C	Opaque	B	All	Would only be used where high strength stiffeness required. Jointing problems. Must be opaque to protect Kevlar.
4. Hypalon Coated Polyester	RM32 – RM100	20 – 300	16 %	C+	Opaque	Not	All	Used for radar domes. Hypalon degrades and powder on the surface can be repainted to extend life.
5. PVC Coated Polyester with Tedlar	RM12 – RM32	50 – 200	16 %	C	7 – 20 %	B	All	Used occsionally in USA. Laminate provides a stay clean surface. Welded joints have low strength.
5. PTFE Coated Glass Cloth	RM100 – RM18(	30 – 150	6 %	A	5 – 15 %	I	Ivory, some colours	Has been widely used for 'permanent' fabric structures.
6. Silicon Coated Glass	RM100	30 – 150	6 %	B – A	20 – 50 %	B	Some colours	New material.

Notes : Durability Grading :
- A > 25 years
- B 20 – 25 years
- C 15 – 20 years
- D 10 – 15 years

Fire resistance Grading : I Virtually incFire resistance Grading : I Virtually incombustible
B Flame resist B Flame resistant with the addition of
flame retarc flame retardant salts.

STRUCTURAL BEHAVIOUR

A coated woven fabric is considered anisotropic because of the behaviour caused by its interstructure as well as the coating condition of the fabric (Figure 5). The peculiarities of fabric in respond to applied loads may attribute to the deformation of one or more mechanisms dominating in certain ranges of loading.



Some of the mechanisms that govern the deformation of such fabrics include crimp interchange between warp and weft, bending and torsion of yarns at crossover points, friction between yarns at point of contact, bending of coating and interaction between the fabric and coating material[2].

Figure 5: Schema of coated fabric

Figure 6 shows a typical, idealized, general stress-strain response of coated fabric. It can be seen that the shape of the stress-strain characterictics is governed by the mutual interaction between the warp and weft fibres.

DESIGN ASPECT

The design of prestressed membranes structures using coated fabrics will usually commence from an architectural sketch in order to outline the space spanning requirements: Unlike in the case of conventional structures, at a stage much earlier the engineer will have to work hand to hand with the architect in the development of the design concept. The principle reason for this is that tensile membranes, in practice, are shear-free prestressed mechanisms of which the form is governed by the surface stress ratios in the main weave direction of the fabric.The process of designing a fabric roof involves the achievement of a number of goals[3].

i. Defining the surface geometry (Form finding).

ii. Analysing the structure's response to load (Load Response).

iii. Dimensioning the parts (Fabrication patterning).

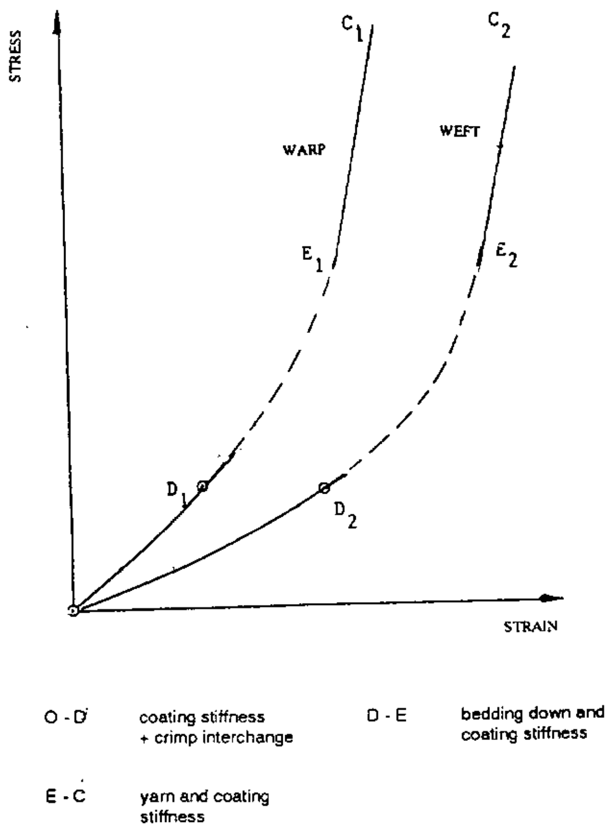


Figure 6: Typical Behaviour of Coated Fabric
Source: Ref.[2]

Form Finding

At the conceptual design stage, simple physical modelling for instance using stockinette material (Figure 7), is effective since it allows a direct communication of design ideas between architect and engineer; And, through the examination of surface curvatures, gives useful guidance on preferred patterning and stress ratios. Even at this stage, however, it is useful to employ, in parallel, a computer simulation of the structural form (Figure 8).

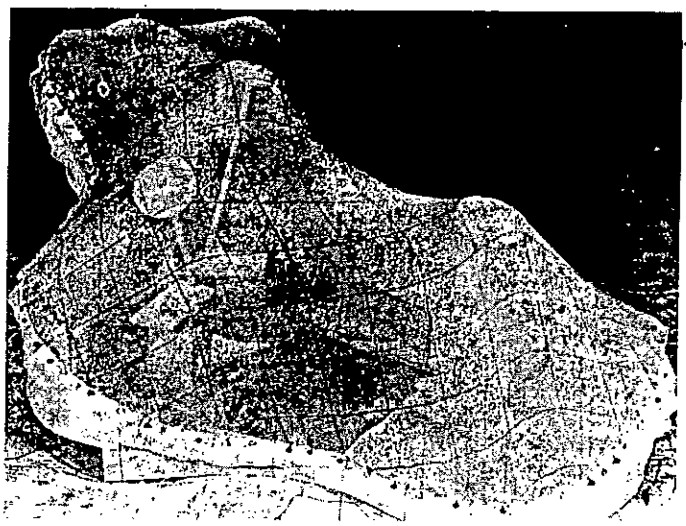


Figure 7: Physical model
Source: Ref.[3]

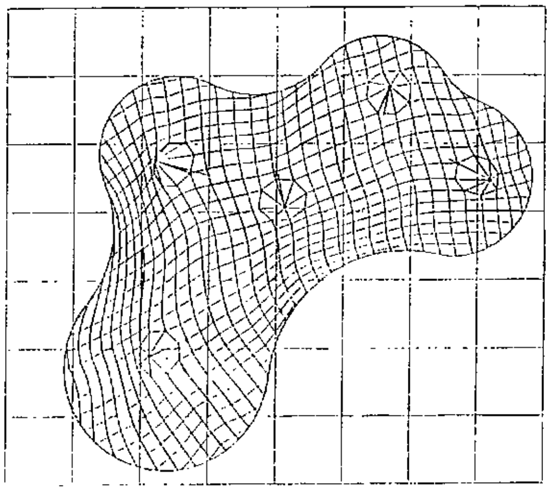


Figure 8: Computer model
Source: Ref.[3]

Starting from the basic boundary co-ordinates, the computer calculates where prescribed forces should lie in space for them to be in equilibrium. One such method called "Dynamic Relaxation"[3] is based upon the fact that to get from one state of equilibrium to another, a structure must move. By writing the equation of motion for the structure and applying damping to make the structure come to rest, one is following exactly the procedure that happen in nature. The method allows one to choose the loading conditions for defining the basic form which optimises the structural behaviour. Computerised methods avoid the serious measurement errors which can occur with physical methods. However, physical models still have the advantage of giving the designer physical understanding.

Load Response

There are two aspects to be studied. The first is to make a design which intrinsically can be prestressed. The second aspect concerns what forces are set up within the membrane during the introduction of prestressing forces and applied load.

Calculation has to be made which establishes the strength characteristic required for the membrane material and its joints. Together with that, studies to find the critical load combinations during erection and service life have to be made. Wind intensities can be established via Codes of Practice and wind tunnel testing.

A non linear method of analysis, such as Dynamic Relaxation can be used to allow for the large changes in geometry that occur under each pattern of applied loads.

Fabrication Patterning

A feature common to all fabric membranes is that the surfaces are manufactured using patterns, as dressmaking, such that when the parts are jointed together they produce a doubly curved surface.

Traditionally this has been done by making accurate models of the surface, laying elements on these model and expanding the resulting patterns by a scale factor (Figure 9).

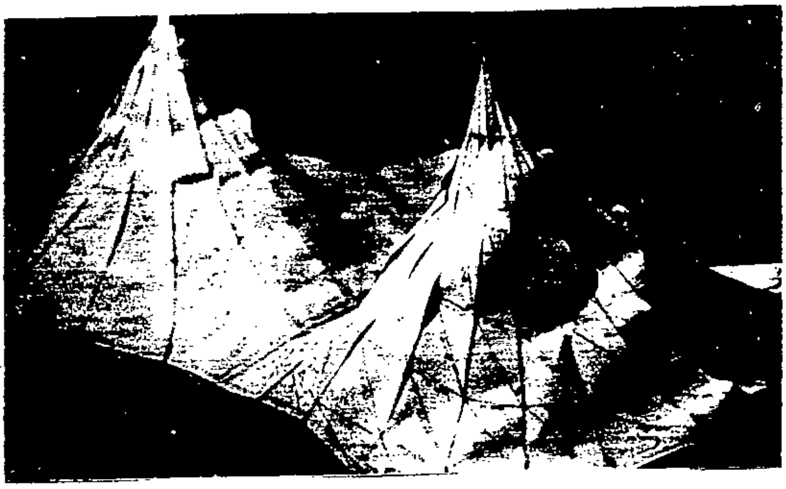


Figure 9: Cutting pattern (physical model)
Source: Ref[4]

However, having computerised the form finding and structural analysis phases of the design process, it became an inevitable step that cutting patterns could be drawn and scheduled automatically by computer.

Many considerations have to be taken into account at this stage as the final surface must be taut in prestressed condition. This involves allowing for the prestress, anisotropic and non linear fabric characteristic. Skillful juggling of positioning of seams is required to avoid wastage of material. Figure 10 shows an example of cutting pattern for fabrication.

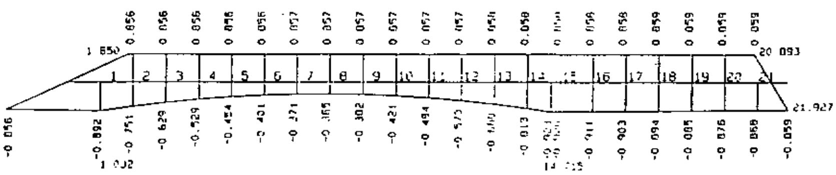


Figure 10: Cutting pattern (computer model)
Source: Ref.[7]

ADVANTAGES OF COATED FABRICS STRUCTURES

Membranes or fabric structures are well suited to broadly distribute dead loads and live loads such as wind and drift forces due to waves. It should not be surprising that lightweight fabric structures will become a popular choice of roofing system for the next decade.

Some advantages of coated fabric usage as structural components are[1,4]:

i. It can provide vast, clear span space-without large supporting members.

ii. It is lightweight and collapsible and therefore easy to transport and erect.

iii. It is entirely pre-fabricated off-site, thereby making erection simple, fast and economical.

iv. It creates outdoor space by protecting against U.V.rays, heat, glare, rain and wind.

v. Natural light through translucent shade sails is soft and cool by day, and dramatic lighting effect can be achieved at night to create a landmark structure.

vi. Design freedom with state-of-the-art materials and process technologies recast an otherwise boring commercial facility into exciting, distinctive community space.

APPLICATIONS

Fabric roofs can now be found throughout the world covering various types of building structures.

The world largest shade structure-the Haj Terminal at Jeddah International Airport covers 500,000m^2 and consists of 45m x 45m mechanically tensionec prestressed membrane surfaces made from PTFE coated glass and reinforce with radial cables. The material's high surface reflection and structural forr help in reducing air temperature under the roof (Figure 11).

A dramatic 50m by 50m fabric roof over two sunken tennis court at Royal Pin Resort, Carrara, on the Gold Coast, Australia (Figure 12).

The wave-form shade structures for EXPO 88, Brisbane consist of se interconnected segmental tents with polyester fabric membrane of 35 00 total area stressed between ridge and valley radial cables (Figure 13).

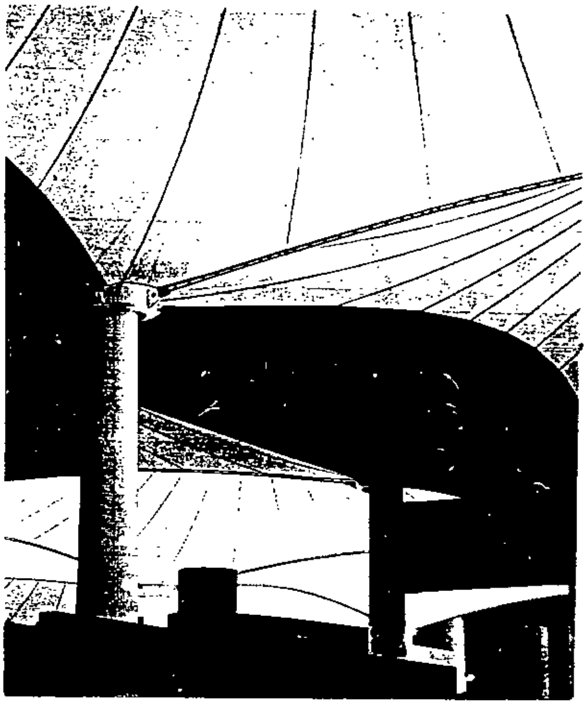


Figure 11:
Haj Terminal,
Jeddah

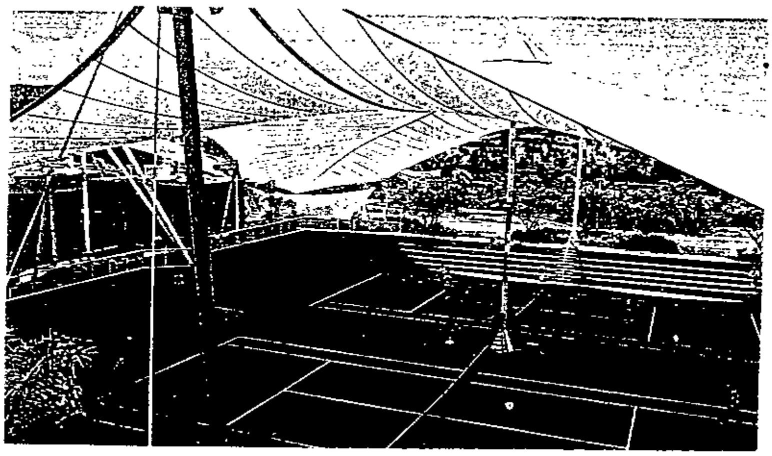


Figure 12: Tennis court at Royal Pines Resort.

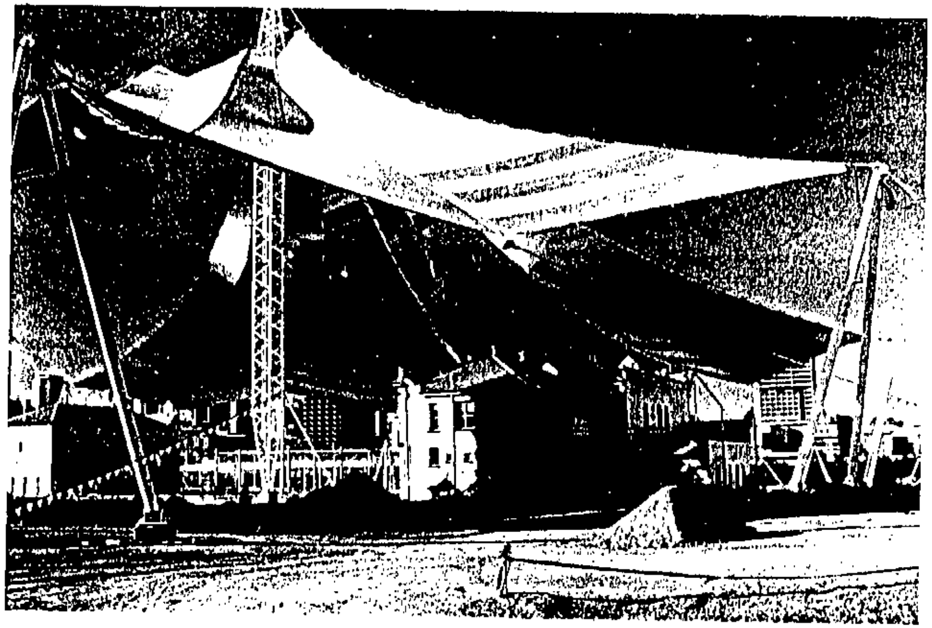


Figure 13: Wave structure for EXPO'88, Brisbane
Source: Ref.[7]

Large areas of sunshading have also been built in other parts of the world using either PVC coated polyester or PTFE coated glass fabric.

CONCLUSION

Even though these types of structures have been erected in many parts of the world, the developments in Malaysia are still new. Review on some technical aspects presented here will be beneficial to the development of this potential structural material.

REFERENCES

1. Leonard, J. W.: *Tension Structures*, McGraw-Hill, New York, 1988

2. Schock, H. J.: *'On The Structural Behaviour and Material Characteristics of PTFE-Coated Glass-Fibre Fabric'*, Journal of Coated Fabrics, Vol.20 April 1991

3. Barnes, M. R., Wakefield, D. S.: *'Form-finding, analysis and patterning of surfaced-stressed structures'*, 1st Oleg Kerensky Memorial Conference, London 1988

4. Salvadori, M., Heller, R.: *Structure in Architecture,* Prentice Hall, New Jersey, 1975

5. Forster, B.: *'The Engineered Use of Coated Fabrics in Long Span Roofs'*, Journal of Coated Fabrics, Vol.15 July 1985

6. Liddell, W. I.: *Current Development in materials for fabric structures,* Proceedings of the 1st. International Conference on Lightweight Structures in Architecture, Australia, 1986

7. Barnes, M. R.:*'Computer Aided Design of the shaded membrane roofs for EXPO 88'*, Structural Engineering Review, 1988