Editorial

This is the fourth issue of TensiNews since EU funding for the establishment of TensiNet ceased and the organisation became self-funded—principally through industrial sponsorship by the major partners, although supplemented by a significant number of individual, company and university membership fees. TensiNet is now on a sound financial footing to cover its publication, symposia and web support costs (which to some extent have previously been supplemented by staffing provided at the VUB in Brussels).

An expansion of the support has come about through the former Working Group for Tensile Architecture who have now joined TensiNet as full partners. One effect of this is that TensiNet will in future be sponsoring the international student design competition (see article in the current issue of TensiNews).

Other wider considerations, which are raised in the short article about the working group meeting (page 2) are:

- the possibilities for further collaborations or amalgamations with other groups
- a possible reconsideration of the aims of TensiNet, or revision of emphasis
- a possible review of the constitution or management of TensiNet

In relation to the latter two aspects it seems appropriate to emphasise that TensiNet was set up with EU funding to be a Europe-wide network for the dissemination of information relating to Tensile structures (particularly prestressed membranes) and to become an industry-sponsored trade, professional and educational organisation managed, according to its constitution, by its founding and subsequent industrial partners. That is a very broad aim and it allows plenty of scope for the organisation to develop however it may wish, and there will be a natural effect for the principal partners who provide most funding to shape future policy, including of course the question of further collaborations. In that context there are three levels of collaboration:

- the first is National—there may be good organisational and perhaps commercial reasons for the formation of local (or national) branches of TensiNet—see for example the article on page 2 concerning the meeting in Madrid
- the second is Europe-wide—in other words increasing the emphasis on the original aims of TensiNet which, in addition to the exchange of information at the professional and educational levels, also had the intention of providing a forum for potential collaborations in research and development, and the development of design guides and eventually codes of practice
- The third is International—for example, in a worldwide context there are four Lightweight Structures associations—LSA in the US, LSAA in Australia, TensiNet in Europe and MSJ (membrane structures association of Japan). Most of these have already agreed in principle to collaborate in the setting up of International Symposia

TensiNews is really an industry news forum, especially relating to new projects. It is not intended to be a magazine for research and the articles are not refereed (or particularly vetted and edited), but it might be appropriate to have a letters section and perhaps some of the issues raised above could be discussed more widely.

Marijke Mollaert
Mike Barnes
Working Group for Textile Architecture: Meeting Frankfurt 19th October 2005

The following members of the Working Group for Textile Architecture did attend the meeting in Frankfurt: Mr. Driesch, Verseidag; Mr. Frisch, Dynoec; Mr. Kleibel, Taiyo Europe; Mr. Jännecke, Messe Frankfurt; Mr. Hohlstein, Messe Frankfurt; Mrs. Heidrun Bogner, TensiNet.

As mentioned in previous meeting reports the Working Group for Textile Architecture will join the TensiNet Association and will no longer continue its activities as an independent Working Group.

The three companies Verseidag, Dynoec and Taiyo expressed their intention to join the TensiNet Association as a partner.

The following main points we discussed: The new partners paying 2400 euro expect to get more power in the management board than the founding partners paying much less!

Regional TensiNet Meeting in Madrid, Spain

The regional TensiNet Meeting organized on March 2nd 2006 was a success. About 30 experts representing around 20 organisations and firms attended the meeting. Prof. Llorens gave a lecture about the evolution of tensile architecture in Spain and Portugal in the last few decades, and Juan Monjo Carrió explained that TensiNet was funded to be a collaborative European venture. The interest of the current TensiNet Association was clarified. Other topics of discussion were the organization of the “Iberica branch”, an Iberian section on the TensiNet website, the organization of seminars and workshops to be held in 2007, and the translation of the Design Guide. There was a good feeling and next meetings are programmed to take place in Barcelona in April and in Madrid in June to take final decisions about entering the TensiNet Association and organize the “Iberica branch”. Even an “Ibero-american branch” was considered.

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**THE INTELLIGENT SHADING MATERIAL**

**heytex® cooltrax® this name stands for a whole new way to enjoy the sun in the shade and for shading places**

The function

cooltrax® is a high-tenacity net fabric with a unique triangular geometry. When the sun shines this structure creates light and shadow fields on the ground that move constantly due to earth rotation. So heat accumulation on the ground is prevented. The special triangular geometry is the only pattern ensuring that each point is evenly shaded. Thus sun or shadow stripes are completely avoided without regard to the material’s angle to the sun. This means a perfect half shadow.

The advantages

cooltrax® withstands high wind loads and only requires light constructions. It offers a maximum cooling effect due to the material structure which has 32% of open surface. This prevents heat accumulation underneath. cooltrax® reduces rain noise on dormer windows and sky lights and protects the window material against e.g. hail. When used indoors cooltrax® is suitable for sprinkler systems.

The coated mesh can be used for sun shields on a bigger scale like for market places, street cafes, school yards, kinder gardens and playgrounds as well as for fields for tennis, football/soccer, golf and athletics.

**The application areas**

At home the shading material lets the light in, but keeps the heat outside. Hence it can be used for sun parlours/winter gardens, dormer windows/attic windows, terraces/patios and balconies as well as for carports. Shading can also be needed in business buildings in open-plan offices, conference rooms, vestibules, light streets or glassy airport halls. The shading material is also appropriate for leisure time canopies over sandpits in the domestic garden, places at the beach, sun lounges by the pool, children’s paddling pools, camping sites, etc.

The base fabric is suitable for sprinkler systems.

**The coated mesh can be used for sun shields on a bigger scale like for market places, street cafes, school yards, kinder gardens and playgrounds as well as for fields for tennis, football/soccer, golf and athletics.
The Munich and London based design firm ‘Architecture and Vision’ presents a new design and prototype for a one-person tent to be used in the extreme temperatures of the desert. The inflatable tent is the result of a study performed for the European Space Agency Technology Transfer Programme and employs several concepts discussed in Space Exploration. The prototype has been manufactured by Italian aerospace company Aero Sekur S.p.A.

The structure is making use of the specific temperature curve in hot and regions, where the air is getting considerably cooler the more distant it is from the earth’s surface. This effect is used by many desert animals like the camel.

The tent has recently been in the exhibition “SAFE: Design Takes On Risk” from October 2005 until January 2006 at The Museum of Modern Art (MoMA) in New York. It will be shown this summer in the Museum of Science & Industry in Chicago in the special exhibition “Leonardo da Vinci: Man, Inventor, Genius”.

To create the vertical element an air beam construction has been chosen to allow a dense packaging and lightweight construction. The air beams form a vertical A-frame, which ends in an aluminium plate, which allows a stand-off for the air-intake. Between these air beams a silver-coated awning is spanned to form an anti-clastic shape. This provides an elegant transition from vertical to horizontal as well as a flutter-free spanned textile surface, which offers good aerodynamics with a low wind-resistance.

The first prototype has been manufactured by the Italian aerospace company Aero Sekur S.p.A. (www.aerosekur.com), specialised in parachutes and lifesaver inflatables. The tent consists of an air beam structure made of yellow PU-coated polyethylene fibre. The two V-shaped air beams are kept on distance by another air beam at the widest part of the tent. At the top and bottom end they are held by an aluminium plate, which defines an end and allow the openings for the airflow.

The awning is a silver-coated high-strength textile to reflect heat and protect from direct sunshine. The awning is-seamed together out of four pre-cut pieces and glued directly onto the air beam to allow an easy set-up also in strong winds. In its longitudinal axis the tent is fixed to the ground from both ends by ropes and two large plastic tent pegs, which allow fixation in the sand, but also in other grounds. The A-frame provides lateral stability.

DESERT SEAL
A Tent with active Cooling

Desert Seal is an inflatable one-person tent for hot extreme environments. The introduction of a vertical element allows a high air-intake for cooling the tent inside. In addition it allows entering the tent upright and taking the cloth of inside, protected from wind. The entrance can be opened and closed by a zipper.

During the day, an electric fan in the top of the tent, 2.26 m above the ground, constantly blows cooler air into the tent, thus reducing the interior temperature. The fan is powered by batteries charged by a flexible solar panel mounted outside the tent. This rollable solar panel is a development by the Swiss company VHF-Technologies. Batteries are standard AA rechargeable batteries.

Recent and near-future developments in battery and solar-panel technology increasingly allow new concepts also in mobile structures, which
New tensioning system for textile façades

Buitink Technology has developed and patented an innovative system to tension textile façades and membranes: an inflatable tensioning tube

Textile façade
When a fabric is used to create a textile façade at the exterior of a building, one has to take into account (large) wind forces. Especially above 10-20m and in case the textile façade is installed at more than 15cm away from the building (which means no or less pressure compensation), the forces on the fabric will be large. In these cases a once-only pre-tensioning of the membranes might not be sufficient, especially when façades for the long term (permanent) are installed.

Existing tensioning systems
By tensioning the panels with a spring system, larger forces can be taken by the fabric, to provide tension and to give the fabric the possibility to deform to a certain extent. This can be done by fixing the panels to a (aluminium) tensioning tube or by providing the fabric with springs or elastic rope. These systems have some disadvantages. Springs and elastic rope will wear in time and will have to be replaced. A tensioning tube needs periodic maintenance and lubrication. Besides, it needs a very precise and controllable measuring and tensioning (also in the long term) of the tubes and fabric. Maintenance and replacement of parts will often have to take place in areas that are difficult to reach. Further, when using springs or elastic rope, space will remain between the fixation points to the façade and the fabric panels. Also the fixation parts will remain visible. Finally, an aluminium tensioning tube is rigid and not flexible, which can make it difficult to introduce forces into the fabric evenly. When e.g. one fabric panel covers the complete width of a façade and is fixed to aluminium tensioning tubes, the wind forces on the panel will vary on different locations of the fabric panel (at the corners there will be probably more force than in the middle).

New: Buitink inflatable tensioning tube
In addition to existing tension systems and to take away some major disadvantages, Buitink Technology developed a new tensioning system: the flexible, inflatable tensioning tube. The system consists of an inflatable tube to which the fabric panels are connected, by means of e.g. a weld or connection profile. By inflating the tube, the fabric is tensioned like a spring system. In case of external forces, the fabric will tend to deform and will therefore need extra length. This length is obtained by deformation of the round tube into a more oval shape. Depending on the diameter of the inflatable tube and the inner pressure, this will result in an opposite resulting pulling force from the tube, which keeps the fabric tensioned and will bring it back to the original state. A simple and central air unit maintains the system of inflatable tubes.

Advantages of the inflatable tensioning tube
The inflatable tensioning tube has a number of major advantages. First of all, the tubes need no or hardly any maintenance. The only maintenance will have to take place at the central air unit (e.g. a yearly inspection), which basically is the complete tensioning system. Besides, architects have more freedom in design, since the tube can be installed out of sight and the fabric can be connected directly on the façade (without having space between the fabric panels and the fixations for the springs or elastic rope). Further, different combinations of diameter, inner pressure and maximum deformation can be chosen. Moreover, the inflatable tubes will provide for stiffness perpendicular to the tensioning direction but at the same time they will remain flexible and bendable. This way, external forces can be introduced into the fabric panels in a more evenly way than in case of a rigid tensioning tube. Finally, it is easy to give the tubes on a higher level on the façade more inner pressure, to take larger wind loads (the tensioning properties can be adapted to local circumstances). A short summary of the advantages: freedom of design and detailing, tensioning of flat fabric panels possible, maintenance only at the air system, many possibilities of application, and evenly introduction of forces.

A large number of applications…..
The system with inflatable tensioning tubes can be used for a lot more applications, like tensioned ceilings, banners, tents and even trampolines!

Rienk de Vries: info@buitink-technology.com · www.buitink-technology.com
Chemically Rigidized Expandable Structures (CRES) for Space Application

Background
Between 1979 and 1992, under European Space Agency (ESA) contracts, Contraves AG (Zurich, Switzerland) undertook to develop a technology for inflatable space rigidized structures (ISRS) — intended to serve a wide range of space applications — that raised interest beyond the original sponsor, e.g., of researchers in the US and in Japan. Unfortunately, this somewhat unconventional technology could not obtain the flight opportunity that it needed to prove itself in a real test environment, leading the Swiss company to abandon active development early in the 1990s then, ten years later, to wholly withdraw from the field. In the meantime, ESA has restarted an effort in this technological domain.

Dr. Bernasconi had the privilege to become involved with this work at its very onset (when he was massively involved both in the technology definition and in the design of the first reflectors) and to accompany it through its expansion phase. Because of his competence, in the 1990s he became the sole point of contact for the ISRS field, and performed a number of studies and assessments for interested third parties. Since Contraves disclaimed any further interest, he has continued to offer his engineering services and his expertise about inflatable expandable structures, doing business under the firm of «MC Bernasconi Consultants» (MCBC, for short) since January 2003.

Below, we summarize some of the past activities related to the three classes of applications: precision structures, backbones, and heavy-duty items.

Precision Structures

For historical reasons, work at Contraves centered on microwave antenna reflectors, whose different forms find numerous uses in communications, astrophysical research, and remote sensing.

Reflectors for Communications Antennae & Radio Telescopes

The experimental activities at Contraves led to the manufacture of some eight complete parabolic reflectors, with apertures ranging from 1 to 10 m. Three early scale models of a symmetric (center-fed) reflector were used to appraise issues such as folding and deployment, manufacture processes, and achievable accuracy. In successive phases, the first-ever "inflatable" offset reflector was built, with three 3 m objects used for extensive tests, collecting data on accuracy (0.7 mm root-mean-square (rms) for the last object manufactured) and electrical performance -- measured at frequencies up to 22 GHz on an object (Figure 2), folded, re-deployed, and cured. Also tested were the concept's high packaging efficiency (Figure 1), its controlled deployment in vacuum, and the chemical rigidization under simulated space conditions. Successively, a 10 m aperture, offset-fed reflector designed for multi-beam operation at 1.6 GHz was manufactured and tested (under clean-room conditions -- Figure 3): while the initial 2.2 mm rms surface error grew to 2.7 mm rms after folding and deployment, the reflector still kept a side lobe level of -33.8 dB. Most communications antennae adopt offset-fed configurations, to minimize interferences: in radio astronomy, where issues of gain and resolution predominate, symmetric (on-axis) designs are more common. Investigating the QUASAT orbital radio telescope, a European scientific group suggested to base it on CRES technology. Supporting activities at Contraves culminated in the manufacture and test of a 6 m diameter Test Article (Figure 4) (1.2 mm rms). Further, we provided assessments and support for scientific projects (e.g. Radioastron, the MODEST concept) and, following up various external queries, we evolved a self-contained, compactly stowed, reflector concept, to create relatively large apertures (up to 6 m) to small-satellite missions.

Solar Concentrators

High-concentration-ratio solar collectors represented a pre-eminent application for flexible wall structures. A study of a Solar-Thermal Upper Stage (Figure 5), led by EADS Space Transportation, offered the opportunity to assess the interest of continuously inflated reflectors for such an application, as the limited life time (up to a month) of such a system makes the use of this technology possible.

Backbone Structures

To satisfy their functions, precision structures demand extended design, analysis, and in-process control measures, but they do build on a technology base that allows realization of bearing elements without...
MCM Consultants bring the accumulated expertise of the pioneering work at Contraves AG into current and future developments

inherent accuracy requirements. Thus, lightweight backbones seem the logical objects to begin implementing a CRES capability, as ESA and industry are attempting today. Analyses showed that -- even with simple morphologies -- the technology's versatility in complying with various needs, still reaches numerous prospective users.

**Planar Instrument Carriers & Solar Sailing**

Any CRES item has an overhead (container, pressure-control items, etc.) that may become too important when used on a "too small" object with "too simple" a function. As a torus replaces several linear elements, such frames return a better value for the investment overhead. And designs where a toroidal structure deploys and supports a flat membrane can suit to a wide range of tasks. In particular, solar sails have been assessed in a number of studies (Figure 6): the torus design remains attractive for such uses up to some 100 m in diameter. Toroidal support structures received attention for a power transmission rectenna, as well as for thin-film photovoltaic solar arrays (TFPV -- Figure 7). To date, no such object has been built in Europe, but experience exists both with more complex items (as used within the FIRST shield model, mentioned below and including rings of 3.5-4 m, each incorporating 12 nodes), and with purely inflatable, but larger (6-15 m), stabilization tori within antenna reflectors.

**Single-Tier Structures: Aero brakes and more**

As the flexible parts grow to a significant size, it appears indicated to position the spacecraft body in the frame by a tripod connection (or one with 4, 5, or 6 legs). Single-tier elements can deploy lightweight aero brakes (e.g. to lower a piggyback satellite's orbit, or to accelerate a spacecraft's end-of-life decay from orbit), to support shadow shields or «instrumented» membranes (microstrip, lens or reflectarray antenna elements, sensors or multifunctional devices, etc.). Our studies have shown the attractiveness of such an option for (slow) aero braking, both in terms of mass and costs (Figure 8).

**Two-tier Structures: Telescopes' Tubes and Thermal Shields**

Mastering the creation of nodes connecting out-of-plane tubes to a flat frame enables the creation of 3-dimensional assemblies, complex truss works and polyhedral skeletons. The initial public proposal for a Far Infrared Space Telescope (FIRST) foresaw an 8 m mirror, radiatively cooled to 150 K, thus requiring an expandable thermal shield in the 10 m size range, for which it suggested a CRES object. We defined this shield as a two-tier assembly, with 48 cylindrical strut elements joined at 24 nodes, each interfacing with either four or three struts. Several ESTEC contracts supported the work at Contraves, including the manufacture of a complete 3.5 m skeleton (Figure 9), used for packaging, deployment, cure, and geometric check activities.

Expandable space structures no more complex than this can cover many applications -- including hangars and other unpressurized enclosures. In their basic form, orbital hangars build an enclosure for shielding astronauts and hardware during maintenance and repair activities, adding services like controlled lighting, some thermal conditioning, work stations and more. Shielding cryogenic upper stages appears an engineering application viable for a FIRST-shield level technology. Also, the use of inflatable structures for realizing greenhouses, particularly operating on planetary surfaces, has been discussed and currently receives an increasing amount of attention.

Heavy-duty Structures for Habitation

Expandable, habitable volumes embody an ambitious use of membrane structures technology. In 2001, the Italian Space Agency (ASI) sponsored the first European study in this direction, in which Dr. Bernasconi consulted for Oerlikon-Contraves Italiana (Rome). In analyzing the packaging of flexible-wall habitats of different basic geometries, he showed that both a full torus and its C-annulus derivative (Figure 8) are most convenient in terms of the achievable expansion ratio -- i.e. the ratio of the volume of the structure expanded to its volume stowed. A recommended modification of the configuration "A" habitat (Figure 10), complying with a 4.7 m high, 4 m diameter stowage volume, would increase the expansion ratio (from 4.5 to 5.9) and thus the habitat's volume (225 m$^3$ vs 135 m$^3$).

If expandable habitats offer a capacity well beyond that otherwise compatible with a transportation systems, they raise the problem of furnishing them. To create secondary internal structures, one can use either conventional, rigid, equipment -- that has to pass through airlocks and hatches connecting with distinct carriers in a time consuming way -- or folding elements. MCB, as part of the HTS (Zurich) team, has addressed the type and layout of auxiliary structures that the «Space Haven» module (under study at Alenia Spazio) would need. But this remains an area for much future work.

<table>
<thead>
<tr>
<th>Client</th>
<th>European Space Agency (ESA), ESTEC, The Netherlands</th>
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<tr>
<td>Original contractor</td>
<td>Contraves AG, Zurich, Switzerland</td>
</tr>
<tr>
<td>Engineer</td>
<td>MCB</td>
</tr>
<tr>
<td>Materials</td>
<td>Textile composite of Kevlar with a modified cycloaliphatic epoxy resin</td>
</tr>
<tr>
<td>Execution</td>
<td>1980 - 1991</td>
</tr>
</tbody>
</table>

http://esprist.bathome.org • Dr Bernasconi, mcbc1@bathome.org
The mechanical behaviour of coated fabrics and films used in prestressed textile engineering:

Its importance in the analysis and how to derive membrane stiffness by simple theoretic considerations

In the beam theory one finds the expression \( E J \) as the bending stiffness in the differential equation for the displacement \( w \):

\[
\frac{d^2 W}{dx^2} = -\frac{M}{E J}
\]

M is the bending moment, \( E \) is the modulus of the material and \( J \) is the axial momentum of inertia of the cross section. Analogue equations are valid for the displacement of plates. In the theory of membranes such an expression for the stiffness is not yet known. The question rises: can one define an analogue expression for the membrane stiffness?

Approximate theory of membrane deformation and stress distribution

To get an expression for the membrane stiffness one starts with the equilibrium conditions for a prestressed membrane. Assuming a covariant formulation, these conditions have the form:

\[
\begin{align*}
N^{ab} B_{ab} + p &= 0 \\
\text{Div } N &= 0
\end{align*}
\]

Here \( N \) is the stress tensor with the contravariant components \( N^{ab} \). \( B_{ab} \) are the components of the curvature tensor. In the pre-stress state one assumes the load \( p \) to zero, and obtains an anelastic surface with a negative Gaussian curvature. The stresses here may be \( n^{ab} \) and the curvature \( b_{ab} \) in the homogeneous equilibrium conditions

\[
\begin{align*}
n^{ab} B_{ab} &= 0 \\
\text{Div } n &= 0
\end{align*}
\]

Under a loading \( p \) perpendicular to the membrane surface the stress will change from the pre-stress \( n^{ab} \) to the \( N^{ab} \) and the curvature will change from \( b_{ab} \) to \( B_{ab} \):

\[
\begin{align*}
N^{ab} - n^{ab} &= \Delta n^{ab} \\
B_{ab} - b_{ab} &= \Delta b_{ab}
\end{align*}
\]

Setting these expressions into the equation above and neglecting expressions of order two one gets:

\[
\Delta n^{ab} B_{ab} + n^{ab} \Delta b_{ab} + p = 0
\]

For the change of curvature \( \Delta b_{ab} \) one gets a linear approximation in function of the displacements \( u \) in perpendicular direction:

\[
\Delta b_{ab} = u_{\alpha/\beta}
\]

Here the suffixes indicate the second covariant derivative of \( u \). For the changes \( \Delta \alpha \) one can write a linear elastic approximation:

\[
\Delta n^{ab} = E^{\alpha/\beta} e_{\alpha/\beta}
\]

The \( E^{\alpha/\beta} \) are the components of the tensor of rank four of elasticity and the \( e_{\alpha/\beta} \) are the components of the tensor of deformations. For a two-dimensional orthotropic material \( E^{\alpha/\beta} \) has the following form:

\[
E^{\alpha/\beta} = \begin{bmatrix} E_{1111} & E_{1112} & 0 & 0 \\ E_{1211} & E_{2222} & 0 & 0 \\ 0 & 0 & f_{1212} & 0 \\ 0 & 0 & 0 & h_{1212} \end{bmatrix}
\]

\( E_{1111} \) is the stiffness in the warp direction. \( E_{2222} \) is the stiffness in the weft direction. \( E_{1212} \) describes the influence of Poisson ratio. \( E_{1122} \) is the shear modulus. For the deformation \( e_{\alpha/\beta} \) one can assume when neglecting the non-linear terms and the influence of the tangential displacements:

\[
e_{\alpha/\beta} = -b_{\alpha/\beta} u
\]

Thus one gets the following expression for the displacement \( u \):

\[
u_{\alpha/\beta} = \frac{n^{\alpha/\beta} - D}{D} u + p = 0
\]

where \( D \) is called the membrane stiffness:

\[
D = E^{\alpha/\beta} e_{\alpha/\beta} b_{\alpha/\beta}
\]

Partial solution

If the load does not change over the surface and if the initial curvature is almost constant, a particular solution of this equation may be written as:

\[
u = \frac{p}{D}
\]

The deflection is indirect proportional to \( D \) and \( E \), and thus indirect proportional to the square of the curvature. The increment of stress results in:

\[
\Delta n^{ab} = E^{\alpha/\beta} e_{\alpha/\beta} b_{\alpha/\beta} p
\]

The increment of stress is independent of the magnitude of the elastic moduli \( E \), but indirect proportional to the curvature. These conclusions are valid for the case that the value of \( D \) is high enough. If \( u \) is a particular solution of the equilibrium conditions it is to state that \( u \) does not fulfill any boundary condition. But then a general solution can be written as the sum of this particular solution and a solution of the homogeneous equation:

\[
u = u_A + p
\]

When neglecting the tangential displacements and assuming the boundary of the problem to be parallel to the \( x_2 \)-coordinate and \( x_1 \)-orthogonal to this boundary, the solution for the homogeneous part along this boundary is:

\[
u = A \exp \left[ -\frac{D}{\sqrt{h_1 n_{11}}} x_1 \right]
\]

The total solution will be:

\[
u = \frac{p}{D} + A \exp \left[ -\frac{D}{\sqrt{h_1 n_{11}}} x_1 \right]
\]

The condition \( u = 0 \) for \( x_1 = 0 \) leads to:

\[
A = -\frac{p}{D}
\]

Thus the solution will be:

\[
u = \frac{p}{D} \left( 1 - \exp \left[ -\frac{D}{\sqrt{h_1 n_{11}}} x_1 \right] \right)
\]

along the boundary \( x_2 = 0 \).

To clarify these results, \( D \) and the static properties under pressure load will be calculated for two cases with finite element models. Here, the approximations mentioned above are not applied; the deflections in the tangential direction are taken into account.

Case study 1

Assume a hyperboloid of the following form:

\[
x^3 = C x^1 x^2
\]

The covariant components of the tensor of curvature can be calculated to be:

\[
b_{\alpha/\beta} = \begin{bmatrix} 0 & C \\ C & 0 \end{bmatrix}
\]

The size of the surface is 20m x 20m projected on the \( x_1-x_2 \)-plane. Assume first that warp and weft are approximately in the directions of the generating
straight lines. Then the membrane stiffness $D$ results in:

$$D = 2 E^{1212} b_{12} = 2 E^{1212} \frac{C}{G}$$

where $C$ is the elevation and $G$ is the determinant of the metric tensor:

$$G = \sqrt{1 + C^2 \left(X^{12} + X^{22}\right)}$$

The term $E^{1212}$ is approximately 300 kN/m. Thus $D$ will be relatively small and the stresses dependent on the height of the elastic moduli $E$. The values for the physical components are assumed to be:

$$E^{\text{phys}} = E \left(\begin{array}{cc} 1 & 0.15 \\ 0.15 & 0.5 \end{array}\right)$$

The load $p$ is considered to be 250 N/m$^2$. (figure 1)

In figure 2 the maximal displacement $u$ in normal direction is shown as a function of the elastic moduli $E$.

The curves plotted differ in elevation of the hyperboloid, or, in other words, with the curvature: the higher the curvature, the lower the displacement. The dependence on the modulus resembles a hyperbola as predicted by the theory, although the stiffness $D$ is very low. There is no difference between the principal behaviour for high and low curvature, respectively $C$.

In figure 3 the maximal stress in warp direction is presented in function of the magnitude of the elastic moduli $E$. The single curves differ in curvature $C$ of the hyperboloid: the lowest one belongs to the largest curvature.

Here the conclusion derived above does not work: one sees a remarkable increment of the maximal stress with the scaling factor $E$.

**Case study 2**

The same shape is used but the main axes of anisotropy are oriented along the diagonal of the surface. The covariant components of the tensor of curvature along these axes are: (figure 4)

$$b^{12}_{\text{phys}} = \left(\begin{array}{cc} C & 0 \\ 0 & C \end{array}\right)$$

Here the membrane stiffness $D$ results in:

$$D = (E^{1111} - 2 E^{1222} + E^{2222}) C^2 \frac{G}{E}$$

This value of $D$ is higher because the stiffness in warp and weft direction is in the order of MN/m.

**Conclusion**

1. It is possible to define a membrane stiffness $D$ which reflects the material tangential stiffness tensor and the influence of curvature.
2. If $D$ is large enough the increase of stress under normal loads does not depend on the stiffness itself. One has not to know the stiffness matrix exactly.
3. Under constant normal load one can find an algebraic particular solution of the equilibrium conditions which do not fulfill the boundary conditions.
4. The deflection under normal loads depends from the stiffness.
5. If $D$ is low the stress increase under normal loads depends on the stiffness. One has to know the stiffness matrix exactly.

**Acknowledgements**

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LITERATURE

Architextiles
by M.G. Garcia
Paperback 128 pages
Publisher: Wiley-Academy, Nov 2006
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Architextiles explores the contemporary intersections between architectural and textile design. Focusing on the possibilities for architectural and urban design, this issue examines the most generative set of concepts, forms, patterns, materials, processes, technologies, and practices that are driving the proliferation of this multi-disciplinary design hybrid.

Architextiles represents a transition stage in spatial design’s re-orientation towards a more networked, dynamic, interactive, multi-functional, and communicative state. The paradigms of fashion and textile design, with their unique, accelerated aesthetics, and ability to embody a burgeoning, composite, and complex range of properties such as lightness, flow, flexibility, surface complexity, and movement, have a natural affinity with architecture’s shifts towards a more liquid state. The emergence of Architextiles to architectural prominence challenges traditional perceptions and practices of interiors, architectural, urban, landscape, and fashion and textiles. Interweaving new designs and speculative projects on the future, Architextiles brings together architects, designers, engineers, technologists, theorists, and material researchers to unravel these new methodologies of fabricating space.

Each of the contributors offers a unique insight into the dimensions of Architextiles. This title includes the work of Nigel Coates, Dagmar Richter, Lars Spuybroek, Frederic Migayrou, Peter Testa, Dominique Perrault, Kennedy & Violich, David Wakefield, Bradley Quinn, Robert Kronenburg, Will Alsop, Matilda McQuaid, Ushida Findlay, Marie O’Mahoney, SHoP, Arup, Tensys, Massimiliano Fuxas, and new projects and writings from young and emerging designers and theorists.

Objectives
The workshop’s objectives are to provide fundamental practical information, as well as presenting the state-of-the-art in textile roof engineering knowledge. In addition to a comprehensive programme of presentations in English by key figures from the membrane structure industry, a unique opportunity for the study and hands-on development of practical case-studies in an informal tutorial environment will be provided. Above all, the workshop aims to provide practical answers to real-world questions.

Introduction
In the last eleven years, ten workshops on the Design and Realisation of Textile Roofs were held in Berlin. Due to the practical emphasis and unique format, these events have proven to be increasingly popular. Textile Roofs is now an established annual event. The 2005 workshop (reports available at http://www.tensinet.com, in the library section) attracted around eighty participants from twenty countries. The series will continue in 2006 with further developments and enhancements to the programme.

The workshops are concerned with the design of architectural membrane roof structures. For most people such roofs are typified by world famous sports stadia and temporary exposition structures. Although prestigious buildings of this type continue to utilize tensile roofing systems, the scope of application has widened considerably over the past decade. Today, tensile roofs are routinely used in shopping centres, corporate headquarters, leisure centres, zoos, schools, and even factories. With a combination of visually dramatic curvilinear forms, and economic efficiency, such architectural solutions represent an attractive option for many situations.

The participants to the previous events have come from a wide range of backgrounds, ranging from established experts to complete novice students. This rich mix appears to explain part of the popularity of the workshops.

Programme and Lecturers
The detailed programme may be found at the workshop’s website.

In addition to a comprehensive series of lectures presented in English by key figures from the membrane structure industry and academia, opportunity for the hands-on development of practical case-studies in an informal tutorial environment will be provided. The following key subjects will be addressed during extended morning lectures:

- Introducing Lightweight Structures
- Computational and Physical Modelling
- Project Management and the Design Process
- Detailing, Connection Design and Fabrication
- Project Case Studies
- Materials for Textile Structures
- Environmental Aspects

During each afternoon, the hands-on workshop will run with opportunities for both computational and physical modelling. In parallel to this practical activity, specialized lectures will be presented on state-of-the-art topics for the more advanced participants.

Students Seminar
This year, an International Students Seminar held from May 23 – 27th is part of Textile Roofs 2006. Selected students with different fields of study and great interest in tensioned structures, have the chance to develop a sense for these structures by practical experience. Finally, they will have the possibility to discuss their work with the participants and professionals of the workshop.

Sponsors
In addition to the Technical University Berlin, Textile Roofs 2006 is supported by technet GmbH (www.technet-gmbh.com), Ferrari (www.ferrari-textiles.com) and Tensinet (www.tensinet.com).
DE-LIGHT AND AIR

International Students Seminar ‘de-light and air’ TU Berlin Mai 24th – 28th 2005

TOPIC

Even today, tensioned and inflated membranes are still fascinating. This fascination is based on the relation of the free shaped tensioned structures to nature, and depends on the organic shapes, the lightness and transparency of textile buildings. Like in nature, the shapes of membrane structures are less determined by the design purpose, and are quite a bit more influenced by the process of development.

Non-tensioned membranes and cables are slack, and can be rolled, or folded up, and only tensioned or inflated membranes get their stiffness and stability. The kinematics and the nearly non-existent bending stiffness of membranes and cables are leading consequently to the tensioned shapes. The shapes are defined by the equilibrium of internal stresses and forces, obeying mechanical principles, and they are not free in their design. Developing tensioned and inflated structures requires an attitude towards designing structures that is not just determined by the will of the designer, but also affected by the process of finding the right shape under given circumstances, and the search for the right solution defined by the structure itself. The main emphasis of the International Students Seminar lies in developing and manufacturing building models for tensioned and inflated structures, including all experiences during the process of development and manufacturing, up to the final and real model. The design of membrane structures is closely related to an interest in new fields of research, and triggered by some form of curiosity while developing, and fun during manufacturing.

Interests in new ways of thinking and unusual approaches are affecting the appearance of the buildings.

TARGET

The major aims of the International Student Seminar are in the design and manufacturing process of tensioned and inflated structures. The building process is influenced by an interest of getting into new fields, the gathering of experience, and the stepwise success. The design of membrane structures is deeply related with the behaviour of the fabric and the possibility to tension, join, and fix the materials. Therefore, one of the targets of the seminar is to point out the relation between form, material behaviour, and structural behaviour which can be realized during manufacturing and construction. Another aim is to get practical experience in designing and manufacturing tensioned and inflated membrane structures. The practical experience can hardly be taught using computer modelling, neither for the 3D-shapes and animations, nor for the numerical simulation of structural behaviour. The gap between virtual designed structures and real building is getting wider and wider, and one of the aims of the international seminar is to show the possibilities and differences between physical modelling and computational design.

Participants of the Seminar are teachers of invited European Universities, and they are bringing eager students along. These students come from different fields of study, but they share an interest in and an enthusiasm for tensioned structures. Students have the chance to develop a sense for these structures by practical experience, and have the possibility to discuss their work with the participants and professionals of the Workshop. Being open minded and free in thinking is the inhibition of designing tensioned and inflated structures, and this will enable a new type of international workshop, combining practical experience and theoretical background, while working in the field of tensioned structures. Main importance is attached to the interplay between massive and light structural elements. The light structural elements have to serve moveability, mobility, sustainability and innovation, challenging the imagination.

DESIGN TASK: MOBILE TEA HOUSE

“A motorcycle with sidecar stopped in front of the hotel. A man removed his helmet and started to work. Within a few minutes the sidecar was changed into a small restaurant with two gas cooker and a nice looking table being piled with small tables full of goodies. By now people stopped and picked spits with minced meat, calamari pieces, sausages and chicken wings. They dipped the pieces into boiling water then into yellow, red or orange dressing, which is added on small plates, eat while standing and paid afterwards the number of empty spits they hold in their hand. Everything was clean, appetisingly and was organised at best. The man was Chinese. The poor Malayan had the impression never to be successful surrounded by such competitor.”


WORK PACKAGE

The project of the seminar is to design and to build on the scale of M 1:5 or M 1:10 a tent which can be stored in the trailer of a bicycle together with all equipment such as cooker, dishes, silverware, tea, milk, cakes etc.. The tent has to serve space for one table with 2 guests. The structure of the tent can be inflated or tensioned. The best designs will be built in scale M 1:1 and presented on the conference in Eindhoven, Adaptables ’06, www.adaples2006.nl
The TensiNet Association and Techtextil - International Trade Fair for Technical Textiles and Nonwovens - are holding the 9th Competition on the subject of ‘Textile Structures for New Building’. TensiNet and Techtextil cordially invite students of architecture and civil engineering to enter this competition. Also invited are all young professionals in these fields who completed their courses of study after January 1st 2006. The competition aims to promote innovative ideas and problem solutions in relation to building with textiles or reinforced materials, which have concrete prospects of being realised. The competition also aims to promote the prize winning students and young professionals. Furthermore, it is hoped that the competition will intensify contacts between the young generation, the universities, the technical textiles industry and broad areas of the building industry.

Tasks: the subject of “re-usability and recyclability”
The competition covers all fields of textile building:
• earthworks, traffic-route construction, landscape engineering, constructions for environmental protection
• civil engineering and industrial constructions,
• building - from building with textile-reinforced concrete or textile-reinforced plastics to building with membranes for permanent and temporary, variable and mobile constructions
• interior fitting - including developments such as the use of polymer optical waveguides for light transmission, textile air-duct systems for draught-free air-conditioning of rooms, mobile sound-insulation walls in production halls, etc.
• product design for architecture.
The subject of ‘Re-usability and recyclability’ has also been included as a main theme. There are no restrictions on the project subject chosen. Both supervised and unsupervised work will be accepted.

Prizes
The prizes will be presented within the framework of a ceremony at Techtextil in Frankfurt in 2007. Additionally, prize-winning projects will be exhibited in a special show at Techtextil 2007. The organisers reserve the right to exhibit the projects at other Techtextil events and to inform the specialist world and the public about the prize-winning projects. A certificate will confirm the prizes.

Jury
The members of the ‘Textile Structures for New Building’ jury will include renowned academics and a number of architects and engineers well known in the field of textile construction. Michael Jänecke, will participate on behalf of the organisers.

Composition of the work
Plans, photographs or models may be submitted. The work should be organised in a manner suitable for exhibition max. 2 plans in A0 or 4 plans in A1, max 12 photographs, format min. 18 x 24 cm, 1 Model in a solid transport box: surface area max. 70 x 70 cm, 1 A4 page description integrated in the work.

Further information may be obtained from Mr. Michael Jänecke, from members of the TensiNet Association or from ILEK, Universität Stuttgart, tel +49 711 685 3599, fax +49 711 685 3789, www.uni-stuttgart.de/ilek

A client wanted to build a traditional typical Bahrain old boat out of fabric. The concept was to make the boat and display it for the Independence Day celebration in Manama.

The idea sounded dull in the beginning. But few sketches and quite some moments of thoughts had formalized the idea of how to do it. Once we knew how to tackle the problem, all aspects of work came to view so clearly.

The first step was to get the shape of the boat hull to match that of the traditional Bahraini Boat. This was done by taken digital photos of boats lying on the shores of the city of Manama. Ratios representing width and heights, and measurements of curvatures of the boat hull were taken from these digital photos.

The measurements were redrawn with AutoCAD. The hull is a very good degree. The utilization of the fabric to create the boat in its traditional look was easy. Some details were compromised. For example, the hull has got an opening at the bottom. This is surely not found in any boat!! However, for us it was necessary for the fabrication of the steel and fabric of the hull. Similarly for the sail, it was manufactured as an independent entity. The mast and the hull are done and fabricated and installed separately. When all parts were put together, the picture was complete.

The design philosophy allowed the fabrication and the installation to be manageable to a very good degree.

FABRIC BOAT

A traditional typical old boat of Bahrain

The forming of the steel masts to mimic that of the traditional Bahrain Boat. We needed to bend steel, CHS of 8 inches with a wall thickness of about 1.5mm, for the support of the sail. We needed to get the right radius of curvature to match that of the fabric.

3D model

General view of the Bahrain boat

6 meter long and the mast is 10 meter high.

Once the shape was complete 3D Studio MAX was used to give the boat a more realistic look. The work was presented to the customer and we got an immediate approval, as the 3D presentation did its magic. From a fabrication point of view, the biggest hurdle in this project was the forming of the steel masts to mimic that of the traditional Bahrain Boat. We needed to bend steel, CHS of 8 inches with a wall thickness of about 1.5mm, for the support of the sail. We needed to get the right radius of curvature to match that of the fabric.

Location

<table>
<thead>
<tr>
<th>Location</th>
<th>Manama</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural Concept</td>
<td>Osama Thawadi</td>
</tr>
<tr>
<td>Concept Development</td>
<td>Yousif Ahmed</td>
</tr>
<tr>
<td>Structural Design</td>
<td>Robert Medina</td>
</tr>
<tr>
<td>Fabrication and Installation Contractor</td>
<td>Gulf Shade - Bahrain</td>
</tr>
<tr>
<td>Year of construction</td>
<td>2005</td>
</tr>
<tr>
<td>Material</td>
<td>PVC polyester fabric: Ferrari 1002, 1050g/m²</td>
</tr>
</tbody>
</table>

www.gulfshade.com • info@gulfshade.com
MULTI-EVENT AREA “LOS TEROS de Melilla”

Description
The project is composed of a pitched roof with a 15° slope that covers an 11m (36ft) space with a repetitive 6m (20ft) module. It is made of hardwood trusses and conic-shaped membranes in PVC, prestressed by means of central regulating masts, with lateral scrollable closures. The membranes are screwed to the structure by means of wood screws with small aluminium plates. The formal solution resembles the existing wooden construction. It was integrated on one of its sides to the main building.

Background Information
Los Teros de Melilla is an estate located on a farm near the city of Montevideo, dedicated to agriculture and cattle-breeding activities, but whose premises can be engaged for hosting parties and events of all sorts.

Objectives of the Roof
1. Eliminating direct solar radiation that can disturb ongoing activities.
2. Allowing entrance of natural light, at least 7%, so the indoor area is not darkened.
3. Rain protection.
4. Low building costs, so as to keep investment risks low, and not generate considerable losses should the enterprise not prosper.
5. Easy installation.
6. Special design to provide distinctive design quality.
7. Integrating with the existing building, without distorting the existing construction.

Reasons for Choosing a Prestressed PVC Membrane
1. It strictly complies with all the objectives.
2. When compared to other traditional systems such as glass, plastic, metal or concrete construction, these traditional systems do not meet all the requirements. Furthermore, some of them add new problems, such as increasing internal heat, blocking light completely, and more importantly, not offering the aesthetic and formal opportunities PVC membranes have to offer.

Design
The roof was generated with a lateral pitch for rain drainage to one side, beginning at the height of the existing buildings. The roof is composed of three 11m x 6m (36ft x 20ft) independent conical shapes, so as to cover the area with the least amount of structural elements.

Design Process
Once the main design parameters were defined, there was special attention to avoid making the conical shapes too high-rising, and that—at the minimum height—the membrane could perform its functions correctly regarding tensions, as well as properly draining rainwater to prevent unwanted ponding.

Building Process
All the woodwork was prepared at the carpenter’s workshop, and the ironwork at the blacksmith’s. The parts were then set up on site by means of a crane. Next, the membranes were fixed to the perimeter with plates and wood screws, and ultimately, the conical shapes were pre-tensed with the specially designed regulating masts.

Prestressing
The pre-tensioning of the membranes was done manually by means of three telescopic central masts with regulation bolts at their base.

Materials
The structure is made of 4x8” Patagonian Walnut (Lapacho), with painted metal fittings, anchored to the ground through concrete bases.

The membranes are made of polyester fabric PES HT 1100dtex, 5x5 threads per cm (12 threads per inch) with PVC coating, UV protection on the outside, a weight of 800gr/m² (230oz/sqyd) and a breaking load limit of 30daN/cm (167lbs/inch).

Conclusions
The objective sought after by the roof was achieved to perfection, accomplishing an enjoyable space for holding events.

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Location
Montevideo, URUGUAY

Construction date
September 2000

Covered surface
200sqm (2.153sqft)

Roof design and project
Roberto Santomauro & arch. Patricia Pinto

Roof structural engineer
eng. Marella & Pedoja

Roof fabricator and contractor
Sobresaliente Ltda

General project
arch. Ritorni

www.sobresaliente.com
tenso@sobresaliente.com, Roberto Santomauro
A combination of tensioned membranes and a laminated wood structure

Buitink Technology recently finished the membrane- and wood structure, which together form the entrance of the Dolfijnarium in Harderwijk (the Netherlands). Buitink Technology engineered, produced, and installed the entrance canopies, as well as the masts with printed flags as decoration. The architect specifically chose this combination of wood and membranes to create the desired atmosphere.

It was a challenge to design all the details of the wood structure to be able to take the large forces resulting from the membranes. For this project several specific details were developed.

The layout of the bearing structure corresponds to a spine. In the centre there is a tower, carrying the logo of the Dolfijnarium. At both sides a wooden laminated Larch (spine) beam is placed. It is carried by portal frames formed by laminated Larch columns and purlins. In between the portal frames purlins are cantilevering from the spine-beam. The architect had designed a rather flat membrane. To prevent large deformations and ponding of the fabric, the pretension is high. The tension forces from the fabric, combined with the relatively large eccentricity, caused by the height and the curvature of the wooden beams, created large permanent bending moments and forces in the wood. This required special detailing of the wood connections.

Special attention is paid to the rain flow over the fabric. Because the structure is an entrance covering, it is not desirable that the water drains all along the boundary of the fabric. At the other hand, the architect did not want to see any water drainage system. A compromise was found by adding rims on the fabric, and guiding the water by means of thin chains to the ground. In the pavement drainage systems are provided.

Buitink Technology builds entrance of Dolfijnarium in Harderwijk

Location: Harderwijk, The Netherlands
Total surface covered:
- Entrance: 205 m²
- Lockers: 75 m²

Owner: Dolfijnarium, Grévin & Cie, Paris, France
Design/Architect: Eremco, Paris, France
Main contractor: GMB Infra BV, Opheusden, The Netherlands
Wood- and membrane structure: Buitink Technology, DUIVEN, The Netherlands
Wood construction: GLC Houtconstructies, ARNHEM, The Netherlands
Engineering Wood construction: Semplonis Adviesbureau, Laag Soeren and Adviesbureau Lüning, Doetinchem
Engineering membranes: Tentech BV, Delft, The Netherlands
Material: 1002 Fluotop T2 (Ferrari)
Year of construction: 2005

Rienk de Vries, info@buitink-technology.com
www.buitink-technology.com

Rogier Houtman, rogier@tentech.nl • www.tentech.nl
The longitudinal courtyard of the Shopping Mall at the Khourais Road Retail Centre in Riyadh (approx. 115 m x 10-16 m) is covered by a Roof Tent Structure. The longitudinal layout of the membrane roof structure is curved in plan and elevation with an axis of symmetry in x- and y direction, and has its maximum width and height at its centre. The maximum dimensions of the roof in plan are approx. 22 x 130 m with a 3D membrane area of approx. 2 350 m² and a glazed area of approx. 180 m². The complete roof structure is generated as a continuous tension equilibrium form, and this results in the dynamic appearance of the roof structure that is full of suspense.

KHORAIISCCH ROAD RETAIL CENTER, RIYADH

The membrane roof consists of 15 single segments that are supported by 14 steel arch structures. The membrane edges are continuously connected along the arched steel frames. The curved membrane roof edges that are cantilevering over the plane of the façade are reinforced by steel cables that are spanning between the tips of the steel arches.

The steel arches consist of two curved steel beams with a skylight glazing in between. This skylight glazing is made of ornamented sun protection glazing. The geometries of the different sized steel frames follow in height and width the overall curved shape of the membrane roof that is at both short sides connected to the concrete roof slab. The two long sides of the roof tent structure have inclined glass façades with an increasing height, approx. 9m towards its centre. These façades are made of an insulated sun protection glazing system. The natural air ventilation and also the emergency smoke exhaust are provided by automated vents that are integrated with the façade. The roof itself does not have any openings. There are special cut and provided by automated vents that are integrated with the façade. The natural air ventilation and also the emergency smoke exhaust are provided by automated vents that are integrated with the façade. The roof itself does not have any openings. There are special cut-out sections integrated into the membrane roof and the top of the façade are connected by a foldable membrane strip to seal the interior air space, and to allow for movement of the membrane under wind.

The rainwater from the tent roof is discharged over the whole perimeter of the roof, onto the roof deck underneath. There are no special rainwater collection points.

All forces resulting from the roof are transmitted to the building structure at the footing points of the steel arch supports, at the two edge beams, and at the tension bar footing points. The concrete structure of the building is designed to carry all reaction forces from the tent roof structure. For this, the anchor bolts to connect the tension bars, and the edge beams are cast with the concrete roof structure. The footings for the V-shaped steel columns are fixed to the concrete structure by vertical anchors. All horizontal forces are transferred to the concrete structure by shear pins.

The “Lleida” prototype has been used in a variety of different locations and purposes.

Furniture and equipment are frequently difficult to integrate into the urban or natural landscape. For monumental sites, historic places, landmarks, and interesting environments, the “Lleida” prototype was designed in order not to interfere visually.
The new Casino will be inaugurated in April 2006. As a part of the rehabilitation works in the existing office building, a new entrance marquee was planned. The canopy roof was needed to protect the entrance from the rain, as well as from the Sevilla sun (more than 3000 sun hours per year, 19ºC year average temperature, 27ºC average in July-August).

Part of the difficulty of this design was to find a way to anchor the roof to the existing building with an “untouchable” skin of glass and precast concrete pillars. It was decided to build a very light structure, with special attention to the transmission of the loads to the right points. Therefore, a curved 26m long beam was fixed to the roof slab, and two masts placed in a V-shape were added in order to stabilize the arch. Smaller masts support the high points.

Client and building type determined the final design. The V-shape is in fact a reference to the symbol of victory in casinos. The fabric is a Ferrari 1202 nacre-silver colour, reinforcing the luxury aspect of the roof. Form and colour provide the roof with its nickname: “The Oyster”.

The fabric is fixed to the arch by a keder and the back borders are pockets with cables tightened to the three corner plates. These corner plates are connected to the small masts placed on the roof slab at appropriate points (heads of pillars, nerves of slabs), and stabilized by means of two cables per mast. These cables are anchored in the level +0.60 slab over the roof, in order to minimize the impact of the forces on the curtain wall. The entire structure was planned, designed, manufactured, and erected in 19 working days.

Textile roof for a stand at TSV Gersthofen

The textile roof over the stand and the terrace has a width of 12m and a length of 54m. Four 13m high masts are placed at a distance of 18m in the longitudinal direction.

The anchorage of the cable, running in the longitudinal direction over the high points of the masts, assures the stability in the longitudinal direction.

Every 6m, a beam spans in the transverse direction. The loads are taken by the connection at the top and the back side of the stand. The high points (every 6m) of the membrane are attached to the longitudinal cable. The anti-clastic membrane shape is tensioned between the high points and the transverse beams of the roof: the snow is carried by the ‘snow bearing direction’, while the upward wind is taken by the ‘tensioning’ direction. The used membrane is PTFE-coated glass.