

# Nice Stadium: Design of a Flat Single Layer ETFE Roof

A. Escoffier, A. Albrecht, F. Consigny

**Abstract**—In order to host the Football Euro in 2016, many French cities have launched architectural competitions in recent years to improve the quality of their stadiums. The winning project in Nice was designed by Wilmotte architects together with Elioth structural engineers. It has a capacity of 35,000 seats. Its roof structure consists of a complex 3D shape timber and steel lattice and is covered by 25,000m<sup>2</sup> of ETFE, 10,500m<sup>2</sup> of PES-PVC fabric and 8,500m<sup>2</sup> of photovoltaic panels.

This paper focuses on the ETFE part of the cover. The stadium is one of the first constructions to use flat single layer ETFE on such a big area. Due to its relatively recent appearance in France, ETFE structures are not yet covered by any regulations and the existing codes for fabric structures cannot be strictly applied. Rather, they are considered as cladding systems and therefore have to be approved by an “Appréciation Technique d’Expérimentation” (ATEX), during which experimental tests have to be performed. We explain the method that we developed to justify the ETFE, which eventually led to bi-axial tests to clarify the allowable stress in the film.

**Keywords**—Biaxial test, creep, ETFE, single layer, stadium roof.

## I. THE STADIUM

IN September 2010, the design team formed by architects of Wilmotte and the engineering company Egis, together with the building company Vinci won the architectural competition for the design and build of a new football stadium in Nice. This project is part of the several newly built football stadiums in France, motivated by the hosting of the Euro cup in 2016.

The stadium, with its 35,000 seats covered by a 40,000 m<sup>2</sup> roof, is under construction in the Plaine du Var and due to completion in summer 2013, roughly 3 years after the competition phase.

The specificity of the project lies in its complex geometry and structure. The roof is a continuous surface enveloping all seats, starting at floor level and going up as a façade then cantilevering over the tiers. The structure is a three dimensional truss combining steel and timber. The timber is located on the inside of the truss, where it is the most visible and structurally efficient.

The membrane comes lightly on top of this lattice, simply providing water-tightness and shading while underlying the undulating shape of the roof. There was no particular interest in typical doubly-curved membrane shapes. For that reason,

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we decided to use flat single layer ETFE where transparency was required and PVC elsewhere.



Fig. 1 Competition rendering – View from outside



Fig. 2 Competition rendering – View from inside

## II. ROOF STRUCTURE

### A. Structural Layout

The roof geometry is generated by the repetition of typical structural modules along the curves of the seat bowl. The modules consist of one row of timber crosses connected by steel tetrahedrons to a steel tube called « Extrados », acting as the upper chord of the truss.

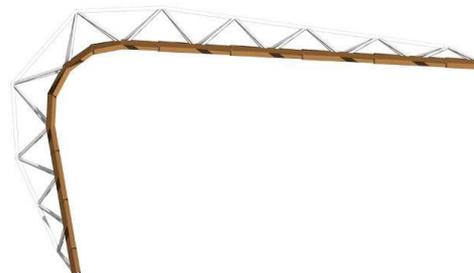


Fig. 3 Typical section with timber as intrados and steel as extrados and diagonals

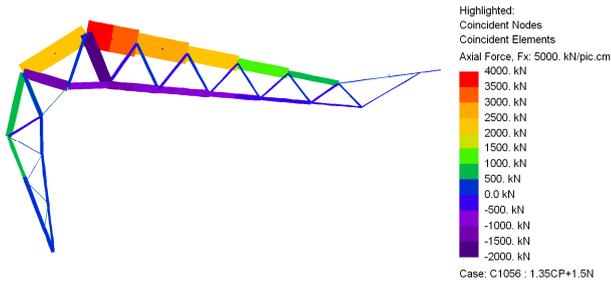


Fig. 4 Axial force diagram – Typical section

In some areas, the extrados move toward the outside to provide rain protection over the main entrances.

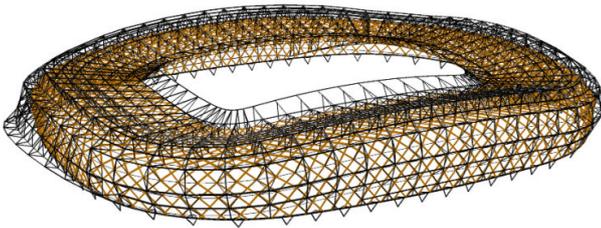


Fig. 5 3D view of structural model

**B. ETFE Panels**

All the extrados generate the outer face of the roof on which the membrane is fixed. Some secondary elements span in between to create rectangular faces. Three rows of faces are formed, which are called « bandeaux ». Each face is clad by an independent ETFE panel.

The maximum cable span on row 1 to 3 is respectively of 5m, 9m, and 10.5m. ETFE panels are up to 180 m<sup>2</sup> big.

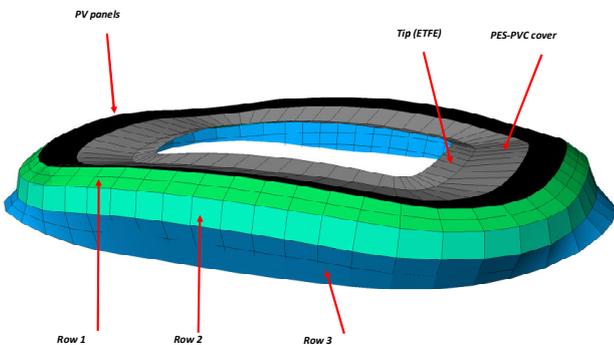


Fig. 6 Membrane panels layout

**C. Controlling Geometry – Parametric Model**

To carefully adjust the roof geometry to structural, programmatic, or fabrication requirements, we developed a parametric model.

As our membrane studies came along, we also used the model to visualize some governing criteria for the ETFE, such as slope direction or cable span. The final geometry was tightly adjusted to meet all criteria.

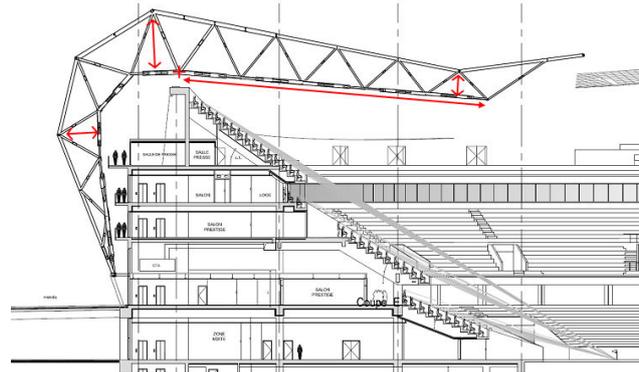


Fig. 7 Section –parameters controlling the shape of the extrados



Fig. 8 Elevation – Visualisation of membrane slopes – Snow applies on blue panels (slope is less than 30°)

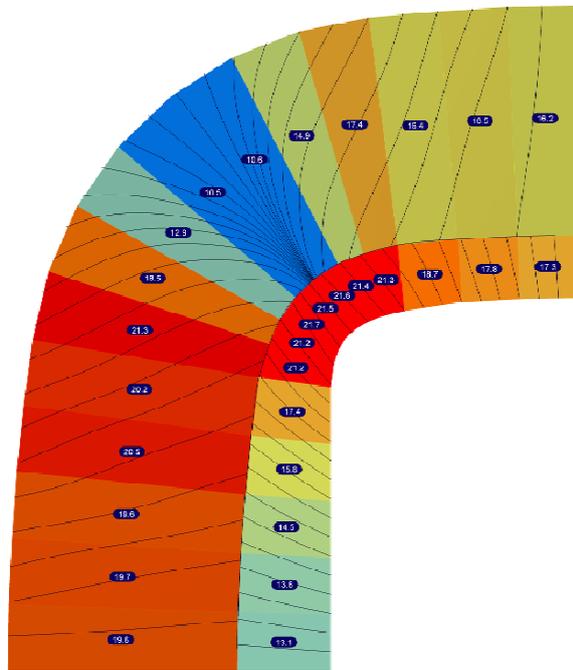


Fig. 9 Plan view of one quarter of cantilevering part of roof – Visualisation of slopes (%) and water flow curves

**III. FLAT SINGLE LAYER ETFE**

In the following, we would like to give some typical figures regarding the structural assessment of the ETFE in order to share our experience of designing membrane for a stadium roof. We hope this can be helpful to engineers who intend to design such structures, in the same spirit of what Tensinet working group has already started [1].

The ETFE panels are made of one layer of 250 $\mu$ m thick ETFE film connected to 10mm diameter stainless steel cables spaced every meter.

#### A. Loads to Sustain

Due to roof inclination, snow only applies on two rows, at the top and on the tip, where the cable spans have been limited. Elsewhere, only wind loads apply. The following figure gives a summary of the maximum pressure values obtained during wind tunnel tests. The values are grouped in rows. The peak velocity pressure is 0.79 kN/m<sup>2</sup>.

A pre-stress of about 0.6 kN/m is applied to the ETFE, and 10 kN to the cables.

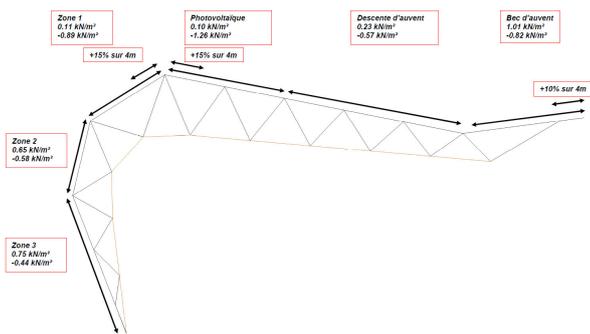


Fig. 10 ELS wind pressure values for each row – Eurocode sign conventions

#### B. Euro-Justification of ETFE

French codes for membrane do not apply to ETFE so we had to develop our own way of checking the membrane, which in the end is a mix of Eurocodes for the global load and safety approach, French codes for membranes for water ponding verification, and Minte  $A_i$  safety factors for ETFE resistance.

The  $A_i$  factors method proved very useful to determine allowable stress in ETFE. The factors allow taking into account the strong time-temperature related behavior of the ETFE [2].

#### C. Load Combinations

We used typical load combinations from Eurocode EN-1991. We checked ELS combinations against creep limit and ULS ones against ultimate strength. We applied temperature loading to the cables only, as transparent ETFE does not reach high temperatures due to its very high transmission factor. Also, we allowed for a tolerance of +/- 0.1 kN in the prestress of the cables to take into account building tolerances.

#### D. Water Ponding

According to the French guide for membrane structures [5], which refers to former French codes NV 65 for wind and snow loads, the snow load considered to check water ponding is of 60 kg/m<sup>2</sup>. No water ponding is allowed under that load, even if a static equilibrium can be found considering extra load from water inside pond.

#### E. Creep

During the ATE<sub>x</sub> procedure, the determination of the  $A_i$  factors values has been a matter of discussion. As opposed to cushions where the ETFE shape and pretension is maintained over time by the control of the inner pressure, in a single layer ETFE it is important that no creep occurs during lifetime not to lose the pre-stress. An incursion into the visco-plastic range of the ETFE would induce a permanent elongation, leading to a permanent loss of pre-stress.

It is known that the extent of this visco-plastic range depends on the nature of the solicitation, whether it is short or long, quick or slow, and also on the temperature of the film [3]. The direction of the solicitation also plays an important role. Under a mono-axial stress, the molecular chains are free to re-arrange themselves, whereas in a bi-axial one this effect is constrained, leading to a higher stress limit for creep. The following images show the biaxial nature of stresses in the ETFE under a typical Wind ULS combination. Maximum and minimum stresses have close values in most part of the film.

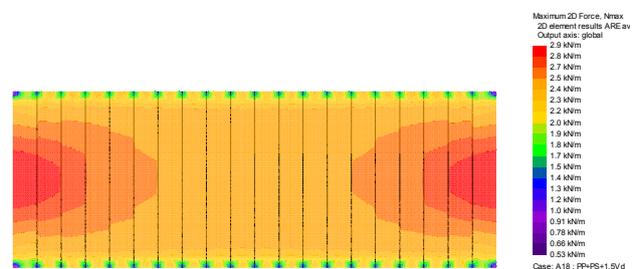


Fig. 11 Finite Element Model - Maximum principal stress in ETFE

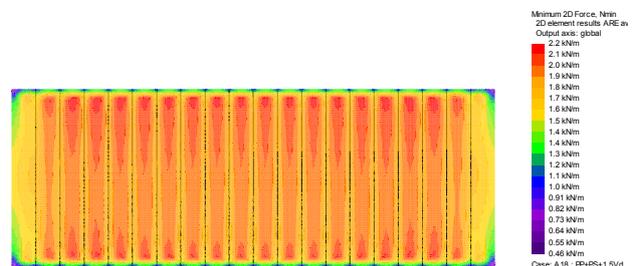


Fig. 12 Finite Element Model - Minimum principal stress in ETFE

Together with the company Iaso who is building the ETFE part of the roof, we made some experimental tests in various loading conditions to determine the maximum stress under which no creep would occur, and we adapted our  $A_i$  values consequently. Ultimately, we found that the governing criterion for ETFE was not the ultimate strength against ULS loads but the creep limit against ELS loads.

More information about the ATE<sub>x</sub> procedure is available in [4].

#### F. Fixation Detail

The complexity of the primary structure led to concerns about allowable tolerances for ETFE. The pre-stress of 0.6 kN/m is achieved by an elongation of 0.3%. That means 3cm for a 10m long panel.

We developed a fixation detail to allow fine pre-stress control and also the possibility to re-stress the membrane in case of defective installation or damage.



Fig. 13 Picture of prototype – Fixation detail seen from inside



Fig. 15 Picture from Birds by A. Hitchcock – Why do birds attack ETFE?



Fig. 14 Picture of prototype – View from outside

*G. Birds love ETFE*

Birds' interest in ETFE is maybe the trickiest issue we've had to deal with. We discovered during the design that many ETFE roofs were damaged by birds. They create holes by picking it with their beak.

It is a very serious problem and a strong argument against the use of ETFE for roofs as the only efficient known solution to avoid birds landing on ETFE seems to be the weekly venue of a falconer.

There are no certainties when it comes to the matter of birds attacking ETFE. It seems that holes are located on quite flat areas where birds can land or close to edges where they can also land on gutters. It seems also that insects that may gather in cable pockets do attract birds and encourage them to pick the membrane. Small holes can easily be repaired by patches placed onto the ETFE, but it can be painful for the maintenance team if such holes appear frequently.



Fig. 16 Picture of Hanover stadium roof – holes close to an edge



Fig. 17 Picture of Hanover stadium roof – patches on a cable pocket and insects

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