Design and Construction of a Light Roof Formed by Composite Beams, Cables and a Fabric Membrane in Tenerife (Spain)

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1. General Requirements

The structure is located inside an aquatic park existing in Tenerife (Spain). The roof had to cover a grandstand for a dolphin show. There was a concrete structure with several columns initially designed to support a cantilever conventional roof.

Photograph 1. Existing grandstand.

The structure had to cover an area of 3000 m^2 with a free cantilever of 15.0 m.

The general condition given by the client was to maintain the activity of the park while the work was done. A light membrane structure was selected to avoid cranes during erection. All the elements were designed to allow the installation by hand.

2. Structural System

The first idea was to take advantage of the concrete supports existing in the upper part of the grandstand. Then composite beams fixed in the backside to the columns are the main structural elements. The beams have a cantilever of 15.0 m and they are separated each 12.0 m. Between

Photograph 3. General view.

curved beams, and also fixed to backside supports, valley cables were placed to get a stable tension surface for the fabric membrane.

In order to diminish bending moments in the composite beams, two cables were located down and over each beam to take wind loads.

The upper cable was located closer to the beam than the downer because the suction forces were bigger than the pressure wind forces added to the self-weight of the structure. The arms of those cables were limited due to geometry requirements of the existing concrete structure.

Photograph 4. Lateral view.

These cables were fixed to the concrete columns and this contributes to stiffen the structure. Both cables were prestressed in such a way to avoid a loss of tension in SLS.

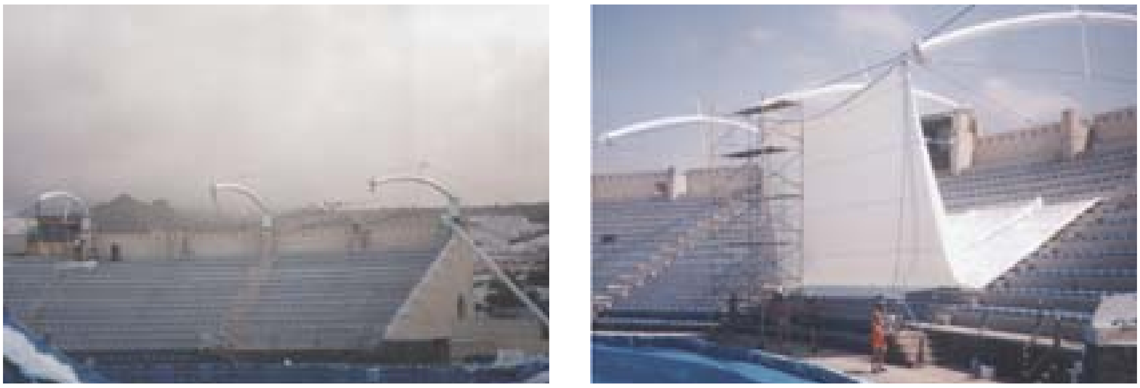
In addition to the beams and located between them, an upper tension bands element are located. The bands were made in armed fibres. They connect the inner circular cable with the existing concrete columns.

Photograph 5. Edge beam.

They are on the top of the fabric membrane so they control its behaviour under suction wind loads

To complete the structural system, an inner cable was located to anchor the internal edge of the fabric membrane and to control the vertical deflection of the composite beams. This cable ends into steel masts stayed to the ground.

This rope also contributes to the stiffness of the structure; their level of prestress was selected, so the system was stable in ULS.This aspect was very important because of its influence in the foundations and the mast design.



Photograph 6. Erection.

3. Structural Analysis

Due to the complexity of the structure different analyses were done:

- Textile membrane analysis.
- FEM composite beam analysis.
- Global non linear model.

3.1. Textile membrane analysis

This analysis was carried out to obtain the geometry and the tension state of the textile structure, under different loads combination (Figure 1).

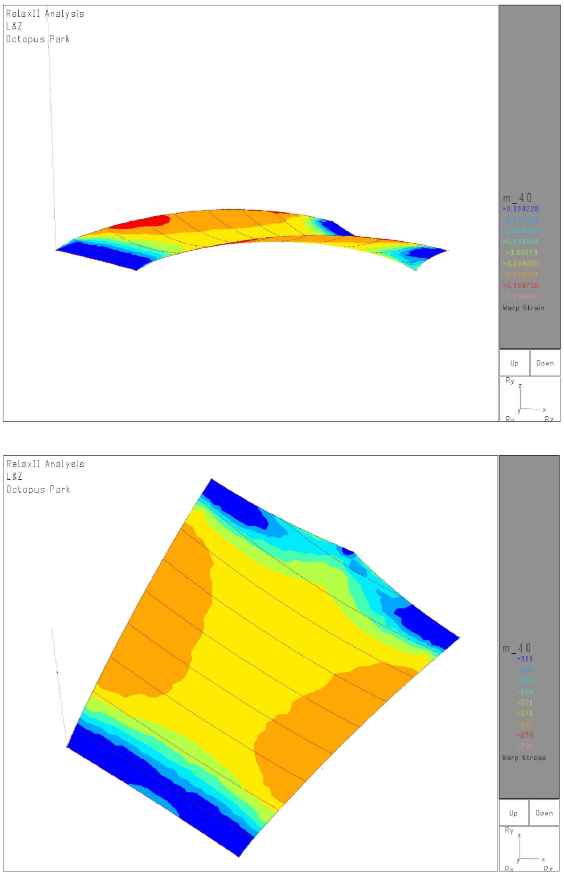


Figure 1. Fabric textile model views.

The textile structure was analysed with a FEM program, which takes into account the non-linear geometric behaviour of the membrane and the non-linearity of the material in each direction. This program produces also the membrane's geometry cutting.

That model geometry, mechanical properties, and prestress forces was adopted for the global model.

3.2 FEM Composite Beam Analysis

To check the composite (Fiberglas/epoxy) beam a FEM was developed. The design values efforts were taken from the global analysis model. A previous design of the element was done to evaluate the material properties and the main mechanical characteristics of the beam to introduce them in the global model.

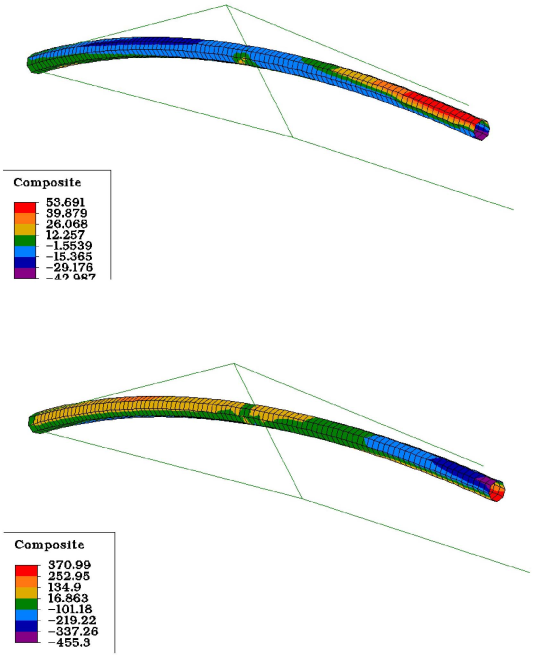


Figure 2. FEM beam analysis.

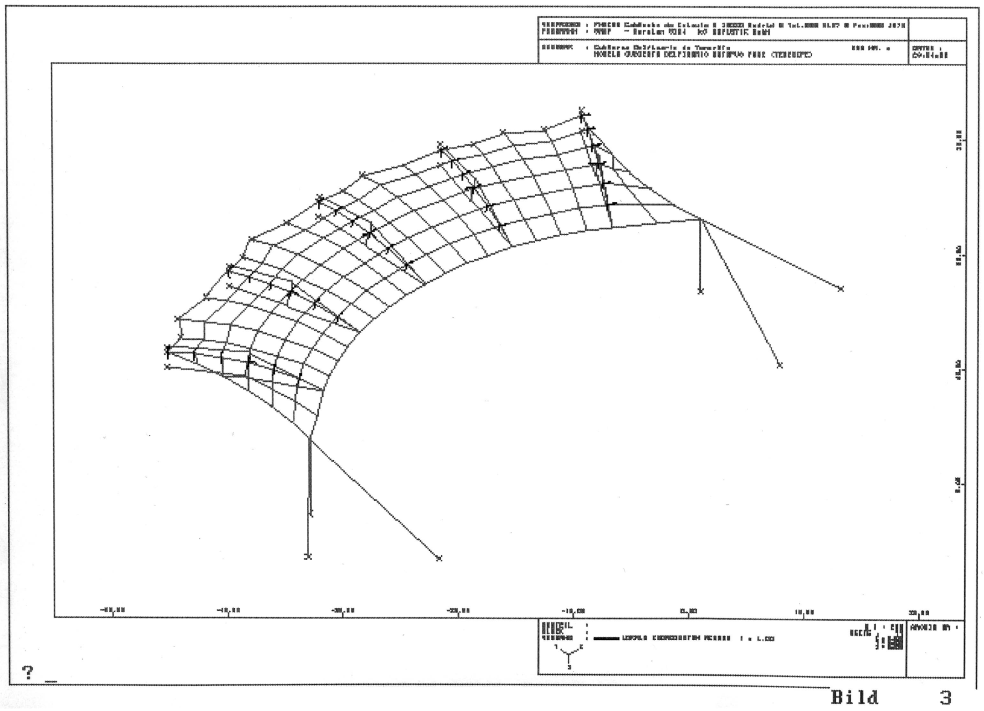
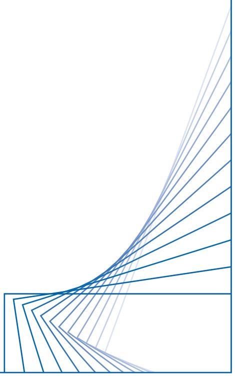


Figure 3. Global model.



3.3 Global Non Linear Model

A non-linear geometric global analysis was done to evaluate the global behaviour of the structure in SLS and ULS. All the components were simplified as bar elements.

The fabric membrane was modelled as cable elements with an initial prestress, which correspond with the state after the installation of the membrane.

The general design requirements were:

- To avoid a loss of tension in cable under SLS conditions.
- To maintain the different materials in elastic range in ULS situation.
- To have an additional safety stability factor from the ULS loads.

4. Composite Curved Beams

The beam elements were designed in composite fibreglass - epoxy to minimise the weight of the element to permit the erection without mechanical devices (Photograph 7). The beams have a circular cross section 350 mm diameter with different composition according to the level of stresses along the element and the position in the cross section. The beams have a circular shape with a radius of 25.0 m.

Photograph 7. Connection between cable and bean.

The beams were fabricated with E fibreglass reinforced with epoxy. Three different cross sections were used: A,B,C. The material used was RE500 (Roving E-Glass 500) and UE500 (Unidirectional E-Glass 500) with the mechanical properties of the following table.

Material	Espesor (mm)	Dens (Mp/m^3)	E_1 (Mpa)	E_2 (Mpa)	V_{12}	G_{12} (Mpa)	X (Mpa)	X’ (Mpa)	Y (Mpa)	Y’ (Mpa)	S (Mpa)
RE500	0.55	1.75	14500	14500	0.08	4500	350	320	350	320	45
UE500	0.5	1.73	45000	8	0.35	5000	1000	400	60	118	65

Table 1.

With:

- E_1 Young Modulus of the laminae in the direction 1.
- E_2 Young Modulus of the laminae in the direction 2.
- u_{12} Poisson coefficient.
- G_{12} Coulomb modulus.
- X Tensile strengh in the direction 1.
- X’ Compression strengh in the direction 1.
- Y Tensile strengh in the direction 2.
- Y’ Compression strengh in the direction 2.
- S Shear strengh in the plane of the laminae.

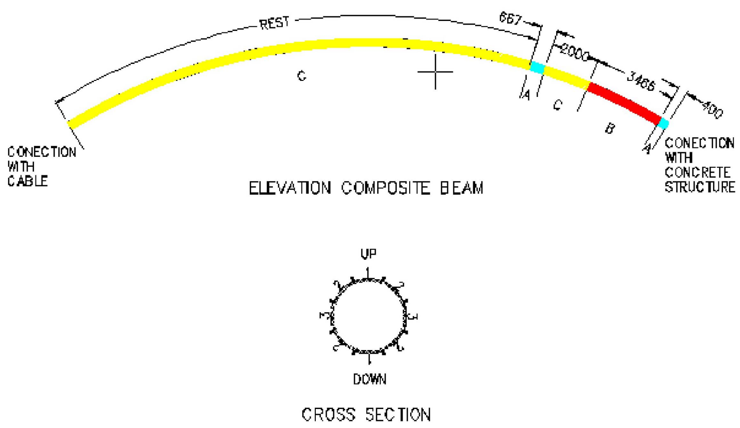


Figure 4. Composite beam.

The E fibreglass is oriented according to the direction of the stresses, so if 0° is the axis of the beam the lamination sequence in the B area of the beam was:

Zone 1	Material	Orientation	Zone 2	Material	Orientation
1	RE500	0/90	1	RE500	0/90
1	UE500	45	1	UE500	45
1	UE500	-45	1	UE500	-45
8	UE500	0	6	UE500	0
1	UE500	45	1	UE500	45
1	UE500	-45	1	UE500	-45
8	UE500	0	6	UE500	0
1	UE500	45	1	UE500	45
1	UE500	-45	1	UE500	-45
8	UE500	0	6	UE500	0
1	UE500	45	1	UE500	45
1	UE500	-45	1	RE500	0/90
6	UE500	0	Zone 3	Material	Orientation
1	UE500	45	1	RE500	0/90
1	UE500	-45	1	UE500	45
6	UE500	0	1	UE500	-45
1	UE500	45	1	UE500	45
1	UE500	-45	1	UE500	-45
6	UE500	0	1	UE500	45
1	UE500	45	1	UE500	-45
1	RE500	0/90	1	UE500	45
Simetric			1	RE500	0/90
		Simetric			

Table 2. Cross section B.

5. Connection Elements

Special elements were designed to connect cables, composite beams and concrete structure. The inner edge of the composite beam is connected with the ring cable, the upper cable and the downer cable of the beam with a steel element (Photograph 8).

This device has a clamp with bolts to connect with the ring cable, and a vertical plate with holes to insert a pin for each cable. That plate was welded to a steel tube which is introduced inside the composite tube beam.

Photograph 8. Edge beam connection device.

The connection among beam, contour cables and beam's cable was made with a steel tube fixed to the concrete columns. Between steel tube and composite beam a neoprene bed was provided. The interior part of the beam in this area was filled up with a concrete mortar to avoid the flatting of the composite.

6. Summary

In some cases membrane fabric roof are adopted when it is not possible to use mechanical erection systems.

In this project a roof had to be installed over an existing grandstand in an aquatic park while the area was in use.

A tension fabric roof was designed. The membrane was used combined with composite curved beams with stiffen cables.

This light system allowed the erection without cranes due to the small weight of the beams.

The use of identical curved beams allowed an economical fabrication of these elements with composite material (fibreglass/epoxy).

Special design problems were solved to match the connection among composite beams, small steel elements, cables and existing concrete structure.