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Dipl.-Ing. Wika Pösl, Project Manager

INNOVATIVE MEMBRANE ARCHITECTURE FOR CARPORT IN MUNICH

Dipl.-Ing. Wika Pösl, Project Manager

Taiyo Europe GmbH, Mühlweg 2, 82054 Sauerlach / Germany
e-mail: w.poesl@taiyo-europe.com - web page: http://www.taiyo-europe.com

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We would like to introduce you some of our most important projects for innovative Membrane Architecture here in Munich – the AWM carport roof.

It's not always easy being green that's what we discovered when attempting to build the carport roof. The project, which involved an ETFE film roof with photovoltaic cells, came under close and critical scrutiny of city officials, engineering specialists and the general public. "For us it was a long and hard way, because every step was controlled."

It was a hard fight to get building approval and then to construct the roof." The city and public had good reason for its skepticism. The new roof was meant to replace one that had partially collapsed in 2006 after a heavy snowfall - an event that gave the city and architect a lot of bad publicity. The same architect, Munich-based Ackermann and Partner, was hired for the re-construction.

In the summer months in 2011, Taiyo Europe GmbH erected the new roof structure for the carport used for under-cover parking of the trucks belonging to Munich's waste disposal companies. This structure comprises a steel construction with a roof cover made of three-layered ETFE film cushions with integrated flexible photovoltaic cells. This innovative project, located near to the famous Olympic Park here in Munich, is also used for all-year electricity generation at the main headquarters of the waste disposal companies in Munich (AWM).

The new carport roof was planned by the architects, in close cooperation with the city's Building Department and AWM. AWM short-listed two versions from the series of possible solutions presented. The roof variant with integrated photovoltaic system favoured by AWM was then approved by the Municipal Committee and thus resolved.

For AWM, the reconstruction work presented the opportunity of designing the large roof area as an innovative photovoltaic structure. The new roof concept thus makes a significant contribution to sustainability, particularly to climate and resource protection, which AWM has declared as one of its major maxims alongside efficiency.

We are very glad and proud, that we completed this new technology project in October 2011. Since then we follow up this project and since today we are very sufficient with the result.

DESCRIPTION OF THE CONCEPT

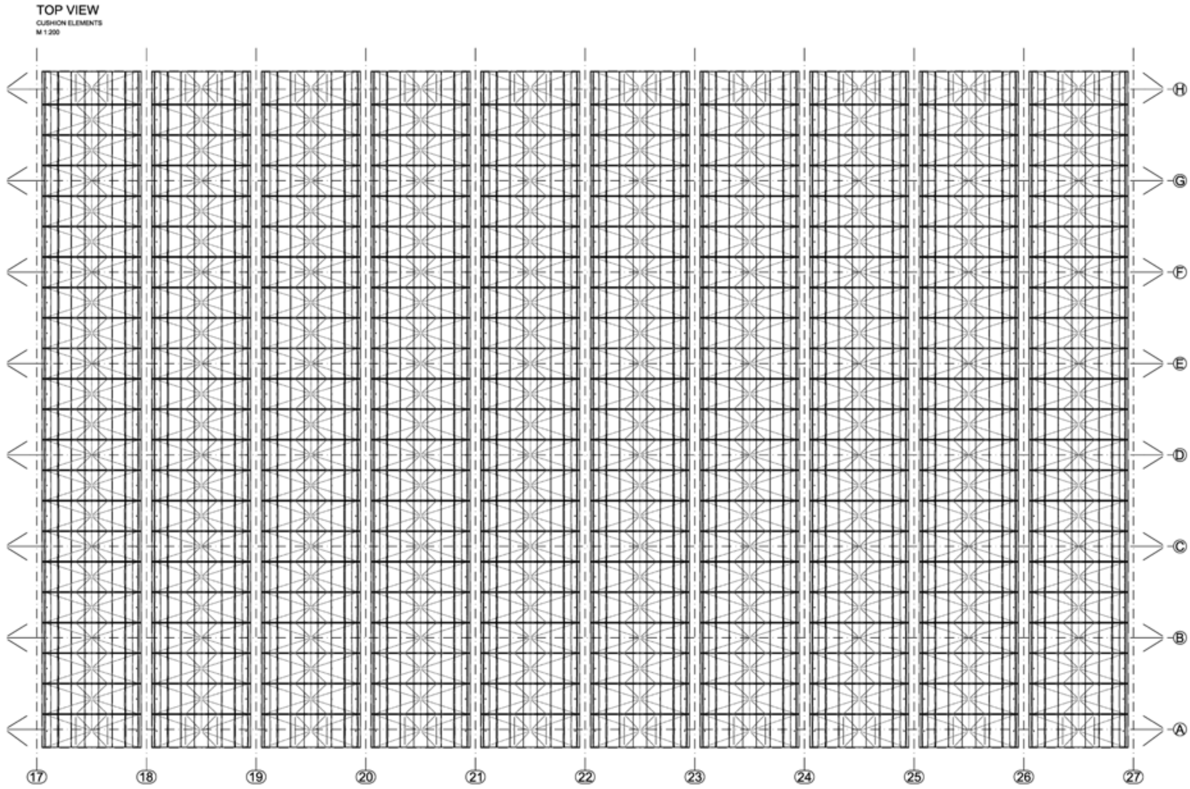

Fig. 1 - View from above (see above)

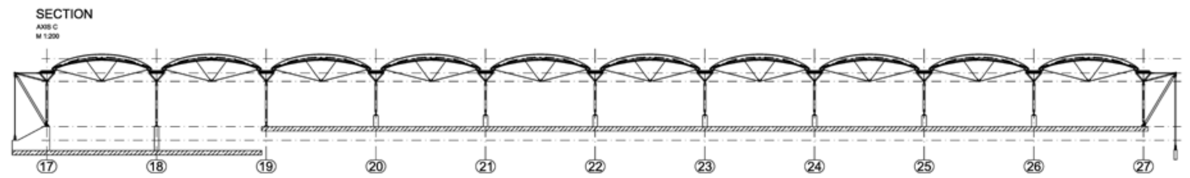

Fig. 2 - Longitudinal cross section (see above)

One basic pre-condition for the new roofing was the use of existing points of support for the hinged columns made of tubular steel with integrated roof drainage. The column grid is 10.00 x 12.00 m in size. The primary load-bearing structure comprises multi-bay frames comprising columns and 3-corded tie bars which are fanned out at the edges using tensioned braces. The trussing meant that the curved tubes could be kept slim. The total steel weight is 480 tonnes, or 48 kg/m² covered area. Unlike the earlier design, the primary load-bearing structure has been designed to be stable irrespective of the roof covering. The steel structure is coated with the classic Deutsche Bundesbahn colour DB 703 high-gloss paint.

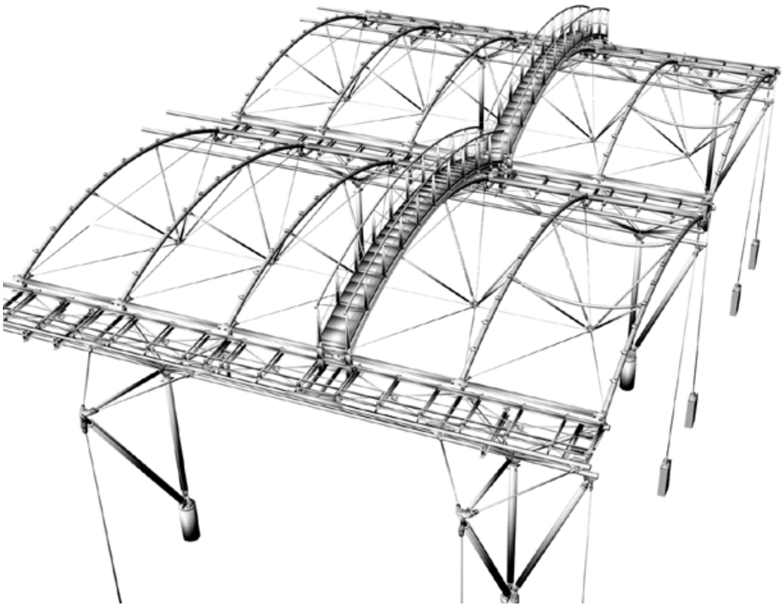

Fig. 3 - Steel bearing structure – 3D animation

The roof area is made from 220 air-supported ETFE film cushions.

The 220 air cushions covering the roof elements are made of ETFE film. This material is very translucent and resistant to the influences of the weather. Each cushion is made of three layers of ETFE film. As is customary in membrane constructions, the layers are termed upper layer UL, middle layer ML and inner layer IL.

The lower film layer is printed to reduce the light transmitted through the film cushions onto the carport deck. There are 12 photovoltaic modules fixed to the middle layer of each cushion by means of mechanical connectors, some of which can be moved, so that the modules are not subjected to any bending, tensile or shearing forces of note even in the event of heavy snow loads. As with bridge supports, for example, one of the PV module attachments is always without a longitudinal hole, in other words it is in a permanently fixed position, preventing the PV module from "floating freely".

The middle layer is mechanically pre-stressed to prevent creasing and is without load in the operating state, since the large ventilation openings in it lead to the same inner pressure above and below the middle layer.

To allow any faulty modules to be able to be replaced easily even in the long term, the upper film layer was fixed separately from the other two heat-sealed film layers in the double-welt clamping profile. This layer can be opened separately and basically works like a service cover.

The load cases pre-tension of the ETFE films, intrinsic weight, snow, wind and change in temperature were considered in the calculation of the roof structure. Whereas the static calculation of the primary load-bearing structure was carried out using a standard calculation program for space bar frames, the calculation software using the force-density method, which has been especially developed for architecture membranes, was used for the final design, static calculation and cutting layout specification of the ETFE film.

Pneumatic pre-stressed systems become tensioned, pre-stressed structures due to the air overpressure on the inside. The pre-stress in the upper and lower membrane is the result of the difference in pressure between the inside of the cushions and atmospheric pressure. It also depends on the bend radius of the corresponding membrane layer. The overpressure in the cushion is maintained using blowers. The membrane layers are always tensioned under load and are thus kept stable. Cushions are usually designed with two or three layers, depending on the structural-physical requirements.

The design of the air supply to the film cushions through blower units primarily depends on the magnitude of the defined inner pressure, the number of cushions and the size of the total area. An air dryer is included upstream of the blower. The supply air is dried to prevent condensation forming in the film cushions.

The air supply is connected to the lower cushion chamber. Air is exchanged between the upper and lower cushion chambers via overflow openings in the middle film layer (two rows of 12 circular holes with a diameter of 90 mm at the edge of the middle layer of the cushion and one row of 12 holes at the peak of the middle layer). The air escapes via the air outlet. The flushing rate of the cushion volume (air exchange of the cushion volume was estimated at 3,000 m³ at planning) was specified by the building engineer to 4,500 m³/ 24 h, in other words 1.5 times per day. The prescribed flushing rate is set using the cross-section area of the air outlet. In the nominal case, the support air pressure inside the cushion is 300 Pascal compared with the atmosphere. In the event of snowfall, this pressure can be increased to 600 Pascal. If the snow load exceeds 0.6 KN/m², the cushion is compressed in a controlled way. In this case, the upper and lower film layers bear the load together.

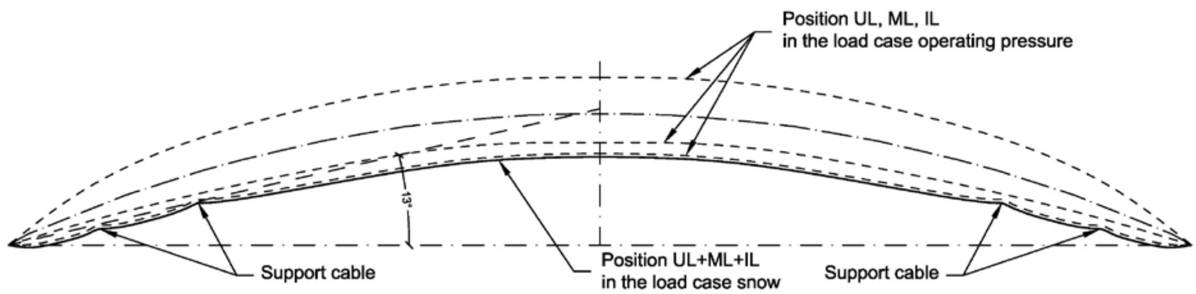

Fig. 4 - Cushion design

The geometric form of the film cushions chosen means that no water pockets will occur even if the blower fails during a period of rainfall. Pockets of snow can form towards the lower edge in the event of drifting snow. However, the local additional loads do not endanger the structural safety and do not lead to any significant deformation.

The stability of the cushion roof structure is not dependent on support air supply. Nevertheless, it was decided to make this supply particularly reliable. Three blower units supply one third of the roof area each. Each station has two redundantly wired blower motors which alternate on a weekly basis and automatically replace each other if one of the blowers should fail. The air supply is connected to an emergency power supply and a remote warning system.

Each cushion assembly with corresponding blower is integrated in a separate ring air pipe. All three ring air systems are separated from each another by valves which enable the area affected by blower station failure to be supplied by a neighbouring station. In addition, an air pipe system with high density class and non-return valves was chosen for the blower stations, making the whole system extremely airtight.

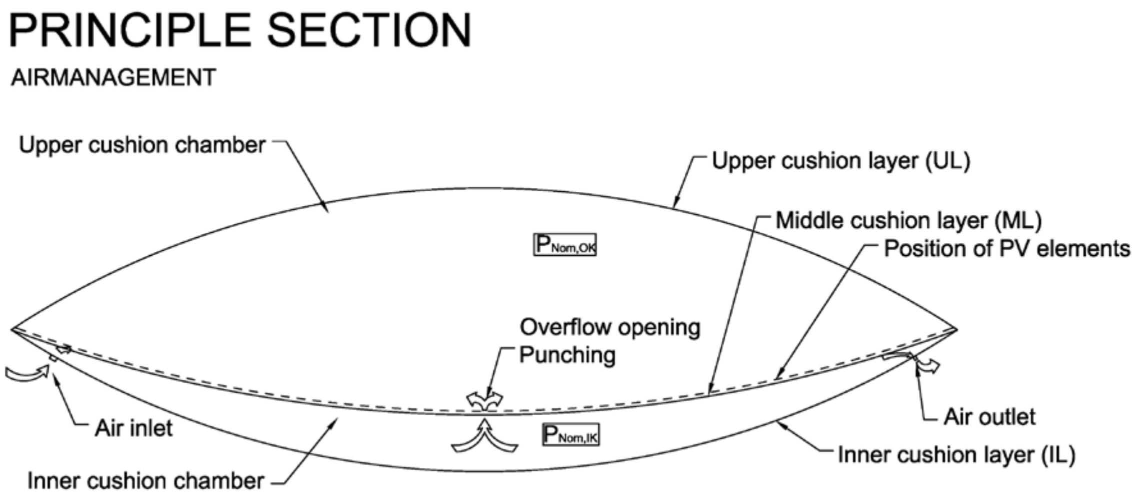

Fig. 5 - Diagram showing the air supply in the cushions

Table 1: Technical data:

Dimensions: Length Width Column grid Eaves height Ridge height Covered area	 120.00m 70.00 m 10.00 x 12.00 m +8.45 m +10.03 m 8,400 m²
Steel structure	S355J2H/ E355+AR/St.52.0 S Total coating 280 µ: (base pre-treatment, primer coat, intermediate coat in the factory and finishing coat on site) with Icosit EG Phosphat Rapid and Icosit Eg 5 and 2K-PUR, DB 703 high-gloss paint
ETFE film cushions	10 x 22 cushions, 220 in total Dimensions 3.33 x 10.40 m Thickness of upper and lower layer: 250 µ Thickness of middle layer: 100 µ Edge clamping profiles made of anodised aluminium
Solar system	12 photovoltaic modules per cushion 2,640 modules in total Power: 145.73 kWp Specific power yield: 889 kWh/kWp Average power yield: 129 kWh/a

Assembly procedure

The static system chosen by the structural planner required assembly to be carried out in several stages. Following erection of the statically stable primary load-bearing structure, the film cushions could be fitted. The film cushions were clamped in all-round aluminium profiles which were then screwed to the sub-structure.

The photovoltaic thin-layer modules fastened mechanically to the middle film layer 100 µ thick were fixed in place on site on a special pre-assembly table before installation of the cushions. So-called welts were heat-sealed at the edge for the linear edge attachment of the film layers. These welts were clamped into the attachment profiles.

Fig. 6 - Fixing the last cushion in place

Properties of ETFE films

The cushion membranes are made of ETFE film (Ethylene TetraFluoroEthylene) – a fluorine-based plastic with outstanding physical properties. The load-bearing films were dimensioned and selected with a thickness of 250 µ due to the loads to be expected. The main reasons the client and architect decided in favour of the version with ETFE cushion roof were as follows:

- High transparency from UV to IR range and a translucency of 90%.
- Flame-resistant and without burning droplets, construction material class B1, additive-free
- Very good separating properties or self-cleaning on the basis of the non-stick surface
- Long service life of at least 30 years

In addition to the standard acceptance test certificates for the material designated to be used, a comprehensive range of tests were carried out on typical details to meet the requirements set in this individual case by the Supreme Building Authorities. There is no generally valid building approval available for Germany for the membrane material ETFE film. For this reason, a new application must be made for every project. In this individual case, approval was granted 4 months after the complete technical documentation had been submitted.

The physical properties of ETFE films are comparatively complex compared to other materials such as steel or concrete. The load-bearing behaviour is non-linear and non-elastic, and the material is anisotropic. The stress-deformation behaviour of the films differs in machine and cross direction, and can vary from one production batch to the next. This means the usual procedure is to determine the specific material properties by means of tests before specifying the cutting layout. In the biaxial test, the load-bearing and deformation behaviour and the compensation values for the pre-stress are determined on the basis of the load to be expected. In the case of the carport project, a mean compensation value of 5% was determined for the cross direction. The machine direction was not compensated.

Table 2: Properties of ETFE films

Properties	ETFE NOWOFLON ET 6235, 250 µ, clear
Printing on the lower layer	Negative dot, silver standard, décor no. 920201, Reisewitz printing
Resistance to high temperatures	Permanently from max. +150°C to a temperature range of up to 230°C for short periods (6-8 h)
Melting point	approx. 270°C
Tear-growth resistance N/mm	470
Mass per unit area (g/m²)	350
Fire behaviour DIN 4102	B1, flame-resistant
Transparency	90%
Anti-soiling properties	excellent
Fungal development	Not possible
Service life	30 years

The ETFE films are manufactured using the slit die extrusion method. The rolls of film used are 1.55 m wide and 250 µ thick in the case of the upper and inner layer, and 100 µ in the case of the middle layer. The density of ETFE is approx. 1.75 g/cm³. Due to the limited film width, individual lengths of film are cut and then heat-sealed together to form a film cushion layer (part-surface connection). At the edge of the cushion the middle layer and the inner cushion layer were heat-sealed to form so-called edge welt pockets using the same method. The upper film layer was also given an edge welt pocket. All three layers or the two edge welts were then fixed in the double-welt clamping profile.

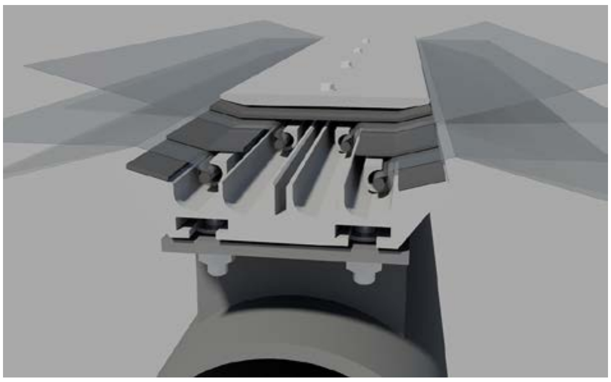

Fig. 7 - Diagram of the clamping profile

ETFE film sealing seams are homogeneous i.e. the sealing seam is made of the same thermoplastic (repeatedly meltable) material ETFE as the part-surfaces it connects. The load transmission thus takes place from film part-surface to film part-surface without an intermediate layer as sealing aid.

Quality assurance for the construction products and their production is carried out from film production through to installation through the following measures:

- Acceptance test certificates from the film manufacturer according to DIN 10204-3.1
- Incoming goods checks at the manufacturing company
- Internal quality control accompanying production by the manufacturing company
- External quality control of production by the membrane expert
- Compliance certificate from the inspection, monitoring and certification office

Description of pneumatically supported film cushions

Film cushions become load-transferring, pre-stressed membrane structures due to overpressure on the inside. During normal operation, the films are tensioned under load and stable even under outer loads such as wind and snow.

Depending on the structural-physical requirements, air-supported film cushions are designed as two- or three-layer cushions. ETFE fluoropolymer film (ethylene tetrafluorethylene) is mainly used as the cushion material. In this project, a solution with three-layer film cushions was chosen for the roofing, which is open at the side, whereby in this case the purpose of the middle layer was not to improve heat insulation but rather to serve as a carrier for the flexible photovoltaic modules integrated in the cushion. The middle layer can contribute to load transfer in the case of a snow load, but it is not necessary here since the upper film layer and the inner film layer are sufficiently dimensioned.

The film cushions (secondary system) are clamped between the steel arch supports (primary system). The primary system is stable without the secondary system. The secondary system is not required for stabilisation, deformation limitation or load transfer.

The film cushions are connected to the primary system all the way round by means of aluminium clamping profiles. The film cushions are interlocked into the clamping profiles and connected by pressure transfer through contact pressure between the welt and welt profile as well as between the welt profile and the basic profile. The interlocking connection between basic profile and steel structure is made using a screw connection.

The air supply to the film cushions was designed and dimensioned by the applicant in cooperation with the blower manufacturer.

The advantages of ETFE air cushions as space-enclosing components lie in their transparency and low weight, which also affects the efficient and aesthetic quality of the primary structure, for example.

The successfully result of this unique project finally dependent on the cooperation of all who are involved in that project.

Therefore we would like to say thank you to our subcontractors for the excellent team work and the power of endurance during the hard times. Without them it would have been never such a good result since now.

Table 3: Those who were involved in the carport roofing project in Munich:

Client	AWM, Munich waste disposal companies
Architecture	Ackermann and Partner; Munich
Structural planner	Dipl.-Ing. Christoph Ackermann; Munich
Contractor for the complete structure	Taiyo Europe GmbH, Sauerlach, in cooperation with Konstruct AG, Rosenheim and the assembly service LB, Hallbergmoos
Steel structure production and assembly	Steel Concept, Chemnitz

This project is a milestone in the development for further applications of photovoltaic in combination with architectural membranes for roof and facade structures. Taiyo Europe GmbH and the Taiyo Kogyo Group will continue further developments to combine this technology with other membrane materials offering owners the possibility of combining the superior esthetic properties of architectural membrane structures and unique energy earnings.