Report Techtextil Symposium

Design and Execution of Light Weight Structures at the Example of the World-EXPO '92

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1. Criteria for the Design of Light Weight Structures

Aspects which play a decisive part in designing such a complex thing as a building may be classified as such:

- The local conditions, such as the situation, environment, context in which the task has to be performed.
- The use, the function, the building must fulfill.
- The structure which best serves the task.
- and finally the form which according to method and attitude may be a synthesis, a consequence of the above listed conditions on one hand or may be interpreted as a deliberately formal design on the other hand.

These conditions are equally valid for designing with conventional and with light materials. Special features of lightweight buildings especially in connection with the EXPO '92 will be lined out in the following paragraphs.

1.1. Local Conditions

Traditionally light structures and especially membrane tents were types of buildings which were not singularly fixed to one place but were capable of being moved around such as circus tents or beer tents.

World Expositions on the other hand demanded structures which were to be integrated into given surroundings. Just remember the arguments concerning the town planning scheme of the first world exposition, the grand Cristal Palace in London's Hyde Park in the year 1851.

In 1967 the first lightweight structure for a world exposition, a building with a light plane load-bearing structure was erected in Montreal, it was the German Pavilion designed by Rolf Gutbrod and Frei Otto. Shortly afterwards the design of membrane structures culminated at the EXPO in Osaka in 1970 with numerous buildings such as the striking Fuji-Pavilion.

The Location of the EXPO '92 posseses a quality which suggests the use of light plane bearing structures: Sevilla is the hottest city in Europe - in terms of weather conditions.

The provision of shade is the fundamental requirement for a fairly pleasant linger. Simple plane structures such as small shading sails have a natural tradition in Sevilla.

Beside these general conditions namely the extreme climate the master plan, i.e. the overall designing scheme, dictates numerous different requirements for each single location of each single EXPO building.

Axial movements and views should not just be considered but as far as possible be upgraded intensified in their function and spatial effect.

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1.2. Use - Function

The function i.e. the use of most EXPO buildings is temporary, it is limited to the duration of the exposition.
Temporary uses are the classical field of application for light plane bearing structures.

In addition functional requirements are usually less complex in a temporary exhibition building than in a permanent multi-funcional building.

Thus the dominating reqirement of some EXPO lightweight structures is sun protection - less important is protection from rain. In addition there are more specific functions such as entrance cover and shelter for the ticket offices: see for an example the entrance gates "Oleada" and "Diadema".

The central action square with its shading structure "Palenque" has to allow for many uses: Concerts and meetings of all kinds will be held here.

And finally the German Pavilion complies with many different functions: exhibition, entertainment, performances, presentations, cafes, restaurants, duties which cannot be fulfilled by lightweight structures in their traditional form.

This however demonstrates how light elements combined with traditional methods of construction can help to solve structural problems and at the same time save material, time and money.

1.3. Structure

The structure is the means to fulfill the tasks given by the previous criteria: location and function, consequently it is a means to an end.

"Light constructions" are defined by the kind of construction used and more precisely by the kind of main plane structure.

Nearly all kinds of plane structures with the exception of pressure stressed shell constructions are dealt with on the basis of the EXPO buildings as follows: prestressed single membrane structures such as Oleada, Diadema, Palenque; pneumatic structures prestressed by air pressure and finally cable net structures both to be seen at the German Pavilion.

Those plane load bearing structures have one thing in common: the geometrical system of double curvature which allows to divert all the acting forces purely by applying tension forces to the material used for the curved surfaces.

At the edges of such a surfaces the tension forces are brought foreward into other structural parts: a) by applying tension forces to edge - and anchoring cables (e.g. Oleada), b) by apllying pressure to a mast (e.g. shading roof of the German Pavilion), and c) by applying bending stress to an edge beam (e.g. bottom and top tubular steel beams supporting the net façade of the German Pavilion).

Each of these constructions (Gesamtragwerke) - of the structures dealt with in this report - belongs therefore to the type of "hybrid" structure which consists of tensile loaded plane structures (zugbeanspruchten Flächentragwerken) and single, differently loaded construction elements.

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1.4. Form

Even more than in case of conventional structures the form of lightweight structures is marked by the type of construction.

The form of the plane structures originates first of all from the choice of the border geometries, e.g. high points, high lines, low points, anchorings, border cables, etc.

This choice can not be freely made, since the above mentioned basic geometrical condition, a double curvature of the area to be tensioned, must be obtained.

Thereupon the real formfinding process for the surface takes place. This process, however, may require to return to the border geometry. In this phase the form is not really "made" but "found", as the term "formfinding" describes the process correctly.

This process is further described in the following paragraph with the aid of the used planning tools.

2. Planning tools

The planning of lightweight structures needs certain methods, auxiliaries and tools which in the following are described as "tools".

2.1. "Conventional" Tools

Absolutely necessary for the concept development is first of all the analysis of the problem and the situation as well as the scheme-like collection of ideas. In the conventional planning process this is usually done by means of paper and pencil.With the results first discussions are held with the client and other planning offices involved.

Working models are still very helpfull for visual control and for a better understanding, even though they may appear old-fashioned in times of the three-dimensional CAD-planning described later.

Since the German Pavilion is a very complex structure it became necessary to build an exact design model with the help of geometries worked out and produced by CAD. In this case the large pneumatic shading roof was cut out of a block (scale 1:200) by means of a CAM-driven milling machine.

However, for the analysis and the cutting patterns of the membranes it is not necessary any more to build models of membrane structures as it used to be done.

Wind channel tests however, can still only be carried out by means of a model. Therefore an appropriate model was built for the German Pavilion. Especially on the bottom surface of the large shading roof the flows could be analysed.

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2.2. Geometrical Formfinding with CAD

When all peripheric geometries (Randgeometrien) are defined in a spatial CAD-model, the formfinding of a grid area or a membrane area can begin.

Peripheric geometries are e.g. -in a quite simple system as the Avenida de Europa- the masts, i.e. the 4 high points, then the cables which pull downwards, i.e. the 4 low points and finally the size of the radius of the border cables, which connect the high points and the low points.

Then a rectangular grid is laid over the projected floor plan in the computer by means of which one can approach the form of the areal membrane. This is still done by means of the 'ordinary' CAD-drawing programme.

Thereupon an "elastic model" (a model made of elastic material) is simulated by means of a special programme, i.e. the originally flat grid is spanned step by step to the high points and low points until a situation with enough double curvature is obtained.

This situation is comparable with the simple elastic model where an elastic fabric is spanned into defined fixing points.

The CAD-model permits however an exact defined geometrical basis for a further calculation with regard to statical and structural aspects.

2.3. Formfinding und Structural Analysis

The analysed form is first of all a pure geometrcial model in which forces for certain load cases are not yet described.

In further analysis forces are calculated by means of finite-element-programmes. These forces occur when definite, previously defined load cases (combinations of dead load, prestress, wind loads etc.) influence the grid.

Figures result out of these calculations, which define the forces inside the grid, i.e. the membrane forces, and the forces which must be calculated from the membrane on the peripherical elements (e.g. cables, masts, etc).

The result can make it necessary that due to extreme forces the peripheric geometries, the form of the grid or the membrane curvature must be modified once more.

In a limited range, an iterative process takes place between geometrical formfinding and structural calculation until the final form with the resulting forces is defined.

The calculated peripheric forces and the membrane forces are then the basis for the calculation and construction of the membrane or the grid and the peripheric elements.

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2.4. Construction of Steel Parts

In single parts, e.g. in mast heads, the different system lines of the total geometry meet. Of course this happens hardly ever in perpendicular lines.

The construction of these elements without the means of a 3-dimensional CAD-system is unthinkable nowadays. When drawing, not only forces and geometrical end situations must be considered, but also the joining and erection of the structure.

Into the slim head of the mast of the German Pavilion for example 22 open spelter or swaged sockets had to be literally threadded.

Due to the complexity of the construction elements of the EXPO-structures - as well as in case of other similar projects - the planning company executed all the workshop drawings for the steel structures. For conventional steel structures this work is usually carried out by the executing company itself.

3. Erected buildings

3.1 Oleada - Entrance Structure in Continuation of the Axis of the Bridge "La Barqueta".

The bridge spans the river Guadalquivir which seperates the Expo site from the old part of Seville and thus serves as one of the main access ways.

The arch which characterizes the bridge and marks its axis is taken up and continued by "Oleada" = "Wave" emphasizing the axial view across the artificial lake on to the Spanish Pavilion and the European Avenida.

The main functions of "Oleada" are to signalize the entrance to the Expo area from the north east and to provide a shaded waiting area outside and inside the Expo site. The structure therefore crosses the border, on either side being half of it.

The membrane spans from the peripheral masts to two prestressed TENSEGRITY-arches (=stabilized by cables), which follow the axis of the bridge. One arch is curved down-, the other upwards. Both are made of several straight tubular steel segments. They are suspended from a V-shaped double mast and kept in position by the membrane which is reinforced by an additional system of steel cables and by anchoring cables spanning from the peripheral masts outwards.

The main as well as the perimetral masts are made of bent sheet metal and square tubes welded together whose sides are tapered towards the ends thus forming typical compression poles: narrow at the ends, wider in the middle to follow statical requirements.

The structure has max. dimensions of 135 x 70m at maximum height of the main masts of 65m.
Covered area ca. 7000m²

Design, structural engineering, execution and workshop design, erection supervision:
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3.2. Diadema - Entrance Structure as a Land Mark

The north entrance to the EXPO-site, where the large parking lots for visitors are situated, is shaded by this roof.

Here we have no bridge nor another strong axial element which marks the entrance like the bridge "La Barqueta" in front of Oleada.

The structure itself must be signal of the starting point for one of the main active and visual axes of the EXPO-site: the Avenida of Discovery.

The form of the shading structure allows the ticket offices, which are shaded by the roof, to be widely spread. For this reason there is enough room to cope functionally with the rush of visitors.

Slender masts are arranged in form of a fan on a circular ring. From these masts a cable net spans to the inside of the EXPO-area. The meshes of the cable net grid are closed by material of slightly translucent yet shade-spending PVC-coated open grid polyester fabric.

In order to stabilize the mesh-membrane-area, a significant valley cable is introduced behind the masts, which causes a bisection of the total area.

The main masts are formally raised over the structurally necessary measure and therefore intensify the effect of the silhouette, especially when viewed from the north.

Looking at the cross section of the main masts and other masts, they are similar to those of "Oleada": narrow at the ends, wider in the middle to oblige statical requirements. As done for "Oleada" all the masts are welded together out of multi bent sheet metal sections forming a gross-triangle shaped cross section.

The structure has max. dimensions of 77 x 74m and a maximum height of the main masts of 57m.
Covered area ca. 4000m².

Design, structural engineering, execution and workshop design, erection supervision:
IPL Ingenieurplanung Leichtbau GmbH, Radolfzell, Germany

3.3. Avenida de Europa - Shading Structure - "Building" Defining a Street Space

The Avenida is the main street of the European area of the Expo. Shading sails span over a wide squarelike street space which with its water basins, footbridges, sculptural elements invites to stroll and linger.

Here again we find the same Leitmotiv of the Expo as at Palenque: the cone shaped flues of the disused ceramic kilns of the monastry "La Cartuja" which penetrate through the shading structure.

Cable networks span between four high points and four low points each. The shading sails are fastened to the net on their four corner points only.

The masts are three chord girders with numerous connecting web plates.

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The monorail running on a stilted track had to be considered at the westerly end of the Avenida. The trains pass right through a mesh of the cable network.

Max. dimensions: 276 x 61.8m
Max height of Masts: 20m
Covered area ca. 12000m²

Design: Arquitectos 92 (Jean Marie Hennin, Paris und Georg Lippsmeier, Starnberg)

Structural engineering, execution and workshop design, erection supervision:
IPL Ingenieurplanung Leichtbau GmbH

3.4. Palenque - Shading Structure Over a Central Square

"Palenque" is the name for a large square with special tasks inbetween the international pavilions on the site of the
Expo '92.

The square offers space for various events: opening ceremonies, meetings, plays, concerts, shows etc., which supplement the individual activities taking place in the national pavilions. The rectangular square is essentually characterized by the shading structure spanning over the entire space.

25 single membrane roof units are added together on the basis of a rectangular grid system to form 5 bays with 5 units each. Each membrane bay is supported by 5 double rows of filigree cross-braced steel masts. These masts do not reach down to the ground but rest on cone shaped concrete supports which are placed on the crossings of the grid system.

The shape of those supports calls to memory an element that appears repeatedly on the entire Expo site: The conical flues of the disused lime kilns of the monastry La Cartuja.

The shading structure rises towards its centre thus forming a slight arch which gives a grand impression of space.

Max. dimensions: 126 x 66m
Covered area: ca. 8300qm

Design: Jose Miguel de Prada Poole, Madrid

Structional engineering, execution and workshop design and erection supervision:
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3.5. German Pavilion - Lightweight Elements in Combination with a Complex Building for Many Uses.

The task to be fulfilled in summer of 1990 was unusual:
A pavilion for the contribution to the EXPO'92 of the reunified Germany had to be planned and built in almost no time.

It would be too elaborate to describe in detail the circumstances which lead to this situation.

It should just be said that a very limited amount of money was allowed to be spent, since this aspect played a very important role in the type and structure of the design.

The pavilion was to be designed for the period of the world exposition to offer frame and space for a thematical exhibition.
Besides some restaurants, a very compulse administration, a large VIP-area and an auditorium with over 200 seats had to be integrated as well as warehouses, workshops, sanitary rooms and last not least a technical area for air conditioning which is almost as large as the whole exhibition area.

The pavilion should not only fulfil all these functions, but also should it offer a space, which is not only visited but is experienced; the pavilion should not only be passed through, but should invite to linger.

Considering the shortage of time and money, these requirements were partially solved by techniques of lightweight structures.

As principal elements there are to be pointed out:
the big shading roof, the rear façade and the cable-net façade, the restaurant roof and the roof of the VIP-area on the large terrace on top of the exhibition hall.

The dominant element of the design is the shading roof.
The main problem that had to be solved by this roof was to cover as much area as possible with as little expense as possible. This was accomplished by an air-supported membrane cushion which spans over an eliptical ring of steel framework in a height of 22m. The ring is suspended with 22 steel cables from only one mast of a length of approximately 60m.

The rear façade must protect the interior from the hot south-westerly summer winds and from the sun. The considerable area of approximately 1.900 m² was closed by pneumatically tensioned membrane elements which run along the whole length of the façade.

The cable-net façade forms a transparent closure of the exhibition area.
The façade is a cable-net curtain made of double steel cables and is only supported by two steel tubes, one on top and one on the bottom of the curtain. 4000 translucent polycarbonate tiles in over 400 different patterns are fastened to the cable-net. The total height and length of the structure is ca. 12.60m by 70m. The lightness and the transparency of this new kind of façade forms a direct relation from the outside to the inside. Thus the whole exhibition turns into a stage, a scene for the actions outside.

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The example 'German Pavilion' shows clearly how classical elements of lightweight structures such as nets and membranes can be used as supporting structures and façades of 'traditional' solid structures and not only in a small additive form, but in a way which essentually puts its imprint on the design.

General planning, coordination and supervision:
IPL Ingenieurplanung Leichtbau GmbH, Radolfzell, Germany

on the basis of a planning study from June 1990 by
Georg Lippsmeier und Partner

Modification of the architectural basic concept - redesign:
IPL Ingenieurplanung Leichtbau GmbH, in cooperation with
Peter Birke, Architect, Stuttgart, Germany

4. Conclusion

The buildings for World Expo'92 in Sevilla show on one single site a large variety of different kinds of lightweight structures.

The process of design, the criteria for design and the results for this type of construction -which still belongs to the 'exotic' type- can be seen quite clearly here.

It becomes appearant that for the design of lightweight structures the criteria for the design of architecture, eg. place, use, construction and form, must also be applied.

However, the most important aspect in this field is often the type of structure used, i.e. the requirements of the function are usually smaller than the requirements and rules demanded by the structure which are more important here than in case of other more conventional constructions.
The German Pavilion, however, is an exception concerning the use of the structure.

The examples show also how the formal and structural range of lightweight structures can be increased and that there is still much room for exploration.

In this field lie still many possibilities in the future.

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