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10. Tent Roof for the Haj Terminal, Jeddah (Saudi Arabia)

Owner: *International Airport Projects, Ministry of Defence and Aviation, The Kingdom of Saudi Arabia*

Architect: *Skidmore, Owings & Merrill, New York, New York, USA*

Engineer: *Skidmore, Owings & Merrill, Chicago, Illinois, USA*

Construction Manager: *Saudi Arabian Parsons Ltd., Daniel International Ltd.*

General Contractor: *Hochtief AG, Essen, Germany*
Fabric Roof System Subcontractor: Owens-Corning Saudi Contracting Services Company

Service date: *Fall, 1982*

The Haj Terminal (Fig. 1), part of the King Abdul Aziz International Airport in Jeddah, Saudi Arabia, il located approximately 70 km west of the Holy City of Mecca. Jeddah is the only large commercial city close to Mecca, so all air traffic bound for Mecca, arrives there and pilgrims proceed by land to Mecca. Normal airport facilities can handle this traffic except at the time of the Haj pilgrimage when, during a 6-week period, 700,000 Muslim pilgrims arrive and depart.

A separate terminal facility of 500,000 m² was needed to process the Haj pilgrims. By 1985 the terminal will handle approximately 950,000 pilgrims during the 6-week period, accommodating 50,000 pilgrims at one time for periods up to 18 hours during arrival and 80,000 pilgrims for periods up to 36 hours during departure. This time is required to transfer between air and land transportation.

The facility consists of a linear, air-conditioned terminal building adjacent to the aircraft parking aprons and a large, sheltered support complex adjacent to the terminal building. This scheme provided minimum walking distance for the pilgrims from the planes to the air-conditioned terminal where all formal processing and baggage handling is accomplished. Pilgrims then move into the naturally ventilated support area where they will organize for land travel to Mecca. Because of the severe environment in the Jeddah area, the support complex must be protected from the sun.

Development of Structural System

Only some form of a long span, lightweight structure with translucent material can adequately respond to the overall environmental needs of this space. To date, the most common form of this system has been the two-way cable net structure with a nonstructural in-fill covering or skin. This system was used on the German Pavilion in Montreal for Expo '67 and the Olympic-Stadium in Munich, Fed. Rep. of Germany, for the 1972 Olympics. However, this system was not economical for the Haj Terminal because of the large number of cables and numerous connections between cables to create a grid network. New and improved membrane materials allowed development of an appropriate structure using the fabric membrane with cables in a two-way interactive system of cables and membrane.

To be used as a structural element, the membrane material had to satisfy numerous performance criteria. In the past, fabric membrane materials had a relatively short life; consequently they were used in temporary structures. However, the fabric membrane for the Haj Terminal need a life of at least 30 to 40 years with minimum maintenance. The time requirement was extremely difficult because this environment is very harsh due to the continuous exposure to ultraviolet degradation and a highly corrosive marine atmosphere. In addition to a long life span, the fabric membrane also had to be:

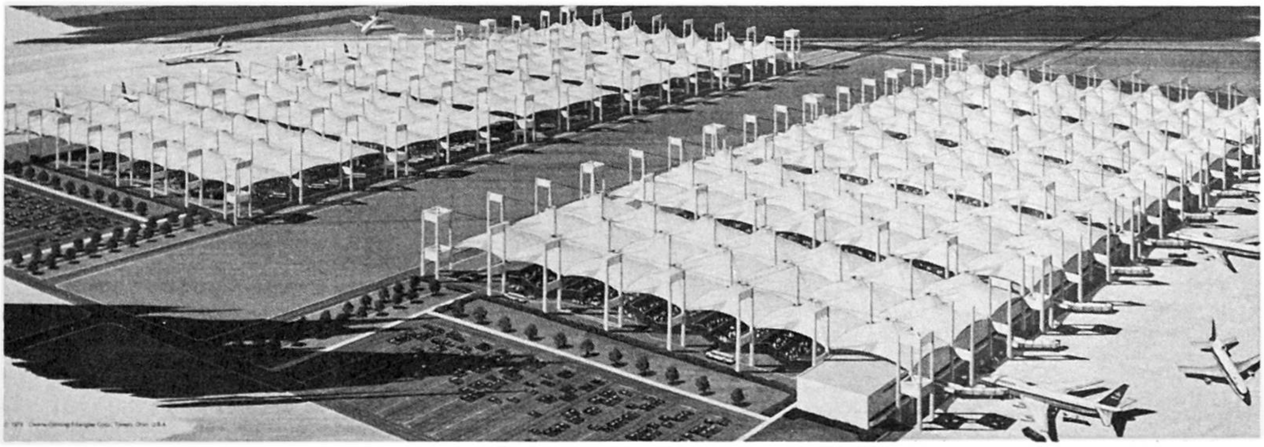

Fig. 1 Artist's perspective of completed Haj Terminal

1. Self-cleaning to insure a lasting good visual appearance
2. Lightweight yet capable of carrying high tensile loads with little or no longterm creep
3. Good thermal insulator to protect the pilgrims
4. Sufficiently translucent so that area is naturally illuminated during the day
5. Non-combustible and also not give off any toxic gases or fumes when subjected to fire
6. Easy to fabricate and ship
7. Repairable on site, if required.

The fabric that met these requirements is a heavy-weight, teflon-coated fiberglass. The fiberglass provides structural strength and the teflon coating protects the fabric.

With selection of the basic materials for the tension membrane structure (cables and teflon-coated fiber-glass) a comprehensive study of shapes and forms was undertaken to develop a shape both esthetically pleasing and structurally feasible.

In making these studies, the cultural heritage of Saudi Arabia was kept in perspective. The tent tradition is a familiar form in the Middle East. Throughout the history of Saudi Arabia, tent structures have provided comfortable shelters by shading while allowing the breeze to flow through.

From a structural design point of view, however, it is important that the design of the membrane surface of a tent shape must result in a double curvature shape to insure stability for both upward and down-ward acting wind loads. Such a shape guarantees tension in the fabric under any loading condition with only an adjustment in the level of tension in one direction or the other depending on whether the wind pressure is up or down. An appropriate initial tension can then be determined so that the fabric will remain taut and stable.

After studying various shapes and proportions, the final configuration and form selected is a two-way grid of pylons from which the high point of the tent (tension ring) are suspended and the low corner points are anchored. The double curva-ture tensile membrane surface is created by holding the membrane at the pylon locations and raising the tension ring thus stretching and pretensioning the membrane. This shape provided for rain drain-age at the pylons and also induced a natural flow of air out from under the tent roof through the opening at the high point at the center tension ring.

Final Structural Design

For the purposes of planning, a module 45 x 45 m was established as one unit. Each module is 3 units by 7 units for a total of 21 units per module. The overall plan is grouped by 10 modules: 5 in a row on each side of a central roadway, with provision for an additional 5 modules on each side.

Steel pylons (45 m high) are located at the corners of each unit. The roof membrane forms the ten shape, springing upward from a 20-m height at the pylons to 35 m at the center tension ring (Fig. 2).

Radial cables extend from the center tension ring to edge or ridge cables connecting the pylons at the intersection of adjoining roof units. The sus-pension cables are arranged in 4 pairs (8 total) and extend down from the top of the pylons to hold the center tension ring in place. Pairs of suspension cables were used rather than single cables to provide redundancy in case of failure. To further protect against collapse due to membrane damage, four stabilizing cables are provided for each unit. These cables extend downward from the center tension ring to the lower tension ring at the pylon. These cables keep the center ring in position if a particular unit's membrane loses tension.

The overall stability and structural integrity of the entire system is achieved by a special arrangement of the pylons around the perimeter of each module. Extending around the perimeter of each module, including the common row of pylons between ad-jacent modules, is a row of very stiff double pylon, portal frames. This stiff edge and separation between modules makes them independent of each other and allows modules to be added or removed.

Also, this system insures that a failure in one module will be isolated and not transmitted to an adjacent module. The Haj Tent Roof thus provides structural stability, safety and redundancy at three levels of the system: 1) individual members cables, 2) unit stability-stabilizing cables, and 3) module stability-perimeter double pylon, portal frames.

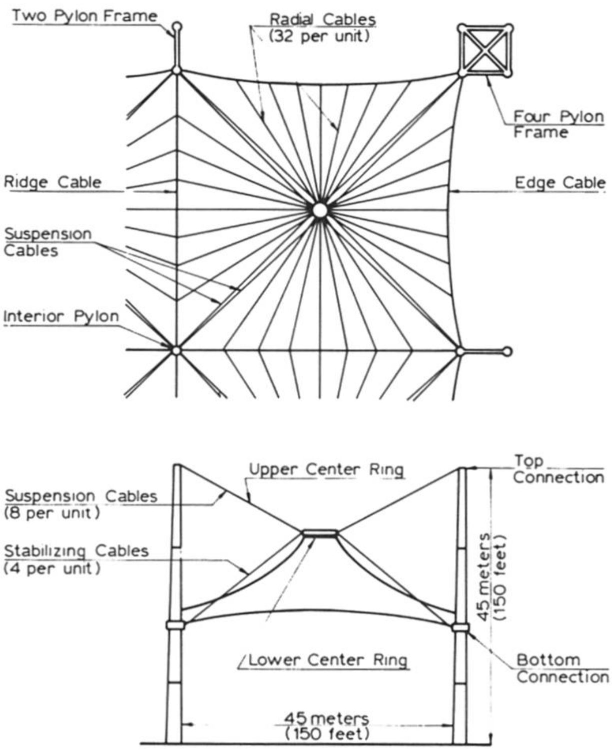

Fig. 2 Haj Terminal Fabric Roof system