The Aga Khan Award for Architecture

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1983 ARCHITECTS' RECORD **CONFIDENTIAL**

I. IDENTIFICATION

A. Projet Title King Abdul Aziz International Airport/Haj Terminal Complex

B. Postal Address Jeddah, Kingdom of Saudi Arabia

II. PERSONS RESPONSIBLE

(Please give name and address for each. If more than one, please state precise roles and relationships.)

A. Client/Owner

International Airport Projects, Ministry of Defense and Aviation, The Kingdom of Saudi Arabia. Brigadier General Said Y. Amin, Director.

B. Architect/Planner

Skidmore, Owings & Merrill - New York and Chicago
Partners in Charge:

Gordon Wildermuth	Roy O. Allen	Raul de Armas
Gordon Bunshaft	Parambir Gujral	Fazlur Khan
John Winkler		

C. Consultants (e.g. Economist, Sociologist, Demographer, Engineer)

(Please see attached sheet for consultants list.)

D. Contractor

1. Owens-Corning Saudi Company (Fabric Roof System Contractor)
2. Hochtief AG, Essen, West Germany (General Contractor)
3. Saudi Arabian Parsons Ltd./Daniel International Ltd. (Construction Manager)

E. Master Craftsman

(Please see attached sheet for master craftsman list.)

(Please continue overleaf if necessary)

II.C. Consultants (e.g., Economist, Sociologist, Demographer, Engineer)

1. Air-ride planners, navigation aids, fuel systems: Trans Plan, Inc.
2. Traffic planners: Wilbur Smith & Associates
3. Graphics: Lance Wyman and William Cannan
4. Security: The Wackenhut Corp.
5. Public address system: Wilke, Inc.
6. Processing analysis: R. Shriver Associates.
7. Special lighting: Edison Price, Inc.

II.E. Master Craftsman (Following were subcontractors to Owens-Corning Saudi Company)

1. Structural Steel Subcontractors: Nippon Kokan K.K. and Mitsubishi
2. Structural Cable Manufacturer: Chiers-Chatillon-Gorcy
3. Structural Cable Coater: Owens-Corning Saudi Company
4. Fabric Roof Fabricators: Owens-Corning Fiberglas Corporation and Birdair Structures, a division of Chemfab
5. Fabric Manufacturers: Owens-Corning Fiberglas Corporation and Chemical Fabrics Corporation
6. Fabric Weaver: Chemical Fabrics Corporation
7. "Beta" yarn Manufacturer: Owens-Corning Fiberglas Corporation
8. Teflon Manufacturer: E.I. du Pont de Nemours & Company
9. Special Erection Equipment Designer and Manufacturer: SIARGA International
10. Special Tooling Designer and Manufacturer: Schueler-Leukart
11. Engineering: URS Corp.
12. Engineering: Geiger-Berger Associates

III. USE

A. Type(s) of Use: Airport Terminal for Muslim pilgrims arriving in Jeddah by air and continuing on their pilgrimage to Makkah.

B. User/Occupant

1. Occupation: Varies.

2. Income Level: Varies.

C. Specify any change(s) between planned and actual use.

None

IV. PROJECT HISTORY

A. Programme Development

1. Date of Commencement: 1975 (under Airport Master Plan prepared by Skidmore, Owings & Merrill/Airways Engineering Corporation, a joint venture.)

2. Date of Completion: 1977

B. Design

1. Date of Commencement: 1977

2. Date of Completion: 1978

C. Construction

1. Date of Commencement: 1978

2. Date of Completion: All tent units presently erected; the remainder of the construction not yet complete.

D. Date of Project Occupancy: 3 of 10 modules were occupied for the 1981 Haj.

V. PROJECT ECONOMICS
(For Costs, please give amounts and currencies. Specify their date(s) of validity)

A. Total Initial Budget: Not available at this time.

B. Total Actual Costs: Not available at this time.

C. Analysis of Costs

1. Land: Not available at this time.

2. Materials: Not available at this time.

3. Labour: Not available at this time.

4. Professional Fees: Not available at this time.

D. Source(s) of Funds (indicate percentage)

1. Private: Not available at this time.

2. Public

a. Local: Not available at this time.

b. National: Not available at this time.

c. International: Not available at this time.

(Please continue overleaf if necessary)

VI. CONSTRUCTION DETAILS

A. Site Area and Characteristics Designed to shelter the pilgrims from the intense heat, the Haj Terminal covers a site of 105 acres (40.5 hectares) at the King Abdul Aziz International Airport on the shore of the Red Sea just north of Jeddah, Saudi Arabia. The climate is hot and (continued)

B. Total Floor Area of Individual Building(s) The lightweight units (45 meters square) are grouped in modules of 21 units. Each module is three by seven units and covers 10.5 acres (4 hectares). There are 10 such modules, five on each side of a landscaped central roadway.

C. Structural System (describe) The 4.6 million sq. ft. (427,509 sm) roof consists of 210 double curvature Teflon-Coated Fiberglas membrane units, each 150 x 150 feet (45.7 x 45.7 m) in plan, used as interactive structural elements with radiating cables, and supported by steel pylon frames.

D. Materials (describe and indicate whether locally produced or imported)

1. Infill The material below the surface is basically coral and coral sand. Suitable fill was obtained on the airport site in several other locations.
2. Rendering of Facades Teflon-Coated Fiberglas fabric roof produced by (continued)
3. Floors Concrete imported.
4. Ceilings See item 2 above.
5. Others (interior and exterior) None.

E. Site Utilities and Building Services (describe) Due to the enormous scale of the project, the utility systems are on the scale of a small city. Basically, the major utilities are heated under the landscaped central mall and service each module through three large underground corridors, containing power, communications, chilled water, potable water, and (continued)

F. Construction Technology

1. Describe the Basic Method of Construction A two-way grid of pylons forms the low point of each membrane unit while an open tension ring, suspended by cables from the top of the pylons establishes its high point at the center of each bay. A row of double pylon portal frames provides a (continued)
2. Indicate which major building parts were fabricated on-site and which were fabricated elsewhere.
   Structural parts were imported from foreign countries and the structure was erected over a period of 29 months. The pylons came from Japan, the cables from France and the fabric from the U.S.A.

G. Type of Labour Force (indicate percentage)

1. Skilled Not available at this time.
2. Unskilled Not available at this time.

H. Origin of Labour Force (indicate percentage)

1. Domestic Not available at this time.
2. Imported Not available at this time.

(Please continue overleaf if necessary)

VI.A. (cont'd)

humid, with a mean maximum temperature of 97°F (36°C) and a mean relative humidity of 64%. Sea breezes which produce high humidity and lower dry bulb temperatures and hot, dry desert winds greatly affect temperature and comfort levels. The mean total annual precipitation is usually quite low, with 98% of the precipitation occurring from November through January.

VI.D.2. (cont'd)

Owens-Corning Fiberglas of the USA; steel pylons produced by Nippon Kokan K.K. and Mitsubishi of Japan; and steel cables produced by Chiers-Chatillon-Gorcy of France.

VI.E. (cont'd)

sanitary sewers. Also located in the central mall are two large exhaust fans for each module which draw off the exhaust fumes of Haji buses.

VI.F.1. (cont'd)

stiff edge for the modules. Using electronically synchronized equipment, modules, or 21 pre-assembled tent units, were simultaneously raised into place. At the same time, each membrane was stretched and pretensioned as the inner tension ring element was lifted and joined to the suspended outer ring.

VII. EVOLUTION OF DESIGN CONCEPTS

Please describe the genesis of the project, through programme, design and construction to final and present occupancy.

The Haj Terminal, situated within the King Abdul Aziz International Airport in Jeddah, Saudi Arabia, is located approximately 70 kilometers west of the Holy City of Makkah. Since Jeddah is the only large commercial city in close proximity to Makkah, all air traffic bound for Makkah arrives in Jeddah and proceeds by land transportation from Jeddah to Makkah. Normal airport facilities are capable of handling this traffic during most of the year; however, approximately once a year, vast numbers of Moslem pilgrims from all over the world travel to Makkah to participate in the Haj pilgrimage. The Haj activity takes place within about six weeks, resulting in unusually high air traffic for this rather short period of time. Since the public facilities at the new airport were designed to handle only the normal flow of domestic and international air traffic, a separate terminal facility was required to process the Haj pilgrims.

The Haj Terminal design requirements were such that the facility had to be capable of handling a large volume of people with highly diversified needs over a short period of time. It is projected that this facility will process approximately 950,000 pilgrims during the Haj period by the year 1985. It is estimated that the Haj terminal complex will need to accommodate 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 in order to transfer between air and land transportation. Therefore, appropriate space had to be created which was adaptable and flexible to the Hajis' needs. It was determined that approximately 500,000 sm of space was required to accommodate these needs.

The Haj Terminal and Support Complex has been designed to accommodate 5,000 pilgrims per peak hour. In plan, the Haj Terminal consists of two identical halves, 1,050 by 2,250 feet (320 by 686 meters), separated by a landscaped central mall, with the adjacent aircraft aprons for docking airplanes. The pilgrims' aircraft land at the King Abdul Aziz International Airport and taxi to one of a possible 20 wide-body aircraft gate positions, two per module, located on the airside of the Haj Terminal Building. Extensive computer analysis was conducted to provide solutions for relieving aircraft congestion on the ground. All 20 terminal gates can accommodate Boeing 747 aircraft. If the Terminal gate positions are filled, the aircraft wait in one of the two holding aprons which can accommodate 26 aircraft of varying sizes. On leaving the plane, the pilgrims enter the second level of the air-conditioned Terminal building where they pass through all the necessary health and immigration formalities before going down a ramp to a lower level baggage claiming and customs area. This process lasts sixty to seventy-five minutes. Upon exiting the Terminal building, the pilgrim arrives in a shaded environment created by the Terminal Support Area roof.

Under each module, areas and facilities are located for the pilgrim to rest, sleep and to acquire both prepared foods or food which the pilgrim himself may prepare. In addition, many washing and toilet facilities have been provided in each module as well as offices providing banking, postal, airline, bus and taxi, and general information support services.

Due to the large volume of space required to properly house the support area functions, it was decided to air condition only certain spaces and to develop a shaded "village" for the remainder of the area. To create such a large, covered, naturally ventilated, highly flexible space within a very short construction schedule, a number of alternative roof systems were investigated. This resulted in a long span, lightweight structure with

(continued)

(Please continue overleaf if necessary)

VII. (cont'd)

translucent material that could adequately respond to the overall environmental needs of such a space. It was determined that a fabric membrane should be used as a structural element, together with a one-way cable system, thus resulting in a two-way interactive system of cables and membrane.

To utilize the membrane material as part of the structure, it had to satisfy numerous performance criteria. It was required that the fabric membrane for the Terminal provide for a life of at least 30 to 40 years with minimum maintenance. This requirement was an extremely difficult one for the Jeddah environment due to the continuous exposure to ultra-violet degradation and a highly corrosive marine atmosphere. In addition, the fabric membrane had to satisfy the following requirements:

1. Self-cleaning to insure a lasting good visual appearance.

2. Lightweight yet capable of carrying high tensile loads with little or no long term creep.

3. Good thermal insulation qualities to insure the comfort of the pilgrims while at the same time providing sufficient translucency to naturally illuminate the vast covered area during daylight hours.

4. Non-combustible and also non-toxic when subjected to fire.

5. Easy to fabricate and ship.

6. Easy to repair on site if required.

As a result of these requirements, a heavyweight, Teflon-Coated Fiberglas fabric was selected as the optimum membrane material which derived its basic structural strength from the fiberglas and utilized the teflon coating for protection and durability.

With the selection of the basic materials for the tension membrane structure (cables and Teflon-Coated Fiberglas), a comprehensive study of shapes and forms was undertaken to develop a structure that is both aesthetically pleasing and structurally feasible.

From a structural design point of view, it was important that the membrane surface should result in a double curvature shape to insure stability for both upward and downward acting wind loads. Such a shape guarantees tension in the fabric under any loading condition.

After studying various possible shapes and proportions, the final configuration selected resulted from a two-way grid of pylons and an open tension ring at the center of this grid, suspended by cables from the top of pylons. The double curvature 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 drainage 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.

Further refinement of the structural system was based on the ease of fabrication and construction. The overall plan of 10 modules with 5 on each side of the central roadway provided for future expansion of 5 additional modules on each side. Steel pylons are located at the corners of each unit and are 45 meters high. The roof membrane forms the tent shape springing upward from a 20 meter height at the pylons to a 35 meter height at the center tension ring. The center tension ring is 5 meters in diameter. A total of 32 radial cables extend from the center tension ring to edge, or ridge, cables connecting the pylons at the edge, or intersection, of adjacent roof units. The suspension 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 rather than single cables were used to provide a degree of safety in the structure in case of accidental failure of one cable. Further, to protect against collapse due to membrane damage, 4 stabilizing cables are provided for each unit. These stabilizing cables extend downward from the center tension ring to the lower tension ring at the pylon. The purpose of these cables is to maintain stability within a unit and its adjacent units if a particular unit's membrane loses tension. These cables maintain the stability of each tent unit by keeping the center ring in position, thus retaining the forces in the suspension cables and pylons.

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 3 x 7 module, including the common row of pylons between adjacent modules, is a row of very stiff double pylon, portal frames. By providing this stiff edge and separation between modules, they become independent of each other and can be added or removed in truly a modular fashion. Also, this system insures that a failure in one module will be isolated within that module and not transmitted to an adjacent module.

An aero-elastic model consisting of 3 x 3 units and closely simulating the dynamic properties of the full-scale structure was constructed and tested in a wind tunnel. It was found that the structure was stabile and did not experience excessive vibrations during a simulated 95 mile per hour wind storm.

As part of the final verification for this unique structure, a full scale prototype of two of the tent roof units was built. The purpose of the prototype was to verify the results of the structural analysis and to demonstrate that the roof system, which includes many connection details, could be constructed. A simulation apparatus was provided along the "interior" edges to simulate the continuity provided by the adjacent units in the actual structure. All roof membrane patterning, construction, fabrication and shipping techniques were carried out exactly as anticipated for Jeddah. Cables were fabricated and shipped to the prototype site from France. As part of the prototype testing program, instrument testing verified the performance of all elements of the roof membrane including cables, fabric and tension rings.

Following the erection and final tensioning of the two roof units, a ground survey and air survey (photogrammetry) were conducted to verify the final shape of the membrane. Confirmation of the shape was not only visually important, but was required to analyze the cable and fabric stress data. By analyzing the stress data together with the shape data, it was possible to evaluate the overall behavior and performance of the structure with reference to the theoretical model. Minor adjustments were then made for the actual construction in Jeddah.

Construction of the Haj Terminal support complex is now complete. Dedicated in April 1981, three of the Terminal's 10 modules were in operation for the October 1981 pilgrimage. For many, the entry to this Haj facility becomes not only an entry to the Kingdom of Saudi Arabia, but the gateway to the Holy Land - the gateway to Makkah. By applying high technology to the environmental conditions of the site and the socioeconomic and cultural needs of the people who use this facility, the Haj Terminal and Support Complex has become a modern version of the traditional desert tent village. The Haj Terminal recalls the traditions of an Islamic heritage in today's world. We are hopeful that it will inspire pilgrims representing 800 million Muslims who turn to Mecca five times daily for prayer and devotion to Allah. The Haj Terminal welcomes believers from around the world as they make this profound journey, their duty to Allah, to the Kingdom of Saudi Arabia and the Holy cities of Islam.

VIII. SIGNIFICANCE OF PROJECT

In what way is this project important?
Please describe the aspect(s) of the project which you feel represent a particular achievement, for example, the technical, economic, or social achievement, or its response to culture or climate, etc.

Islam requires everyone who is physically able to perform Haj at least once in his or her lifetime; it is therefore a most significant journey. Many pilgrims are inexperienced travellers, separated from their culture and familiar surroundings for the first time. The Haj Terminal design responds to the Hajis' physical needs and comfort in a form that is technologically appropriate for its use and architecturally responsive to the surrounding environment. The translucent fabric roof helps create a naturally ventilated and lighted open space which prevents distraction from the Hajis' spiritual objectives, yet affords the pilgrim needed shelter and minimizes walking distance. The Terminal prepares him for his next journey which will take place in a similar open air setting. The Terminal is a transitional shelter, yet it is a visually powerful and well-organized transportation facility which attempts to avoid confusion or cultural shock for the Haji. Because the Terminal is only minimally mechanized, the need for extensive maintenance for a building that is active only a few weeks of the year is eliminated.

The research and time devoted to the Haj Terminal structural design has no doubt advanced our state-of-the-art knowledge of large scale, long life, fabric membrane structures. The very size of the Haj Terminal required a more sophisticated design process than is usually applied to fabric roofs. This project has stimulated tremendous interest in the development and use of fabric roof structures not only in the Mideast, but throughout the world.

(Please continue overleaf if necessary)

IX. DOCUMENTATION

Please indicate the materials you enclose for project documentation:

- X 10 Photographs; Color, and Black & White; 8″ × 10″ (18 × 24 cm).
- X 20 Slides; Color, and Black & White; 35 mm.
- X Drawings: Community plan, Site plan, Floor plans, Sections, Elevations.
- X Project Brief/Programme
- __ Biographical Data
- X Other (Please specify: Firm History).

Please note: The submission of this Record is a prerequisite to candidacy for the Award. All information contained and submitted with the Form will be kept strictly confidential until the announcement of the 1983 Award recipients. Subsequently, such information may be made available by the Aga Khan Award Foundation for scholarly purposes only. Nevertheless, persons wishing to publish, reproduce or reprint such information shall be required to secure prior permission in each instance.

Authorized Signature [signature] Date 6/11/82

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