Hong Kong Stadium Roof

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ABSTRACT

The Royal Hong Kong Jockey Club held an international design and construct bid for the fabric and steel roof of their new $140m stadium, home to the Hong Kong Sevens.

The Australian team, consisting of Permafab Pty Ltd in association with Bond James Norrie Marsden Pty Ltd was successful in their bid, competing against the United States, Germany and Japan.

1. BRIEF DESCRIPTION

The architects envisioned a shell–like roof structure, restricted to two halves each side of the playing field to maximise the amount of sunlight onto the playing field.

The roof consists of 15,000m^2 of SHEERFILL^R Architectural Fabric Teflon$^{(TM)}$ coated fibreglass on 1460t of CHS steel structure. The front of the roof is supported by a 406 CHS arch truss 3.5m deep, spanning 235m. Shape to the fabric roof is provided by alternating trusses at 12m centres and 76 diam valley cables to a zig zag edge at the back of the seating.

The translucent fabric roof was chosen for its durability, self cleansing, light transmission properties and its potential for dramatic architectural form with minimum structural support.

2. LOADS

Wind tunnel tests were undertaken by RWDI in Toronto on a model of the stadium together with the surrounding approaches. Wind load cases were obtained for three tiers of design:

- global loads for the design of steel structure
- intermediate loads for the design of the fabric cladding panels
- local loads for the design of the cladding clamping

Fortunately the site is very sheltered, nestled in an amphitheatre at the foot of hills. Ironically the same hills that provide shelter reducing the uplift loads, cause turbulence which dramatically increases the down loads, up to 2.7 kPa. We sometimes felt we were designing a long span office floor rather than a lightweight roof.

3. STRUCTURAL DESIGN

Three bracing options were considered:

1. End bay bracing off stubs, cantilevering off the concrete rakers supporting the precast seating

2. Global bracing, which did not require these cantilever stubs and finally
3. An ingenious system of overlapping catenary cables in the plane of the roof, proposed by Professor Max Irvine. The advantage of this system was its ability to handle large out of balance loads which were anticipated, but which were subsequently found not to occur after the wind tunnel testing had been completed.

The analysis model has approximately 2300 members and was designed for 18 different load case combinations, including the loss of a fabric panel.

The roof deflects around 350mm under wind load and sways approximately 200mm sideways.

The natural frequency of the roof is 0.8 Hz which places it comfortably above the critical frequency of 0.3 Hz for resonance.

4. STEEL FABRICATION AND ERECTION

The CHS C350 steel sections were supplied out of Britain and fabricated in China in 12m lengths, trucked to site where they were welded to length before lifting. Each arch was lifted in four pieces and temporarily supported off three scaffolding towers. Then the trusses were lifted and pinned to the arch and off the rear of the seating. When the steelwork was completed and the temporary supports removed the roof settled about 150mm. At this stage the diagonals in the bracing bays go into tension, slightly prestressing the roof and hence increasing its natural frequency.

5. FABRIC

5.1. Sheerfill

The two identical roof structures with an area of approximately 15,000m^2 are covered with a combination of SHEERFILL I HT and SHEERFILL II LT PTFE coated woven fibreglass architectural fabric manufactured by Chemfab Corporation of Merrimack, New Hampshire, USA.

SHEERFILL is the trade name for a fabric woven from fibreglass yarn and then coated with PTFE (polytetraflouroethylene – commonly referred to as Teflon). The material was developed by Chemfab Corporation of the US in association with the Du Pont Company and Owens Corning Fibreglass Corporation. It has been in continuous service since the first installation at La Verne College in 1972 and has been used as the material of construction in the majority of permanent fabric structures worldwide. These include the 105 acre Haj Airport Terminal in Jeddah, Saudi Arabia; the 500,000 square feet main terminal building roof of the International Airport at Denver; the 15,500 square metre Burswood Superdome roof in Perth; and the recently completed 37,200 square metre cable dome roof in Atlanta, Georgia.

As a result of specific wind tunnel testing carried out in Canada on a model of the Hong Kong Stadium, a higher strength fabric was required to be used in the four corner catenary edged panels thus the use of SHEERFILL I. Nine rolls of SHEERFILL I were used for these four panels which have a surface area of 1,100m^2 each. Eighteen rolls of SHEERFILL II were used for the remaining six panels of which four had a surface area of 1,714m^2 each and the two centre panels at 1,844m^2.

SHEERFILL is subjected to the highest possible levels of quality assurance programmes. Every roll is subjected to four tests for each of twelve properties. Visual inspection is undertaken by passing the entire roll over light tables at the manufacturer's factory and again at the Permafab factory in Brisbane. Additionally, bi–axial tests are conducted on every roll and the data obtained is fed into Permafab's computer to adjust the nominal cutting patterns to ensure a smooth wrinkle–free finished membrane surface.

5.2. Patterning

Patterning of the ten panels was carried out by Permafab's in–house engineers progressively over the period August 1992 to May 1993 using a purpose–written finite element analysis computer programme. The three dimensional geometry of the steel structure with fabric work lines was provided on floppy disk by BJNM which was then refined by Permafab to produce the final patterning geometry. The same 3D geometry was used to give the architect the roof shape, by BJNM for roof steel and fabric analysis and by the steel fabricator in China to produce steel shop drawings.

Based upon the quarter symmetry of the structure, there are 162 basic patterns but with the application of the varying bi–axial results from the 27 rolls of fabric, a total of 531 patterns were required.

5.3. Fabrication

The ten panels required for the project were progressively manufactured under licence to Permafab by Structureflex Australia in Brisbane over the period October 1992 to July 1993.

The many compensated patterns were provided by Permafab to Structureflex both in hard copy and on floppy disk with the information being fed by Structureflex into their computer to produce the various templates, with that information then being used to drive their 10m x 4m plotter which marks directly onto the fabric.

Each template is checked twice for correct measurement, once from the computer printout before fabric plotting and then again after plotting before the fabric is cut.

The individual fabric pieces (648 total in the ten panels) are sealed together under pressure at 370 degrees Celsius causing the PTFE contact surfaces to weld together in the 70mm wide seam. The roped edges are then stretched to a pre–determined distance before the bolt holes are marked and punched, following which the fabric is cleaned and folded before packing into suitable wooden crates for shipment.

Due to their large size, the individual panels could not be completely spread out on the factory floor, therefore manufacture was organised around how they were to be packed for shipment and subsequent deployment. This involved progressively finishing portions of each panel and folding it onto the skid as further sections were added to it.

The six larger panels were shipped in 40ft crates with the smaller corner panels in 20ft crates.

5.4. Erection

Installation of the fabric and cables was carried out from late August 1993 to mid February 1994 during which time Permafab had a site staff of Project Manager, Site Manager and three installation supervisors.

The two most critical areas during the erection phase were fabric deployment and cable installation. Both posed problems due to their size, weight and location. Access to the workface and cranage were also central in the methods finally chosen.

1. Deploy the membrane from the back of the steel structure using winches to pull front edge toward the main arch.

2. Valley cables to be installed over the main arch using a specially designed movable cable guide, a crane and short spreader for lifting, and a tirfor winch for pulling the cable into the valley.

3. Catenary cables to be installed using a fully length spreader beam and crane to lift into position over the main arch.

4. Walkways using steel tube and fitting scaffold to the perimeter of all modules except the catenary edges, and a 2.4m wide deck over the rear bracing at the back of the structure for landing the fabric skid and unfolding the membrane.

5. Cranes for lifting 4 tonne fabric crates to a height of 50m and radius 54m, and 2 tonne valley cables over the main arch would be available from Argos, the structural steel contractor, on a 2nd preference basis until late October.

6. Precautions against typhoon wind damage to the fabric are to check the forecast daily and schedule site work appropriate for the expected weather. That is not to deploy fabric when there is typhoon in the South China Sea.

7. Tension the cables using centrehole hydraulic jacks mounted on chairs and connected to high strength steel threaded rods. Allow enough jacking equipment for two modules so that both fabric and cables can be tensioned concurrently.

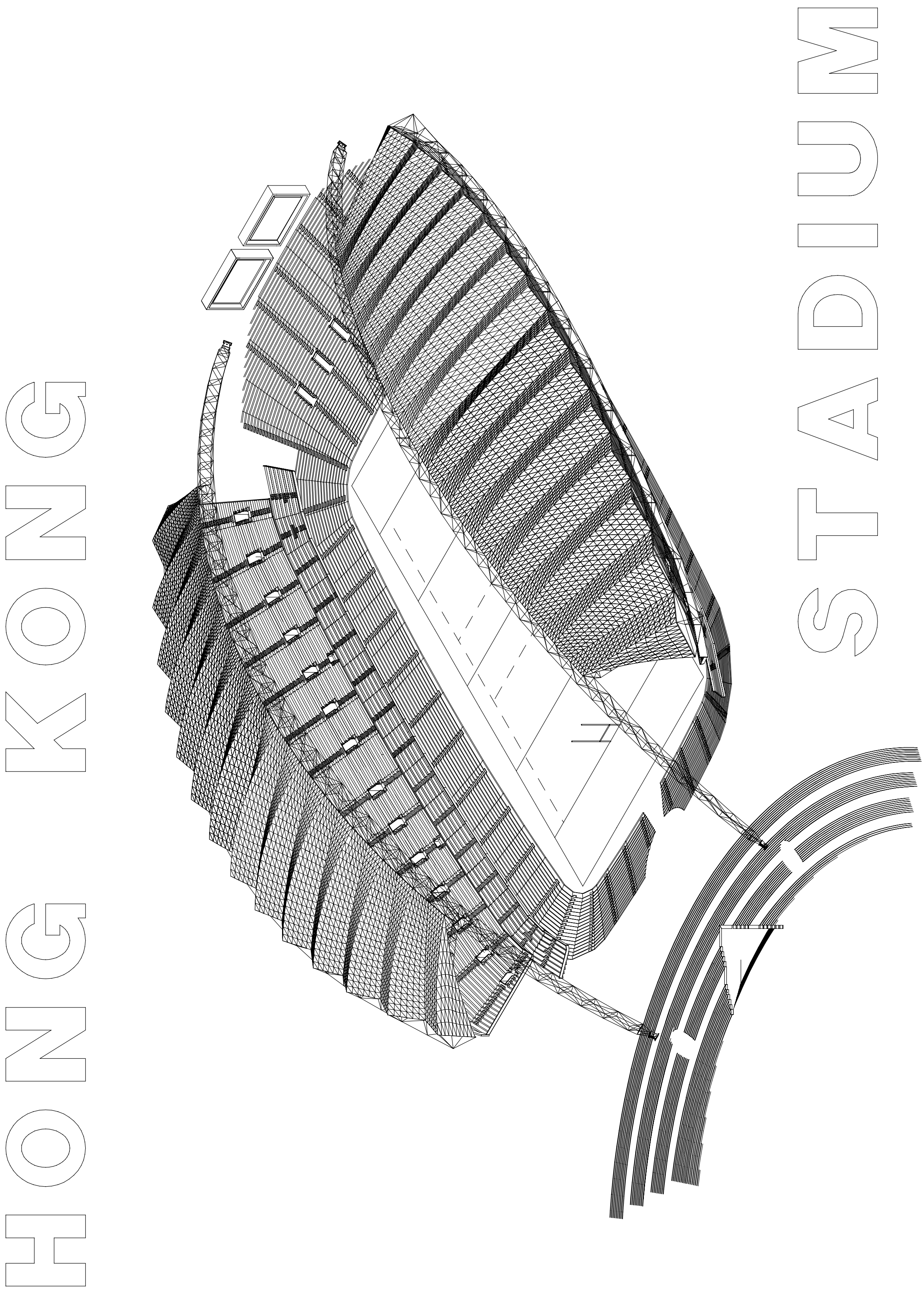
It was estimated that each of the ten modules would take 5 weeks to install – 5 days to prepare, 1 day to deploy and 4 weeks to attach hardware, lift cables, tension and bolt up. Based on this and a four month construction period (early August to early December) there would be three modules in progress at most times. Approximately one month was allowed at the start for organising site accommodation and communications, labour and equipment to be fabricated. Also in this period steel and paint check would start, workshop containers would be delivered to site and unpacked, and scaffold erection would commence. One month was allowed after bolting up of the last panel for fixing the walking strips and seal flaps between the panels. In line with the steel erection programme the East roof fabric would be erected first.

It became evident upon arrival on site to mobilise that there would be problems with the time required to complete. This was due to Argos running about six weeks behind schedule with the steel erection and Dragages insistence that the pitch be vacated by mid December so they could start reinstatement work. This was achieved by revising the schedule such that for the West side all resources concentrated on deploying fabric and cables with tensioning carried out later. Also four of the five fabric crates on the West side were lifted at the end of October before the Argos crane left site. Extra labour was also employed to speed up completion of the East side in order to release scaffold with limited Sunday and night time work also carried out. At the peak of activities there were over 30 men working under Permafab control.

The result of this was that the last cable was lifted on 14 December and the crane removed from the pitch on 15 December 1993 as required by Dragages.

6. CREDITS

Client:	Royal Hong Kong Jockey Club
Builder:	Dragages et Travaux Publics (HK) Ltd
Architect:	H O & K Sport, Kansas City, Missouri
Structural	Steel roof and fabric design
Engineers:	Bond James Norrie Marsden Pty Ltd, Sydney
Fabric Roof:	Patterning and Installation: Permafab Pty Ltd, Sydney Fabrication: Structureflex Australia Pty Ltd, QLD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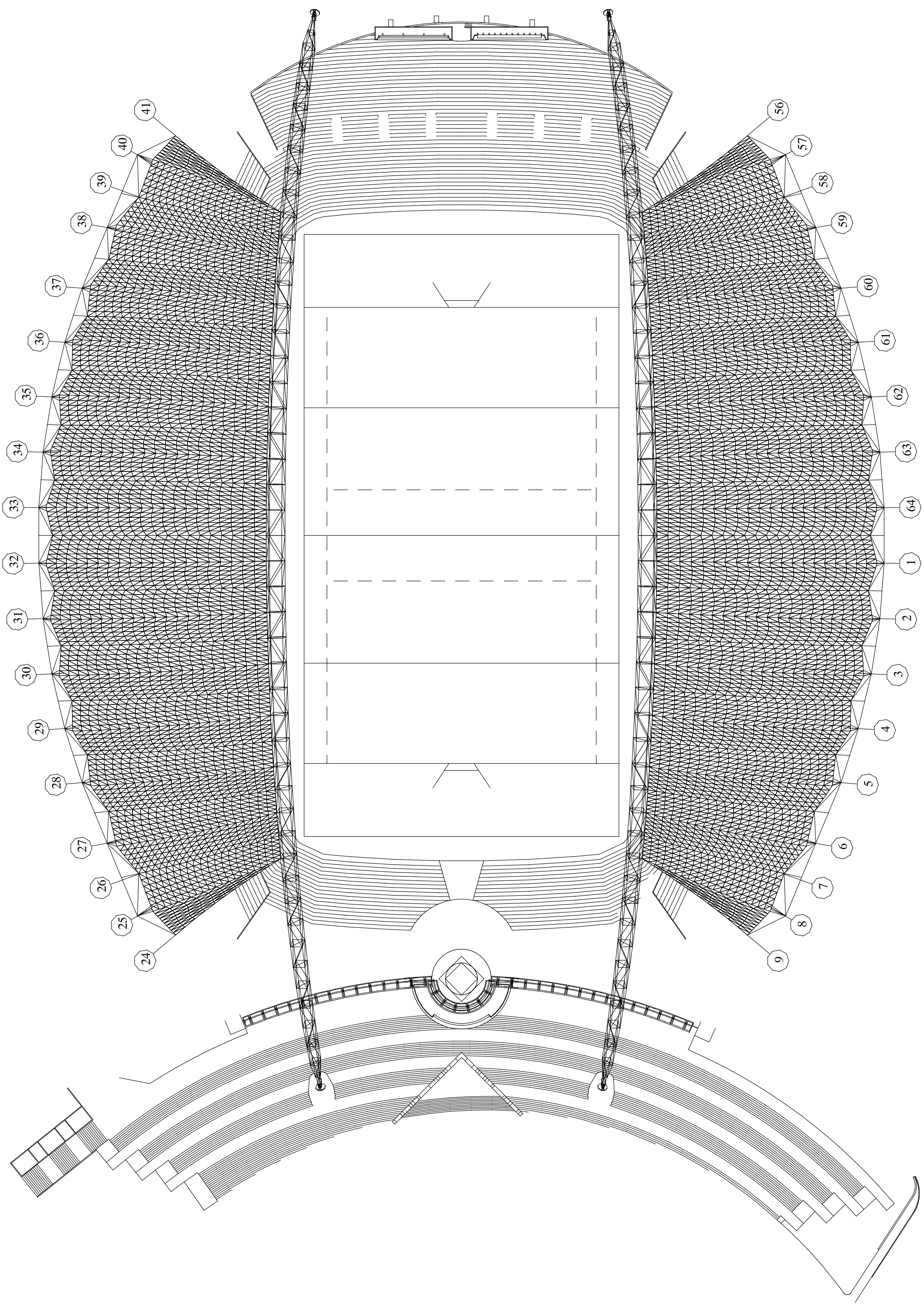
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