Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 71 (1994)

Artikel: Roof structure for the new Singapore convention centre

Autor: Chin, D. / Rogers, E.J. / Forrest-Brown, G.

DOI: https://doi.org/10.5169/seals-54132

Roof Structure for the New Singapore Convention Centre

Toiture du nouveau centre de congrès à Singapour

Das Dachtragwerk des neuen Kongresszentrums in Singapur

D. CHIN
Project Manager
Maunsell Consultants Ltd
Singapore

E.J. ROGERS
Project Engineer
Maunsell Consultants Ltd
Singapore

G. FORREST-BROWN
Chief Executive
Maunsell Consultants Ltd
Singapore

SUMMARY

The roof of the convention centre has overall dimensions of 173 m x 144 m. This paper focuses upon the design of this structure, which is believed to be unique in terms of the configuration of the space frame modules.

RÉSUMÉ

La toiture du centre de congrès a des dimensions extérieures de 173 m x 144 m. Ce rapport traite en particulier le concept de cette structure, qui est unique en ce qui concerne la configuration des modules d'espace du cadre.

ZUSAMMENFASSUNG

Das Dach des Kongresszentrums hat Aussenmasse von 173 m x 144 m. Dieser Bericht konzentriert sich auf den Entwurf dieses Tragwerkes, das hinsichtlich der Gestaltung der Module des Raumfachwerkes als einmalig gilt.

1. INTRODUCTION

The new Singapore International Convention and Exhibition Centre is a major feature of the Suntec City Development, the building is due for completion in 1994.

The total development comprises (refer to Figure 1):

- Convention and Exhibition Centre
- Four 45-storey high rise office towers
- One 18-storey rise office tower
- Extensive low rise retail podium

The Convention and Exhibition Centre will provide world class facilities aimed at maintaining Singapore as one of the major convention and exhibition centres in the world. The Convention Hall alone will be capable of accommodating up to 12,000 people.

The roof of the convention centre has overall dimensions of 172.8m x 144m. It is a special feature of the development and this paper focuses upon the design of this structure, which is believed to be unique in terms of the configuration of the space frame modules.

2. LAYOUT AND GEOMETRY

The roof structure comprises an external, fully exposed, space frame (exoskeleton) and a series of secondary roof structures suspended from the exoskeleton that support the roof cladding systems.

The roof exoskeleton is essentially a single layer 7.2m deep space frame with a square on square diagonal topology, with a node spacing of 20.36m. The basic frame extends to form two intermediate spine trusses which optimise the aspect ratio of the frame throughout the central 172.8m by 86.4m clear span. The frame also partially extends around the perimeter of the roof to facilitate the suspension of the secondary roof panels along the edge of the building.

The roof frame has a clear span of 172.8m by 86.4m; it has a total of 28 supports, and comprises tubular sections ranging from 400 to 900mm diameter. It is a fully welded structure using purpose designed node assemblies.

The overall configuration of the roof exoskeleton is illustrated in the views shown on Figure 2, 3 and 4.

The secondary roof is composed of three different forms of structure designed in response to the requirements of cladding systems (refer to Figure 5). These are as follows:

a) Type 1 -- Opaque roof structure, supporting a full acoustic roof and ceiling cladding system, with a depth of 1250mm sufficient to accommodate the air-conditioning ducting for the Convention Hall.

b) Type 2 -- Louvre roof structure supporting louvred roof panels above the service driveway and M&E Rooms, and fully exposed to the atmosphere. Structural depth is 1000mm.

c) Type 3 -- Skylight roof structure supporting glazed roof panels above the atrium area. Structural depth is 1000mm.

All secondary roof structures are essentially pyramidal 'pseudo' space frames with a base dimension of 20.36m x 20.36m and an apex height of 7.2m. All panels, except on the perimeter, were designed to be fully assembled as basic frames. Each frame was lifted from the roof apices by jacks fixed to the exoskeleton nodes.

Both the louvre and skylight structures are fabricated from circular hollow sections which were chosen for both appearance and ease of maintenance. The opaque structure is constructed from standard rolled sections.

3. DESIGN OF EXOSKELETON

3.(a) SPACE FRAME

The space frame was analysed using the Structural Analysis Program SAP90, and checked using the Structural Analysis Computer System SACS.

The frame was analysed assuming fixed concentrically loaded nodes except for the spine truss top chord nodes which were required to have a 200mm vertical eccentricity. Vertical loading was applied at the top and bottom nodes of the space frame to represent the actual loading pattern from the secondary roof structures. Support conditions simulated the actual roof articulation, which is fixed against translation about Grid lines D and 10.

Lateral wind loading on the roof is applied eccentrically to the nodes via the secondary roof structure hangers and the extended support stubs.

Tubular members were designed using purpose-written software for compliance with the requirements of the current edition of API (RP2A) 'Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms'. This approach, although perhaps more stringent than BS 5950, was considered appropriate in view of the unconventional scale of the roof frame. The effective length of compression elements was taken as the full distance between node centres in view of the node detail adopted.

Tubular member sizes range from 400 to 900mm diameter with wall thickness varying from 10mm (taken as a practical minimum for general construction robustness and weldability) to 40mm. The sections were fabricated from a mixture of Grade 43A and 50B steels to achieve minimum overall weight.

The frame was also checked to ensure that there would be no progressive or catastrophic collapse if one tubular was removed or one weld totally failed.

3.(b) NODE ASSEMBLIES

The connection of frame tubes of this size required the development of a special node assembly, comprising a vertical thick walled cylinder with plate stub tube connectors. The final arrangement, as shown in Figure 6 was chosen for its simplicity of fabrication and architectural merit.

The roof frame consists of a total of 109 of these standard nodes and 38 non standard nodes confined mainly to the spine trusses and the perimeter roof hangers. At the spine truss locations, additional in-plane inclined and vertical members lead to the use of a more conventional gusset plate connection, with a non-structural node can for architectural purposes.

The diameter of the structural node cylinders was chosen to be as compact as possible within the constraints of having sufficient space for up to 10 tubular connections and the architectural requirements. The following diameters were chosen:

a) 600mmΦ x 65 thick - for the standard case
b) 770mmΦ x 65 thick - for the bottom chord at the spine truss
c) 300mmΦ x 25 thick - for the perimeter top chord at hanger locations.

The design of the node was initially developed by preliminary analysis as a ring frame subject to point loads and then refined by finite element analysis using the program SACS. Furthermore, because of the unconventional nature of the structure full-scale load testing was be undertaken on typical nodes to verify the design in respect of the strength and stiffness of the overall node assembly.

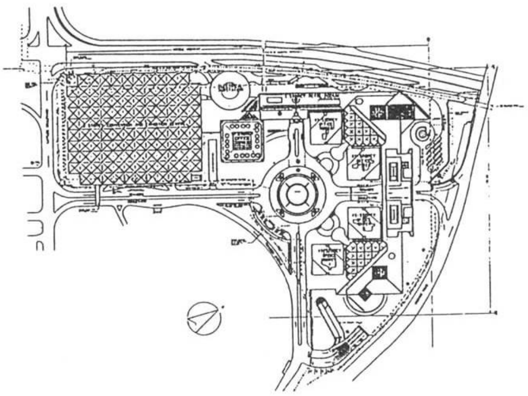


FIG. 1 SUNTEC CITY PROJECT

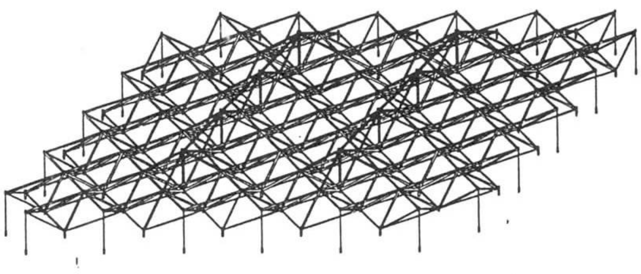


FIG. 2 ROOF FRAME – ISOMETRIC VIEW

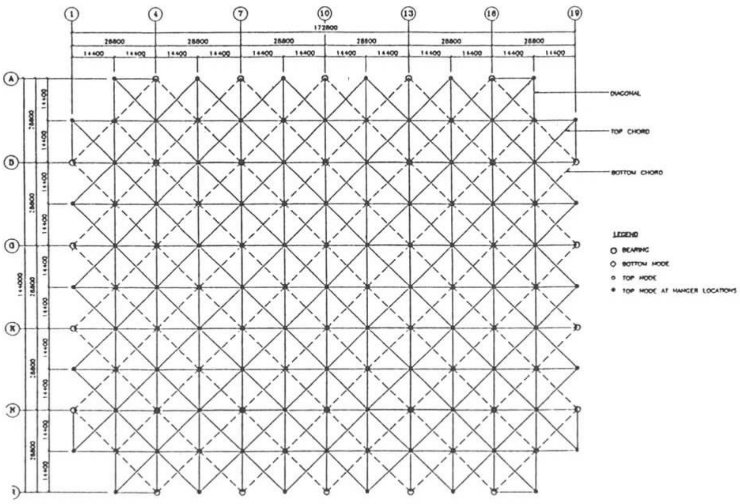


FIG. 3 ROOF FRAME – PLAN VIEW

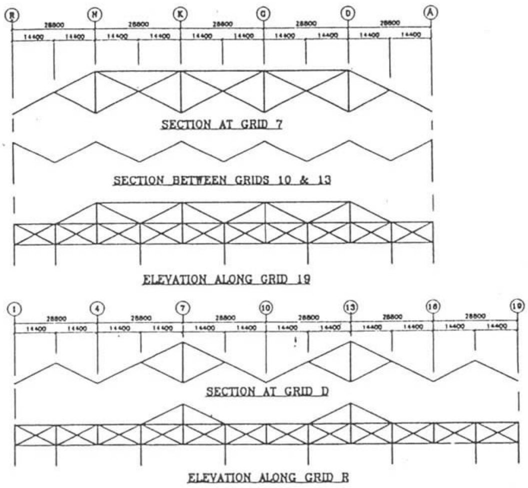


FIG. 4 – TYPICAL SECTIONS AND ELEVATIONS

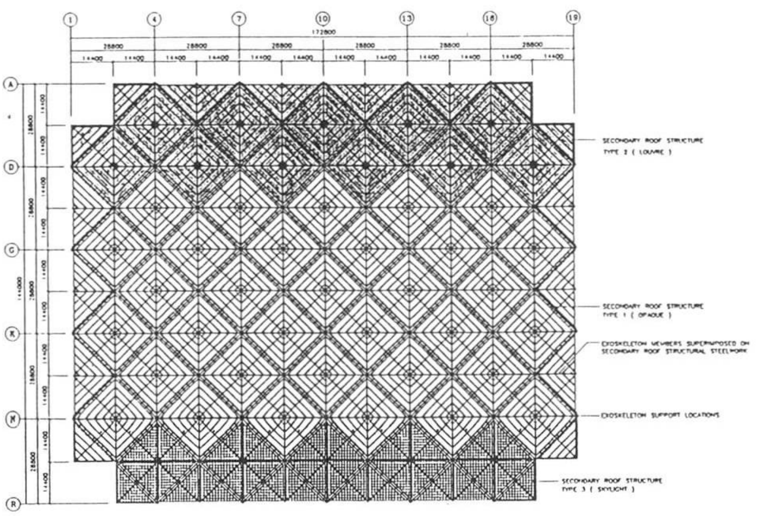
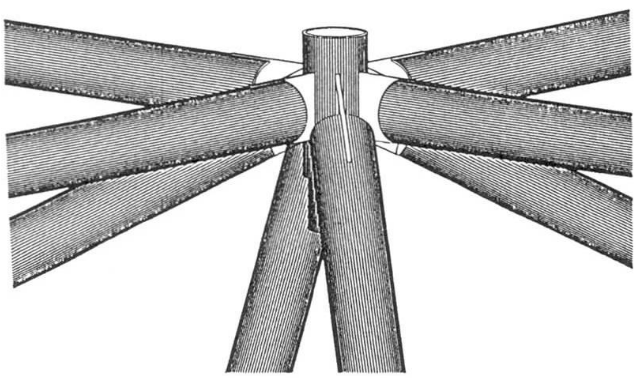


FIG. 5 – SECONDARY ROOF LAYOUT PLAN

FIG. 6 – TYPICAL TOP NODE ASSEMBLY



3.(c) ROOF SUPPORTS

The roof exoskeleton is supported at a total of 28 supports, 18 around the perimeter of the building and 10 internally. At each of these locations, the frame is supported on a single disc or confined elastomeric bearing with load capacities up to a maximum of 1000 tonne (spine truss supports).

The bearings are required to accommodate rotations and translations due to vertical loading and thermal changes of the exoskeleton estimated to be in the order of 60°C (-5°C+55°C about a mean of 25°C). The overall roof articulation arrangement is shown on Figure 7.

As the secondary roof structure is suspended below the exoskeleton, the supports for the main frame were required to accommodate eccentricities, from the nodes, approaching 2000mm. The moments generated by this eccentricity, because of horizontal wind loading and bearing friction effects (taken as 5% of DL reaction), must also be accommodated by the frame.

4. DESIGN OF SECONDARY ROOF STRUCTURE

4.(a) FRAMEWORK

Each of the three types of secondary roof structures are designed to support vertical loading appropriate to the type of cladding system they support. They also support M&E services and the general live loading required in accordance with BS 6399.

Structural analysis of the roof frames was carried out on three dimension models using SAP90, and individual members are designed to BS 5950.

Each secondary roof structure pyramid was designed to be lifted from its apex as a basic frame and then hung from the exoskeleton nodes at the apex and four lower corners. All loads applied to the secondary roof are subsequently distributed to all five supports. This beneficial use of construction staging results in a saving in overall member sizes. The special secondary roof panels, around the perimeter of the building, are designed to lift from their permanent supports under certain load combinations.

The basic configuration chosen for the louvre and opaque roof structures is a welded two-way truss system comprising primary ridge and perimeter elements connected by square bolted connections.

The skylight structure, on the other hand, is designed as a welded two-way vierendeel truss system with triangulated ridge and perimeter elements; all trusses are orientated vertically for aesthetic reasons.

Tertiary steelwork is provided between the roof pyramids to accommodate gutters, services and ceilings, etc.

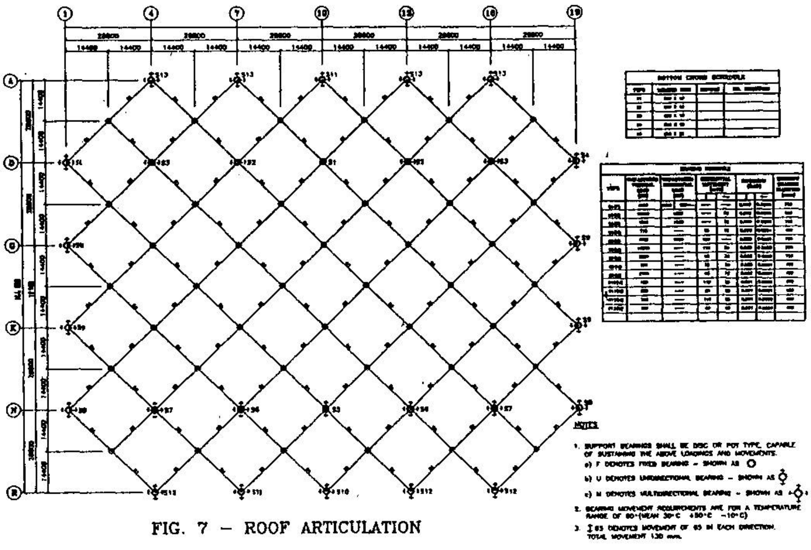


FIG. 7 – ROOF ARTICULATION

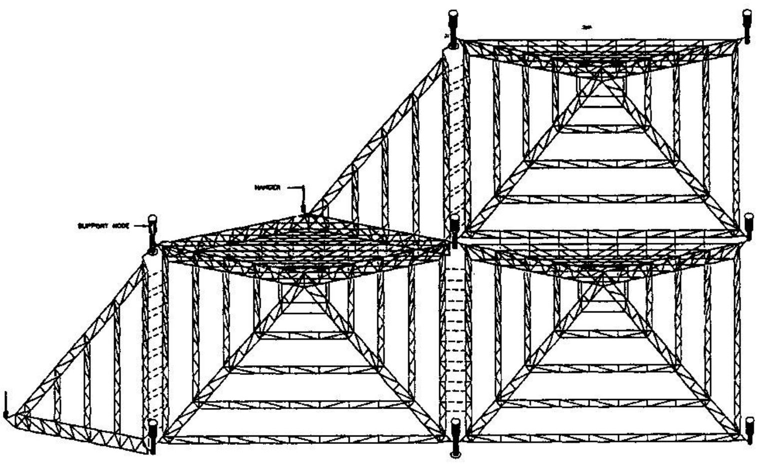
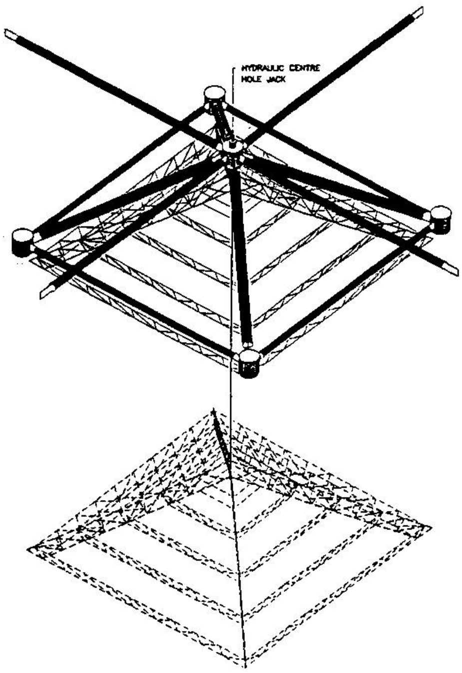


FIG. 8 – PART ISOMETRIC VIEW AT CORNER OF OPAQUE SECONDARY ROOF



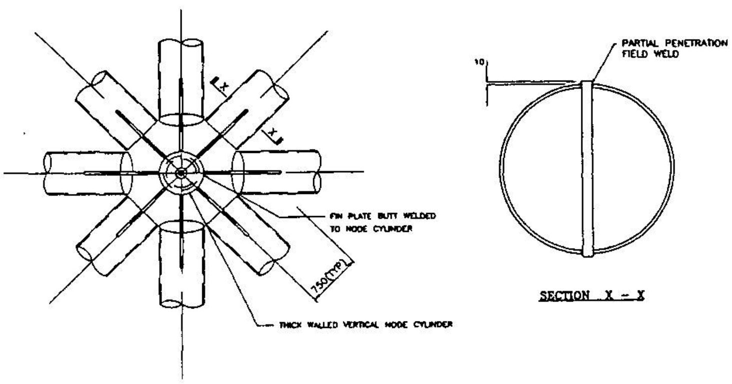


FIG. 9 – TYPICAL CONNECTION NODE TO TUBE

FIG. 10 – ERECTION OF SECONDARY ROOF STRUCTURE

4.(b) SUPPORTS

Secondary roof structures are supported from hangers that project below the exoskeleton nodes. The hangers and associated branch elements are arranged to suit the geometric requirements arising from the secondary roof structural types, and in response to their location within the main frame.

In order to provide sufficient articulation for each pyramid under vertical loading and differential thermal effects a simple support detail was devised for the lower node supports, consisting of:

a) Dual 20mm diameter prestressing bars with spherical washers top and bottom to accommodate lateral translation.

b) A shear plate assembly to control direction of movement and provide restraint to lateral wind loading. (A minimum of two shear assemblies will be activated regardless of the direction of the wind.)

The central apex connection is a fixed bolted connection utilising eight M24 H.S bolts in all cases.

The secondary roof around the perimeter of the building is composed of half or quarter inverted pyramids as shown in Figure 8. The lower corners of these panels are suspended from the top chord of the main roof frame by 100 mm diameter hangers. The hangers are provided with stainless steel prestressing bars concealed within the top roof frame node in order to facilitate adjustments in the level of the roof structures. At the lower end of the hangers, the secondary roof is connected by means of a concentric pin connection.

5. NODE TESTING

Because of the unusual nature of the nodes it was decided, early in the project, to carry out full-scale prototype testing of the nodes to test the assumptions and results of the finite element analyses. This testing was done by Det norske Veritas Industry at their facilities in the Singapore Science Park.

Testing was completed on three full size nodes, to ensure that the roof possessed adequate stiffness to resist the expected load patterns without unusual or excessive deformation of the node assemblies or the completed roof.

An 85 tonne rig was specially designed for the testing of the nodes which were fabricated with eight stub tubes in three dimensions to simulate the real conditions as closely as possible. Testing took place over a period of five days and included maximum loads equal to twice the design load. Data was logged from 300 points on each node.

The stiffness test (deformation measurements) required a force equal to the dead load plus 1.5 times the live load. The strength test was taken to twice the total load. Excellent correspondence with the analysis was achieved.

6. CONSTRUCTION

6.(a) ROOF EXOSKELETON

All of the steel for the roof was manufactured in Korea and Japan with fabrication taking place at Hyundai Heavy Industries in Ulsan, South Korea.

Tubular members were shop fabricated to their full length of up to 26m and weighed up to 22 tonnes. Nodes assemblies were also shop fabricated with fin plates and secondary roof hangers attached before being painted and shipped to Singapore. The remainder of the frame was field welded as shown in Figure 9.

The connection of the tubular members to node fin plates was developed with a view to simplicity of welding and maximum accommodation of angular tolerances.

In order to control the node positions such that they remained within the specified tolerance of ±5mm it was necessary to rigorously control when tubes could be connected to the node finplates. Tight tolerances were achieved by fixing the nodes at grid N in position and progressively working away from that grid. Tubes were tack-welded to node fin plates when the average temperature of the tubes was in the temperature window of 28 to 32°C. Final welding could then be carried out at any time of the day or night.

The 6th Storey slab was designed for a live load of 17.5 kN/m^2 allowing the roof exoskeleton designed to assume assembly on the structural slab. The roof was lifted by jacking of the complete frame from the 10 internal supports.

The jacking operation requires the installation of temporary towers between roof frame elements and a total jacking load of approximately 2400 tonnes.

Because of the number of members connected to each of the 10 nodes used for lifting, the temporary towers were designed to have 1 level of horizontal braces to the columns temporarily removed during the lifting operation. This need to frequently remove and reinstall braces meant that the 8m lift was carried out over an extended period after the critical lift off and survey checks. The jacks were capable of operating at a stroke speed of 1.5m/hour.

6.(b) SECONDARY ROOF

The secondary roof structures were assembled upon the 6th floor slab following lifting of the roof exoskeleton. Each internal pyramid structure was, after assembly, lifted from its apex by jacks placed upon the roof frame top chord nodes as shown in Figure 10. The maximum weight of secondary roof frame lifted is 25 tonne.

Perimeter half and quarter structures were erected by mobile crane. Following erection of all secondary roof structures the roof cladding systems and M&E services were installed to complete the roof of the Convention Centre.

6.(c) PROTECTIVE COATING

The protective coating system of the exoskeleton and the louvre secondary roof structure consists of

1)	Blast clean to Swedish Standard Sa 2.5 grade	
2)	Inorganic zinc	DFT 65-80 microns
3)	High build epoxy MIO	DFT 125-150 microns
4)	Aliphatic polyurethane	DFT 50-75 microns

The internal exposed skylight structure has a similar system except that the undercoat DFT is reduced to 75-100 microns.

The opaque secondary roof structure has surface preparation comprising of

1)	Blast clean to Swedish Standard Sa 2.5 grade	
2)	Epoxy Zinc Phosphate Primer	DFT 75-90 microns
3)	Epoxy Enamel	DFT 50-70 microns