Lightweight Structures Over Swimming Centres

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INTRODUCTION

Australia is one of the world's most successful nations in the sport of swimming. It has not achieved this status by weight of numbers but by leading the world in sports technology and its application. So what better place to show case some of Australia's best examples of lightweight structures.

This paper outlines some very good examples of Connell Mott MacDonald's creative lightweight structures utilising latest materials and new technologies to strive for lightness, the aesthetic of the exposed structure and economy. This paper highlights the collaborative relationships and the special skills required by the structural engineer to development and deliver lightweight architectural structures. The paper will then describe the structural form of the following projects:

- Goldfields Oasis Aquatic Centre, Kalgoorlie (WA)
- Sydney International Aquatic Centre (NSW)
- Inglewood Aquatic Centre (WA)
- Melbourne Sports and Aquatic Centre (VIC)
- Warnbro Aquatic Centre (WA)

IMAGINATIVE COLLABORATION

The language of the lightweight structure is minimalist and so delivers physically less material and therefore we use less of the earth's recourses. This imagery reflects the current generations thinking, and the direction many architects are pursuing for modern swimming centres. As a result the forms for these buildings are more often than not, engineer driven. Therefore to achieve the best collaborative outcome for the project the structural engineer has to have a certain passion for and understanding of form and function. The engineer must become involved early, before the form of the building is set and to be prepared to extract from the architect the essence of his thoughts and the desired aesthetic. The structural engineer must have a feel and understanding of the influence of the structure and its detailing will have on the aesthetic and also possess the ability to interpret the architect. The engineers ability to visualise and to express through 3D sketches is extremely important in developing **imaginative collaboration**, the "brainstorming" and development of ideas between architect and engineer provides the drive and passion to develop imaginative solutions.

GOLDFIELDS OASIS AQUATIC CENTRE – KALGOORLIE

The $14M development for the Cities of Kalgoorlie and Boulder will satisfy their indoor recreation and aquatic needs well into this century.

The centre features a 50m pool, a leisure pool with a beach, a toddler pool, a spa pool, saunas and a water slide. The recreation centre contains three basketball courts, with the flexibility of playing other sports and a grandstand. Between these areas is a central spine continuing offices, gym, aerobics, creche, function centre, changerooms, etc.

The challenge for the design and construction team was to efficiently create an aesthetically pleasing environment which is unique. This was achieved by using the latest technology to design extremely lightweight bowstring trusses, which were tied down for the wind case by splayed, raking cables through the roof space. They span uninterrupted 30m across the aquatic centre, almost disappearing into the ceiling. Close attention to connection details was required to architecturally enhance the appearance of the trusses.

The downward loads are carried by a light bow string arch with 273 CHS rafters and 24 diameter VSL MT 600 bottom cord with 76 diameter CHS 'V" struts. The 'V' struts prevent 'snap through' under asymmetric loading.

The upward wind loads are framed out using a splayed catenary of 32 diameter VSL MT600 cable tied to a buttress at one end and the suspended floor at the other.

The whole structure compliments the architectural form and provides a significant economy in weight of steelwork.

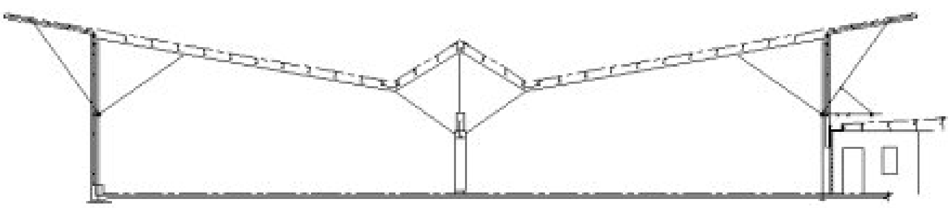

Figure 1.

SYDNEY INTERNATION AQUATIC CENTRE, HOMEBUSH (NSW)

A very interesting type of cylindrical shell has been adopted for this project. It falls into the “lattice” family of structures, and has been called “diagrid”. The diagrid shell can be likened to a series of arches with members running on uniform diagonals, 6.3m apart. While the diagrid resists uniform vertical loads through its arch action, stiffening ribs are provided to prevent the global and “snap-through” buckling of the arch. These stiffening ribs, which are constructed as double-layer shell (1m deep) and are positioned at 25m centres, also provide the required flexural stiffness and strength to resist non-symmetrical loading conditions. The diagonal arrangement of the shell members automatically provides all the bracing to the roof and the membrane action necessary to affect the stiffening ribs actions. This enables the roof to behave as a stiffened shell, and significant economy of material and lightness of appearance is gained. The members of the lattice shell structure are only 270mm deep, which is extraordinarily light for a span of 67m.

Figure 2.

The opportunity to use the natural curve of the roof to span the hall using shell action has been fully utilised. With a rise of around 9m, a very economical shell structure has been designed which uses significantly less material than a system using trusses. Furthermore, the adoption of diagonally aligned members has led to a uniform and repetitive structure, where members are straight, of identical length and generally identical size. All members of the diagrid are 273mm CHS sections with wall thicknesses ranging from 6.4mm through to 28.6mm. The latter thicker wall tubes, which had to be imported, were used at limited highly stressed locations.

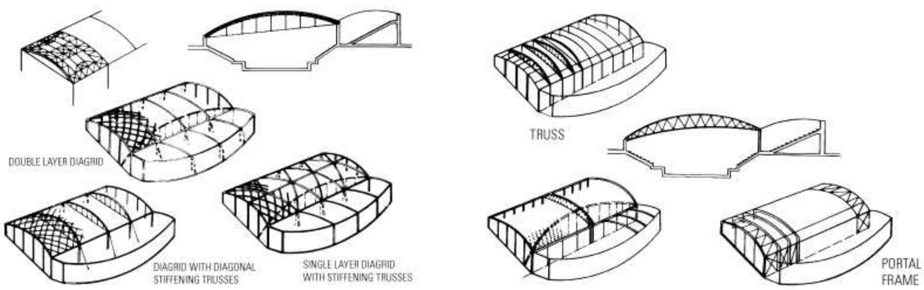

Figure 3.

Intersecting ties have been provided at 25m centres across the roof span to resist the lateral thrust of the shell structure under downward (dead, live and wind) loadings. These ties are 50mm diameter bars, stressed to approximately 600kN to control movements, and fully grouted inside a special sleeve for corrosion protection. To resist uplift, the shell structure goes into tension as a catenary with an external tie provided to complete the catenary action.

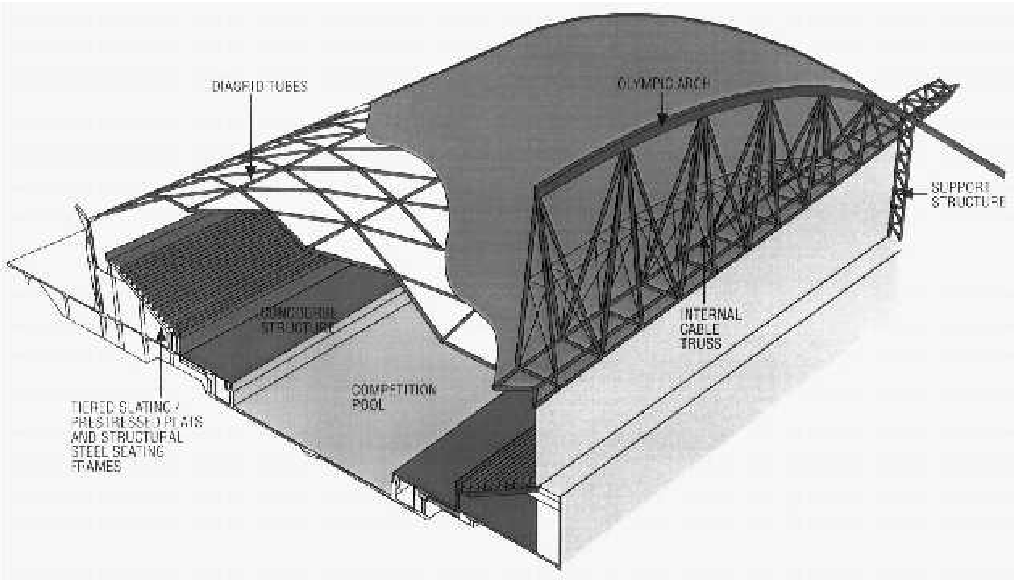

Figure 4. Sydney International Aquatic Centre Roof Cutaway

INGLEWOOD AQUATIC CENTRE

The new centre features an indoor 25metres x 8 lane lap pool, a large leisure pool, spa pool, gymnasium, aerobics centre, social and sports related facilities under one roof.

Connell Mott MacDonald, together with the architect, developed a striking, lightweight roof over the pool hall that features a 30 metre span central spine truss with a steeply pitched central roof section which maximised the use of natural lighting over the pool area. This ‘butterfly’ design also reduced rafter spans and resulted in a very low mass, structurally efficient roof system.

Figures 5. and 6.

The spine truss is manufactured from CHS and supports 310UB rafters at 9m centres. The rafters are propped, using 114 diameter CHS to reduce the span and form ‘knee braces’ to provide lateral stability. External ‘V’ layout 64 diameter CHS struts support 45m overhands. These overhangs shade direct sunlight from the full height glass facade whilst providing maximum indirect light.

MELBOURNE SPORTS AND AQUATIC CENTRE

The selected structure consists of a cable stayed curved rafter solution, where five guyed masts with radiating rods act as the primary support for downward loadings acting on the roof. To resist the wind uplift, the upward curving rafters are restrained at their ends enabling them to resist net uplift pressures by tension action. This is a far more structurally efficient method than conventional flexural (bending) action. As a consequence the main rafters in the Aquatic Centre, which span 48m, are only 460 mm deep. If flexural action was the only method used, trusses in the order of two metres deep would have been required at 10.5 metre centres.

The area housing the main pool is 100m long and 50m wide and is supported by two masts, which are located on one edge of the building with backstays.

The section below shows a section through the competition pool enclosure with its mast support system on the west side of the pool. On the east side of the pool, the rafter tension forces under uplift are transferred to vertical bracing by way of a horizontal truss within the lap pool roof structure.

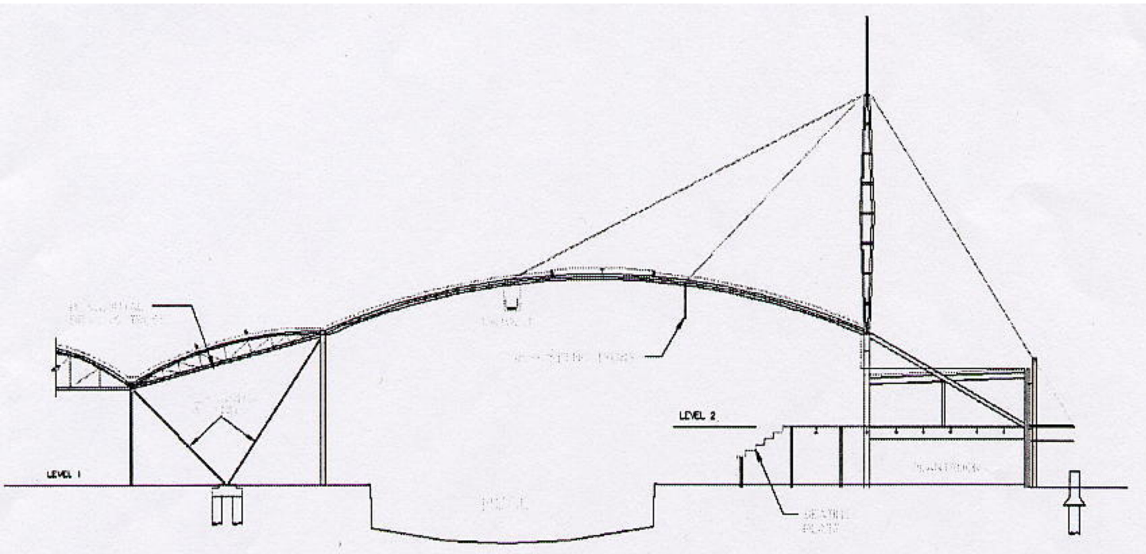

Figure 7. Competition Pool Hall

A similar scheme was adopted for the dry sports hall. The hall is approximately 160m long and 70m wide, but has only three internal columns. Two of these columns extend into masts, which protrude 20m above the roofline and support the roof via suspension rods. However, in this case the masts are centrally located within the hall, resulting in a balanced cable stayed scheme. The roof design is both light and elegant, with the dry sports roof structural steelwork weighing only 20kg/m^{2,} and the competition pool roof (with its heavier ceiling and catwalk requirements) only 24kg/m^2.

This is very light for structures with roof spans up to 70 metres.

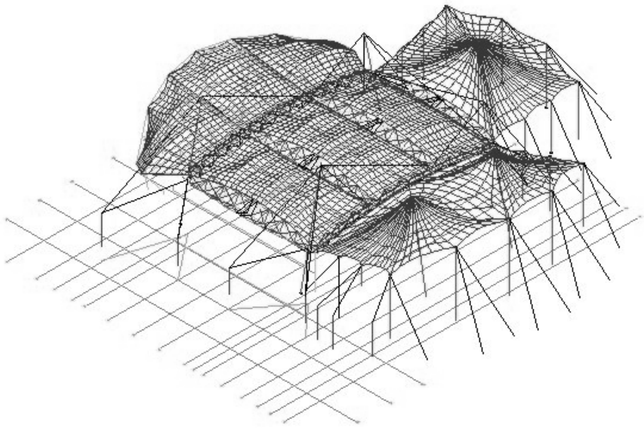

Figure 8.

WARNBRO AQUATIC CENTRE

The Warnbro Aquatic Centre is located south of Perth. A covered area of approximately 4,200m^2 houses a 25m lap pool, leisure pool, water slide and a hydrotherapy pool.

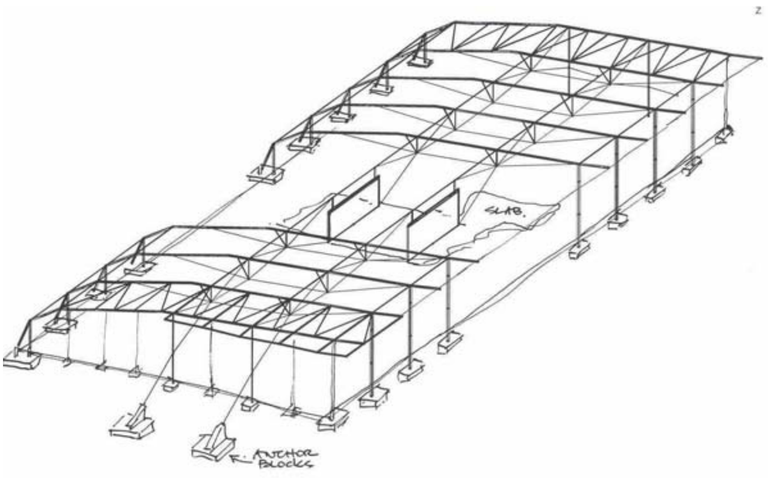

Figure 9.

The design for the Aquatic Centre centres on the idea of producing a clear, bold, striking built form within the fragmented suburban landscape of the Warnbro area. The presentation of the building has been considered with respect to passing traffic, the approaching vehicle, and the visiting patron throughout their journey in and around the building.

The road-side elevation of the building envelope consists of a large, monolithic ‘skin’ of folded roof – a sleek, crisp surface readily identifiable from a distance: uncluttered, unfragmented and unambiguous. This unique light weight steel structure supports down ward vertical loads and up ward vertical load on separate structural systems perpendicular in plan. The main members consists of 250 x 150 RHS rafters with 36 diameter VSL MT600 series rods supported with SHS ‘V’ struts. The ‘V’ strut configuration prevents ‘snap through’ under non-symmetrical loading.

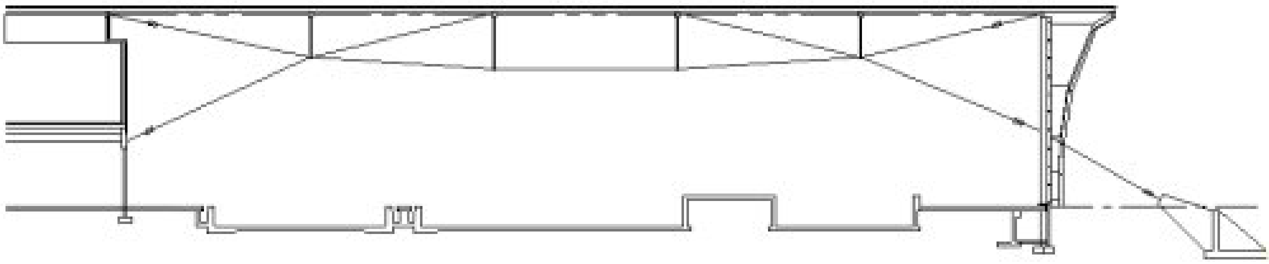

Figure 10.

The wind ribs which run at 90^{o} to main ribs consist of 140 diameter CHS struts with 45 diameter VSL MT 600 series double catenary cables which pass through the nodes of all main members then tie to a buttress at one end and the suspended slab at the other end.

The double catenary is used to control asymmetrical loading. Lateral stability is gained in a direction by all tied cables and in the other by curved braced frame. The aim is to produce a world-class aquatic centre complex that exhibits both the aspirations of the client body and satisfies the desires of the potential patronage for a delightful environment in which to spend their leisure time.

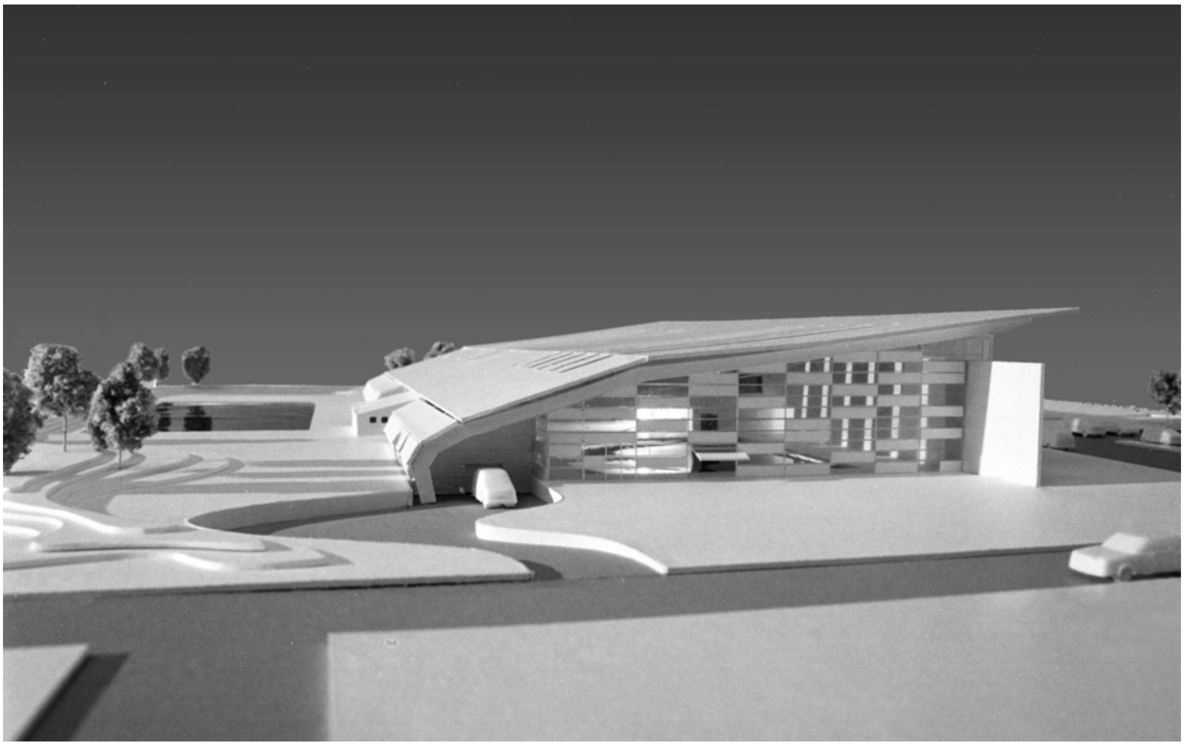

Figure 11.

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