Lightweight Structures for the Olympics 2000

Owen Martin
Connell Wagner, Consulting Engineers, Sydney

1. SUMMARY

The Sydney International Athletics Centre and the Sydney International Aquatic Centre have both been constructed to form part of Sydney's facilities for the Olympic Games in the year 2000.

Both facilities incorporate lightweight structures throughout. This paper will examine these structures with extensive use of pictures as it is the visual aesthetics of the result which defines them as lightweight structures.

The technical aspects of the structures are dealt with in references 1 and 2.

2. SYDNEY INTERNATIONAL ATHLETIC CENTRE FINISHED STRUCTURE

Cantilever structures have been the most common structural form for stadia; recent examples of which include the new Southern Stand at the Melbourne Cricket Ground and the Sydney Football Stadium.

The Sydney International Athletic Centre

1

1 & 2
A very light structure supports the rear of the roof as cantilever action is not required. Simple pin connections connect the girders to the supporting columns.

2

At the Sydney International Athletic Centre an alternative solution to this has been provided and this is a structure which spans over the roof from end to end.

One advantage of this is that the stand structure and all of its connections are not penalised by the need to resist the cantilever action of the roof. The roof beams comprise a simple spanning structure.

The cable roof structure is very light and uses a minimum of material as it utilises tension to transfer all vertical loads from both dead load and wind load. This is the inherent efficiency of this structure which minimises major flexural and compressive actions in its members.

The ability to attach the floodlights to the masts required to support the cables contributed dramatically to the economy of this scheme, as effectively two major lighting structures were able to be deleted.


3


4


5

3 Cable connections with battened roof support members prior to erection of roof panels

4 Due to the critical nature of the connection required between the forestays and the continuous catenary cable, a special connection detail was developed.

5 Light roof girders are permitted as the cable structure location minimizes large cantilever members.

6 Tensioning the friction connection which joins the catenary cables to the forestay cables.

7 Construction of the roof was simplified by erecting large panels which were suspended from the already erected cable.


6


7

3. THE SYDNEY INTERNATIONAL ATHLETIC CENTRE ROOF

Following a study of many alternative methods of roofing grandstands, a unique and innovative scheme was selected. A fully tensioned cable structure spans the entire length of the stand, some 150 metres, and supports a simple steel framed metal deck. The stressed catenary cable resists the wind uplift whilst the dead loads and live loads are resisted by the cable forestays supported on 45 metre high masts at each end. The masts themselves are cable stayed tubular structures which also act as light towers for the stadium.

8


8 Simple pin connections throughout.


9

9 "Off-the-shelf" termination and connectors were used at the ends of each cable and a sample of these were tested to confirm their rated capacity.

10 Transportation of the Mast. In order to carry a load of 3500kN at the top of the mast and to achieve a visual lightness of structure a combination of a core of 4 clustered tubes braced by pretensioned high strength rod bracing elements was concluded to be aesthetic and economic following a study of seven alternative structural mast schemes.

10

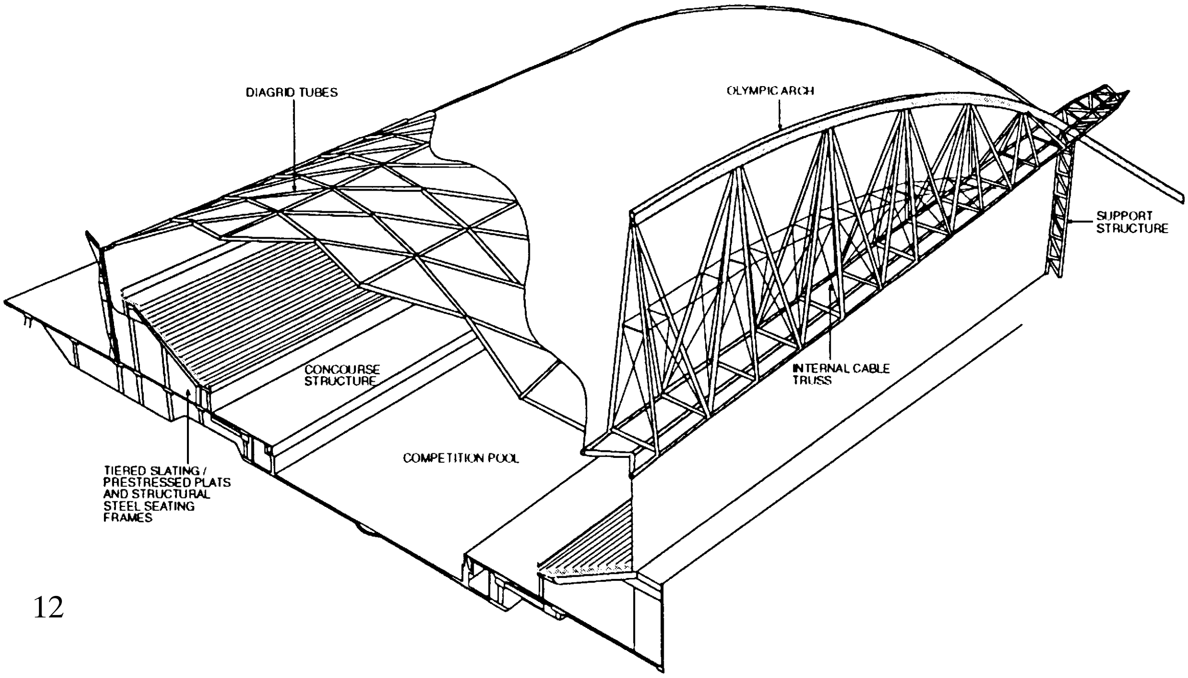

4. THE SYDNEY INTERNATIONAL AQUATIC CENTRE

Three structures in the Sydney International Aquatic Centre are classified as lightweight and these are the main pool hall roof and the supporting Olympic Arch, the leisure pool roof and the external wall structures.

11

11 The main pool hall showing the diagrid arch and it's stressed ties.

12 Aquatic Centre Cross Section



12

5. FACADE STRUCTURES

The external walls on the Aquatic Centre cover an area of approximately 4,500m^2, with the two principal walls 138m long, and 10¨12m high. The structural system developed to provide lateral support to the facade consists of a web of tensioned catenary cables, both horizontally and vertically.

The resulting system is a 2 way structure which is light and structurally efficient as all the loads are resisted by tension. The structure is placed on the outside of the walls to give clean internal lines. Furthermore, the internal environment is very corrosive, and having an external structure presents no penalty from a corrosion point of view. The system has been designed to permit future removal during Olympic mode and this has been achieved by the use of pin connections and turnbuckles throughout.

13

13 Vertical tensioned catenary rods providing lateral support to the facade.

14

14 Facade structure in place prior to erection of curtain wall.

15

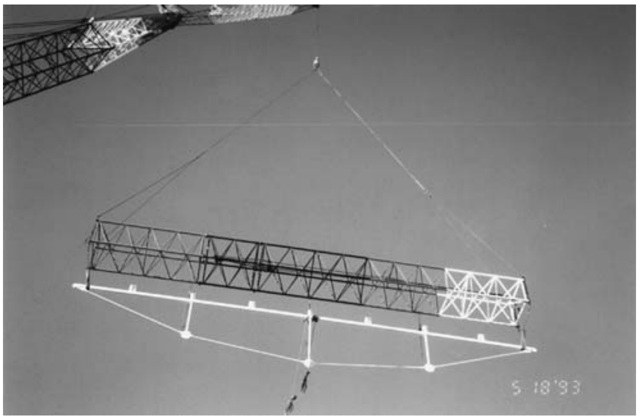
15 Horizontal and vertical catenary rods meeting at a neat cruciform connection using "off the shelf" components.

16

16 From the inside, with the facade not yet in place, the lightness of the facade support system can be fully appreciated.

6. LEISURE POOL ROOF

The leisure hall roof comprises two separate structural solutions – a curved and diagonalised structure that resists uplift and lateral loads by membrane action, sitting on top of a system of bow string girders which resist all gravity loads. The bow string girders consist of a 219CHS member with an under-slung tensioned rod of 32mm diameter, and a catenary profile 3.2m deep. With spans ranging up to 32m very light supporting structures weighing some 7kg/m^2 resulted. This compared very favorably with more conventional truss schemes which weighed 60% more.

17


17 Erection of a 30m span bow string girder using a truss strong back.


18

18 The bow string girder in position gives an overall lightweight look to the roof.

19


19 The skylights aesthetic appeal are enhanced by the lightness of the supporting structure.


20

20 Bow string girder rods connected to vertical compression members using ”off the shelf’ forkends.

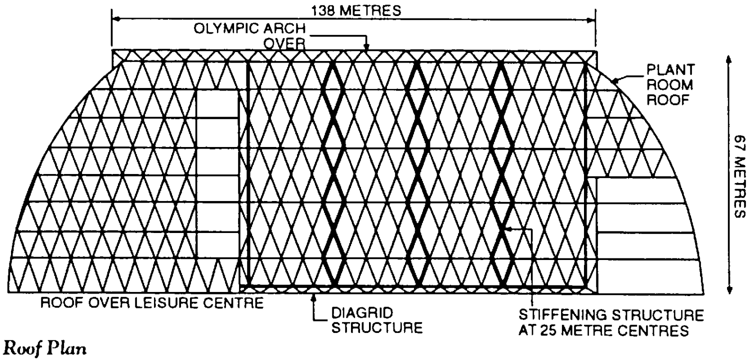
7. THE MAIN POOL HALL

The solution adopted for the roof is a tied arch with diagonal members and is termed a ”diagrid”. The diagrid is a series of parallel circular arches on the diagonal 6.3m apart. Stiffening arches 1m deep are provided at 25m centres to prevent buckling. These arches also provide the necessary flexural stiffness to resist non-symmetrical loads.

The adoption of the skewed arches lead to a very uniform and repetitive structure as all members are straight, and of identical length, and of the same size throughout and no additional bracing is needed for stability.

The arch is tied across its span, and stressed to control movement, and the result is a stiffened shell in which gravity loads are resisted by tied arch action; buckling and flexural resistance being provided by the stiffening arches. To resist uplift, the structure goes into tension, as a catenary with an external tie required to complete the catenary action.

With a rise of 9m, a very economical arch structure results.



Roof Plan

21

21 The members of the diagrid in position before placement of the roof cladding

22

22 Structural steel castings connect diagrid members.

23

23 Careful attention to complicated junction leads to a simple, aesthetic appearance

All members in the diagrid are of a constant diameter (273 CHS) with wall thicknesses ranging from 6.4mm through to 28.6mm; the latter heavy wall thickness only being used at points of maximum load. These heavy wall thickness sections were imported from the United States.

An interesting feature of the design of the roof has been the use of structural steel castings as the connection points between diagrid members. These are in the shape of a cruciform and provide a simple, repetitive and aesthetically pleasing connection.

An extremely important consideration in the design of lightweight structures is the detailing of all connections which are exposed to view. The resulting exposed structure is unobtrusive yet visually stimulating.

8. REFERENCES

1. Martin, O., Berriman, M. *The Sydney International Aquatic Centre.* Paper presented at ASEC Sept 1994

2. Martin, O., Dracopoulos, K., Grayson, W., *The Structures of the Sydney International Athletic Centre.* Paper presented at ASEC Sept 1994

24 The main pool hall roof under construction.

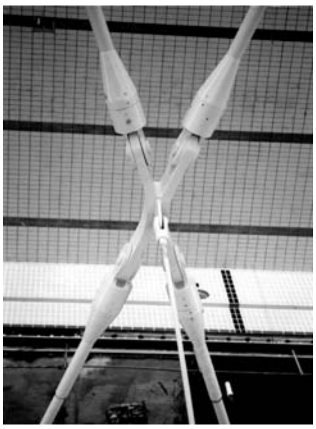
24

25

25 The design of the Aquatic Centre roof structure was required to be one which is capable of future expansion to Olympic mode in the year 2000. The Olympic mode requires a clear span structure of 138.6m to support the entire roof along one side as columns are not permitted in the viewing area. A structurally efficient arch was constructed for this using a light truss to prevent "snap through" buckling and provide the necessary flexural stiffness for non-symmetrical loads. The diagonal members of this truss are 19m long and are braced using a light cable system at approximately mid height to reduce the buckling length of individual members.

26

26 View looking up at Olympic Transfer Arch showing cable bracing of truss web members.



27

27 View looking down at the diagrid roof stressed ties which meet in a cruciform.