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Olympic Speedskating Oval, Calgary, Canada

L'anneau olympique, stade de patinage de vitesse à Calgary au Canada

Das olympische Eisschnellaufstadion in Calgary, Kanada

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SUMMARY

The design and construction of the Olympic Speedskating Oval for the 1988 Winter Olympics is described. Particular emphasis is given to the design of the long-span roof structure, a unique system of intersecting segmental precast concrete arches.

RÉSUMÉ

Il s'agit de la description du concept et de la construction de l'Anneau olympique où auront lieu les compétitions de patinage de vitesse des Jeux olympiques d'hiver de 1988. Il y a lieu de noter en particulier la conception du long toit voûté, un système unique d'arcs surbaissés entrecroisés en béton préfabriqué.

ZUSAMMENFASSUNG

Es werden Entwurf und Ausführung des Stadions, in welchem während der Olympischen Spiele 1988 die Eisschnellauf-Wettbewerbe stattfinden werden, beschrieben. Besondere Aufmerksamkeit wird der weitgespannten Dachkonstruktion gegeben. Sie besteht aus einem einzigartigen System von sich überschneidenden, vorfabrizierten Flachbögen aus Stahlbeton.

1. INTRODUCTION

In the realm of building technology, it is a rare occassion for the Architect and Engineer to be presented with the challenge and opportunity to design a building for which there is no precedent, for which there are no established rules or conceptions. The Olympic Speedskating Oval in Calgary, however, offered the Designers just such a challenge. The 400 metre covered speedskating track, with a footprint which is significantly different than other long-span recreation or sports facilities, required the Designers to follow a logical step-by-step design process in order to achieve a successful cost-effective solution and to satisfy a very tight budget.

2. BUILDING DESCRIPTION AND USE

Although constructed for the primary purpose of staging the speedskating events during the 1988 Olympics, the Olympic Oval is a multifunctional field house. The building is part of the Physical Education complex at the University of Calgary and includes in its "winter" mode (Figure 1) a 400 metre speedskating track with hockey and figure skating on two Olympic size ice hockey surfaces. The summer mode (Figure 2) includes artificial turf, tracks and facilities for football, soccer, lacrosse, field hockey, tennis, and track and field events. Electrical conduits cast into the floors allow for on the spot measurements of athletes' vital signals with direct transmission to the University's sports medicine computer terminals. The support spaces on either side of the Oval contain locker rooms, class rooms, faculty offices, judges and officials spaces, ice making equipment, Zamboni rooms, turf storage, and mechanical rooms. Total floor area is approximately 26,184 m^2 (282,000 sq. ft.).

The building is fully heated and ventilated, and lighting is provided through a combination of two lighting systems; an indirect natural lighting system around the perimeter and a direct metal halide system for the event floor.

All building finishes, systems and equipment were chosen to be of the highest quality as befits an Olympic building and to provide minimum maintenance and long-life.

3. RESEARCH AND CONCEPTION OF THE ROOF SYSTEM

The design of the roof structure was the key element in the success of the building architecturally, structurally and economically. A substantial amount of research was expended in the review of available structural systems and materials and a great deal of emphasis was placed on conceiving a structural system which would satisfy all of the design parameters of the Owner and the Architect. The Owners parameters included:

- to provide the competition area for the speedskating events at the XV Olympic Winter Games and to accommodate a variety of other sports in either a summer or winter operation mode.
- to create a low maintenance, durable, long-life building.
- to create a warm receptive environment through the introduction of natural light.

- to provide the complete facility within a maximum building budget of $30 million (Canadian funds in 1985).

Architectural parameters:
- the facility must not overwhelm the remainder of the campus. The profile must be low and, because of its huge size, the building must not be monumental.
- the roof should meet the ground and, through its shape and detail, the spanning system should be visible and expressive.
- the roof must be unadulterated with no penetrations or joints.
- to minimize cost, only those functions which require a long-span space will be included within the Oval itself. All other program requirements will be housed in short-span spaces adjacent to the Oval.

As the conceptual design progressed, the application of these qualitative design parameters evolved into a set of design criteria. First, the need to meet a very tight budget dictated that the minimum building area be constructed and that the structure fit the Oval footprint as closely as possible. This resulted in a preliminary roof plan of approximately 100 m x 200 m with rounded ends and eliminated circular dome solutions.

Next, in order to provide maximum height over the playing surface with minimum perimeter wall height, flat roofs using truss and girder type solutions were eliminated and, due to building code requirements for safety in the event of deflation, inflated fabrics were disregarded because of the height of perimeter wall required.

In order to avoid "monumental" solutions and, again, to adhere to minimum cost requirements, a structure using a large number of small, repetitive elements which were locally available and simply constructed was desired. Further, to avoid roof penetrations and joints it was desirable that the structure be thermally flexible to accommodate temperature changes.

The structure which accommodated all of these requirements was found to be a unique system of intersecting arches. Comparative designs were carried out on this arch system in both precast concrete and structural steel and the costs were comparable. But, since the forces were predominantly compressive and since concrete was the most economical material available in the local market for resisting compression loads, the logical choice for the arches was determined to be concrete.

While arches are one of the oldest structural forms and have long been recognized for their efficiency, the intersecting arch system was found to offer several additional advantages. A high level of structural redundancy occurs as a result of the alternative load paths created by the intersection of the arches and point loads are distributed throughout the structure. Further, the arch grid is stable, both during erection and permanently, without relying on lateral support from the deck. This allows the outer envelope to "float" on the arches and offers the possibility of a large number of external skins including glazing and fabrics.

4. DESIGN

The principal components of the main structure are the intersecting arches; the perimeter roof beam; the perimeter columns and buttresses; and the lateral load resisting foundation system. These components are shown on the building section and plan on Figures 3 and 4. Each of these components will be discussed in detail.

4.1 Intersecting Arch Roof

In order to minimize the initial capital cost and the long term operating costs the plan layout was adjusted to fit the Oval footprint as closely as possible. In fact, at certain locations the perimeter support columns are only 6 mm from the minimum clearance line dictated for international speedskating events. Low roof height and reduced interior volume were accomplished by recessing the event floor 4 metres below grade (deeper penetration was prevented by the presence of the natural water table at 5 metres below grade) and by using a very low rise arch cross-section.

A wind and snow loading study was carried out which dictated roof design live loads varying from .91 kN/m^2 of wind uplift to a maximum 2.5 kN/m^2 of downward snow load in several alternative configurations. The intersecting arch structure was analysed with a computer frame analysis program for a wide variety of loading conditions including erection conditions, dead loads, wind, snow, creep, shrinkage and thermal effects. Using the results of the initial computer runs, cracked section properties were predicted and were used in an iterative P-delta analysis to review the deflection behaviour of the structure.

Maximum compression in a single arch segment is 7700 kN under the worst combination of factored loads. Vertical moments in the arches vary from +860 kN m to -890 kN. m. The arch is very rigid under uniform loads with midspan deflection of less than 100 mm under full dead and live loads. With non-uniform snow loads and wind uplift occuring on opposite sides of the structure, a very likely occurrence during winter blizzards, upward deflections of 100 mm may occur at the quarter point on the windward side while a similar 100 mm downward deflection occurs at the quarter point on the leeward side.

The final arch section is shown in Figure 5. Longitudinal reinforcing ratio is approximately 1%. A closely spaced layout of longitudinal bars and stirrups was used due to the torsion which occurs in the arch segments when unbalanced snow loads occur on either side. Because of the very high positive and negative moments, additional concentric axial compression was provided by post-tensioning with a single duct in each corner of the segment. Each duct contained 7-16 mm strands to provide a total axial compression of 4110 kN. All of the longitudinal reinforcing and post-tensioning is continuous throughout the full length of each arch. The precast arch segments and the cast-in-place intersection "nodes" are poured with a high strength semilightweight concrete mix designed to produce a 28 day compressive strength of 40 MPa at a maximum air dry unit weight of 1770 kg/m^3.

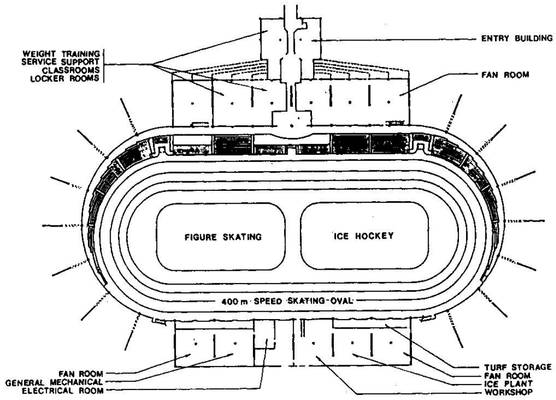


Figure 1 WINTER FOOTPRINT

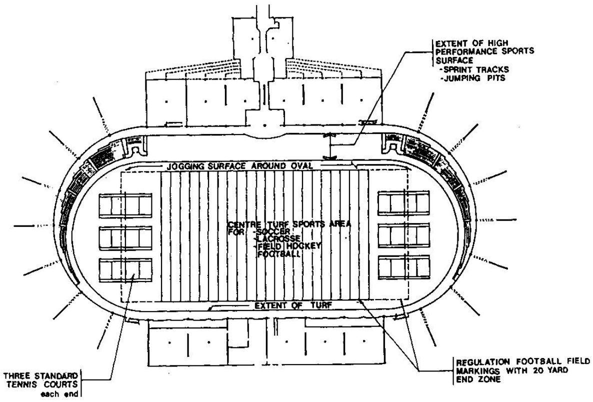


Figure 2 SUMMER FOOTPRINT

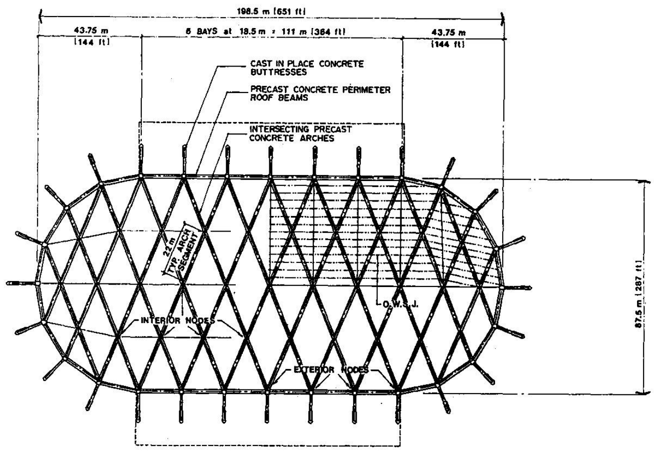


Figure 3 ROOF PLAN
SHOWING ROOF COMPONENTS

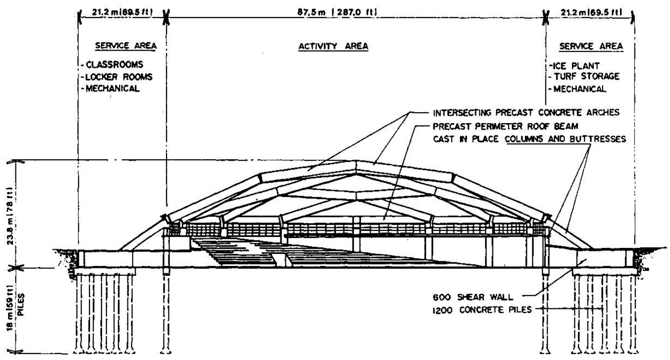


Figure 4 SECTION

4.2 Perimeter Roof Beams

The typical perimeter roof beam is shown in Figure 6.

Due to the fact that the forces in the arch segments vary with each particular loading condition and due to the change in the direction of thrust which occurs between the arches and the supporting buttresses, the perimeter roof beam acts as a tension tie to distribute the offset axial loads from the arches to the perimeter columns. In those bays in which the perimeter beam serves this purpose, a heavy hollow steel section is cast into the hollow concrete beam and attached to the buttress head over the columns with high strength threaded bars. The intersecting arch roof structure is thermally flexible with volume changes due to creep, shrinkage and temperature being accommodated primarily by the rise and fall of the arches themselves. The substructure, however, being over 200 metres long is broken by a series of control joints at every second or third column line. The layout of the building control joints and perimeter roof beam ties is shown in Figure 7.

4.3 Buttresses and Columns

Supporting the arches around the perimeter and spaced at 18.5 m on centre are 1500 mm circular concrete columns and 1000 wide x 1800 deep buttresses. At each buttress "head" a circular multidirectional disc bearing transfers the arch thrust to the buttress. These bearings are designed for a maximum unfactored compression of 8453 kN and a maximum lateral shear of 1495 kN with a rotation of up to 2-1/2%.

4.4 Foundations

The vertical and horizontal components of the arch reactions are transferred by the column and buttresses to a lateral load resisting substructure of large diameter concrete piles. These piles are designed to transfer the horizontal arch thrusts directly into the silty soil through lateral bending in the piles and were determined to be substantially more economical than horizontal ties under the floor of the Oval.

The magnitude of the lateral loads (up to 8000 kN unfactored) at each buttress was far beyond any previously recorded literature on laterally loaded piles and prompted the designers to resort to an extensive load test program in order to define the design parameters for the piles.

In order to minimize the number of piles and also to prevent differential lateral movements from occurring, all of the substructure piles are tied together by the concrete floor slabs of the service areas and are designed to share the lateral roof loads. Lateral load capacities of 1000 kN, 750 kN and 500 kN were assigned to the 1200 mm, 900 mm and 600 mm piles respectively. Further, because the substructure is buried 4 metres below grade, lateral soil pressures against the foundation walls are used to balance the horizontal thrusts due to live loads on the roof.

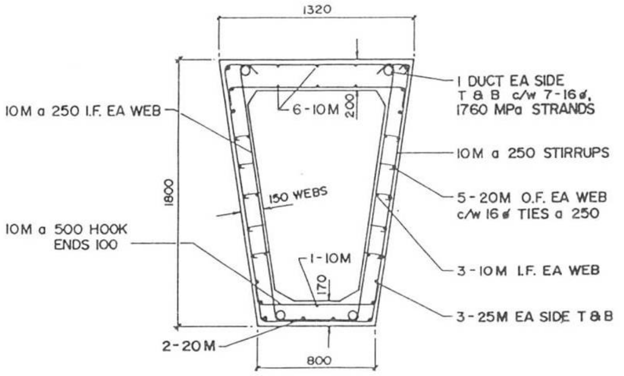


Figure 5 TYPICAL ARCH SEGMENT

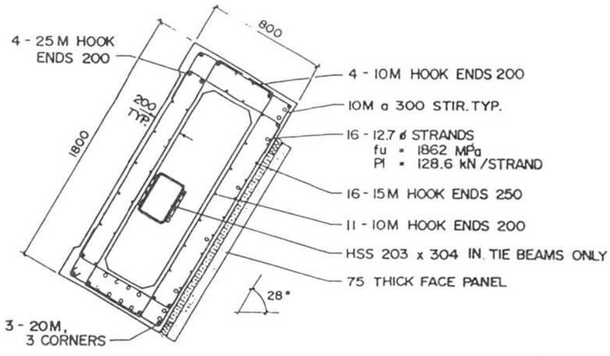


Figure 6 TYPICAL PRECAST CONCRETE PERIMETER BEAM

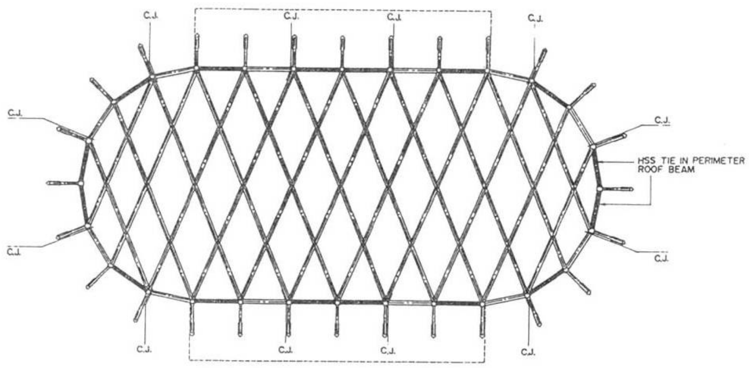
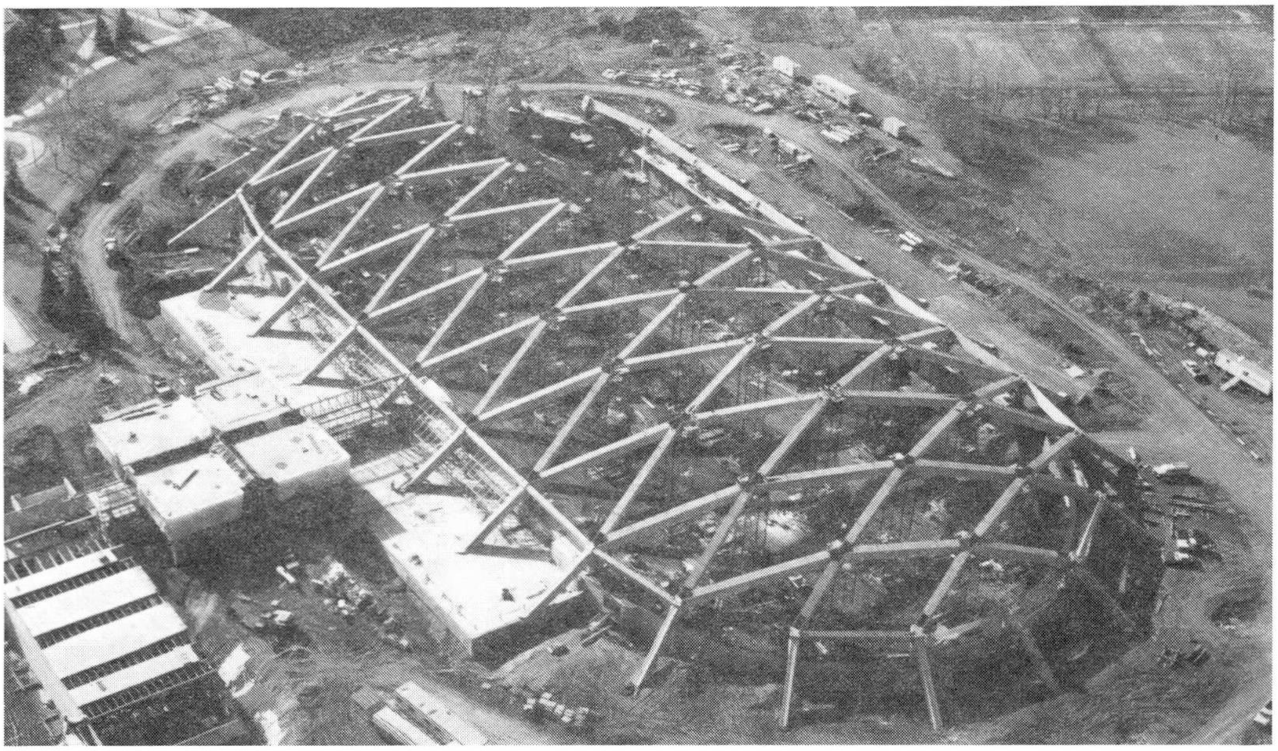


Figure 7 ROOF PLAN

SHOWING TIE BEAMS AND CONTROL JOINTS



5. CONSTRUCTION

Construction commenced in March 1985 and the roof structure was effectively completed by June 1986. Finishing trades and interior work continued until April 1987. Erection of the segmental intersecting arch roof is of particular interest.

The arch segments, each weighing approximately 50 tonnes, were plant cast in a single steel form, trucked to the site, and erected on a temporary scaffolding system consisting of a single steel tower supported by temporary timber piles under each interior node location and a cantilevered steel truss under each exterior node.

Once the arch segments were erected onto the tower, the reinforcing and post-tensioning ducts at each node were coupled together, the sides and soffit of the node formed, and the node cast using the same lightweight concrete mix as the arch segments. Good bond between the precast arch segment and the node concrete was ensured by heavily sandblasting the ends of the precast segments prior to erection. After placing concrete in all of the interior nodes in a single arch, the arch was ready for post-tensioning and, as post-tensioning progressed along the building, the exterior nodes, connecting the arches to the bearings cast into the buttress heads, followed.

Once the concrete in the nodes had reached 75% of its design strength, the General Contractor removed the shoring; first around the perimeter, then under the interior nodes. Because of the inherent stability of the structure it was not necessary to remove all of the shoring simultaneously. Lowering commenced at one end and was carried out in increments of 10 mm with the only requirement being that no tower could be more than 10 mm lower than an adjacent tower. The deflections predicted by the computer analysis during lowering were approximately 30 to 40 mm resulting in approximately 4 increments of jacking being required in order to completely unload a single tower.

6. CONCLUSION

The total construction cost of the Olympic Oval including one of the largest refrigerated ice plants in the world; artificial running tracks and sprint tracks; broadcast level lighting systems; fixed and moveable bleacher seating; acoustical systems and surface treatments; and a "permanent" porcelain enamel steel panelled roof envelope is only $27.2 million Canadian ($19 million U.S.). Through the design stage, low cost and maximum operating life were the two most important criteria used in every decision. The low construction cost achieved through the use of the concrete arch structure allowed the highest quality and minimum maintenance factor to be achieved in other building components, a benefit which will accrue to the Owner through lower operating costs in the future. Yet the final building is anything but low-cost in appearance. The intersecting arch roof structure, exposed on the inside of the building and visibly expressed by the faceted roof on the outside, results in a unique, aesthetically pleasing addition to the campus of the University of Calgary.