RICHMOND OLYMPIC OVAL

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"The final result was a ceiling structure of stunning beauty and great practicality."

The Richmond Olympic Oval in Vancouver, Canada is the largest structure built for the 2010 Olympic Winter Games. Dramatically located beside the Fraser River, with expansive views north to the Coast Mountains, this monumental building stretches to a length of five football fields laid side by side. It will host the long track speed skating events along with the 8000 expected fans. This distinctive structure, shown in Fig. 1, will be the architectural symbol of these games.

The City of Richmond wanted an iconic building that could accommodate multiple uses and also attract public attention and development to the area. They selected a wooden structure designed to highlight the local wood industry and give the main hall a warm ambiance. From the outset, the building was intended for adaptive reuse after the Olympic Games. The Oval will be converted into a multi-use sports facility for the citizens of Vancouver, with two ice rinks, racquet courts, a 200 meter track, rubberized turf area and even a high performance workout area.

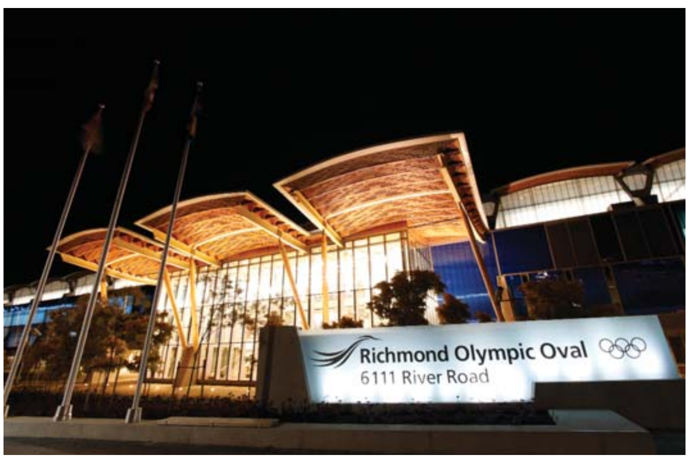

Fig. 1. Exterior view of the main entrance to the Richmond Olympic Oval at night (Photo by Kam Lau http://kamlau.com).

The design team consisted of Fast & Epp Structural Engineers, Cannon Design Architects, design-builder StructureCraft Builders, and Marshall Long Acoustics Acoustical Engineers. George Third & Son, Ltd. Steel Contractor and twenty-four other firms also contributed to the construction.

The visually spectacular six-acre free span roof had to provide not only the structural capacity, but also had to meet stringent acoustical requirements. The structural system had never before been built, so extensive modeling and testing was required. Shown under construction in Fig. 2, it is shaped like a turtle's back with upturned sides.

The roof is supported by massive curved wood and steel composite beams spanning 330 feet from end to end across the structure. Between the beams are striking vee-shaped WoodWave© panels constructed from Pine Beetle-killed trees that were sawn into 2x4s and bolted together in undulating sections to create a rippled effect. These shapes create an impressive visual appearance, giving the ceiling its signature look. The Main Hall is shown in Fig. 3.

Virtually all rooms of this size are hampered by long reverberation times and poor speech intelligibility. This is particularly troubling for public gatherings and sporting events where communication is essential. With a conventional hard roof the reverberation time (the time it takes for a sound to die out in a room) would have been many seconds, making speech nearly impossible to understand. The solution to excess reverberation is to install large amounts of

Fig. 2. Curved rooftop under construction with view of the Fraser River and Coast Mountains (Photo by Ziggy Welsch, George Third & Son Ltd., ziggy@gthird.com Courtesy Wood *WORKS!* BC*).*

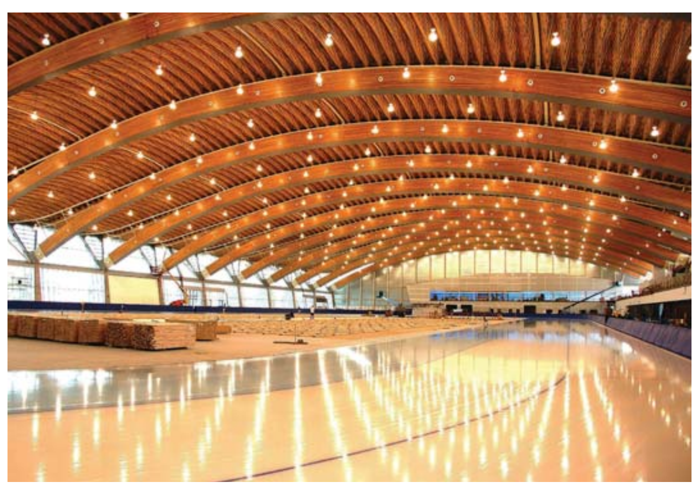

Fig. 3. Main Hall with massive curved beams and WoodWave© panels (Courtesy Fast & Epp Structural Engineers and Wood *WORKS!* BC*).*

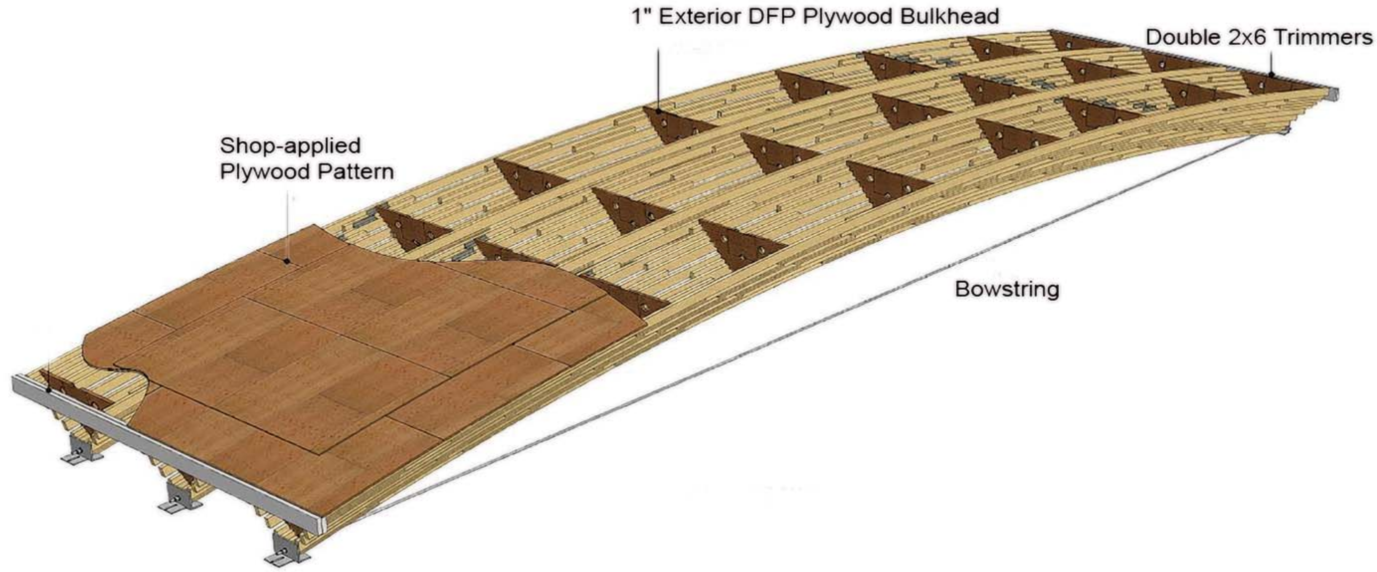

Fig. 4. Rendered WoodWave© panel with bulkheads, stressed skin, and bowstring (Courtesy StructureCraft Builders).

absorptive materials. The largest space available for locating this material is in the ceiling. Local engineers hired by the City of Richmond set the required absorption coefficient (the fraction of the incident sound energy absorbed by a surface) to 1.0.

The absorption is characterized by its Noise Reduction Coefficient (NRC) rating. The NRC is the arithmetic average of the sound absorption coefficients measured at the 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz third octave bands rounded to the nearest 0.05, measured in accordance with the ASTM C 423 testing standard. The test is performed by laying the material of interest on the floor of the test chamber with its absorbing surface facing upward, exposed to the sound field. The chamber is a rectangular room with hard concrete surfaces that is ensonified with band limited pink noise. The sound source is interrupted and the rate of decay of the sound in the chamber is measured with and without the presence of the sample under test. Using the rate of decay under the two conditions, an absorption coefficient can be obtained for the material.

When we were first involved with the project, the engineers at StructureCraft wanted to use a vee-shaped wood structure that could be built out of 2x4s. The normal approach to a covered acoustical absorber is to leave the surface with at least a 20% open area. When the openings are round holes, they must have a diameter greater than the thickness of the panel to minimize tube resonances. The holes have to be arranged so that there are several within the dimension of a wavelength otherwise the absorption will revert to the value of the open percentage multiplied by the effective area of the panel. Thus at high frequencies the absorption can be expected to drop as the wavelength decreases.

The WoodWave© panels provided an opportunity to achieve a lightweight structure with the necessary structural strength, acoustical absorption, and desired visual appearance. Their acoustical requirements dictated openings in the surface of the vees with a thick absorptive material behind. Early in the design I suggested a 20% open area with a 2 inch thick black fiberglass liner, held in place with wood battens. Their first design was about 27% open, which was later reduced to about 24%. Because the slots were primarily on the bottom of the vees, not on the face of the panel, I was concerned that it might reduce the amount of the exposed area. Because most of the sound would be coming from under-

Fig. 5. Interior of vee-shaped WoodWave© structure during construction (Courtesy StructureCraft Builders).

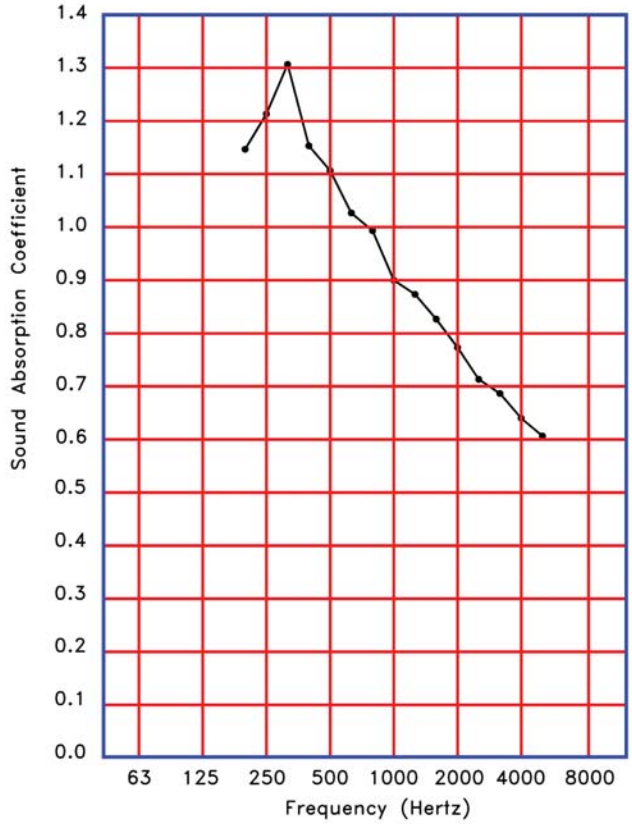

Fig. 6. Final result of absorption test.

neath the panels, I thought the opening location would probably work.

The WoodWave© panel design is shown in Fig. 4. StructureCraft lined the inside of the vees with a black cloth and 2.5 inch thick mineral wool that helped meet the fire code requirements. The 2x4s surfaces are positioned and held in place by means of plywood bulkheads. These also support the sprinkler pipes and give the panels their shape. The panels are formed in a curve, much like an archer's bow. A steel cable bowstring added additional structural strength.

The panels were constructed in StructureCraft's shop. The process is shown in Fig. 5 with the black cloth in place. The interior plywood bulkheads are notched to secure the 2x4s in their proper locations. Conduit for the lighting is also placed in the hollow panels.

Because of the added area provided by the saw tooth surface, I predicted an NRC of about 1.2 and suggested that they mock up a sample and have it tested. In early 2006 a sample was built and sent to the Western Electro-Acoustic Laboratories (WEAL) in Los Angeles. The first test yielded an NRC of about 0.85, much less than I had calculated. At the time I was quite puzzled by the result. The reason, as it turned out, was that the absorptive material had not been properly secured and was jostled during the transport from Vancouver. It had fallen to the bottom (roof side) of the test sample. Since there was a black cloth between the wood and the mineral wool, this displacement could not be seen from the outside.

Fig. 7. Main Hall and rink with skaters (Photo by Stephanie Tracey www.photographywest.ca Courtesy Wood *WORKS!* BC*).*

StructureCraft sent an engineer down to Los Angeles, who took the sample apart, discovered the problem, and rearranged the mineral wool. At the suggestion of Rick Talaske, another acoustical engineer on the project, StructureCraft also added additional 1 inch thick mineral fiber material on the inside faces of the plywood bulkheads. The sample was retested and the result, shown in Fig. 6, met the design criteria.

It is interesting that at the low frequencies the tests yielded the absorption coefficient value of 1.2 that I had predicted. At the higher frequencies the shorter wavelengths caused the sound to interact with the solid portion of the vee rather than spanning open portions of the slotted surface, thereby reducing the absorption. The absorption values greater than 1.0 are due to the additional area from the angled surface compared to the flat ceiling area used in the ASTM test standard.

The final result, shown in Fig. 7, was a ceiling structure of stunning beauty and great practicality. The acoustical absorption was what the City of Richmond had requested. As Rick Talaske pointed out in the final report, not only was the absorption on target, the lack of high frequency absorption from the ceiling was offset by the high frequency absorption provided by the air contained in the large room volume. The saw tooth shape of the vees also provided helpful diffusion to reduce focusing and echoes.

The building, with its ingenious roof structure, has attracted worldwide attention and received several prestigious awards. These include an Award of Excellence for Innovation in Architecture, in the Science category, from the Royal Architectural Institute of Canada, and the 2009 Award for Sports or Leisure Structures, from the Institution of Structural Engineers, UK.**AT**

Marshall Long received a BSE degree from Princeton University in 1965, attended the University of Grenoble in France and the University of Madrid in Spain in 1966. He received M.S. and Ph.D. degrees in engineering from UCLA in 1971. While still a graduate student, he founded his own acoustical consulting firm, now in its 38th year. Marshall Long Acoustics specializes in architectural acoustics, audio visual design, noise and vibration control, and other technical areas related to acoustics. He enjoys sailing, judo, soccer, reading, and writing, and is living with his family in Sherman Oaks, California. He is a Fellow of the Acoustical Society of America.