Hitting the SLOPES

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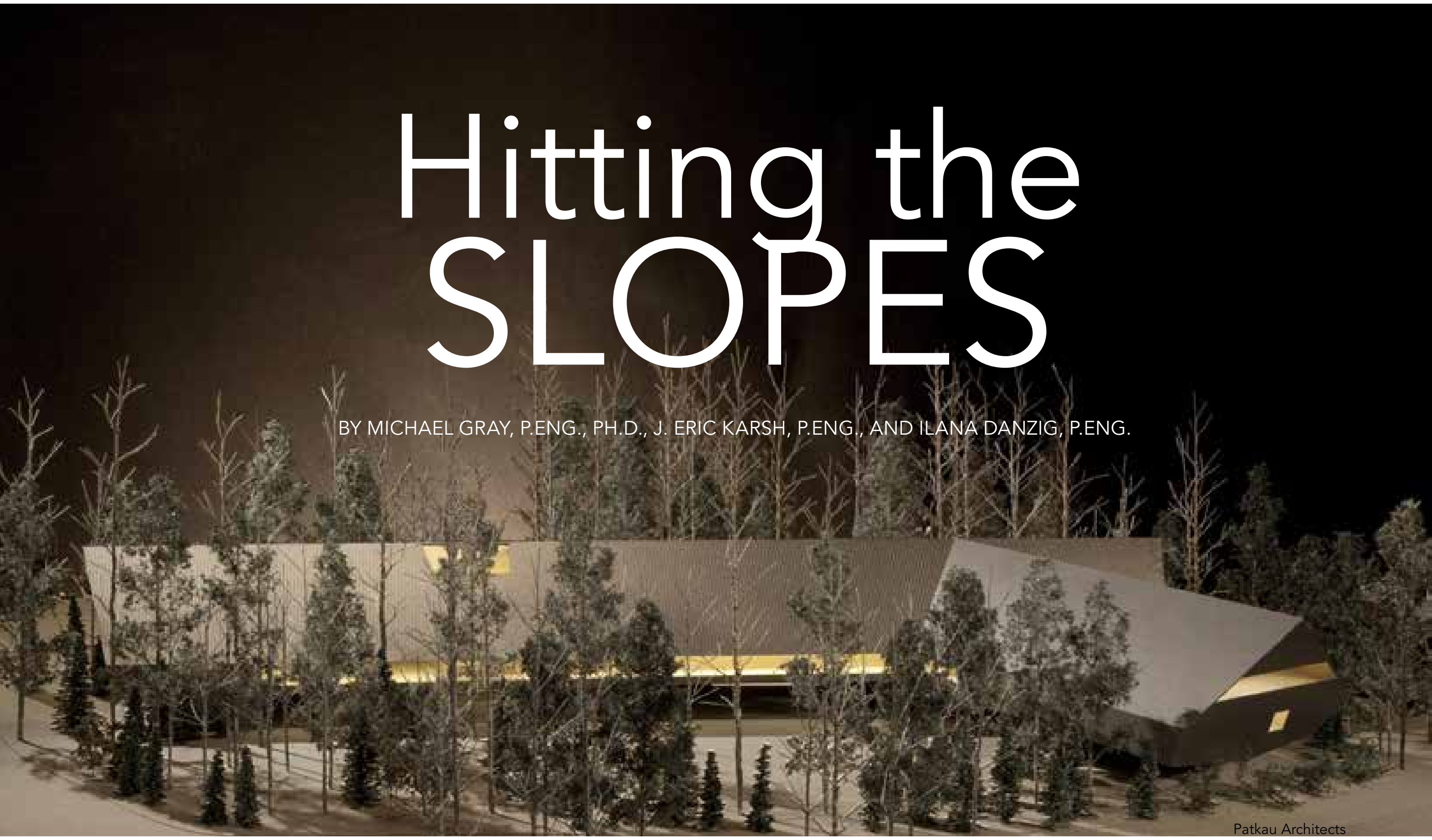


Patkau Architects

Seismic considerations led to the selection of an innovative bracing solution for an art museum at one of the world's best-known ski areas.

WHISTLER BLACKCOMB has long been known for world-class skiing and spectacular scenery.

And now it's fortifying its position as a destination for art lovers, as a new 56,000-sq.-ft art museum is currently under construction in a grove of spruce trees just on the edge of the famed skiing mecca's Whistler Village. The project will house the personal art collection of homebuilder Michael Audain—one of Canada's most preeminent art philanthropists—a visual record of the heritage of British Columbia that includes a collection of First Nations Masks and works by Emily Carr, Jack Shadbolt, E. J. Hughes Gordon Smith and others.

As a reflection of both the outer environment and the art contained within, the building invokes the image of a traditional longhouse of the First Nations people of the Pacific Coast. It is "hockey stick " shaped in plan, with a 390-ft "shaft" and 105-ft "blade." The steel frame, using nearly 1,000 tons of structural steel, was developed in close cooperation with the architectural team using advanced 3D CAD modelling in Revit and Rhino to ensure that it is fully integrated within the elegantly sculpted architectural envelope.

A Floating Hockey Stick

The building's primary space is on the second story, which appears to float in the air, only touching the ground at seven locations. The cross section is essentially a pentagon, extruded along the hockey stick and suspended over several piers. The simple and elegant appearance hides the complexity of truss work designed to keep gallery spaces clear and open and to have minimal impact on the floodplain below (the building is located near Fitzsimmons Creek).

The structure is framed with three longitudinal trusses extending along the length of the building. These trusses, from 16 ft high to 40 ft high, are trussesessentially the building's "spine," supported at 65 ft by transverse trusses providing the pentagonal shape of the building. Each transverse truss is supported by only three columns, with the outer edges of the truss cantilevering past the columns by up to 30 ft. This intricate steel network supports two floors of gallery, storage and administration space designed to meet stringent vibration and serviceability standards suitable for a Class A art gallery.

To resist seismic loads, the building's longitudinal direction is supported by a moderately ductile concrete core while the transverse direction's seismic force resisting system is provided by the transverse steel trusses, which include steel braces between the columns that extend to the foundation. These braces, concealed within the building's piers, were initially designed to be buckling restrained braces (BRBs) with a high ductility (R) factor. By yielding at the design load, the braces would dissipate energy and limit the demand on the rest of the truss and, by extension, the rest of the building. In a high-seismic event, all steel truss members beyond the BRBs are designed to remain elastic.

Opposite page: The new 6,000-sq.-ft art museum is currently under construction in a grove of spruce trees at Whistler Village.

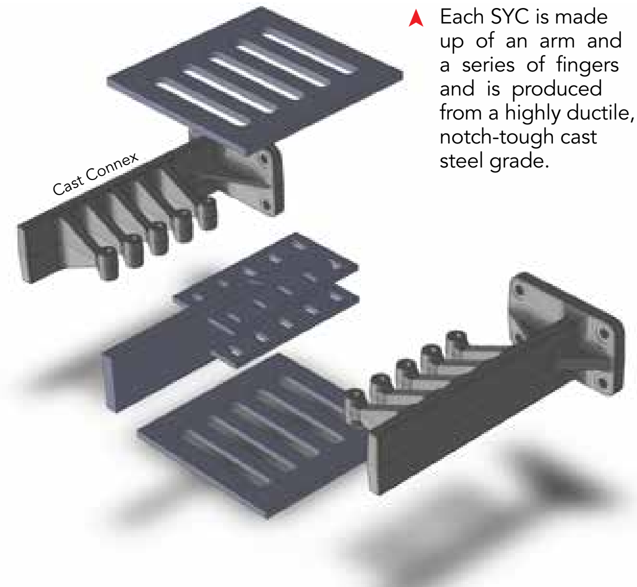
The cross section is essentially a pentagon, extruded along the building and suspended over several piers.

One of the 12 braces incorporating Scorpion Yielding Connectors from Cast Connex.

The structure is framed with three longitudinal trusses extending along the length of the building.

Michael Gray is cofounder and executive vice president of Cast Connex, **J. Eric Karsh** is a principal with Equilibrium Consulting, Inc., and **Ilana Danzig** is an associate with Equilibrium Consulting.

The Audain Museum is the first building to implement Scorpion Yielding Connector (SYCs).



Each SYC is made up of an arm and a series of fingers and is produced from a highly ductile, notch-tough cast steel grade.

The various components of the SYC. The moniker comes from the original prototype's resemblance to a scorpion, with the connectors forming the "claws."

Scorpions on the Slopes

In place of the BRBs, however, the steel fabricator George Third and Son suggested using Scorpion Yielding Connectors (SYCs) by Cast Connex, which offered several practical and performance advantages. The museum became a project-specific test for the system, demonstrating that these University of Toronto-developed connectors could provide sufficient strength and ductility to achieve the performance required by the building's design. It is the first project to implement them, incorporating 12 braces with SYCs in all, each with a nominal yield strength of 120 kips.

A brace in an SYC frame consists of two cast steel connectors connected to the end of a W-shape or other structural member. Each connector is made up of an "arm" and a series of "fingers" and is produced from a highly ductile, notch-tough cast steel grade. In a brace assembly, the fingers of both connectors are bolted to a splice plate that is connected to the beam-column intersection through a traditional gusset plate connection. The other end of the brace is connected to the beam-column intersection with a conventional gusset-to-W-shape connection that can either be field welded or bolted. Energy dissipation in the brace is provided through the flexural yielding of the connector's fingers. (The Scorpion moniker comes from the original prototype brace assembly's resemblance to a scorpion, with the connectors forming the creature's claws.)

The connectors are specially designed hysteretic devices that, when installed between the end of a brace member and a typical beam-column corner gusset plate, can create a non-buckling, axially yielding brace assembly with a fully symmetric hysteretic response. During an earthquake, they dissipate seismic energy through flexural yielding of specially designed cast steel fingers while the brace member remains predominantly elastic. In addition, the connectors include cover plates spanning between the arms of the castings on each side of the device. The cover plates equilibrate the bending moments that are developed in the yielding fingers on each side of the connector, which enables a bolted SYC-to-brace connection that need only be designed for the axial force in the connector—and also makes the connectors more compact.

The building's framing configuration resulted in very short braces relative to the rest of the building. BRBs, which rely on axial yielding of brace elements, suffer reduced deformation capacity as brace length decreases. This is not the case with the SYC, as the inelastic deformation capacity of the connector (and subsequent brace assembly) is entirely dictated by the design of its yielding fingers. As such, using SYCs in the short braces enabled those members to provide a highly ductile response to earthquake loading. In addition, one particular frame was originally designed with a chevron bracing configuration at a very steep angle, which would have reduced the overall effectiveness of the brace members. Since all of the brace assembly's ductility is contained within the SYC, the brace members themselves are not considered a protected zone (they are merely capacity-designed elements), and as such, an "X" brace configuration was developed in which one brace was segmented and spliced *around* the other, allowing the two brace assemblies to behave independently within a specific deformation range. This reduced the brace angle, increasing the ductile brace assembly's effectiveness in carrying lateral force through that frame.

Building on a Mountain

The fact that the building is located in a heavily forested flood plain, combined with shipping limitations of British Columbia's steep, winding Sea to Sky Highway, meant that the trusses were shipped to site in pieces, and 90% of the structure was assembled on-site. As all of the full moment connections were field bolted, the project required more than 25,000 bolts.

The erection sequence was a significant challenge, especially due to the long-span longitudinal trusses supported by transverse trusses with large cantilevers. If an element was slightly out of true, that effect was compounded over the whole structure, which would potentially result in large deflections. Careful and thoughtful erection sequencing during construction, along with adequate shoring, was key for keeping the building within acceptable tolerances. To mitigate some of these issues, structural engineer Equilibrium Consulting performed a very careful analysis of the cambers required of the steel beams and also allowed for some tolerance in the concrete topping, ensuring that the project ended up with a level floor at the end of the day.

Another challenge was the size and irregularity of this project. Every single truss was different and there was little repetition. 3D modelling was crucial not only during design but also during construction coordination. Detailed coordination between the structural Revit model and the architectural Rhino model meant that many conflicts were found and addressed early in the design process. Those design models continued to be key during coordination with George Third and Son and the Tekla 3D model that they developed for shop drawings and fabrication. Using these models, all parties were able to flag concerns and track progress, which meant that by the time the steel was erected, most of the wrinkles had already been ironed out.

When it opens early next year, the Audain Art Museum will stand as an outwardly simple and elegant building that maintains harmony with its natural surroundings by seemingly floating over the ground, minimizing the disturbance of the local environment through its minimal supports. It will display an impressive collection of culturally significant British Columbian art while at the same time concealing an innovative and seismically significant structural system. ■

Owner
Michael Audain

General Contractor
Axiom Builders

Architect
Patkau Architects

Structural Engineer
Equilibrium Consulting

Erection Engineer
Somerset Engineering Group

Steel Team

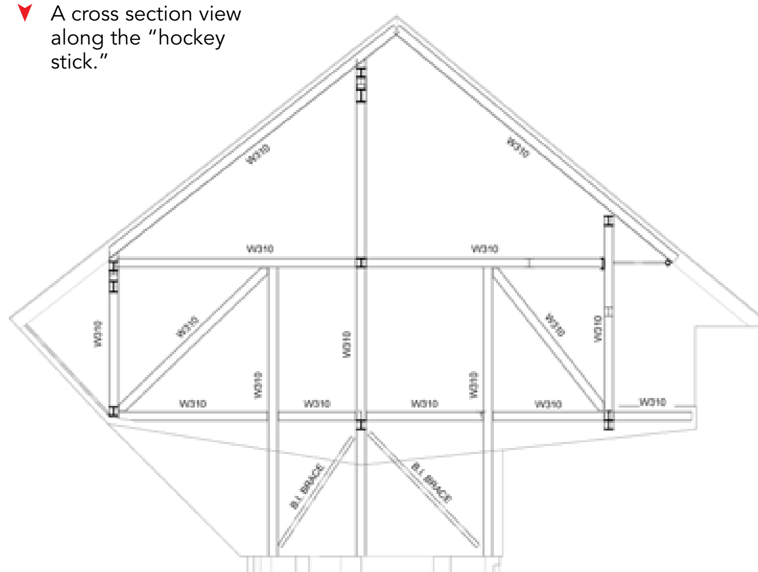
Fabricator
George Third and Son

Erector
KWH Constructors

Detailer
Somerset Engineering Group

Castings Manufacturer
Cast Connex Corporation AISC ASSOCIATE

▼ A cross section view along the "hockey stick."



Equilibrium Consulting

▼ The museum is shaped like a hockey stick in plan, with a 390-ft "shaft" and 105-ft "blade."

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