APA CASE STUDY

The Ultimate Engineering Challenge

The Cathedral of Christ the Light in Oakland, California replaced the Cathedral of St. Francis de Sales, rendered unusable following the 1989 Loma Prieta earthquake. Project leaders wanted the new structure to have a design life of 300 years.

"To an engineer, locating a 110-foot-high cathedral made of delicate materials so close to an active fault line and expecting it to survive an earthquake like the 1906 temblor – that is the ultimate challenge," said Mark Sarkisian, S.E., Director of Structural Engineering at Skidmore, Owings & Merrill, San Francisco. Yet, this is precisely what the new cathedral achieves. The 21,660-square-foot, 1500 seat, $80 million cathedral is an exemplary structure that utilizes traditional building materials in modern ways.

The outcome is a space-frame structure with a glued-laminated timber beam (glulam) and steel-rod skeleton veiled with a glass skin. Using light as a central theme, the glass skin is composed of recently developed materials including dichroic glass and ceramic fritted glass, which emanate prismatic effects and add patterns of tone and line for additional color and texture. A series of glulam louvers enhance the dynamic lighting by filtering the effects of the glass as the sun moves through the sky.

The floor plan of the building is in the shape of a Vesica Pisces that creates a spherical elevation. The Vesica Pisces is a shape of religious significance, two intersecting circles of the same radius, connected in such a way that the center of each circle lies on the circumference of the other. Historically, this shape is an ancient sign among many Eastern and the Western cultures for a gathering place and a symbol among Catholics for the miracle of the loaves and fishes.

Project Summary

PROJECT:
Cathedral of Christ the Light

LOCATION:
Oakland, California

OWNER:
Roman Catholic Diocese of Oakland

DESIGN ARCHITECT:
Skidmore, Owings & Merrill
San Francisco

EXECUTIVE ARCHITECT:
Kendall/Heaton Associates, Houston

STRUCTURAL ENGINEER:
Skidmore, Owings & Merrill
San Francisco

GENERAL CONTRACTOR:
Webcor Builders

LANDSCAPE ARCHITECT:
Peter Walker and Partners

COST:
$80 million

SIZE:
224,000 square feet

COMPLETION DATE:
September 2008

The floor plan of the building is in the shape of a Vesica Pisces creating a unique spherical elevation. The Vesica Pisces is a shape of religious significance, two intersecting circles of the same radius, connected in such a way that the center of each circle lies on the circumference of the other. © John Blaustein 2008.

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Structural System

The Cathedral's strength is achieved through the creation of glulam and steel rod space frames. The Vesica Pisces is constructed with 26 glulam ribs measuring 10-3/4 inches wide by 99 feet, 9 inches long that vary in depth from 30 inches at the base to 19-1/2 inches at the top. Between each rib are 32 glulam louvers measuring 5-1/8 inches wide and varying in depth from 22-1/2 to 39 inches. The louvers are installed at seven different angles to optimize the light effects. The roof of the cathedral is composed of a tension-free glass oculus supported by a steel compression ring that resists the horizontal thrust of the glulam ribs. Parallel to each rib is a glulam mullion 10-3/4 inches wide by 15 inches deep and 103 feet long. The mullions are installed 80 degrees from horizontal and are connected to the wooden vaults of the Vesica Pisces by turned glulam struts with tapered ends of lengths varying from 2 to 15 feet.

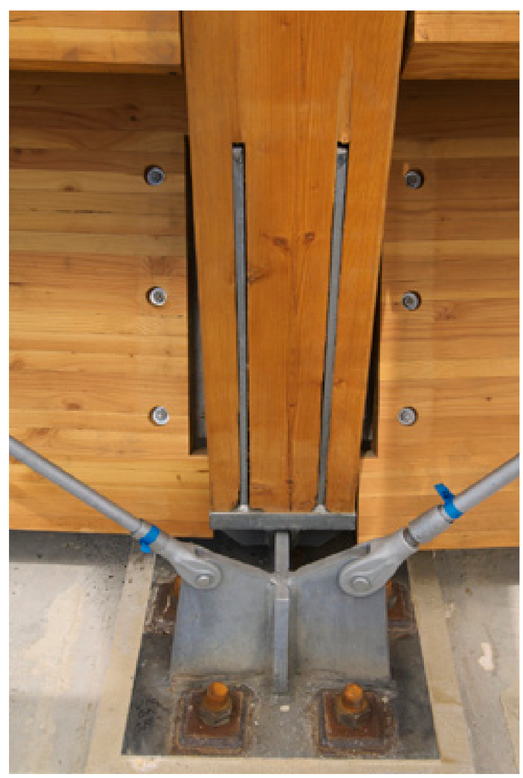
The space frame's diagonal members are made with pre-tensioned, high-strength steel rods installed such that in an earthquake they will always be in tension. The building is subdivided into five levels where fixed connections tie the louvers to the ribs completing the structural frame. To minimize the seismic load on the cathedral, 34 seismic base isolators were installed beneath the 12-foot concrete reliquary wall in a matrix to evenly distribute the load. The specified isolators, double-concave, friction-pendulum base isolators, have a 4-foot-diameter steel bearing and employ a sliding system with an interfacial material that slides across stainless steel. This isolation reduced the seismic motion by a factor of 5.

Given the cathedral's proximity to fault zones (4.7 km from Hayward and 25 km from San Andreas) and its nonconformance to a standard California Building Code lateral system, the City of Oakland hired a peer review committee, composed of three university professors and one industry expert, to establish the required toughness and ductility requirements.

Load Testing

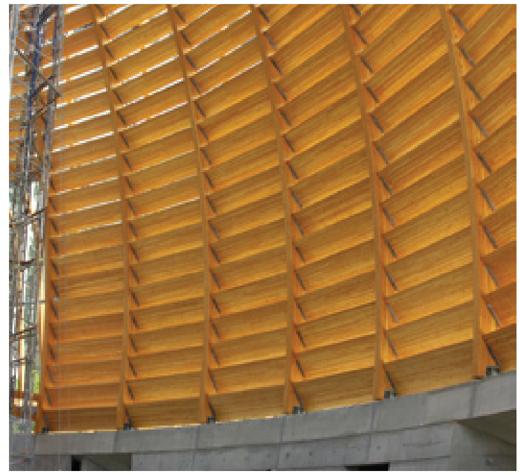
First, the committee determined that the glulam timbers must remain elastic under cyclic load conditions. Second, all of the ductility of the system was required to come from the pre-tensioned steel rods. This required ductility testing of the tension members to demonstrate that they could achieve 2.1 percent elongation over the entire length of the rod, not just at the threaded ends. The rod manufacturer, Halfen Anchoring Systems, tested all five rod diameters. The initial testing pointed out that the two largest rod diameters did not meet this requirement as the elongation was limited to the threaded portion of the rod. Halfen therefore re-tooled their machinery to upsize the threads on these rods and achieved the required elongation. The resulting stress strain curves of the testing were input into the SAP2000 computer model to define nonlinear behavior of the structure. Third, the rods were required to be pretensioned to between 3 and 10 percent of their yield stress so that they were never loose and would be in tension immediately when loaded with seismic forces. The glulam supplier/erector, Western Wood Structures Inc. (WWSI), Tualatin, OR, developed an ingenious tightening sequence to eliminate force interference between rods. Without this sequence, tightening one rod would affect the forces already applied to all the other rods, tightening some and loosening others. WWSI also developed

Given the asymmetry of structure and the curvature of the interior and exterior walls, very few connections were the same. As a result, AutoCAD 3D was utilized to model 220 unique connections. © John Blaustein 2008.



Double kerf plates and hidden 1" steel pins were used to connect the ribs and mullions. These intricate connections were shop fabricated for ease of construction. © John Blaustein 2008.

The oculus "skylight" weighs 24 tons. It had to be positioned exactly on target and then braced to prevent movement during installation of the glulam structure. Photo courtesy Webcor Builders.



As the louvers were installed the ribs became more and more stable because of the spherical shape of the structure and the radial orientation of the ribs. Photo courtesy Webcor Builders.

the required tightening torques, which were calibrated to the desired pretension and ambient rod temperatures. Fourth, the criteria specified a nonlinear push-over analysis. This analysis required a progressive failure model, which recalculated the stiffness based on the surviving structural elements to determine structure viability along the way. The final requirement was a Time History Seismic Analysis essentially scaling the Loma Prieta earthquake to a 1,000-year event.

Specification of Glulam Beams

Given the architectural significance of the glulam timbers, their appearance is crucial to the aesthetics of the structure. SOM and WWSI collaborated to develop a customized appearance specification that provided a more appropriate finish than the standard premium appearance grade. WWSI worked with the glulam manufacturers to hand select the lumber used in the laminations to minimize knots and voids on the faces of the members. The few remaining voids were left unfilled. The louvers were originally intended to be covered with an acoustical material. In the end, it was decided to leave them exposed to view, saving the project nearly a million dollars.

Conclusion

In the process of designing the cathedral, engineers at SOM were able to achieve appropriate structural strength and toughness for this building using a structural system not recognized by the building codes. This was accomplished by carefully defining the ductility requirements of the structure, modeling its nonlinear behavior, testing the components that were relied on for ductility and field verifying the installation of these components.

The design team at SOM worked closely with the glulam supplier to achieve appropriate finishes of the various glulam members. The use of a full-scale mock-up was instrumental in allowing the architects and engineers to see how the structure would appear when completed. This allowed changes to be made that had little or no economic impact, but greatly improved the structure's appearance and performance.

The design and erection of the Cathedral of Christ the Light demonstrated that modern glulam construction could be used to build a significant building intended to be structurally capable and architecturally worthy of lasting 300 years.

The Cathedral of Christ the Light is an extraordinary timber structure meeting demanding seismic and architectural design criterion that is more economical and aesthetically pleasing than conventional steel or a reinforced concrete moment-frame building.

This case study was prepared by APA Market Development Specialist Karyn Beebe, and Paul Gilham, Western Wood Structures. It first appeared in Wood Design and Building *magazine.*

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