

WOOD DESIGN & BUILDING®

FALL 2008 — NUMBER 44

Ping Village

Maple and cedar provide the perfect backdrop for modern Chinese fusion restaurant

Cathedral of Christ the Light

Exemplary California cathedral uses traditional building materials in modern ways

Clear Space

Wood promotes creative expression in Taubman College's student resource lounge

(cover)

Cathedral of Christ the Light

Skidmore, Owings and Merrill (SOM), San Francisco

Photo by John Blaustein



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Cathedral of Christ the Light

Exemplary Oakland, California cathedral utilizes traditional building materials in modern ways

Paul C. Gilham, P.E., S.E. and Karyn Beebe, P.E.



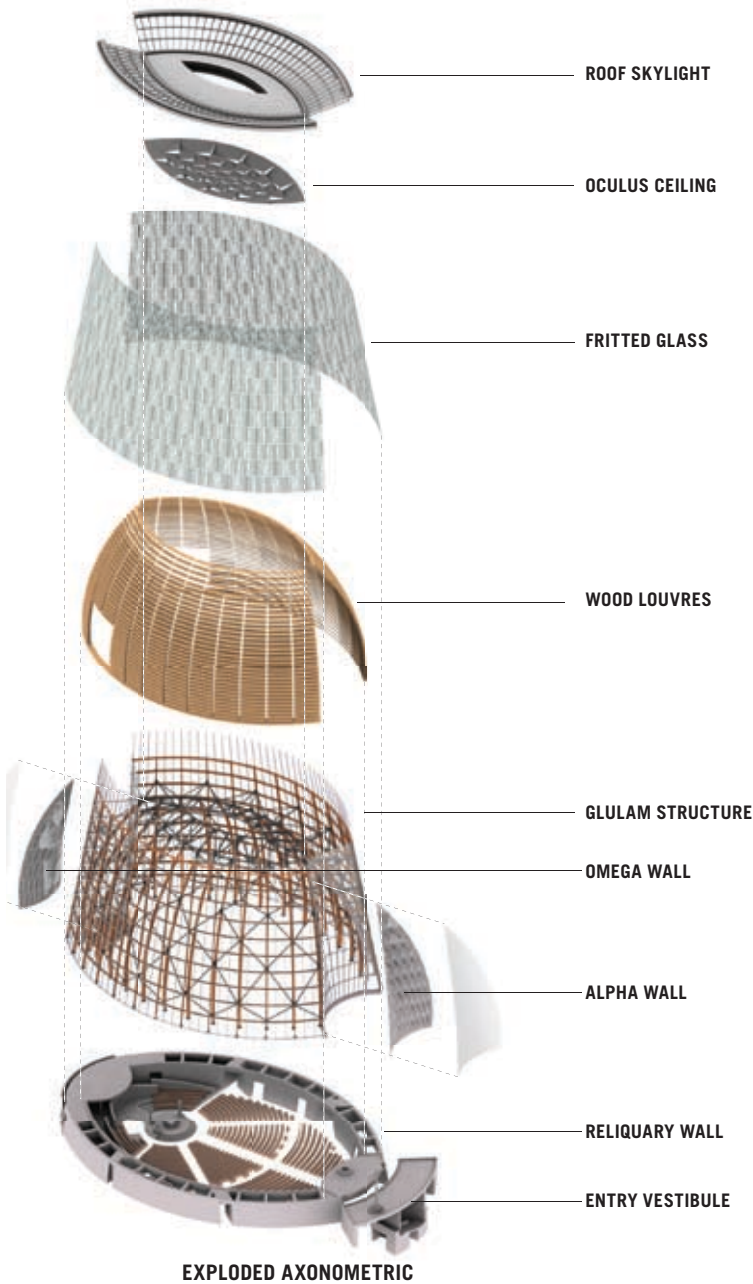
Cathedral photos by John Blaustein,
courtesy of The Cathedral of Christ the Light
and Skidmore, Owings and Merrill

*The Cathedral of Christ the Light
in Oakland, CA, replaces 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-ft. 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 (SOM), San Francisco. Yet, this is precisely what the new cathedral achieves. Set for a September 2008 opening, the 21,660-sq.ft., 1500-seat, \$80-million cathedral is an exemplary structure that utilizes traditional building materials in modern ways.

Exceeding a typical building design life by 200-250 years, required special consideration structurally, as well as architecturally. Given the site’s seismicity, the building was analyzed to resist a 1000-year earthquake. Furthermore, the building needed to be architecturally worthy in 300 years. The outcome is a space frame structure with a glue-laminated timber beam (glulam) and steel rod skeleton and 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.

“Wood, rather than steel, forms the cathedral’s supporting lattice because of its warmth and reference to light, as well as its religious significance,” Craig Hartman, SOM. Furthermore, wood has an economic advantage over comparable building mate-



rials. “When I designed this building seven years ago, we were just on the cusp of an unbelievable escalation in construction costs, especially in steel. And had this building been fabricated in steel, which would have been the other choice, there is absolutely no way we could have afforded it.”

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.

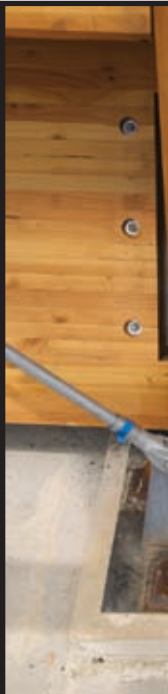
Structural System

The cathedral’s strength is achieved through the creation of glulam and steel rod space frames. The Vesica Pisces is constructed with 26, 10¾-in. wide by 99-ft. 9-in. long glulam ribs that vary in depth from 30 in. at the base to 19½ in. at the top. Between each rib are 32, 5⅞-in. wide glulam louvers varying in depth from 22½ in. to 39 in. 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 oculis supported by a steel compression ring which resists the horizontal thrust of the glulam ribs. Parallel to each rib is a glulam mullion 10¾ in. wide by 15 in. deep and 103 ft. 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 ft. to 15 ft.

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-ft. concrete reliquary wall in a matrix to evenly distribute the load. The specified isolators, double concave friction-pendulum base isolators, have a 4-ft. 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 five.

Given the cathedral’s proximity to fault zones (4.7 km from Hayward and 25km 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 per cent 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 diam-

eters 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 non-linear behavior of the structure.

Third, the rods were required to be pretensioned to between 3 per cent and 10 per cent 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 (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.

The tightening sequence was developed using a time step analysis on one-half of the structure. In this analysis, a pretensioning force was applied one at a time to each rod member until all were tightened. WWSI engineers determined if two opposing rods at a joint were tightened simultaneously the loads induced into adjacent rods was minimized. WWSI also developed the required tightening torques,



was utilized to model 220 unique connections and resulted in over 84 pages of shop drawings. Double kerf plates and hidden 1-in. steel pins were used to connect the ribs and mullions. These intricate connections were shop fabricated for ease of construction.

Another proactive step by the design team required WWSI to build a mock-up of the structural system equivalent to two bays in width and one fifth the total structure height. The mock-up, 22 ft. high by 30 ft. wide, revealed several issues that would have significantly impacted the building. First, they learned that normal wood shrinkage would expose the steel kerf plates. Therefore, the plates were trimmed 1/2 in. to accommodate material changes and maintain the hidden nature of the connections. Second, the moment connections of the steel girts (glass support) to the mullions needed to be tested to verify the rigidity of the connection. The design relied on a steel assembly connected with slip critical pre-tensioned bolts in order to minimize the deflection. This was necessary to prevent serviceability problems with the windows such as a break in the window seals. During this process, the connection was tested and showed the need to

which were calibrated to the desired pretension and ambient rod temperatures. To verify this analysis and tightening procedures in the field, WWSI hired VGO Testing and Inspection Engineers, Tigard, OR, to install 24 strain gauges on the rods to monitor the forces in the rods during the tightening process. The strain gauge readings confirmed appropriate pretensioning forces were developed.

Fourth, the criteria specified a non-linear 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 1000 year event.

Connections

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

strengthen the connection by installing stiffeners inside the first 4 in. of the tube.

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. Furthermore, to minimize the appearance of glue-lines on the face of the rib members, any finger joints on the ribs facing the seating area were located more than 15 ft. above the reliquary walls where they would be less noticeable by the congregants. 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 struc-

tural 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 non-linear behavior, testing the components which 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. 🏡

About the Authors

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STRUCTURAL ENGINEER: SKIDMORE OWINGS AND MERRILL, SAN FRANCISCO, CA

CONTRACTOR: WEBCOR BUILDERS, SAN MATEO, CA

GLULAM SUPPLIER/ERECTOR: WESTERN WOOD STRUCTURES, TUALATIN, OR

PHOTOGRAPHY: JOHN BLAUSTEIN

