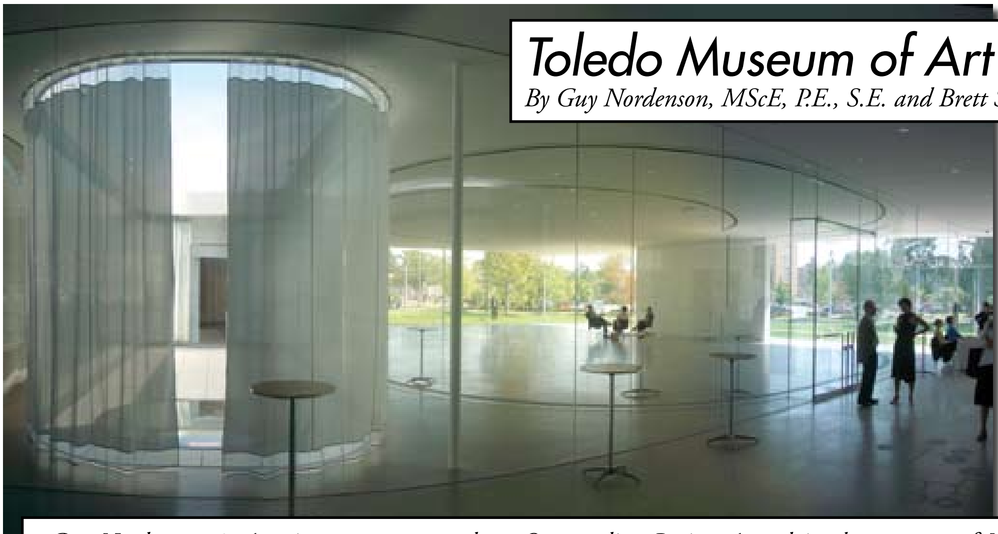

Toledo Museum of Art Glass Pavilion

By Guy Nordenson, MScE, P.E., S.E. and Brett Schneider, BA, MEng

Project Credits
Owner:
Toledo Museum of Art, Toledo, OH, USA
Architects:
Kazuyo Sejima + Ryue Nishizawa/SANAA, Tokyo, Japan
Kendall/Heaton Architects, Houston, TX, USA
Structural Design:
Guy Nordenson and Associates, New York, NY, USA
Sasaki Structural Consultant, Tokyo, Japan

*Guy Nordenson & Associates was presented an Outstanding Project Award in the category of New Buildings Under $30M in the NCSEA 2008 Excellence in Structural Engineering Awards program. More information on this program can be found in the December 2008 issue of STRUCTURE® magazine (**www.STRUCTUREmag.org**) or at the NCSEA website (**www.ncsea.com**).*

The Glass Pavilion is a freestanding addition to the Toledo Museum of Art in Ohio, and intended to house galleries for the museum's extensive collection of art glass alongside publicly accessible glass blowing workshops. The architectural design called for a building with a single level above ground, approximately 200 feet by 200 feet in plan, with a roof height of 15 feet. The interior galleries and workshops are typically independent rounded rectangles in plan, enclosed by full height glass walls with an inaccessible 30-inch wide cavity between each room's perimeter partitions.

The use of glass for the majority of the interior partitions required that the building systems (mechanical, plumbing, and structural), typically enclosed in the walls of most buildings, be distributed to other locations or left exposed. In the case of the structure, the resulting coordination to the architecture and building systems required the application of unorthodox solutions for the steel roof framing, steel vertical support and lateral systems, and cast-in-place concrete suspended framing for the ground floor.

Steel Roof Framing

In the final design, the roof sandwich of the Glass Pavilion is 24 inches from top edge of fascia to the bottom of the ceiling. The structural steel framing in this sandwich is limited to a nominal depth of 12 inches with spans between columns of up to 60 feet – a span to depth ratio of more than 50:1. A few details are of particular note in this unconventional system.

First, the girders and joists are all continuous, allowing for the distribution of the total moment to both positive and negative bending to reduce in the critical design moments for both girders and joists. The girders were constructed with 4-foot long perpendicular joist "stubs" shop welded with full moment connections on each side so that infill joist spans could be field bolted in between for simplified erection.

Second, the girder lines are not straight across the building, but are kinked to follow the irregular location of their supporting columns. The girders are continued straight over columns to the next joist line where the moment connections to the joists at the "kink" resolve the torsion developed at the "kink" into direct bending and shear along the joist span.

Third, the roof sandwich has a clearance of 6 inches below the nominal bottom of steel to the underside of the ceiling. The few opaque partitions limit the possible locations for drain lines to drop and vertical ductwork to be located. Piping penetrates through the regular joist framing, or under haunches where the pipe would intersect the joist bottom flange. The ceiling is partitioned to provide for return air plenums, with additional penetrations to allow for the required volume of air flow where required.

Steel Vertical Structure

The number of columns in the building is minimized and they are purposefully kept off a regular grid to prevent the perception of a regular pattern. The exposed columns are solid steel rods 3.5 or 4.25 inches in diameter, specified as architecturally exposed structural steel and do not require fireproofing. In order to maintain this minimal diameter, the girders above bear on pins at the top of the columns in double shear. The pins are fabricated from high-strength quenched and tempered ASTM A514 steel in order to minimize diameter and keep the connection detail above the ceiling.

The number of opaque walls in the building is few, and the requirements of mechanical and plumbing distribution in those walls left few locations for lateral bracing. In addition to three braced frames located in the opaque

Construction photograph of full steel frame.

walls at the Southwest, Northwest and Northeast corners of the structure, the majority of the building's lateral stiffness is derived from the use of ¾-inch architectural steel plate shear walls that form the Lampworking room at the Southeast corner of the building. The curved corner sections of the wall serve as columns to the girders above, with the curvature providing the necessary buckling resistance. The flat sections of plate are connected to the framing above with vertical slotted connections for the transmission of lateral loads only where buckling under vertical loads would be more critical.

Concrete Ground Floor Structure

As with the roof structure, the use of glass partitions on the ground floor presented significant challenges to the design of the ground floor structure, including the integration of supply air systems from below and the accommodation of the deflection criteria for glass partitions.

The design solution was to frame the floor in cast-in-place concrete with wide and flat band beams (typically 24 inches deep by 6 feet wide) with one-way slabs spanning between them. The use of one-way slabs allows for linear supply air grills in the direction of the span in the galleries by simply making 6- to 8-inch wide slots through the slabs fed by continuous sheet metal plenum attached to the bottom side of the slab. In order to minimize floor movement at the glass partitions, additional top compression reinforcing was added to approximately 25% of the ground floor beams to reduce the long term creep of these elements.

Conclusion

While these structural systems are unorthodox they allow for a highly integrated final building that is both highly efficient in the aggregate and surprisingly affordable for its unique character.▪

Brett Schneider, BA, MEng is an Associate with Guy Nordenson and Associates. Mr. Schneider served as Project Engineer for the Pavilion project. He has previously taught integrated design at the Columbia University Graduate School of Architecture.

Guy Nordenson, MScE, P.E., S.E. is a structural engineer and professor of architecture and structural engineering at Princeton University. In 1987 he established the New York office of Ove Arup and Partners and was its director until 1997, when he began his current practice. Mr. Nordenson served as Partner-in-Charge for the Pavilion project.