Arena Stage at the Mead Center for American Theater

Excellence, Creativity and Innovation

By Gerald Epp, M.Eng, P.Eng, Struct.Eng, P.E.

Courtesy of Bing Thom Architects. Fast + Epp was an Award Winner for the Arena Stage at the Mead Center for American Theater project in the 2011 NCSEA Annual Excellence in Structural Engineering Awards Program (Category – New Buildings over $100 Million)

Engineers rose to the demand for an exuberant free-form expression with practical and elegant solutions to the project's complex technical challenges (and shrinking budget). Two major elements enclose the existing theaters, isolating them from the noise of the busy capitol:

High Roof

The initial fully-designed and peer-reviewed scheme had the roof cantilevering 180 feet, supported by harped steel cables anchored into a custom steel space truss. Post-9/11 funding shortfalls necessitated redesign. A 500-foot-long steel truss structure was introduced, retaining drama by bringing a support wall only part way along the back side, leaving an 85-foot cantilever which appears similar to the original.

The large, complex roof that spans over the theaters – cantilevering toward the Washington monument – required close collaboration between engineer and erector. Every nine-foot-deep truss is unique, has one-of-a-kind support conditions, and spans up to 170 feet. A sharp edge was efficiently achieved with light steel framing. To accommodate the multiple orientations of the leaning support columns, a single 2½-inch diameter bolt connection was devised, speeding erection of the large trusses. A simple "bounce test" (one engineer, all alone) was used to test the stiffness of the cantilever tip, resulting in an instruction for minor stiffening in the secondary trusses.

Timber Façade

The roof is supported by large engineered timber columns, which also serve as backup to a sinuous 650-foot long, up to 58-foot tall suspended glass façade; the acoustical and environmental barrier. The geometric complexity is exacerbated by a four degree tilt from vertical. For efficiency, two-thirds of the double-glazed facets were designed to be identical in size. The remaining bays unnoticeably take up the irregular geometry.

The timber columns are set back, receiving tapered timber arms that reach out to laterally support timber muntins, to which the glazing units are clipped. All of the timber is engineered wood – parallel strand lumber (PSL).

The 20-inch by 30-inch elliptical timber column is designed to carry axial forces (up to 400 kips) and out of plane near hurricane wind-forces while minimizing the amount of PSL used. Deflection actually controlled the design. The column cross-section was designed with a partially restrained relief joint through the neutral axis to manage the strong potential for movement and checking. The base connector for the columns visually references a lightly touching ballet slipper, heightened by "pencil-sharpened" tapering on the bottom nine feet of the timber. Non-linear 3D solids finite element analysis and full scale load testing were performed to minimize the weight of the ductile iron casting.

The roughly 16- by 12-foot glazing units and shaped PSL muntins are suspended from ⅝-inch diameter stainless steel cables via fully adjustable connectors. In order to accommodate erection tolerances and ensure tension during the life of the building, a carefully calculated assembly of three plates as "leaf springs" was installed at the top of each cable.

The entire façade is structurally complex; lateral deflections occur in both the span of the columns and in the slender spans of muntins between the columns, which gain their stiffness through a combination of bending and axial forces (catenary action). Analysis determined stiffness in the system was quite dependent on bending moments being carried through every PSL muntin-to-muntin joint, making the connection an important part of the overall design.

Research and load testing was carried out on a tight-fitting multi-pin connector which would allow the connection to be virtually invisible, yet efficiently carry the high forces. It was further proved on a system basis when a full size 50- by 60-foot mock up was constructed and tested with full design wind forces.

All the lateral forces from the roof and façade were focused into the petal-shaped architectural concrete walls of the new "Cradle" theater, eliminating the need for visually disturbing bracing along the length of the façade.

This is believed to be the tallest free-span timber-backed glass façade in the world.

Complexity and Design Sustainability

This was in every respect a complex structure to build. The general contractor and the entire team of consultants were highly engaged with the project, paying close attention to detail in planning, 3D-modeling and shop drawings. To ensure smooth execution of the timber façade, a related design-build company took on the contract for its design, testing, fabrication and installation.

This project involves the unprecedented use of architecturally exposed engineered wood. Such wood is far and away the most sustainable structural material. Extensive use of efficient architecturally-exposed structural materials starkly contrasts with the heavily clad structures of Washington. Persistent "value engineering" eliminated superfluous finishes and put pressure on the structural engineer to provide an aesthetically satisfying structure. For example, the custom timber façade is not only structurally unique, but also uniquely serves as acoustical barrier and roof support, yet costs less than commercially available alternatives.▪

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