Rave Reviews

BY BARTLEY J. MILLER, P.E.

Large trusses provide a wide-open venue for sports and entertainment alongside the Ohio River.

THE UNIVERSITY OF LOUISVILLE men's basketball program has led the NCAA in revenues for the last five years and has ranked in the top five in attendance for the last 21 seasons—all while playing in tradition-rich but aging Freedom Hall, its 18,665-seat home since 1956. The new, $238 million Louisville Downtown Arena, scheduled to open in November 2010, will accommodate more than 22,000 fans for basketball and provide the revenue-generating amenities, luxury suites and premium seating that are missing in the Cardinals' current facility. Situated prominently on the banks of the Ohio River in historic downtown Louisville, the arena also is an iconic architectural landmark and a catalyst for new economic development.

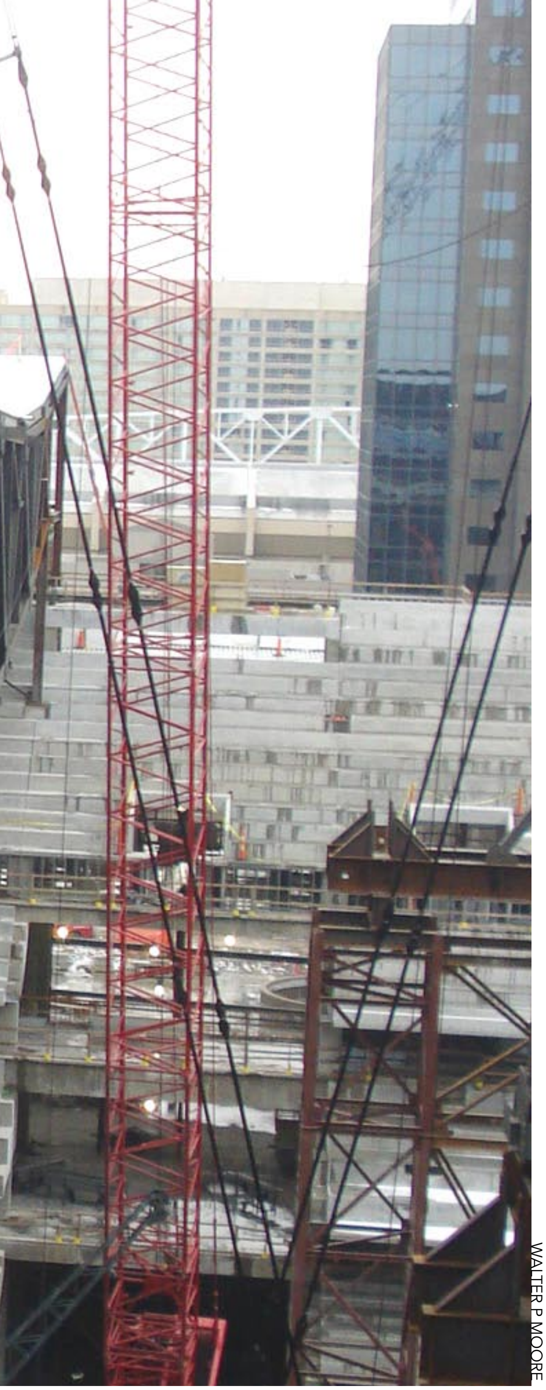
The Louisville Downtown Arena combines unsurpassed basketball facilities and world-class amenities with the maximum flexibility of a public, multi-purpose arena. Several of the building's structural components feature long spans, complex geometry, and are visually exposed, which demand the beauty, versatility and efficiency of structural steel.

Taking Flight

The most recognizable symbol incorporated into the arena design is its signature curving roof. Consisting of over 1,750 tons of structural steel, the dynamic roof is inspired by the wing of a Louisville Cardinal and imitates the flow of the nearby Ohio River. The project structural engineering firm Walter P Moore collaborated with sports architect Populous to develop an efficient truss profile to achieve the wave-like roof shape with the primary truss

The entry lobby, one of the largest of any arena in the U.S., is completely transparent to allow the movement of fans to be expressed through the façade and provide views of the public plaza at the south end of the arena.

The "waterfall" is an 11,000-sq.-ft curving glass façade that provides panoramic views of the Ohio River. It is supported by visually exposed HSS 12x8x¼ rolled "the hard way" to a 280 ft, 11 in. inside radius. Another 54 tons of curved W33x152, also rolled the hard way to a very tight outside radius of a little more than 59 ft, provide additional support for the façade.



The segmentation of the primary truss top chords achieves the roof's distinctive curvature. After each half of the roof structure is independently de-centered, they will be connected with steel framing across the center bay.

top chords while the bottom chords provide the functional characteristics required in an arena.

Walter P Moore modeled the entire structure in Revit Structure to accurately coordinate complex geometry and encourage timely decisions from both the design and construction teams. The long-span roof of any arena is an intricate collection of trusses and bracing, catwalks, rigging beams, mechanical and electrical equipment and fall-protection systems. With the roof serving as a key architectural feature, collaboration between consultants and contractors was even more critical.

To accommodate the roof profile, the four primary roof trusses span 406 ft and consist of W14 wide-flange chord and web members, webs horizontal, in a Warren-type configuration. The truss depth varies from 21 ft, 6 in. at the north end, to 44 ft at the highest

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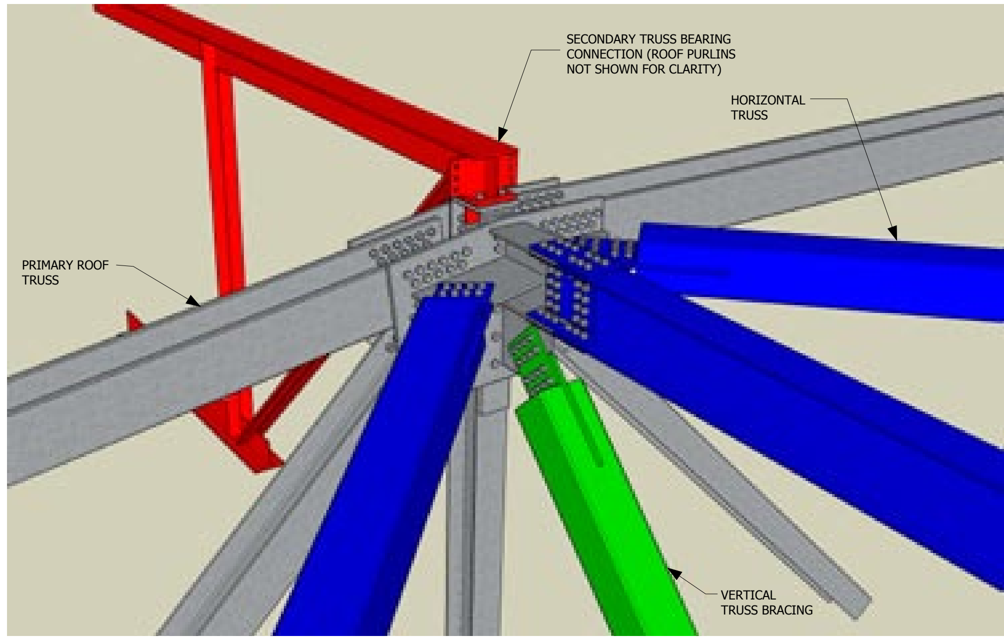
The intersection of primary, secondary and horizontal trusses, in addition to vertical truss bracing and roof purlins, results in several 12-member nodes. A built-up gusset assembly and seated secondary truss configuration simplified design and erection.



point of the roof, to 15 ft, 6 in. at the south end. The top chord is segmented at each panel point and forms the curved roofline through subtle variations in each truss chord connection. The bottom chords provide a nearly flat plane for attachment of the rigging grid, catwalks and fall arrest system. The overall depth of the trusses was optimized to maintain 100 ft clear from the bottom of the roof steel to the playing surface without camber and to ensure that all truss members could be produced domestically using A992 Grade 50 steel.

Vertical truss web ("post") members are spaced at 37 ft, 6 in., and intermediate sub-post members, where required, are at the mid-point between the main truss posts. The upper sub-post members brace the top chord in its weak axis, while the lower sub-post serves as a hanger to transfer loads from the rigging grid into the truss without loading the bottom chord about its weak axis.

All truss connections use $1\frac{1}{8}$-in. and $\frac{7}{8}$-in.-diameter A490X bearing bolts in standard holes in order to minimize gusset plate sizes and the number of bolts required, and to eliminate the need for costly specialty primers and time-consuming painting procedures associated with slip-critical bolts in oversized holes. The fabricator pre-assembled major truss components in the shop in order to ensure proper fit up in the field. Walter P Moore designed all truss connections both to expedite steel connection detailing and submittal review, and to eliminate the potential confusion resulting from issuing connection forces that envelop the numerous load cases and more than 1,400 load combinations used in the analysis.

The primary trusses support 22 secondary trusses that span approximately 136 ft in the east/west direction. Because the curved geometry of the roof structure is accomplished by the four primary trusses, the secondary trusses are straight, repetitive elements. The secondary trusses are a shippable 14 ft deep, and are composed of WT chords and double-angle (2L) web members in a Pratt-type configuration with shop-welded connections and field-bolted splices. These trusses are spaced at 37 ft, 6 in. on center to align with the primary truss post spacing and the arena column spacing below. Each secondary truss is located immediately below the roof deck to allow an efficient and easily erectable bearing connection. Each vertical post extends up through the primary truss chords to provide a flat bearing surface for the secondary truss top chord. The configuration also simplifies the purlin connection and ensures that secondary truss loads do not create an eccentricity in the connection.

The primary trusses are supported at each end by wide flange "smart" columns. Smart columns, which have been widely used by Walter P Moore on past steel projects, are oriented so that their weak axis is aligned with the length of the truss. The columns are designed for axial forces but no compatibility moments induced by the horizontal movement of the primary truss bottom chord. Smart columns "know what to do;" they move laterally as required to accommodate the outward thrust of the bottom chord, but maintain their vertical alignment in proportion to their stiffness. This approach produced significantly smaller columns, eliminated column bracing and allowed horizontal movement at the truss support points without slide bearing assemblies.

Lateral System

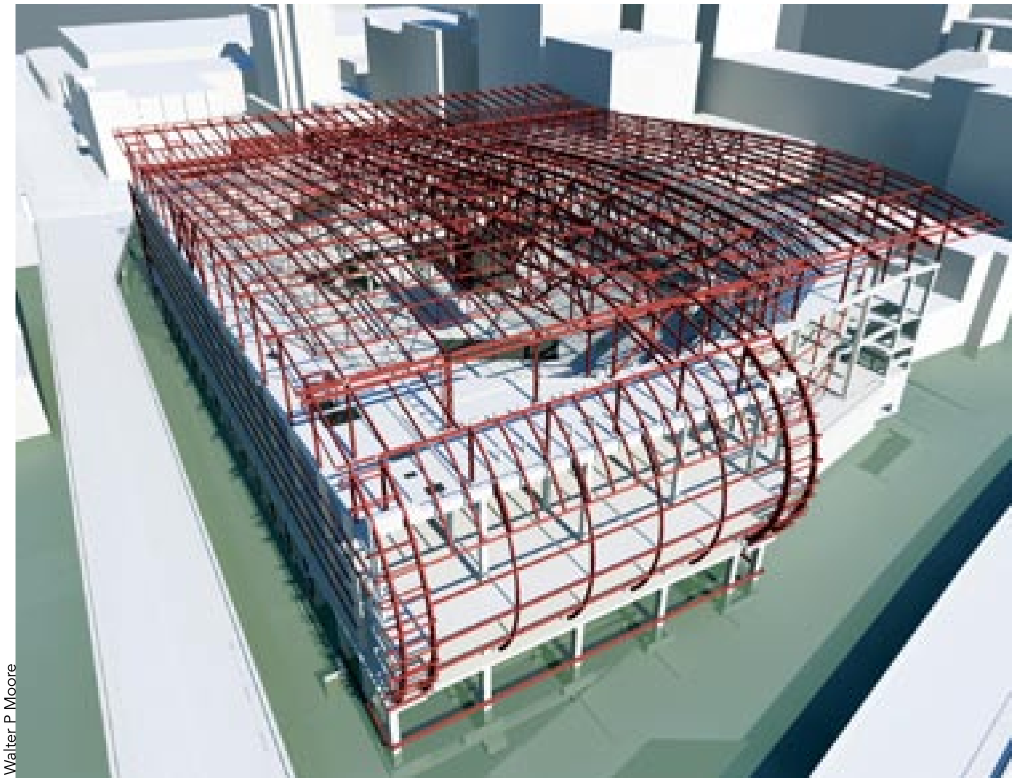
The complex and asymmetric geometry of the roof and bowl structure combined with poor soil conditions and proximity to the New Madrid fault resulted in significant seismic forces. The lateral system for the arena roof consists of the metal roof deck, collector elements and ordinary concentric braced frames (OCBFs) that transfer lateral loads to the concrete bowl. The use of OCBFs, with an *R*-value of 3.25 and an Ω-value of 2.0, reduced design seismic connection forces in braces and collector elements by approximately 25% when compared to the common approach in the region of not detailing for any level of seismic ductility. Walter P Moore designed all brace connections using HSS diagonal members with shop-welded, knifed gusset plates that are field-bolted to column gussets.

To stiffen the roof structure against seismic loads, two curved, horizontal trusses follow the undulating plane of the top chords of the primary trusses and transfer wind and seismic loads to the braced frames at the north and south sides of the roof. They were analyzed using the Direct Analysis Method to provide global stability to the roof trusses. The trusses consist of HSS diagonals and W18 "vertical" members that also serve as girders supporting typical roof beams.

The primary and horizontal trusses were lowered to 2 ft below the bottom of the roof deck to maintain the alignment of work points at horizontal truss to vertical truss connections, while simplifying steel erection. Roof beams were installed above the horizontal truss members using seated, bearing connections, eliminating conflicts with horizontal truss diagonals and significantly reducing the number of roof beams required. Additional beams directly above the primary truss top chord were required for deck support, but because they were connected at primary truss connections only, these beams eliminated all weak-axis loading of the truss chords from the roof beams and deck, which significantly reduced the weight of the chords (see Figure 1).

Flexibility Is Crucial

Today's most successful arenas are multi-purpose venues that accommodate a variety of entertainment events. Seating 23,000 and 17,500 for center-stage and end-stage concerts, respectively, the Louisville Downtown Arena will be the premier concert venue in the region, expected to host up to 170 events per year.



Walter P Moore

Figure 1: Walter P Moore modeled all structural elements in Autodesk Revit Structure. The model was critical in enabling efficient and accurate communications between project team members and encouraging timely decisions.

Given the number and variety of events anticipated, the rigging grid was developed to support rapid loading and unloading of shows for a wide range of rigging configurations. The rigging grid is 206 ft by 112 ft, 6 in., located within the boundaries of the four primary trusses, and boasts a capacity of 200,000 lb. Its 175 tons of W14 beams are spaced in an 18 ft, 9 in. by 12 ft, 6 in. orthogonal grid. The spacing of the rigging beams was chosen so that connections to primary truss bottom chord members would be located only at the posts and hangers to avoid loading the chords with substantial, cumulative rigging loads in weak-axis bending.

All rigging beams are designed to resist 5,000-lb to 8,000-lb rigging loads applied at up to a 45° angle from vertical, in anticipation of bridling common to today's entertainment events. For added convenience to the riggers, the bottom chords of the four primary trusses were designed to also withstand rigging point loads of up to 5,000 lb at any point along their length to allow for the maximum number of rigging arrangements.

The rigging beams that span from truss to truss combine with HSS vertical truss bracing members to stabilize the bottom chord of the primary trusses. They also provide an essentially flat bearing surface for catwalks, spotlight platforms and scoreboard access.

The arena features 250 tons of catwalks organized in a nearly ½-mile network that provides access to suspended equipment and hoists, smoke exhaust fans, lighting, and spotlight and camera platforms. The catwalks were designed and modeled as repetitive, modular components to aid in fabrication and erection. Catwalk modules up to 37 ft, 6 in. long were fabricated in the shop. At the spotlight platforms, an innovative, hinged "tailgate" detail was created to eliminate interference with the spotlights. The top handrail is a standard steel rail that can be lowered by 1 ft, 8 in. without any removable parts that could fall from the catwalk level. The steel rail when in place provides better strength and stability than the removable chain or cable rails that often are used at such platforms.

The spacing and depth of the primary trusses allows a 65,000-lb, center-hung scoreboard to be recessed completely into the roof structure during concerts and other shows. The offset hoist machine for the scoreboard is located on and can be easily accessed from a widened portion of the catwalk adjacent to the scoreboard. Game-in-progress statistics boards are located in each corner of the roof, and can be raised or lowered for maximum venue flexibility.

The 14,000-sq.-ft entry atrium will be one of the most expressive and memorable features of the arena experience. The enormous pre-function space is column-free and completely encased in glass supported by horizontal HSS mullions. The lobby roof consists of W36 wide flange girders spanning up to 97 ft that are supported by 77-ft-tall W27 wide-flange columns.

Falls of the Ohio

The wave-like form of the roof continues its downward curvature on the north face of the arena, transitioning from steel-supported roof deck to aluminum panels and then to glass to form the arena's other signature architectural element. The "waterfall" is a three-story, curved glass facade that provides panoramic views of the river from three levels of meeting rooms and restaurants, and creates a spectacular setting for arena events and special occasions. Outdoor balconies at each level heighten the experience with even greater connection to the river below.

The 11,000-sq.-ft window is supported by curved HSS that carry all gravity loads and lateral loads perpendicular to the glazing back to the superstructure. The 20-in.-deep vertical members and 16-in.-deep horizontal members are exposed on the inside of the arena, but are aligned behind the aluminum window mullions to minimize visibility from the exterior. The east and west ends of the waterfall are framed by curved verendiel trusses consisting of rolled wide-flange members that resist in-plane wind loading and anchor the remaining members.

To allow for construction tolerances and to accommodate the expected difference in deflections between the superstructure and waterfall framing, maximum adjustability was incorporated into every connection. Each intermediate connection features permanent vertical slotted holes and temporary, horizontal slotted holes to aid with fit-up. At the base of each element, base plates incorporate oversized holes and 2-in.-thick grout beds beneath. A pin connection was used at bases that were architecturally exposed.

Home Court Advantage

As the new home of one of the premier collegiate basketball programs in the country, the Louisville Downtown Arena will boost interest and revenue and become a major asset in recruiting. As a public, multipurpose venue, it already has attracted new investment and numerous events to the city. With its signature curving roof and bold architectural elements comprised of exposed structural steel, the Louisville Downtown Arena is a venue fitting this powerhouse program and deserving of its position on the increasingly dynamic Louisville skyline. MSC

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