Steel **Expansion**

by Michael Gustafson, P.E.

The DeVos Place convention center in Grand Rapids, MI, is undergoing a multi-year expansion featuring steel-framed column-free exhibit space.

Located along the Grand River in downtown Grand Rapids, MI, DeVos Place is a one-million-sq.-ft expansion and renovation of an existing convention center. The facility is in operation and open to the public throughout the construction schedule. The project is being delivered in three phases, from April 2002 to January 2005. The construction budget of $169 million includes Phase 2 steel costs of $15 million.

Grand Rapids-Kent County Convention/Arena Authority owns the project, and requires 162,000 sq. ft of a column-free exhibit space, a 41,000-sq,-ft ballroom that can double as exhibit space, 20 meeting rooms, and a large public gathering space called the Grand Gallery. Other program requirements include 700 parking spaces below the concrete waffle slab designed to a floor-loading requirement of 500 psf for the Exhibit hall and 250 psf in the Grand Gallery. The architectural designers and structural engineer worked with the owner to blend the facility with its downtown surroundings and the Grand River. The waved roof and rolling structure over the Grand Gallery create a five-sided building that offers interest from all viewpoints and angles.

Selection of Building Systems

The building design was conducted in accordance with the 1996 BOCA code. For the foundations, the geotechnical engineer was concerned about the effects of pockets or voids in the existing bedrock. The foundation design was comprised of drilled pier/mini-piles with void-filling compaction grouting. The below-grade structure, which includes the parking ramp, was constructed of cast-in-place concrete.

The above-grade superstructure was constructed of structural steel. Composite floor-deck construction was used at all elevated floors. To resist gravity and lateral loads imposed on the exhibit hall roof, two long-span steel box trusses were used. Steel diagonal braces in combination with the box trusses and their concrete support piers resist lateral forces imposed on the exhibit hall area. Structural steel also was used to resist forces imposed on the grand gallery area. The composite floor-on-deck and roof-deck structural systems were designed with RAM Structural System's software. The grand gallery and exhibit-hall steel frame systems were designed with RISA 3-D.

Photo courtesy Progressive AE

Above: Shoring towers, located at the third points along the span of each box truss, were used for the erection of the box trusses.

Right, middle: Two large box trusses span 360' over the exhibit hall area while supporting the entire roof structure.

Right, bottom: Aerial view of the exhibit hall during the later stages of construction.

Why Steel?

Structural steel was the material of choice for the superstructure. Steel allowed a potentially higher level of quality control: the structural engineer specified an AISC-certified steel fabricator, that minimized errors and kept the project on schedule and within budget.

To ensure the high level of material quality of the large box-truss structural members, Group 4 and 5 W-shape steel members were subjected to straight-beam ultra-sonic testing. All members ultimately met specification requirements; but with a tight schedule, any members not meeting the test could have posed schedule problems.

Structural steel also was chosen to meet specific design challenges of the grand gallery and exhibit hall.

The waved roof is visible from the waterfront.

Challenges: Grand Gallery

The grand gallery is both an entrance and an assembly area. The 80′-high atrium space accommodates natural light, with many skylights in the roof and curtain-wall systems at its ends. Due to the desired sleek aesthetic of the gallery-space structural system, steel was chosen, since concrete or other building materials would not have been financially feasible.

To support the roof structure, 17 curved, steel-bent beam-columns or "ribs" were used. The ribs connect to the grand gallery floor with a fixed base-plate connection, and connect to W24 columns at the north end of the gallery space. The ribs support round HSS16 that run continuously along the length of the grand gallery, spaced at approximately 8′-0″ on center. These HSS provide bearing for the roof deck and skylight systems. To keep the ribs from becoming too visually overpowering, the structural engineer worked with the architect to integrate form with function. The depth of each rib is narrower at the base, and widens as it arches up into the gallery space. Each rib is composed of an HSS10 bottom chord and a 2″-by-24″-plate top chord connected with a 1″-thick web plate. Because the bottom chord is a compression element, full-height web-stiffener plates were added along the web of the arches to provide lateral bracing of the bottom chord. This structural feature added both function and aesthetic value.

Seventeen curved, steel-bent beam-columns or "ribs" support the roof structure. The ribs were erected in two pieces with a bolted and welded splice connection approximately 60′ above grade

The arched profile and depth of the ribs varied along their lengths, and several radius points were needed to communicate the intent of the design to the fabricator. Such a complex geometry would not have been financially possible a few years ago; however, recent advancements in computer-aided fabrication processes now allow unusual steel shapes to be built cost effectively. The 17 bents were fabricated in two pieces, each weighing 17,000 lb. They were trucked to Grand Rapids from Detroit and, in many cases, set in place with one pick from the flat-bed truck to the anchor bolts.

Other design challenges included the design of the roof diaphragm. Because most of the roof is composed of skylights with no roof-deck diaphragm, the continuous round HSS16 and the rib top flanges had to be designed as a Vierendeel truss to act as a type of diaphragm. This was most prominent at the ends of the gallery, where the roof and ribs were exposed to higher wind forces on the roof canopy and marquee reader board. Also, the roof members had to be stiff enough to meet the stringent skylight deflection requirements.

The ribs were erected in two pieces with a bolted/welded splice connection approximately 60′ above grade. The continuous round HSS16 were erected in segments and field-welded into place.

Challenges: Exhibit Hall

It was not feasible to span the exhibit-hall roof structure in concrete, given the desired architectural design concept. Using long-span steel truss construction was the most cost-effective way to support the roof, and the 162,000-sq.-ft exhibit hall requirement would have proven nearly impossible to meet with an alternate system.

The exhibit-hall area, which lies to the north of the Grand Gallery, is an approximate 360′-by-450′ column-free exhibit space. To accommodate such a large column-free space, two large "box" trusses span 360′ over the exhibit hall area while supporting the entire roof structure. The roof of the structure is broken into three different roof sections. The middle section is supported by 15′-deep by 150′-long secondary trusses that span between the two box trusses. The two outside roof sections are supported by 12′-deep by 120′-long secondary trusses that span between box truss and W36 perimeter columns. The secondary trusses were constructed with W and WT chord members and double-angle lace members. The two outside roof sections curve along in the north-south directions in an S-profile, while the inner section curves in a C-profile. The height inside the exhibit hall varies between 40′ and 80′.

Each box truss is supported by four large concrete piers that carry most of weight of the roof structure and also transfer most of the wind forces that are imposed on the exhibit hall. The concrete support piers are 4′ by 10′ in cross section and stretch more than 50′ above the street level. The box trusses connect to each pier with a pin assembly connection.

Each box truss weighs about 1,800,000 lb. The truss members were made of a combination of 50 ksi and 65 ksi steel members. Some top-chord members were as large as W14×605, Grade 65 ksi material. Construction costs were minimized by using Grade 65 ksi high-strength steel in the roof box trusses, since using the higher-grade steel allowed the use of smaller truss members. The "sticks" of the box trusses were fastened together with steel gusset-plate connections. Some of the gusset plates are over 3″ thick. ASTM A490-X bearing bolts were used in lieu of slip-critical bolts, since they allowed the use of smaller gusset plates and a smaller number of bolts due to the added shear capacity. The fit-up of the truss members using bearing bolts was not a concern because the holes in the connection pieces were drilled all in one operation, and sections of the box trusses were pre-assembled in the fabrication shop.

The box trusses had to be designed to accommodate all types of loading. The box trusses house a majority of the mechanical and electrical equipment supporting the exhibit hall and Grand Gallery. Therefore, a composite floor slab was framed into the base of each box truss to support those loads. Loads from special rigging, roof catwalks, moveable partitions, thermal effects, wind, and erection methods were used to design the box trusses.

The lateral design was complex: the facility was designed to exposure-C wind criteria, and story heights in the exhibit hall were unusually high. Specifically, the roof-deck fastening requirements were very critical in being able to transfer lateral forces from the exterior walls into the roof deck and eventually into the perimeter diagonal bracing and box-truss elements.

Another design challenge was accommodating the rotation and deflection of the long-span roof structure. As the box truss deflects, the truss bearing points (i.e., the pin assemblies) induce horizontal thrust forces into the tops of the concrete support piers. To minimize these thrust forces, the elevation of the pin assemblies were established near the bending neutral axis of the box trusses, thereby minimizing the amount of horizontal thrust at the support. The box trusses were cambered with efforts to minimize the amount of total deflection.

Because the box trusses were designed to take vertical loads and lateral loads in both directions, diagonal cross bracing was required in all three planes. The resulting connections were very complex to detail. Field welding in combination with field bolting was utilized to simplify the detailing of some of the more geometrically challenging details.

The box trusses connect to each concrete pier with a pin assembly connection.

Longitudinal view through one of the two steel box trusses supporting the roof structure.

Erection Challenges

The erection of the box trusses required coordination between the construction manager, engineer, erector, and steel fabricator. The concrete support piers were designed to support the box truss piers only with the street-level concrete-floor diaphragm in place and bracing them. Because most of the street-level floor system would not be placed until near the completion of steel erection, temporary shoring of the concrete piers was used to provide stability to the concrete piers until the street-level slab was in place.

With the temporary pier bracing in place, the next step was to install temporary shoring towers at third points along the span of each box truss. The shoring towers were used to support sections of the box trusses as they were assembled on the ground and lifted into place. The erector worked closely with the engineer to ensure that localized erection loads on box truss elements did not exceed their capacities.

Coordination

Due to the fast-track nature of the project, file share of AutoCAD drawings with the steel fabricator and detailer accelerated the shop-drawing review

Interior view of the Grand Gallery during construction.

Some of the gusset plates in the box truss are more than 3” thick

A box-truss top-chord connection

process. Furthermore, shop drawings were transferred electronically between detailer and engineer using an Internet file-transfer site instead of e-mail or traditional mailed drawings. It is estimated that one working week of time was saved per shop drawing submittal by using this process, which saved piles of paper.

Conclusion

DeVos Place is, from any viewpoint, a unique and complex building. Designing such a structurally unconventional building in a conventional Midwest city required careful coordination between the architectural designers, structural engineers, steel detailers and the steel fabricator. The integrated design process utilized the experience of designers and builders who were well-versed in building complex structures that are both constructable and economical. It proves once again that designers and builders are not commodities in their industry. The best firms can differentiate themselves from their competitors through their enthusiasm to collaborate with all parties involved in the design and construction process, and share their creativity and technical expertise from successful projects such as DeVos Place. ★

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