Congregation Micah

RELIGIOUS ARCHITECTURE OFTEN EXPRESSES SYMBOLISM IN ITS DESIGN, and the new synagogue for Congregation Micah in Nashville is no exception. From the layout of the building to the exposed steel in the sanctuary, the new reform facility contains numerous subtle references both to history and religion.

The 27,000-sq.-ft. reform synagogue was designed for a congregation of 600 families. It includes religious space, a social hall, library, chapel, 16 classrooms and administrative offices. The sanctuary normally seats 300, but is expandable to 1000 seats during special services and major religious holidays.

The building is located on a semi-rural, 38-acre site (24 acres of which are wetlands) and is set well back from the road to take advantage of the best views of the surrounding natural environment, including the nearby hills and a small river at the southern edge of the property. The lawn and subtle landscape in the foreground emphasize the natural settings and are differentiate the synagogue from several nearby churches.

Circulation to the site begins with an axial view of the sanctuary with its glass crown, then winds through a mature grove of trees in the northwest corner of the site, which shield parking from pubic view and provide for

The exterior of the synagogue belies the dynamic interior. The building's design is rampant with both aesthetic features and religious symbolism. For example, the sanctuary at left is not merely visually exciting but also is a stylistic representation of the tree of life.

a secular transition zone. The drive then splits to allow direct access to the covered main entry and pedestrian plaza or to allow drop-off and pick-up at the school wing. Private outdoor spaces—facing on the best views to the rear of the bucolic site—includes outdoor social space, seating for outdoor services, a playground and a sculptural garden and court—which will double as a religious space during Sukkoth, a Jewish festival commemorating the harvest.

The building itself is composed of two interacting geometries. The public spaces are formed by a half cylinder with concentrically ringed elements juxtaposed with the orthogonal, linear and rhythmic forms of the educational wing, administration and support spaces. These contrasting yet complementary elements create a dynamic dialogue and establish a clear hierarchy, which culminates with the raised "Bimah", from where the

Project Team

Structural Engineer:
Structural Affiliates International, Inc., Nashville

Architect:
Michael Landau Associates, P.A., Princeton

General Contractor:
The Parent Company, Nashville

Owner:
Congregation Micah, Nashville

Steel Fabricators:
Hickory Steel, Inc.

Steel Detailers:
Bruce Vaughan

services are conducted, and Ark, which houses the Torah (Jewish holy scriptures).

The core of the cylinder contains the sanctuary (including the Bimah and Ark), while the outer ring includes the social hall, foyer and library. The shape of the religious and social end of the building is intended to suggest the nested hierarchy of the Temple of Solomon, which contained an outer court for the people, an inner court for the Levites, and—at the center—the holiest space for the priests and ceremonies.

The Bimah is framed by large glass windows, which highlight views of the surrounding countryside. The curved walls are made of a warm masonry to echo the colors of Jerusalem with the sanctuary wall crowned by a curved glass clerestory and skylight. The Bimah itself is accentuated by a pool of natural light spilling down from a skylight and windows above the Ark, to create a symbolic engagement of light and shadow at the focal point of the sanctuary. The sanctuary also features exposed structure, which is intended to contribute a lacy effect to humanize the scale of the space and provide a delicate armature of light and shadow. In addition to their practical purpose, the exposed trusses also have a symbolic meaning and represent both a "tree of life" as well as the arms of a menorah (candelabra from the ancient Hebrew temple).

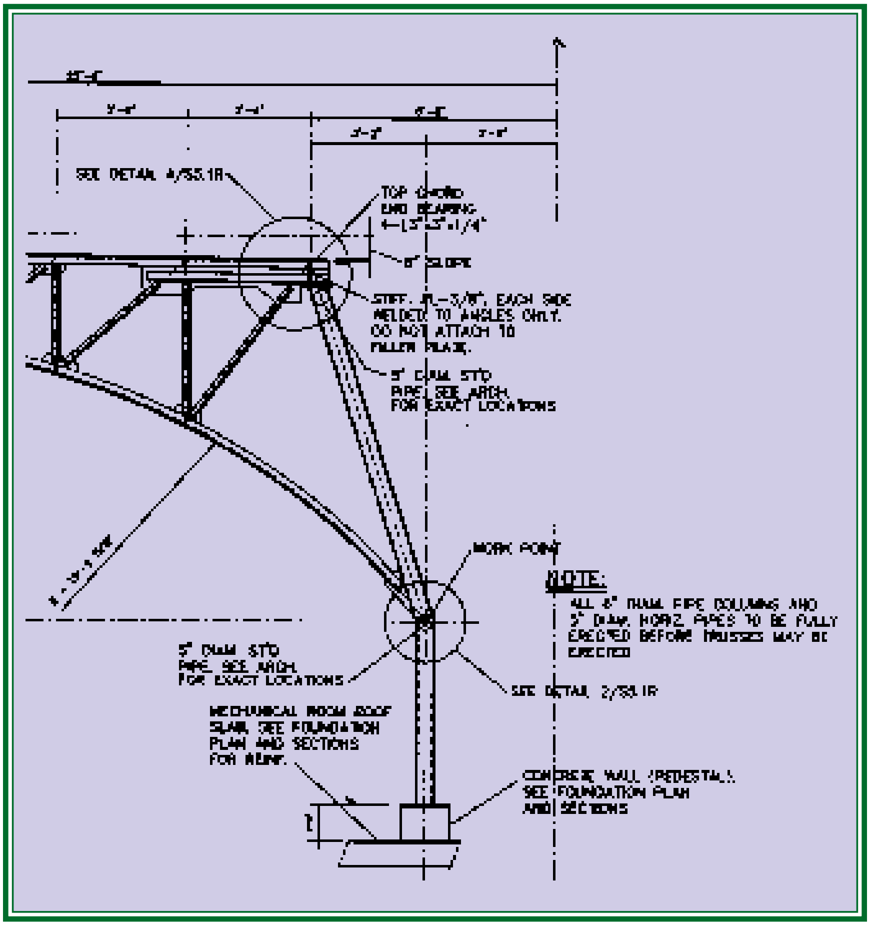
To handle the flexibility of increased seating during major religious holidays, the sanctuary includes operable panels that lift vertically to provide additional seating capacity in the adjoining social and library space. The panels display works of art, which are visible in both the raised and lowered positions.

The classroom features three student clusters to house children in grades K-2, 3-7 and 8-12. A youth lounge is part of the last cluster and all three clusters are connected by a gallery leading directly to the main foyer. Butterfly roofs with clerestory windows allow maximum natural light penetration into the multipurpose common areas of each cluster.

Structural Considerations

The design of the building was truly a collaboration between the architect and the structural engineer. "We were able to use our intuition to marry the structure with the function," explained Socrates A. Ioannides, P.E., S.E., Ph.D., of Structural Affiliates International, Inc., the project's structural engineer. Architect on the project was Michael Landau Associates, P.A., of Princeton, NJ, a design firm known for its work nationally on synagogues. Though the building is non-pretentious from the outside, the use of exposed structural elements on the inside to symbolize various elements of the Jewish religion makes the structure truly unique.

Many forms in the building intersect. The main sanctuary



and the social hall on a circular grid juxtapose with a rectangular grid coming in from the educational wing. Working with the geometry of different forms coming together in three dimensions and at different elevations made the project challenging. In total, there were seven different framing elevations.

The tall glass wall is a load bearing wall integrating the structure while maintaining transparency. The curved wall behind the sanctuary is a movable wall system designed, however, to provide the necessary lateral stability. As can be imagined, this required special connections between the roof system and the supporting walls.

The entrance canopy also was a collaborative effort between the architect and structural engineer. "We wanted to eliminate certain columns from the driveway and in the process, the entrance canopy was configured such that the name of the temple is reflected in the structural shape," Ioannides explained.

Structural Efficiency

The center core was designed to be the main lateral load resistance system with help from X-bracing around the perimeter of the sanctuary. The doors were a challenge, however, and the X-braces were only used down to the head of the movable partitions while moment connections were used below that point. Thus, as much as possible, the structural complexities inherent in the use of moment connections was minimized.

In order to achieve the desired aesthetic, the bottom chord of the trusses in the sanctuary feature a composite curve. In addition, however, these light trusses, consisting of 3" x 3" x ¼" angles, were more structurally efficient than such alternatives as steel rigid frames or hot rolled sections. Since the trusses radiate from a central point, the deck span between the trusses increased. To minimize secondary framing, 3" deck was used. However, when the space between the trusses exceeded the deck span limit, secondary support elements were added in the form of hot-rolled shapes so that the secondary members did not compete with the open lattice work of the trusses.

The continuous semicircular clerestory was achieved through coordination between the architect and engineer so the effect was achieved at minimal cost.

The efficiency of the space was enhanced by exposing the structure, including the deck. Acoustical considerations were partially accommodated by using acoustically enhanced decking.

The education wing has a standard, efficient structural system, so more construction dollars were available for the intricacies of the sanctuary, which is the main focal point for the congregation.

The entire frame, with the exception of the central HSS braced core, is bolted. However, to maximize efficiency, the central core was shop fabricated and field erected.

Coors Field Baseball Stadium

CONTINUING A TREND BEGAN MORE THAN A DECADE AGO IN BUFFALO, designers of professional baseball stadiums have engendered to create not just magnificent venues for viewing the game, but also architectural and structural masterpieces that enhance the community in which they are located. The new Coors Field Baseball Stadium in Denver is one of the most magnificent of these efforts.

The owner's and architect's fundamental objective with Coors Field was to create a dynamic and unique home for the Colorado Rockies baseball franchise. Not only did the stadium need to have its own special characteristics, but it had to fit-in well with a historic part of downtown Denver, an area featuring brick buildings that date back to the 1800s.

In order to accomplish this, brick and masonry are prominent on the stadium's façade, along with an exposed structural steel frame that supports the main grandstand. Brick walkways leading up to the stadium, Terra Cotta tiles (with a design of the state flower, the columbine) on the façade, pedestrian friendly surroundings and numerous other elements all contribute to a design that captures the essence of a historic baseball stadium and also fits in well with the visual identity of lower downtown Denver. Despite

The use of masonry and exposed steel helps the new baseball stadium fit in with the surrounding formerly industrial neighborhood.

its traditional look, however, the stadium features all the modern amenities required by fans today.

Coors Field sits on a four square block area in the midst of refurbished historic buildings. The locale was originally a warehouse district and in recent times the area had fallen into disrepair. Today, though, in part due to the rejuvenating influence of the stadium, the area is filled with restaurants, clubs and other businesses that thrive both in-season and out. As an added bonus, it is situated in an area that provides panoramic views of the Rocky Mountains and has a stunning, modern backdrop provided by downtown Denver's modern office towers—all just a mile from the stadium.

Exposed Structure

The exposed structure of Coors Field is critical in adding to the historic flavor of the

Project Team

Structural Engineer:
Martin/Martin, Inc., Consulting Engineers, Wheat Ridge, CO

Architect:
HOK Sports Facilities Group, Kansas City, MO

General Contractor (joint venture):
Mortenson/Barton Malow, Denver

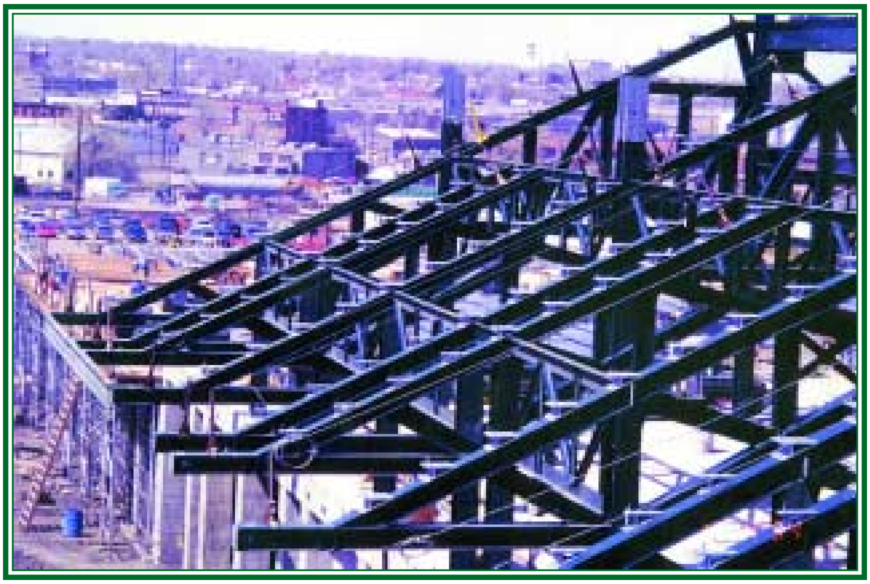
Owner:
Denver Metropolitan Major League Baseball Stadium District

Steel Fabricators:
Havens Steel (AISC Active Member)
Zimmerman Metals (AISC Active Member)
Zimkor Industries (AISC Active Member)

Steel Erector:
LPR Erectors (AISC Associate Member)

Steel Detailers:
Shawer-Price

Pictured is the upper concourse grandstand frame during construction.



Pictured are the right field mezzanine raker frames.

design. The structure itself includes an exposed structural steel frame that was erected from the main concourse up to the grandstand. All of the exposed steel on the project underwent initial sizing for structural optimization and then was reviewed with the architect for size and proportion. The shape of the trusses in the exterior frames was developed in concert with the architect's overall design concept for the masonry façade. Connection details were developed in exposed frames using gusset plates with rounded headed tension control bolts to give the appearance of "old time" riveted construction. The project required 8,975 tons of steel in 15,000 separate pieces and structural bid packages issued over 15 months included 250 sheets of structural drawings.

Martin/Martin, the project's structural engineer, worked closely with the fabricators and erectors in order to detail the steel in the manner most efficient for the construction team. On-site engineers participated in development of the erection scheme with the contractor and erector. In addition to traditional responsibilities, Martin/Martin integrated the input of the architect and contractor into a coherent package that could be constructed within a very tight schedule—despite a major design change.

Because of growing interest in season tickets from fans, seating capacity was twice increased after construction had already begun. As a result, more than 5,000 seats were added. Despite these changes, the stadium opened in time for the 1995 season. The finished stadium includes 50,249 seats, with field level seating, a main concourse, an upper level concourse and a multi-level grandstand. There also is club seating (4,513 seats), 797 luxury suites, and wheelchair areas (507 with 578 seats for companions). There also is ample space in the main and upper level concourses for fans to walk and purchase food and beverages, souvenirs and other merchandise. In addition, there is a complete children's playground, a batting cage and other baseball oriented games, a restaurant and brewery, along with plenty of concession areas and restrooms located at various points on the concourses.

Advantageous Features

Beyond the fact that the skeletal structure of Coors Field gives the stadium the ambiance of a true grandstand park, there are several unique technical aspects of the stadium's design.

For example, during the schematic design, Martin/Martin evaluated the anticipated thermal motions of the stadium due to seasonal temperature changes. Based on this review, the main concourse level was broken into 12 pieces with 13 expansion joints. Both a double column scheme and a single column scheme with slide bearings were studied. The slide bearing scheme was selected to reduce

the amount of material and increase floor space availability in the suites.

Martin/Martin also designed and detailed all steel connections and worked with both the architect and contractor to create aesthetic and constructible details. Truss and braced frame splices and connections were detailed on an individual basis while typical floor framing connections were scheduled. Seated connections were used at all girder-to-column connections to ease erection and provide a consistent look with the slide bearing connections at expansion joints.

Schedule Considerations

The schedule for Coors Field also resulted in the architect specifying that all structural steel be pre-painted with both primer and finish coats of 6 mils. This required special handling of the steel and verification that the painted surfaces met critical slip criteria.

Tests also were conducted in advance of construction to assure headed shear studs could be effectively welded through both the 16 gauge decking and heavy paint to the beams and trusses. Welded connections were typically seal welded to prevent future rusting of surfaces, which might not be accessible to provide full coverage while painting.

Martin/Martin performed a comprehensive vibration analysis of each of the unique bents supporting the grandstands to consider the baseball fan's dynamic loading of the structure. Many of the structural members, particularly the cantilevered trusses at the upper concourse, were governed by limiting accelerations at the suite boxes. Truss members ranged in size from W14x90 to W14x211.

The design of Coors Field provides baseball fans with a modern venue to watch major league baseball games, a stadium that is both "user-friendly" and traditional in appearance. In addition, the structure has helped revitalize an economically challenged neighborhood.

Engineering Awards of Excellence

National Winner

The Artsgarden at Circle Center

SITTING 17' ABOVE A MAJOR INTERSECTION IN DOWNTOWN INDIANAPOLIS is the new Artsgarden. A domed glass atrium, the building curves 95' above street level (equal to seven stories) and is 118' in diameter. The architectural marvel serves as both a venue for the arts and also acts as a bridge connecting the retail buildings on three of the intersection's corners, along with a park on the fourth corner.

Owned and operated by the Arts Council of Indianapolis, the glass building and central location makes it the perfect spot to promote cultural and arts activities. Each day, at least 10,000 people are estimated to walk through the building, bringing exposure to the programs offered at the Artsgarden. The building adds a new dimension to the blossoming arts scene in Indianapolis.

There are over 300 events a year held at the Artsgarden. Some of the events at the atrium include art exhibits, visual arts

The Artsgarden is supported by two 185'-long steel plate girders spanning each direction across the intersection. The top of the dome soars some 95' above the street.
Photo (above and opposite page) by Timothy Hursley

and craft exhibitions, music, theater and dance presentations, lectures, films, readings, artists-in-residence, educational projects, fairs and festivals. The building can house up to 600 people standing, 400 people seated for a performance and 250 people seated at tables. It also acts an information center for other art and cultural events in Indianapolis by providing calendars, schedules, maps, directories, and other information.

Even those not there for a per-

Project Team

Structural Engineer:
Weiskopf & Pickworth LLP, New York City (AISC Professional Member)

Architect:
Ehrenkrantz & Eckstut Architects, New York City

Construction Manager:
DeMars Program Management, Indianapolis

Owner:
Simon Development Company, Indianapolis

Steel Fabricator:
The Kilroy Structural Steel Co.

Steel Erector:
Runyon Erectors

Steel Detailers:
Associated Drafting Service, Inc.

The dome takes its shape from a steel-framed skylight consisting of a series of circular arch trusses with pipe section chords and tie rod diagonals. The chords of each truss converge to a single pipe column ringing the perimeter of the Artsgarden space.
Photo by Timothy Hursley

The Artsgarden is the central civic element in a city that boasts many remarkable public spaces. This nighttime photo shows the headlights of traffic flowing under the Artsgarden. Note the sloped glass at the base of the smallest arch, which creates a more circular floorplan.
Photo by Timothy Hursley

formance can enjoy the Artsgarden as they relax in the sunlight under a grove of Black Olive trees. Movable café chairs and tables also provide visitors with a place to socialize.

Lilly Endowment, Inc. funded the project, which cost $12 million. The structure, which encompasses 19,000 sq. ft. (including bridges), utilizes 1.1 million pounds of steel in addition to 32,000 sq. ft. of glass.

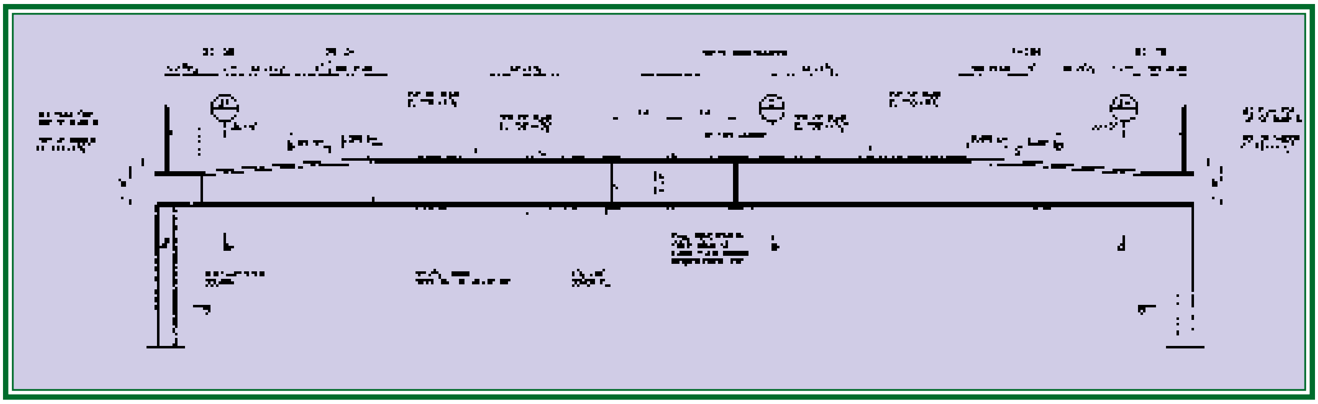
In order to create an open, airy feel to the structure, hollow structural sections with elegant designs were used to create semi-circular arch trusses. Reaching up 75’ above the floor level, the dome has a 110’ column-free span.

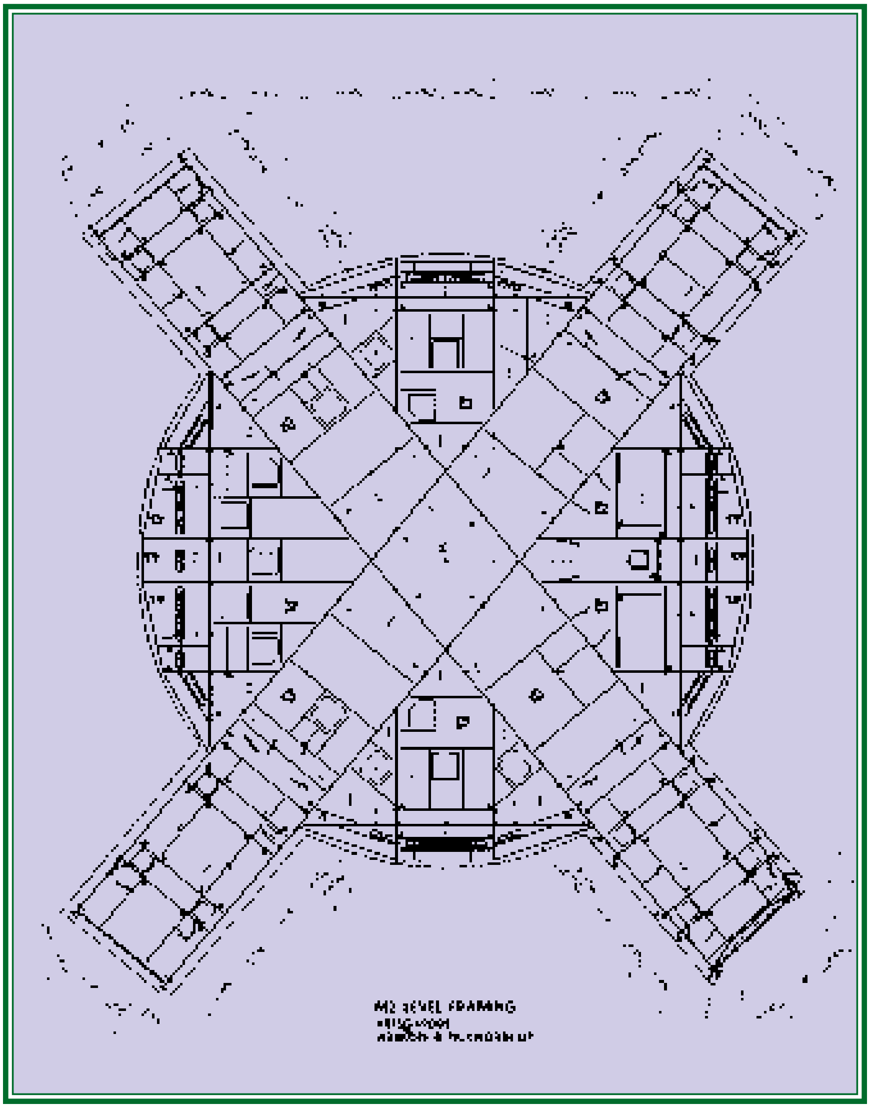
A series of arched trusses support the skylight roof of this structure. The trusses have HSS chords, verticals and diagonals with tie rods acting as lateral braces between the trusses. The chords of each truss rise from a single pipe column. These columns form a ring at the perimeter of the Artsgarden space. The lighting and sound canopy is suspended from the arches, forming a cloud-like illusion.

HSS Columns

The surrounding buildings did not have the additional capacity to support the new “bridge” across the intersection. In order to tie together the four corners, the designers supported the dome on built-up plate girders that span 185’ diagonally across the intersection – two in each direction. Columns either embedded within the surrounding buildings or freestanding at the stair tower that leads down to a neighborhood park support these girders.

The eight support columns were built up from plates up to 2½” thick to form 28” square box sections. None of the columns interfere with the intersection or pedestrian walkways. Also, with 17’ clearance below the Artsgarden, there is plenty of room for truck traffic.





The Artsgarden structural also acts as bridge linking the buildings on the interesection's four corners. The bridges are supported by three pipe columns as they converge with the glass dome.

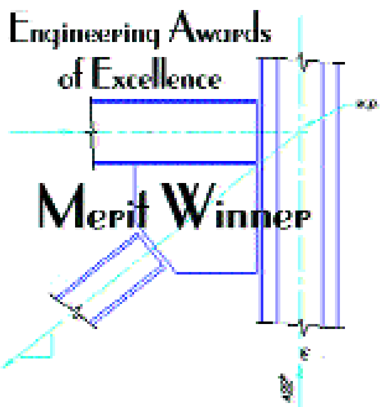
At the outer ends, the bridges are supported either on columns embedded within the buildings or on freestanding columns with stairs.

The dome itself reaches 75' above the floor level and boasts a 110' column-free space.

Lateral support below the floor of the Artsgarden is through moment connections, while diagonal bracing was used in the dome itself. The stepped profile of the structure allows more light and air to the street, along with extensive lighting to enhance the environment below.

The Artsgarden is a part of an on-going effort by the city to revitalize the downtown area. It now serves as the bridge between the new Circle Centre (see April 1997 *Modern Steel Construction*), which contains 970,000 sq. ft. of retail, parking and entertainment, the Claypool Shops and Merchants Plaza. The fourth corner links to a public park, connecting the Artsgarden to Indianapolis Monument Circle.

The Arts Council said that the building's visibility has already increased interest in their programs, as well as improving the credibility of the arts.



Jacobs Field

FOR 62 YEARS, CLEVELAND MUNICIPAL STADIUM WAS HOME TO THE CLEVELAND INDIANS. They played their first game at the stadium, originally built in a failed attempt to attract the 1932 Olympics, against the Philadelphia A's. The Indians lost. The enormous stadium located next to Lake Erie had over 74,000 seats, more than any other major league baseball stadium. However, that wasn't necessarily a positive, especially for those stuck in "the Dawg Pound," center field's bleacher seats – a place no batter had ever reached with a home run.

It was only a matter of time before the Indians would find themselves in a new home. Originally, the plan was to build a domed stadium in downtown Cleveland, but voters who didn't want the increase in their property tax rejected this proposal. Finally, in 1992, construction began downtown on Jacobs Field. Both public and private money helped finance the building of the stadium. Richard Jacobs, owner of the Indians, provided $91 million; the rest of the money ($84 million) came from a 15-year tax on cigarettes and alcohol in Cuyahoga County.

The Osborn Engineering Company, structural engineers for the project, was given several constraints for design of the ballpark. They included finding an alternative lateral bracing system, aesthetics, multiple levels of suites, unobstructed views, asymmetry and a fast track schedule.

When the design architects first approached them, they suggested modeling the cross section after the ballpark at Camden Yards, home of the Baltimore Orioles, a project the architects had just completed. However, one major variation was needed—elimination of the primary vertical cross bracing system. Though an efficient means for stabilizing the ballpark and economizing the structural design, primary vertical cross bracing interferes with circulation space behind the suites.

Another reliable method of lateral support would have to be found if this was to be done. Different methods were explored, and it was finally decided welded trusses were the best option. They were chosen in order to develop large couples within their top and bottom chords to resist lateral forces. Trusses at least 6' in depth were required based on spans. Wide flange beams 24" to 36" in depth were coupled with welded moment connections when floor to floor heights prevented the use of trusses.

After a short study of the advantages of concrete versus steel, it was decided steel would provide a quicker and more aesthetically pleasing ballpark. They wanted the stadium to fit in with the present structures along the Cuyahoga River. Also, steel could be erected easier in the winter. In order to meet the unobstructed view and the three levels of suites requirement, column location would have to optimized versus allowable spans for cantilever framing. There were 32 separate "events" around the ballpark and each had a different structural response. In the end, 41 separate cross-sections were analyzed and designed.

Columns

Jacobs Field's layout involves 37 grid lines used with 74 column lines, one 4' each side of a primary grid, making it very asymmetrical. The layout features a twin column arrangement with 24"-diameter and ¾"-thick columns spaced 4' on each side of the 42'-6" gridline. For three-dimensional stability of the large unbraced length, round columns were necessary, along with all columns at one row being staggered one-half bay in plan. This created triangular framing in the floors, which made up for the absence of cross bracing.

By cantilevering three levels of suites, extremely large moments were formed creating the need for a row of W36x300 columns. The cross sectional spacing of columns across a bent line was optimized in order to balance loads about this row of columns and reduce the tendency for the structure to drift inward toward the playing field. The cross bracing in the exterior elevations does not resolve itself to the main concourse, but instead was used to reduce the unsupported length of columns rising to support the upper concourse level 60' above.

Trusses

For aesthetic purposes, the exposed trusses were composed of wide flanges with W12x40 top chords, W8x40 bottom chords and W8x31 verticals and diagonals. Truss members were connected with 5/16" fillet welds. Welding came into play when the trusses were connected to the round columns in manner that would allow the chords develop the required moments and axial forces necessary to develop lateral force resisting couples. While the proportions of the trusses and round columns eliminated the need for bracing, large moments resulted at connections of trusses and girders to the columns.

Project Team

Structural Engineer:
The Osborn Engineering Company, Cleveland

Architect:
HOK Sport, Kansas City

Construction Manager:
Huber, Hunt & Nichols, Indianapolis

Owner:
The Gateway Economic Development Corp., Cleveland

Steel Fabricator and Detailer:
Kilroy Structural Steel

Unfortunately, the columns used to carry the vertical loads were 24"-diameter, ¾"-thick HSS members, which created a problem. The design team modeled stability of the 24"-diameter column shell at primary connections for local buckling by finite element methods. Now it was necessary to reinforce the column at primary connections, so a 24" diameter, 1.75" wall insert of 46 KSI steel was used. Using semi-automatic SAW techniques, an 8'-long insert was full penetration welded to the ¾" wall standard pipe column and located at the proper elevation in relation to the 6' deep trusses framing to the column. As many as five trusses were framed into one insert without having to add any internal stiffeners. As a result, thicker tubular steel was located in columns only where it was needed, with thinner tubular cross sections used elsewhere to reduce costs.

Since it was desired to have a vertical member approximately 10" from the face of the column, the exterior truss to column connections was complicated. A connection plate was welded continuously to the vertical and top and bottom chord extensions. In the connection of top and bottom wide flange chords of trusses to the insert, complete penetration welds were necessary. Slip critical, A-490 type F bolts were also used in these connections.

Floor Framing

The floors were designed with composite floor deck spanning over non-composite beams. The need for studs in beams and tops of chord trusses was eliminated because of the triangular configuration of framing for a typical bay with offset columns at line H. The plan specified for a 3", 20-gage composite deck with multiple spans. Normal weight concrete was used, which also added dead weight to counter balance the overturning moment of the Level Three suites. (The pedestrian ramps and bridge ramps were framed this way, too.)

Suite Framing

There are 121 suites at Jacobs Field, most of which are stacked three levels high. The suites are all cantilevered approximately 30'. In order to insure vertical support, hangers were made using two 1¼" x 6" steel plates spaced 1" apart for loads up to 300 kips. At the lower club suite levels, TS4x4x5/16 hangers were used. Additional diagonal struts (two 1¼"x10" plates) had to be added at the lower and club level suites to redistribute loads back to the primary columns because a single line of hangers generated so much reaction.

A problem arose because on each side of the hangers located on the primary grid line, the structural framing was offset. The girders, which were carrying large reactions over 400 kips that had to be connected back to the columns, needed to be laterally braced. Stiff, triangular transfer frames were made from W27x102 and W27x89 shapes welded together, and were placed in the 8' space between floor girders in front of the columns and centered on hangers. The two W27x102 floor girders at each level were tied. It also resolved the horizontal and vertical components of the diagonal struts, through welded gusset plates into the transfer frame.

Cantilever Trusses

Three triangular welded cantilever truss styles were used in the project. The first was shallow with a long span and was used to support the club seating along the first base line and mezzanine seating in right field. The design, which was 9'-9" deep but only cantilevered 32'-6", was controlled by deflection. The second cantilever truss style is a simple design (common to ballparks) where the truss is used at each column line to cantilever the front third of the upper seating level. This design was slightly modified to accommodate seating for the disabled. A different style of truss was used for the large portions of the upper and club level concourses behind right field and to support the club lounge and its 30' high curtain wall. The last cantilever style was used for aesthetic purposes and to support the sunscreen over the back of the upper seating bowl. The top chord of these trusses have a 50' radius and the bottom chord is angled 10 degrees upward from the playing field. Attached to the bottom chord are purlins spaced 10' on center, which support the metal panels making up the roof. A brace (W12x40) was welded behind the sunscreen trusses to resolve the bending moments into 24" round columns supporting the roof load. This was repeated every third point in each bay around the ballpark to for a "crown," unifying the design and adding an aesthetic element.

Stadium Club

The design of the stadium club involved the complicated task of trying to juxtaposition the terraced multi-level floor system at a 45 degree angle into the 42'-6" ballpark grid system. The use of suspended structural glass curtain walls (built to provide unobstructed view of the field from the terraced dining room) provided another problem. Welded trusses with heavy top and bottom chords were used, along with additional cross bracing within the depth of the truss system to laterally brace jack trusses at reaction points.

Upper Seating

The upper seating bowl was designed using precast concrete, double tread and riser unites that were supported by brackets welded to W36x118 rakers. Both ends of the precast units spanning the 8' simple span were fixed between the twin belt lines, adding lateral support.

The diaphragm created by this, along with additional X-bracing in the plane of the rakers, provided necessary longitudinal stiffness. The beams and trusses that ring the back of the seating bowl provide additional lateral support. The upper structure is anchored by the stub extensions of the W36 columns at line E, which extend 8' above the upper concourse level. The W36 x 118 rakers are attached with full welded moment.

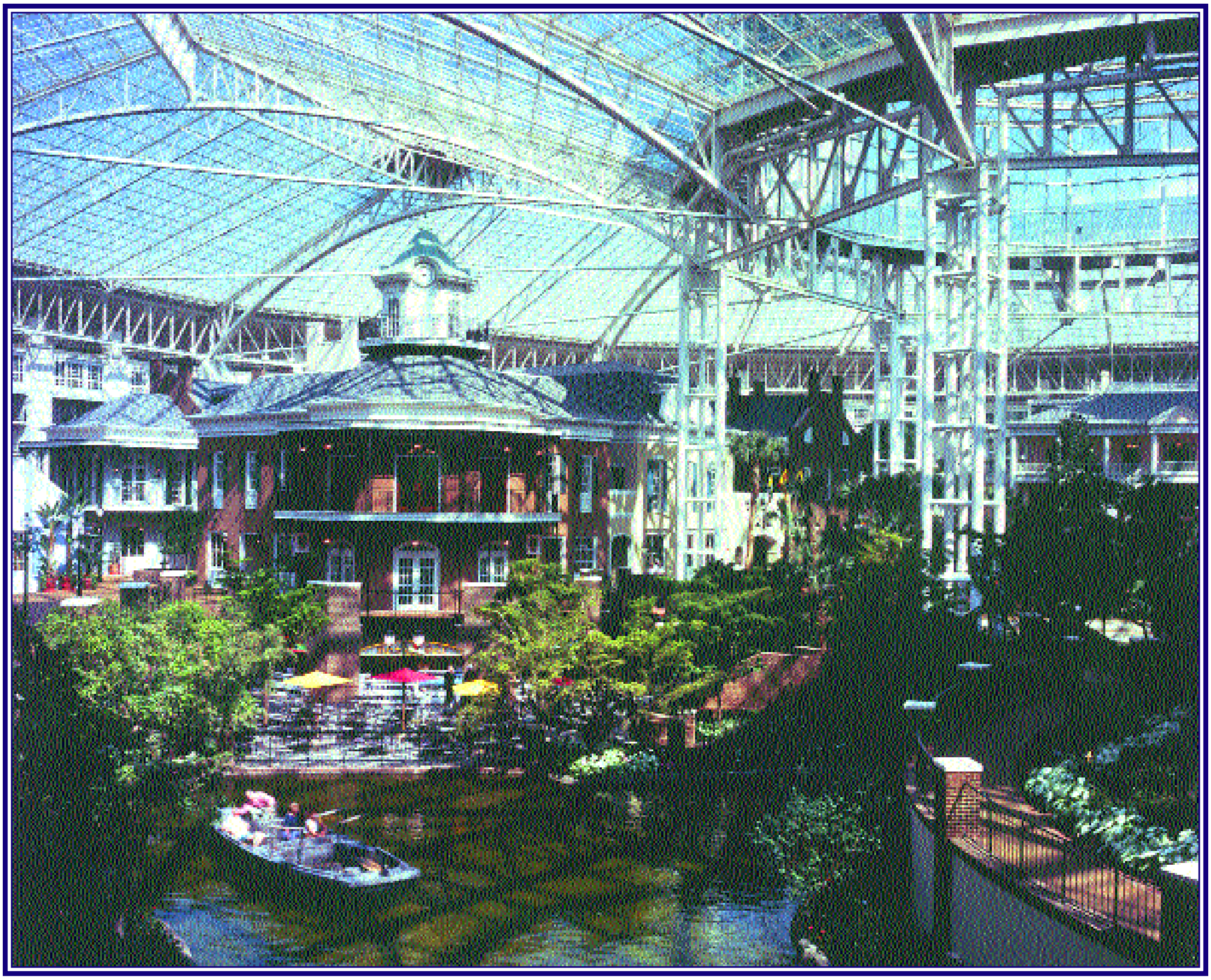
Light Towers

A cantilever structural design is used to support 19 separate banks of field lighting that are arranged vertically. The height of the lights made a third 24" round column necessary in order to support the reactions and deflection. The column springs from a system of welded x-braces arranged in a triangle below the upper concourse.

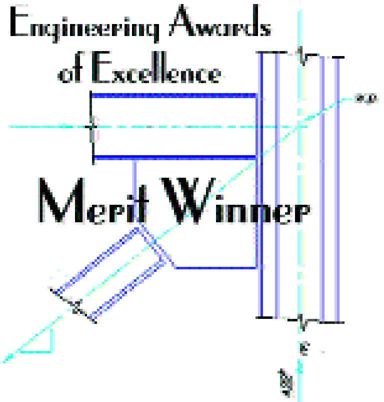
Scoreboard

The stadium is home to the world's largest freestanding scoreboard, with a combined surface area equal to the façade of a 5-story building (200' long). It was structures from five triads of 24" diameter by 1.75" wall pipe columns centered in an isosceles triangle with an 8' base and a 7' altitude. Twin shear walls that spring from the foundation of the center field bleachers buttress the columns. Large reactions developed through welded couplers transfer the reactions into No. 11 rebar developed in the buttresses, making connections of shear walls to 1½" thick embedded steel plates possible.

Over 10,000 tons of steel and 18 months later, the construction of Jacobs Field is complete. While the new stadium is smaller than Cleveland Stadium (almost 20,000 fewer seats), this hasn't hurt the ballpark. Ticket sales have actually increased for games, making the stadium a success.



Opryland Hotel



ONE OF THE LARGEST—AND MOST INTERESTING—HOTELS IN THE UNITED STATES is the Opryland Hotel and Convention Center in Nashville. First opened in 1977, it has undergone three expansions, with the most recent one, known as the Delta, consisting of a giant, 179,000-sq.-ft., steel-framed skylight covering 4.2 acres.

Under the skylight is an antebellum mansion housing a 400-seat restaurant that overlooks a lazily flowing quarter-mile-long "river". The river runs around a New Orleans-style island village, complete with riverboat rides, retail shops, a jazz bar, food court and meandering walkways that connect the addition to the convention center and other areas of the hotel. Full-size trees—including a 40'-tall West

Indian Mahogany—fit easily into the landscape, as do fountains, a 110'-wide waterfall, and a wedding gazebo.

The owner, Gaylord Entertainment in Nashville, and architect, Earl Swensson Associates, also of Nashville, envisioned for the Delta a unique area designed to mesh with earlier additions to the hotel—the Cascades and Conservatory—while providing a new and different experience. After careful study of hotel traffic patterns, the addition was placed on the west side of the facility to serve as a connector between the convention center and the hotel. The goal was to give conventioneers and meeting attendees an environment "away from it all" to relax, grab a bite to eat, and unwind. In addition, it was also designed to accommodate other hotel guests and visitors, who could explore the shops, people watch and take a lazy trip down the river. The use of full-grown trees, flowers and other foliage would enhance the feeling of outdoors. However, the soaring 15-story glass skylight is double-paned to ensure energy conservation, human comfort, safety and plant growth.

The challenge to the structural engineers at Stanley D. Lindsey and Associates, Ltd., was to provide a structural system to support the 4.2 acre skylight that would be aesthetically pleasing while also providing a column-free interior that would complement the roof lines of the Conservatory and Cascades areas.

The resultant bar joist and tied-arch roof system is light and elegant, as well as structurally sound. The gabled top chord and circular arched bottom chord of the trusses are aesthetically pleasing and create a roof line that complements the adjacent roof areas. Additionally, the tied-arch truss configuration permitted the use of a shallower truss profile and also minimized the thrust forces at the supports. The support design was thereby

Project Team

Structural Engineer:
Stanley D. Lindsey and Associates, Ltd., Nashville

Architect:
Earl Swensson Associates, Nashville

General Contractor:
Hardaway Construction Corporation, Nashville

Owner:
Gaylord Entertainment

Steel Fabricator:
Wylie Steel (AISC Active Member)

Steel Detailer:
Steelcon, Inc.

Steel Erector:
Structural Steel Erectors

more economical than other systems since the design was governed by lateral wind forces as opposed to thrust forces.

Structural Details

The design for the Delta roof evolved from the construction of the previous additions. The Conservatory roof consisted of long-span bar joists and truss girders supported by steel tube columns. Since a larger column-free space was desired for the Cascades, a system of tied-arch trusses spaced at approximately 27' on center and spanning up to 165' was selected. This structural system and concept for column-free space carried over to the new Delta skylight.

The complex structural system for the skylight is comprised of seven tied-arch trusses that radiate from a somewhat central gazebo structure. These tied-arch trusses clear span up to 214' between the gazebo structure and X-braced, box-type vertical trusses at the skylight's perimeter, which creates a distinctive "interiorscape". With tributary widths of approximately 100', the tied-arch trusses' member sizes are much larger than those of the Cascades. The top chord of the tied-arch truss is a W14 and the bottom chord is typically a W24. The curved bottom chord member is turned on its weak axis to minimize bottom chord bracing where this member is in compression. The tension tie member of the tied-arch truss is an 8"-diameter, double extra strong HSS.

Spanning between the ridge of the tied-arch trusses is a 10'-deep, parallel chord truss. The ends of the tied-arch trusses opposite the gazebo structure are tied together by two parallel chord trusses approximately 17' apart. The ridge truss and perimeter trusses span between 100' and 160'. The trusses are typically comprised of W14 top and bottom chords, and double angle web members. These trusses support conventional truss girder spaced equally between tied-arch trusses. Bar joists, approximately 26" deep, frame between the truss girders to support the skylight system.

The Delta skylight has two hipped roof sections on opposite sides of the gazebo. A tied-arch truss is located at the ridge of the hip with parallel chord trusses framing into the peak to create the hip. The remaining framing in this area is similar to the typical roof area.

The gazebo is a 12-sided structure whose structural function is to support one end of the tied-arch trusses. In addition, the gazebo structure also resists a portion of the lateral loads from the roof structure. Architecturally, the gazebo was designed as a visual focus point. A 15'-deep ring truss at the tied-arch truss-bearing elevation acts as a tension ring to support gravity loads and resists lateral forces through frame action. Approximately 20' above this level is a second tension ring truss to support the gazebo roof. The compression ring at the top of the gazebo roof is a 24"-deep wide flange section fully welded together in a 12-sided "ring". Framing between the tension and compression ring are W24 rafters radiating from the top. A combination of wide flange sections and bar joists span between rafters supporting the skylight section. A smoke evacuation cupola comprised of wide flange sections frames up off of the compression ring.

The Delta skylight structure is bounded by previous construction phases not designed to support the new roof structure. Therefore, the roof structure is a completely independent structure supported on by the gazebo structure and seven, box-type vertical shear trusses. These shear trusses use 16” square HSS and double-angle X-bracing to resist gravity and lateral loads.

The complex shape of the roof led the design team to enlist the services of the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario to perform a wind tunnel study to establish the actual design wind pressures. These wind pressures were used in the three-dimensional analysis and design of the structural members. The three-dimensional model also was used to distribute the lateral loads between the lateral resisting shear trusses and the gazebo.

The glass skylight system is incapable of acting as a diaphragm to brace the trusses and transfer lateral forces to the resisting elements. To create a diaphragm, a system of diagonal rod bracing in the plane of the joist top chord is provided. Compression forces are specified for the joist top chords, which also participate in the lateral bracing system for the roof trusses.

Fabricator on the $175 million project was AISC-member Wylie Steel. Erector for the 2,000-ton steel project was Structural Steel Erectors, Mt. Juliet, TN. Detailer was Steel Con, Inc., in Memphis.

System Advantages

The tied-arch truss also is more economical compared to a conventional truss of similar geometry because the arch is typically in compression instead of bending, minimizing the material required. Turning the bottom chord compression member on its weak axis also allowed a larger distance between bracing points, reducing the amount of bottom chord bracing.

The tied-arch truss also is an efficient configuration for limiting the deflection of long-span members. Deflections of the structure had to be limited to satisfy glass deflection criteria and prevent leaks within the skylight system. The tied-arch trusses also participate with the supporting vertical box trusses and central gazebo structure to resist large gravity loads along with lateral wind forces.