TILTING THEATER

Structural steel was the natural choice for a skewed, canted, sloped, tilted, rotated, conical and spherical building

Top: View of top of the existing museum; note the sloping precast support beam.
Above: View of nearly complete theater. Note the varied slopes and angles on the project.

By Rod McComas, P.E.

WHILE THE PROGRAM FOR A NEW IWERKS THEATER WAS VERY STRAIGHTFORWARD, the desire by the owner and architect to create a Midwestern "icon" made the design incredibly complex. As the largest of its kind anywhere in the world, the Children's Museum of Indianapolis is always working to not just maintain visitor interest but also to attract new visitors.

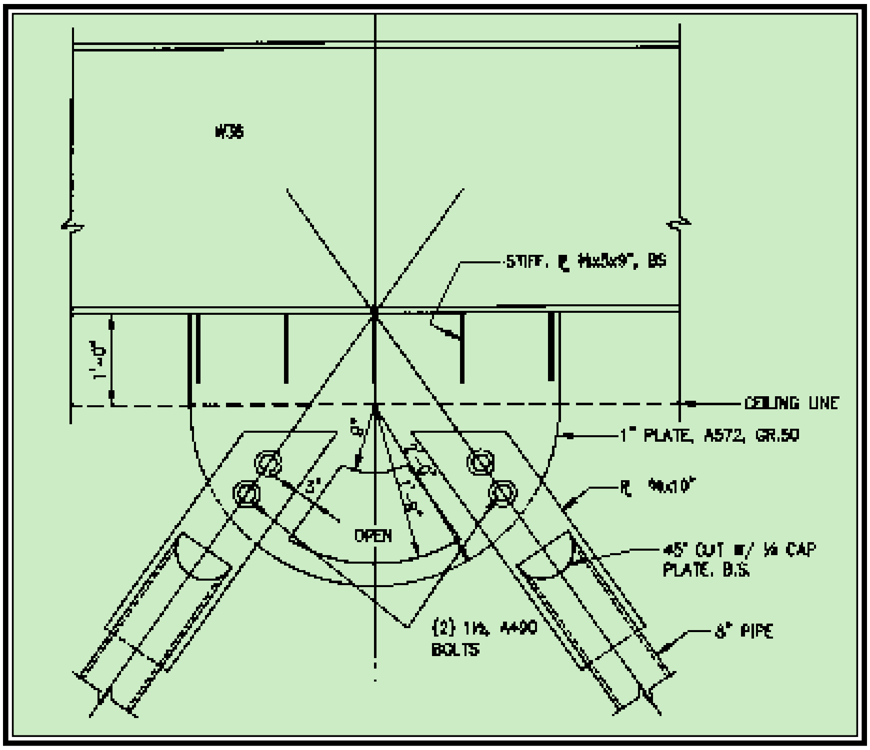
The program was to design a building to house an IWERKS domed theater with seating for approximately 312 people. In addition, the lobby space should be large enough to provide for private parties, receptions, etc. The new theater building is set away from the existing museum and is connected by a concourse. All design must be appealing and stimulating to children of all ages, and adults. With all of this in mind, the project architect designed a frustum to house the domed theater. The building footprint is approximately 12,000 sq. ft. with a total building area of approximately 31,000 sq. ft.

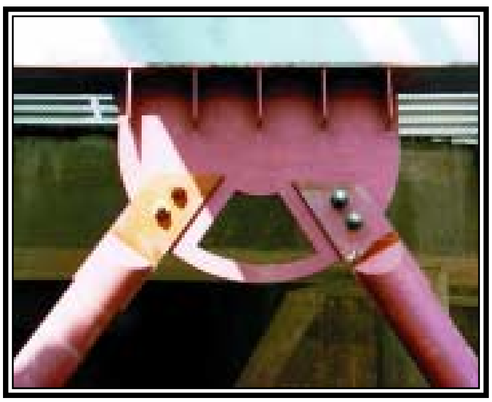
STRUCTURAL DESIGN

Structurally, the project is divided into two areas, the theater and the rotunda/concourse. The theater building houses the concrete seating, IWERKS projector and domed, aluminum screen and is a very dynamic area. The theater building is a frustum (or the remainder of a truncated cone), with the cone sloped at 10 degrees, then tilted at five degrees. The entire theater building is then rotated 15 degrees relative to the major axis of the project. Additional complexity is derived from the three floor plates curving and intersecting the tilted, conical building.

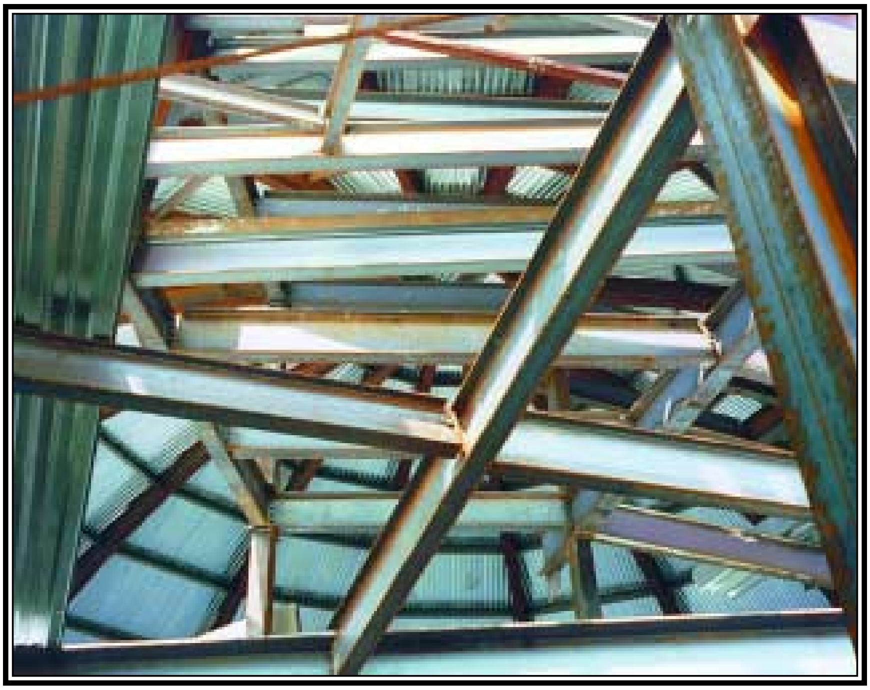
The concourse/rotunda area was slightly less complex. The concourse is all exposed structural steel with a seven-foot deep utility tunnel below. Half the concourse "fans" out as it intersects the tilting conical building. At the opposite end, the rotunda is another truncated conical building, rotated 15 degrees in the opposite direction of the theater building. It was determined that the most efficient means of analyzing the structure for both gravity and lateral loading would be a complete three-dimensional analysis of the structural steel framing. Two different analyses were done. The first was an analysis of the structure during erection. Because shear walls and ancillary framing would not be completed until several months after the primary steel erection, the structure had to be capable of withstanding loads alone. The second analysis was of the completed structure with all items in place. The three-dimensional computer model was developed. Eagle Point Software's Structural Expert Series Space Frame Analysis and Design (formerly sold by ECOM Associates) was then used to design the structure. Ram Analysis' RamSTEEL program was used to design the floor and roof plates for gravity loading.

Deflection, drift and thermal criteria were strictly adhered to for the design of the framing. The exterior of the building is clad in curved, trapezoidal shaped precast panels, glass, copper and brick. As with any museum or monumental type structure, long-term serviceability is a major concern. The connections for most of the materials to structure were designed to provide maximum flexibility under all loading conditions. The





Exposed structural steel was used throughout the project. Shown at left is a close-up of an exposed gusset plate in the lobby. The photo above shows the interface between the steel and concrete portions of the project.



The photo above pictures five different levels of steel framing and demonstrates the complex and intricate design demanded in this project.

precast panels are supported with separate, curved, sloping steel beams. This allowed the precast panels to move independent of the main building structure.

Design Alternatives

Cast-in-place concrete was initially considered for the building structure. However, after several meetings with the construction manager, it was determined that concrete would not be economically feasible due to the complexity and height of the formwork required. A concentrated effort was then made toward framing the entire building using structural steel.

Because most of the connections on the project are both sloped and skewed, rolled angled could not be used. Instead, plates had to be welded together to form the required angles, and therefore double angle connections would have been difficult to fabricate. As a result, a design was developed using single plate connections instead of double angle connections. McComas Engineering and AISC-member United Steel Fabricators, the project's fabricator, worked together to develop standard, single plate connections that could be used throughout the project.

Steel joists were investigated for use on the roof. However, very few joists would have been the same length or depth. Therefore, fabricated steel was determined to be the more economical solution.

Unique Features

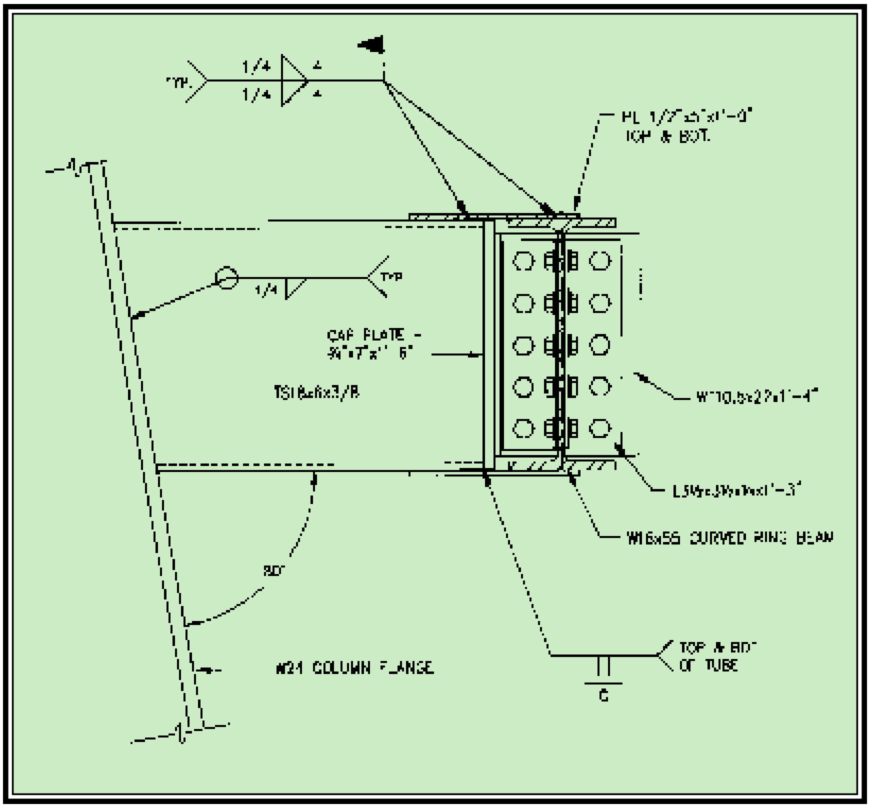
Cast-in-place structural concrete was chosen for the seating risers and screen support. Concrete provided the flexibility required to build a sloping base ring to set the aluminum screen on. The base ring forms a circle, sloped at 30 degrees. The top of the base ring also slopes in the opposite direction. In addition, the seating area is a true ellipse, in plan. This could not be accomplished using structural steel. The exterior, below grade concrete walls have an elliptical shape and curve, both horizontally and vertically, in plan and elevation.

ATSM A572, Grade 50 steel was selected for the building because of availability and cost effectiveness. For connections and miscellaneous angle framing, A36 steel was used. Steel provided the fastest and most economical solution to framing the building. The conical theater building has sloping columns varying from five to 15 degrees from vertical. This presented a unique erection challenge. Because the structure was unstable until all members were in place, two cranes were used. One crane held in place the compression ring at the top, while the other moved around and set the rest of the steel. The individual columns, baseplates, anchor bolts and foundations were also designed to be freestanding during erection. This had to be done because beams could not be immediately framed into the columns do to the complexity of the connections. The lateral bracing system is a combination of diagonally braced frames and masonry shear walls. Because the main building is conical, tilted and skewed, the only symmetry comes about the major axis of the ellipse.

Composite beams were used for all floors. The loading criteria included very large air handling units, large displays that hang and set on the floor, and 200 to 300 people gathering in small areas. With floor-to-floor heights limited and large amounts of ductwork all over the building, composite beams proved to be a very good choice.

Different structural shapes were used to enhance the overall aesthetics of the building. Many areas have exposed tubes, pipes, rods and wide flanges. The architect wanted to showcase the structure in the lobby, concourse and rotunda. Uniquely shaped gusset plates were uses, in addition to rolled shapes to accomplish the goal.

The approximate constructed cost of the project will be $9 million, with the structural portion consisting of \$2.7 million. Construction manager on the project was F.A. Wilhelm Construction Co., Inc., Indianapolis. Through value engineering, McComas Engineering was able to significantly reduce the cost and cut time out of the schedule by changing connection design, using high strength steel allowing for innovative concrete forming techniques. McComas Engineering worked very closely with architect Browning Day Mullins Dierdorf of Indianapolis in trying to simplify the architecture while not compromising aesthetics. McComas Engineering also provided three-dimensional data to assist in building layout, formwork layout and steel detailing. All members of the engineering, architectural and construction teams take great pride in designing and constructed a very complex and detailed building for children to enjoy for decades to come.



OTHER CONSIDERATIONS

Most of the steel within the building envelope was supplied unpainted because of fireproofing requirements. Cementitious fireproofing was applied. Chevron pipe braces are exposed in the lobby area. The gusset plates are also exposed with holes cut in them for aesthetic treatment. The exposed bracing in the lobby is an important architectural statement showing that the tilting building was indeed designed that way and is rigidly supported. All of the exposed steel had SPCC SP-6 surface preparation and was delivered to the jobsite with an epoxy primer.

While snug-tight bolting was specified, the fabricator and erector chose to use direct tension indicating, "twist-off" bolts for all $\frac{3}{4}$-in. A325 bolted connections. The erector felt more comfortable using these bolts because the firm had never erected a leaning building before. $1\frac{1}{2}$-in. A490 Bolts were used for the exposed chevron bracing connections. The architect felt the scale of the bracing would read better using larger bolts.

The domed roof is constructed using W24x68 beams, rolled the "hard way" to a 60-ft.-6-in. radius. A compression ring beam frames out the top and $1\frac{1}{2}$-in. x 20 gage galvanized metal roof deck was erected curving up the roof. Wheeling Corrugating supplied the metal roof and floor deck. The erector, Recast, Inc. of Indianapolis, cut the deck over the purlins and "walked" it, full length up the dome. Four inches of low slump concrete was then poured on the dome.

There were many beams, from W18x35 to W30x99, that had to be rolled the easy way and the hard way. Chicago Metal Rolled Products and Hardwick's rolled the beams for United Steel Fabricators.

Because of the large volume of concrete on the walls and roof, seismic forces governed the design of the lateral load resisting system. Chevron bracing was chosen to accommodate the many corridors and ducts within the building. Due to the seismic forces and the tilting geometry of the building, high shear reactions had to be transferred at the column bases. The column bases were also modeled as partially-pinned, thereby, transferring moments to the foundations. To transfer these forces, 6-in. pipe shear lugs were used in addition to $1\frac{1}{2}$-in. A36 anchor bolts.

A building that tilts is something people do not see everyday. The design and construction team has done an outstanding job in giving The Children's Museum Of Indianapolis a Midwestern icon. With the project being on schedule and on budget, everyone is very proud to have played a part in the engineering, architecture and construction of the new CineDome Theater.

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