



GATEWAY TO THE CIRCLE CITY

By Scott E. Rouse, P.E.

New Indianapolis Airport Terminal and Enplanement Drive.

Some people call it a saddle, a clamshell, a snake's head, a bike seat, a potato chip, or a tortilla chip.

The mathematical description is a 1260-foot radius, double reverse curve in one direction with a single 1260-foot radius curve intersecting the double curve in the orthogonal direction.

The Indianapolis Airport Authority's objectives for a new Airport Terminal included the design and construction of a modern, efficient gateway, uniquely representative of the history and future of Indiana. The design architect responded with an undulating aerodynamically shaped terminal roof of structural steel to work with the wind and the sun. The result is a graceful, elegant structure featuring a 200-foot diameter circular skylight sixty feet above a grand civic plaza, a fitting metaphor for the city's defining downtown space known as Monument Circle.

Terminal Roof Design

Geometric Complexities

The challenge was mathematically defining the intersection of the saddle shaped roof surface with the perimeter of the 200-foot circular skylight as well as the roof's perimeter gutter condition, and converting it into constructible components. Since the curvature was not confined within one plane, the members had to be made of built up plate box girders bent to a varying radius rather than conventional shapes rolled to a constant radius. The curve of the perimeter steel then matched the curve of the architectural finish. Therefore, the attachment detail could be a constant condition around the entire perimeter. This was considered more economical than using straight segments of structural steel with constantly varying conditions for the finish attachments.

Structural Design

Wind tunnel analysis and snow deposition studies were performed to compare the wind and snow loads to the code prescribed forces for this project. The design snow load for this project was determined to be less than the International Building Code (IBC) prescribed forces for the Indianapolis area, due to its relatively open exposure to wind during snow storms.

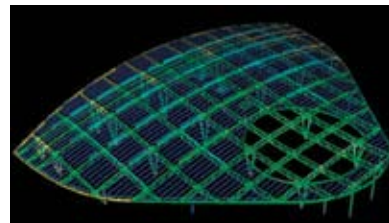
A two-way truss system offers the redundancy that is not provided by one-way trusses. The primary trusses typically span 112 feet in each direction, with the main space in the terminal ticket counter area being 140 by 112. The primary trusses carry a series of two-way

secondary trusses at 56 feet on center in each direction. The trusses cantilever nearly sixty feet out over the enplanement drive at the most extreme condition.

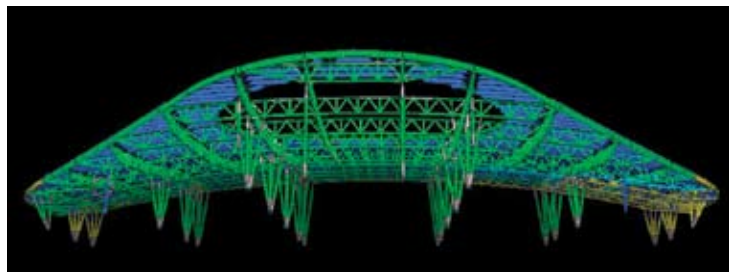
The trusses consist of round HSS bottom chords and diagonal web members, and wide flange top chords. The top and bottom chords were all continuously rolled to the 1260-foot radius rather than provided in straight segments, to meet the architectural aesthetic requirements. As a result of this, the quantity of fully welded splices that would be necessary was significantly reduced.

The roof joist purlins of the terminal serve multiple functions beyond the standard vertical load carrying duties. The typical joist spans 56 feet between secondary trusses. Axial loads were specified at each end of the joists top chords based on the lateral bracing requirements for the top chords of the two-way trusses. Even the joist bridging was designed for specified loads by the structural engineer to torsionally restrain the curved box girder at the roof perimeter, and to prevent twist buckling of the primary truss wide flange top chords.

The runoff from rain on the roof is collected by a perimeter gutter system designed as an open channel with weirs to control the flow into the roof drain system, which consists of eighteen inch diameter stainless steel piping. There are more than 7 acres, about 320,000 square feet, of surface runoff from the roof. The routing of the roof drains were carefully coordinated with the joist supplier, due to the significant loads generated by the fully loaded 18-inch diameter piping. The joists were designed and reinforced locally for the individual concentrated loads from the piping hangers. A series of guardrail systems to contain sliding snow on the steeper parts of the roof protect the perimeter gutter system.



Tekla X-Steel Isometrics of the roof.



Tekla X-Steel Isometrics of the roof.

Terminal Columns

The structure's hallmark feature is the slender pencil shaped columns supporting the roof framing. Each column consists of a 24-inch diameter main body, with each end tapered to a 13-inch diameter over an eight foot length. A cluster of four columns supports each intersection of the primary two-way trusses. Each spindle in each cluster varies in length due to the curvature of the roof's surface.

The connection at each end of the columns consists of an elegant, single 4-inch diameter pin and gusset plate system. Since each spindle of the column cluster is pinned at each end, the columns supporting the roof were not stable until they were fully connected to the roof framing and the floor framing, and not until after the roof framing was temporarily stabilized.

This presented several challenges to the erector. The trusses were erected on a temporary shoring support system for construction gravity and lateral loads. The pinned columns were suspended from each truss connection without the bottom gusset plates. The gap at the base was then field measured, the gussets field ground to fit and then field installed at the base of columns before removing the temporary shoring system.

The cone shaped portions of the columns were meticulously fabricated from individual trapezoidal shaped pieces of rolled plate, which were



Slender roof columns taper at each end to a single pin connection.

welded up after rolling. Nonconventional means were necessary to roll the plate material since the radius of curvature varies linearly from one end to the other. A disc shaped internal plate stiffener was installed at the transition point between the straight portion of the column and the tapered portion, to handle the forces due to the change in direction of the column wall.

Signature Building Features: Curtain Wall and Skylight

Natural light was paramount in the design of the building, which is one of the earliest airport terminal facilities to apply for LEED certification. The 200-foot diameter skylight, as well as the full height structural curtain wall system on three sides of the ticketing and baggage halls, allow plenty of natural light into the building, saving significant amounts of energy for lighting and heating in the winter. The structural requirements at the interface between these major systems were carefully detailed in the construction documents, and coordinated with the cladding system's engineers. A preliminary analysis of these components was performed

by the design team prior to bidding and construction. Each support condition and structural deflections at each attachment point to the primary structure were detailed in the bid documents for the cladding suppliers to use in detailing their respective systems. The structural

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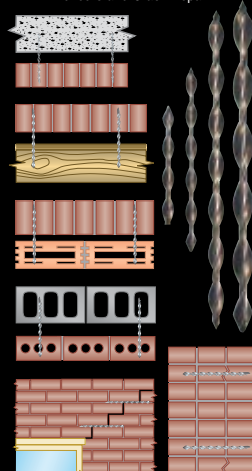
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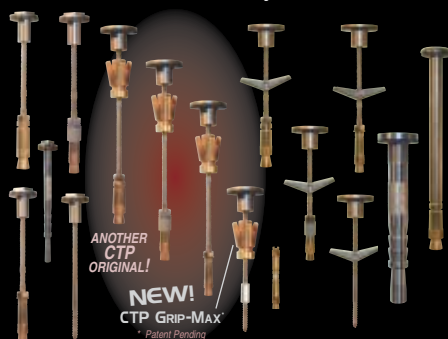
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Architect of Record: Aerodesign Group, Indianapolis, IN
Construction Manager: Hunt/Smoot Construction Managers A Joint Venture
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Steel Erector: Ben Hur (Terminal) St. Louis, MO and FA Wilhelm (Concourses) Indianapolis, IN
Steel Joist Manufacturer: Canam Steel Corporation, Washington, MO



Concourse construction.

drawings included architectural elevations of the cladding systems, with symbols for each assumed support condition and the anticipated primary structure's deflection at each connection point. The systems were performance specified, with the design responsibility for the components within the system's boundaries assigned to the supplier.

Terminal Floors

The terminal floor framing system is made up of a more conventional structural steel framing system compared to the roof. However, a typical 56- by 56-foot bay along with numerous transfer conditions presented plenty of challenges to the designers. The floor framing had to be carefully coordinated with the baggage conveyor systems suspended below. Vibrations were a concern, as with all large open spaces with very little damping available. Natural frequencies of the floor framing were calculated, and peak accelerations and velocities were checked against the AISC *Design Guide 11* recommendations.

Concourse Design

Vibration concerns are especially pertinent for the floor framing in airport concourses, since this is where passengers spend most of their time in the facility. Vibrations due to walking are most easily mitigated in a cast-in-place concrete framing system. The concourse floor framing spans were small enough to warrant a comparative study of cast-in-place framing versus structural steel framing. It was determined that, to get the same vibration resistance characteristics from a structural steel system as a cast-in-place concrete system of comparable depth, the steel tonnage had to be significantly increased. Furthermore, the repetitive nature over the 1200-foot length of each of the concourses framing lent itself to significant economies in formwork. The design team and owner selected the cast-in-place concrete system for bidding. The contractor was able to design a flying form system for each bay, and the forms were "flown" horizontally as the construction progressed from one end to the other.



Skylight trusses support suspended artwork.

The concourse roof system is free of interior columns. The curved trusses and joists span from exterior wall to exterior wall. The columns are architecturally expressed in a V shaped arrangement, and also provide the lateral stability of the system due to the moment capacity at the top of the V connection to the long span trusses. No obtrusive bracing was needed stabilize the roof system.

AESS

Architecturally Exposed Structural Steel (AESS) components were a critical aspect of the project, although special requirements were relaxed for the high roof portion. The terminal columns, concourse columns, ticket counter canopies and front drive up canopy were meticulously detailed and coordinated with the architectural design. Special requirements for grinding of welds, removal of backing bars, fabricator piece marks, and removal of surface imperfections were explicitly spelled out in the specifications.

Conclusion

The result speaks for itself. The designers and builders created a graceful, aerodynamic roof of subtle undulating curves. Although the building is very modern in style, it has been noted by some that the interior spaces harken back to the grand terminal spaces created earlier in the century for rail transportation. ■

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