As Austin continues to soar in size and importance, so must its airport.

Looking SKYWARD

BY JOEL BLOK AND RICHARD LIU, P.E.

Joel Blok

IN RECENT YEARS, Austin, Texas, has grown from a sleepy college town (and state capital) to an international hub of live music, food, art, business and technology.

And until recently, its airport had struggled to keep up.

Austin-Bergstrom International Airport (ABIA) opened in 1999, replacing the city's Robert Mueller Municipal Airport. Since 2010, the airport has seen nearly uninterrupted passenger growth and served more than 10.7 million passengers in 2014. In anticipation of continued growth, a 55,000-sq.-ft expansion to ABIA's terminal was planned; the $62 million project also includes renovation of 17,000 sq. ft of existing space. Design of the project, known as the Terminal East Infill (TEI), began in January 2013 and construction was completed this summer.

The design-build team was led by the Hensel Phelps; Page (formerly Page Southerland Page) is the architect of record and Architectural Engineers Collaborative (AEC) provided structural engineering services. The team was tasked with developing a space that honored the vocabulary of the existing terminal building while adopting a fresh and bold new aesthetic to reflect the vibrancy of the city the airport serves.

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Exercising Efficiency

In its entirety, the new space is an exercise in efficiency. Shoehorned into a site framed on the east, south and west by the existing terminal and on the north by the terminal access road, the location was nothing if not challenging. Efficiency studies by the design-build team led to the adoption of an oval building measuring roughly 115 ft by 200 ft, its perimeter defined by five distinct radii and its centerline rotated roughly 15° from the existing terminal. While the north and east sides of TEI serve as the new landside exterior face of a portion of the airport, the south and west faces of the new building were designed to facilitate seamless passenger flow between the existing terminal and the new space. As such, the three main floors of the new space—baggage (ground), apron and concourse—align with and extend to the floors of the existing terminal, linking the landmark oval shape with the current building.

The existing terminal at ABIA is a celebration of structure in support of architecture, with exposed steel pipe trusses that carry the airside concourse roof to tall glass curtain walls. Early

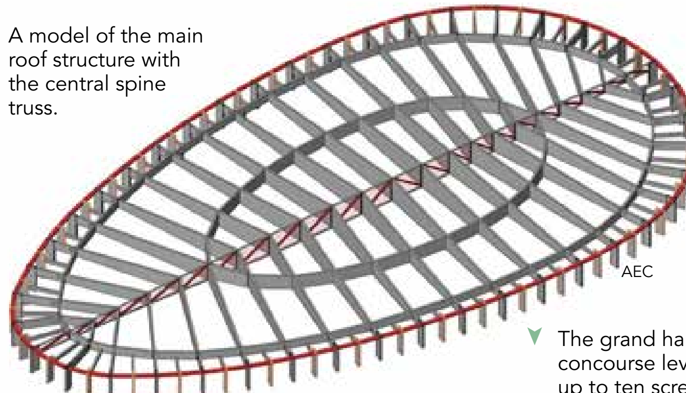
A look at the perimeter columns.

Construction of the main roof.

Richard Liu

on, the design-build team decided to expand upon the exposed steel motif and extend it to the new TEI, employing a variety of custom built-up steel sections that both complement the existing facility and furnish the new space with an exciting and modern expression.

A key component of the new space is a grand hall on the concourse level that will include up to ten screening lanes for outgoing passengers. It was essential that this space be kept free of interior columns in order to facilitate passenger queuing, preserve sightlines for TSA security requirements and enhance the soaring aesthetic of the hall's high roof. As such, a long-span roof system was required. Traditional systems such as long-span trusses and space grids were considered but did not meet the architect's vision for the space. Instead, the team collaborated on an elegant exposed roof structure that lacked the traditional bolted connections seen in long-span trusses or nodes in a space grid. The result was a complex yet graceful "two-way" roof system in which loads are distributed in both the short-and long-span directions to the supporting elements around the perimeter.



A model of the main roof structure with the central spine truss.

AEC

The grand hall on the concourse level will include up to ten screening lanes for outbound passengers.

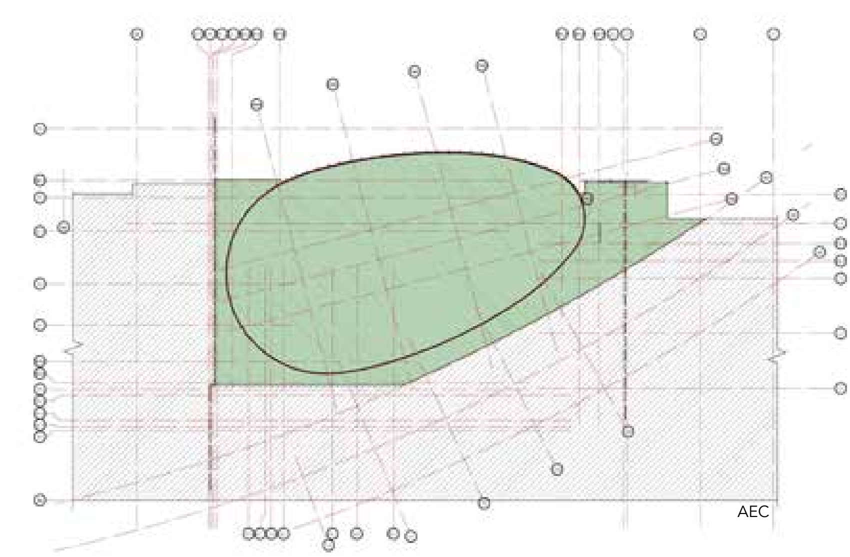
Joel Blok

Simple and Streamlined

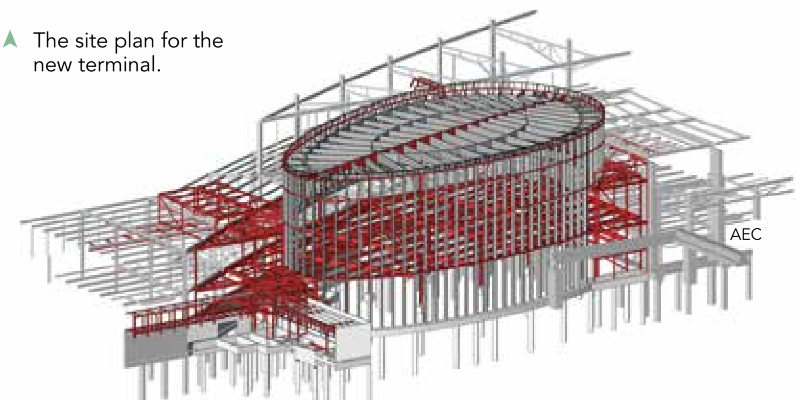
To achieve the simple, streamlined form, custom steel shapes were created by welding steel plates into unique built-up sections; these shapes were used for all primary exposed structure in the new building. All around the oval shape, the perimeter columns and the roof beams took on a simple, slender box shape. Meanwhile, conventional steel framing with composite concrete slab-on-deck construction was used on the apron and concourse floor levels. A conventionally steel-framed low roof, midway between the concourse floor and the new high roof, bridges the gap between the primary oval shell and the existing terminal.

The two-way high roof system in the oval—50 ft above the concourse floor—is comprised of a central spine that runs nearly 200 ft between the east and west ends of the building. From this spine, symmetric pairs of roof box beams flare out to perimeter box columns spaced at 12 ft on center

The building measures roughly roughly 115 ft by 200 ft.



The site plan for the new terminal.



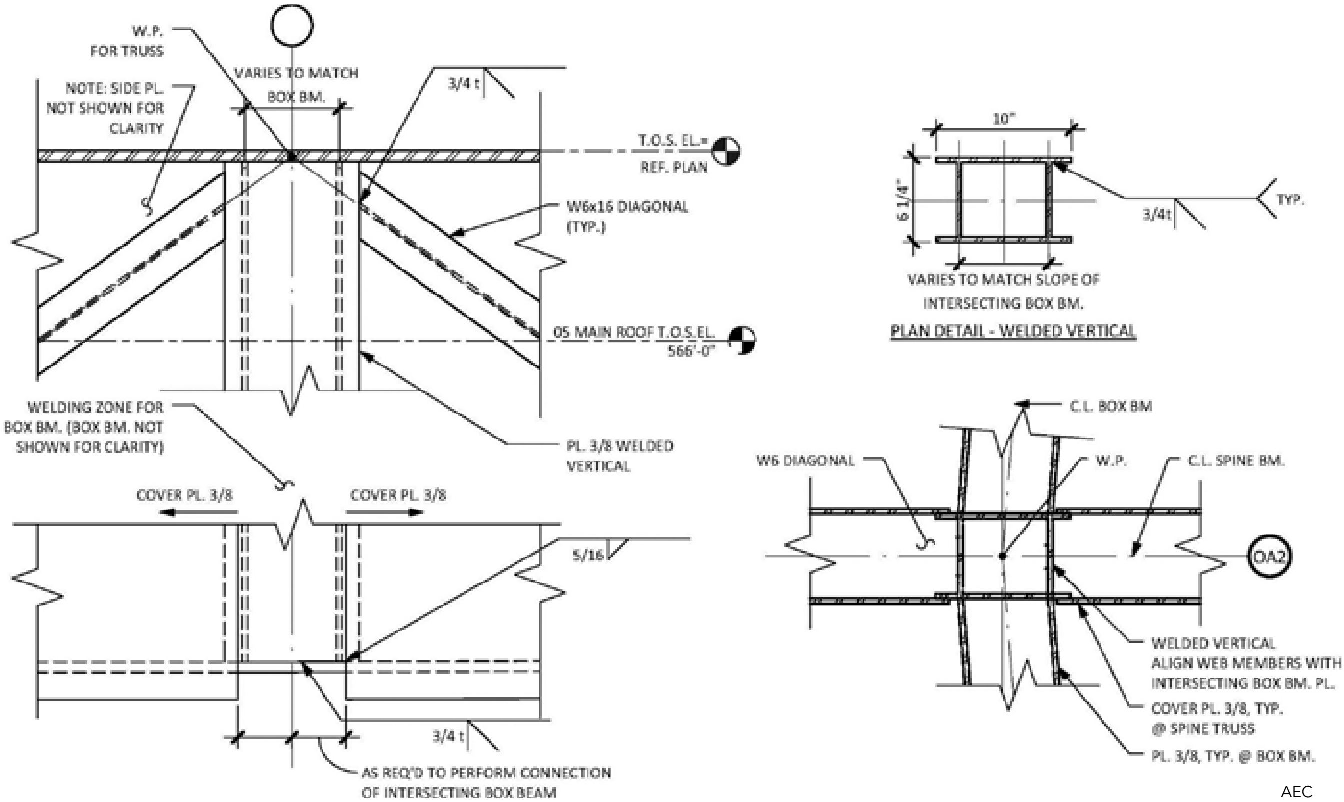
The terminal, viewed in Revit.

around the perimeter of the space. Each pair of beams joins the spine in a visually seamless "node," with welded connections providing an elegant transition between roof elements. Similarly, the roof beams are welded to the tops of the box columns at the perimeter.

The roof structure varies in depth from perimeter to center and along the length of the central spine. In keeping with the architect's desire for the structure to be exposed and honest, the depth of the members roughly follows the moment diagram of the two-way system. Individual beams are tapered, deepening towards the center of the room, where the moment demands are highest. This relationship was further exaggerated to achieve a curved "belly" to the underside of the roof. The deepest roof beams taper from 30 in. at the perimeter (also the uniform depth of the perimeter columns) to over 70 in. at the center. Two rings of bracing members—consisting of the same built-up box sections—were added. The first follows the inflection point at the transition from negative moment at the columns to the positive moment region towards the center of the roof, and the second is positioned roughly at the middle of the positive moment region in the more heavily loaded roof members. Similarly, standard HSS12×6 wall girts ring the oval perimeter at three different elevations, tying together and stabilizing the dozens of moment frames comprised of pairs of box columns and roof beams. As a whole, the steel system creates an elegant, minimalist appearance that belies the robust structural work it is performing.

Columns and beams both use welded plates to form a box shape: twin ⅜-in. web plates with ⅜-in. or ¾-in. top and bottom flanges. A key design consideration throughout the development of these shapes was the local buckling behavior of web elements that would often be categorized as either non-compact or slender. Ultimately, the decision was made to add intermediate W6×16 internal members where the depth of any built-up box shape exceeded 60 in. (This threshold ensured that the AISC-defined slenderness ratio of the plate elements remained compact or non-compact and the web plates would not be classified as slender.) These internal W6 elements provided not only additional stiffness for the web plates, but also a convenient location to accommodate splices of the side plates.

The new structure's perimeter is defined by five distinct radii, and its centerline is rotated roughly 15° from the existing terminal.



AEC

▲ Details of the central spine truss.

Much-needed Mockup

Early in the design, given the unique nature of the built-up shapes and welded nodal connections, AEC commissioned the fabrication of a mockup node connection to simulate the fabrication of box beam elements and their intersection at the roof. Of particular interest were the localized deformation effects due to welding during fabrication and fit-up. This mockup proved invaluable in detailing the project. For one thing, it revealed unacceptable localized heat-induced warping at the connection. Additionally, several specified welds were modified to enhance constructability and consistency in quality. In response to the findings in the mockup, additional W6×16 members were added at each node between roof beams and bracing members to stiffen the web elements and provide a positive back-up for the welded connections. Similarly, several details were modified to eliminate difficult welds and to maintain fit-up tolerances.

Perhaps the most significant impact of the mockup study was the decision to modify the central spine member to more closely function as a truss than as a true built-up section. In an effort to maintain the continuity of the roof beams through the nodes at the roof spine and to mitigate localized weld deformations, custom internal node verticals (roughly resembling a pound sign) were built up at each roof beam connection to the spine. This allowed for full fixity in the roof beam connections and minimized any localized weld deformations at the node. However, it also required that the side plates on the spine member be interrupted by the roof beam connections, thereby compromising the spine member's continuity as a box beam during erection. Instead, internal W6×16 members were added on the diagonals between built-up node verticals, resulting in a long-span spine truss aligned with the long direction of the building. This central spine truss also facilitated a segmented erection sequence, in which portions of the prefabricated truss could be lifted into position and shored while the intersecting roof beams were placed, fit up and welded.

In addition to eliminating the problematic welds and localized weld effects, special care was taken during detailing to reduce welding costs. Preference was given to shop welding where automated welding processes could be employed; intentionally reducing the number of required field welds enhanced the quality and consistency of welds while cutting field labor and inspection costs. In general, welds were carefully selected to be strong enough to transfer all the applied loads through the connection in an efficient manner. This included minimizing the number of specified full-penetration welds in favor of partial-penetration welds or partial-penetration welds reinforced with fillet welds, reducing the number of welds requiring ultrasonic testing. Similarly, weld lengths were reduced in some locations, including connections of web plates to internal stiffening elements or connections of bracing beams to primary roof members. In these cases, the connections were welded top and bottom for the required load demand, and the gaps between welds were filled with an approved structural filler epoxy to complete the visually seamless connection.

An Asymmetrical Relationship

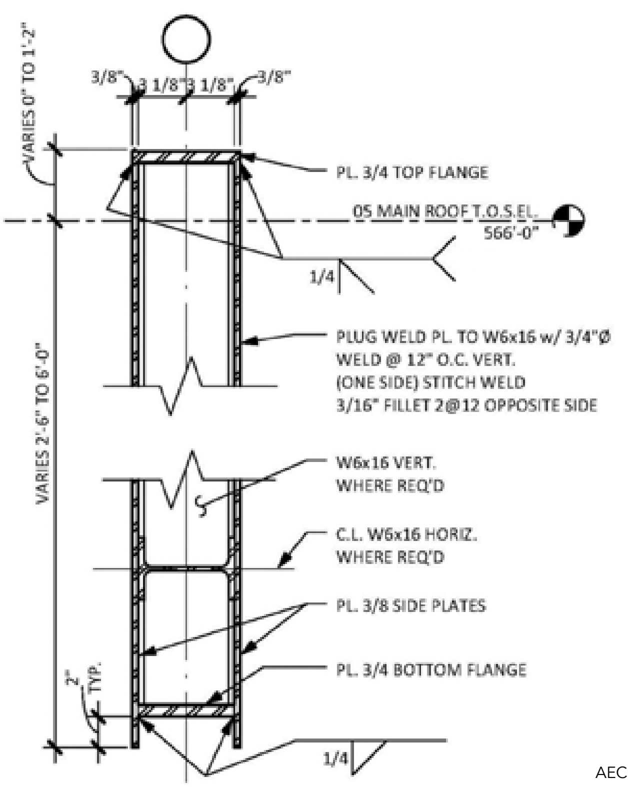
Another key challenge in the project was to ensure the stability of the new building, given its somewhat asymmetric relationship with the existing terminal. On the north and east sides of TEI, the roof beams are supported by perimeter box columns that extend full-height from the ground level to the high roof. However, on the west and south sides, passengers are to pass free-

▲ A curved plate girder at the low roof.

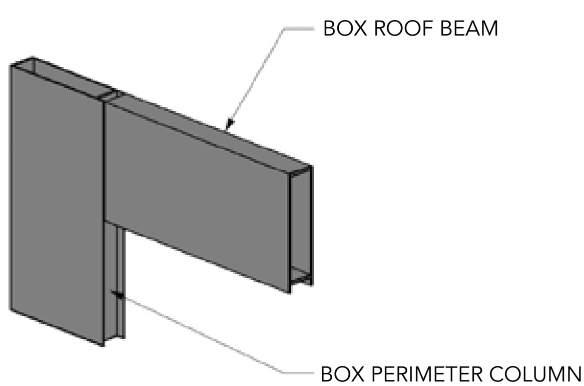
▲ The exposed roof structure lacks the traditional bolted connections seen in long-span trusses or nodes in a space grid.

▲ A low roof bridges the gap between the primary oval shell and the existing terminal.

▼ A typical box beam detail.



▼ Looking up at the main roof.




Joel Blok

International arrivals.

ly between the new concourse space and the existing terminal. As such, the box columns supporting the high roof cannot extend to ground, but are supported by a continuous 54-in.-deep plate girder at the low roof level, curved to match the perimeter of the new building and cantilevered from offset wide-flange columns tied back to the existing structure. Lateral stability for the new building is achieved through a combination of the frame action of the individual moment frames (tied together by rings of wall girts) and new braced frames extending from the ground level to the low roof between the ovoid and the existing building. The existing terminal was also engaged for stability.

The new structure's low roof is itself designed to function as a horizontal truss; both the low roof and the concourse slab were tied back into the corresponding levels of the existing building, combining the new and existing diaphragms to offer additional stability to the new space. Finally, the existing expansion joints were preserved (and continued into the new space) at the east and west ends of the new building.

Erection of the oval high roof began by erecting the central spine truss segmentally. Three total segments were used, with temporary shoring towers erected at the splice locations. Pairs of box beams were dropped in and welded off, and roughly two months after the first roof beams were lifted into place, the shoring towers were removed. Deflections of representative points on the roof, columns and curved plate girders were monitored throughout the de-shoring operations, and all deflections fell well within the expected ranges.

Structural steel proved an excellent system for ABIA's TEI. Given the site's complexity, the bold design intent, the aggressive project schedule and the challenges of construction without significant interruption of the daily operations of a busy airport, the advantages of significant off-site fabrication and segmental erection proved to be critical in expediting the work. Additionally, the design-build project scheme allowed for early involvement by a steel fabricator and erector, whose input during design and detailing helped cut construction costs and eliminate potential delays.

Bold and complex yet efficient and honest, the new building is a testament to the successful union of structure and architecture. With its celebration of unique steel shapes and the ample display of the works of local artists, ABIA's new Terminal East Infill seems the perfect fit for the one-of-a-kind city it serves.

Owner
City of Austin, Austin-Bergstrom International Airport

Design-Build Contractor
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Page (formerly Page Southerland Page), Austin

Structural Engineer
Architectural Engineers Collaborative, Austin

Steel Fabricator
Hirschfeld Industries, San Angelo, Texas

Steel Erector
Patriot Erectors, Dripping Springs, Texas