Traffic Control

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Philadelphia International Airport's new steel-framed ramp control tower makes the most of its tight site.

As an integral part of the ongoing expansion of the Philadelphia International Airport, a new ramp control tower was necessary to oversee taxi lanes and gate areas of the planned International Terminal One facility. The existing tower, which had served the airport for nearly 50 years, was not tall enough to provide a clear line of sight for the east side of the new terminal. Also, available space within the existing tower was insufficient to house the additional staff for the new terminal.

The overall project presented two challenges: to design a stable and cost-effective structure, and to create a significant architectural statement in keeping with the tower's functional requirements. Klein and Hoffman Consulting Engineers, in collaboration with a design team headed by PGAL Architects, provided structural and foundation engineering on this project.

A feasibility study prepared by the Terminal One design team established an optimal location for the new ramp control tower between existing Terminals A and B. Limited real estate was available, and an existing planter bed located between the Departures Road and the north side (landside) of the A-B connector bridge provided the only feasible location for construction of the tower. Consequently, the tower base is limited to a 20′-by-36′ footprint supported on six columns. The tower's control room is approximately 149′ above grade and its overall height rises 182′ above grade at its highest point, making it the most visibly prominent structure on approach to the airport. From this location the new tower oversees all taxi-lane and aircraft gate areas west of existing Terminal E.

US Airways required that the elevator and exit stair be located as far north in the structure as possible to provide a minimum 275-degree clear line of sight toward the airfield from the control room. Given the limited available base dimensions of the tower and the large-diameter floor space necessary to house the 21 required working positions, the tower cab had to be cantilevered significantly to the south from the six-column core structure that houses the exit stairway and elevator shaft. The cab component of the structure, comprises four operational levels, and is designed as an inverted truncated cone. This allows the glazing to be inclined 15 degrees downward to control glare. The cone is formed from steel spokes supported by center and perimeter columns, and rests upon an exposed-steel space truss cantilevered from the core structure.

A hybrid structural system with a structural steel cab and a concrete support tower was considered but rejected. While it would have been heavy enough to eliminate uplift on the foundations, it was determined that a structural steel tower could be built in less time than a concrete tower. Since speed of construction was among the most important issues governing the design, use of a structural steel support tower and cab was selected.

An intumescent coating protects the cantilever truss members against corrosion and fire while providing a smooth appearance.

TOWER DESIGN

The tower structure is designed as a fully braced structural steel frame supported on six steel columns that are sized to limit lateral displacement under design wind and seismic loads. Each column is supported on a single drilled shaft foundation, each 6′-0″ diameter by 60′-0″ deep. Steel anchor piles are embedded the full length of each concrete-filled shaft to resist the significant overturning forces resulting from the tall, slender proportions of the tower structure and the asymmetrical configuration of the cab area. Two drilled shafts function only as tie-down anchors for the structure and are each designed for a working uplift load of 450 kips. Downward loads on the drilled shafts are as much as 1,240 kips. Since there is minimal redundancy in the foundation system, significant attention was given to the installation, inspection and testing of the drilled shafts. No space was available to construct a load platform to test the drilled shafts. Consequently, an Osterberg Load Cell was installed in one of the production shafts to test a completed foundation shaft and confirm the adequacy of the design.

The tower is supported by six main building columns that vary in size from W14×370 at the tower base to W14×233 at the top. The structural steel is ASTM A572, Grade 50, although serviceability requirements governed the design for many of the key members. The column size was dictated by the sway of the structure, which was limited to H/400 or less at the operating floors and H/360 at the roof level. Under the 80 mph design wind speed, the maximum expected east-west displacement was calculated to be 5.62″ at the roof level, which is 168′-3″ above ground level; and 4.46″ at the cab level, which is 149′-6″ above ground level. Although not nearly as critical, the maximum north-south displacement under the design wind speed was calculated to be 1.33″ at the roof level and 1.20″ at the cab level. These displacements are approximately H/1518 and H/1495 at the roof and cab levels, respectively.

The space truss used to support the portion of the cab which projects out from the main shaft utilizes fully welded construction. The members vary in size from W12×53 to W12×87. The truss size and configuration was determined by the project architect, and provided the exposed-steel appearance that was desired. Truss splices were all field welded, instead of bolted, to maintain the smooth appearance of the members. The truss members were coated with an intumescent coating to protect the steel against corrosion and fire, and to provide the desired smooth appearance of the wide-flange sections.

A central W14×145 column and perimeter HSS 12×6×$^3/_8$ columns provide vertical support of the 43′-high cab portion of the structure. A grillage of steel beams set at the top of the truss supports all of the columns. The steel beams vary in size from W24×94 to W24×146. Because the truss is much narrower than the diameter of the cab at its base, the steel grillage beams cantilever out beyond each side of the truss by as much as 12′. The perimeter columns are supported at the cantilever ends of the beams, which were also sized to limit deflection.

The perimeter HSS columns are inclined at 15 degrees, and provide support for the floor and roof decks, and for the curtain-wall system. In order to minimize interference with the sight lines within the cab, the perimeter columns were aligned with the vertical curtain-wall supports.

Lateral stability for the tower is provided by heavy, double-angle cross bracing in each of the five primary column lines. Bracing sizes vary from 2L4×3$^1/_2$×$^1/_4$ to 2L6×6×$^3/_8$. The bracing configuration was adjusted throughout the structure to accommodate corridors and door openings.

A W14×132 steel anchor pile was installed in the core of each of the six supporting caissons for its full depth to transfer the tension forces from the building columns to the caissons. The anchor piles were installed as part of the foundation package contract. Due to the anticipated difficulty of hanging the 60′-long anchor piles within the caisson and holding their alignment during concreting operations, a 4′-long piece of W14×233 was provided above the anchor pile for final adjustment. The adjustment pieces were also installed during the foundation package and were field-welded to the top of cap plates provided with the anchor piles. The adjustment pieces were set by survey to the correct elevation and location, and full-penetration groove welds were made to connect the pieces. The building columns were then bolted to the adjustment piles under the structural-steel package. The adjustment pieces were installed accurately and the 1$^1/_4$″ diameter, ASTM A490 anchor bolts used to connect the column base plates to the adjustment pieces required no field adjustment.

The floor decks at each of the upper level floors are 4″-thick composite decks (1$^1/_2$″ deep, composite steel floor deck with 2$^1/_2$″ concrete above the deck). The roof deck is 1$^1/_2$″ wide-rib steel roof deck.

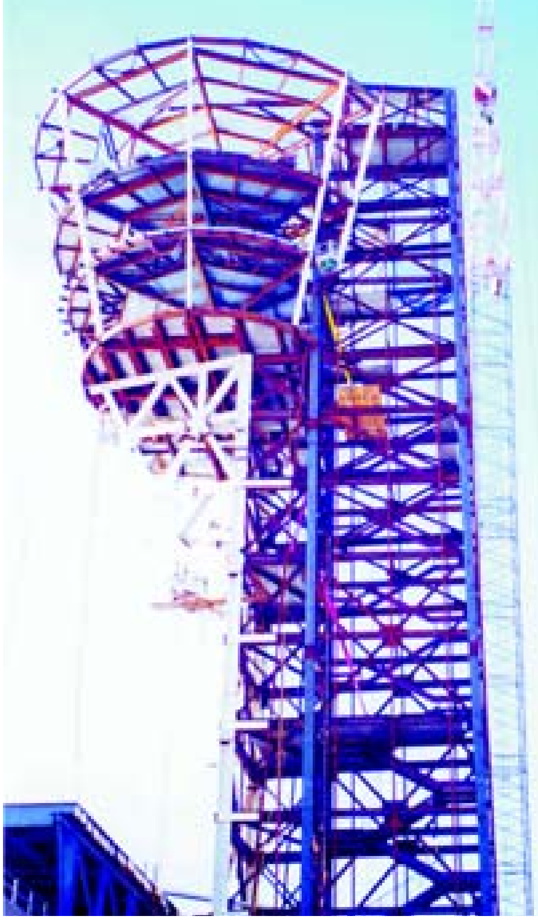
SCHEDULE CHALLENGES

In addition to design complexity, the project also had significant schedule constraints. Design and construction of the tower structure, exclusive of finish work and instrumentation, was completed in only 18 months. To meet this aggressive schedule, the design team worked closely with US Airways and the construction manager, Turner Construction Company, to prepare three separate bid packages for the tower construction. A foundation package was issued based on preliminary engineering for the tower superstructure. While the drilled shafts were still under construction, the superstructure analysis was completed and a structural steel package was prepared and awarded to Cives Steel Company. Accelerating these two construction packages allowed the project team to complete the complex architectural and instrumentation designs, which required significantly more involvement by US Airways. The general construction package, awarded to Keating McKendrick Construction Company, commenced two months prior to the completion of the tower framing.

The structural steel design was only about 90-percent complete when the construction manager sent the structural steel package out for pricing, and the architectural design was only about 60-percent complete. This caused some difficulty in the structural design process because all design changes that commonly occur between 90-percent completion and final completion had to be tracked very closely so that the selected steel contractor could be advised of the changes to member sizes and details. The architect also had less leeway to modify the 60-percent design since steel was already in the detailing stage at the time of design completion.

SITE CONSTRAINTS

Structural steel erection was a difficult task due to limited space at the project site. The tower is situated on a very small parcel of land and is surrounded on all four sides by airport facilities that are integral to day-to-day operation. The departure roadway that provides access to all the terminals for departing flights is on the north side of the tower. The connector bridge that ties Terminals A and B together is on the south side of the tower. An under-



The control tower cantilevers from a six-column cross-braced steel tower.

ground baggage tunnel is located adjacent to the tower on the west side. An access gate and roadway are located adjacent to the east side of the tower, and provide access to the airfield for oversize emergency vehicles.

The airport allowed one lane of the departure roadway to be taken out of service for construction. This allowed just enough space for a single steel-delivery vehicle to pass through the site, and provided a small shakeout area. The contractor used a lattice boom truck crane staged from various locations on the north, east and west sides of the structure for steel erection. Due to the limited available space, the steel essentially had to be erected as it was delivered.

Another site constraint was that the connector bridge between terminals A and B needed to remain in operation throughout construction of the new tower. In order to protect the connector bridge, a large temporary steel canopy structure was constructed over the bridge. Timber grillage and steel plates were installed on top of the canopy to shield the bridge against falling objects and falling debris from the construction activities.

The total quantity of steel for the superstructure is approximately 380 tons, of which, approximately 140 tons is in the weight of the six supporting columns. The total project cost was about $15 million. ★

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