Special

Shop-fabricated cruciform columns were used to provide high biaxial strength and convenient field bolted connections.

UPS

An expansion to UPS' "ultimate factory" needed to be designed around the facility's intricate conveyor system.

THE UNITED PARCEL SERVICE quietly runs one of the world's largest airlines, operating hundreds of aircraft and servicing more than 200 nations and territories. The heart of the company's sophisticated global distribution network is the UPS Worldport in Louisville, Ky., which was recently featured on the National Geographic Channel's "Ultimate Factories."

The bulk of the existing 4 million sq. ft of building footprint was constructed in the late 1990s, at the time called Hub 2000, giving UPS the ability to sort more than 300,000 packages an hour traveling on 110 miles of conveyors. Square footage statistics don't do justice to the sheer size of the building, since the facility is packed full of millions of square feet of conveyor platforms and mezzanines that do not count towards official square footage numbers.

Despite the massive volume of the facility, by 2006 UPS' air shipping business had grown enough that it became necessary for them to expand the facility's footprint to 5.2 million sq. ft, or the area of 80 football fields, providing the required space to expand the potential capacity of the materials handling system to 170 miles long and almost a half-million packages an hour. The original Hub 2000 project and this expansion have resulted in the erection of nearly 43,000 tons of structural steel and more than $2 billion in total construction cost.

Fast-Tracking

From an engineering perspective, the key to successful fast-tracking is acquiring the necessary information as early and accurately as possible in order to minimize changes after procurement. This can sometimes be achieved by erring on the conservative side, but the design team had no such luxury for the Worldport. Early attempts at designing around upper-bound estimates of conveyor loading resulted in unreasonable designs such as W24x370 columns being required to support a two-story portion of the structure. Such an approach would result in delays and tens of millions of dollars of cost to the project. Thus, floor dead and live load information had to be well coordinated with the conveyor system to account for the extreme variability in weight and layout of the conveyors. The geometry of the facility was similarly constrained. The footprint, roof elevation, and floor-to-floor heights had to be coordinated with UPS Airlines' operations, the Federal Aviation Administration, the airport control tower line-of-sight, require-

Delivery

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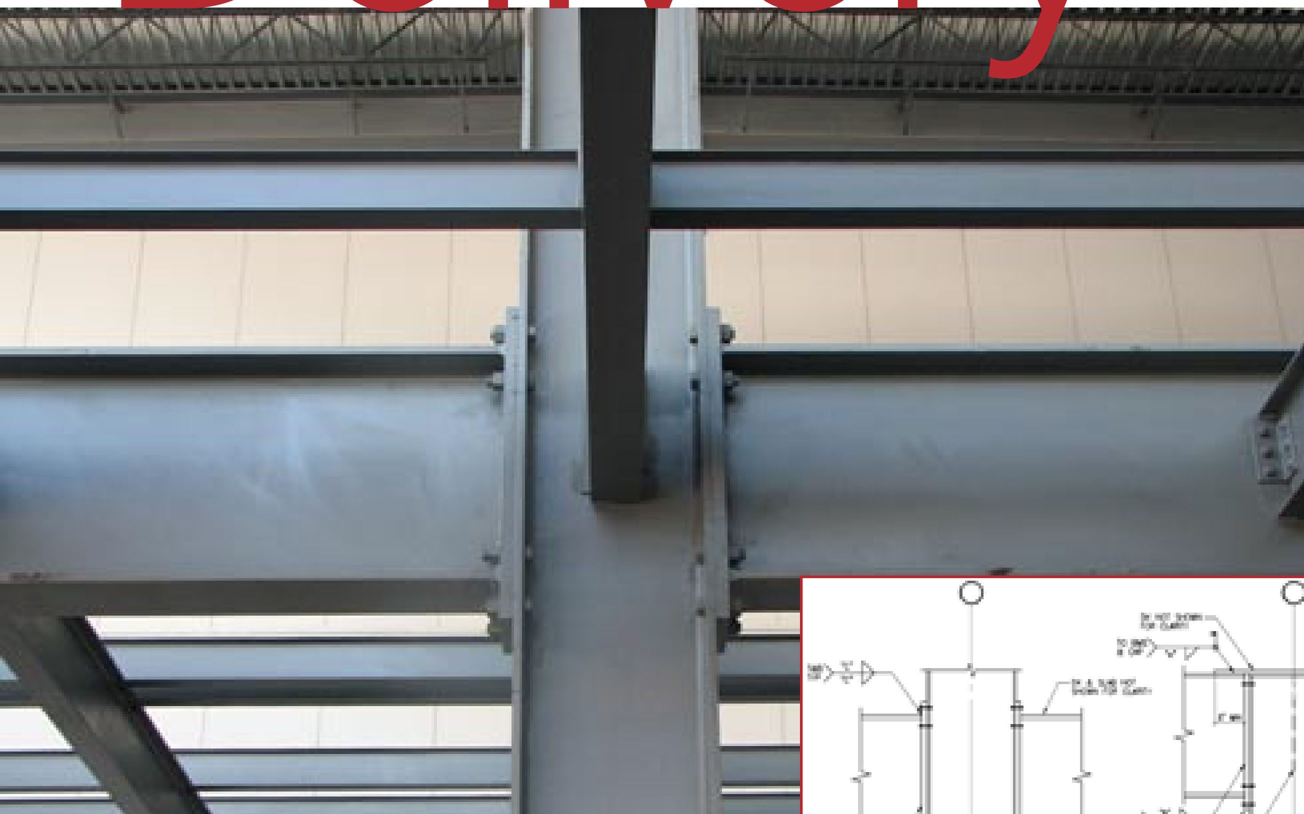

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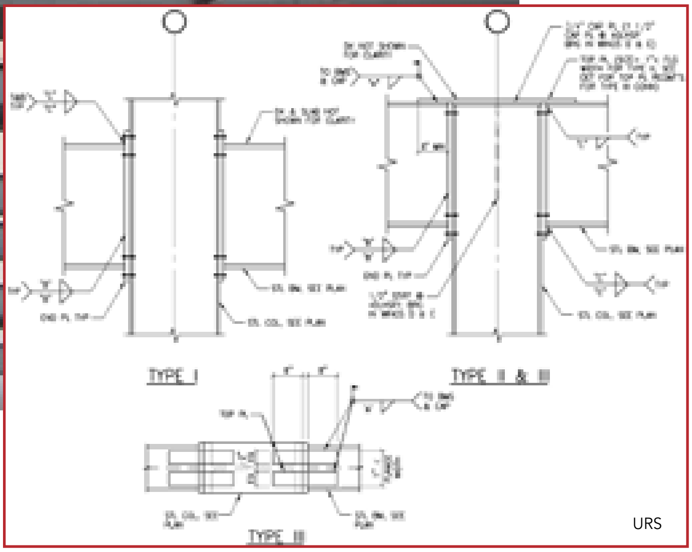

URS

Right: Extended end-plate moment connections on paper.

Above: Extended end-plate moment connections in action.

ments of the new conveyor system, and connectivity with the conveyor system in the existing Hub.

Working backwards from the desired occupancy dates, the construction manager, Hunt Construction, and steel fabricator used Nucor-Yamato's published rolling schedules to estimate when they would need construction documents, mill orders, and mill reservations. The dates were eye-opening to everyone and it soon became obvious the building and conveyor design teams had quite a challenge ahead of them. With those dates in hand, structural engineer URS began a series of smaller meetings with UPS and the conveyor designers to work out a schedule that would provide them enough time to design the system to a reasonable level of accuracy, while still leaving URS adequate time to design the structure prior to the required mill order dates. The largest difficulty was developing an efficient but not overly conservative means of communicating loading information, while still providing a versatile set of criteria that wouldn't require changing the design when minor modifications were made to the materials handling system. This was initially done using large spreadsheets developed by the conveyor vendor's structural design consultant (SSOE, Inc. of Toledo, Ohio).

However, this proved cumbersome, made changes difficult, and didn't provide an intuitive picture of what was going on in the building. The process was streamlined into color-coded load maps. The maps were easily understood and provided the entire team with a better understanding of the conveyor system. They were precise in areas where the conveyor design was well developed and appropriately conservative in areas where there was uncertainty in the materials handling system design. The team worked diligently to determine what was "appropriately conservative," with URS providing guidance on areas where overestimating the loads would be very costly and areas where it would have little effect on the cost of the structure. For instance, overestimating the loads on a 100-ft clear span would be much more detrimental than placing a conservative point load on a moment frame girder that had been sized based on lateral drift criteria and had reserve strength. The load maps developed during this stage of the project were eventually incorporated into the construction documents for use by UPS

Kentuckiana Aerial Photography, Inc./UPS

Following its expansion, the UPS Worldport facility in Louisville now contains 43,000 tons of structural steel and has a footprint of 5.2 million sq. ft.

as they modify the conveyor layout in the future as necessary.

With all of the design information coordinated, URS produced three stages of deliverables for the structural steel packages:

- An early size and length estimate in spreadsheet form used for cost estimating, fabricator feedback, and coordination with steel mill rolling schedules
- A size and gross length schedule in spreadsheet form outlining the total length of each member size required, for placing the mill order.
- Structural steel construction documents for detailing and modifying the mill order.

The process proved effective, as UPS' management team monitored the complex lines of communication, with designers, contractors, and vendors interacting both directly and through UPS. The construction schedule was met and often exceeded, and the changes to the structural steel framing system were relatively small considering the size of the project. In fact, few of the changes were necessary due to modifications in loading; most were related to spatial changes in the materials handing system.

It's what's on the Inside that Counts

There are few, if any, facilities like this in the world. So while the exterior may be a simple precast concrete façade, it is the inner workings of the UPS Worldport that make it a unique structure with its own set of design challenges. It is as much a machine as it is a building.

Selection of the superstructure framing system was the easiest part of the original building and its expansion. There really wasn't any alternative to structural steel; the facility demands the flexibility to adapt during construction and in the future. Additionally, the speed of erection offered by steel could not be matched by any other construction material.

Design of the gravity framing system was complicated by the heavy weight and variability of the conveyor system. Additionally, floor-to-floor elevations were very tight, deflection limitations were strict, and every element had to be coordinated with the conveyor system. Additionally, there is a mixture of framing designed by both URS and SSOE. In some areas URS designed the entire floor as a relatively heavy composite framing system. In other areas designated as "transport bays," URS' design was limited to "fly beams" or "primary steel" running column to column. In the transport bays SSOE designed "secondary" and "tertiary" infill that connected to the URS system. This meant lateral torsional bracing assumptions had to be well coordinated with the SSOE structural systems, and the convenient simplifications possible with a wall-to-wall rigid diaphragm could not be used within the transport bays. The roof framing was often charged with supporting the massive air-handlers necessary to regulate the temperature of the facility, given the massive heat load from thousands of electric conveyor motors operating throughout the building. In areas without rooftop equipment, the roof framing typically consisted of open-web steel joists supplied by Nucor-Vulcraft. In order to coordinate all of this framing with the materials handing system, the conveyor designers incorporated URS' design into an AutoCAD 3D model for clash detection.

Design for lateral loads and stability was the largest structural design challenge. Though the expansion is not particularly tall (35 to 60 ft, depending on the area), the large dead loads created relatively high seismic demands and second-order effects on the structure. These obstacles were heightened by the lack of a complete floor diaphragm system and the inability to use any form of braced frames due to potential interferences with the conveyor system. Even simple column stability under gravity loads was sometimes difficult to assess because of the unique characteristics of the building configuration.

While meeting the explicit requirements of the AISC LRFD (load and resistance factor design) 3rd edition *Steel Specification*, URS relied upon the work of the Structural Stability Research Council and the methods within the yet-to-be-adopted AISC 360-05 Direct Analysis Method to evaluate the stability of columns that didn't easily fit within the assumptions of the current steel specifications. An early design directive was to avoid using hollow structural section (HSS) columns. The building's use demands many modifications both during and after construction, and UPS prefers to make field-bolted connections to columns, which is easier with wide-flange sections. This created difficulty in the transport bays where tall W-shapes were heavily loaded and more vulnerable to minor axis buckling than HSS sections. In order to solve the problem, URS used Joseph Yura's Σ P concept to develop the column layout.

Using this method for evaluating lean-on column bracing, the system was designed so that W24 columns, oriented in their strong direction and unbraced from ground to roof, were capable of providing minor axis bracing to as many as two neighboring wide-flange columns. In a few isolated areas, this relationship could only be maintained by using shop-welded cruciform columns fabricated from a W24 and two WT12s to provide a column with equally large biaxial stiffness. With the preliminary design complete, the final framework was analyzed and designed using RAM Structural and SAP 2000.

Though the State of Kentucky had not yet adopted it and SAP 2000 had not yet incorporated it into the software, elements of the AISC 360-05 Direct Analysis Method were applied to the final models, which had already been designed to the LRFD 3rd edition, to ensure overall stability to the system, considering the unique loading parameters and structural configuration.

UPS directed the team from the beginning that field welds and column stiffeners/doubler plates were not acceptable elements of the design. Despite the structure containing hundreds of moment connections, field welds were eliminated through the use of bolted extended end-plate moment connections designed and detailed in the URS construction documents. Columns were up-sized as necessary, resulting in zero stiffeners and zero doubler plates on the entire project.

Paperwork

The project was released in four stages; first, the North Core expansion was released in halves, followed by Wing D extending out from the northwest corner of the core, and finally Wing E extending from the northeast. The team began design in July 2006 and released the construction drawings for Wing E in late May 2007, documenting approximately 16,000 tons of structural steel along the way.

UPS

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As mentioned earlier, a portion of the framing was designed by SSOE and a portion by URS. While URS was the engineer of record for the project, SSOE's documents contained thousands of small pieces of "secondary" and "tertiary" framing that connected to the large "primary" framing designed and detailed by URS. However, both firms had to know what the other was doing and had to confirm the shop drawings were a correct interpretation of their design intent. This was an inefficient aspect of the Hub 2000 project that UPS solved by mandating that information from both URS and SSOE be compiled into a single set of shop drawings prepared by a single detailer.

The fabricator/erector received separate sets of construction documents from the two structural engineering firms, and Arcan Detailing, the steel detailer, created a 3D SDS/2 model of the structure, which was used to produce a set of shop drawings containing both designs. Arcan's ability to absorb revisions and coordinate the work of two structural firms was the keystone to the entire construction process. The shop drawings were sent electronically to SSOE, then a single copy was printed, marked up, scanned, and sent directly to URS. URS then repeated the process and sent the completed electronic copy back to the construction manager.

Using this process, large packages of shop drawings were able to be reviewed by the construction manager, SSOE, and URS in less than two weeks, keeping the aggressive schedule on track. The team was able to complete major structural steel erection on time in May 2008; conveyor system fit-out efforts are expected to continue well into 2009. MSC

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URS Corporation, Columbus, Ohio

Steel Erector
Ben Hur Construction, St. Louis, Missouri (TAUC Member)

Steel Detailer
Arcan Detailing, Inc., Windsor, Ontario, Canada (AISC Member)

Construction Manager
Hunt Construction, Indianapolis

Software
SAP 2000
RAM Structural
AutoCAD
SDS/2