Precast Concrete Value Engineering Accommodates Difficult Site

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New construction that requires working within the confines of an old structure in poor condition is a nightmare come true for many contractors. Such was the case of the Logan International Airport Central Parking Expansion Project, which required the building of a three-level, 2900-space parking structure on top of a deteriorated, five-level parking structure. The owner required that the existing parking facility remain open and functional during erection of the new structure, a mandate that severely limited many viable construction means and methods. Logan Airport’s flight control tower stands immediately adjacent to the existing parking structure, and the site is further restricted on four sides by busy roadways. Facing site, structural, operational, and access limitations, engineers and designers evaluated three systems for the airport expansion project. A precast concrete system emerged as the best solution because of its economy, quality, durability, and constructibility. In this article, the project team explains a value engineering effort; special rigging and erection equipment; an exceptional foundation design; and the atypical operation of gantry-mounted erection cranes above the roof of an aged, deteriorated, cast-in-place concrete structure.

On the coast of the Atlantic Ocean, Logan International Airport serves over 27 million passengers annually and moved almost 750 million lb (340 million kg) of cargo in 2005. Located on 2400 acres (972 ha) in East Boston, Mass., Logan Airport is owned and managed by the Massachusetts Port Authority, commonly known as Massport (Fig. 1). Now under way, the $205 million Logan International Airport Central Parking Expansion Project is the largest component of Massport’s comprehensive plan to substantially increase conveniently located parking spaces to accommodate the growing number of Logan Airport customers (Fig. 2, 3).

At the start of this major expansion project in 2003, Massport was looking for ways to remedy a serious parking shortage at Logan Airport. Originally, Massport intended to repair and partially rebuild its five-level, 4800-car, cast-in-place concrete central parking structure with new cast-in-place construction. After the rebuilding of the existing structure was complete, a new three-level precast concrete parking structure was to be constructed on top of the old structure, adding another 2900 parking spaces and increasing vehicle capacity for this central airport facility 60%. Comprehensive renovations and upgrades to the existing parking structure include a new exterior facade, elevators, stair towers, and improvements to pedestrian circulation and security. The ongoing expansion project will be complete in 2007.

Massport selected Parsons Brinckerhoff Quade & Douglas Inc. (PB) of Boston, Mass., as prime consultant on a multidiscipline team for the design and construction inspection of the central parking facility expansion. When complete,
The eight-story parking structure will provide convenient, short-term public parking and easy access to Logan Airport's Terminals B and C through new pedestrian walkways. The project also includes connecting bridges to the existing and adjacent west parking structure (Fig. 3), which provides access to Terminals A and E through two pedestrian bridges and moving walkways. PB is responsible for overall project management, including civil, traffic, and structural engineering design. Fay Spofford & Thorndike (FST) of Burlington, Mass., under a separate contract with Massport, is responsible for the renovation of the existing lower levels and the foundations for the combined structure. In addition, PB, with FST as subconsultant, is providing construction phase services with a full-time resident inspection team.

**TWO PROJECTS, ONE RESTRICTIVE SITE**

One of the most important things to understand about the Logan Airport parking expansion project is that the project team really faced two projects on one site. The first project
entailed repairs to the existing, deteriorated central parking structure (a five-level facility), the first two levels of which needed to be taken down to the columns for rebuilding. The first three levels of the existing structure (including slab-on-grade) were built in the late 1960s with cast-in-place concrete. In the early 1970s, two additional levels were added, also of cast-in-place concrete, but with precast concrete double tees making up the deck (Fig. 4–7).

The second project included the expansion of the parking structure. Final design began in August 2001 after completion of the preliminary design phase, during which several expansion options and alternatives were considered for providing two, three, and even four additional levels of parking on top of the existing structure. Various pedestrian and vehicular circulation options to service the additional levels were also evaluated.

Parking Decks

Built of cast-in-place concrete (beams and girders), the first two levels of the existing structure plus slab-on-grade were falling apart. Repairs to the existing parking structure meant removal of all original cast-in-place concrete except for the columns. All cast-in-place concrete deck members were removed and replaced with precast concrete double tees on new cast-in-place girders.

For construction of the three additional parking levels directly on top of the existing structure, new columns were installed between the existing columns and are supported on new and independent deep foundations. The decks and framing consist of high-strength, high-quality precast, prestressed concrete construction. To maximize visibility and openness and to reduce cost and schedule, the new precast concrete 2 ft × 4 ft (0.6 m × 1.2 m) columns were spaced at 50 ft (15.2 m) on center in the north-south direction, forming a 50 ft × 60 ft (15.2 m × 18.3 m) typical column bay. Bays in the existing

Fig. 4. This schematic drawing illustrates the original 1960s, cast-in-place concrete, three-level parking structure at Logan International Airport with the two additional upper levels (cast-in-place concrete with precast concrete decks) that were added in the 1970s. New construction of the outer perimeter wall foundation appears on the left.

Fig. 5. This rendering shows the demolition of existing cast-in-place beams and decking bounded by the red perimeter barrier. The erection of a new precast concrete architectural and structural facade is shown on the left in blue.

Fig. 6. New precast concrete replacement decking is shown at the first and second supported levels of the 1960s-built structure. The grade level is slab-on-grade. Note the new drainage system.

Fig. 7. This drawing depicts all precast concrete restoration work to the existing parking structure.
Table 1. Precaster Production and Erection Rates

<table>
<thead>
<tr>
<th>Precast Concrete Component</th>
<th>Production Rate per Day</th>
<th>Average Erection Rates per Day*</th>
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</thead>
<tbody>
<tr>
<td>Precast columns</td>
<td>1–2</td>
<td></td>
</tr>
<tr>
<td>T-beams</td>
<td>2–3</td>
<td></td>
</tr>
<tr>
<td>Spandrels</td>
<td>3</td>
<td>6–15</td>
</tr>
<tr>
<td>Double tees</td>
<td>8–16</td>
<td></td>
</tr>
<tr>
<td>Wall panels</td>
<td>2–4</td>
<td></td>
</tr>
</tbody>
</table>

*Erection of each bay took about five days.

structure are spaced 25 ft × 60 ft (7.6 m × 18.3 m), so a new column was placed between every other existing column. Precast, prestressed concrete inverted T-beams rest on the new columns and support the precast, prestressed double tees forming the floor system of the three new levels.

Vehicular Bridges

Vehicular bridges connect the central parking structure with the adjacent existing west parking structure located 120 ft (37 m) away. A new bridge, built between the two existing structures, provides a connecting vehicular bridge at every newly constructed level built with precast concrete beams and special double tees to expedite construction over the operating roadway directly below.

Stairs and Elevators

Existing stairs and elevator structures were demolished and replaced with new structures at the same elevation as the new levels. The existing stair structures were too far apart and exceeded current code requirements for egress travel. The new west vertical circulation towers were built to replace the demolished structures. These two new stair/elevator structures are the most centrally located towers and service all levels (ground level to level seven), and are composed of precast concrete stairs enclosed in glass and architectural/structural precast concrete panels.

Public access to the parking structure had to be maintained during construction. The difficult logistics surrounding the replacement of the stair towers included phased and staged demolition and replacement of the old towers with new stair and traction elevator structures, which were fully conditioned from ground to the new roof. The elevator shaft and lateral load resisting system comprised horizontal precast concrete structural/architectural wall panels. The stairs and the floor system are framed with structural steel surrounded by a glass curtain wall system that incorporates artwork.

Exterior Facade, Columns, and Bracing

Just as new interior columns were inserted between the existing columns in the old parking structure, new columns were also placed around the exterior just outside the existing facade. These new exterior precast concrete columns and spandrels serve to support the end bays of the three new levels. Architectural precast concrete spandrels with attractive reveals conceal the sides of the old structure at each existing level. Precast exterior columns and facades provide structural stability through moment frame action. New bracing/framing elements are located around the perimeter of the parking structure (and at the center ramp core) to resist the applied lateral loads. These elements receive the loads from the level five floor diaphragm (which collected loads from level four and the lower levels) and from the upper levels.

Several schemes were considered and evaluated for combined appearance and structural efficiency. The preferred and recommended scheme consisted of providing essentially a new precast concrete facade all around the parking structure perimeter from grade to the new roof level, thus hiding the old facade and giving the parking structure a uniform and attractive appearance. Precast concrete moment frames met structural requirements and provided the desired architectural finish.

A second scheme consisted of precast concrete columns and spandrels on the new levels only and concrete structural bracing as needed on the existing levels. The lower existing levels would remain set back, exposed, and could be refinished to closely match the color of the new levels. A final scheme called for a steel "cage" system that was intended to partially cover existing spandrels and/or use steel bracing instead. Both latter schemes were not chosen.

Code Issues

When expansion is complete, Logan Airport's central parking structure will have eight levels of parking, to a height of 77 ft (23.5 m) above grade, and will provide about 7500 total parking spaces on an overall 750 ft × 490 ft (229 m × 150 m) footprint, an area of about 8.5 acres (3.4 ha) per level. The structure is not in compliance with the high-rise provisions of Massachusetts General Laws, Chapter 148, because its height exceeds 70 ft (21.3 m). A variance was granted from the State Building Code to exempt open parking structures from the high-rise requirements. The Logan Airport parking expansion project meets the Construction Type 2A, non-combustible rating for 2- and 1.5-hour fire resistance.

Seismic Design and Temporary Erection Stability

Second to safety, speed of erection is paramount in order to maintain the Logan Airport parking expansion project sched-
ule. Determining the location of final lateral load resisting elements around the structure's perimeter and at the central core (located midway between the north and south sides) required special engineering studies to ensure temporary erection stability during the partial completion of the three new overbuild levels. By using as few of the connections designed for final in-service conditions as possible and installing pipe and cable bracing during erection allowed the job to proceed at better-than-typical rates (Table 1). Backup welding crews completed final stability connections as erection proceeded.

Stability of the entire structure against in-service lateral loads (seismic, volume change, and wind) is achieved with a combination of resisting elements that interact through structural compatibility between the existing and new structure. Lateral seismic loads acting on the existing structure are resisted by the new level five (and a portion by the existing members), which collects the loads from the existing lower levels through the new columns that act as vertical transfer components. The new levels span as rigid horizontal diaphragms, transferring lateral loads to the external bracing/frame members along the exterior facade and the central ramp core. The balance of the lateral load is transferred directly to the foundation system. Similarly, a lateral load applied on the new upper levels is resisted by the floor members, which act as diaphragms by transferring lateral loads to the bracing/frame members. Lateral loads acting on the new roof level are transferred to the lower level by bending/frame action as well as by partial-diaphragm action to the external members.

Precast Concrete Complies with New Seismic Code

The design of the lateral load resisting system requires that a substantial portion of the structure's entire lateral load be resisted by the new precast concrete portion of the expansion. Therefore, it was very important that the floor be designed to handle larger-than-normal lateral loads. The floor members, bracing/frame systems, and connections were evaluated and designed at a preliminary level for the various loading imposed by both gravity and lateral loads. Likewise, the beams, columns, and bracing/frames were checked for gravity and lateral loading. Of equal importance in resisting loads is the structural compatibility and continuity of the lower-level structural elements with the new levels.

Design challenges at Logan Airport were further complicated by compliance with a seismic code that was not in existence when the combined five-level structure was built in the 1960s and 1970s. To achieve seismic code compliance with minimal retrofit of the existing structure, the new levels were designed to resist the entire earthquake force with the new precast concrete columns installed from the ground to the roof. Acting as vertical spanning components, the new precast columns transfer all lateral loads from the existing levels up to the new levels. The new precast concrete levels span horizontally and transfer lateral loads by diaphragm action to the exterior precast frames. The main advantage of this seismic design is the elimination of interior K- or X-bracing—objectionable elements to the owner because bracing impedes parking availability.

EVALUATION OF THREE STRUCTURAL SYSTEMS

Because the structural system of a parking structure represents the largest portion of the construction cost, it was important to thoroughly evaluate various materials and systems during the preliminary design phase to determine the one that best met the specific needs and requirements of the project. Three structural systems were evaluated and analyzed. Proposals included a two-, three-, and four-level expansion as well as internal column bay spacings of 25 ft × 60 ft (7.6 m × 18.3 m) and 50 ft × 60 ft (15.2 m × 18.3 m).

By increasing the north-south interior column spacing from 25 ft (7.6 m) to 50 ft (15.2 m), the project team reduced construction cost and schedule. Using the 50 ft (15.2 m) column spacing produces a more open parking structure by reducing (by half) the number of originally planned columns for levels four and up and by establishing longer lines of sight in the lower levels. Exposed cast-in-place concrete for the parking structure exterior was not acceptable to the owner. Structural steel framing was also rejected because it requires fireproofing to meet the fire rating requirement of the building code and it presents the added concerns of corrosion potential and increased maintenance.

Three types of structural systems were considered:
• Option 1: Precast concrete.
• Option 2: Cast-in-place, post-tensioned concrete.
• Option 3: Combined steel and concrete.

After a careful weighing of all systems, a precast concrete construction plan proved most beneficial for superior product quality, long-term durability, desired aesthetics, and facade treatment. In short, a precast concrete system best met Massport’s structural requirements and mandates for constructibility, schedule, and economy of construction.

Option 1: Precast Concrete

Option 1 specified a high-quality precast concrete system using high-strength concrete with pretopped double-tee floor members. The double tees are 12.5 ft (3.8 m) wide and span approximately 60 ft (18.3 m) in the east-to-west direction between inverted T-beams along interior column lines and exterior spandrel beams. The beams are supported on interior precast concrete columns (spaced at 50 ft [15.2 m] and located midspan between the existing columns) and on exterior precast concrete columns (spaced at 25 ft [7.6 m] on center and concealing the existing cast-in-place columns).

A life-cycle cost analysis determined the durability advantages of a precast concrete system:
• Precast concrete is fabricated in plant conditions, resulting in superior material quality and durability. Consistent high-strength concrete values (with strengths of 6000 psi [42 MPa] and higher) are easily attainable in controlled production. A low water-cement ratio (w/c) of 0.40 (maximum) and generous cement content in the mixture ensure a durable concrete surface finish and long service life.
• Double-tee floor members are simply supported between supports (single curvature bending), creating no negative moments along the span. Plant-cast members
are typically crack-free and occasional minor top cracks (resulting from stripping, transportation, or erection) tend to close up after erection.

- Main reinforcing (prestressing steel) is positioned at a maximum distance from the top concrete surface and well down in the stems of the precast concrete double tees—away from exposure to deicing chemicals and, thus, less vulnerable to corrosion. Controlled clear cover is one of the main reasons that well-designed precast, prestressed concrete is virtually free of corrosion problems.

- The majority of precast concrete elements are cast before erection so that most of the elastic shortening, shrinkage, and creep occurs at the precast concrete plant, thereby reducing in-service concrete stresses.

- Proper design of connections and selection of quality sealants/sealers ensure satisfactory performance and low maintenance of concrete elements.

- Fabrication/erection tolerances are carefully specified and controlled; tolerances are critical for this project where new structural components must fit closely within and upon existing older construction.

- Adverse weather conditions do not affect precast concrete installation, and variability in temperature and humidity require minimum protection for materials. Weather delays are a key factor in this project, as airport construction must progress as quickly as possible to return parking spaces to revenue-producing assets for the owner.

Drainage and Head Room Issues—In the 1970s and 1980s, the standard practice of locating floor drains close to columns and girders in parking structures posed serious problems, such as debris buildup, deterioration, and safety hazards. Consequently, floor drains in this project are located at least 2 ft (0.6 m) clear distance away from columns and girders and are designed with a steeper pitch; this ensures that drains are located at a low point of the floor. Locating drains at midspan of a bay was also avoided—this positioning had the potential to loosen the drain body due to vehicular impact, slab deflection, and cracking of concrete around the drain (Fig. 8). Deterioration of a midspan drain also poses a walking hazard as the drain would be exposed. There is also the potential for water ponding or icing around drains in exposed areas.

Other historical issues are associated with close beam stem spacing and low headroom (≈ 7 ft [≈ 2.1 m]), which can prevent adequate sign visibility. These issues were successfully addressed in this project by providing higher floor-to-ceiling heights (8.5 ft to 9 ft [2.6 m to 2.7 m] clear headroom), which allowed signs to be set approximately 6 ft (1.8 m) or more above the precast concrete double tees for visibility from a distance.

High-Strength Precast Concrete Design—The design criteria for durability included the use of high-quality, high-strength structural concrete and proper detailing and material selection for minimal maintenance. The precast concrete design includes the use of:

- High-strength concrete (at least 5000 psi [35MPa] typical and 7000 psi [48 MPa] for columns and frames).
- A low w/c of 0.40 (or lower).
- Use of slag and corrosion inhibitors in concrete.
- Minimum 2 in. (50.8 mm) concrete top cover to reinforcement.
- Proper drainage to eliminate water ponding, icing, and impact damage.
- Good quality surface sealer applied at the concrete top surface.
- Good quality joint sealant.
- Crack-free design (reduced concrete stresses).
- Stainless steel and galvanized connections to prevent corrosion.

Option 2: Cast-in-Place, Post-Tensioned Concrete

Option 2 was an all cast-in-place, post-tensioned concrete system consisting of post-tensioned concrete slabs, beams, and girders supported on cast-in-place columns with spacing similar to that of Option 1. With the cast-in-place concrete post-tensioned slab system, conventional formwork and shoring were required during slab construction and had to remain in place until completion of post-tensioning operations. Because cast-in-place concrete construction is a monolithic operation, continuous over interior supports, tension stresses along the top concrete surface must be eliminated by an efficient post-tensioning design.

During cast-in-place construction, proper placement of the post-tensioning tendons in accordance with specified tolerances is critical and must be ensured by providing careful inspection. Maintaining stringent minimum cover tolerances in the field is tedious, and a consistent clear cover in cast-in-place concrete is not easily achieved. A cast-in-place concrete design needs to take into account increased tolerances for better corrosion control. On-site curing and quality control—particularly during the cold winter months in the
Boston area—would slow down construction progress and require special attention to quality and appearance of the finished product.

**Option 3: Combined Steel and Concrete**

Option 3 used a combination of structural steel and concrete (cast-in-place or precast) similar to Option 1 but used structural steel girders and steel columns instead of concrete. Fire rating requirements for steel members call for an expensive field-applied fireproofing system. Structural steel construction presents chloride-induced corrosion concerns and requires more frequent and costly maintenance.

**PROJECT BIDDING AND VALUE ENGINEERING**

**Three Bidders**

In 2003, Turner Construction Co. of Boston was one of only three bidders to compete for the Logan Airport parking expansion project. This unusual dearth of bidders was a direct result of the complexity of the job, the age and deteriorated condition of the existing parking facility, the proximity of construction of the project’s work to the heart of Logan Airport’s active operations, and the extremely limited site access—all making for a logistically challenging project. Final bids ranged from $189 million to $250 million; even the low bid, however, exceeded Massport’s budget.

To bring the project cost more in line with Massport’s original budget, Turner quickly became a member of the project team and worked closely with the designers and owner in a value engineering effort to reduce construction costs. For six months, project principals looked in detail at all the aspects of this complicated job. This intense collaborative team effort resulted in optimal efficiencies in both the design and construction approach while delivering major cost savings to the owner and maintaining the project’s original program.

**Unprecedented Challenges**

It is a serious construction challenge to erect three new parking structure levels above an active five-story parking structure. It is also an unprecedented challenge when the expansion work is concurrent with the removal and replacement of three levels of an existing parking structure down to its structural frame (columns). A major change to the original Massport specification was the design team’s proposal to adjust the project’s public operational restrictions, specifically with regard to plans for pedestrian access to the parking structure and adjacent terminals.

In addition to continuous public access within the existing central parking structure, Massport originally insisted that the existing parking structure remain open for use during construction. Specifically, only 850 spaces could be unavailable to Logan Airport customers at any one time for the duration of a construction project scheduled to last four years. In response, the project team proposed that a maximum of 1350 parking spaces be lost to the central facility at any given time during construction but that, in return, Turner would complete the project in only three years. Revising the parking space restriction allowed for a more efficient and economical construction approach, which was the cornerstone of the value engineering effort by the project team.

**Value Engineering Specifics**

The following are some of the value engineered design revisions that helped facilitate a more manageable construction approach and schedule:

- Pretopped precast concrete double tees were used for the floor structure at levels one and two (in lieu of cast-in-place post-tensioned slabs). The feasibility of this option was made possible by use of a one-of-a-kind hoisting rig. (International Erectors Inc. of Kenosha, Wisc., owned and operated the Carry-Lift crane, which met the challenge of rigging very long and heavy precast concrete members. Conventional erection equipment could not accommodate such difficult rigging—into, under, and through the existing structure.)
- Combined structural and architectural precast concrete spandrels reduced the number of precast pieces produced and erected.
- Operational restrictions and logistics completely changed the contractor’s approach to construction and revamped original plans for public access, interface, and facility availability.
- Mini-piles eliminated the need to penetrate the old structure to establish roof-to-bedrock foundations required for seismic code compliance (Fig. 9).
- Exterior facade spandrels with deep reveals are used on conspicuous sides of the structure and modified slightly (made thinner and flatter) for use on non-prominent sides, saving formwork and material costs.
- West-side stair/elevator towers eliminate the steel framing and cast-in-place landing and stair treads of the original concept. Architectural precast concrete serves a dual role as architectural facade and lateral
Fig. 10. This drawing shows the cross section between columns G and H, looking east.
Fig. 11. This drawing shows the cross section between column lines 10 and 11, looking north.

July–August 2006
Fig. 12. This drawing shows the interior column elevations, exterior frame columns, ramp columns, typical column base elevation (interior), typical column base elevation plan (interior), and typical column base elevation (exterior, ramp, and bridges).
Fig. 13. This drawing shows the double-tee strand pattern schedule, the typical double tee at the expansion joint, double tee reinforcing, typical expansion joint design, and a typical double tee flange connection.
Fig. 14. This drawing shows typical north-to-south and east-to-west facade frame elevations.
load resisting shear walls (instead of steel framing to resist lateral loads).

- Northeast and southeast stair/elevator towers are significantly larger than the west towers because this access is on the terminal side of the parking structure and receives more pedestrian traffic. Significant savings were gained by replacing steel with architectural precast concrete facade and shear walls. Precast concrete design solutions saved $600,000 to $700,000 over the original design.

- The vehicular bridge connects the adjacent seven-level parking structure to the three new levels of the expansion. Framing consists of two vertical precast concrete "boxes," one at each end of the bridge with double tees spanning between them to make a 30-ft-wide (10 m) roadway. Again, the structural steel framing of the original concept was totally replaced by using the architectural precast concrete facade as structural units. The lateral seismic loads in the north-south direction are resisted by precast moment frames made up of precast concrete beams and enlarged column sections cast monolithically with the architectural panels. The east-west lateral seismic loads are resisted by shear walls, which also provide the architectural features originally desired.

**LOGISTICS AND PUBLIC SAFETY**

Massport specified that traffic around the construction site could not be impeded at any time during construction. Both vehicles and pedestrians had to have unobstructed paths at all times, making Turner Construction Co. responsible for keeping traffic flowing smoothly. Keeping the required number of parking spaces open, accessible, and available to the public called for complex project logistics planning. The contractor’s goal was to minimize loss of existing parking spaces at any point in the three-year construction process. With these restrictive site logistics, cranes and crews coordinated closely to erect the precast concrete components concurrently on different portions of the project.

Public safety was of paramount importance while the parking structure remained operational and open to vehicular and pedestrian traffic during construction. Factors of safety were increased for all aspects of the project and included the adoption of a jobsite practice that required all precast concrete pieces to be double slung for hoisting and erection.

**Drawings Expedited in Team Meetings**

As with any precast, prestressed concrete structure, the precaster creates erection drawings for the erector to determine how to build the structure (Fig. 10–14). Erection drawings list piece details identifying individually manufactured components. The magnitude of the Logan Airport parking expansion project meant compiling a daunting number of drawings for the 5100 precast concrete components (Table 2). Hundreds of logistical drawings were developed to keep the construction schedule on track and within the public parking access mandates of Massport. Drawings were completed and submitted for approval in phases consistent with the production schedule established to feed the overall construction schedule.

Major construction phases included exterior facade H-frames and spandrels; each of four respective stair/elevator towers, inclusive of a temporary precast concrete stair tower and walkway; the underbuild for ground, first, and second levels; and the three new overbuild levels. To facilitate the drawing review and approval process, numerous design meetings were held in Boston. All project team members were present at each meeting and were expedient in finalizing drawings.

**PRODUCTION AND TRANSPORTATION FOR A RESTRICTED SITE**

After reviewing the contract documents, Blakeslee Prestress Inc. (BPI) of Branford, Conn., the precast concrete contractor, had an in-house meeting to discuss how to solve the several unique problems this project presented. There were many issues with producing and transporting the large pieces of precast concrete of many shapes over a 24-month period. The overriding issue, however, was erection of the precast concrete products given the restrictions on work areas—specifically, phasing of the work and the heavy pieces that had to be erected over long distances over an existing structure.

**Team Develops Means and Methods**

BPI decided to bring a team together that could provide the expertise needed to engineer, manufacture, and safely erect the project. Marino Crane Service of Connecticut was brought in to discuss what cranes were available and how the cranes could be utilized to erect the new structure over the existing parking structure. It turned out that Marino Crane had two 600-ton-capacity (550 tonne) cranes that were able to travel on trolleys and be supported by heavy rail beams that would do the job. To support the rails, it was decided to use the 2 ft x 4 ft (0.6 m x 1.2 m) precast concrete columns spaced at 50 ft (15.2 m) as part of the final design. These columns were then redesigned to carry the crane loads down to ground level through the existing structure.

Later, spliced extensions were added to the lower columns after the gantry cranes had passed by (carrying the new upper three levels of precast concrete structure), thereby avoiding the placement of any gravity loads onto the existing structure. The BPI team had worked on previous projects with H. Wilden & Associates (HWA) of Allentown, Pa., and knowing its capabilities, HWA was asked to join the Logan Airport Central Parking Expansion Project team. Precast Erectors Inc. (PEI) of Hurst, Tex., was also called in to determine its interest in the project and what level of expertise PEI staff might be able to provide. With the team in place, the following means and methods were worked out over several meetings:

- Stair elevator towers would be erected by 300-ton-capacity (272 tonne) ground cranes set at designated locations and in phased sequences.
- Perimeter precast concrete H-frames and spandrels would be set by ground cranes all around the building.
Table 2. Precast Concrete Pieces, Dimensions, and Tonnage

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<th>Precast Component</th>
<th>Number</th>
<th>Dimensions, Maximum</th>
<th>Ton, Maximum</th>
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</thead>
<tbody>
<tr>
<td>Double tees, expansion</td>
<td>1304</td>
<td>12.5 ft (3.8 m) wide x 58 ft (16.8 m) long</td>
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<td>Double tees, repair</td>
<td>824</td>
<td>12.5 ft (3.8 m) wide x 55 ft (16.8 m) long</td>
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<td>Slabs</td>
<td>78</td>
<td>8 ft (2.4 m) wide x 25 ft (7.6 m) long</td>
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<tr>
<td>Beam caps</td>
<td>230</td>
<td>3 ft (1 m) wide x 40 ft (12.2 m) long</td>
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<td>Wall panels</td>
<td>511</td>
<td>12.5 ft (3.8 m) high x 40.5 ft (12.3 m) wide</td>
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<tr>
<td>Stairs</td>
<td>38</td>
<td>5.5 ft (1.7 m) wide x 16.5 ft (5 m) wide</td>
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<td>Rectangular beams</td>
<td>62</td>
<td>1.5 ft (0.5 m) wide x 1.5 ft (0.5 m) deep x 15 ft (7.6 m) long</td>
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<td>Inverted T-beams</td>
<td>390</td>
<td>3.3 ft (1 m) wide x 3.5 ft (1.1 m) deep x 46 ft (14 m) long</td>
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<td>Interior columns</td>
<td>93 spliced (186 each)</td>
<td>2 ft x 4 ft (0.6 m x 1.2 m) x 44 ft (13.4 m) long</td>
<td>26</td>
</tr>
<tr>
<td>Exterior columns</td>
<td>30</td>
<td>2.5 ft x 2.5 ft (0.76 m x 0.76 m) x 45 ft (13.7 m) long</td>
<td>21</td>
</tr>
<tr>
<td>Column covers</td>
<td>64</td>
<td>5 ft (1.5 m) wide x 14.5 ft (4.4 m) high</td>
<td>5</td>
</tr>
<tr>
<td>Exterior H-frames</td>
<td>268</td>
<td>12 ft (3.7 m) high x 27.5 ft (8.4 m) wide</td>
<td>32</td>
</tr>
<tr>
<td>Interior H-frames</td>
<td>70</td>
<td>12 ft (3.7 m) high x 31 ft (9.4 m) wide</td>
<td>19</td>
</tr>
<tr>
<td>Interior K-frames</td>
<td>70</td>
<td>12 ft (3.7 m) tall x 31 ft (9.4 m) wide</td>
<td>35</td>
</tr>
<tr>
<td>Loadbearing spandrels</td>
<td>99</td>
<td>7 ft (2.1 m) deep x 25 ft (7.6 m) long</td>
<td>30</td>
</tr>
<tr>
<td>Non-loadbearing spandrels</td>
<td>385</td>
<td>6.5 ft (2 m) deep x 30 ft (9.1 m) long</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>4200 (expansion) + 900 (repairs) = 5100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 1 U.S. short ton x 0.907 = 1 metric ton (Mg or tonne).

in phased sequences for the lower four levels.

- Once new interior foundations were in place and openings were cut through the existing structure, a 400-ton-capacity (365 tonne) ground crane would be assembled at the south end and precast concrete columns would be dropped through openings. The crane would then assemble the gantry runways (rails) on those columns and the gantry cranes would be mounted on the rails. Sections of the gantry rails would be “leap-frogged” toward the north as the gantry moved forward and precast concrete components were erected behind it. Precast concrete products would be trucked to the parking structure perimeter and picked up by the cranes from those locations.

- When the cranes reached the north end, they would be taken down by the ground crane that had assembled them at the south end. The ground crane would then be used to close out that end of the building. (Note: During the process of developing the job, the direction in which the overbuild cranes were to progress was reversed to allow demolition and rebuilding of the two lower levels of the existing parking structure simultaneously with the overbuild erection.)

**Unique Proposal Presented to a Skeptical Massport**

BPI’s proposal was presented to Turner at bid time and compared with other erection schemes. To alleviate Massport/Turner concerns with the team’s proposed concept, if BPI was awarded the job, Marino Crane Service offered to set up one of the gantry cranes at its yard in Middletown, Conn., to demonstrate the stability and smoothness of
these cranes in handling 35 ton (32 tonne) loads at a 140 ft (43 m) radius.

Because the total cost to Massport was well over budget, several value engineering items were developed and accepted by Massport/Turner:

- Four stair towers were changed from steel frame and architectural precast cladding to all precast structural concrete with an architectural finish.
- Use of white cement was eliminated from the concrete.
- Combining the exterior cladding into the structural concrete eliminated a large number of pieces and connections.

Blakeslee was awarded the contract in March of 2004.

**Special Frame and Transport Needed for Precast Tonnage**

With a job of this complexity and size, the coordination of shop drawings and plant production schedules required an enormous amount of careful attention. Because there were many special types of precast concrete products, new forms had to be purchased. This meant shop drawing development was critical so that the forms could be detailed, ordered, and built and then enough pieces produced to meet the schedule on this multiphase project.

The heavily reinforced H-frames, K-frames, and shear walls, all utilizing NMB Splice-Sleeve® connections, along with the heavily reinforced 2 ft x 4 ft (0.6 m x 1.2 m) columns and prestressed girders, presented a real challenge in getting the reinforcing cages assembled to maintain the daily production schedule (Table 1). The H-frames, K-frames, and shear walls (up to 35 ton [32 tonne]) required special yard storage frames, shipping frames, and expandable low-bed trailers because of their length, height, and weight. A fleet of about 100 specialty trailers was used to deliver the precast concrete components to a marshalling yard within the airport, where they were escorted to the cranes by Massachusetts State Police when the crane crews called in precast concrete product (Fig. 15–17).

**AN UNCONVENTIONAL CONSTRUCTION AND ERECTION APPROACH**

**Unique Gantry-Mounted Roof Cranes and Low Headroom Rigging Equipment**

At 35 ton (32 tonne) and almost 60 ft (18 m) in length, the large and heavy precast concrete double tees presented challenges for transportation, rigging, and erection—over and within the deteriorated parking structure. Traffic on the busy airport surface roads enclosing the old parking structure could not be adversely affected by the transport or delivery of these very large precast concrete components.

Most parking structures that undergo a vertical expansion use a conventional approach to erection; erection cranes typically set up along the outside of the structure's long sides. In the case of the Logan Airport parking expansion project, there is no access for very large cranes with long booms at the perimeter, or outside, of the existing parking structure. Even
TEMPORARY BEAMS AND COLUMNS ANSWER TO CRITICAL CONDITIONS

There were two locations on the existing structure where support for the gantry crane header beams did not exist within the typical 50 ft x 60 ft (15 m x 18 m) grid. At the northeast and southeast corners, the east-west bays were 67 ft (20 m) apart, whereas the north-south bays were 47 ft (14 m) apart. In both cases, the 1.2 m columns were not positioned to support the gantry crane beams. In response, a unique solution was implemented.

On the columns existing at the 67 ft (20 m) span, two temporary prestressed concrete beams were poured between the columns of the H-frames. These temporary beams were then able to support the header beams, which were extended to match the span. Each temporary beam (25 ft 4.7 m long) was designed to support 800 kips (3540 kN) concentrated load from the header beam. Special vibrated devices were used to connect the temporary beams to the typical girders of the H-frames. Temporary connections were then included as part of the design to connect the typical NMMI Splice Sleeves' connection between H-frames. These two temporary prestressed concrete beams were poured on the existing structure for each of the four locations.

At the north-south end of the structure, it was proposed that the gantry crane would be moved into the fourth level of the existing parking structure and the remaining one or two days would be completed with a ground crane. The site was extremely tight, and the structure was positioned just north of a well-used roadway that could not be closed at any time. The gantry crane needed to be moved far enough south to erect the new overhead levels for a point that the site was in the parking garage. In the remaining process, the existing columns were removed. Several options were considered, but the most logical one was to build a holding tower south of the building line and support the rail beams from the top of the holding tower. This design necessitated heavy machinery to remove and install bearings but enough to prevent settlement while the crane was erected. The tower was designed, and the lift beam was set up for the crane to be erected. The bottom sections of the temporary columns matched the 30 ft x 30 ft (9 m x 9 m) geometry of the H-frame columns, and the top sections were 2 ft 4.7 ft (6 m x 1.2 m) to match the typical 47 ft (14 m) grid where the header beams were supported. These temporary columns were set on top of the H-frames at the south end of the structure and were located for the existing sections. In the north-south wind loads and east-west wind load.

Both of these solutions demonstrated the ingenuity of the team and how creative thinking can solve many unique problems.
if access existed for positioning a crane outside the existing building, it would not be possible for standard ground cranes to access and rig precast concrete sections over the 725 ft × 480 ft (221 m × 146 m) parking structure footprint.

While Sweden had a tower crane available with a boom length and picking muscle to accommodate the building dimensions (Kroll K-10,000), it was too heavy and big. The boom of this very large crane would interfere with open lines of sight required by the Logan Airport control tower. Site and Federal Aviation Administration restrictions on the positioning of erection equipment left one option open to the design team: to construct the new precast concrete facility from the existing roof—supported on new overbuild columns and two custom-built gantries.

The supports for each of the two gantry systems required six large overbuild precast concrete columns, 42 ft (12.8 m) in length, to sit upon the new mini-pile deep foundations. These six columns supported the gantry crane rails in a temporary condition and allowed for 750,000 lb (340,200 kg) of reaction load. It took about one month, or 18 to 20 working days, to set up each gantry and crane. Precast Erectors Inc.—the erector for all precast concrete supplied by Blakeslee Prestress—erected the gantry on the roof, set up the second gantry for the second crane, and started setting the expansion portion of the precast concrete system (Fig. 18–20). Marino Crane supplied the gantry cranes and gantry system. Once the cranes had set columns in advance of their path, the cranes then moved themselves forward on the gantry rails to the subsequent position for precast erection. Use of new permanent columns prior to the new overbuild section meant that the gantry was essentially self-moving on the tops of the same columns used for the permanent expansion component of the project. Using this method, the weight of the cranes and rails never rested on the existing parking structure. Instead, they essentially floated over the existing structure supported by
The new precast concrete columns.

Using precast concrete columns to support the two gantry cranes for the overbuild portion of the new structure reduced risk; existing supports in the older deteriorated structure were not compromised. Erection proceeded from north to south for the overbuild component. The underbuild portion of the project also required custom erection and rigging equipment for placement of new 12.5-ft-wide (3.8 m), 57-ft-long (17.4 m) double tees under the existing levels three and four that remained in place. The underbuild double tees were “walked” into the parking structure using specially designed Carry-Lift equipment supplied by International Erectors. Underbuild erection proceeded from south to north (Fig. 21-25).

The resultant movement of erection equipment from opposite sides of the site is known as the “reverse direction” erection option. To provide the necessary lateral stability for the structure during the erection phase, the exterior H-frames were in place to support complete erection of the overbuild portion. The gantry cranes provided virtually zero dynamic load to the structure, which was demonstrated at a mock-up event in October 2004 at Marino’s yard. Positioning of the H-frames around the entire perimeter of the existing parking structure, in turn, created a restricted access for the repair erection equipment required for the precast concrete double tees at levels one and two. A beam-and-roller method of erection proved to be a successful solution. In this method, the
double tees at the constricted end bays are temporarily double stacked within the new structure and at an adequate distance from the exterior H-frames. Double tees are then rolled on slide rails and lowered into their final position.

Foundation and Column Support Erection Equipment

The original proposal called for new foundation elements to be drilled from the roof to bedrock. Foundation caissons, 3 ft to 5 ft (1 m to 1.5 m) in diameter, were to be drilled down 40 ft (12.2 m) from the roof through the existing structure to grade and then drilled another 100 ft (31 m) down to bedrock. Rather than drilling a large-diameter caisson foundation all-

most 140 ft (42.7 m), the project team, in another clever approach, elected to drill mini-piles within and under the existing structure using 5-ft-long (1.5 m) threaded shafts.

Three to eight foundation mini-piles, ranging from 9 in. to 12 in. (230 mm to 305 mm) in diameter, were clustered every 50 ft x 60 ft (15 m x 18 m) along the grid line established for the bays (Fig. 9). Oil rigging shafts in pipe segments 5 ft (1.5 m) in length were used. In this way, the means and methods of the
new foundation did not need to penetrate the existing structure. About 800 mini-pile foundations were drilled in all.

CONCLUSIONS

Adding a 2900-space parking structure to an existing structure in an open environment is one thing, and certainly not exceptional as construction projects go. It is a totally different scenario, however, to erect three new levels on top of an existing, feeble, and aging five-level structure—all while the facility remains open and operational throughout three years of construction. Balancing passenger convenience and level of service with economy of construction and schedule, the Logan Airport parking expansion project team chose a precast concrete structural system that addressed both the site restrictions and accessibility concerns and delivered the most economical construction package.

Three systems were evaluated, and a precast concrete system proved to be the system of choice when compared with the other building systems. A precast concrete system provides quality, long-term durability, the desired aesthetics in the facade treatment, and constructibility within an abbreviated schedule—and last, but not least, precast concrete delivers the necessary economy of construction. Architectural precast concrete clearly establishes the desired look and a positive public image for the parking structure, an important consideration because of the structure's central and strategic location as the gateway/arrival entry to Logan Airport (Fig. 26).

Very tough site and logistical challenges made being a part of this remarkable expansion project one of the most exciting projects for the authors and the project team members, professionals with many decades of experience in the precast concrete construction industry. The concept of a completely new precast concrete facade that serves as the lateral load resisting system is truly a unique and innovative solution. Use of precast concrete interior columns to support the three new levels and the two roof-mounted gantry cranes is an innovative, safe, and cost-effective way to erect the overbuild levels. The Logan Airport parking expansion project is truly an outstanding construction achievement made possible by an exceptional spirit of innovation, cooperation, and ongoing teamwork.

ACKNOWLEDGMENTS

Coauthors Helmuth Wilden, P.E., (WEI) and Camille Bechara (Parsons Brinckerhoff) extend their thanks to staff members for an outstanding job on the Logan Airport parking expansion project. Wilden acknowledges HWA employees who performed the design and shop drawings, with special thanks to Stephen Gold, senior project coordinator, for his persistence and attention to detail; to Dave...
Fig. 26. Pictured are the early stages of the overbuild erection of Logan International Airport Central Parking Expansion Project.

Schreffler, P.E., project engineer, for his calm demeanor during times of crisis in satisfying tight production schedules; and to Todd McCoy, president and CEO of HWA for his continued support of the HWA staff throughout. Bechara extends his thanks to Parsons Brinckerhoff staff members who were involved in the structural design of the expansion and new structures, including Joseph Fersan, Teresa Vangeli, and Shin Chen, for the design of the parking structure, stair towers, and bridges, respectively, and their review of the shop drawings; to Peter Mainville for the review of constructibility and gantry crane design and erection; to Tony Dubrowski (PST) for overseeing the precast erection; and to Jeff Myung for ensuring safety during erection. Special appreciation goes to Steve Marshall, Massport’s project manager, for his support and commitment to the project, and to Sam Sleiman, Massport’s director of Aviation Administration & Development, for his cooperation and contribution to construction operations and logistics.

Pete Hamill of Turner Construction Co. would like to acknowledge the efforts of Blakeslee Prestress Inc. and its subcontractors—Precast Erectors Inc., Grout Tech, Marino Crane, and International Erectors Inc. In particular, Hamill would like to recognize Mario Bertolini and Mark Biebig-hauser for steadfast leadership through the course of the entire project. Hamill also congratulates the project team’s field management staff, consisting of Turner Construction Co., Parsons Brinckerhoff, and Fay Spofford & Thorndike, for its tireless team approach to ensuring the project’s success. The project’s success could not have been achieved without the cooperation and commitment of Massport, particularly Aviation and Capital programs.

CREDITS

Owner & Property Manager: Massachusetts Port Authority; East Boston, Mass.


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Precaster Concrete Contractor: Blakeslee Prestress Inc.; Branford, Conn.

Precast Concrete Erectors: Precast Erectors Inc.; Hurst, Tex.

Crane Supplier: Marino Crane Service; Middletown, Conn.

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