JFK Airport Light Rail Transit System

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ABSTRACT

The John F. Kennedy (JFK) Airport Light Rail Transit System was a design-build project of 9 miles (14.5km) of elevated precast concrete segmental superstructure. Due to construction congestion and relatively high labor cost, the designer worked closely with the contractor to create a flexible and cost-efficient erection system to erect 461 spans using span-by-span and balanced cantilever techniques. Several spans were erected using a 335-foot (102.1-meter) rolling truss method within the median of the six-lane Van Wyck Expressway.

Key Words: precast segmental, concrete, design-build, span-by-span, cantilever
INTRODUCTION

The JFK Airport Light Rail System is a $1.4 billion project owned by the Port Authority of New York and New Jersey. This design-build-operate-and-maintain project included the construction of six new airline terminals, connected by 11 miles (17.7km) of rail, of which 9 miles (14.5km) are elevated (Figure 1).

There are 461 spans in all, using 5408 segments, and the elevated portion is the longest precast concrete segmental bridge in the U.S. This light rail system will allow passengers to travel between airport terminals (Central Terminal Area), long-term and employee parking (Howard Beach), and rental car areas (Federal Circle). The rail crosses over and runs within the median of the congested six-lane Van Wyck Expressway. This link runs 2.3 miles (3.7km) to Jamaica Station, a hub for the Long Island Railroad, the New York subway, and 40 bus lines. It has been estimated that as many as 34 million passengers will use the rail system each year using 32 driverless, environmentally friendly trains.

DESIGN-BUILD SOLUTION

This light rail system was bid as a design-build-operate-and-maintain (DBOM) project. The design-build process allowed the construction to begin before the design was completed. This ensured a quick construction start-up and enabled the owner to begin operation of the facility at an earlier date.
The design-build project provided a unique and efficient relationship between the contractor and the designer, by establishing a direct line of communication between the two groups. A typical design-then-build project tends to separate the original designer from the contractor, whereas a design-build relationship encourages discussion of innovative ideas from the beginning of the bid process through design and construction. The superstructure team for the JFK Light Rail project was Koch-Skanska, contractor, and Figg Bridge Engineers, Inc., designer. To add to the efficiency of the design-build process, the designer supplied two construction, engineering and inspection (CEI) engineers on site to act as technical support and as liaisons between the contractor and the designer.

The DBOM process underscored the importance for innovation in all areas of the project. These innovations began with the design. The shear size of the project created a challenge to come up with a system where the precast segments could be cast and then erected in an efficient way. To start, the segments were designed with consistent lengths.

**PRECAST SEGMENTS**

The project consists of 7’-2” (2.2m) deep Type I and Type II segments, where the 19’-3” (5.9m) wide smaller Type I segment (*Figure 2*) supports a single rail and the 31’-0” (9.4m) wide Type II is a dual track segment. Typical intra-span segments have lengths of 8, 8.5, 9 and 9.5 feet (2.4, 2.6, 2.7, 2.9m) on center with variable widths. Pier segments and expansion joint segments are 7 feet (2.1m) and 6.5 feet (2.0m) long, respectively. Near the third points of each typical span are
deviator segments, two per span. Deviator segments accept the external tendons that run from end to end of each span. With vertical and horizontal curves, typical segments are cast pie-shaped, where the pier segments and expansion joint segments are cast rectangular-shaped. In fact, this is believed to be the first application where the curvature of a precast segmental bridge was developed solely over the typical segments with consistent lengths, leaving the pier segments and expansion joint segments rectangular in plan, not pie-shaped. This allowed for the complexity of the geometry to be controlled in the casting using new computation techniques developed in the software program, “Precision Cast 3D”, provided by Figg Bridge Engineers, Inc.

With the curvature taken up by the segments between the piers, almost every segment was different. Therefore, the wing lengths, rebar lengths, tendon trajectories, and pipe bends were different from span to span. To accommodate the segment variables, and eliminate the necessity to produce shop drawings for each of the 5408 segments, the designer developed tables showing the variable reinforcing and dimensions for each segment. The reinforcing bar types and their dimensions, wing lengths, etc. were provided for each joint of each segment. The tables incorporated 22 possible variables that the casting yard, Bayshore Concrete Products, needed to cast the segments. These tables were included in the design drawings with the typical dimension and reinforcing sheets for the different lengths and types of segments. Bayshore had 14 casting cells at peak production, so efficiency and consistency were top priorities.

To highlight the significant variations in the superstructure geometry, the 3D tendon paths were calculated to determine the anchor locations, the tendon entry and exit locations, and the angles
for the pipes cast into the pier, expansion joint and deviator segments. This information was provided to Bayshore via electronic files for the individual segments.

**CONSTRUCTION INNOVATIONS**

This unique relationship between the designer and the contractor led to many innovations in the construction side of the project. These innovations were developed to encompass the variables that this project produced. Almost all of the 461 spans are different. Therefore, this project required an erection system that could be transformed to meet each variable. These variables were introduced by different obstacles, such as different span lengths with changing horizontal and vertical curves and constantly changing MOT within the already heavily trafficked airport. The erection system had to be diversified enough to build over major highways, within inches of buildings, and be supportive while straddling underground utilities.

To accomplish this, both span-by-span and balanced cantilever erection were used. Span-by-span construction was used to build 90% of the spans. Cantilever construction was used in areas with tight horizontal curvature or where span lengths were too long for typical span-by-span construction. For the span-by-span erection of the smaller Type I segments, the span lengths ranged from 52 feet to 130 feet (15.8m to 39.6m), with radii as small as 650 feet (198.1m). Balanced cantilever erection of Type I segments was used for spans ranging from 70 feet to 130 feet (21.3m to 39.6m) long, with radii as small as 235 feet (71.6m). The larger Type II segments were also erected with both methods. The Type II span-by-span erection covered span lengths
from 80 feet to 140 feet (24.4m to 42.7m) and radii as small as 300 feet (91.4m). Balanced cantilever construction was used for Type II spans up to 150 feet (45.7m).

**SPAN-BY-SPAN CONSTRUCTION**

Span-by-span construction for the JFK project used temporary underslung trusses (Figure 3) to support the precast segments from pier to pier. The segments were cast against each other to insure an exact fit between the segments. Slow-set epoxy was applied to the joints to secure the bond between the segments and help protect the utilities and the external post-tensioning that run inside the box from the environment. These joints were temporarily stressed with P.T. bars across the top and bottom slabs. Once the segments were temporarily stressed and set to the desired geometric location, two concrete closure pours were formed and placed, one on each side of the span. The closures connect the typical segments to the pier segment and/or expansion joint segment at both ends of the span. Once the closures met the desired minimum strength, the span was stressed with external post-tensioning. The span was then self-supporting and the trusses were lowered and advanced to the next span.

**Underslung Trusses**

Four sets of underslung trusses were used at peak production. Two were designed for the erection of the smaller Type I segments and two for the Type II segments. The trusses were made of interchangeable pieces with lengths of 10 feet, 20 feet, 30 feet, 40 feet, and 50 feet (3.0m, 6.1m, 9.1m, 12.2m, 15.2m). Although the ability to change the lengths of the trusses was
necessary, a great deal of time was spent in discussion between the CEI engineers and the contractor to prevent the need for reconfiguration. Changes in span lengths, tight horizontal curves, straddle beams and traffic clearance restrictions typically dictated the need to reconfigure the trusses.

Another important reason for innovation and accuracy was the relatively high labor cost in the New York area. Anything that the contractor could calculate, design or use to save 15 minutes a day during erection could be a big cost savings over the two plus years of construction, especially when at peak production with four erection crews. There were several opportunities for the office engineers to analyze the erection process and provide the field personnel with simplified but detailed information that they could use to erect a span as quickly as possible, particularly for the span-by-span erection.

**Segment Support System**

The segments were supported under the wings on the trusses with adjustable jacks. One way to save time during construction was to provide the ironworkers with the stroke heights for each side of each segment. To calculate the stroke heights, the loaded truss deflections, changes to the vertical and horizontal curves, and the variable wing depths were incorporated. These variables were then combined with the tower elevations. The stroke heights were given to 1/8th of an inch (3mm) to approximate the final position of the segment and keep the adjustments in the field to a minimum (*Figure 4*).
The stroke heights were needed to place the segments at the approximate elevation. To estimate the transverse alignment, the position of the truss underneath the wing was dimensioned. These locations were chalk-lined underneath the wing to give the ironworkers the position to land the segment on the jacks (Figure 5).

**Tower Supports**

The trusses were supported on rocker bearings set on temporary towers. These towers were designed to adjust to the constant change in elevation and curvature of the superstructure. To help accommodate these changes, a screw jack frame was developed (Figure 6). These frames supported the towers and had an adjustable screw foot that ranged from 0 to 24 inches (0.61m). The stroke lengths were calculated according to the survey shots for each tower leg and provided to the field personnel for erection.

Also to accommodate the height variations, the tower components, like the truss, were made of interchangeable parts. Along with the screw jack frame were 6-inch, 12-inch and 18-inch stools (0.15m, 0.30m, 0.46m), along with 3-foot, 5-foot and 10-foot panels (0.91m, 1.5m, 3m). These components supported one of three upper bracket frames, which in turn supported the truss. The typical two-piece upper bracket frame was unique due to a dual-pin connection at the longitudinal center of the tower (Figure 7). This enabled the contractor to remove the tower from under the completed span and keep the truss support beams intact. One disadvantage to the split frame was that it had to be disassembled from both sides of the pier. Due to existing buildings, active roadways and other obstacles, the removal of the frame from both sides was not an option.
Therefore, a single transverse beam was designed that supported both trusses. However, the assembly and removal of this tower setup was more time consuming.

The upper bracket frames supported the longitudinal beams, which supported the rocker bearings (Figure 8), which in turn supported the trusses. Bolt holes were spaced every 6 inches (0.15m) along the top flange of the frame to accommodate the horizontal curvature. To simplify the erection of the towers, each hole was lettered across the top of the beam. The CEI engineers provided the location of the longitudinal beams along the transverse beam for each truss. In a similar fashion, the longitudinal beams had numbered holes along their lengths to receive the rocker bearings. These values were also provided for each span. For added stability, the towers were connected to the pier using cable bands that attached to the top of the tower and wrapped around the pier. The towers were also attached to the footing with epoxy anchors set into the footing.

**Straddle Noses**

Throughout the project, there were areas where the use of towers was not feasible. Straddle beams (Figure 9) were used instead of piers when the position of the pier landed in the middle of a road or on top of some other obstacle.

The cast-in-place straddle beam “straddled” the obstacle and supported the guideway without changing the natural geometry of the structure. Also, at a few locations where the elevated portion of the superstructure transforms to grade level, an abutment was used. To erect a span on
top of straddle beams or abutments without a tower, a straddle nose was designed (Figure 10). This nose was attached to the truss at a typical splice and was placed directly on the straddle beam. The nose had three support locations, 4 feet (1.2m) apart, to add to its versatility.

TRUSS MOBILIZATION

“C-Hook”

The trusses supported the segments under the wings and could be advanced from span to span in different ways. Typically, the truss was moved using a C-hook (Figure 11). The C-hook was placed at the center of gravity of the truss. The crane attached to the top of the C-hook and lifted the truss, removing it from underneath the completed span.

“Rolling C-Hook”

Another, more innovative, way to move the truss was developed using a “rolling C-hook”. The rolling C-hook involves positioning the C-hook at the backend of the truss and attaching a “bogey” (Figure 12) to the beam that was cantilevered over the top slab.

The bogey was a rolling device that supported the tail end of the truss and was steered with a lever while the truss was in motion. A crane was set ahead of the next span to be erected and attached to a 55-foot (16.8m) long launching nose that was connected to the front of the truss. The crane lifted the launching nose and pulled the truss forward while steering with the bogey.
Rolling 335-Ft. Truss Along The Van Wyck Expressway

The 100 plus dual track spans erected along the six-lane Van Wyck Expressway introduced an impressive way to erect an elevated structure where there is minimal existing right-of-way remaining along the highway. An approximately 10.5-foot (3.2m) median was available between the six-lane highway. It was a diverse layout along the Van Wyck, with overpasses, raised shoulders and retaining walls throughout the length of the expressway. With precise planning, the shoulders and lanes were shifted and combined with the original median to create a work area of 24 feet (7.3m) (Figure 13), just wide enough for the crane. This meant that only 12 feet (3.7m) of right-of-way was needed from each side of the highway.

The Van Wyck Expressway is a major entrance to and exit from the JFK Airport. It runs north and south from the Belt Parkway to the Long Island Expressway. The volume of traffic (24 hours a day) is tremendous. Therefore, the goal was to achieve the least possible amount of traffic disruption. Due to the traffic studies, the contractor was only allowed to close the left northbound and southbound lanes between 10 a.m. and 2 p.m. and between 11 p.m. and 5 a.m. To stay efficient, the contractor eventually went to separate day and night crews. This also meant that the 24-foot (7.3m) wide crane could not go out to the side of the span to remove and advance the trusses when only a 12-foot (3.7m) lane was taken. Therefore, it was decided to mobilize the trusses in the longitudinal direction. With these constraints, a launching system was developed to connect two sets of Type II trusses together, plus a 55-foot (16.7m) launching nose, totaling 335 feet (102.1m) of truss.
This launching system used the crane to pull the truss forward. To start, the crane was positioned ahead of the span to be erected. While using the crane’s main hook to pull the truss and the ball hook as a brake, a pulley system was arranged to launch the truss to the next pier. A couple of large rollers (Figure 14) at each tower were used to help roll and guide the truss from pier to pier. The 335-foot (102.1m) truss length was used to insure that the truss was always supported by at least two towers at any time during the launch.

For safety reasons, a hook was secured to each tower with a choker that could be attached to the truss every ten feet (3m) as the truss rolled into position. The hook acted as a safety line to prevent the truss from rolling away from the crane. Once the truss was in its final position, it was raised to the given elevation and secured to the rocker bearings. With optimal conditions, both trusses could be launched to the next span within an hour and a half.

With the truss in position and one lane of traffic closed, the segments were delivered into the left lane, lifted and loaded by the crane (Figure 15). The crane remained ahead of the span and only had a limited amount of room to lift and place the 30-ton (27.2 kg) segments.

Due to the restrictions of the upstation pier and the truss itself, the crane had a reach of about 40 feet (12.2m) (Figure 16). Therefore, the segments were placed on the truss and rolled downstation into position. The same calculations used in the typical span-by-span erection became even more important in this time-restrained process. During the day, the time allowed to launch the truss and set segments was only four hours, 10 a.m. to 2 p.m. Using the
predetermined stroke heights and position of the chalk-lines under the wing, the segments could be set quickly and rolled into place. To roll the segments into position, the trusses needed to be set parallel to one another. The jacks that supported the segments sat on rollers that allowed for only 2 inches (50mm) of play in the transverse direction. Once that was exceeded, a temporary jack had to be used to lift the segment, reposition the original jack on the roller and remove the temporary jack. This could be very time consuming and was avoided whenever possible.

The unique qualities end at this point and the typical span-by-span erection sequence was continued without any lane closures. Safety netting and burlap was used along the truss to help prevent any debris or epoxy from landing on the expressway or the traffic below. With optimal conditions, the contractor was able to use this erection sequence to average 1½ days per span. Once the superstructure erection was completed and the equipment was moved ahead, a wall was placed within the median between the piers, taking up about the same width as the original median (Figure 17).

**CLOSURE POURS**

The desire for efficiency and quality led to a productive way of mixing the closure pours. These closure pours were required for each span, and usually ranged between 5 and 10 inches (0.13m and 0.25m) long. For typical precast segmental construction, a contractor orders the one or two cubic yards of concrete from a batch plant and has it delivered via a concrete truck directly to the span being erected. With the congested traffic throughout the JFK Airport, as well as the
limited working area, the contractor decided to mix the concrete on-site. In fact, the concrete mixer, sand, and aggregate were stored on top of the span being erected (*Figure 18*).

This process not only insured that the contractor could schedule the pour time precisely, it also gave them direct control of the mix, which worked very well. Due to the strong attention to the color of the structure, an effort was made to match the color of the closure pours with the piers and precast segments. After many samples, they found it necessary to use the exact same sand, aggregate, water ratio and admixtures that the casting yard used to cast the segments.

**CANTILEVER ERECTION**

Ten percent of the spans erected at the JFK Airport Light Rail Transit Project were constructed using the balanced cantilever method. Some were needed due to the tight curvature and others due to the longer length of the spans. Balanced cantilever erection involved the erection of one segment at a time on each side of the pier segment, keeping the unit no more than one segment out-of-balance at a time. To accommodate this out-of-balance force, a tower was set around the pier with adjustable jacks at the top corners of the tower (*Figure 19*). Also, post-tensioning bars were anchored into pre-set couplers cast inside the pier capital. The segments were connected temporarily with post-tensioning bars across the top and bottom slabs across each epoxied joint. Internal top slab post-tensioning tendons were stressed at different intervals throughout the erection (*Figure 20*). For cantilevers with tight curvature, the transverse overturning forces had to be considered. To prevent overturning, post-tensioning bars were placed through the wing on
the appropriate side and anchored into the footing. The bars were stressed at different intervals as the cantilever progressed.

At several points in the project, two cantilevers came together at expansion joints. A unique system was designed to hold the segments in cantilever with the 3-inch (76mm) gap between the expansion joint segments. Similar to the typical cantilever, a tower was used with vertical P.T. bars coupled into the top of the pier and placed through the expansion joint gap. These bars were anchored to cross beams that held the expansion joint segments on the pier capital. Temporary stressing blocks were poured in the gap between the expansion joint segments in certain locations along the top and bottom slabs. The segments were longitudinally connected with P.T. bars across the top and bottom slabs, and the adjacent segments were placed while coupling to these bars. Concrete closure pours were placed between these segments and their adjacent cantilevers. Finally, external post-tensioning was installed between the cantilever pier segment and the expansion joint segment and stressed.
CONCLUSION

Within the design-build process, the designer and contractor worked together to develop the innovations needed to confront the many superstructure obstacles within the JFK Airport Light Rail Transit Project. Reinforcing and dimension tables were prepared by the designer to eliminate shop drawings for individual segments. Variable erection trusses and towers were designed to conform to the vertical and horizontal curvature of the superstructure. The more impressive innovation was the 335-foot (102.1m) longitudinally-launched truss system that was used along the median of the six-lane Van Wyck Expressway. The success of this erection process was encouraging for highways where it is believed that there is not enough right-of-way to erect a structure.

Span-by-span and cantilever erection was used to complete the 461 spans with an average of over 17 spans a month. This aggressive schedule positioned the contractor to complete the erection by August 2001 (Figures 21 & 22), ahead of schedule by 2 months, even though superstructure erection began 2 months later than expected.
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