Precast Concrete Light Rail System Provides Mass Transit Solution for JFK International Airport

José M. Rodriguez, P.E.
Senior Project Director
Figg Engineering Group
Tallahassee, Florida

Majid Hedayati, P.E.
Vice President and Project Director
STV Incorporated
New York, New York

Antonio Taddeo, P.E.
Senior Estimator
Koch Skanska Corporation
Carteret, New Jersey

Jennifer K. Parks
Project Manager
Bayshore Concrete Products
Corporation
Cape Charles, Virginia

John F. Kennedy International Airport in Queens, New York, is one of the world's busiest hubs, a vital facility where travelers might expect to find state-of-the-art surface transportation systems. Prior to 2003, however, travel to and from the various airport terminals and parking areas required curb-access bus transportation that was often inconvenient and slow. After years of failed attempts to rectify the situation, a rapid transit plan emerged that successfully solved right-of-way, environmental, and public opinion obstacles. The new 8.2 mile (13.2 km) light rail line was built at a cost of $1.9 billion under a design-build-operate contract using a consortium of design and construction firms. The light rail system comprises over 5400 precast concrete segments. One of the greatest accomplishments of the project was the rapid truss erection of precast concrete girders within a narrow 10 ft (3.0 m) median with minimal disruption to major roadway traffic on either side.

Travelers to one of the world's busiest international airports might expect to find a sophisticated and user-friendly transportation system. At New York's JFK International Airport, however, inter-terminal transport was commonly and politely described as a major challenge. In the past, access to any of the airport's six terminals, parking lots, or ground transportation services required travelers to use a slow and inconvenient bus system at terminal curbsides. In addition, highways leading to the airport were severely congested – a situation that caused a negative impact on airport usage for years. As a result, New Yorkers and international travelers often turned to other regional airports for their transportation needs.

Over the past 35 years, more than 20 proposals had been submitted for creating an efficient transit system that could link JFK International Airport to existing public transportation. All of these plans were rejected for various reasons, including insufficient funding, legal hurdles, or problematic connections to existing modes of transportation. Finally, in 1996, the Port Authority of New York & New Jersey authorized a proposal that successfully addressed the airport's transit needs with a community-supported plan that both optimized existing infrastructure and minimized environmental impact.

PROJECT DESCRIPTION

In April 1998, the Port Authority awarded a $1.9 billion design-build-operate-maintain (DBOM) contract to the AirRail Transit Consortium (ARTC), a strategic joint venture between the AirRail Construction Joint Venture (Slattery Skanska, Koch Skanska, Sardoni Skanska, and Perini Corporation) and Bombardier Transportation. The Construction Joint Venture (JV) retained STV Incorporated as the design engineer and Figg Engineering Group as consultant for the precast concrete segmental construction. Bayshore Concrete Products Corporation of Cape Charles, Virginia, was contracted to fabricate the precast concrete segments.

The JFK Light Rail System (AirTrain) links ten airport stations with fast and dependable service to the mass transit system of New York City. Two examples reveal the significance of this transit project. Prior to construction of the light rail system, a trip from Midtown Manhattan to JFK terminals took two hours or more by automobile; today, passengers on the light rail system can complete the same trip in 45 minutes. Further, a trip that used to take 30 minutes around JFK's central terminal area now takes only eight minutes.

Completion of the new light rail system provides fast and reliable airport transportation (see Fig. 1). In addition to linking the airline terminals, the new rail system provides a convenient connection to car rental agencies, airport parking lots, and major external transit systems including subways, railways and highways.

Cost for the entire light rail program was estimated at $1.9 billion; the precast concrete production and erection portion was over $110 million. No tax dollars were used to fund the project; rather, the AirTrain system was funded through a combination of revenue from an existing $3 surcharge on


Fig. 1. This night-time photo shows erection of the last precast concrete segment – three months ahead of schedule. Photo courtesy: Figg Engineering Group.

Fig. 2. The Van Wyck Expressway offered very limited space in which to construct a light rail system. Beyond the challenge of erecting the superstructure in a very restricted space, three lanes of traffic on either side of the rail line had to be maintained during the course of the project. Photo courtesy: Figg Engineering Group.

departing passengers and Port Authority funds.

The elevated precast concrete superstructure runs above and along the existing 10 ft (3.0 m) median of the Van Wyck Expressway, a congested six-lane urban highway (see Fig. 2). The Van Wyck portion of the rail line is 2.3 miles (3.7 km) long and connects to Jamaica Station, a network hub for the Long Island Railroad, the New York City (NYC) Subway System, and over 40 bus lines. It is estimated that over 34 million passengers utilize this transit system annually.

The project's economic parameters required innovative approaches to design and construction. Assembling a DBOM team with the appropriate expertise, along with the selection of concrete as the primary building material, was crucial to the project's success. Precast concrete segmental construction provided an economical solution to meet the complex geometrical requirements and ensure rapid, high-quality construction. As regional labor costs are extremely high, the precast superstructure needed to be constructed as quickly as possible, while maintaining safety standards.

Project teamwork was crucial for success. The engineering design firm worked closely with the construction team and the precast concrete supplier to complete a functional and aesthetically pleasing superstructure within a 20-month construction timeframe. Productive interaction between the engineer, precaster, and contractor kept the project on a fast-track schedule. The design firm provided two full-time construction engineers on-site to assist the contractor with the erection process. As a result of this close collaboration, in August 2001 the precast superstructure was completed – three months ahead of schedule.

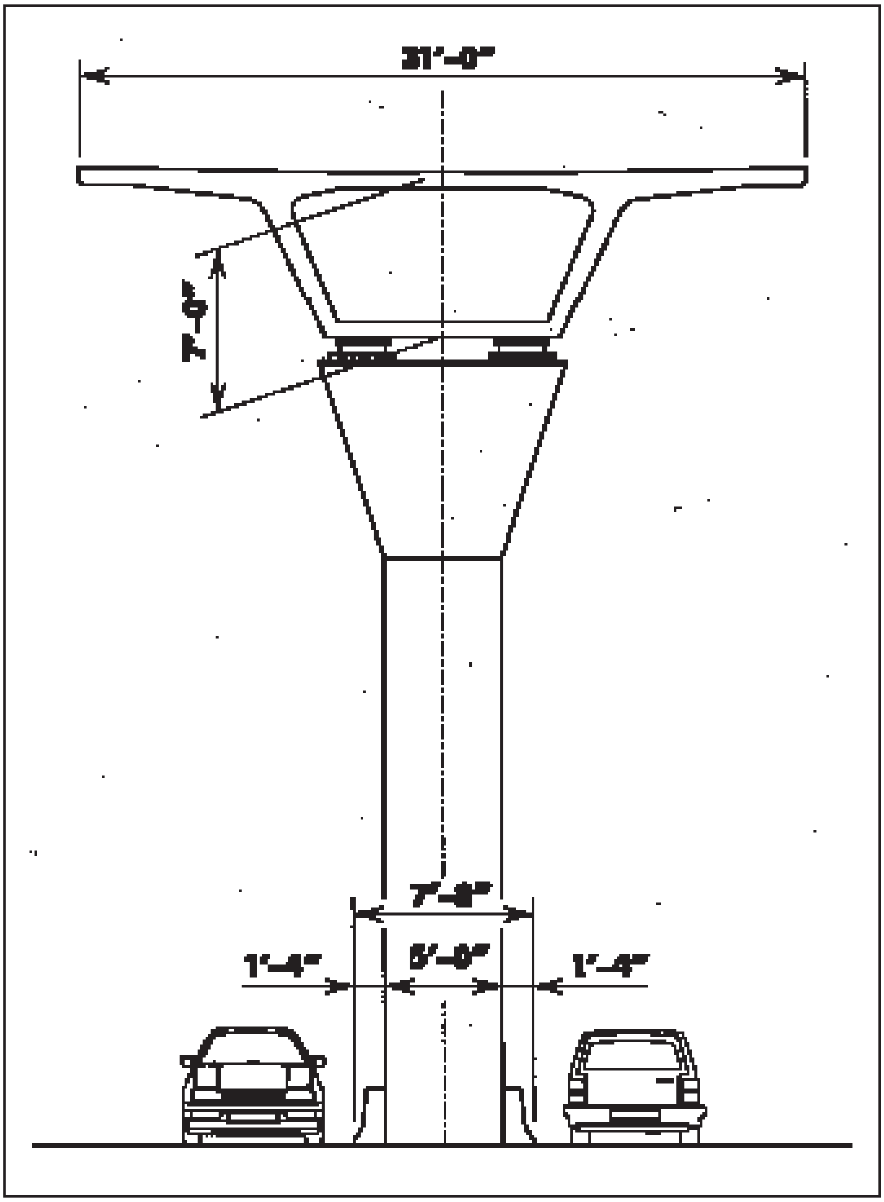

Fig. 3. This section through the structure clearly illustrates the site restrictions of a very narrow median and proximity of traffic.

DESIGN OF PRECAST CONCRETE ELEVATED GUIDEWAY

The light rail transit system consists of 11 miles (18 km) of railway, nine miles (14.5 km) of which are elevated on a precast concrete segmental superstructure, and includes ten fully enclosed, climate-controlled stations. About 3 miles (5 km) of the elevated section runs on a 7.67 ft (2.3 m) wide support within the narrow median of the congested Van Wyck Expressway (see Figs. 2 and 3).

Two tracks were required for the AirTrain project to meet specifications for center-platform stations. A single-track guideway section runs on each side of the station, and outside the station areas the two tracks run on a single precast guideway.

The elevated guideway portion consists of a precast concrete segmental box girder structure built with 461 spans using 5409 precast segments – the most of any known bridge project in the United States. After testing the trains, the entire system was opened to the public in December 2003.

Precast concrete segments were of two sizes, weighing an average of 25 tons (22.7 Mg) apiece and designed with a consistent length of 10 ft (3.0 m), which provided production economies to help maintain the project budget.

Two types of precast concrete segments were designed with a uniform depth of 7.17 ft (2.19 m):

- Type 1 – 19.25 ft (5.9 m) wide segments support the single rail. Over 3560 Type 1 segments were required to construct 539,000 sq ft (50,070 m^2) of deck surface (see Fig. 4).

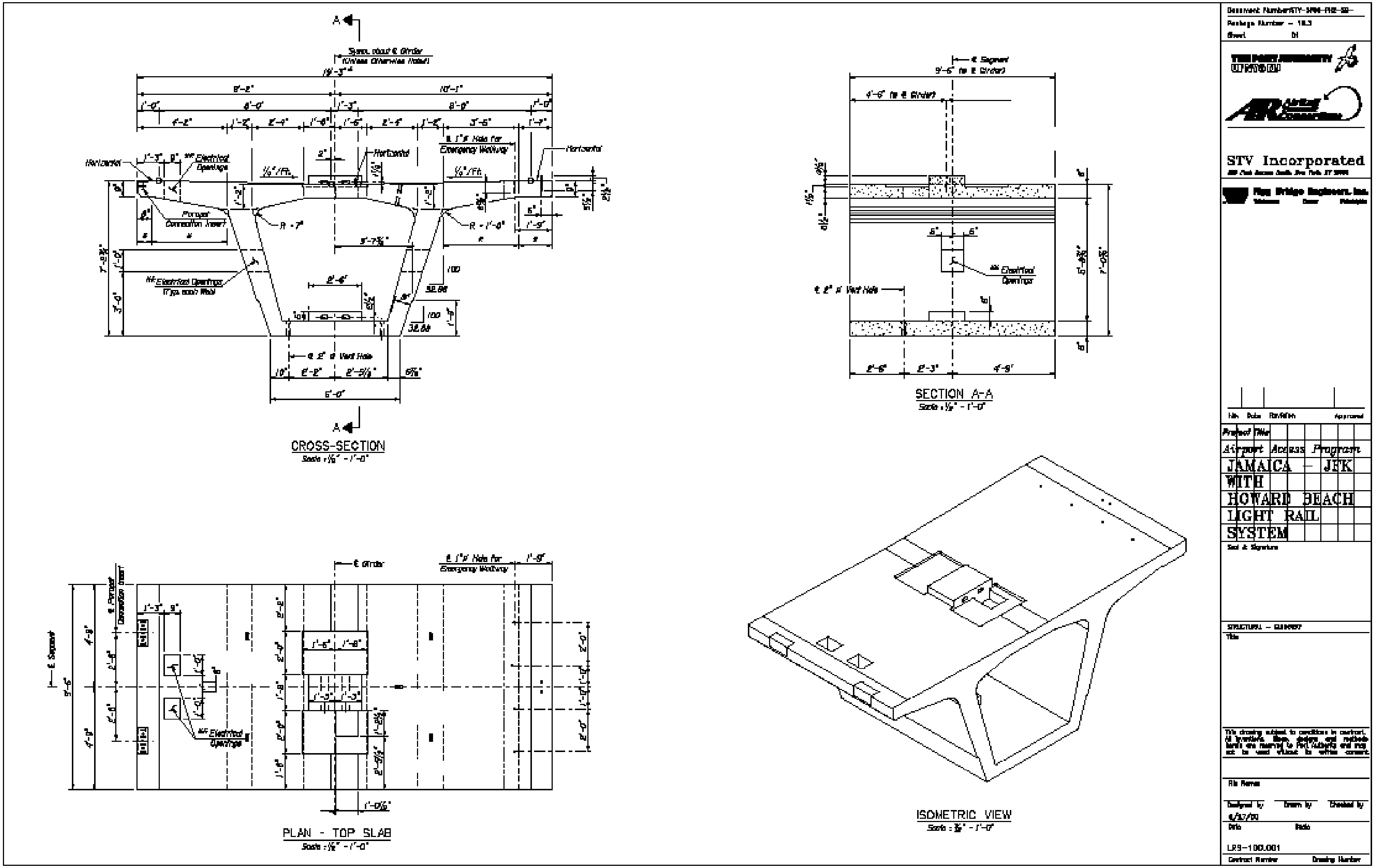

Fig. 4. Type 1 segments weighed from 20 tons (18 Mg) for the shortest typical segment to about 30 tons (27 Mg) for the pier segments.

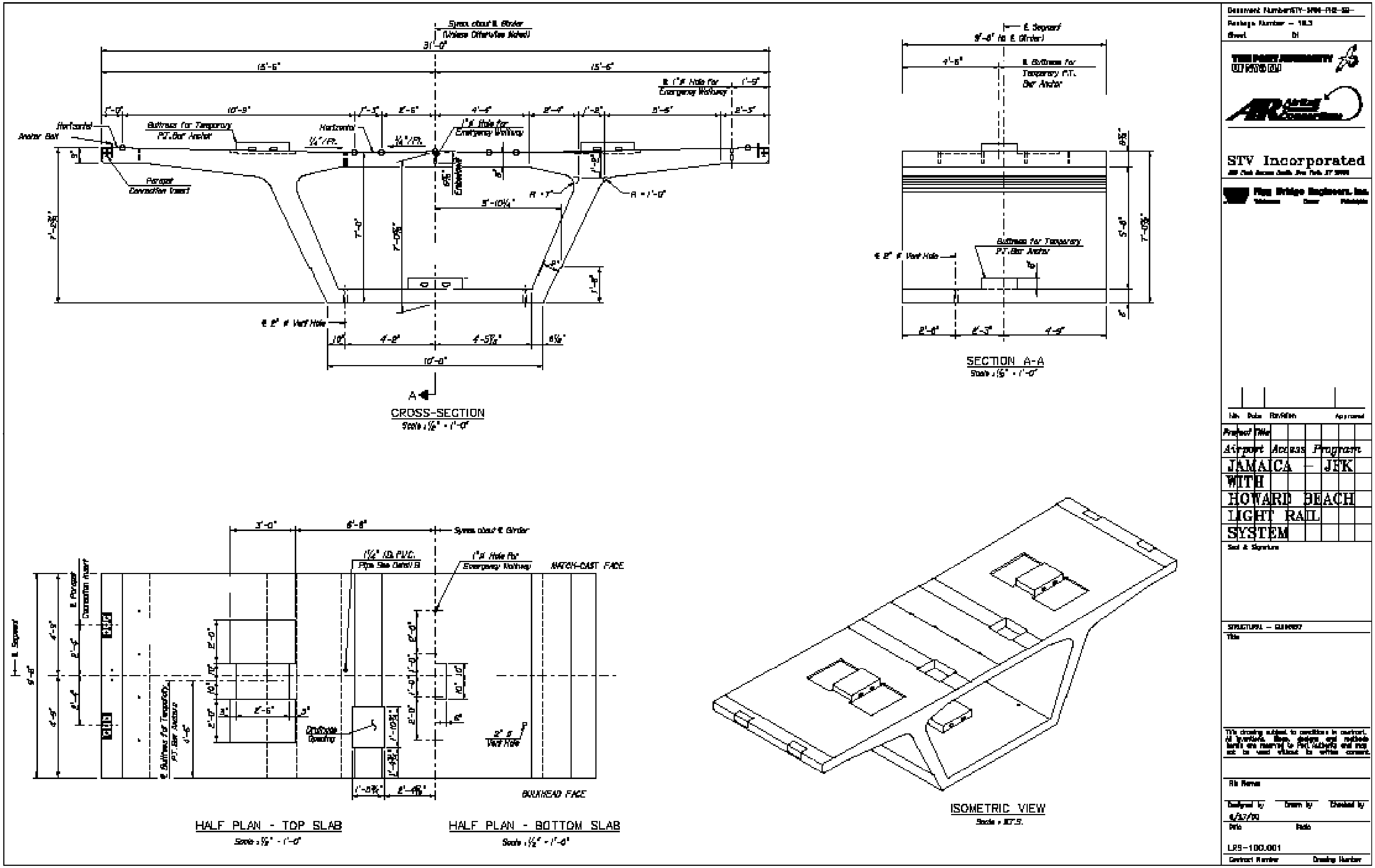

Fig. 5. Type 2 segments have a top slab of 31 ft (9.4 m), a bottom slab width of 10 ft (3.0 m), and an overall depth that matched the Type 1 segments.

- Type 2 – 31 ft (9.4 m) wide segments support the dual rails. Over 1840 Type 2 precast segments were required to construct 558,000 sq ft (51,840 m^2) of deck surface (see Fig. 5).

Type 1 segments were primarily used around the central terminal area and in locations where stations were situated to allow access for a single platform, while Type 2 segments were used mainly in long stretches between stations, as in the Van Wyck Expressway section. The constant depth of the box girders provides seamless transitions at the numerous merge areas within the system (see Fig. 6).

Fig. 6. The seamless transition and sleek line of the precast concrete superstructure is apparent in this ground shot. The beauty and elegance of the precast concrete design overcame over 30 years of public opposition to a light rail transit project.
Photo courtesy: Bayshore Concrete Products.

Complex curvature — Due to the complex curvature of the superstructure, nearly every precast segment is unique (see Fig. 7). To accomplish the required curvatures, typical segments were cast in a pie shape, while the pier segment and expansion joint segments were cast in a rectangular shape.

The project's complex geometry was controlled during fabrication through the use of computer software developed and provided by Figg. Typical pie-shaped precast segments were 8.0, 8.5, 9.0, and 9.5 ft (2.4, 2.6, 2.7, and 2.9 m) in length along the girder centerline, with variable wing depth. Expansion joint segments were 6.5 ft (2 m) long.

Acoustic precast panels — Precast concrete was also used to make 10,818 individual 2.5 ft (0.8 m) high acoustic panels, which were attached to each box girder segment on either side. These panels visually screen the wheels of the light rail vehicles and reduce noise levels to the surrounding communities by sending sound waves upward, while the guideway's solid track bed keeps sound from penetrating through the underside of the structure (see Fig. 8).

The precast concrete guideway is supported by cast-in-place (CIP) con-

Fig. 7. In areas with tight curvatures, spans were constructed in a balanced cantilever method. Balanced cantilever construction was used on about 50 of the 474 spans of the AirTrain project. Photo courtesy: Figg Engineering Group.

crete columns on pile-supported foundations ranging in height from 15 to 50 ft (4.6 to 15.2 m) depending on the clearance required for structures that the guideway passed over, with a typical diameter of 6 ft (1.8 m). Supporting piers are housed within concrete traffic barriers to protect the piers from vehicular collisions.

Shop drawings — Segments were cast at the Bayshore facility in Cape Charles, Virginia, utilizing 14 casting cells daily at peak production. Segments were cast using design drawings and detailed tables provided by the engineer. The tables included up to 22 possible variables needed to cast each segment, including segment dimensions, reinforcing bar types and bar lengths. This approach eliminated the need for conventional shop drawings and minimized the precaster's efforts in developing casting data for operation workforces.

Fig. 8. Precast concrete side parapets functioned in dampening sound to the surrounding neighborhoods as well as concealing the track. Photo courtesy: Bayshore Concrete Products.

Fig. 9. Bayshore added $7 million in casting facilities to produce the different precast products required for the AirTrain System. The casting facilities encompassed a large portion of the 85 acre (34 ha) Virginia facility. Photo courtesy: Bayshore Concrete Products.

Fig. 10. Bayshore's casting cells (single-track segments shown) were set up with waiting positions in which segments were prepared for storage after being removed from the match-cast position. Photo courtesy: Bayshore Concrete Products.

PRODUCTION CHALLENGES

The JFK AirTrain Light Rail System required the largest casting operation in Bayshore's history. The project required fast-pace production of many custom products, concrete color consistency, and complex loading and transportation of multiple precast components.

Labor — Over the course of producing the light rail system segments, Bayshore's labor force grew by nearly 40 percent to about 200 additional employees. A core group of experienced segmental technicians trained the new employees in record time. Setup began nine months before the first segment was cast, which occurred in February 1999.

Fabrication — Casting facilities were added to the existing plant to accommodate the four different precast concrete products (see Fig. 9). Fourteen casting cells were set up around the existing production facility so that all existing contracts could be completed without interruption. The $7 million setup called for establishing casting facilities in an undeveloped area of the 85 acre (34 ha) plant site. The contract required production of 5409 precast concrete segments. This quantity was the driving force behind the number of casting cells that had to be in production in order to meet the fast-track schedule.

In addition to modifying the existing four-segment casting cells to accommodate the dual-track typical and deviator segments, Bayshore constructed six single-track casting cells for typical and deviator segments, one single-track pier cell, one single-track expansion cell, one dual-track pier cell, and one dual-track expansion cell.

Erection Schedule

Segments were cast at a rate of 12 per day to meet the erection schedule. In addition to the segmental production, 15 parapets, 15 walkways, and five parapet/walkway combinations were produced daily. From 250 to 300 custom precast concrete elements were produced weekly; over 16,700 bridge components were produced in total (see Fig. 10).

Production began at 4 a.m. with the as-cast survey of the segments. Forms were removed with overhead cranes or truck cranes. At least two truckloads of reinforcing steel were consumed in daily production along with large quantities of post-tensioning tendons, deviation pipes, and anchors.

The reinforcing cages were fabricated in jigs ahead of production and then placed into the forms by overhead or truck cranes (see Fig. 11). Segments were surveyed according to the program data provided by Figg. Segments were cast using 2 cu yd (1.5 m^3) buckets and concrete delivery vehicles from Bayshore's central-mix batching facility. Out of a daily total of 450 cu yd (344 m^3) of concrete produced at the batch plant, 200 cu yd (153 m^3) were dedicated to the precast components for the JFK project.

Parapets and walkways — Bayshore had 30 forms set up to cast the parapets for the light rail system. At one point in production, all forms were turned daily to support the fast-paced schedule. Typically, 15 forms were set up and poured while the remaining 15 were simultaneously stripped out. Each parapet was custom made to match the wing dimensions of its corresponding segment wing (see Fig. 12).

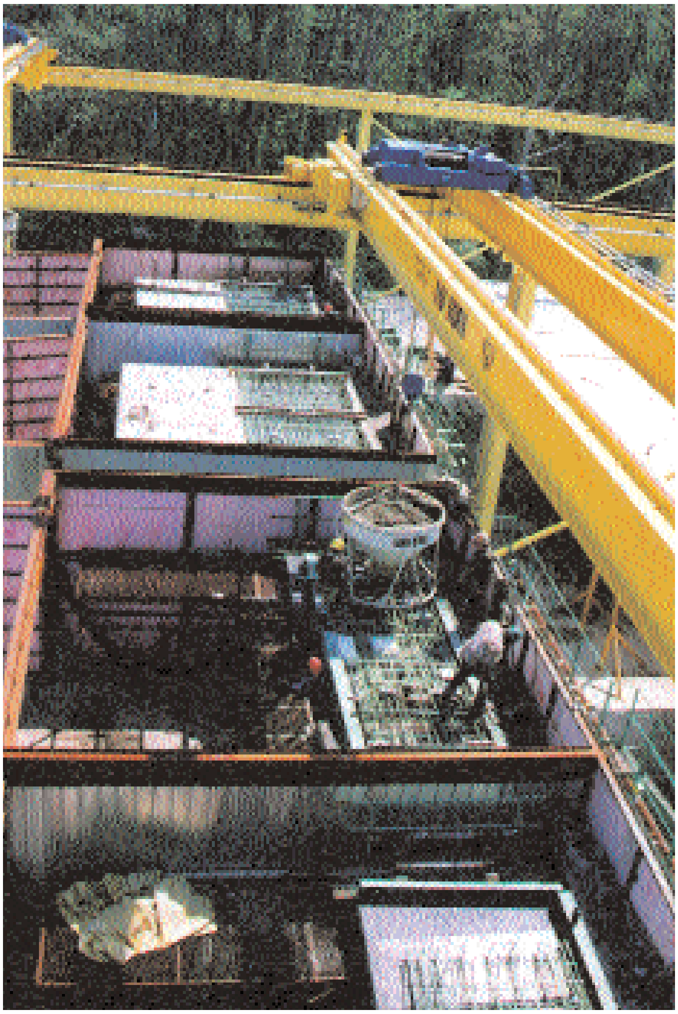

Fig. 11. Bayshore production operation shows the precast casting setup with concrete being poured from overhead buckets onto reinforcing steel in forms. Photo courtesy: Bayshore Concrete Products.

Fig. 12. The fast pace of the schedule required the precaster to turn over 30 forms daily to maintain production. Parapets and segments shown here were stored at the plant site. Photo courtesy: Bayshore Concrete Products.

In addition to meeting the tight tolerances of $^1/_4$ in. (6 mm) in length specified for the parapet pieces, a formliner on the exterior face was also required to provide an architectural line and finish. Extra attention to detail was required to maintain finish consistency as this step was a new procedure for Bayshore in structural concrete.

Fig. 13. After casting, the segments were barged 250 miles (402 km) before being transferred to a low-boy tractor-trailer for the 100 mile (161 km) trip to the site. Photo courtesy: Bayshore Concrete Products.

Fig. 14. On average, one loaded barge per week left the precast facility carrying approximately one week's production of segments. Photo courtesy: Bayshore Concrete Products.

Three types of walkways were cast. Single-track walkways were designed to support a grating, the dual-track walkways were flat, and the parapet/walkway combinations were used in rail transition areas. As with the parapet production, 15 forms were cast daily while the remaining 15 forms were stripped and prepared for pouring the next day. Five combination forms were set up and cast daily.

Color Consistency

Segment color was a critical issue for the owner. The color of the segmental precast pieces had to match that of the CIP concrete substructure portions of the light rail and the surrounding structures. Much effort was taken in the design of the concrete mixture and control of its subsequent set color to ensure that all elements of the precast superstructure blended together at each location.

The precast products were cast with two different sand types – white gray and mesa beige (typical) – to allow for color changes from one line to the next. As a result, two separate concrete mix designs were necessary, requiring a significant investment by the precaster to ensure quality control for the non-typical fine aggregates.

Storage and Transportation

Over 10 acres (4 ha) of storage area were required for the precast segments and other project components. During the initial production periods prior to erection, this space was barely adequate for the stored production elements that were required to start and maintain the fast-track erection schedule. Due to the sprawling locations of the plant's casting areas, there were challenges in transporting the segments and other products to the various storage areas and load-out areas.

In response to these logistical issues, Bayshore purchased a 92,500 lb (41950 kg) capacity forklift to handle the majority of the products; this eased the stress (operating hours) on rail-mounted cranes and provided additional access to remote areas.

A 65 ton (59 Mg) American Whirly Crane was barge-delivered from Bayshore's Chesapeake, Virginia, plant and reassembled at the slip (dock) on rails to aid in loading the product onto the barges (see Figs. 13 and 14). On some occasions, to maintain the fast pace of the jobsite erection, segments as well as parapets and walkways were shipped by truck.

On average, one loaded barge per week left the precast facility carrying approximately one week's production of segments. The parapets were stored in racks holding six pieces each and shipped by truck or barge. Walkways and parapet/walkway combinations were barged every 10 to 14 days with over 100 pieces per barge shipment.

CONSTRUCTION METHODS AND CHALLENGES

Precast concrete segmental construction was selected for the AirTrain project for many reasons, the primary one being the production speed and quality control afforded by a precast concrete system. Off-site casting and on-site post-tensioning resulted in a high quality structure in a relatively short timeframe.

Site congestion — The construction path for the elevated portion of the

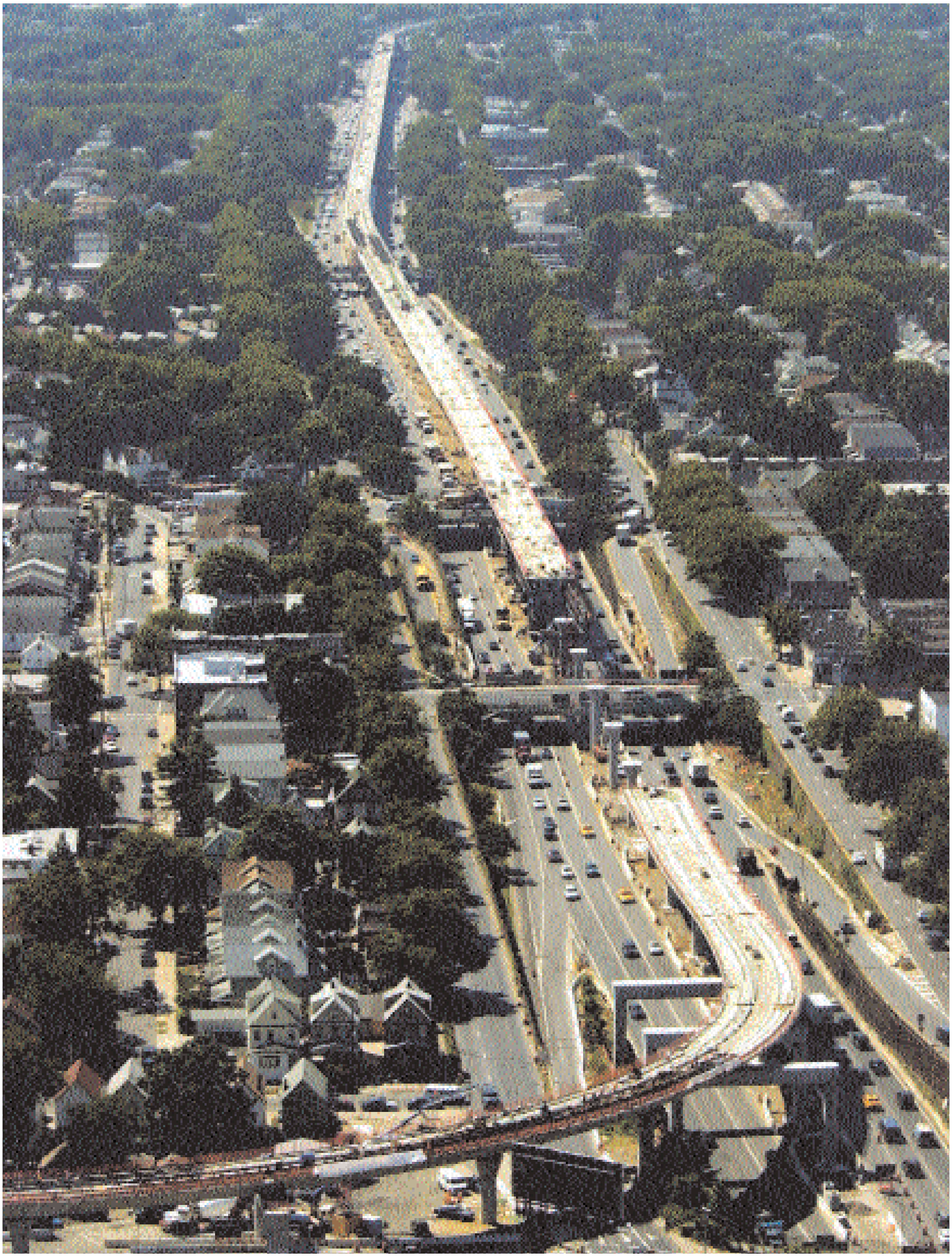

Fig. 15. The superstructure erection system had to be flexible enough to accommodate placing segments within inches (25 to 50 mm) of existing buildings, over major highways and service roads and around utility locations. Photo courtesy: Figg Engineering Group.

system was extremely congested, both above the surface and underground. The superstructure erection system had to be flexible enough to accommodate placing segments within inches (25 to 50 mm) of existing buildings, over major highways and service roads, and around utility locations (see Fig. 15). In this particular area, and for much of the NYC environs, the nature and extent of subsurface utilities presents formidable construction challenges even when accurate as-built drawings are available.

Design and construction in such a complex and restricted space led the design team to derive solutions that maximized efficiency during construction in one of the world's most expensive labor markets. At the same time, impact to existing heavy vehicular traffic flow in and around the construction site had to be held to a minimum.

Maintenance of traffic flow — The 2.3 mile (3.7 km) long Van Wyck Expressway portion of the AirTrain project connects the system to major public transport hubs – including the NYC Subway System. The very nar-

Fig. 16. The guideway management team was faced with developing an erection system that would accommodate the different span configurations, be able to negotiate problematic radii on curves, and function in an extremely restricted area. Photo courtesy: Figg Engineering Group.

Fig. 17. The truss design consisted of two different types of trusses, one for Type 1 precast segments, and the other to accommodate the loading requirements of both Type 1 and Type 2 segments. Photo courtesy: Figg Engineering Group.

row median of the Van Wyck Expressway abutting a heavily congested six-lane roadway was intentionally designed to preclude mass transit construction. In fact, Robert Moses, mastermind and architect of much of present-day New York City infrastructure, actually restricted potential mass transit development by minimizing the amount of right-of-way acquired when the expressway was originally planned.

Maintenance of traffic flow on the expressway, a critical transportation concern, was solved with a bit of ingenuity. The 100-plus dual-track spans were erected within the median by utilizing the existing roadway to maintain traffic. By converting the 8.5 ft (2.6 m) shoulders to travel lanes, the two center lanes could be periodically closed to traffic to create a 26 ft (7.9 m) wide construction zone, while still maintaining six travel lanes. On occasion, roadways were completely closed at night to accommodate the launching of segments over major routes that intersected the expressway. The complicated logistics required to minimize traffic disruptions required concerted planning throughout the project.

Innovative erection method — Erection of the guideway structure was a keystone operation in the construction of the light rail system. The design-build team devised an innovative erection system with sufficient diversity to maneuver deftly around structures, over major highways, and through other numerous obstacles (see Figs. 16 and 17). By utilizing versatile erection trusses designed by the engineer, the contractor was able to accomplish this difficult task efficiently.

To stay within the allowable construction zone along the expressway, it was necessary to mobilize the trusses in a longitudinal direction. Two sets of trusses, together with a 55 ft (16.8 m) launching nose, totaling 335 ft (102 m) of truss, provided the solution. The 335 ft (102 m) truss length was used to ensure that the truss was always supported by at least two towers during each launch. Under optimal conditions, both trusses could be launched by a single winch to the next span within 1.5 hours. Due to restrictions of

Fig. 18. The AirTrain Light Rail System was officially dedicated and opened to the public on December 17, 2003. Photo courtesy: Figg Engineering Group.

the upstation pier and the truss itself, the crane had a reach of about 40 ft (12.2 m) to lift the 30 ton (27 Mg) segments into place.

Using a specially designed erection truss, a span-by-span construction technique was used to build 90 percent of the 461 spans. A balanced cantilever sequence was used on the remainder. Balanced cantilever construction met the requirements of tight horizontal curvatures with radii as small as 235 ft (72 m) or where span lengths were greater than 150 ft (46 m) – too long for typical span-by-span construction.

Where span-by-span erection was employed, specific stroke heights were provided to the ironworkers to position the adjustable jacks supporting the wings of the segments on the truss. To calculate the stroke heights, truss deflections, changes to the vertical and horizontal curves and the variable wing depth data were incorporated to establish the tower heights. By providing stroke height tolerances to within $^1/_8$ in. (3 mm) of the approximate final position of the segment, adjustment in the field were kept to a minimum, speeding erection and controlling labor costs.

In areas where interferences prevented use of a typical pier, straddle beams were used to span over the traffic, utility locations and other obstacles. The CIP straddle beams support the guideway, without changing the natural geometry of the structure. To erect a span on top of a straddle beam without a tower, a straddle nose was designed. This nose is attached to the truss at a typical splice and then placed directly upon the straddle beam. The nose has three support locations for required maneuvering versatility.

Roughly 10 percent of the spans were erected by balanced cantilever method – used predominately on the longer spans and in areas with tighter curvature. The selection of a precast concrete segmental system and the efficiency of the construction methods allowed as much as 800 ft (244 m) of the superstructure to be completed system-wide in one week.

Precast transportation — After casting, the segments were barged from Cape Charles, Virginia, to Camden, New Jersey – a distance of 250 miles (402 km). The segments were unloaded and transferred to a low-boy tractor-trailer for the 100 mile (161 km) trip to the site. Segments were timed for delivery within days of erection due to the nearly non-existent storage space at the construction site. Segment delivery timing was crucial in maintaining the erection schedule.

Off-site precasting of the superstructure, while construction of foundations and substructure proceeded on-site, reduced the construction time and trade interference and provided quality assurance. Additionally, once erected and post-tensioned, each superstructure span was structurally complete and available for track installation, ensuring that the project moved rapidly toward completion.

Erection of the elevated superstructure was completed in August 2001 – three months ahead of schedule, saving a significant expense. In just 11 months, 12,144 linear ft (3700 m) of guideway superstructure was precisely erected within the median.

SUMMARY OF PRECAST ADVANTAGES

Overall, selection of a precast concrete system for the AirTrain project guaranteed its success and owner satisfaction. Precast concrete construction afforded the following crucial advantages in meeting the contract specifications:

- Elimination of typical shop drawings through the use of novel design software significantly reduced segment casting time.
- Maintenance of concrete color consistency through precast plant quality control measures in mixture design, forming, and curing procedures. These procedures minimized staining of the concrete, eliminated the need for finish coatings, met strict contract color specifications, and saved construction and maintenance costs.
- Production efficiencies through off-site precast operations and the precaster's ability to meet peak production quotas for a fast-track schedule. Site congestion was minimized by just-in-time delivery of precast pieces to the construction site with negligible storage space.
- Precast aesthetics for legislative and community support. Previous efforts to construct a light rail system were effectively blocked by local citizens' opposition to proposals to construct unseemly structures that were perceived to impact negatively on property values and standards of living. The sleekness and beauty of the precast superstructure design garnered the vital legislative and community support for the project.

CONCLUDING REMARKS

Given the intricate nature of designing a mass transit system in an extremely congested area at one of the world's busiest airports, many complex and formidable obstacles faced the project team. One of the greatest accomplishments of the guideway's construction was the speed and flawlessness at which over 100 dual-track spans on the expressway section were built, with a minimal disruption to expressway traffic. The use of precast concrete products, flexible erection methods, and the aesthetic appeal of the precast design were essential in delivering a maintainable, on-time, and on-budget finished project.

The great success of this project proves the suitability and adaptability of precast concrete segmental construction for use in tightly congested urban corridors. The knowledge, design, and construction techniques developed for the JFK International Airport Light Rail Transit System will benefit future mass transit systems in increasingly congested urban areas worldwide (see Fig. 18).

This project recently won the 2003 PCI Design Award for Best Non-Highway Bridge. In making its selection, the bridge jury commented: "The precast method chosen for this project was most suitable for the structure. The tight curves were easy to construct, and the box girders offer superior structural rigidity and aesthetics."

CREDITS

Owner: Port Authority of New York & New Jersey, New York, New York

Design-Build General Contractor: Air-Rail Construction JV

Engineer of Record: STV Incorporated, New York, New York

Precaster: Bayshore Concrete Products, Cape Charles, Virginia

Precast and Superstructure Specialty Engineer: Figg Engineering Group, Tallahassee, Florida

Precast Erector: Koch Skanska (Construction JV Partner)

Station Construction Manager: Sardoni Skanska (Construction JV Partner)

Substructure, Sitework, and Track Contractor: Slattery Skanska (Construction JV Partner)

Post-Tensioning System: Dywidag Systems International

Foundations: Muesner Rutledge Consulting Engineers

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