Segmental Aerial Structures for Atlanta's Rail Transit System

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ABSTRACT

The typical superstructure of the aerial structure of the Metropolitan Atlanta Rapid Transit Authority (MARTA) rail transit system is a rectangular box girder supporting a concrete deck for the two parallel tracks. Alternative designs permit a steel box girder with either a precast or cast-in-place deck or a monolithic girder and deck of cast-in-place concrete. Segmental construction of the monolithic superstructure is permitted. Precast monolithic superstructure is not practical, however, because of highway load limits. On two separate projects constructed from 1982 to 1984, the contractor elected to build the monolithic superstructure by the segmental method and gained approval for a value engineering proposal to change the girder cross section from rectangular to trapezoidal and to increase its width and depth. One of the projects (on MARTA's South Line) included 65 spans with a total superstructure length of 5,231 ft and the other project (on MARTA's North Line) included 20 spans with a total length of 1,880 ft. Some property that had been acquired for the proposed parking lot for MARTA's Oakland City Station afforded the contractor a convenient site for a casting yard (within 1 mi of the centroid of the South Line aerial structure). Although the same yard was used for casting segments for the North Line aerial structure, those segments had to be hauled more than 10 mi to the erection site. The completed structures have been in service since late 1984 and represent what is believed to be the first employment of segmental construction methods for rail transit aerial structures in the United States.

Early route location studies for Atlanta's rail transit system placed considerable portions of the system in corridors occupied by existing transportation facilities such as railroads or streets, or both. In most locations, the corridor was too narrow to accommodate the rail transit system either at-grade or on conventional aerial structure.

STRUCTURE CONCEPT

The solution to the constricted corridor was an aerial structure with single-shaft piers and a single box-girder superstructure supporting a 2-track deck slab. This concept permitted the transit system to be fitted in a ground-level strip only 8 ft wide. Another advantage was that it enabled the use of a minimum-height aerial structure as follows: by supporting the tracks on the cantilevered portion of the deck slab, the transit system track profile could be set as little as 2 1/2 ft above the ceiling of the clearance envelope of the underlying street or railroad. Certainly the concept exemplified the adage that form follows function.

EARLY SUPERSTRUCTURE DESIGNS

When the design of the standard aerial structure was undertaken in 1973, the intent was to provide a single type of superstructure: a steel box girder acting compositely with deck slabs of precast, transversely pretensioned concrete. The goal of providing a family of standard designs for span lengths up to 100 ft was satisfied with a box girder that was 7 ft wide and nominally 4 ft deep. To facilitate steel fabrication, a rectangular girder cross section was chosen. Deck slab width was 30 ft 3 in. with a depth varying from 13 in. over the girder to 8 in. at the outboard edges. Composite action between the girder and the deck slabs was achieved by shear studs (or lugs) and bolted hold-downs in slab block-outs along the top flanges of the girders. Deck slabs were nominally 10 ft long, keyed together at transverse joints.

Although the single type of superstructure afforded a market for both steel and concrete, the concrete industry was not satisfied with its share. In response to its requests, alternative designs were developed as follows: (a) a cast-in-place deck slab, transversely post-tensioned; (b) precast, prestressed (pretensioned or post-tensioned), concrete box girders with precast or cast-in-place deck slabs; (c) a monolithic girder and deck of cast-in-place, post-tensioned concrete; and (d) although no design was presented, the prescription of requirements to be met if the contractor elected to build the superstructure segmentally. All alternatives preserved the superstructure cross section that was initially established to optimize the steel-and-concrete design.

EARLY SUPERSTRUCTURE CONSTRUCTION

On Projects CE125, CE130, CW560, and CW565, which were the first four construction projects to include the standard aerial structure, the contractor elected to use steel box girders and precast, pretensioned deck slabs. The box girders for all four projects were fabricated in Japan. The results would perhaps

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have been different had current "Buy America" provisions (Federal Public Transportation Act of 1982, P.L. 97-424) been in effect, but those contracts were awarded in the mid-1970s, when American steel was rapidly increasing in price and was, at times, available only with long lead times.

DESIGN REFINEMENTS

It became evident during the late 1970s that all the design alternatives being offered were not practical. The Department of Transportation of the State of Georgia made clear that it intended to enforce the highway load limits, which restrict gross vehicular weights on the state highway system to 75 tons. As a result, the portfolio of designs was reduced by eliminating the precast concrete girder alternatives. There was some degree of discomfort with those alternatives anyway as the degree of composite action between the precast concrete girders and the precast deck slabs was based on design assumptions whose validity was made questionable by tests conducted by the Construction Technology Laboratories of the Portland Cement Association.

MONOLITHIC SUPERSTRUCTURE

Project CS310 and CS350, started in 1979, utilized a superstructure in which the girder and deck were of cast-in-place concrete, the girders post-tensioned longitudinally and the deck slabs post-tensioned transversely. Project CS520, which was started in 1984, was constructed in the same manner.

SEGMENTAL STRUCTURE

It was on two projects in the early 1980s that the segmental method was proposed for construction of the aerial structure for Atlanta's rail transit system. The two projects had some common characteristics and some differences. The most relevant common characteristics were that the two projects were to be built during the same period and that the same contractor, J. Rich Steers, Inc., was the low bidder for each. This commonality had the obvious advantage of enabling the contractor to spread over two projects the design and mobilization costs of pioneering the segmental construction method for MARTA aerial structures. Bid documents for both projects presented the design, among others, of a monolithic girder and deck of cast-in-place, post-tensioned concrete and permitted the contractor to build that structure segmentally provided that he develop and gain the engineer's approval of the segmental design and preserve the dimensions of the superstructure cross-section.

PROJECT CS360

Bids for MARTA Project CS360 were opened in August 1981. The project, which was designed by Parsons Brinckerhoff/Tudor, included the construction of 65 spans of aerial structure with span lengths between 70 and 100 ft. All spans were simply supported with expansion bearings at both ends. The total length of the superstructure is 5,231.1 ft. The aerial structure extends south from a pier, built under an earlier contract, near the intersection of West Whitehall Street and Lee Street to an abutment near the intersection of Oakland Lane and Lee Street. Its narrow corridor, bounded on the west by Lee Street and on the east by the tracks of the Atlanta & West Point Railroad, roughly parallels those two facilities. The elevation difference between finished grade and the soffit of the girders is typically about 20 ft.

The contractor retained Figg and Muller Engineers, Inc., for the preparation of the segmental design. The contractor proposed, as a value engineering change proposal, increasing the girder depth and width and sloping the girder webs 60 degrees from horizontal. The proposal was accepted, although, obviously, the girder cross section was changed. What appeared from the ground to be a 4-ft-deep by 7-ft-wide rectangle was instead a 6-ft-deep trapezoid with a bottom width of 8 ft and a top width of 14 ft 11 in. The cross section offered obvious advantages such as greater torsional stiffness, lower prestressing requirements, lower cantilever moments in the deck slab, less differential deflection of the deck slabs at girder ends, and the ability to span greater distances (the original cross section limited the span of the steel girder to 100 ft and the span of the cast-in-place monolithic concrete girder to 96 ft).

On acceptance, in principle, of the contractor's proposal, Figg and Muller proceeded with redesign. The typical interior segment was 10 ft long. The segment at each end of each span was 5 ft long, and the length of the next segment was between 2.5 ft and 7.5 ft as required to achieve the span length. Longitudinal post-tensioning tendons were encased in ducts run in the girder voids and were held down in interior segments by deviation blocks cast into the top of the bottom flange at its juncture with the girder webs. The steel sleeves in the deviation blocks and the subsequent grouting of the tendons with portland cement grout achieved bonding of the tendons to the concrete only at the locations of the deviation blocks. For purposes of determining ultimate moment capacity, the structure could therefore not be considered fully bonded. The joints between segments had multiple shear keys.

MARTA made the property acquired for the proposed parking lot for its Oakland City Station available to the contractor for use as a casting yard. Segment casting was thereby made possible within 1 mi of the erection site. Segments were match-cast by the long-line method. (Note: match-casting is the use of the end of a previously cast segment as the end form for the abutting segment; long-line casting is the use of a single bed for the sequential casting of all the segments making up one girder.) Transverse prestressing of the deck slab was achieved by pretensioning strands in a portable steel frame and then supporting the frame in position while placing the deck slab concrete. The project required 643 segments.

Segments were hauled to the erection site individually on modified dump trucks and set by crane on a pair of erection trusses temporarily supported by brackets on the aerial structure piers. The trusses, triangular in cross-section with the apex up, supported each segment by its wings. Shims and rollers between the top chord of the erection truss and the underside of the deck slab facilitated erection; the rollers enabled the segments to be set at one end of the span and winched longitudinally to their final position; the shims made it possible to adjust the vertical position of the segments preparatory to their being longitudinally post-tensioned. After post-tensioning, the girders were lowered onto their bearings and around their anchor bolts by means of hydraulic jacks between the trusses and the truss support brackets. Tendon grouting followed. When lowered, the rear of the truss was supported, through a C-frame, by a rubber wheel that ran on the top of the deck. The front of the truss was then supported by crane, and the truss was advanced to the next pier. The contractor achieved maximum erection rates of 1 span per day and 4 spans per week.

PROJECT CN480

Bids for MARTA Project CN480 were opened in January 1982. The project, designed by Anderson-Nichols & Company, Inc., included the construction of 20 spans of aerial structure with span lengths between 75.2 and 142.7 ft. Twelve simply supported spans were under 92 ft long and therefore could have been either steel box girders with concrete deck slabs or monolithic girders and decks of cast-in-place concrete; four other simply supported spans were nominally 115 ft long and were designed as 7-ft-wide by 8-ft-deep steel box girders with cast-in-place concrete deck slabs. The four longest spans were comprised of two 2-span, continuous steel box girders with cast-in-place concrete deck slabs; box girders were 8-ft wide and 6-ft deep. The total length of superstructure is 1,879.8 ft. The aerial structure extends north from an abutment near the intersection of Burke and Canterbury Roads, runs alongside and east of the tracks of the Southern Railway, crosses over the tracks, then runs alongside and west of the tracks of the Southern Railway to an abutment near the intersection of Lenox Square Parkway and East Paces Ferry Road. The elevation difference between the existing ground line and the soffit of the girders varied widely but averaged about 30 ft.

Figg and Muller served as the contractor's engineer for preparing the segmental design for this project also. The contractor's value engineering change proposal included more than just changing the cross section of the 4-ft by 7-ft box girders, however. The contractor proposed using the section developed for Project CS360 for the entire superstructure and also proposed a reconfiguration of the continuity of the spans. As designed by the Anderson & Nichols Company, Spans 8 and 9 were a 2-span continuous girder, Spans 10 and 11 were a 2-span continuous girder, and Span 12, as well as the other 15 spans, were simply supported. The contractor proposed to build Spans 9-12 as a 4-span continuous girder and Span 8, as well as the other 15 spans, as a simply supported girder.

On acceptance, in principle, of the contractor's proposal, Figg and Muller proceeded with redesign. Much of the design done for the simple spans of Project CS360 was reusable. Like Project CS360, typical interior segments were 10-ft long, and the segment at the end of each simple span was 5-ft long. The length of the precast segment next to the end segment was between 4.4 and 7.6 ft, as required, to achieve the span length.

The 4-span continuous girder, with a total length of nearly 448 ft, necessitated additional original design effort, including consideration of the long-term moment redistribution due to creep. On top of each of the three interior piers of the 4-span, continuous structure, a 10-ft-long pier segment was created by placing a 2-ft 6-in.-long, cast-in-place segment between the 3-ft 9-in.-long end segments of the two spans. To provide a construction tolerance, a 6-in. cast-in-place closure pour was placed at each side of the three pier segments and between the first and second segments at the simply supported end of Span 9. To resist the negative moment over the interior supports, longitudinal post-tensioning tendons for the 4-span continuous girder were overlapped through the tops of the 10-ft-long pier segments at those supports.

The 223 segments for this project were cast at the yard developed by the contractor for Project CS360. The location of the erection site required that the segments be hauled more than 10 mi. The erection trusses from Project CS360 were reused although the greater span lengths necessitated intermediate supports for the trusses. The overlapping of prestressing tendons between adjacent spans of the 4-span continuous girders necessitated that the segments for those spans be erected at their final elevation rather than be lowered into place after being post-tensioned together.

PRECAST SEGMENTAL VERSUS CAST-IN-PLACE

Compared with casting the superstructure in place, the segmental construction method had the following several advantages:

1. Precasting enabled better control of the quality of both the concrete and its finish; steam curing was used, as were steel forms.
2. The requirements for falsework and elevated formwork were eliminated for Project CS360 and for the majority of the spans of Project CN480.
3. Traffic disruption in Project CS360 was reduced because of shorter occupancy times of the curb lane of Lee Street.
4. Except for the pier segments and closure pours of Project CN480, cure time for field-placed concrete did not delay post-tensioning.

No construction method is completely problem-free, however, and minor difficulties were encountered such as

1. Prediction of segment lengths required to achieve the specified girder length in the post-tensioned structure was not always accurate. As a result, slotted holes in the girder sole plates did not always align with the anchor bolts, and the width of the transverse joint in the deck between girders was not uniform.
2. Provisions were inadequate for moving the post-tensioned girders longitudinally to achieve centering over design bearing locations.
3. Minor spalling of concrete occurred at the match-cast joints during handling in the yard, transportation, and erection. Some also occurred during post-tensioning, presumably due to imperfect alignment of the segments on the erection trusses.

Available cost data for these projects in Atlanta do not make it possible to determine the cost advantage, if there is any, of building transit aerial structures by the segmental method. The MARTA contractor benefited from (a) being able to set up his casting yard on a site near one of the erection locations and (b) being the contractor for two projects built at the same time. It is the author's opinion that the cost advantages of segmental construction are not fully realized for typical transit aerial structures in an urban/suburban environment (i.e., for short spans built from 20 to 30 ft off the ground in accessible areas).

CONCLUSION

The two projects including aerial structure constructed by the segmental method were incorporated into MARTA's operating rail transit system on December 15, 1984, when the system was extended by five stations and 8.8 mi. The structures are believed to represent the first employment of this construction method for rail transit aerial structures in the United States. Subsequent utilization will therefore not be a "first" but a mere application of a technique whose practicality has been proven by the joint efforts of the MARTA, Parsons Brinckerhoff/Tudor, Figg and Muller Engineers, Inc., and J. Rich Steers, Inc.

Publication of this paper sponsored by Task Force on Rail Transit System Design.