CENTRAL ARTERY/TUNNEL PROJECT: SEGMENTAL CONSTRUCTION INNOVATIONS

Paul J. Towell, P.E., Parsons Brinckerhoff Quade & Douglas, Inc., Boston, MA
Vijay Chandra, P.E., Parsons Brinckerhoff Quade & Douglas, Inc., New York, NY
Peter A. Mainville, Parsons Brinckerhoff Quade & Douglas, Inc., Boston, MA
Elie Homsi, P.E., Rizzani de Eccher, Aventura, FL

ABSTRACT

The Central Artery/Tunnel Project (CA/T) will relocate Interstate 93 (I-93) underground through downtown Boston before it re-emerges onto a new cable-stayed bridge crossing the Charles River. The other segment of the project involves the extension of Interstate 90 (I-90 or the Massachusetts Turnpike) from its intersection with I-93 to Logan International Airport via South Boston and the Ted Williams Tunnel. At the intersection of I-90 and I-93 and also north of the Charles River (I-93 with Route 1), major interchanges are under construction utilizing segmental concrete.

KEYWORDS

Central Artery/Tunnel Project, Precast Concrete Segments, South Bay Interchange, I-93/Route 1 Interchange, Erection, Span-by-Span, Balanced Cantilever, Precast Fixed Bent Segments, Saw Cut Segments, Straddle Bent

INTRODUCTION

The approximately $14.8 billion CA/T is a major reconstruction of the urban interstate highway through downtown Boston, Massachusetts. This article focuses on the interchanges that act as gateways to the project in various parts of the city.

Two major interchanges are located at the north and south ends of the I-93 corridor through Boston: the I-93/Route 1 Interchange in Charlestown (see Fig. 1) and the I-93/I-90 South Bay Interchange just south of downtown Boston (see Fig. 2). The viaducts for these interchanges were designed with both steel box girder and precast segmental box girder alternatives, with the precast segmental alternative being selected by the low bidder. The structures are being built using either span-by-span or balanced cantilever construction techniques.

Fig. 1: I-93/Route 1 Interchange

Fig. 2: I-93/I-90 South Bay Interchange

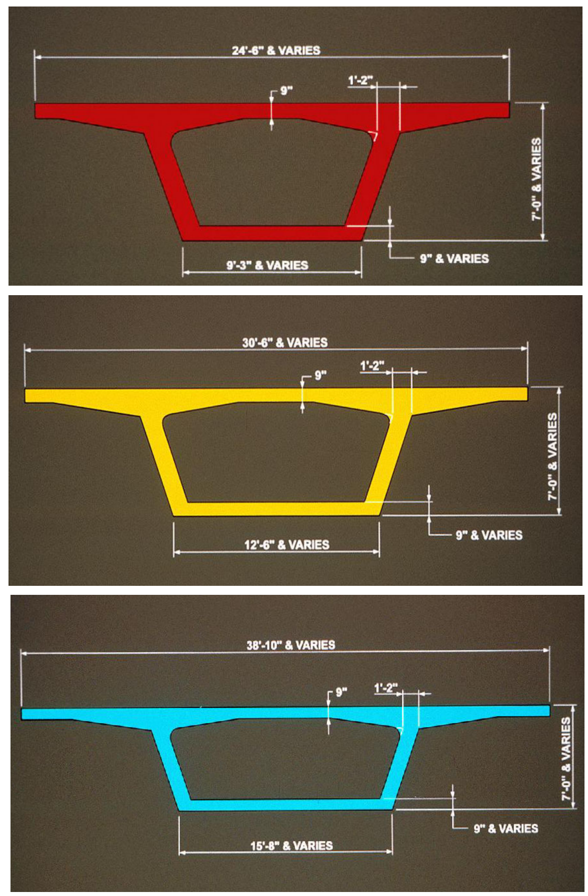

Fig. 3: Three segment types

At project inception, three basic types of precast concrete segments (see Fig. 3) were standardised for this undertaking:

- All segments have a transversely post-tensioned top flange.
- For roadway sections, which require greater width, a combination of segment types is placed side by side and connected with a concrete closure strip.
- All viaduct riding surfaces are topped with a 1.5-inch-thick micro-silica wearing course.

Table 1 provides the salient features of each of these interchanges.

Table 1: Important Interchange Facts

Description	I-93/I-90 at South Bay	I-93/Route 1 in Charlestown
Number of Segmental Viaducts	14	9
Segmental Viaduct Area	594,170 square feet	488,140 square feet
Segmental Viaduct Length	16,400 feet	11,320 feet
Number of Segments	2,249	1,540
Span Lengths	89 to 217 feet	98 to 197 feet
Superstructure Width	22 to 96 feet	24 to 94 feet
Curvature of Roadway	220 to 10,500 feet	300 to 7,610 feet

I-93/I-90 SOUTH BAY INTERCHANGE

The $650 million South Bay Interchange is a key segment of the CA/T. It will replace and expand an existing deteriorated interchange in stages to handle increased traffic volume. The new massive multi-level interchange will be all-directional and include the I-90 extension to Logan International Airport through the Fort Point Channel and Ted Williams immersed tube tunnels.

The interchange, the junction of I-93 and I-90, is located to the south of downtown Boston. The new interchange construction is a combination of precast segmental viaducts, jacked tunnels, slurry wall tunnels and open boat sections.

In January 1997, two contracts were awarded: a $108 million contract for the I-93 Southbound/I-90 portion of the interchange, and a $398 million contract for I-93 Northbound/I-90 portion of the interchange. Two follow-on contracts, for completion of the I-93 ramps, were awarded in May 2001 and February 2002 with segmental concrete designs to match the viaducts under construction. The bid price for these contracts was $33 million and $179 million, respectively.

I-93/ROUTE 1 INTERCHANGE

The I-93/Route 1 Interchange is the northern gateway to Boston in Charlestown, and is located just north of the state-of-the-art Charles River Crossing bridges. In January 1998, a $188 million contract was awarded for interchange construction. The huge interchange, which connects Route 1 with I-93 and Leverett Circle, is very complex. As such, the interchange consists of numerous viaducts and ramps, some with a tight radius of curvature (see Fig. 4).

The new interchange construction primarily consists of precast segmental viaducts. The main line viaducts for I-93 have a relatively tangent alignment; however because of site restrictions, the ramps connecting I-93 to Route 1 have a tight radius of curvature of less than 328 feet.

An additional contract to complete the final ramp connection north of the Charles River has been designed with segmental concrete viaducts to match the viaducts under construction and is scheduled for bid letting in Fall 2002.

Fig. 4: Curved ramps over railroad tracks

PRECAST SEGMENTS

All precast segments for the Central Artery/Tunnel Project are cast at remote facilities away from the project site. The segments for the South Bay Interchange are produced in western Massachusetts, while the segments for the I-93/Route 1 Interchange were produced in southern Maine. The segments are matchcast using the short line casting method. The forming system consists of a fixed form for the exterior surfaces of the web and top flange cantilevers, a fixed vertical bulkhead for the segment face, and a moveable mandrel form for the box girder void. A moveable pallet forms the segment soffit and allows movement of the segment from the form to the matchcast position after casting.

Casting begins with a starter segment that is either a pier segment, expansion joint segment or segment adjacent to a straddlebent. The starter segment is placed on the moveable pallet positioned next to the segment form. Hydraulic jacks in the pallet allow vertical and rotational adjustment of the starter segment to establish horizontal and vertical geometry for the next segment. Subsequent segments are cast in a similar fashion using the previously cast neighbouring segment to establish geometry. A casting run proceeds until a cantilever of segments is complete for balanced cantilever construction or a span is complete for span-by-span construction. After completion of a run, the next run begins with a new starter segment and production continues. Casting curves, including highway geometry and structural camber, are calculated for each segment and daily surveying is performed for geometry control of the casting operation.

Epoxy coated reinforcing steel cages are preassembled in a jig prior to placement in the casting forms. Steam curing is used to speed production of the segments and to allow for a cycle of one typical segment per day from each casting form.

A typical day begins with aftercast surveys of the previous day's segments. After the survey is completed, the forms are stripped and the segment moved to the matchcast position. After the forms are cleaned and oiled, the rebar cage is placed in the form and the mandrel form is positioned. While the rebar cage is completed, the matchcast segment is aligned and the set-up survey is performed. After completion of rebar and final survey checks, segment casting is ready to proceed.

Due to lack of storage space at the project site, segments are stored at the precast facility and transported at night, as needed, to maintain the erection schedule. Table 2 lists the major particulars of the precast concrete segments.

Table 2: Precast Segment Facts

Description	I-93/I-90 at South Bay	I-93/Route 1 in Charlestown
Precaster	Unistress	Sanford Precast
Precast Yard Location	Pittsfield, MA	Sanford, ME
Distance from Boston	118 miles	81 miles
Number of Casting Cells	4	5
28-Day Concrete Strength	6,000 psi	6,000 psi
Type F Fly Ash Content	5-15%	5-15%
Segment Weight	44.2 to 59 tons	44.2 to 59 tons
Segment Length	7.9 to 11 feet	7.9 to 11 feet

ERECTION

The new I-93 Southbound viaduct is located in the footprint of the existing I-93 alignment. This requires multiple and complex staging of the work to allow traffic to flow uninterrupted as the existing structure is demolished and replaced by the new structure. The new I-93 Northbound viaduct is located to the east of the existing I-93 alignment and is less restricted by the existing viaduct, but is coincident with the Ramp L tunnel alignment connecting with the Fort Point Channel Tunnel. Both southbound and northbound viaducts cross the Amtrak/Massachusetts Bay Transportation Authority (MBTA) rail lines, which have recently had overhead electrification installed as part of Amtrak's Northeast Corridor Upgrade.

At the South Bay Interchange, the I-93 viaducts are being constructed by both the balanced cantilever and span-by-span method. For I-93 Southbound, balanced cantilever construction was accomplished using a crawler crane and temporary falsework towers to erect the segments. As the crane erects the segments, epoxy adhesive is applied to the segment face and then temporary 1.4-inch-diameter post-tensioning thread bars connect it to the previously erected segment. After both segments of a pair are erected, permanent 0.6 x 0.6-inch-diameter strand post-tensioning tendons are installed.

At no time is more than one segment out of balance. Segment erection adjacent to expansion joints is accomplished with falsework. In locations where the crane cannot be positioned for lifting, a special beam and winch are used. This self-launching erection device (SLED) is supported on the leading edge of one cantilever and lifts segments from directly beneath the leading edge (see Fig. 5).

Fig. 5: Beam and winch erection of segment; low headroom segment transporter

For I-93 Northbound, a specially built self-launching overhead gantry is being used (see Fig. 6). This allows all work to be carried out from above ground, which eliminates possible conflicts with ground operations. The gantry comprises two 427-foot-long triangular trusses, supported on moveable support legs. Segment erection adjacent to expansion joints is accomplished by aligning and supporting the segments from the erection gantry similar to the span-by-span erection method.

Development of the span-by-span construction method is currently under way for the I-93 ramps.

Fig. 6: Balanced cantilever erection using a gantry

The new I-93/Route 1 Interchange is located west of the existing I-93 alignment and both erection techniques are being used during construction. For the I-93 viaducts, the span-by-span erection method using a specially built self-launching overhead gantry is being used, while for the tightly curved ramp structures a balanced cantilever construction method using crane and temporary falsework towers is being used.

In the span-by-span erection method, all segments of a span are aligned and supported by the gantry (see Fig. 7). As each segment is erected, epoxy adhesive is applied to the segment face and temporary 1.4-inch-diameter post-tensioning thread bars connect it to the previously erected segment. After all the segments of a span are erected, permanent post-tensioning tendons are installed. A typical span has eight 0.5 x 0.6-inch-diameter strand post-tensioning tendons and two 0.7 x 0.6-inch-diameter strand post-tensioning tendons.

Fig. 7: Span-by-span erection at double-deck bents with overhead gantry

INNOVATIVE CONSTRUCTION TECHNIQUES

At the start of construction, the I-90/I-93 Northbound contractor proposed several innovative construction concepts to improve construction operations and to provide an improved product. These proposals were welcomed by the project, and in a co-ordinated partnering effort, the schemes were discussed and developed by the contractor and section design consultant under the direction of the managing consultant. A brief description of these proposals follows.

PRECAST FIXED BENT SEGMENTS

The viaduct design required fixed bents with a cast-in-place box girder segment monolithically connected to the bent column. As part of the value engineering process, the contractor proposed that a precast fixed bent segment be used in lieu of the cast-in-place fixed bent segment. The shell of the fixed bent segment is precast using the typical segment forms (see Fig. 8). A hole in the bottom slab allows the column reinforcement to terminate inside the bent segment diaphragm, which is cast after erection of the precast segment. Cast-in-form inserts allow for the continuity of rebars between the precast segment and the cast-in-place diaphragm. The interface between precast concrete and cast-in-place concrete is roughened to 0.2-inch amplitude to provide for shear transfer.

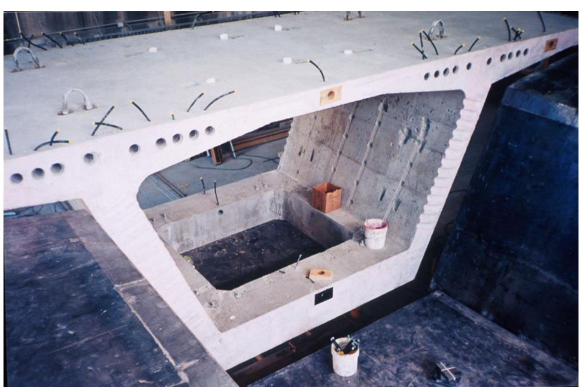

Fig. 8: Precast fixed bent segment

A specially built frame is attached to the bent column for support and alignment of the segment during erection. The three-level frame comprises an upper level that supports the segment on hydraulic jacks and allows for vertical and rotational adjustments; a middle level that allows for translational adjustments; and a lower level supported on brackets attached to the pier by 1.4-inch post-tensioning thread bars placed in ducts that extend through the pier.

During erection, the precast segment is placed on the support frame using a crane (see Fig. 9). After alignment of the segment, the space between the soffit of the segment and the top of the pier cap is grouted, the diaphragm reinforcement is placed, and the diaphragm concrete is cast. After completion of the diaphragm, typical cantilever construction may begin.

Fig. 9: Precast fixed segment in place on support frame

The advantages of this construction method include:

- Good quality control on site
- Ability to erect segments in winter
- Accelerated construction
- Adjacent segment fit up is ensured through the matchcast operation
- Cost savings

PRECAST EXPANSION BENT SEGMENTS

This concept is similar to the precast fixed bent segment. In this case, the weight of the Type II expansion bent segments was greater than the capacity of the precast yard's handling equipment. To alleviate this problem, the shell of the expansion bent segment is precast using the typical segment forms with the diaphragm cast-in-place after erection of the segment. As with the fixed bent segment, cast-in-form inserts allow for the continuity of rebars between the precast segment and the cast-in-place diaphragm. The interface between precast concrete and cast-in-place concrete is roughened to 0.2-inch amplitude to provide for shear transfer.

STRADDLE BENT CONSTRUCTION USING SAW CUT PRECAST SEGMENTS

The viaduct design includes a monolithic connection between the cast-in-place straddle bents and the precast box girders, proposed by the contractor as a value engineering alternative. The straddle bent design includes a short length of the superstructure cross-section extending from the side face of the straddle bent. These extensions are a starter section for the superstructure with a cast-in-place closure joint between the extension and the first precast segment.

Typically , the alignment of the superstructure is not perpendicular to the straddle bent, but is at a skew angle of less than 90 degrees. To improve contructibility, the cast-in-place extensions have been replaced with precast starter segments that have the skew angle built into the segment geometry. Shear keys are cast into the face of the straddle bent to provide for shear transfer.

Fig. 10: Saw cutting of segment

The starter segment is produced by saw cutting a typical rectangular segment along the required line of the skew angle, using a large diameter diamond blade circular saw (see Fig. 10). Guides for the saw are placed on the top slab, the interior surfaces of the webs, and bottom slab. The initial top slab cut extends down into the webs so that the secondary web and bottom slab cuts complete the operation.

After saw cutting is complete, the two segment pieces are held together using post-tensioning bars and shear keys are added at the cut face using a coring machine (see Fig. 11). Typically, one rectangular segment will provide two starter segments with the required skew angle.

Fig. 11: Coring of shear keys

During erection, the starter segments are hung from temporary support and alignment beams (see Fig. 12). After alignment of the segments, the 6-inch nominal closure joint between the segments and the straddle bent is formed. A block out is provided in the top surface of the straddle beam to allow for placement and alignment of the longitudinal post-tensioning ducts after erection of the segments.

The surface of the block out is roughened to 0.2-inch amplitude and block out concrete is placed concurrently with the closure joint concrete to provide integration of the secondary cast-in-place concrete with the initial cast-in-place concrete. After curing of the closure, typical cantilever construction may begin (see Fig. 13). This technique was successful with very complicated geometry. The most extreme case involved 7% profile grade, 2% cross-slope, and 11° skew.

The advantages of precasting and then cutting the segments include:

- Good quality control on site
- Construction of straddle bents simplified without starter segment casting with the bents
- Proper alignment of the starter segments on both sides of the straddle bents ensured

- Eliminates starter segment construction on site
- Cost savings and schedule benefits

Fig. 12: Saw cut segments being erected

Fig. 13: Straddle bent with precast segments

CONCLUSION

The massive Central Artery/Tunnel Project is the largest infrastructure project of its type ever undertaken in a major U.S. metropolis. Concrete segmental construction has played an important part in the project. Its flexibility, speed of segment casting and erection, innovative cost and schedule saving ideas—in the form of integrating precast segments with piers to realize good seismic details—and the saw cutting of segments attached to straddle bents to overcome alignment issues, have all combined to made a strong impact on the project in particular and segmental construction in the U.S. in general.

CREDITS

Owner:	Massachusetts Turnpike Authority, Boston, MA
Managing Consultant:	Bechtel/Parsons Brinckerhoff, Boston, MA
Section Design Consultants:	Maquire/Harris, Boston, MA
	Berger/Lochner/Stone & Webster, Boston, MA
Contractors:	Slattery/Interbeton/White/Perini, Boston, MA
	Modern Continental Construction, Cambridge, MA
Precasters:	Unistress Corporation, Pittsfield, MA
	Sanford Precast, Sanford, ME