Central Artery/Tunnel Project: Innovative Use of Precast Segmental Technology

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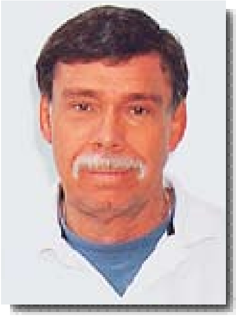

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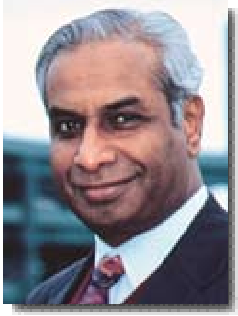

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Part 1 of this series of articles on Boston's Central Artery/Tunnel Project presented an overview of the scope of the work. This Part 2 article describes the innovative use of precast concrete segments, as well as other construction techniques, on two major interchanges.

The $13.2 billion Central Artery/Tunnel Project (CA/T) is a major reconstruction of the urban interstate highway through downtown Boston, Massachusetts. In the last issue, an overview of the entire project was given. This second article on the project will focus on the interchanges that act as gateways to the project in various parts of the city.

Most of the new structures are being built over and around existing deteriorating interchanges that must carry traffic during construction. As a result, maintenance of traffic flow through existing interchanges and phased construction of new interchanges were given priority. This, coupled with making the interchanges aesthetically pleasing and addressing urban planning issues, has been a challenge.

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. The structures are being built using either span-by-span or balanced cantilever construction techniques.

Fig. 1. I-93/Route 1 Interchange.

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

- All segments have a transversely post-tensioned top flange.
- For roadway sections, which require greater width, a combination of segment types are placed side by side and connected with a concrete closure strip.
- All viaduct riding surfaces are topped with a 1.5 in. (38 mm) thick micro silica wearing course.

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

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

I-93/I-90 South Bay Interchange (see Fig. 2)

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 massive, new 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. A follow-on contract for completion of the I-93 ramps will be bid in 2001 with segmental concrete design to match the viaducts under construction.

I-93/Route 1 Interchange (see Fig. 1)

The I-93/Route 1 Interchange is the northern gateway to Boston in Charles-

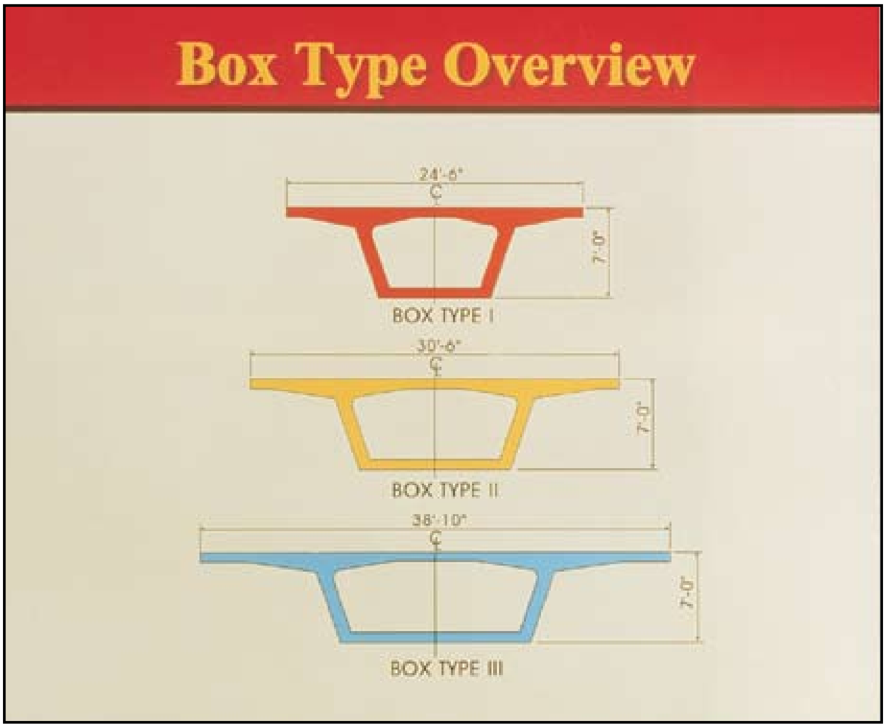

Fig. 3. Three precast concrete segment types.

Table 1. Pertinent interchange facts.

Description	I-93/I-90 at South Bay	I-93/Route 1 in Charlestown
Number of segmental viaducts	14	9
Segmental viaducts (area), sq ft	594,170	488,140
Segmental viaducts (length), ft	16,400	11,300
Number of segments	2,249	1,540
Span length, ft	89 to 217	98 to 197
Superstructure width, ft	22 to 96	24 to 94
Curvature of roadway, ft	220 to 10,500	299 to 7,610

Note: 1 ft = 0.0348 m; 1 sq ft = 0.093 m^2.

Table 2. Particulars of precast concrete segments.

Description	I-93/I-90 at South Bay	I-93/Route 1 in Charlestown
Precast producer	Unistress Corporation	Sanford Precast
Precast yard location	Pittsfield, Massachusetts	Sanford, Maine
Distance from Boston, Massachusetts	120 miles	80 miles
Number of casting cells	4	5
28-day concrete strength	6000 psi	6000 psi
Type F fly ash content	5 to 15 percent	5 to 15 percent
Segment weight	50 to 65 tons	50 to 65 tons
Segment length	8 to 11 ft	8 to 11 ft

Note: 1 mile = 1.62 km; 1 psi = 0.006895 MPa; 1 ton = 0.907 t; 1 ft = 0.3048 m.

town, 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.

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 ft (100 m).

PRECAST SEGMENTS

The segments for the South Bay Interchange are produced in western Massachusetts, while the segments for the I-93/Route 1 Interchange are produced in southern Maine. The segments are match-cast using the short line casting method. Casting begins with a starter segment that is either a pier segment or the first segment adjacent to a pier segment. The starter segment is then used to establish horizontal and vertical geometry for the next segment.

Subsequent segments are cast using the previously cast neighboring segment to establish geometry. 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.

Reinforcing 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. 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.

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 are currently having overhead electrification installed as part of Amtrak's Northeast Corridor Upgrade.

At the South Bay Interchange, the I-93 viaducts are being constructed by the balanced cantilever method. For southbound, a crawler crane and temporary falsework towers are used to erect the segments. As the crane erects the segments, epoxy adhesive is applied to the segment face and then temporary 1.375 in. (36 mm) diameter post-tensioning thread bars connect it to the previously erected segment. After both segments of a pair are erected, permanent 15 x 0.6 in. (15 mm) 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. 4).

For northbound, a specially built self-launching overhead gantry is being used (see Fig. 5). This allows all work to be carried out from above ground, which eliminates possible conflicts with ground operations. The gantry comprises two 427 ft (130 m) 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.

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. As each segment is erected, epoxy adhesive is applied to the segment face and temporary 1.375 in. (36 mm) diameter post-tensioning thread bars connect it to the previously erected segment.

Fig. 4. Self-launching erection device.

Fig. 5. Self-launching overhead gantry.

After all the segments of a span are erected, permanent post-tensioning tendons are installed. A typical span has eight 12 x 0.6 in. (15 mm) diameter strand post-tensioning tendons and two 19 x 0.6 in. (15 mm) diameter strand post-tensioning tendons.

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 engineers, and in a coordinated 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 follow.

Precast Fixed Bent Segments

The viaduct design includes fixed bents with a cast-in-place box girder segment monolithically connected to the bent column. As an alternative, a precast fixed bent segment is 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. 6). 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 reinforcing bars between the precast segment and the cast-in-place diaphragm. The interface between precast concrete and cast-in-place concrete is roughened to 0.25 in. (6 mm) amplitude to provide for shear transfer.

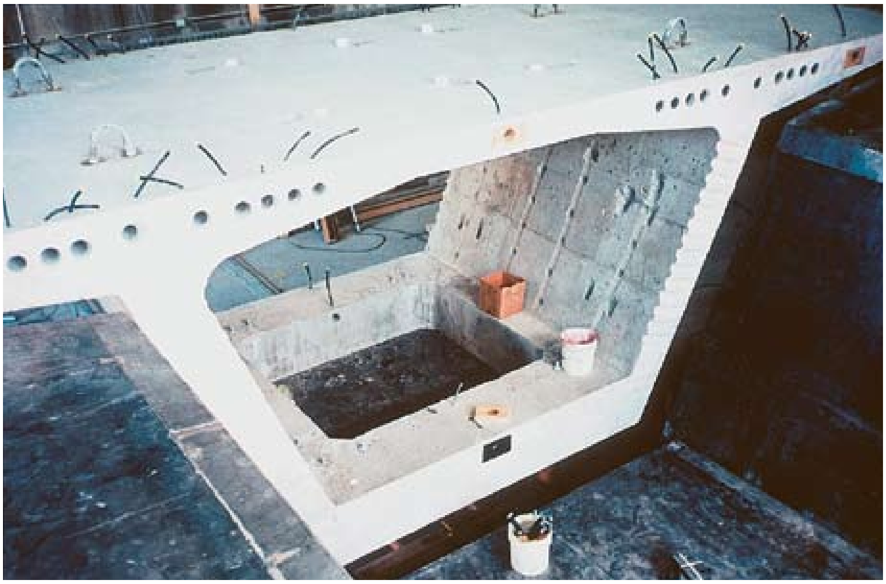

Fig. 6. Precast fixed bent segment.

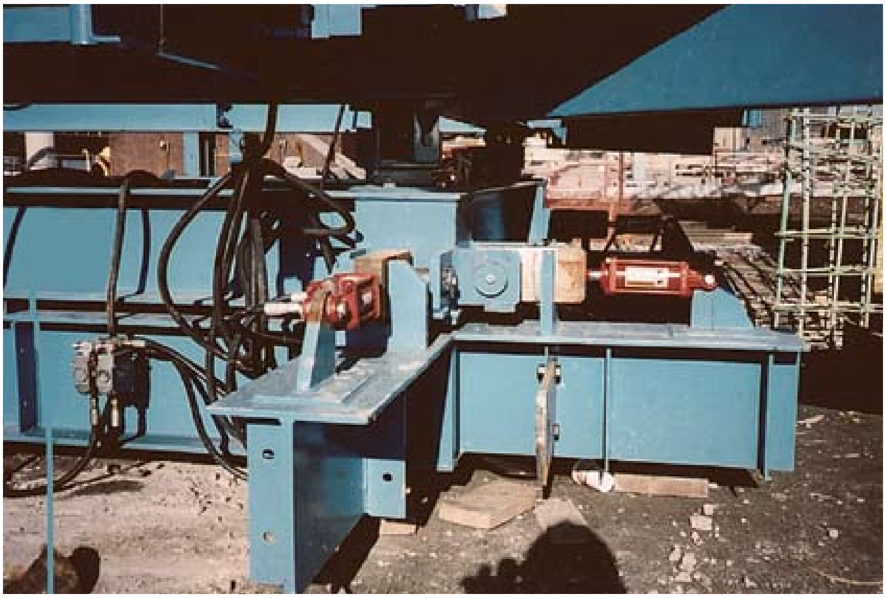

Fig. 7. Precast fixed bent segment support frame.

A specially built frame is attached to the bent column for support and alignment of the segment during erection (see Fig. 7). 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 1.375 in. (36 mm) 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. 8). 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.

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. 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 skewed to the straddle bent which makes forming difficult. To improve construction, the cast-in-place extensions have been replaced with skewed precast starter segments. Shear keys are cast into the face of the straddle bent to provide for shear

Fig. 8. Precast fixed bent segment in place.

transfer (see Fig. 9).

The skewed segment is produced by saw cutting a typical rectangular segment along the required skew line, 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 skewed starter segments, one on either side of a straddle bent.

During erection, the starter segments are hung from temporary support and alignment beams (see Fig. 12). After alignment of the segments, the 6 in. (150 mm) nominal closure joint between the segments and the straddle bent is formed. A blockout 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 blockout is roughened to 0.25 in. (6 mm) amplitude and blockout 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 can begin.

CONCLUSION

The massive Central Artery/Tunnel Project is the largest infrastructure project of its type ever undertaken in a major U.S. metropolis. The hubs of the project are the many interchanges that receive and redirect traffic between the various interstate highways, state highways, and local streets. The extension of I-90 (the Massachusetts Turnpike) to Logan Airport provides the last connection between a major urban airport and the interstate highway system.

Construction is taking place as existing traffic is maintained, and precast segmental concrete construction has proven to be versatile and adaptable for use in complex urban interchanges.

Fig. 9. Straddle bent with precast segments.

Fig. 10. Saw cutting of segment.

Fig. 11. Coring of shear keys.

Fig. 12. Precast segment supported at straddle bent.

Variable width main line roadway cross sections with numerous intersecting ramps have been smoothly integrated to provide highly functional and aesthetically pleasing structures.

CREDITS

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- Greenman-Pedersen Inc./Vollmer/Ammann & Whitney, Boston, Massachusetts

Contractors:

- Slattery/Interbeton/White/Perini, Boston, Massachusetts
- Modern Continental Construction, Cambridge, Massachusetts

Precasters:

- Unistress Corporation, Pittsfield, Massachusetts
- Sanford Precast, Sanford, Maine