INTRODUCTION

Since its opening in 1962, Washington D.C. area residents have needed a transit-based means to access Dulles International Airport. As the Northern Virginia metropolitan population has grown, increased traffic congestion has helped motivate the inclusion of a light rail option that will connect existing Washington Metropolitan Area Transit Authority (WMATA) stations in East Falls Church, Virginia to Dulles International Airport, and extend westward into Loudoun County. The Metropolitan Washington Airports Authority (MWAA) is building this extension of the existing Metrorail system to service the city of Tysons Corner, Virginia's largest employment center, the Reston and Herndon areas which contain the state's second largest employment concentration, as well as residents in emerging activity centers just west of Dulles International Airport.

The goal of Dulles Metrorail is to provide high-quality, high-capacity transit service through the Dulles Corridor. This will result in travel time savings between the Dulles Corridor and downtown D.C., while offering a viable alternative to automobile travel and expanding the reach of the existing regional rail system. Eleven new stations will be added as part of the Metroline Extension. This 23-mile alignment was funded in two phases and will be operated by WMATA. The total cost of both phases of construction is estimated to be $6.6 billion. Once complete, area business and residential centers will be permanently linked.

In order to minimize construction impacts to area businesses and residents in a metropolitan area such as Northern Virginia, pre-cast segmental box girders were selected for the majority of elevated spans. Selection of truss-erected precast segmental box girders was influenced by physical constraints including pedestrian access, traffic densities, and project construction schedules. Use of precast segments provided additional concrete durability and allowed for the expedited erection schedule required for such an endeavor. Both Span by Span and Balanced Cantilever erection are being completed utilizing three simultaneous launching girders in conjunction with crane erection; this has allowed progress to occur at up to five locations concurrently. It should be noted that no other current precast segmental projects in North America are utilizing three concurrent launching girders.

The first phase of construction extends 11.6 miles toward Wiehle Avenue and was awarded to Dulles Transit Partners, LLC, a joint venture between Bechtel Infrastructure and the Washington Group. In March of 2008, MWAA and Dulles Transit Partners (DTP) signed a $1.6 billion fixed-price contract to build the project, limiting the costs of the project to $2.6 billion. The final design of this phase included approximately 2.6 miles of elevated bridges comprising roughly 2770 precast segmental box girder segments. Of the five stations to be constructed, three are located along the precast elevated guideway. In March of 2009, Construction of Phase 1 of the Dulles Corridor Metrorail Project (DCMP) began along Route 123 at the tunnel connecting Route 123 to Route 7. This was followed up in October of 2009 with casting of the first single-track precast segment by Rizzani de Eccher USA (RdE USA). A portion of the elevated alignment passes over the I-495 corridor and was constructed using the Balanced Cantilever (BC) Method. All active works along this portion of the alignment have additionally required concurrent scheduling between DTP and Capital Beltway Express, a Fluor joint-venture simultaneously constructing High Occupancy Toll (HOT) lanes along a 14-mile segment of the I-495 Capital Beltway. Completion of DCMP Phase 1 construction is scheduled in 2013.

Phase 2 of construction will connect Wiehle Avenue to Ashburn in eastern Loudoun County. The alignment will require extensive elevated sections that will be precast as this portion of the extension traverses Reston Town Center, Herndon, Dulles International Airport, Route 606, and Ashburn. The extent of precast segmental construction to be included within the design is yet to be finalized. Upon completion, the Metrorail extension will connect Northern Virginia to the rest of the Washington D.C. metro area in conjunction with the integrated system of trains, buses, pedestrian walkways and parking facilities currently in existence; completion of construction is preliminarily scheduled in 2016.

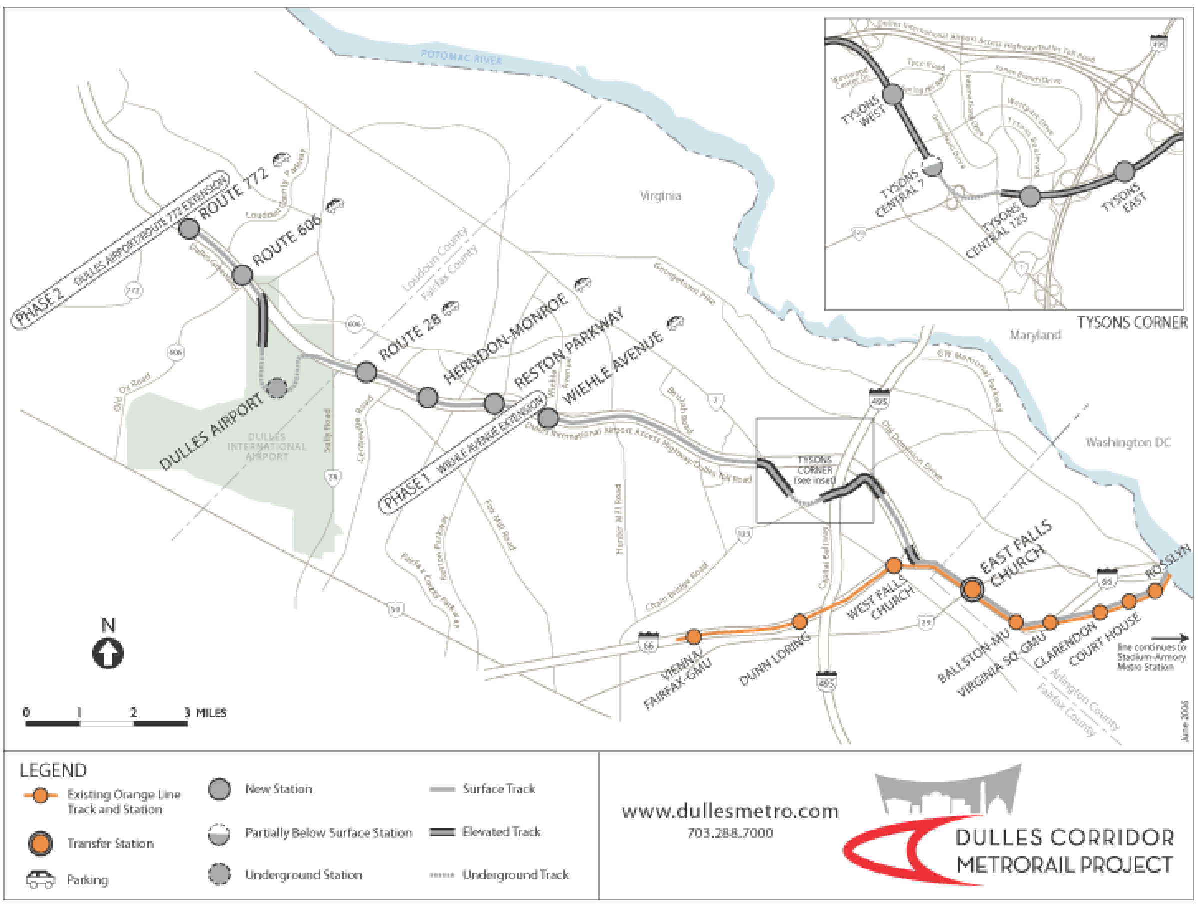

Fig. 1 Alignment of Dulles Corridor Metrorail Project

PHASE 1 OF CONSTRUCTION

Dulles Transit Partners began utility relocations and tunneling in 2009. Additional surface work construction including installation of the AASHTO Standard Bridge sections that interface with precast segment construction began shortly thereafter.

All precast segmental box girder spans were designed by Corven Engineering, Inc. and supplied by Rizzani de Eccher USA, Inc. The final design of Phase 1 segments included three variable cross-section segments to be erected using both Span by Span and Balanced Cantilever erection. Deal supplied 12 total casting moulds and three total launching girders for casting and erection of the 254 spans that comprised Phase 1 of this project. Due to site constraints, casting activities occurred on airport property beginning in October of 2009. Erection of precast segments by DTP began in May of 2010, with all segments being shipped approximately 15 miles on trailers operated by an area trucking firm.

Casting Totals for Phase 1 Segmental Construction:
Precast Segment Quantities by Type (Phase 1 - DCMP)

	Total Casting Moulds		Total Segments
Span By Span - Typical & Pier Moulds	5	Typical Segment	1817
	2	EJ Pier	356
Span By Span - Long Line Moulds	3	Station Typical Segment	290
	-	Station EJ Pier	116
Balanced Cantilever - Typical / Pier Moulds	1	Typical Segment	180
	1	Pier	12
Totals	**12**		**2771**

Fig. 2 Casting Totals for Phase 1 Segmental Construction

PRECASTING OPERATIONS

All precast segments were designed to provide single-track light rail service. Both internal and/or external longitudinal post-tensioning were incorporated throughout the alignment. Although the design loading for the single-track segments did not require transverse post-tensioning, casting yard activities did include stressing and grouting of all vertical bars.

Casting of Phase 1 segmental box girders required approximately 39,000 CY of concrete and 4,300 tons of reinforcement bars.

Additionally, the design required extensive cathodic protection accomplished through establishment of electrical continuity circuits extending between each adjacent pier column over the full alignment. All reinforcement cages therefore required additional continuity welds at multiple connections as well as surface embedment of galvanized plates connecting each adjacent segment.

The design of the precast segments also included plinth recesses to allow for secondary post-erection construction of track slabs. Due to the increased elevation tolerance this allowed, the overall geometry control requirements during precasting operations were easily attainable.

Concrete strength requirements dictated use of three different mix designs, each capable of providing either 6,000 PSI or 8,500 PSI at 28-days. Radiant heating in conjunction with real-time monitoring of thermo-curing curves during the initial curing period provided added control over curing by production personnel of all segments. This ensured concrete would perform as designed while allowing precast production to meet the daily casting cycle requirements typical in segmental construction.

As the complexity of the design was limited to three variations in cross-section, use of only five types of casting moulds were required. All Balanced Cantilever segments were cast on either the BC Typical Mould or the BC Combo Mould capable of casting both BC Pier and Typical segments. With the exception of the station segments, all Span by Span segments were cast out of either a SBS Typical Mould or SBS Pier Mould. Due to the straight alignment and shorter length of each station span, a total of three Long Line moulds were able to produce all Station Typical and Pier segments. All Station Spans were approximately 67’ long; all other typical span lengths were 120’ +/-, on average. Balanced Cantilever segments were utilized at locations spanning 155’+.

Resources: Labor & Production

RdE USA supervised all casting operations; DTP and MWAA provided second and third-party inspection and testing. RdE USA self-performed all casting activities with the exception of reinforcement supply and assembly, continuity welding, concrete testing, and segment shipment. Truss erection activities were self-performed by DTP, with RdE USA providing limited oversight.

Local labor resources were able to effectively meet production requirements without impact to construction schedules. Due to impacts of available segment storage and progress of erection, weekly casting production was typically 30 segments. Casting rates during normal production weeks produced roughly 10 Pier Segments/mould/month, 20 Typical Segments/mould/month, 20 Pier and/or Typical BC Segments/mould/month, and 12 Station Pier and/or Typical Segments/mould/month. Completion of Phase 1 casting operations will require approximately 2 years, and will conclude in October of 2011.

Precast Yard Site

RDE USA established the Sterling, VA Precast Yard (PCY) site beginning in June of 2009. The layout included a pre-engineered steel building that housed the nine total Span By Span and Balanced Cantilever moulds, a Post-Tensioning Preparation Station, and nine total rebar jigs used to pre-assemble each reinforcement cage. In order to minimize potential down-time arising from unexpected crane maintenance, all casting operations within the steel building were serviced by four overhead cranes.

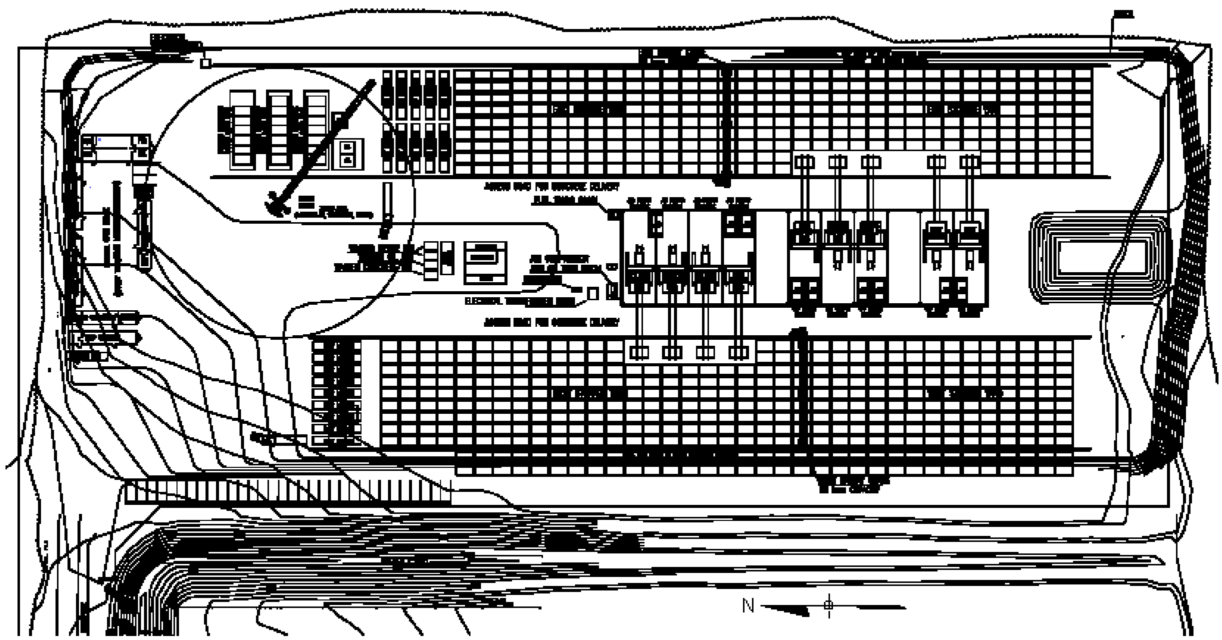

Fig. 3 Sterling, VA PCY Layout – Plan View

The 3 Long Line Station Moulds were left uncovered with segment casting occurring during portions of the year with mild weather. Casting on these moulds is typically more labor intensive. This is due to lack of a hydraulic manipulator, which all other Deal moulds require. Station Moulds were serviced by a tower crane that allowed progression of Long Line casting without impact to segment handling or load-out. Two storage yards were established capable of temporarily storing just over 1000 segments. Each of these yards is serviced by a railed Gantry Crane supplied by Cimolai.

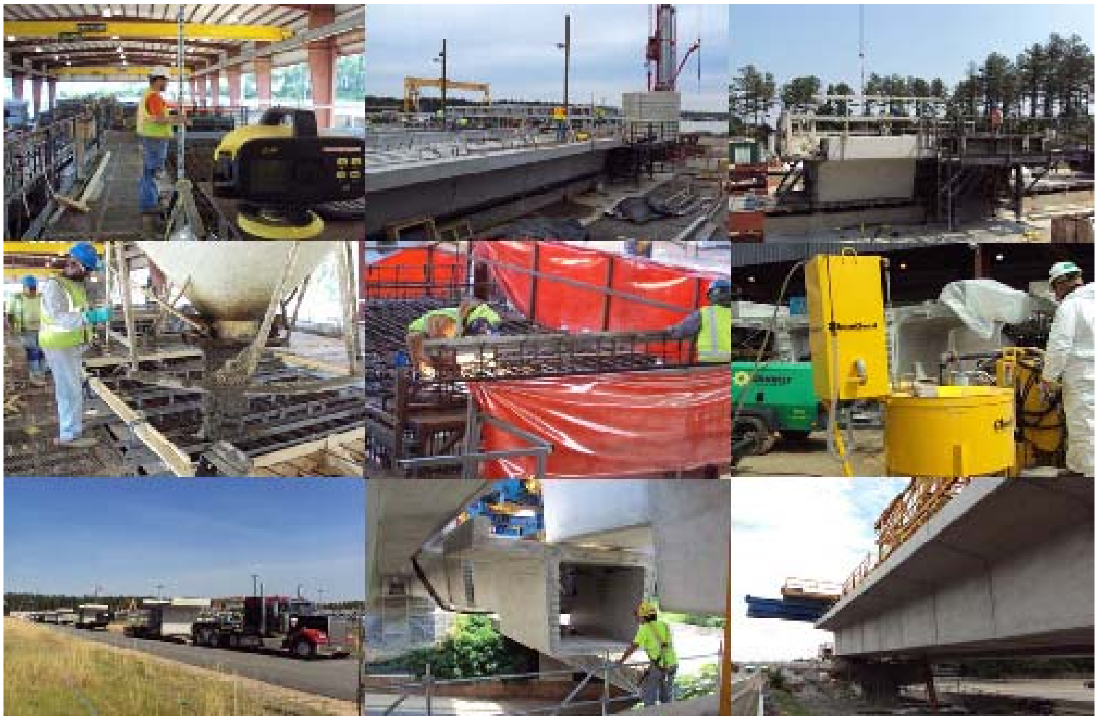

Fig. 4 Stages of Segmental Work (Clockwise from top left: PCY Survey 1, PCY Survey 2, Long Line Mould, PCY Grouting Operations, SbS Erection 1, SbS Erection 2, Shipment, Concrete Placement, Continuity Welding)

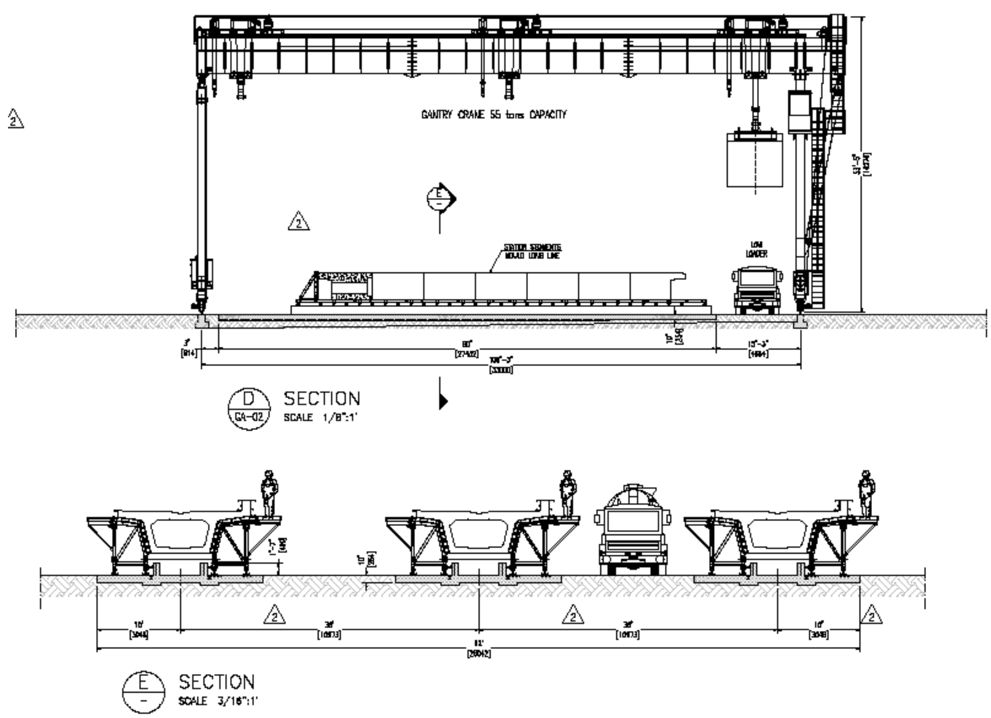

Fig. 5 Long Line Station Moulds – Profile View

Use of the Deal Geometry Control System does not require casting yard installation of survey target towers, which increased the available site area designated for segment storage. Use of the Deal system of geometry control not only decreased the footprint of each mould, but also expedited casting yard survey operations.

All PCY post-concrete placement inspections and remedial works occurred while segments were staged in temporary storage. Stressing and grouting operations of PT bars were accomplished within the designated transfer area prior to relocation to the temporary storage area. By employing a sequence that took each segment from the Match Cast position in each mould to a staging area for remedial works and post-tensioning before being stored, the PCY maximized use of available storage with minor impact to remedial works. The common practice of double stacking all segments whenever possible was also employed.

The PCY also designated separate centralized load-out areas which helped expedite segment shipment. In order to further increase available storage and expedite SbS erection, approximately 450 segments were staged along the alignment. However, due to DOT lane restrictions, erection activities required both day and night shifts to achieve scheduled construction.

SITE SPECIFIC BENEFITS OF SEGMENTAL PRECASTING

Prior to the onset of casting operations, the PCY developed a Segmental Quality Management Plan that addressed all stages of casting. This included the development of work procedures in-line with accepted PCI & ASBI practices covering everything from concrete testing to deficiency repairs. By implementing such an approved plan, production activities through all stages of construction including erection were expedited. Precast Quality Control and Quality Assurance practices that were employed helped ensure that any unexpected deviations were addressed by precast personnel timely, without impact to erection operations. Additionally, precast engineering coordination with the client and designer were instrumental to the successful production and construction of the precast segments.

By precasting the segmental box girder segments, it is easier to maintain control over the physical environment in which construction occurs. This typically results in both safety and production benefits to the precaster. The hazards associated with a conventional cast-in-place bridge project are drastically minimized due to the decreased exposures experienced by production personnel. As daily production activities are fairly regular, segmental precasting can be significantly more efficient; moulds can produce any type of segment in 1 to 2 working days. It should be noted that unlike typical precast segmental forms, Deal employs barrier wall forms during precasting operations. This practice expedites post-erection works along the elevated guideway.

In order to ensure the maximum amount of working days, RdE USA setup nine casting moulds in the steel building (see Fig. 4). Unlike the three outdoor Long Line Station Moulds which experienced winter shutdowns and delayed production due to rain events and extreme heat, casting operations in the Steel Building proceeded year-round with minimal impacts due to weather or other natural events.

Scheduling of all casting operations was necessary to minimize potential lost time and to ensure staging areas for deliverables were provided. As such, the precast quality plan required that all supplied reinforcement utilize a color coded system and that each separate segment's reinforcement bars be bundled together. Furthermore, PCY engineering had to efficiently coordinate deliveries of all reinforcement in order to minimize the utilized staging area of all deliverables. This lean construction practice was also utilized for all supplied items.

Concrete was subcontracted to an off-site ready-mix supplier in order to alleviate on-site staging-area constraints. This additionally avoided the setup and maintenance costs of running a batching plant. However, precast personnel had to effectively coordinate off-site batching due to variable delivery times typical with metropolitan construction.

The general layout of the PCY site maximized available storage in order to ensure an early casting start. This was necessary for casting production to maintain ahead of erection. At the onset of casting, available storage was capable of handling approximately 1000 segments, or roughly 1/3 of the total required production. A portion of the employee parking area was later re-designated for segment storage to accommodate scheduled casting.

ERECTION OPERATIONS

As truss erection activities are fairly regular, segmental erection is generally quite efficient. Nonetheless, DTP accelerated erection operations along the alignment through the use of mobile cranes in conjunction with three separate launching girders. Two of the launching girders used erected the majority of Span by Span segments. The remaining Balanced Cantilever truss constructed the guideway segments that straddled Washington D.C.'s I-495 corridor. The staging of erection activities which began at the east end of the elevated sections required relocation and re-assembly of a SbS truss to the elevated section west of the tunnel through Tysons Corner. Thus far, erection activities have progressed slower than expected, mainly due to traffic constraints.

Fig. 6 Span By Span Segmental Erection during Night Shifts

For the purpose of practically, Rizzani supplied trusses capable of erecting 60 m spans. The combo trusses responsible for SBS erection are able to erect in four directions (i.e. forward, backward, shift left, shift right). The length of each truss is roughly 100 m, with an average weight of 250 T. When fully assembled, the balanced cantilever truss can erect 110 m long spans, and weighs roughly 300 T at a length of 100 m. As this type of elevated crane travels horizontally, launching trusses are positioned at the apex of each pier in order to minimize the conflicts with the ground traffic while traversing the alignment. In order to allow for truss relocation at various portions of the alignment, multiple spans were designated 'drop-in' requiring additional use of structural bars for truss tie-downs. The coordination of this work remains crucial to the successful completion of Phase 1 construction.

CONCLUSION

The Washington D.C. metro area's need for an efficient alternative to vehicular access of the Dulles Corridor is being addressed through the use of precast segmental construction. Phase 1 of construction required casting of 2771 precast segmental box girders that were produced over a two year time frame. An experienced QC/QA team is necessary to ensure proper precasting procedures are followed. Although deficiencies did exist, the approved Segmental

Quality Management Plan helped expedite all required repairs without impact to segmental erection. Extensive preplanning and oversight by casting management has avoided the majority of quality issues experienced during typical precast construction. By utilizing a sequence that takes a segment from the matchcast position, to a staging area for inspection/deficiency repair/finishing prior to storage, multiple handling of segments can be minimized without impact to any casting operations. Although available storage may increase, a potential impact to remedial works exists.

By keeping the design of all segments single-track in conjunction with post-erection track slab construction, DCMP pre-casting could be conducted in an expedient manner. With less experienced and skilled labor, certain works required subcontracting in order to achieve a daily casting cycle that could adhere to scheduled production. Use of Long Line moulds is effective for casting shorter, straight spans. However, the manual nature of Long Line mould adjustment is labor intensive. For any type of mould that requires a daily casting cycle, it is preferable to cover with an enclosure as this minimizes both weather related delays and lost-time due to crane delays.

Efficient construction in a metropolitan environment requires preplanning and coordination; staged work must consider local environmental concerns while accommodating all other area activities. The ability to re-direct efforts to an alternate and concurrent work area allows for continued work progress when physical constraints cannot be alleviated. Furthermore, supply of deliverables on such metropolitan jobs must be effectively controlled. This concept must also include segment shipment.

Effective coordination with erection site personnel requires significant preplanning as well. It is necessary that pre-casting operations remain ahead of erection activities no matter if work occurs at concurrent locations; it is also important that available storage be sufficient for any required PCY operation. In order to avoid shipping delays, centralized loading areas are frequently justified.

When comparing cast-in-place construction with segmental pre-casting, the safety and health exposures on this project were significantly decreased. It should be noted that during precast operations, no lost-time injuries were occurred. Due to physical site constraints and the minimal amount of concrete supply delays experienced, the use of an on-site batching plant was not warranted on this project. Although not as beneficial to erection operations, use of the Deal Geometry Control system additionally expedited casting of Phase 1 segments. By employing adequate coordination in conjunction with these concepts, segmental pre-casting in a metropolitan area can safely provide a very effective and efficient construction method while allowing significant control over the construction site.