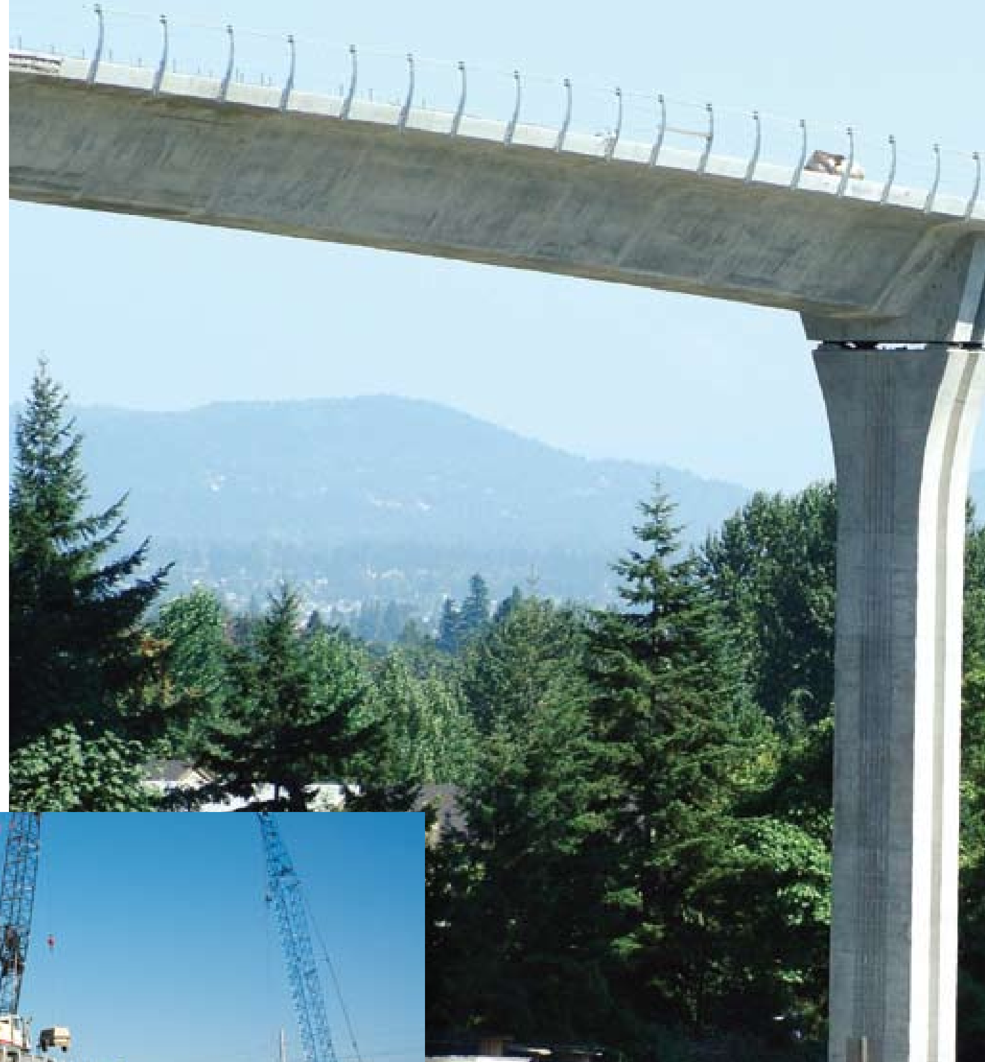
Precast Segmental Guideway Forges Important Transit Link

by Wayne A. Endicott



Construction of the 350-ft span over the Duwamish River. Photo: IBT.

'Big, long viaduct' completes Seattle's new light-rail system with airport link

When engineers were tasked with the assignment of designing the last link in the new Seattle Sound Transit light rail system, they already had a model to work from. The same group had recently completed a similar project in Vancouver, British Columbia, Canada. "Conceptually, we looked at a lot of different possibilities for the project, but our experience from the Vancouver project pointed us toward building an elevated system employing segmental precast concrete bridges," says Christopher Hall, Senior Project Manager for International Bridge Technologies (IBT) in San Diego, designers of the bridges.

profile

SEATTLE SOUND TRANSIT LIGHT RAIL / SEATTLE, WASHINGTON

PRIME DESIGN CONSULTANT: Hatch Mott MacDonald, Bellevue, Wash.

PRECAST SEGMENTAL GUIDEWAY DESIGN CONSULTANT: International Bridge Technologies, Inc. (IBT), San Diego, Calif.

CONSTRUCTION MANAGEMENT CONSULTANT: Parsons Brinckerhoff CS, Seattle, Wash.

PRIME CONTRACTOR: PCL Construction Services, Inc., Bellevue, Wash.

CONSTRUCTION ENGINEER: T.Y. Lin International, Olympia, Wash.

PRECASTER: Bethlehem Construction, Inc., Cashmere, Wash., a PCI-Certified Producer

The winding, twisting bridge includes super elevations as well as horizontal and vertical curves, all compensated for in the casting of the segments. Photo: Hatch Mott MacDonald.

Alternative Dramatically Speeds Construction

This alternative solution appealed to the team and to the system's owner, Seattle Sound Transit. The first consideration was the promise of completing the project more rapidly. "The whole rapid transit system had schedule challenges for a variety of reasons," Hall says. "As the last section of the light rail project to be constructed, there was already a potential deficit in the scheduled completion time. We proposed precast concrete segmental construction as a way of cutting that deficit. We felt that we could complete this portion of the system—the last link to the airport—a full nine months faster than the project could be built in the original plan. This would allow us to cut into that time deficit and give the owner flexibility in the schedule."

Hall points out that the contractor could perform multiple operations, including

Constructing the project within a tight right-of-way was challenging enough, Hall says. But several other factors entered into the planning, not the least of which was the sensitive environmental area the system was to traverse. "Access and mobility problems for other traditional bridge structures would have caused a loss of efficiency in the construction of the link. The need to work within the limitations of the area would have required much longer to complete," explains Hall.

Armed with the knowledge gained during the construction of the Vancouver project, the team, which included Hatch Mott MacDonald in Bellevue, Washington, as the prime consultant, proposed the precast segmental solution over twin, full-length precast box girders.

The construction system allowed the guideway to be built over I-5 with little disruption to traffic. Photo: PCL.

PRECAST SEGMENTAL BOX GIRDER / SEATTLE SOUND TRANSIT, OWNER

BRIDGE DESCRIPTION: 4.2 miles of 26-ft 6-in. wide precast concrete segmental box girder (plus 0.9 miles of on-grade railway) carrying two light rail tracks with an emergency exit walkway

POST-TENSIONING SUPPLIER: Schwager Davis, Inc., San Diego, Calif.

STRUCTURAL COMPONENTS: 2207 V-shaped precast concrete segments and 160 cast-in-place piers. Typical spans are 120 ft with longer spans (220 to 350 ft) carrying the line over I-5, the BNSF tracks, and the Duwamish River.

CONSTRUCTION COST: $270 million

We felt that we could complete this portion of the system a full nine months faster.

site work, foundations, piers, and similar activities, while the precast concrete segments were being cast.

"Our staff has done precast concrete segmental bridges on several light rail projects," Hall explains. "We have found that the process especially lends itself to this type of project. By building it over everyone's head, we were able to avoid a great deal of the traffic. It was especially critical in this job, since the new rail line is adjacent to surface streets and also spans I-5, the main West Coast artery between San Diego and Seattle." By "going over the top," the new rail line avoids the necessity of disrupting traffic on that major thoroughfare.

The benefits of building an elevated rail line were not limited to traffic impacts, Hall explains. The line, which crosses a river and spans some sensitive wetlands, creates a much smaller footprint than a surface rail line would require. "By building it overhead, we were able to stay out of the water where the line crosses the Duwamish River and minimize its impact on the wetlands, which pleases the multiple groups and state agencies charged with oversight. The cost of mitigation that otherwise would have been required was also reduced. Other challenges included crossing a large Burlington Northern Santa Fe (BNSF) rail yard, a large intersection at a Boeing company access road as well as the freeway. It's difficult to imagine one project facing so many challenges, and being able to solve them all with a single construction technology."

The overhead gantry places the segments from above, keeping contact with environmentally sensitive areas to a minimum during construction. Photo: IBT.

Costs Lower than Estimated

Surprisingly to all parties concerned, the project, which was bid at a time of sharply rising material costs, actually proved less expensive than originally estimated, Hall says. Four contractors submitted bids, and two were at least 10 percent under the engineer's estimates. With the reduced construction time, further savings will be realized and Seattle Sound Transit will have its last link to the airport completed sooner and open to traffic. In fact, Hall says, the original plan called for the link to end short of the airport, but the lower bids allowed the owner to extend and complete the line to just outside the Seattle-Tacoma International airport.

The final design of the 5.1-mile-long project, which is approximately 80 percent above ground, includes 4.2 miles of elevated guideway carrying twin tracks with continuously welded rails fastened to the top of the superstructure. The grade level portion of the project sits atop retained cut and fill. The track elevation ranges from 20 ft above ground to as high as 70 ft.

The guideway spans the Duwamish River. The longer segmental spans allowed the crossing to be made while keeping the construction process out of the riverbed. Photo: IBT.

The gantry holds several segments, ready to be epoxied to adjoining segments and post-tensioned. Photo: PCL.

Foundations typically consist of single 10-ft-diameter drilled shafts to minimize the impact of construction on the right-of-way. A few piers rest atop spread footings. Steel pipe piles are used at special locations where the drilled shaft would be uneconomical to build because of the required depth.

The superstructure features a 7-ft-deep precast concrete segmental box girder, with the segments put into place by an overhead traveling gantry. Typical spans for the project are 120 ft. However, where the structure crosses I-5, the Duwamish River, and the BNSF tracks, spans vary from 220 to 350 ft. The superstructure is 26 ft 6 in. wide and carries two light rail tracks. It also contains a maintenance and emergency exit walkway between the tracks.

Girders Feature Triangular-Shaped Cross-Section

An important decision early in the design process led to the development of a unique triangular-shaped cross-section for the box girder. This design was developed for several reasons. First, the appearance of the 4-mile-long ribbon of concrete entered into the design equation. For this reason, the width of the bottom slab was sized to satisfy the box girder bending stresses.

A precast pier segment is lowered into place by the overhead gantry. Photo: IBT.

The superstructure is supported with buffers and tie downs at the top of the piers to resist seismic loads. Photo: IBT.

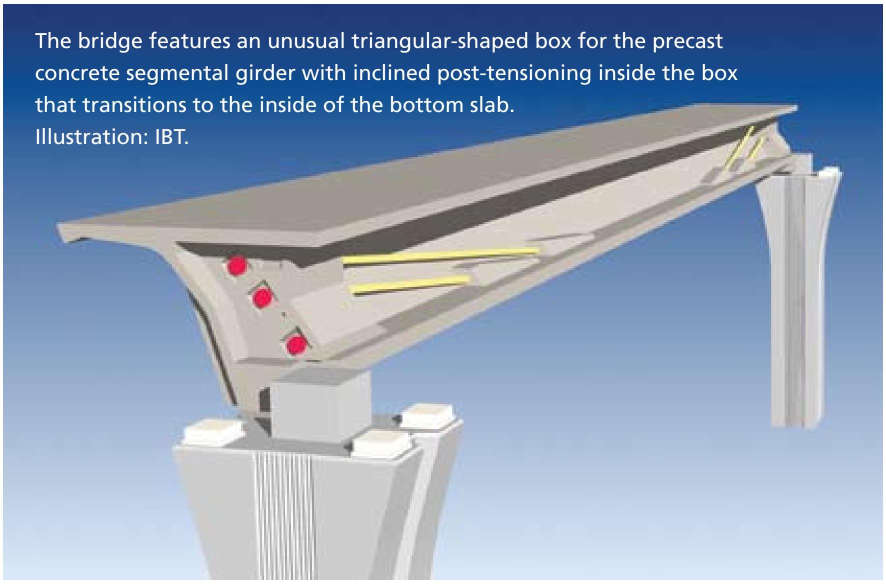
A unique triangular-shaped cross-section was created for the precast concrete box girders.

Lateral stability at the piers was provided by external diaphragms. These outside diaphragms were integrated with the pier shapes designed as twin walls with a center diaphragm. The resultant profile produces a sleek, narrow section. This significantly reduces material quantities when compared with traditional box girder designs. The inclined webs of the V-shaped box girder also provide a less intrusive appearance to the guideway.

Within the core of the box girder, post-tensioning tendons start outside the concrete section and then transition to the inside of the bottom slab, allowing them to be bonded in the mid-span sections. Small blisters at the point of entry on the bottom slab simplify the core forms.

The twisting, rising, and falling path of the alignment was cast into the guideway, which allowed the rail's concrete plinth dimensions to be reduced. The box girders are designed to follow all aspects of track alignment geometry, including super-elevation and horizontal and vertical curvature. The resulting rail plinth maintains a constant shape and greatly simplifies casting in the field, replacing the common detail of casting the rail plinth alone to accommodate the trackwork alignment.

Another feature is a continuous transverse diaphragm cast with the pier segment at the end of each span. This could easily be adjusted in the casting yard so the bottom face of the diaphragm was always parallel to the



The bridge features an unusual triangular-shaped box for the precast concrete segmental girder with inclined post-tensioning inside the box that transitions to the inside of the bottom slab. Illustration: IBT.

horizontal surface at the top of the piers when it is necessary to rotate the box girder. This accomplishes several things, he explains, including creating a constant gap between the bottom of the plinth and the top of the pier, thereby simplifying detailing for bearings and seismic buffers. It also improves the visual melding of the superstructure and substructure.

Designed for High Seismic Needs

The structure was designed to resist large seismic loads. Large vertical accelerations as large as two-thirds of the horizontal accelerations played a part in the design. The typical spans are simply supported with buffers and tie downs resisting seismic loads at the top of the piers. These are contained in the space between the two half-pier segments at the top of each pier.

As the practice of seismic design advances, greater demands are placed on designers to accommodate higher loads for elevated structures, Hall says. For this project, pioneering work was performed to develop project specific criteria to ensure a design approach that was consistent with the precast segmental structural scheme.

The piers themselves are designed as rectangular double walls with a center diaphragm. The flaring shape of the pier cap matches the shape of the outside pier segment diaphragms. The heavily-reinforced piers utilize ductile detailing to satisfy the area's high seismic demands. The contractor fabricated the pier cages in one piece and was able to place the pier concrete in one continuous placement.

Throughout the design process, aesthetics remained a key concern. For example, instead of traditional straddle bents typical in high-seismic regions, resulting in bulky rectangular boxes atop circular columns, the straddle bents received the same reveal treatments provided on typical piers. The sloping sides of the bent beams and lower arch-shaped reveal treatments give the effect of reducing the depth of the bent beams.

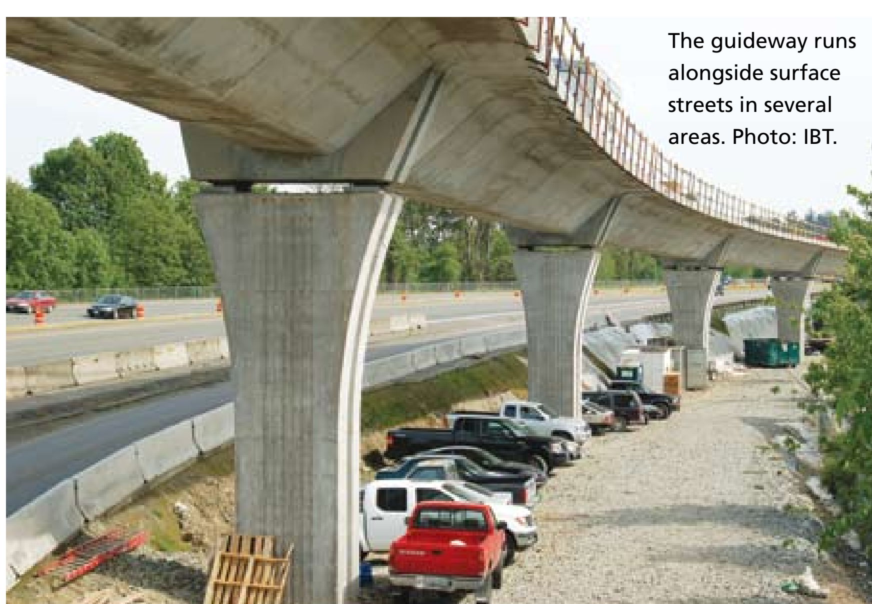
Precast segments were cast in the precaster's casting yard about 145 miles from the site. The firm employed nine casting cells, including five for typical segments, two for pier segments, and two for variable depth segments. After transporting to the site, the segments were erected with an overhead erection truss.

The total cost of the rail line, including the airport extension, is set at $270 million, a full $20 million less than the engineer's estimate and $30 million less than the original concept. Hall says that the project began in February 2005 and is scheduled to be finished in March 2008.

"This was the first project to utilize the 'V-box' shape that was developed by IBT president Daniel Tassin," he says. "Because of the multiple challenges, much of the work needed to occur up in the air, making it ideal for precast concrete segmental construction and an overhead truss."

For more information on this or other projects, visit www.aspirebridge.org.

'Much of the work needed to occur up in the air, making it ideal for precast concrete segmental construction and an overhead truss.'



The guideway runs alongside surface streets in several areas. Photo: IBT.

AESTHETICS COMMENTARY

by Frederick Gottemoeller

This issue of *ASPIRE*™ brings an embarrassment of riches to someone who likes to see improved appearance in bridges—they are all noteworthy. Spokane's Monroe Street Bridge is a particularly fine example of the sensitive reconstruction of an existing historic bridge. However, I decided to focus on the Seattle Sound Transit light rail link because it helps answer a question that I am often asked: what is the increased cost of aesthetics?

The preliminary design for the rail link was quite a different structure. Based on the region's experience in the construction of highway bridges, it had been assumed that precast concrete U-shaped girders would once again offer the most economical solution. After all, it is a long viaduct with many similar spans. However, that led to a design that required hammerhead pier caps at each pier and one girder for each rail track. The weight of the precast girders created construction difficulties, as did the many curves that had to be accommodated. With all of that in mind, the designer asked for and received permission to evaluate the original assumption.

The result is the design now under construction. It turned out to be 15 percent less expensive than the preliminary design. It is also a more attractive design. With a single segmental box section and without the miles of hammerheads, it is much sleeker, less massive, and more transparent. The designers did an excellent job of marrying the piers and the girders in an attractive and structurally honest way. Finally, the piers have vertical insets that create shadow lines that minimize their apparent width. At piers near stations mirrored tiles are set in these insets to create a flash of color for users approaching the structure, something that will surely be appreciated during Seattle's rainy weather.

So now, when I am asked the question about the added cost of aesthetics I say, based on the Seattle Sound Transit light rail link, the cost could be less. Of course, the real answer is, it depends. If you start with a standard structure and just add decoration to it, you automatically add cost. But if you look at the problem from the ground up, consider all of the options and try to improve the structure's efficiency, economy, and elegance all at the same time, you will certainly come up with a better-looking structure. You might even reap some savings.