Application of Precast Segmental Bridge in Large Scale Design-Build Project, Port Mann Bridge

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ABSTRACT:

The new 2.02km long Port Mann Bridge will carry the Trans Canada Highway (TCH) with ten lanes of traffic across the Fraser River just east of Vancouver, British Columbia. The crossing includes an 850m-long cable-stayed main span unit with a combined length of 1170m-long precast concrete segmental box girder approaches on the north and south sides of the bridge. The approach span is approximately 50m wide in order to carry 10-lanes of vehicles and a pedestrian/bike lane. To accomplish this width, three parallel box-girders were used with a connection at the wing tips. The top slab utilizes transverse post-tensioning to support the roadway loads. The approach span to the north was a combination of simply supported spans ranging from 35m to 45m, and longer spans of 92.5m built in balanced cantilever form. The approach structure to the south was all simply supported spans with the same span lengths as the north. At 59,000m2 of deck area, the approach spans represent one of the largest precast segmental projects ever constructed in North America, and is an example of the advantages of precast construction. Due to the urgent nature of getting revenue started on this toll bridge, construction proceeded at an accelerated pace. Casting of the segments began shortly after foundation construction and allowed for simultaneous construction activities to occur. The bridge deck included a total of three parallel box girders side-by-side. Due to the proximity of an existing bridge, two of the three boxes will be constructed at the ends of the approaches to allow traffic and toll collection to start while demolition occurs on the old bridge. This feature played a major role for the contractor to win the design-build project. Innovative features were also employed to resist the high seismic forces required for the project.

Keywords: Bridges, Precast Segmental Construction, Highway, Seismic, Bridge Aesthetics

INTRODUCTION

The new Port Mann Bridge is to be completed as part of the Port Mann/Highway 1 Improvement (PMH1) Project, which is part of the British Columbia Ministry of Transportation and Infrastructure Gateway Program. This 37km project is being constructed just east of Vancouver, British Columbia, and an overview of the project is shown below in Figure 1.

Fig 1 Gateway Program Overview

A major component of this project is a new Port Mann Bridge. Presently crossing the Fraser River, the existing bridge is located just north of the city of Surrey, which, in addition to the surrounding area, is one of the fastest growing population centers of the lower mainland. The community is currently served by the existing 5-lane Port Mann Bridge, an iconic arch bridge built in 1964, that cannot accommodate the current vehicle volumes and is creating a choke point along the critical Trans Canada Highway. Traffic along this section is congested much of the day, limiting the economic potential and quality of life for many of the local residents. The PMH1 Project was identified as having high urgency to provide better access to the city of Vancouver and act as a seamless transportation link for the shipment of goods throughout the region.

In August of 2008, a joint venture team of Kiewit/Flatiron was identified as the preferred proponent to build this $2.2 billion dollar project, with the new Port Mann Bridge itself as the centerpiece, and to be designed by the lead team of TY Lin International in partnership with International Bridge Technologies, Inc.. The total bridge length is 2.02km, with a 850m cable-stayed bridge crossing the primary navigation channel, a 820m approach bridge on the north, and a 350m approach bridge on the south. The bridge is designed to carry 10 lanes of traffic plus a pedestrian/bike lane.

The project was original procured as a PPP (public-private partnership) with the team acting as operator and charging tolls under a 35 year agreement with the Province. However at the time the project was awarded, the world banking crisis was near its worse time. The Province was able to borrow money at a lower rate, and therefore executed the agreement with Kiewit/Flatiron as a design-build contract.

Because the project was procured through a competitive process, multiple studies were performed during the tender phase to determine the optimal solution for the river crossing. Ultimately the precast concrete segmental option was chosen, due to a combination of considerations including cost, speed of construction, constructability, advantageous seismic performance, and aesthetics.

THE PROPOSED SOLUTION

During the tender process, an interesting alternative was presented to the proposing teams; either build a companion span to the existing arch bridge, or build an entirely new bridge with some compensation to reward the replacement of an older facility. A photo of the original bridge is shown below in Figure 2.

Fig. 2 Existing Port Mann Bridge

Keeping the old bridge was a tricky proposition. It had already been retrofitted for both the addition of a traffic and pedestrian lane, in addition to seismic strengthening. However a field assessment had identified possible long term maintenance problems, and additional seismic strengthening was going to be required. In accepting the toll concession, the winning team would also accept the original bridge as-is without warranty. While keeping the bridge appeared to be the cheapest for original construction costs, it carried risks. A rendering of the Province's concept is shown in Figure 3.

Fig. 3 Twinning Concept

Under the bidding process, the Province's selection of a preferred bidder was not solely based on lowest bid, but best value. Considering the benefits of an entirely new bridge, and including the risk factors with the old bridge, the decision was made to develop a full replacement, as shown in the rendering in Figure 4.

Fig. 4 Full 10-Lane Bridge Concept

Once making this decision, the Kiewit/Flatiron team and their financing partners determined that it would be possible to begin tolling on the new bridge with 8-lanes in place, then tear down the old bridge, and complete the rest of the 10-lane project. This would allow tolling to start earlier than planned and begin generating revenue well in advance of the original opening date, and significantly reduce the bid price by reducing the amount required for financing.

This innovate decision is an example of the benefits of a competitive bidding process that allows the design/contracting team to adapt their design to an optimal solution. Of course, in this case it did not result in the most efficient structure. In order to build next to the existing span, part of the approach spans would need to be delayed and constructed after demolition.

This, plus many other factors, went into the decision to use precast segmental as the solution for the approach structures.

CHOOSING PRECAST SEGMENTAL CONCRETE APPROACHES

The approach structures to the main cable-stayed bridge start at grade and rise to an elevation approximately 50m above ground. The north approach is shown in Figure 5 and the south approach in Figure 6.

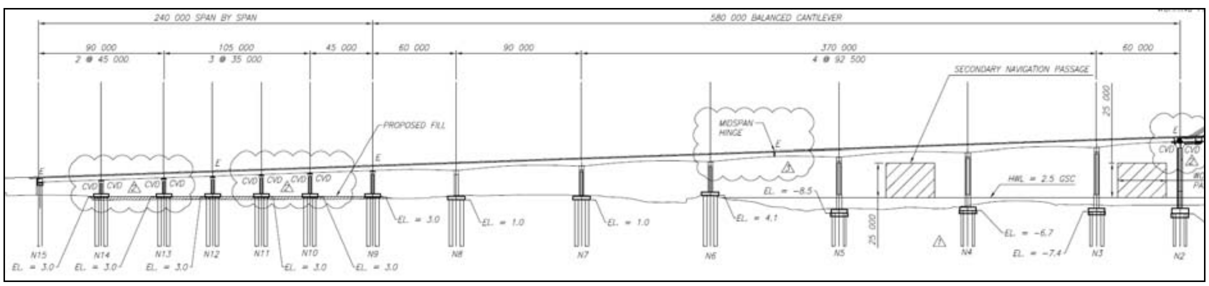

Fig. 5 North Approach

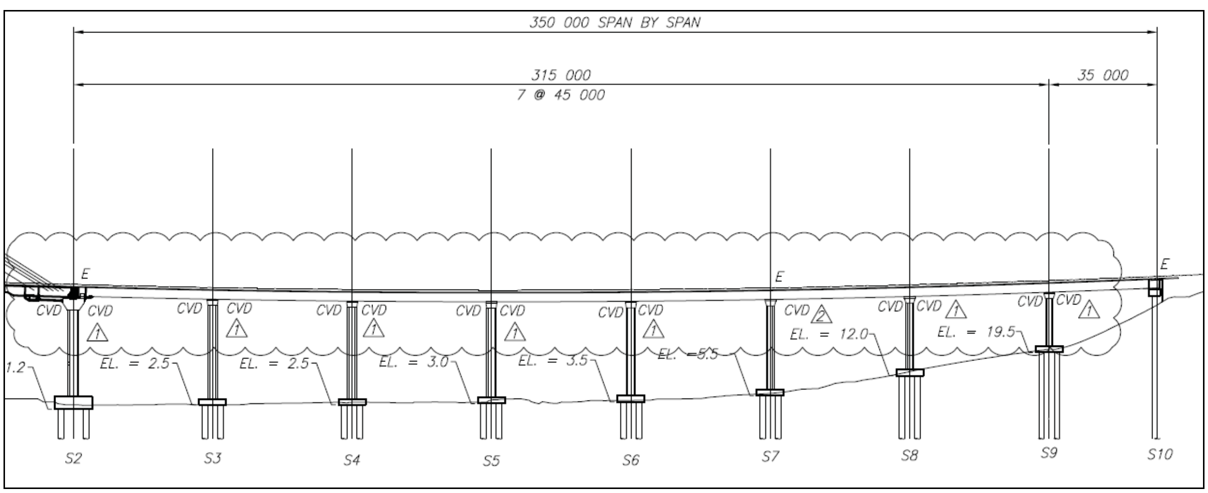

Fig. 6 South Approach

Bridge types including precast concrete I-girders, steel I-girders, and precast segmental concrete (PSC) were considered. After a comparative analysis was performed with the contractor, where alternates were developed for each of the bridge type, the PSC was selected as the preferable option. Because of the nature of the project as a toll road, a premium was placed on early completion. PSC had a significant schedule advantage as fewer pieces require handing, the secondary stage of casting a deck over girders was not required, and the erection equipment could construct the spans from above, thereby avoiding ground obstructions on the river.

PSC is also adaptable for longer spans. While steel girders and spliced precast girders can be implemented for longer spans, the box-girder section is the most efficient. This proved useful at the north approach where ground obstructions could be avoided in a critical zone, and fewer foundations were needed for the river.

The Port Mann Bridge project criteria also included very large seismic forces. A four-level earthquake demand was specified, with the lowest level a serviceability earthquake and the largest level an ultimate earthquake with a 1:2500 year return period. Both I-girder options required a sizeable cross-beam to support the wide deck. This concentrated mass for the higher level approach spans resulted in larger inertial loads being generated, and made the PSC option more competitive with the normally lighter steel option.

DESIGN CHALLENGES

Once the PSC option was selected, a primary challenge was to stage the construction for the initial 8-lane condition and allow for the future 10-lane condition. This was achieved by implementing a 3-box-girder-wide superstructure. Half of the approach structure was built out to full width, however the other half was built with only two box-girders. The transition occurred at expansion joints to allow the structures to behave in isolation from one another and eliminate any awkward load paths in the first stage.

The box girders deck width ranges from 15m to18m. The variation is taken out in the wing tips such that an identical core box-girder shape is used at all locations.

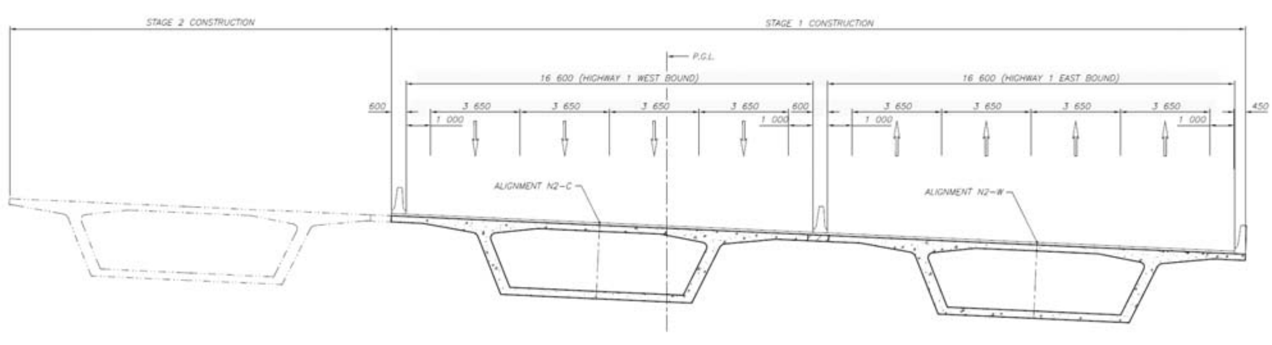

Fig. 7 Construction Staging

ADVANTAGES OF DESIGN-BUILD PROCUREMENT

The Port Mann Bridge project is a good example of the advantages using design-build and/or PPP procurement procedures. By maximizing the amount of options for the proposing teams to consider, economies of scale can be achieved on a large magnitude.

The approach spans noted above are good case study. Using a simple cost per deck area comparison, the precast or steel I-girders would have shown a significant advantage over PSC. However, once evaluated by the contractor with project priorities in mind, the evaluation changes. With a premium on schedule, the contractor was able to determine that the PSC could be constructed at a much more rapid pace, and the segments are a one-step procedure for constructing the superstructure, as opposed to a girder-and-deck scheme that require two distinct operations with the girder placement and deck casting. Once the evaluation was performed, it was clear the PSC offered savings in multiple millions of dollars, while taking advantage of economies of scale (i.e. creation of a casting yard and a uniform construction approach.)

SUPERSTRUCTURE DESIGN

The superstructure for the approach spans utilized two types of PSC structures; a simple span supported on bearings and continuous spans built in balanced cantilever construction. As noted earlier the deck width is composed of three box-girders abreast and is connected with an 850mm wide closure strip at the wing tips. The spans are supported on the tops of the reinforced concrete piers with elastomeric bearings. After final construction a 100mm asphalt layer is added with a waterproof membrane.

The simple spans were either 35m or 45m in length and were used in areas without significant at-grade obstructions. The segments were 3.0m deep and post-tensioned longitudinally and with transverse post-tensioning in the deck. A cross-section is shown below in Figure 8, and photos from the casting yard are shown in Figures 9 and 10. As seen by these figures, an efficient and streamlined section was developed.

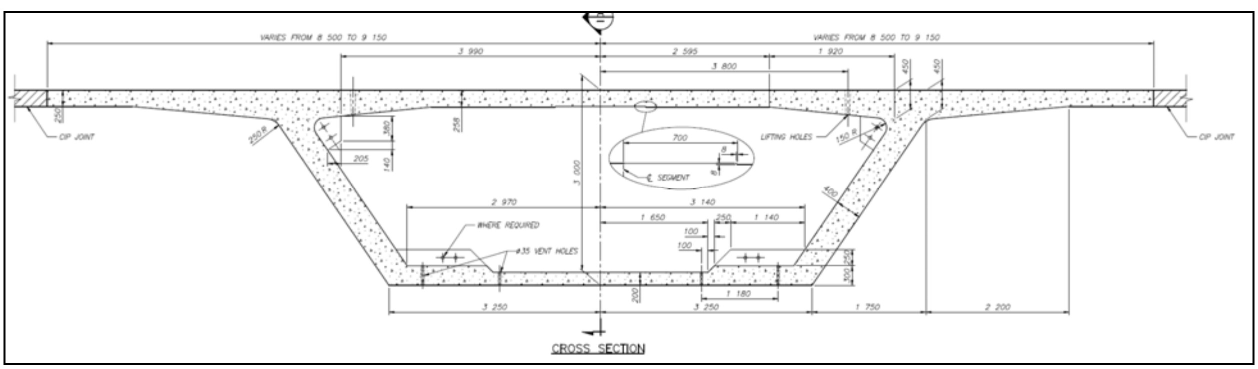

Fig. 8 Pier Segment

Fig. 9 Casting Yard, Typical Segment

Fig. 10 Casting Yard, Typical Segment Storage

The longer spans were continuous and built with alternating segments about the pier to minimize temporary loads in the pier and foundation. These spans were typically 92.5m long, and included a variable depth structure with 5.0m deep at the pier and 3.0m deep at midspan.

SIMPLE SPAN INNOVATIONS

A couple innovations were adapted for the simple span structures. First, the segments supported over the pier are typically constructed with solid diaphragms except for an opening to allow passage and reduce weight, however in this case the precast segments were on the upper bound of size for a single box-girder segment. Also, the seismic forces generated very large overturning forces to transmit loads between superstructure and pier. To solve these multiple issues a delta frame was developed. This greatly reduced the weight and allowed for an efficient use of material. To add to the efficiency, the contractor pre-casted the struts in advance, which simplified the forming of the segment. A photo of the pier segment is shown in Figure 11.

Fig. 11 Pier Segment

Another innovation for the PSC design, at least not typically used in North American segmental projects, was the implementation of a link slab. These were used at many locations between simple-span joints in place of movement joints which are more expensive and require higher maintenance. Of the 16 simple-span joints, 10 implemented the link slab component. The slab is detailed to act as a hinge, and therefore a tight spacing of reinforcement is provided. Across the control joint epoxied bars are used, as shown in Figure 12 below.

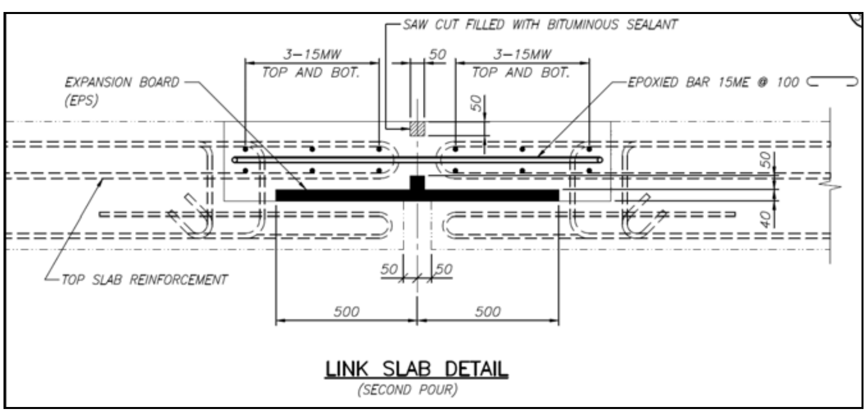

Fig. 12 Link Slab

As mentioned earlier, the seismic loads were very large for this project, and a robust resistance system was required. This was achieved by using a combination of seismic buffers and stiff dampers. As seen above in Figure 8, two large blocks are included at the base of the pier segment. A concrete buffer is cast between the blocks at the top of the pier. The buffer extends between the two pier segments that sit on a single pier. A detail is shown below in Figure 13.

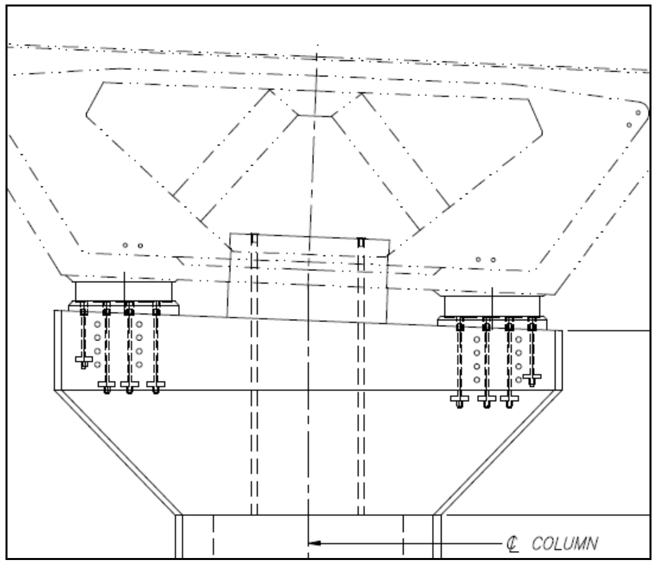

Fig. 13 Seismic Buffer Detail

The buffer is cast once the segments are placed to form a customized fit. The buffer reinforcement uses unstressed PT bar for load capacity. The vertical sleeves shown above are used to provide support cable access for maintenance inside the hollow pier.

The seismic buffers provide resistance for transverse loading to the superstructure, however for temperature and long term span movements the span is disengaged from the buffer. Therefore longitudinal seismic loads are resisted by stiff dampers. A sketch of the layout is shown below in Figure 14.

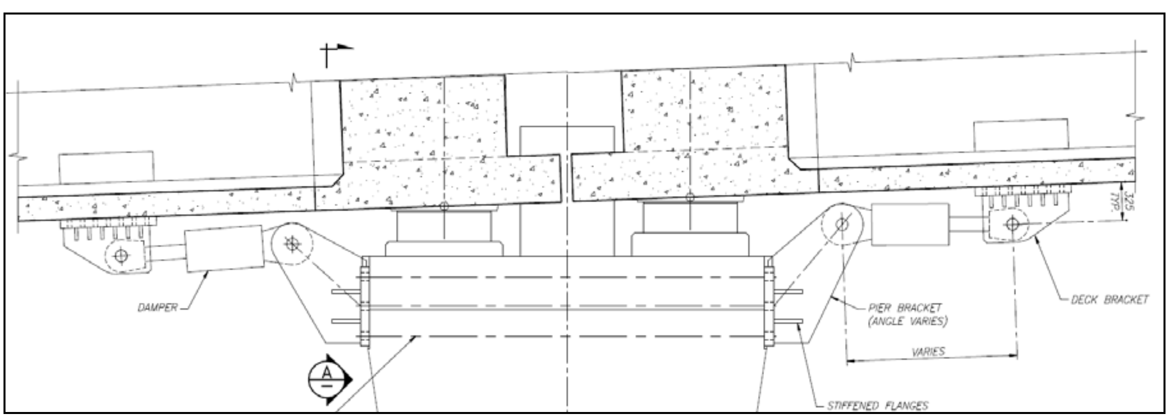

Fig. 14 Damper Layout

Initially the dampers were design as shock transmission units (STU's) that would allow movement but seize upon the onset of longitudinal load. However it was found during detailed time-history studies that the STU's were a stiff point that carried very large loads. Then working with the supplier Taylor Devices, it was found that the STU and damper units were effectively the same, only with modification to the manifold to control fluid flow. Once the structure was analyzed with the dampers, using a stiff design that limited stroke, the design forces came down significantly to a range of 1.7MN to 2.7MN per unit. Two units were used per box-girder and per side of the pier. At a given bent line 12 units were used in general. A photo of installed dampers is shown below in Figure 15.

Fig. 15 Start of Cantilever Construction

LONG SPAN INNOVATIONS

The long span structures are fairly standard by PSC standards, however given the overall length (580m) an expansion joint was needed. This is done often with a pier and a standard expansion joint, however for the Port Mann Bridge a midspan hinge beam was used. This is shown below in Figure 16 between piers N5 and N6.

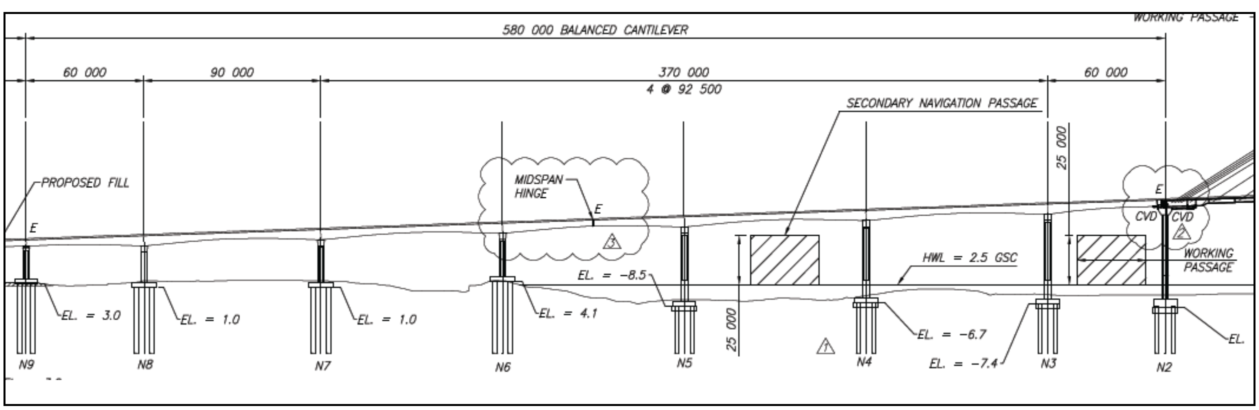

Fig. 16 Additional Balanced Cantilever Segments awaiting Placement

The midspan hinge is not a totally new innovation. The design consultant IBT and their staff have been involved in projects using the midspan hinge dating back 15 years to the Confederation Bridge at Prince Edward Island, Canada, and has been included in multiple projects since. Design partner TY Lin has also used them for the East Bay Bridge replacement project near San Francisco.

The original concept was developed and patented by renowned bridge engineer Jean Muller, and it serves as a functional tool for this type of structure. It allows the inclusion of an expansion joint within a long stretch of structure without the use of a pier, and is integrated within the balanced cantilever process. A steel beam is inserted to carry moments across the joint and limit long term deflections. Other alternates, such as a quarter point hinge would require blocking during construction and the inclusion of an atypical segment type. The midspan hinge is adopted within the standard segment envelope, with internal diaphragms to carry the transfer of load. Figures 17 and 18 below show the general layout.

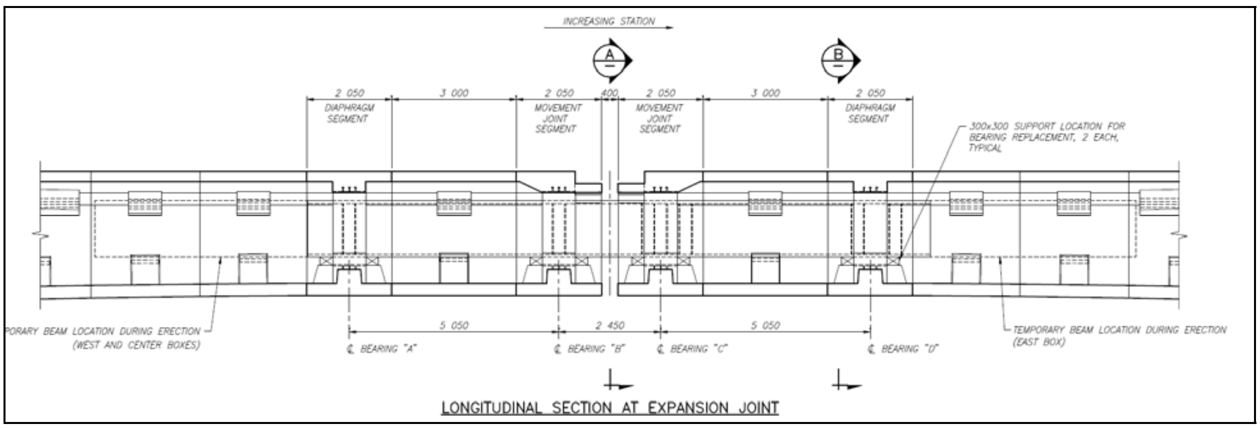

Fig. 17 Elevation View of Midspan Hinge Beam

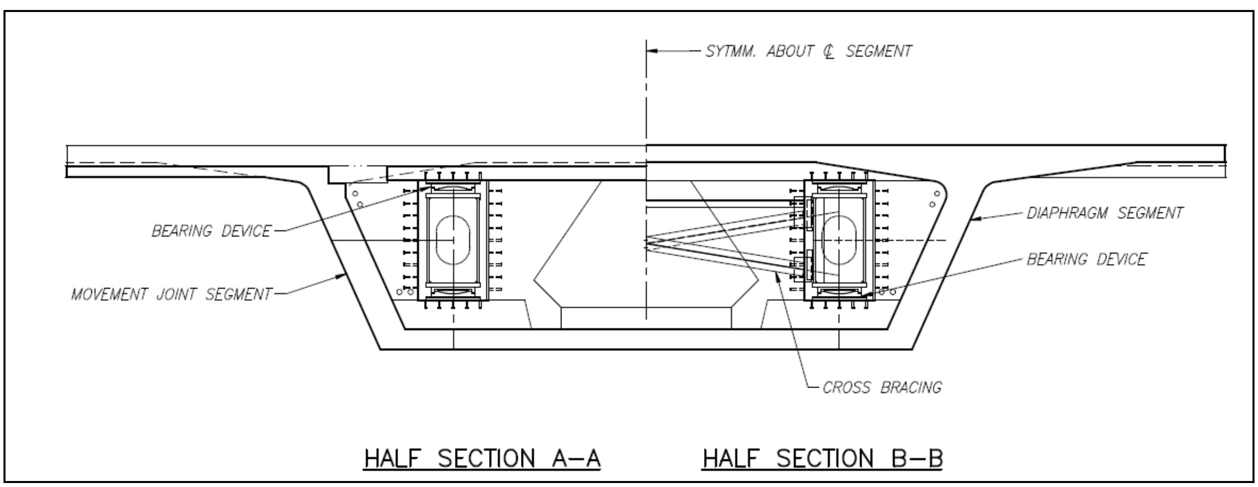

Fig. 18 Cross-Section View of Midspan Hinge Beam

By providing two points of support on the steel beam within the end of the cantilever, it provides the capability to carry moments across the joint. Otherwise the cantilever would be too flexible for normal service operation. The beam is fixed on one side of the cantilever and free on the other to allow sliding and an axial release between cantilever tips.

In a competitive bid, the midspan hinge was a helpful component to maximize the efficiency and cost of the long span superstructure construction.

SUBSTRUCTURE DESIGN

The substructure design for the approach structures was fairly conventional for most components. The foundations included either 1.83m diameter driven piles with a partial height reinforced concrete core, 1.83m drilled shafts, or 2.5m drilled shafts.

The piers for the span-by-span structures have 3 standard shapes and the long spans have a single shape. Within the river the bottom portion of the hollow piers are filled with concrete for vessel impact. A typical elevation is shown below of the piers in Figure 19.

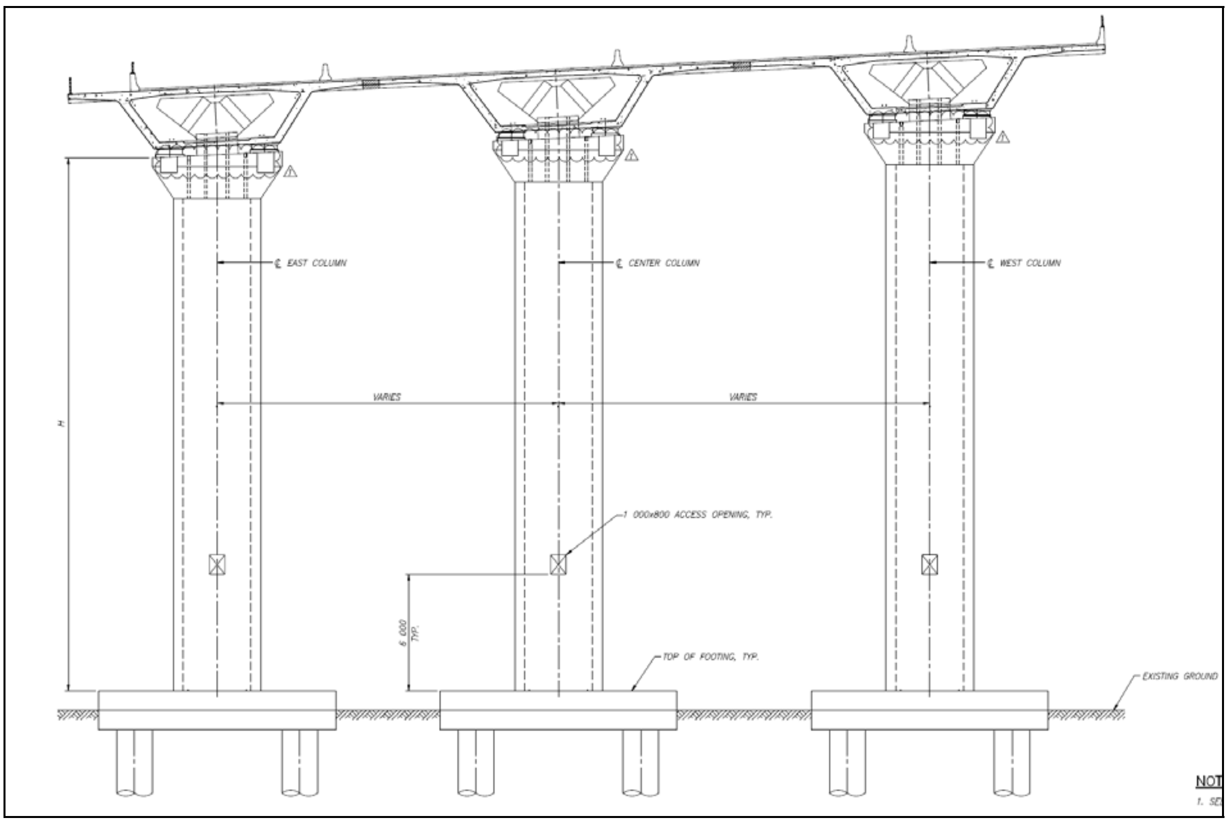

Fig. 19 Pier Elevation

To reduce weight the piers are hollow, with an outside dimension that ranges from 2.5m x 3.5m for the shorter piers to 3.0m x 4.5m for the taller piers. The walls are 0.5m thick for the smaller dimension and 0.6m thick for the larger dimension. A sample cross-section is shown below in Figure 20 and a site photo of a completed column is shown in Figure 21.

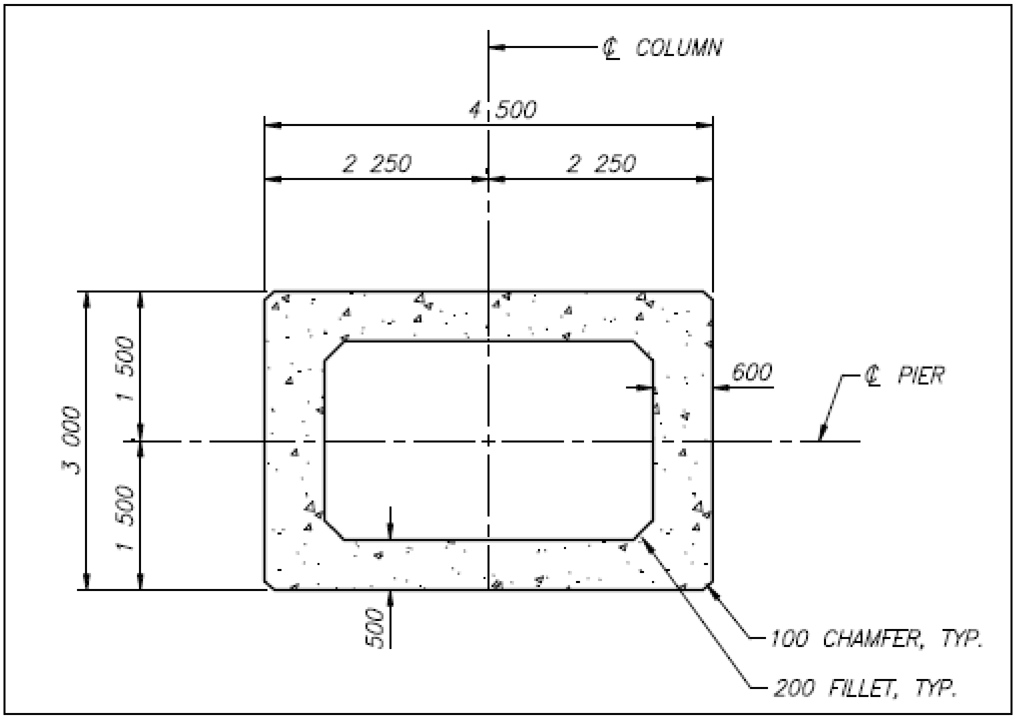

Fig. 20 Column Cross Section – Tall Pier

Fig. 21 Site Photo of Column Construction

Due to the high seismic loads, conventional confinement reinforcement was provided. For the simple span structures, the plastic hinging was limited to the base of the pier for the confinement reinforcement. A photo is shown below in Figure 22 as a typical example. Tie set spacing ranged from 100mm to 125mm in the hinge zone. Even outside the hinge zone, tie bar was provided across the pier walls.

Fig. 22 Pier Reinforcement

One innovation for the substructure was the elimination of a cross-beam at deck level for the simple span structures. The nature of the column is act as a flag-pole under lateral loads. By including a cross-beam, a stiff element is added that attracts large loads. However with the 3-box-girder wide superstructure, the coupling between spans was utilized. The local torsion in the box-girder is resisted by the bearing pair, while the global transverse loading is resisted by the top slab linking the boxes. Because it is continuous, the loads are distributed over a longer length, and due to the thinness of the slab, the compatibility type forces are reduced to a level that the slab can resist, resulting in a clean, inexpensive solution to resist the loads. Figure 23 below highlights this detail.

Fig. 23 Typical Pier Segment being transported

SUMMARY AND CONCLUSIONS

The Port Mann Bridge project approach structures highlight the effectiveness of precast concrete and the economies that can be achieved with precast segmental concrete construction. Due to the scale of the project and the need to start toll revenue as early as possible, savings in schedule was a premium.

In addition, the design-build or PPP process allows for collaboration with the contractor to implement cost-savings features that are directly correlated with their planned means of construction. The use of precast segmental, link slabs, hinge beams, cross-beam elimination and span staging all led to significant cost savings that were pass on to the owner. Such a level of prescribed design features would be more difficult to implement within a traditional design-bid-build process.

Substructure construction began in September of 2009 and is due for completion in August of 2011. Stage 1 segment erection began in June of 2010 and is scheduled to be complete near the end of 2011. Once the main cable-span is complete, it is anticipated that traffic will begin at the end of 2012, and impressive feat for such a large and complex project.

REFERENCES

N/A