Design of the Canada Line Extradosed Bridge

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Summary

In 2005, TransLink procured the new Canada Line rapid transit system that will connect Richmond, the Vancouver International Airport and downtown Vancouver. The Line is scheduled for completion in 2009. An extradosed precast segmental box girder bridge was designed for the longest span on the Line, which crosses the Fraser River North Arm. The North Arm Bridge which carries two rail tracks and a suspended walkway/bikeway, is 562 m long with extradosed 180 m main span and 139 m side spans and 52 m transition spans.

Keywords: Extradosed, precast segmental bridge, stay cables, composite pylon, train dynamics.

1. Introduction

In 2005, TransLink initiated a process to finance, design, build, operate and maintain the Canada Line, a new 19 km long rapid transit line. Scheduled for completion in 2009, it is being designed and constructed by a joint venture (RSL) of Rizzani de Eccher SpA, of Italy, and SNC-Lavalin, of Montreal, Canada. Buckland & Taylor Ltd., as consultants to the joint venture, designed an extradosed precast concrete segmental box girder bridge for the longest span on the Line, which crosses the North Arm of the Fraser River, as shown in Figure 1.

Figure 1: View of Completed North Arm Bridge

2. Extradosed bridges

Extradosed bridges are a hybrid of traditional cable-stayed and box girder bridges. They have been designed for medium spans of 150 m to 270 m, typically using concrete box girders. Extradosed bridges offer advantages over concrete box girders designed for the same span because the optimum tendon profile required to resist the bending demands at interior supports can be provided without increasing the girder depth and weight. For the North Arm Bridge, the French SETRA standard was used to compute the stress limit to apply to the stays. For the live load cable stress range on the North Arm Bridge SETRA specifies a limiting cable stress of 0.55 F_{GUTS}. This is 22% higher than the 0.45 F_{GUTS} that would have been permitted had North American code provisions for conventional stay cables been applied.

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3. Design constraints

The structural form of the North Arm Bridge was selected to fit within upper aviation and lower marine navigational clearance envelopes, to satisfy rail profile requirements and to minimize the number of deep marine foundations. Although the poor Fraser River delta deposits would suggest a lightweight steel or composite superstructure to minimize foundation costs, uncertainty in steel supply and price, and economies resulting from compatibility of materials and construction methods with the remainder of the Line, led to the choice of a concrete superstructure and pylons.

4. Design Elements

4.1 Cables

In the main and side spans, the girder is supported by 24 extradosed cables. Each cable comprises 58-15.7 mm individually sheathed, galvanized and waxed 7-wire strands. The cables were installed strand by strand with light monostrand jacking equipment and are replaceable. A conventional anchorage system that anchors each stay in the pylons and a cable saddle system which allows the cables to pass continuously through the pylon and only be anchored at deck level were considered. The conventional anchorages were found to be more cost-effective, and were therefore used.

4.2 Extradosed cable anchorage at deck level

A single plane of cables is provided to support the box girder, therefore the cable intersects the girder along its centreline and the vertical cable force must be transferred to the webs. This force transfer is generally accomplished using large concrete diaphragms or precast, post-tensioned concrete struts inside the box girder. As an alternative to concrete struts, a simple detail was developed to provide this load transfer using steel struts anchored into the concrete. The steel struts minimize the cable anchor segment weight.

4.3 Pylon

Structural steel, precast concrete, and precast concrete/steel composite pylon options were considered. Cast-in-place concrete pylons were dismissed as an alternative because they provided a significant schedule disadvantage over prefabricated solutions. The composite pylon option was found to be the most effective solution because it incorporated the advantages of precast segmental construction, eliminated the need for transverse post-tensioning in the cable anchor regions and allowed for the use of the more cost-effective conventional dead-end anchorages.

5. Dynamic train-structure interaction

In rail structures, discontinuities or "bumps" in the rail profile, or rapid structural displacements caused by the dynamic vehicle loading can excite the sprung and damped vehicle suspension system. This induces structural vibrations and demands which can exceed those caused by the statically applied vehicle weight. For the North Arm Bridge design, the effects of this dynamic train-structure interaction were considered at both ultimate and serviceability limit states.

The dynamic train-structure interaction was analyzed by running a dynamic train time history analysis. The train was stepped across the bridge at the 60 km/hr design velocity using a time step of 0.01 s. The vehicle suspension is excited by specifying the height of a "bump" at a particular point along the rail. The impact factor specified for design was verified and passenger compartment vibrations were found to be within the passenger comfort threshold.

6. Summary and conclusions

The North Arm Bridge is the first of its kind in North America. An extradosed bridge with its short pylons and shallow cables that minimize the depth of the superstructure was well suited to satisfy the clearance envelopes required for the airport glidepath above, the marine navigation channels below and the span requirements. Economies of scale, schedule, constructibility and construction costs were fundamental to the design of the girder, pylons and cables. The dynamic train-structure interaction analysis confirmed that the assumed impact factor was conservative and that the peak accelerations that will be experienced by the passengers are within the recognized comfort criteria.