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Modifications to Queensborough Bridge, New Westminster, BC

Abstract

Reconstruction of the Highway 91A corridor to improve traffic mobility involved safety upgrades on the Queensborough Bridge, reconfiguration of the existing north-end Queensborough interchange, and construction of a new south-end interchange at Howes Street. Numerous technical and logistical challenges were overcome to successfully deliver this complex, $65 million project. The main challenge was to reconstruct an existing interchange in a confined urban space, without inconveniencing the community or the 100,000 daily road users. The design team was tasked with improving safety and efficiency; satisfying the interests of a variety of stakeholders; and delivering the project on time and within budget. The implemented improvements have accessed previously unused traffic capacity on the bridge which now functions more effectively for all users.

Focused engineering design and innovative construction techniques resulted in an efficient traffic management strategy; uninterrupted transit service; improved sorting of local and regional traffic; creative structural solutions to overcome bridge limitations; and a facility that satisfies a diverse range of user requirements. Accommodation of cyclists, pedestrians and wheelchairs was a key component of the community consultation process, which resulted in fully separating active transportation modes from vehicular traffic. The economic, social and environmental benefits that derive from improved goods movement, reduced congestion, and support for active transportation modes, will benefit the regional economy for years to come.

The cornerstone of this project was to carry out major structural modifications under traffic to the 847 m long, 50-year old, Queensborough Bridge – a critical link in the regional highway network. With the bridge already at its load capacity, the vital safety improvements had to be incorporated without increasing gravity loads – achieved through a unique, ultra-light, concrete-surfaced steel sidewalk design. Other important bridge modifications needed were adding a lane to the north end of the bridge; removing two redundant spans; placing a traffic barrier between opposing traffic lanes; and installing new parapets at the roadway edges.

Background

Improvements to the Highway 91/91A corridor were a key component of the Border Infrastructure Program, a joint federal/provincial initiative which was launched in 2003. The principal program objective was to improve access to BC's border crossings and stimulate international trade. Highway 91A terminates at the Queensborough Interchange in New Westminster where the highway connects with the Marine Way/Stewardson corridor. Immediately south of the interchange is the Queensborough Bridge which carries the highway across the North Arm of the Fraser River.

The bridge's four-lane traffic capacity was restricted at the south end by a signalized intersection with Howes Street; and at the north end by poor ramp geometry and two signalized intersections for westbound Marine Way traffic. As construction of the Queensborough Bridge dated back to 1960, neither its load capacity nor its safety provisions met current standards. As a result, the Highway 91A corridor improvements focused on eliminating the signalized intersections, upgrading ramp geometry, and providing enhanced safety for bridge users.

The design team was led by Associated Urban Consultants acting on behalf of and working closely with the BC Ministry of Transportation and Infrastructure. The designers recognized that in recent years, development of the Queensborough community has resulted in a significant increase in the pedestrian and cycle traffic, with a large number of commuters using the Queensborough Bridge daily to access the

22nd Street Skytrain rapid-transit station at the bridge's north end. The existing single 1.5 m sidewalk was inadequate for the current volume of non-vehicular traffic, and its lack of separation from the roadway posed significant risks. This vulnerability was underscored by a serious accident involving a pedestrian early in the project. The design team was acutely aware that the most pressing community issue was the poor standard of the sidewalk facility, which clearly needed addressing to achieve a successful design.

Queensborough Bridge

Designed to prevailing standards in the 1950's, the Queensborough Bridge commenced service in 1960 as a tolled community facility connecting the Queensborough community on Lulu Island with the rest of New Westminster. Originally 920 m long, the bridge configuration consists of three continuous spans of 61, 91, and 61 m crossing the North Arm of the Fraser River along with north and south approach viaducts. The main bridge system is a pair of steel plate girders supporting transverse floor beams and a reinforced lightweight concrete deck. The south approach originally consisted of twenty seven spans of about 18 m, while the eleven north approach spans were either approximately 18 or 24 m long. All the approach spans consisted of normal weight cast-in-place reinforced concrete girders spaced at 3 m centres with parabolically-haunched profiles.

In the mid 1980s the bridge was acquired by the BC Ministry of Transportation and used to connect Highway 91A with Marine Drive. In adapting the bridge for its new purpose, the Ministry removed the two southernmost spans and replaced the next four with precast concrete girder spans on a new horizontally curved alignment. In the early 1990's the bridge underwent a seismic safety retrofit which addressed the seismically vulnerable substructure elements.

The Border Infrastructure Program required several significant modifications to address both the functional requirements of the new Queensborough Interchange, and the safety modifications required to meet the program objectives (Figures 1 and 2). The new interchange involved replacing the geometrically sub-standard loop on the east side of the bridge with a new loop on the opposite side. As a result the two northbound spans which curved to the east were no longer required, and were replaced with embankment fill. Also, the 20th Street and 6th Avenue exit for northbound traffic was relocated from the south side to the north side of Marine Way. To accommodate the change in traffic movements, a second northbound lane was added north of the four-span east exit ramp to Stewardson Way. As a result, there are now four traffic lanes across the full length of the main bridge.

Having four lanes throughout enhances traffic flow and is a distinct safety advantage as a concrete median barrier is now installed across the previously undivided bridge deck. New roadside traffic barriers with top-mounted bicycle railing to replace the original back-of-sidewalk parapet railing are a further safety improvement. As the traffic barriers were located on top of the former roadside curbs, the sidewalks were repositioned further to the outside to maintain operating width. The aging sidewalk deck panels were replaced with new lightweight decking and bicycle railings. Work under the program also included improved traffic signage, which required three new sign bridges to be mounted on the Queensborough Bridge. These significant structural modifications were all carried out while accommodating the existing bridge users with the minimum of inconvenience.

Parapets

The existing steel railings at the back of the sidewalks (Figure 3) were replaced with new PL-2 type roadside barriers mounted on top of the curbs (Figure 4). This important change separated the vehicular traffic from the sidewalk users and added significantly to the safety and reliability of the Queensborough Bridge. On the concrete approach spans, dowels were drilled through the curbs into the fascia girders to resist anchorage forces. As a result, the parapets became vertical extensions of the fascia girders. As the shorter spans were less weight sensitive, the parapets were formed from cast-in-place concrete. On the more weight-sensitive main steel spans, the upper portion of the parapets were lightweight steel fabrications. The steel sections were anchored by drilling through the existing lightweight-concrete curbs and installing anchor bolts, which reacted against washer plates on the underside of deck.

Steel bicycle fences were installed along the full length of parapets which were located between sidewalk and roadway (Figure 4); other parapets had the standard pedestrian handrail mounted on top. The approach span parapets were used as support structures for the three sign bridges and were locally widened to accommodate the sign-bridge anchorages. To minimize the effect of forces from the sign bridges applied to the fascia girders, custom-designed sign bridges supported by vertical trusses were used with the widened section of parapet acting as a distribution beam.

Sidewalk Replacement

The existing bridge sidewalks consisted of thin precast concrete panels, about 1.2 m wide, spanning 3 m between concrete beams cantilevering from the fascia girders. The panels were very lightweight with only a 38 mm thick deck spanning transversely between three stiffening ribs. Despite their ultra-light construction and low cover to the wire fabric reinforcement, the panels had survived nearly 50 years of exposure and several unintended vehicle loads. However, they were at the end of their serviceable lifespan. The supporting cantilever beams were about 380 mm square in section and had fared much better. Some had suffered accident damage but the beams were considered fit for continued service.

Given the lack of spare capacity to resist gravity loads and seismic forces in the existing structure, the adopted design philosophy was to maintain approximately the same applied dead load. A slight increase in sidewalk width to 1.6 m was made possible by using steel parapets over the main spans and by recognizing the stiffening effect of the parapets over the approach spans. The section of west sidewalk north of the exit ramp to Marine Way is expected to be more heavily used and is widened to 2 m. The additional loading is accommodated by fascia girder strengthening.

An extremely light sidewalk replacement design was needed. Steel gratings are not appropriate for this application, and with almost 1.5 km of replacement sidewalk required, steel plate decks were too expensive. To provide the desired concrete surface, a unique design was developed using steel metal decking with a minimum of 25 mm of concrete topping (Figure 4). The metal decking was supported from new galvanized steel framing; an angle bolted to the back of curb, and an HSS fascia beam supported by angles extending from the existing concrete cantilever brackets. Connector plates for the bicycle railing were welded to the HSS fascia beams. Given the minimal thickness of the concrete topping, all embedded reinforcement was hot-dip galvanized, and drain holes were detailed at the low end of troughs to address concerns about moisture entrapment at the interface at the concrete / metal deck interface.

The design team recognized that this special lightweight sidewalk design will not meet the S6-06 design code durability requirements. However, as the existing bridge is nearly 50 years old, a notional design life of 25 years was adopted for the sidewalk design. The design team expects that in a protected location and with only lightweight live loading, the replacement sidewalks will serve for the remainder of the bridge’s useful life, but if necessary, the components are replaceable.

The Queensborough Bridge was originally constructed with two sidewalks, but in adapting the bridge to accommodate Highway 91A, the Ministry abandoned the east walkway. Key to accommodating sidewalk traffic during replacement was to reactivate the east sidewalk. This was done by installing new elevated ramp connections to the south side of Marine Way, and building new on-grade ramp connections with Boyd Avenue at the south abutment to set up sidewalk diversions. The sidewalks were then closed alternately for reconstruction work. The new elevated ramp connections consist of a three-span 60 m long east ramp, and a four-span 80 m long west ramp (Figure 5), each 2 m wide and placed at 7% grade. The ramps consist of flanged precast box-girders with cast-in-place topping, supported by discrete concrete columns and pilecaps. The pilecaps are each supported by four micro-piles consisting of cased threadbars, drilled in to underlying dense till to provide sufficient bearing and uplift capacity.

To provide the necessary construction working space for sidewalk replacement, a precast concrete median barrier was positioned alongside one of the curbs, offset by 0.6 m, and the traffic lanes were narrowed to 3.3 m. In the radiused section near the east exit ramp, the barriers were secured to the deck to prevent displacement into the working space by road traffic.

North End Bridge Widening

Adding a second northbound lane to the original three-lane deck section was undertaken to relocate the exit point for traffic accessing 20th Street and 6th Avenue to the north side of Marine Way. This eliminated the two traffic signals that were backing up westbound Stewardson Way traffic. Now with four traffic lanes between the north and south abutments, the bridge cross section permitted the installation of a median barrier to guard against cross-over accidents, improve user safety, and enhance service reliability. The traffic pattern changes resulting from the deck widening and relocation of the 20th Street and 6th Avenue traffic exit, also permitted the existing east-side two-lane exit ramp to Stewardson Way to be limited to one traffic lane. This freed up deck space for an impact attenuator to guard the exit nose, thereby addressing an important safety issue.

The north end widening is a 6-span structure between the east ramp and the new north abutment. Spans are arranged to match the existing bent locations and are typically 18 m long, with one 24 m span over Marine Way (Figure 6). Near the north end, the deck flares in plan to accommodate the geometry of the new exit ramps. The deck widening is typically 5 m but flares to 8 m locally at the new abutment. The widening was sufficient to accommodate a two-lane detour during removal of the two north-end spans.

The new superstructure design does not replicate but complements the original construction. The additional northbound traffic lane is carried by a single line of precast box beams and cast-in-place concrete deck, supported by a row of discrete cast-in-place concrete columns. Foundations consist of pilecaps, supported by 12 micro-piles drilled in to underlying dense till; or on spread footings where the till was close to grade.

In order to closely replicate the existing girder profile, the precast box girders are parabolically haunched, with a depth of 1.4 m at the supports and 0.7 m near mid-span. The girders are erected as simple spans, but act compositely with a 250 mm thick deck slab to resist imposed loading as two three-span continuous units. The two three-span units are connected above a common pier by a link deck which was then extended across the deck of the original bridge, replacing an expansion joint. The inboard edge of the new deck slab was supported from the former fascia girder after the original cantilevered portion of deck had been removed. Supporting the widened deck slab placed additional loading on the former fascia girder which was strengthened accordingly.

The box girders for the superstructure widening were cast using 1.2 m wide BC-standard prestressed box-beam forms. Other than the section width, the box girders are far from standard, comprising innovative steel-concrete composite box-sections. The girders are specially cast with a curved soffit profile which required a special form inside the box section. The curved soffit form was sized for the shortest girder segment, and lengthened with additional sections of form at mid-span to accommodate length variations. As conventional prestressing was impractical given the curved bottom flange, the required tensile capacity was provided by embedded steel soffit plates. Up to 18 m in length, the plates are connected to the concrete box sections by rows of shear studs, and are metalized for corrosion protection. This novel form of construction is dictated by the fact that the box beam depth is at a minimum where the demands are highest. Continuity for imposed loads is achieved by overlapping projecting reinforcement in the cast-in-place end diaphragms above the intermediate support columns.

The new section of deck was cast to the required profile allowing for a 50 mm thick asphalt wearing surface similar to the existing bridge. However, considerable re-profiling of the asphalt on the existing deck was required near the east exit ramp to accommodate the new northbound lane; and at the new north abutment, where three traffic lanes now curve in a westerly direction instead of east. As the re-profiled asphalt thickness is up to 200 mm at the North Abutment, the original expansion joint was removed. The ballast-retaining wall at the new North Abutment spans between new pinned connections with the deck slab and abutment seat beam (Figure 7).

North End Span Removal

The two northerly spans followed the original alignment of the Queensborough interchange curving to the east, whereas the new interchange configuration has north-end ramps curving in the opposite direction. The plan adopted was replacement of the two redundant spans with approach fill. However, the spans were carrying traffic and supporting a duct-bank of electrical power cables throughout construction. The redundant spans were therefore buried in the approach fill and the duct bank was encased in concrete. To mitigate the formation of hard spots above the girder lines as the approach fill consolidates, the buried girders were disconnected from the substructure.

To avoid future maintenance issues, the bridge deck of the redundant spans was removed in stages. Two traffic lanes were detoured over the north end deck widening onto the east section of the new approach fill, while the remaining southbound lane continued in operation on the west side of the spans (Figure 8). The east half of the deck was then removed and the approach grade completed. Next, all three lanes were detoured to the east side and the remainder of the deck was demolished. The traffic staging was developed as an integral part of the design to ensure that traffic could be maintained throughout construction with the minimum of interruption to operations. Except on exit ramps, lane detours were designed to the posted construction zone speed of 50 km/h.

Fascia Girder Strengthening

The structural modifications at the north end resulted in additional forces being applied to the fascia girders. The original interior girder loads were only marginally affected in localized areas and were assessed as adequate. However, the fascia girders were more lightly reinforced and inadequate to meet the additional demands over six spans adjacent to the new North Abutment. As conventional structural strengthening was impractical, designs using advanced composite materials were prepared.

The fascia girders were assessed as being deficient in both shear and flexural capacity in the positive-moment zones. This deficiency was rectified by applying bonded advanced composite materials while the bridge continued in operation. The west fascia girder only experiences minor additional forces from the widened sidewalk, and so the strengthening design used bonded glass fibre external reinforcement. The east fascia girder, which receives additional live loading from the additional traffic laning at the north end of the bridge, required more significant strengthening. Accordingly, the strengthening design used much stronger carbon fibre external reinforcement (Figure 9).

The design philosophy was to provide shear strengthening to ensure a flexural failure mode. Flexural strengthening was carried out only in the positive-moment regions, which would force initial yielding to occur in the negative-moment regions where ductility is available. The original ductility in the positive moment regions is available for secondary yielding following rupture of the external reinforcement.

Application of the bonded advanced composite materials was carried out using a combination of suspended scaffolding and overhead lifting equipment, which ensured minimal interference with traffic operations beneath the bridge. The work took place in the spring and summer of 2005 which ensured that temperatures were well above the minimum for curing of the epoxy adhesive bonding layer.

Marine Way Flyover

To enable eastbound Marine Way traffic heading for southbound Highway 91A to access the north end of the Queensborough Bridge, a crossover with westbound Marine Way traffic was required near the west end of the new Queensborough Interchange. Constraints to both single-lane ramp alignments resulted in a severe skew to the crossover structure and only a shallow structural depth was available. A tunnel structure seemed suitable, but would have been visually confining for the eastbound-to-southbound traffic. The lengthy retaining walls required were not favoured by the design team and the overall aesthetics qualities were below the desired standard. Accordingly, a flyover structure was investigated.

Firm ground support for foundations was available, but the main challenges for a flyover were the extreme skew angle of the crossing, and the limited structure depth available. The eastbound ramp was climbing at maximum grade towards the north end of the Queensborough Bridge, while the westbound ramp was crossing beneath 230 kV overhead power lines with minimum clearance. Only 1200 mm of structure depth was available near the westbound ramp centerline and 800 mm on the north edge. By using an 80 m long three-span continuous structure with a main span of 32 m, single-column intermediate supports could be placed outside of the roadside barriers and the abutments could be placed normal to the control line. The solid cast-in-place reinforced concrete superstructure is 8 m wide and tapered from 800 mm deep on both edges to 1200 mm near the longitudinal centerline, utilizing all the depth available for the structure. The columns support the superstructure via fixed bearings, and torsional loads are resisted at the abutments by pairs of laminated elastomeric pads (Figure 10). The abutments are large gravel-filled concrete box structures which resist seismic forces. The superstructure is restrained by a link deck at the west abutment and a shear key at the east abutment where the expansion joint is located. The estimated cost for the flyover was similar to the tunnel solution, and was adopted because of its open appearance. Its excellent aesthetic qualities were enhanced by detailing vertically grooved finish to the external faces of the abutments and wingwalls.

Construction was in a green field location adjacent to Marine Way westbound traffic. To form the heavy superstructure after casting the substructure elements, the contractor used fill falsework. The fill was later excavated in controlled fashion from beneath the span.

22nd Street Pedestrian Overpass

The final structure required for the new Queensborough Interchange was a pedestrian overpass linking the bridge's west sidewalk with 22nd Street at 7th Avenue. The overpass crosses three ramp alignments curving to the west from the bridge's north end. The pedestrian trail is a popular commuter route as it ends near the 22nd Street Skytrain Station. As a new stand-alone facility accommodating pedestrians, cyclists, and wheelchairs, a deck width of 3 m was selected for the overpass.

A span of 32 m with headroom of 5.5 m was adopted (Figure 11). As the superstructure needed to be placed above an operating roadway, prefabrication was essential. A steel trapezoidal-box spine beam 1.1 m deep was used, with precast stay-in-place full-width deck panels, and a cast-in-place concrete overlay. Weathering steel is used for the girder and deck reinforcement is galvanized for durability. The girder was supported from hollow box-abutments and was cast in to the end diaphragms to eliminate bearings and expansion joints. Simply supported for dead loads, imposed loading is resisted by the composite girder acting as part of a portal frame structure.

Aesthetic qualities are emphasized by the simple, elegant form of the overpass. The exposed concrete areas of the abutments and wingwalls are provided with a vertically grooved finish.

Howes Underpass

By removing a signalized intersection, the new interchange at Howes Street facilitates uninterrupted traffic flow at the south end of the Queensborough Bridge. The depressed-diamond interchange was constructed using the on-grade ramps for the traffic detour while the highway embankment was built in between. The major challenge was the highly compressible subsoil which included several metres of peat and extensive soft silts and clays. A sand layer was available for piled foundations from about 20 to 30 m depth below grade. Lengthy pre-loading of the approach fills and the use of lightweight fill material was necessary.

The optimum solution was obtained by using the thinnest possible superstructure depth for the underpass which minimized the thickness, width and length of expensive expanded polystyrene fill required for the approach embankments. In addition, retaining walls are difficult and expensive to construct on very soft ground and were avoided. Accordingly, the selected overpass configuration was a 22 m wide, 76 m long, four-span structure; all supports being multi-column bents (Figure 12). The configuration accommodated four lanes on Howes Street and turning lanes in the centre two spans, while the end spans accommodated sidewalks and the embankment end slopes. The 1100 mm diameter columns in the support bents were above-grade extension of the 1200 mm diameter steel pipe piles, which were driven closed-ended into the sand layer. Pile capacity was verified using a 5.2 MN test load. The use of "extended pile" bents avoided the need for pile caps and the resulting ground "hang up" associated with subgrade settlement. To minimize "down drag" the piles were sleeved through the denser surficial deposits. Seismic forces on the support bents were high as a result of the heavy superstructure, soft subsoils, and lack of abutments or approach fills to "anchor" the superstructure. The box girders were dowelled to each pier cap using 50 mm diameter high-strength steel bars.

The four 19 m long spans consisted of multiple box beams of BC-standard 1200 mm width. A special ultra-thin design, using 550 mm deep single-cell boxes which act compositely with a 200 mm thick deck slab, was used for the spans. The deck provided the necessary shear connection between boxes which avoided the requirement for shear keys, and also provided a robust diaphragm to resist seismic loading. To maintain diaphragm continuity over the piers and eliminate maintenance-prone expansion joints, link decks were provided above intermediate supports. The lack of shear keys allowed variations in the box girder spacing which accommodated the plan curvature of the highway. The fascia girders were carefully placed to minimize the variation in width of the short deck-edge cantilevers.

At $3.5 million the overpass was both economical and constructible, and has simple elegant lines. The elimination of expansion joints will minimize maintenance requirements and the careful detailing will ensure that the settlements that are inevitable in the soft subgrade will not affect the structure of the overpass.

Summary

The complex modifications to the Queensborough Bridge were carried out while the bridge continued in operation with only minor inconvenience to users. By improving access to and egress from the bridge, the modifications enable spare capacity in the bridge to be utilized. At the same time, significant improvements were implemented which improve safety and reliability for all bridge users.

The modifications were aimed to address functionality, but involved the replacement of components which would have required significant future maintenance. As a result, the historic Queensborough Bridge has been given a new lease on life.

Figures

Figure 1 Previous Queensborough Interchange

Figure 2 New Queensborough Interchange

Figure 3   Previous Queensborough Bridge North End and Sidewalk Details

Figure 4   New Queensborough Bridge Sidewalk Details

Figure 5 New Queensborough Bridge West Pedestrian Ramp

Figure 6 Queensborough Bridge North End Widening

Figure 7 Queensborough Bridge's New North Abutment

Figure 8 Queensborough Bridge - Traffic Detour for North End Span Removal

Figure 9 Queensborough Bridge - Fascia Girder Strengthening

Figure 10 Completed Marine Way Flyover

Figure 11   22nd Street Pedestrian Overpass

Figure 12   Completed Howes Overpass