Unique New Bridge Designs for Four Highway Interchanges in BC

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Abstract

Four highway interchanges were recently constructed under the Federal Economic Stimulus Initiative. The projects were built to provide much needed traffic capacity, enhanced safety, and economic sustainability. The projects are:

- McTavish Interchange, Highway 17, Saanich, BC
- McCallum Interchange, Highway 1, Abbotsford, BC
- Clearbrook Interchange, Highway 1, Abbotsford, BC
- Nelson Interchange, Highway 99, Richmond, BC

Each interchange was built around an operating highway and had individual circumstances that influenced the design of the new interchange bridge. As a result, custom designs were created with unique features which stretched the boundaries of the conventional approach to bridge design. In all cases the projects were challenged by a fixed project completion date of March 31, 2011, which allowed only very short time for project delivery and which was particularly inconvenient for bridge construction and finishing work. In consequence, a non-traditional approach was taken to achieve accelerated delivery using a modified design-bid-build approach which included pre-procurement of long lead-time components and advanced works for site start-up using day labour.

The paper describes the particular and unusual factors that drove the design process for each project and the interesting bridge designs that resulted. The paper also discusses how significant savings in project schedule were achieved by overlapping design with construction; how the risks inherent with this process were controlled; how highway and bridge designs were optimized holistically; and how significant economic advantages were achieved by the novel project delivery method that was used.

1. Background

The recent Federal Economic Stimulus Initiative provided the opportunity for the replacement of two existing interchanges and the construction of two new interchanges in British Columbia to take place. The interchanges were needed to better accommodate traffic demands and improve safety.

The McCallum and Clearbrook interchanges with Highway 1 in Abbotsford, BC, were constructed in the 1960s. In the meantime Abbotsford has experienced significant growth and the interchanges had become an impediment. As part of planned improvements to McCallum Road and Clearbrook Road, the City partnered with the federal and provincial governments to replace the aging interchanges.

The BC Ministry of Transportation and Infrastructure is undertaking a program of grade separating the intersections along Highway 17 on Vancouver Island between Victoria and the ferry terminal at Swartz Bay. Previously the signalized intersection at McTavish Road provided access to the Victoria Airport and was located on a horizontal curve in the Highway. The conflict between turning traffic and high volumes of ferry traffic was causing significant delays and presented safety concerns. The federal funding contribution enabled the Ministry to bring forward construction of the new interchange.

In recent years there has been a considerable expansion in the Port of Vancouver facilities at the south end of Nelson Road in Richmond, BC. Port traffic is currently forced to use Westminster Highway to access Highway 91. While improvements have been made in the road connection to the east, access to Highway 91 west is via a narrow two-lane roadway which services local businesses and farms. The solution is a new directional interchange with Highway 91 to the west, which was supported by all project stakeholders including the City of Richmond, the Port of Vancouver, the Ministry of Transportation and Infrastructure, and the local community. The interchange design was required to minimize the additional land needed; any additional land had to be transferred from the Agricultural Land Reserve. The federal funding contribution enabled the project to be delivered by the Ministry on behalf of the funding partners.

2. McTavish Interchange

There were numerous constraints on the design of the new interchange including:

- Maintaining traffic flow on Highway 17
- Maintaining intersection movements at McTavish Road
- Provision of a new multi-user trail across the highway
- Compressible silty subsoil beneath the project site
- Major utility relocations
- Multiple construction phases
- A tight timeframe for project delivery.

At El. 10.0 m, the highway elevation is lower that the surrounding terrain, and to eliminate highway detouring, an elevated interchange on McTavish Road was selected. A diamond configuration with two roundabouts on McTavish Road will provide adequate future traffic capacity. The bridge cross-section consists of two westbound lanes, one eastbound lane, with a raised median and sidewalk. The two westbound lanes are needed to accommodate the high-volume traffic between Victoria and the airport. To avoid at-grade crossings of the interchange ramps, the multi-use pathway is routed across an elevated pedestrian bridge to the south of the interchange. The pathway connects Lochside Drive with a new transit interchange on the west side of the highway.

The soft clay subsoil at the site required different solutions for each structure foundation. The lightweight pedestrian bridge is supported by large spread footings with low bearing pressure to limit anticipated settlements. To accommodate differential settlements, the three bridge spans of 14.5 m, 27.8 m, and 23.4 m, are simply supported; however, the deck slab is continuous over all three spans. The use of a continuous deck diaphragm is highly beneficial for resisting seismic loads; and improves safety by enhancing resistance to collision forces applied to the superstructure or piers.

At each end the bridge is flanked by staircases and curvilinear approach ramps with 7% grades. In view of the proximity to the new transit interchange and the potential for use by wheelchairs, landings were included in the ramp profiles. To limit settlements, the approach ramps consist of 70 m long lightweight hollow boxes on raft foundations, with adjacent retained earthfill ramps up to 3 m in height.

The foundation for the much heavier interchange bridge was complicated by the presence of a large storm sewer at a high elevation close to the west side of the highway. With the roadway flares for the adjacent roundabouts located close to end of the tangent main span, abutment structures were needed. With the narrow cross-section highway on a super-elevated horizontal curve, a median pier was precluded by sightline and constructability considerations. As a result, a 34 m long clear-span bridge, on tangent, at a skew of 25^o was the selected bridge configuration.

To control settlement of the highway approaches, expanded polystyrene (EPS) embankments were used. The solution chosen for the abutments was to support each end of the bridge on a single row of piles with an elevated pier cap supporting the bridge bearings. As the piles provide 100% of the seismic load resistance, six 762 mm diameter concrete-filled steel pipe piles were required at each end of the 17.3 m wide bridge deck. The piles were driven through the clay subsoil into underlying bedrock. Vertical concrete facing walls were placed in front of the EPS approach fill. Experiencing only limited backfill pressures, the lightweight facing walls consist of precast vertically-ribbed panels embedded in cast-in-place concrete footings, which are wrapped around the piles. The west side footing is placed immediately alongside the 1.2 m diameter storm sewer.

The most cost-effective superstructure design would have been to use precast concrete I-girders; however, by using low-profile steel box beams acting compositely with the concrete deck slab, the roadway profile was lowered by approximately 600 mm. A superstructure consisting of three 1200 mm deep trapezoidal steel box girders at 6 m on centre was selected. The selected design resulted in a saving of approximately $400,000 in EPS fill and retaining wall costs; this saving was approximately double the estimated cost increase of the superstructure using steel box beams, and confirmed the steel box beam design as the optimal solution. The box beams are 2.9 m wide out-to-out of top flanges, and are provided with bolted field splices at mid-span to simplify transportation. Access for future inspections and removal of formwork is via hatches near each end of the bottom flanges.

To simplify deck construction above the operational highway, precast concrete stay-in place deck panels 130 mm deep were used. The reinforced concrete panels were detailed across almost the full deck width including cantilevers, and act compositely with 140 mm of cast-in-place reinforced concrete topping. A narrow cast-in-place concrete strip is provided along the deck edges. For enhanced durability, stainless steel reinforcing is used in the cast-in-place deck concrete, and the deck surface is covered by a waterproof membrane and 100 mm of asphalt. The precast panels are divided into three segments across the deck width, with the centre segment placed between the centre box beam flanges. The 2.7 m long panels are connected by 350 mm wide concrete field splices. The field splices were cast along with the deck concrete supported by formwork hung from the panels. There are blockouts in the panels above the outer box beam flanges to accommodate the groups of shear connector studs which are welded to the girder top flanges.

The bridge superstructure is semi-integral; the concrete end -diaphragms enclose the steel girder ends, and support one end of the approach slabs. Movement joints are located between the elevated pier caps and the end diaphragms. Each box beam is supported by a laminated elastomeric bearing at each end. Generally these unusual deck design details worked well in construction; however, because of capacity limitations in the precast deck panels to resist heavy concentrated loads, the contractor placed the deck finishing machine support rails directly above the outer girder fascias. As a result, the cast-in-place topping for the deck edge cantilevers was cast subsequently.

The pedestrian bridge superstructure reflects the appearance of the interchange bridge. The 3.4 m wide superstructure is supported by a single 890 mm deep trapezoidal steel box beam, 1.75 m wide out-to-out of flanges. The box beams are supported by elastomeric bearing pads on top of the hollow-box approach ramps and the 1050 mm square intermediate support columns. The 150 mm thick composite cast-in-place concrete deck has a precast stay-in-place deck form between the girder flanges. To enhance resistance to seismic and impact forces, the deck slab is structurally continuous between the abutments via link deck connections above the intermediate supports. The slender superstructure was chosen in order to provide visual conformity between adjacent bridges, and to limit the length and cost of the pedestrian bridge approach ramps.

The project was delivery by the Ministry of Transportation and Infrastructure under a very tight time frame imposed by the federal funding restrictions; there was approximately one year available for the main construction contract, and completion was scheduled for March 2011. To avoid problem with installing the waterproof membrane during the winter, there was a need to construct the bridge decks before the fall of 2010. Accordingly, the bridge superstructure designs were completed as a priority and the supply of structural steelwork and bearings was tendered under an advance contract. This saved the general contractor nearly three months of supply lead time for these critical path components. While the Ministry is contractually responsible for delivery of the pre-procured materials, the risk can be controlled by careful coordination of interface issues between the two sets of contract documents. In the event, the pre-procured materials were available to the contractor prior to the specified date.

Following the relaxation in the timing of work qualifying for federal infrastructure funding, completion of the main construction has been extended to July 2011. The contract extension will enable finishing work to be conducted during better weather conditions of spring and summer. The total tender prices for the two bridges were $1.88M for the interchange bridge; and $1.76M for the pedestrian bridge including stairs. Net deck areas are 614 and 884 m^2 respectively, which results in unit costs of approximately 3000 and 2000 $\$/m^2$.

3. McCallum Interchange

The new McCallum interchange was delivered by the City of Abbotsford on behalf of the funding partners – the BC Ministry of Transportation and Infrastructure, the Federal Economic Stimulus Initiative, and the City. Designed in the 1960s, the original McCallum interchange with Highway 1 was proving inadequate for current traffic levels. Over the past half-century, traffic on the Trans-Canada Highway has grown significantly and the City of Abbotsford has experienced a massive population growth over this time frame. As a result, the City's infrastructure growth was noticeably constrained by the existing municipal road connections with Highway 1.

With federal and provincial funding in hand, the City of Abbotsford needed a more modern interchange to provide adequate capacity for future traffic needs. The engineering team retained by the City to upgrade the McCallum interchange recommended a new two-roundabout elevated-diamond interchange design as providing the best level of service within available funding.

A replacement for the aging McCallum Underpass was needed as part of the new interchange. The new alignment for McCallum Road allowed the planned four-lane replacement to be constructed alongside the original two-lane bridge. Once traffic had been detoured through the new interchange, the original bridge structure was demolished. Design of the new structure was relatively straightforward. Ground conditions are favourable and construction access is readily available; however, roadway geometrics are a significant constraint. As a result of the roadway flares associated with roundabouts, the use of side spans is undesirable and abutment structures were preferred. Highway 1 through Abbotsford has a median width of over 30 m. Accordingly, separate bridges were used over the eastbound and westbound highway lanes, with median fill placed between the spans. The bridge spans were sized to permit Highway 1 to be widened to six lanes. The chosen bridging scheme reduced the bridge deck area considerably and resulted in significant savings to the project budget.

The design selected for the two identical bridges consisted of 14 precast box girders 1600 mm wide by 900 mm deep spanning 22 m between spread footings perched on Mechanically Stabilized Earth (MSE) abutments. The box girders act compositely with a 200 mm thick cast-in-place concrete deck which is provided with a waterproof membrane and 100 mm thick asphalt wearing surface. The deck thickness is increased to 300 mm for the concrete-surfaced 2.5 m wide sidewalks. To maximize durability, silica fume concrete with stainless steel reinforcement is used for the cast-in-place superstructure. There is a raised median between the tangent northbound and southbound traffic lanes, resulting in an overall deck width of 25.2 m which is skewed at 9^o to the highway alignment. There are generally 35 mm nominal gaps between adjacent box girders. However, a 900 mm gap beneath the median is provided as space for future utilities. Along each edge, the deck cantilevers 700 mm beyond the girder fascias.

The bridge design was chosen for its shallow construction depth, construction simplicity and overall economy. However, interchange construction was complex, requiring multiple construction phases and traffic stages. Construction complexity was exacerbated by the March 2011 completion date originally imposed by the federal funding restrictions, which resulted in a very tight schedule for the main construction contract. The completion date created the further challenge of completing weather-sensitive operations during winter months. Accordingly, an early decision was made to pre-procure the long lead-time bridge components, which were the precast concrete girders and proprietary MSE abutment materials. Advance procurement shaved over three months from the project schedule and approximately $500,000 from the estimated project cost.

The City was acutely aware of its contractually responsible for the pre-procured materials. The designers minimized the City's risk by ensuring that the materials were supplied in good time for the main contractor to install. As a result the new bridge was completed and opened to traffic in the fall of 2010, which avoided the very real threat of completing weather-sensitive bridge work over the winter. The main contract completion date was later extended to enable paving and finishing work to be completed in the spring of 2011. The total tender price for the two bridges was approximately $2.54M. The total deck area is around 1200 m^2 which results in a unit cost of approximately 2100 $\$/m^2$.

4. Clearbrook Interchange

In common with the adjacent McCallum interchange, the new Clearbrook interchange was delivered by the City of Abbotsford on behalf of its funding partners; the BC Ministry of Transportation and Infrastructure, and the Federal Economic Stimulus Initiative. Similarly, the 1960s-era Clearbrook / Highway 1 interchange was inadequate to cater for current traffic levels and was impacting the City's infrastructure growth. A particularly troublesome feature of the original Clearbrook interchange was the use of very tight (30 km/h) radii for the highway exit ramps which were causing an unsafe operating condition for users. The challenge for the City was constructing a more modern interchange to improve safety and traffic capacity within the $25M of funding available.

As a result of the funding limit and property restrictions, the engineering team quickly realized that an interchange meeting current standards was not feasible. Accordingly, the design team recommended an interim solution which retained the current interchange configuration with improved exit ramp geometry; enhanced operational safety; and upgraded intersections between the interchange ramps and Clearbrook Road. To do this the designers took advantage of the generous (30 m wide) median and the six-span bridge carrying Clearbrook Road across the highway. The westbound highway lanes were realigned through the median which freed up space for the increased radius (50 km/h) westbound exit ramp.

The original two-lane Clearbrook Underpass was also used to accommodate traffic while the six-lane replacement structure was built alongside. However, with the westbound lanes detoured, the new bridge design could be much shorter and less costly. As a result, the median was reduced to the minimum width which accommodated future six-laning of the highway. The highway detour therefore became the first project construction stage, which when opened to traffic, would facilitate construction of the new bridge.

Ground conditions are favourable for the new bridge, and construction access is readily available. Conceptually the new Clearbrook Underpass and the McCallum Underpass are similar; however there are several important differences which include the following:

- Clearbrook Underpass required support from a pier within the future narrow median.
- Exit ramps for the Clearbrook interchange pass beneath the bridge spans.
- An earlier completion date was required for the Clearbrook Underpass.
- The constrained schedule required significant advanced works for the Clearbrook interchange.

Both underpasses required a shallow construction depth to lower the height of the roadway profile. The slim-line superstructure reduced earthfill quantities and minimized approach grades to the north and south ramp intersections on Clearbrook Road. Accordingly, the two clear spans of nearly 30 m were bridged using precast box girders 1600 mm wide by 1100 mm deep. The 29 m wide roadway cross section required 14 precast box girders across the width, acting compositely with a 200 mm thick cast-in-place concrete deck slab, which is increased to 300 mm for the concrete-surfaced 2.4 m wide east sidewalk. The roadway deck has a waterproof membrane and 100 mm thick asphalt wearing surface. Silica fume concrete and stainless steel reinforcement are used in the cast-in-place concrete superstructure for maximum durability.

The new Clearbrook Underpass deck is located on a 300 m horizontal radius, and is skewed at approximately 35^{o} to the highway alignment. The bridge deck supports electrical ducts for BC Hydro, and communication ducts for Telus, in two separate corridors. Also, the sidewalk is supported by a separate box girder, gapped 1 m from the adjacent girder. The deck weep pipes which drain the asphalt surfacing are all detailed within this 1 m gap. To minimize variations in the deck overhangs and duct corridor widths, the girders were arranged in non-parallel banks of one, three, six and four girders with individual lengths and skews. While this adds a degree of complexity to the manufacturing, the result is highly beneficial for construction of the overhangs and to the finished appearance.

To improve seismic behaviour of the two-span superstructure and to limit seismic demands on the median pier, a central link deck was provided. The link deck above the median pier provides a continuous deck diaphragm to transfer lateral loads to shear keys at the abutments. The link deck spans in flexure over a short distance above the girder ends, and eliminates the requirement for an expansion joint above the pier. This feature is highly beneficial for enhancing seismic load resistance; but also in reducing capital costs, eliminating maintenance, avoiding structural deterioration beneath a leaking deck joint, and improving vehicular ride quality. With an overall superstructure length of approximately 60 m, thermal and creep strains are small enough to eliminate deck expansion joints and provide buried joints at the semi-integral abutments, which consist of spread footings perched above the back-filled concrete abutment retaining walls.

The project team adopted a very aggressive schedule which called for completion of the Clearbrook Underpass in the summer of 2010, some three months into the main construction contract. This schedule was only possible with pre-procurement of the precast box girders and advanced construction of the substructure. The work required under the advanced works program included construction of the highway detour, bridge substructure, utility diversions, and supply of precast girders. This extensive program required about 30% of the construction budget to be allocated to a series of material supply and minor works contracts. The advance work program paralleled the design development and shaved a significant amount (roughly a third) from the project estimate. The result was favourable bids for advance work packages, and streamlining of the main construction contract.

Construction of the pier for the Clearbrook Underpass was required as a matter of urgency as diversion of the westbound highway lanes would occupy the space needed for construction. The design required a slender, ductile multi-column bent, on a large, low bearing-pressure spread footing. In the event, the median pier was designed, bid and built within only four weeks, and was followed immediately by construction of the adjacent highway detour.

While the initial construction work was occurring, design of the abutments was underway. There was insufficient time available to procure proprietary MSE abutments; as a result cast-in-place concrete was used to permit rapid implementation. The cantilever abutment wall design also used a large, low bearing-pressure spread footing with horizontally cantilevering wall stems to facilitate construction beneath the deck of the original Clearbrook Underpass alongside. The 70 m long south abutment wall was remote from the highway detour and was similarly designed, bid and built within only four weeks. The north abutment construction commenced some two weeks later following switchover of highway traffic to the detour. While normally MSE walls are considered faster and more economical than cast-in-place wall construction, the abutments for the Clearbrook Underpass were built very rapidly and for much less cost than the estimated installed cost of MSE.

Following form stripping, the abutment wall stems were then quickly backfilled with bridge end fill under the advanced works program. Soon afterwards the main construction contractor was able to start bridge work by building the perched abutment footings. When the footings and wingwalls were ready, the contractor then erected the pre-procured precast girders and commenced deck construction.

The superstructure was completed in October 2010; the installation of deck waterproofing and the first lift of asphalt surfacing were delayed by inclement weather. Traffic on Clearbrook Road was then detoured across the new bridge and the original structure demolished.

Installation of the second lift of asphalt pavement and finishing works were deferred until 2011. Overall contract completion was delayed by utility work and civil tie-ins, and wrapped up in the spring of 2011. The total tender price for the new Clearbrook Underpass was approximately $4.2M, which compares favourably with the original engineering estimate of $4.9M. The total deck area is around 2100 m^2 which results in a unit cost of approximately 2000 $\$/m^2$.

5. Nelson Flyover

The new Nelson interchange was delivered by the Ministry of Transportation and Infrastructure on behalf of its funding partners; the Port of Vancouver, the City of Richmond, and the Federal Economic Stimulus Initiative. The Nelson interchange with Highway 91 interchange was built to accommodate significant traffic growth associated with expansion of the port terminal at the south end of Nelson Road in Richmond, BC. Port traffic previously used Nelson Road and Westminster Highway to access the highway system; however, to the west of Nelson Road, Westminster Highway is a narrow two-lane community road which services local businesses and farms. To the east, Westminster Highway has been widened to accommodate the increased traffic, but the community opposed improvements to the west. The solution was to extend Nelson Road north of Westminster Highway and construct a new directional interchange with Highway 91. The main challenges for the project team were to build the new interchange in an area of soft subsoils, adjacent to and above an operational highway, in a very short time frame, and within the $24M of project funding available.

Highway 91 is the Richmond East-West freeway and is built on low lying land in the Fraser River delta. The subsoils are soft, potentially liquefiable, and contain peat deposits. Road embankments experience significant settlements and ground improvement is necessary. There is a layer of Fraser River sand, usable for piled foundations, from around 20 to 30 m below grade. The highway was built circa 1990 and the 2 m high embankment was preloaded for over one year. The typical cross section of the four-lane highway has a 4 m raised median; however, at Nelson Road the highway follows a sharp S-curve alignment, with the median widened to around 10 m, in order to provide the required stopping sight distance on the curves.

The Nelson interchange consists of an on-grade eastbound Highway 91 to southbound Nelson Road off-ramp; and a northbound Nelson Road to westbound Highway 91 on-ramp. The on-ramp crosses the highway on a new flyover, and the new ramps terminate at a signalized intersection with Nelson Road.

The highway passes through an area of agricultural land consisting of cranberry and blueberry farms. An important project requirement was to minimize the footprint of the new interchange to limit the area of land that had to be transferred from the Agricultural Land Reserve. As a result, west of the undeveloped Nelson Road right-of-way, the ramp alignments closely parallel the highway alignment. The on-ramp crosses the highway on a curvilinear alignment at a severe skew of about 57^o.

A major constraint to design development was the limited time available for construction which forced the design team to make a number of key decisions including:

- An early start on ramp construction to maximize the time available for preloading
- Undertaking as much advanced work as possible under day labour contracts
- Pre-procuring long lead-time components for the flyover
- Using EPS fill for the flyover approach embankments.

Because preloading time of only 5 to 6 months was available and the peat deposits were at depths of 2 to 6 m below the new ramps, the design team elected to sub-excavate the peat material and backfill with river sand. This decision greatly reduced settlements and speeded up preloading. Had river sand been chosen for the flyover approach fills, ground improvement would have been needed to limit post-seismic liquefaction displacements of the soil around the bridge foundations. However, the design team considered ground improvement in close proximity to the operating highway to be impractical. Instead, lightweight EPS embankment fills were used to limit soil displacements, in conjunction with a robust piled foundation design. The choice of using EPS embankment fill added value; the estimated cost was approximately half the cost of ground improvement.

The Nelson Flyover has a relatively narrow deck, measuring 8.3 m between parapets, to accommodate the on-ramp and shoulders. The median was wide enough for a support pier and therefore two-span and four-span bridging solutions were investigated. The two-span scheme required additional EPS fill and concrete facing walls behind the abutments in addition to heavier and deeper girder sections. The estimated overall cost was slightly greater than the four-span scheme which used a shallower continuous girder section. Importantly, the four-span design significantly reduced the volume of EPS material required for the flyover approach fills.

The 130 m long flyover has spans of 24, 36, 39, and 31 m, measured from south to north. The selected girder section has a constant web depth of 1.6 m. Steel plate girders were selected for their overall economy, ease of erection, and slender profile. Bridge articulation comprises fixed pot bearings at the intermediate piers and expansion bearings at the abutments. Cellular strip seal expansion joints and approach slabs are provided at each abutment.

The bridge cross section consists of two steel plate girders at 4.5 m on centre supported by fixed pot bearings above the piers and laminated elastomeric bearing pads at the abutments. The substructure consists of single-column piers with hammerhead pier caps placed square to the ramp alignment. To support the girders, the bearings are anchored to the 5.7 m x 1.8 m variable-depth cap beams. The narrow girder centres reduce the cap width sufficiently to fit within the space available in the highway median. However, measuring approximately 2.3 m, the resulting deck edge cantilevers were relatively wide.

The deck had to be constructed above an operating highway which would have complicated placing and stripping deck formwork. Accordingly, to improve constructability and safety, a novel deck design using full-width precast pre-tensioned stay-in-place deck panels was used. The 130 mm deep precast panels have a 130 mm thick cast-in-place concrete topping which includes the continuity reinforcing above the intermediate supports. The cast-in-place concrete wraps around the panel ends to provide a continuous deck fascia. The 8.6 m by 3.0 m deck panels are temporarily supported on EPS strips on top of the girders while the haunches are filled with grout. The precast deck panels are provided with block-outs to accommodate the shear connector studs which are welded to the girder top flanges in in clusters.

To accommodate the curved portion of the flyover deck, the steel girder segments are deflected at the bolted field splices. In addition, the precast deck panels are positioned in a series of small steps to follow the increased superelevation of the deck around the spiral portion of the curve. The deck has concrete parapets along the edges and is protected by a waterproof membrane and 100 mm asphalt wearing surface. For maximum durability, the cast-in-place superstructure components consist of silica fume concrete and stainless steel reinforcement.

The intermediate piers consist of 1.35 m diameter concrete columns supported by 5 m x 5 m pile caps. The columns are carefully sized and detailed to capacity-protect the foundations under seismic loading. The intermediate piers are each supported by four 914 mm diameter concrete-filled steel pipe piles, approximately 27 m long, driven closed-ended into the sand bearing layer. The 6 MN factored pile capacity required was verified using an advanced pile test and PDA testing. Similar piles are used in groups of three at the abutments to support an elevated pile cap on which the bridge girders are placed. The abutment piles are surrounded by EPS fill. The pile diameter was selected for overall economy and for having sufficient strength to resist post-seismic ground displacements in the soft subsoils.

Steel pipe piles, steel plate girders, precast deck panels, bridge bearings, and expansion joints were pre-procured under supply contracts. These contracts were awarded approximately two months prior to the main construction contract which commenced in August 2010. Construction was largely carried out during day time hours; however, several operations, including concrete placement and superstructure erection, were timed to take advantage of the availability of night-time highway lane closures.

Originally scheduled in March 2011, the date for contract completion was extended to July 2011 once the timing for federal funding eligibility was relaxed. The extension allowed weather-sensitive items, including deck waterproofing and paving, to be deferred until the spring. The total of the tender prices for the new Nelson Flyover was approximately $3.25M, which compares favourably with the original engineering estimate of $3.7M. The total deck area is around 1200 m^2 which results in a unit cost of approximately 2700 $\$/m^2$.

6. Summary

Each of the four new highway interchange projects was challenged by fiscal constraints and a rigid completion date. The four projects had several common features requiring an unconventional approach to project delivery. In all cases the conventional design-build-build approach was modified to suit the accelerated delivery requirements. These common features include:

- A teamwork approach to the development of optimized solutions
- The use of time-saving methods of construction
- Using readily available materials
- Maximizing the use of advance works under day-labour contracts
- Paralleling construction with design development
- Careful management of project risks
- Pre-procurement of long lead-time components
- Rapid decision-making and pro-active project management.

While all of these techniques have been used previously, the combined use of all of them for the four interchange projects is unusual. A commonly-used technique for project fast-tracking is design standardization. However, on these four highway-interchange projects, this approach was not appropriate and would have precluded out-of-the-box thinking. In reality, all four projects demanded a novel approach which resulted in very different technical solutions.

Accordingly, custom bridge designs were specifically developed for each project. Designs were developed from previously-used solutions, extended to new applications. For each project, the challenge of building a new interchange, under traffic, for less than $25M was significant. While this achievement is partly the result of the favourable bidding climate in 2010, it is also the result of the engineering teams seizing the opportunity to let contracts, and secure significant portions of work at favourable prices. In particular, the use of extensive day labour work resulted in significant project cost savings while allowing project implementation to take place in parallel with the design phase. However, the common feature behind each of the successful project outcomes is good decision making and effective engineering.

Acknowledgements

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McTavish Interchange

P**roject Manager:** BC Ministry of Transportation and Infrastructure
Civil Design: Urban Systems Ltd
Bridge Design: Associated Engineering
Geotechnical Design: Thurber Engineering Ltd
Construction Manager: Focus Corporation

McCallum Interchange

Project Manager: City of Abbotsford
Civil Design: ISL Engineering and Land Services Ltd
Bridge Design: Associated Engineering
Geotechnical Design: Golder Associates Ltd

Clearbrook Interchange

Project Manager: City of Abbotsford
Civil Design: McElhanney Engineering Services Ltd
Bridge Design: Associated Engineering
Geotechnical Design: Trow Associates Inc.
Construction Manager: Focus Corporation

Nelson Interchange

P**roject Manager:** Promana Project Strategies Inc
Civil Design: Urban Systems Ltd
Bridge Design: Associated Engineering
Geotechnical Design: Thurber Engineering Ltd
Construction Manager: Focus Corporation

Figures

Figure 1: McTavish Underpass South Elevation

Figure 2: McTavish Underpass South Fascia

Figure 3: McTavish Pedestrian Bridge East Stair and Ramps

Figure 4: McTavish Pedestrian Bridge North Fascia and West Ramp

Figure 5: McTavish Pedestrian Bridge Deck Looking East

Figure 6: McCallum Underpass MSE Abutments

Figure 7: McCallum Underpass above Eastbound Highway 1 Nearing Completion

Figure 8: McCallum Underpass Deck Looking North

Figure 9: Clearbrook Underpass Pier

Figure 10: Clearbrook Underpass West Elevation

Figure 11: Clearbrook Underpass and Nearby Mount Baker

Figure 12: Nelson Flyover: EPS Fill Placement for North Approach Embankment

Figure 13: Nelson Flyover Nearing Completion