Pattullo Bridge Replacement: Rehabilitation of Royal Avenue Underpass

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Abstract

The Royal Avenue Underpass rehabilitation was part of the City of New Westminster roadwork and structure improvements portion of the overall design-build Pattullo Bridge Replacement Project. Originally designed and constructed in 1956, the structure had exceeded its design life and did not meet the current seismic design requirements – but was essential infrastructure for the drivers of the 80,000 vehicles per day that cross over or the under the structure.

While complete replacement of the underpass with a new concrete structure would have been the conventional approach to meeting the requirements for this structure upgrade, that approach would have resulted in lengthy road closures and traffic disruptions, and presented environmental concerns as both the demolition and production of concrete result in significant greenhouse gas (GHG) emissions. Through careful investigation and design, Hatch was able to work towards net zero infrastructure objectives in rehabilitating the underpass to meet current seismic standards and project durability criteria, salvaging the original abutments, wingwalls, and approach embankments.

In order to meet current seismic standards, the original cantilever abutment walls were rehabilitated and thickened, including additional front face reinforcing to accompany a change in structure articulation. The new superstructure is fixed to the top of both abutment walls using large cast in anchors, and acts as a prop to stabilize the abutment walls against seismic earth pressures.
The new superstructure was completely assembled off site, and moved into place using a Self-Propelled Modular Transporter (SPMT) for removal and replacement of the superstructure during a single weekend traffic closure. This approach resulted in significant reductions in the use of heavy equipment, reduced concrete demolition and production, and avoided the increased commuter travel times resulting from lengthy detours.

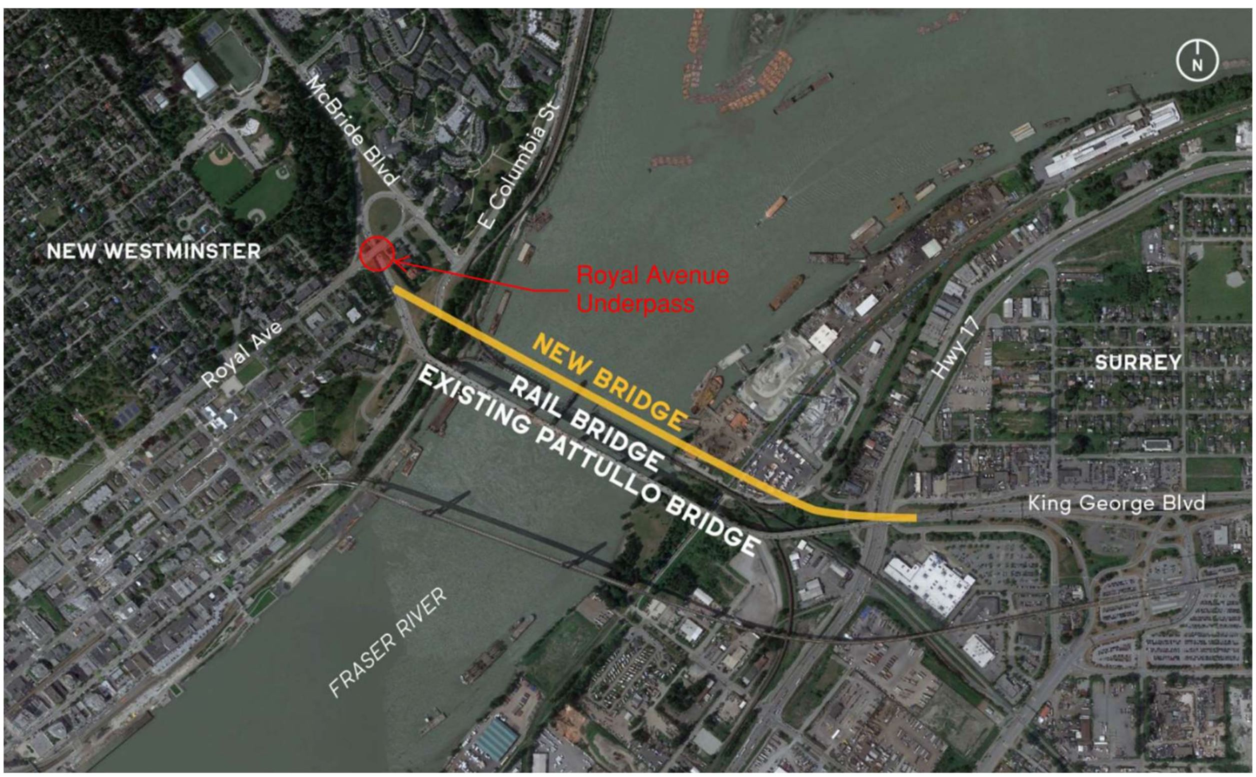
This methodology was successfully implemented on an aging structure in a densely populated area with high seismic demands, and is highly adaptable to many other applications.

Introduction & Project Location

The Pattullo Bridge Replacement project consists of design and construction of a new 1,235m long structure over the Fraser River to replace the 1,227m long existing bridge constructed in 1937, as well as significant onshore work in both New Westminster and Surrey British Columbia to tie in the approaches of the new bridge. Fraser Crossing Partners (FCP), a Joint Venture between Acciona and Aecon Constructors is responsible for delivering the overall design, construction, and partial finance of the project. Hatch has been engaged by FCP as the prime design consultant for the project.

Upgrading of the Royal Avenue Underpass was part of the onshore structures scope at the north approach of the new Pattullo bridge. The underpass structure is located approximately 150m north of the north abutment of the replacement Pattullo bridge in New Westminster, BC.

Figure 1. Project Location



Source: Province of BC Pattullo Bridge Replacement Project Website

Original Structure Details

The original Royal Avenue Underpass was constructed in 1956 and carried Royal Avenue over Highway 1A (now known as the Bridge Connector) in New Westminster, BC. Both roads are Highway Class A with posted speed limits of 50km/h. At the underpass, the Bridge Connector consists of three northbound lanes (including exits to westbound Royal Avenue) and one southbound lane. Royal Avenue at the structure location includes two westbound lanes, one eastbound lane, and sidewalks on both sides of the roadway.

The single span structure consisted of 6-7m tall cast in place concrete cantilever retaining wall abutments supporting a voided post-tensioned concrete slab deck simply supported at the top of both abutment walls. Independent cast in place concrete wingwalls parallel to the abutment walls and Bridge Connector retained the embankment fill at all four corners of the structure.

Figure 2. Pre-Construction Google Maps Streetview of Structure (2019) – Looking North

Source: Google Maps

Performance Objectives and Design Criteria

The Project Agreement stipulated replacement of the existing superstructure of the Royal Avenue Underpass and additionally outlined a number of performance objectives for the rehabilitated structure, should rehabilitation prove to be feasible. The performance objectives and design criteria for the structure were as follows:

- New structural components of the rehabilitated structure were to be designed to the requirements of new structures, including:
  - Seismic retrofit to comply with the requirements of new Major Route structures
  - New and existing structure components must be seismically compatible
  - Minimum 100-year design life for non-replaceable components of structures (including foundations, substructures, decks, and both primary and secondary superstructure members)
- Design Live Loading per CAN/CSA-S6 Section 14 BCL 625 and the Ministry's 85-tonne GVW special permit vehicle loading (load postings not permitted).
- Barriers to be upgraded to comply with CAN/CSA-S6 and BC Supplement to CAN/CSA-S6

Seismic performance criteria for this Major Route structure were immediate service and minimal damage for the 1/475-year seismic event, meaning that the structure must be fully serviceable for normal traffic, with no observable damage, and requiring no repairs causing service disruptions after an earthquake with a 10% likelihood of occurring in a 50-year period.

Extensive damage and service disruptions were permitted to occur in the 1/2475-year seismic event, meaning the structure must remain open for emergency traffic and shall be repairable in the event of an earthquake with a 2% likelihood of occurring in a 50-year period. Inelastic displacement including the failure of bearing anchors was permitted in this scenario.

Design Constraints

A major constraint in the design of the structure rehabilitation and deck replacement scheme was the Project Agreement restriction on full closures of the Bridge Connector, which were only permitted on weekends from Friday at 10pm to Monday at 5am – a maximum closure window of 55 hours. Any activities requiring closures of the Bridge Connector needed to be investigated in significant detail to validate that they could be accomplished within the permitted closure window. As such, Hatch and Fraser Crossing Partners spent significant effort developing a detailed construction sequence to achieve the following:

- Pre-Closure works on the existing structure (abutment wall demolition and rehabilitation) were staged to allow for traffic flow over and under the existing structure during all construction prior the 55-hour weekend closure for superstructure replacement.

- Pre-Closure works in the assembly of the replacement superstructure were completed in a nearby staging area prior to the 55-hour superstructure replacement weekend closure. The complete superstructure (including girders, deck, sidewalks, barriers, and diaphragms) was pre-assembled in the staging area.

- Removal of the existing superstructure and placement of the new superstructure was completed in a single 55-hour weekend closure. Removal of the existing superstructure and erection/placement of the new pre-assembled superstructure was achieved by a Self-Propelled Modular Transporter (SPMT).

- Post-Closure works to complete construction (all items detailed in the design drawings and not completed in the steps above) were staged to allow for staged traffic flow over and full traffic flow under the structure during all construction after the 55-hour weekend closure.

Design Development

During the bid and preliminary design phases of the project, the plan was to seismically retrofit (stabilize) the abutment walls using dozens of inclined soil nails installed through the concrete walls and deep into the soil behind the walls as shown in Figure 3 below. This would have also included significant thickening to the abutment walls to anchor and protect the new soil nails as shown in Figure 4.

Figure 3. Bid Phase (Preliminary) Substructure Strengthening Scheme

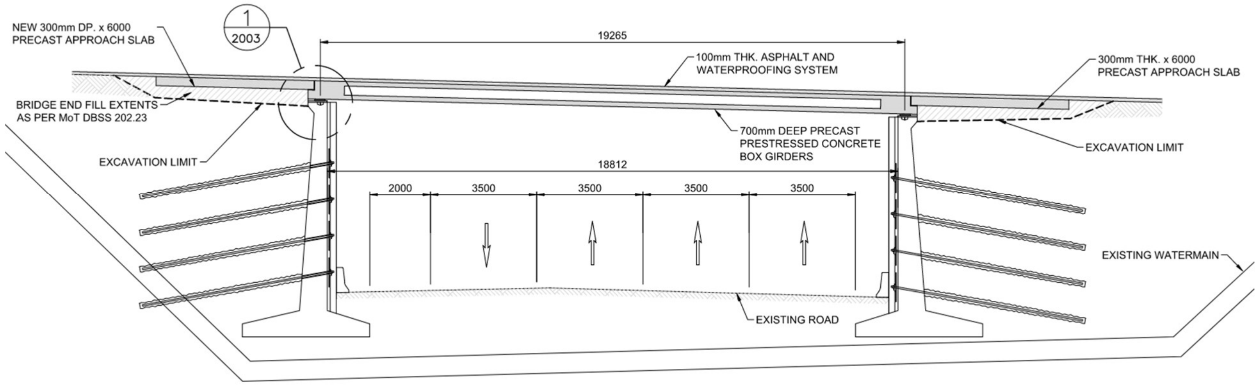
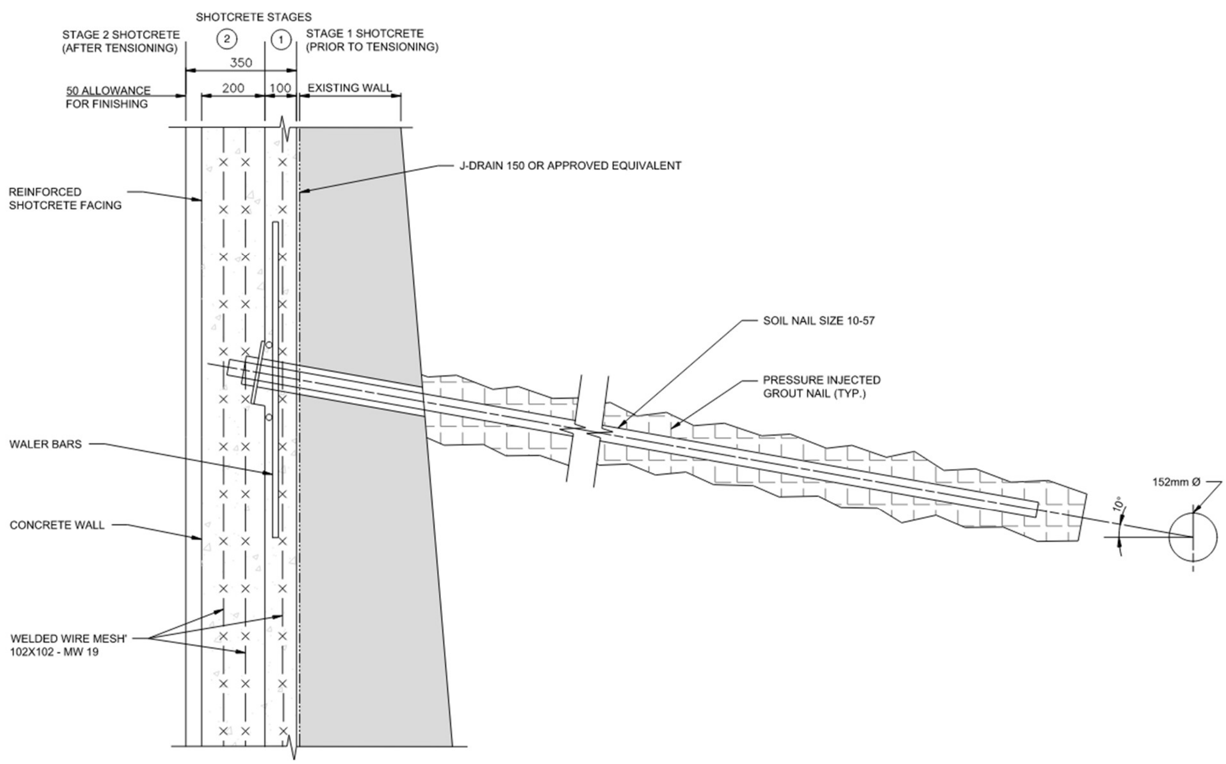


Figure 4. Bid Phase (Preliminary) Abutment Wall Thickening and Soil Nail Detail



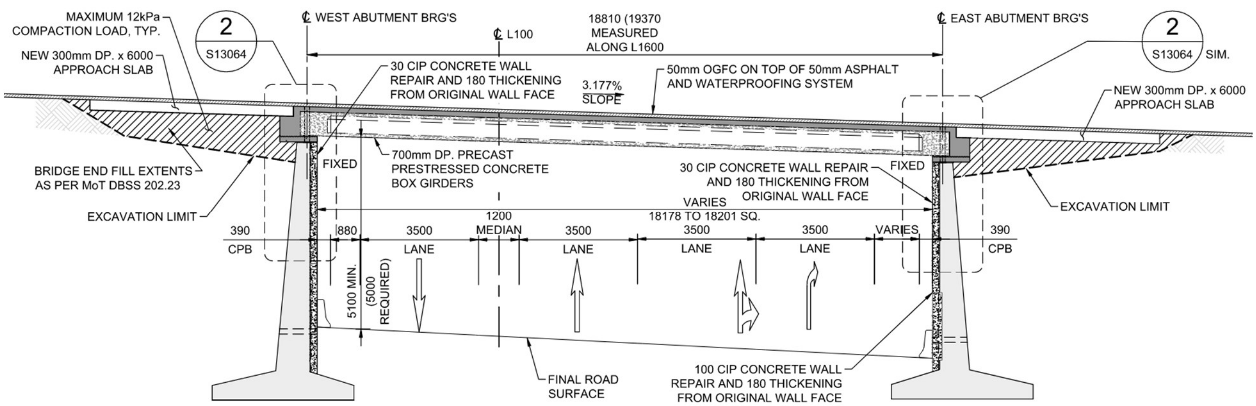
As design progressed, this concept proved to be quite cost prohibitive due to the requirements for specialized equipment and the relatively long duration that equipment would need to be on site to install all of the soil nails. Additionally, installation of the 7+m long soil nails would require closure of a significant width of the Bridge Connector below the structure, with traffic staging to accommodate rehabilitation of both abutment walls. Work on the two abutment walls could not be advanced in parallel in this arrangement, as the staging areas required on either side of the underpass would not have left enough room to accommodate the traffic passing below the structure.

The original structure consisted of typical cantilever retaining walls serving as the abutments, supporting a pin connected (simply supported) superstructure. The main issue with this arrangement was the lack of restraint at the top of the cantilever abutment walls. In a significant seismic event, the abutment walls would have been pushed inwards by the retained soil, shearing off the relatively small pins connecting the superstructure to the abutments. The small pins in the original structure configuration were intended only to resist horizontal traffic loads (i.e. braking), not resolve the significant seismic forces required to be analyzed under modern codes.

As design developed, it became clear that both the soil nail concept and the original structure articulation were problematic. Both issues were resolved through a change to the articulation of the structure, and a different approach to resolving the large seismic forces governing the stability of the abutment walls.

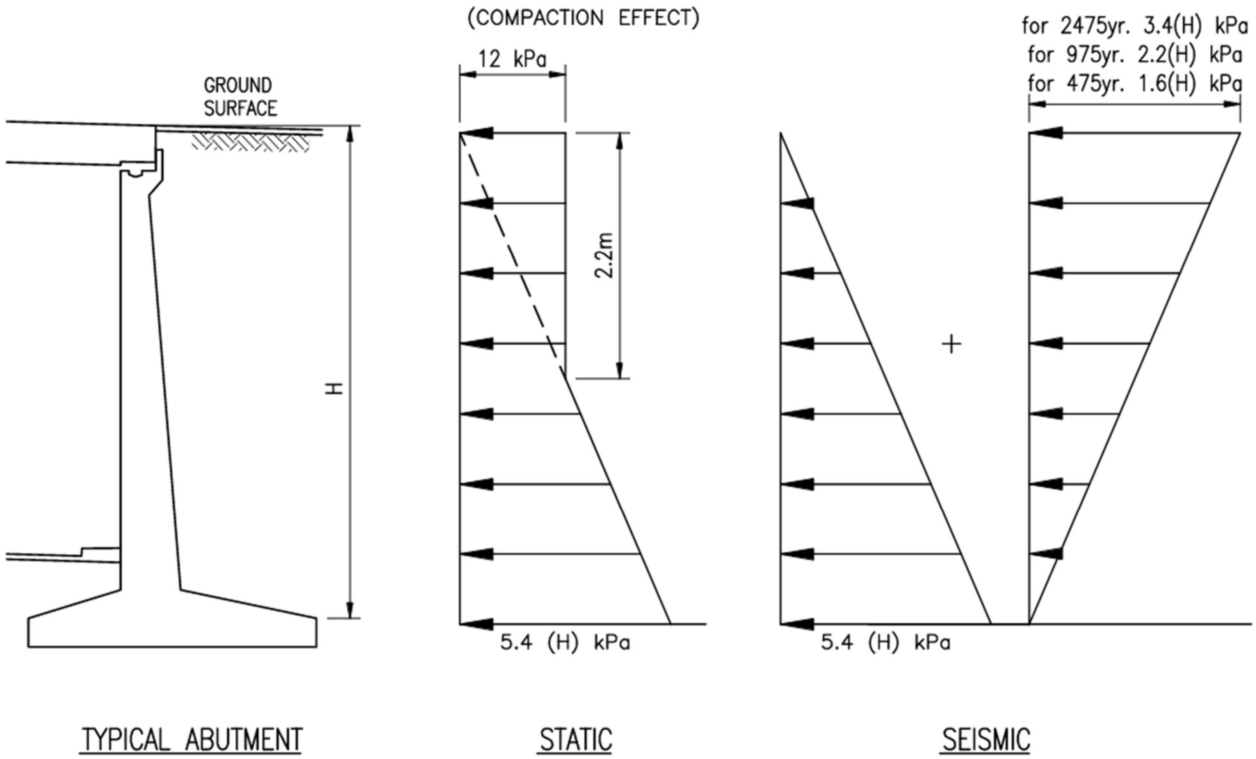
In the final structure configuration as shown in Figure 5 below, the connections between the abutment walls and the superstructure are fixed. This arrangement makes use of the significant longitudinal stiffness of the reinforced concrete superstructure as a prop between the previously free tops of the abutment walls, providing a second lateral support to the walls.

Figure 5. Final Structure Section



As the seismic soil forces driving the design of the abutment walls were focused at the top of the walls (greatest at the ground surface as shown in Figure 6 below), laterally supporting the tops of the abutment walls was also more structurally efficient than resolving that load across a grid of soil nails installed throughout the entire wall elevation.

Figure 6. Soil Forces on Abutment Walls

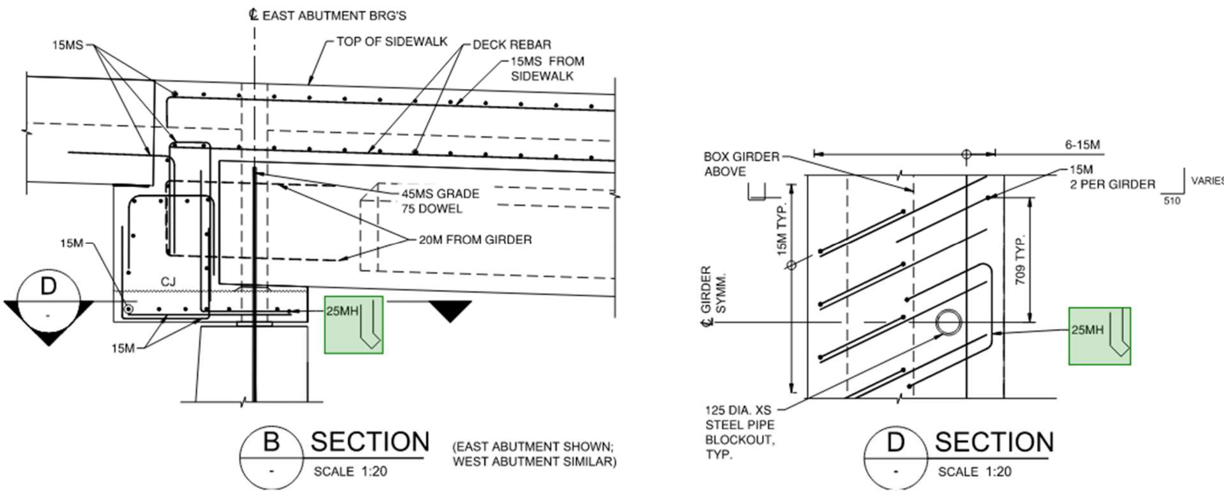


This resulted in the abutment walls being effectively simply supported between their footings embedded in the soil (both friction and passive pressure) and the fixed connections to the superstructure. The major impact to the design of the abutment walls in this configuration was that instead of the back face of the wall being in tension as is typical for cantilever retaining walls, the front of the abutment walls would now be the tension face. This required a significant increase in reinforcement on this face compared to the original design.

As the front faces of the existing abutment walls were showing some concrete carbonation and general deterioration that would need to be addressed to comply with the 100-year design life criteria for the structure, concrete had to be removed from the exposed faces of the abutment walls. This aligned well with installation of new wall thickening concrete, which would contain the additional reinforcing to facilitate the new simply supported wall configuration. The old and new concrete was connected by a grid of post installed dowels drilled into the old concrete and connected to the new mat of reinforcement installed in the wall thickening.

Fixed connections between the abutment walls and superstructure were achieved with a 45M Grade 75 stainless steel dowel embedded through both ends of each girder deep into the abutment walls, grouted into the girders and diaphragm and cast into the abutment walls. Hairpin bars were designed to resolve the large horizontal forces at these fixed connections, passing the loads into the primary reinforcing at the front of the walls and back of the diaphragm. These bars can be seen in Figures 7 (superstructure hairpin bars) and 8 (substructure hairpin bars) below.

Figure 7. Superstructure Hairpin Bars



The dowels connecting the abutments to the superstructure were designed to be installed in two halves to facilitate the construction sequence (see Figure 8 in the following section). First, the bottom half of the dowels complete with couplers were cast into the abutment walls during the wall rehabilitation and strengthening work with the original superstructure in place above. Months later, the top half of these dowels were threaded into the couplers embedded in the abutment walls during the placement of the new superstructure, and then grouted in place through CSP blockouts cast into the girders, diaphragm, and deck.

Final Construction Sequence

The final construction sequence was a result of significant coordination between Hatch and FCP. Development of this sequence heavily influenced the design of the structure upgrades. Figure 8 below shows the final configuration of the connection between the abutments and superstructure, for reference in reviewing the simplified version of the final construction sequence listed below:

Prior to the weekend closure:

1) Concrete removal, reinforcing repair, and surface preparation along the entire front face of both abutment walls.
2) Install shear dowels (drill & epoxy) and new front face abutment wall reinforcing. Place wall thickening concrete in lifts to the bottom of the wall hairpin bars.
3) Install temporary supports for existing superstructure in front of both abutment walls.
4) Stage traffic to close 1/3 of the width of the bridge deck, excavate behind abutment walls, and remove existing curtain wall and bearing shear dowels along closed portion of bridge.
5) Install trench plate over excavation and repeat the above step for the remaining bridge width.
6) Jack up entire superstructure and demolish bearing seat concrete (top of abutment walls).
7) Instal hairpin bars (to support new bearing dowels), new bearing seat reinforcing, and bottom half of new bearing dowels complete with couplers. Pour bearing seat concrete.

During the weekend closure:

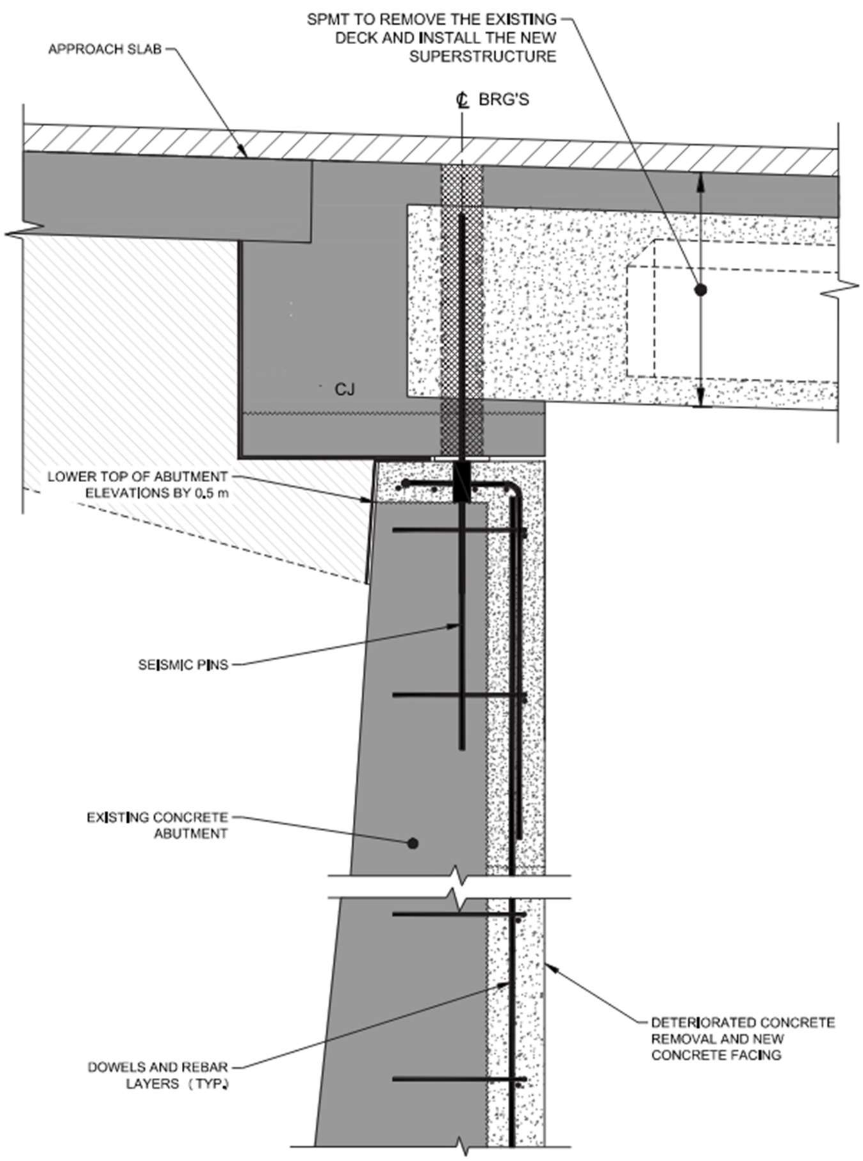
8) Remove existing superstructure (via SPMT) and temporary supports.

9) Place new pre-assembled superstructure (consisting of concrete girders, diaphragms, deck, sidewalks, and barriers) via SPMT.
10) Connect top half of bearing dowels (threaded in through blockouts in girders).
11) Grout dowel voids in girders and diaphragms.
12) Place temporary backfill and asphalt at bridge approaches.
13) Complete road safety assessment and reopen for traffic.

Following the weekend closure:

14) Stage traffic similar to Step 4 above for installation of waterproofing, drainage board, backfill, approach slabs, and temporary asphalt at both approaches.
15) Install final bridge deck asphalt and waterproofing system.

Figure 8. Final Abutment Section



The staging area for all of this work was located inside the northbound Bridge Connector exit ramp to westbound Royal Avenue, just north of the underpass as shown in Figure 9 below. This is where assembly of the replacement superstructure was completed in parallel with the abutment wall rehabilitation and strengthening works, and later where the SPMT equipment was configured for the superstructure replacement.

Figure 9. Staging Area and SPMT Path

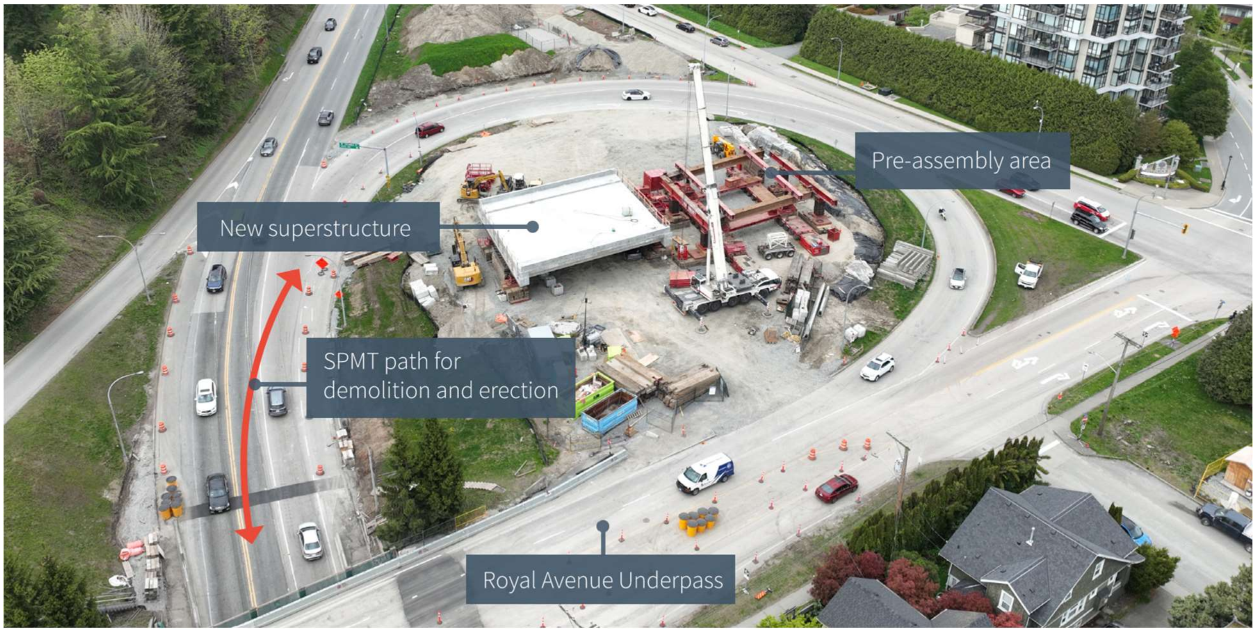
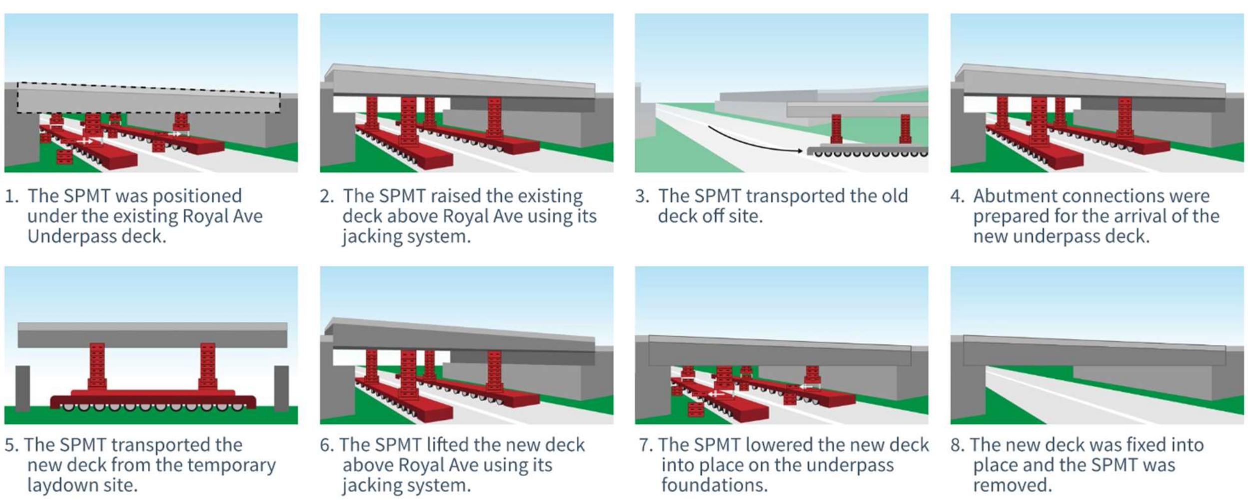


Figure 10 below contains a simple summary of the SPMT activities as shown in a public information notification of the (at the time) upcoming works.

Figure 10. SPMT Activities



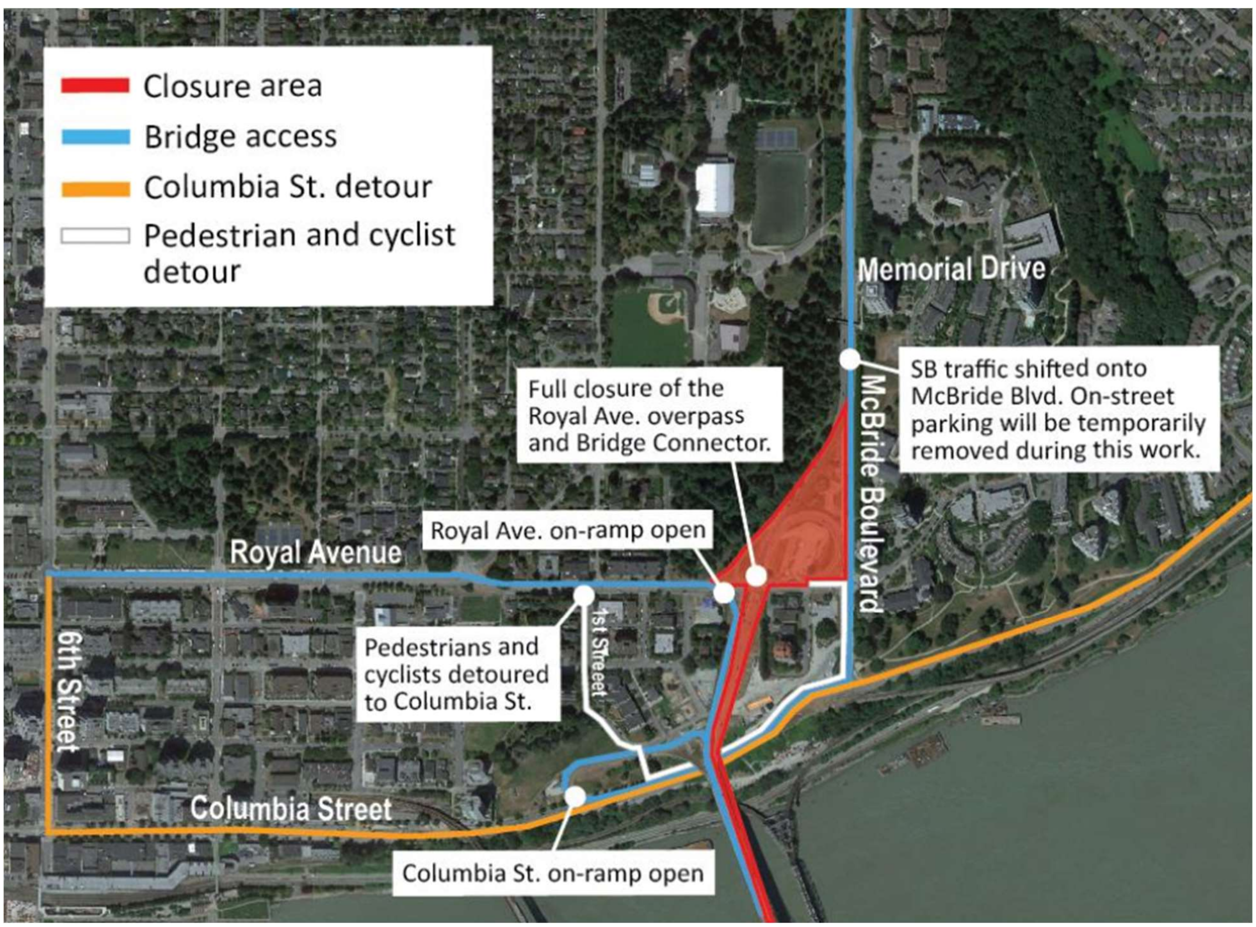
Source: Province of BC Pattullo Bridge Replacement Project Website

Removal and replacement of the underpass superstructure was successfully completed May 19th & 20th, 2023. SPMT activities for removal of the old superstructure were initiated at approximately 10pm the evening of May 19th, with the actual lift of the superstructure occurring around 1am on May 20th. The new superstructure was set on the bearings under 24 hours later, just before midnight on the same day.

Impact of Construction Sequence

The construction sequence detailed above resulted in very minimal impacts to the public when compared to conventional construction methodologies for similar projects. Conventional construction of an underpass rehabilitation and superstructure replacement would have resulted in at minimum several weekend closures of the Bridge Connector and a multi-month closure of Royal Avenue, disrupting the tens of thousands of commuters that pass through this key intersection daily. Figure 11 below shows the detour routes implemented for replacement of the superstructure. When compared to typical traffic conditions, the southbound detour route resulted in a 15-minute increase in travel time. Westbound traffic saw a 6-minute increase in travel time through the site. The site was completely closed to northbound and eastbound traffic.

Figure 11. Superstructure Replacement Detour Routes



Leveraging state of the art equipment and a well thought out construction sequence resulted in major time savings for the members of the public passing through the construction area. Minimizing travel delays resulted in both reduced public impacts during construction and associated greenhouse gas emissions resulting from vehicle idle times. Additionally, salvaging and rehabilitating the existing substructure resulted in further emissions reductions through a reduction in quantities of concrete demolition and production.

Conclusions

The upgrading of the Royal Avenue Underpass to suit the requirements of new structures as part of the Pattullo Bridge Replacement project was faced with many constraints, primarily the restrictive closure window for the highways crossing the structure, but also including limited space for construction staging, maintaining the pedestrian crossing, and neighbourhood noise restrictions.

It would have been possible to complete an off line replacement of the structure with fairly minimal impacts to commuters, but this would have resulted in very significant and costly property acquisition impacts resulting from realignment of the highway. It also would have been possible to completely replace the structure in place, with no highway realignments, but with significant impacts (delays, reduced accessibility) to commuters and neighbourhood traffic as detailed in the section above.

These potential impacts to the public were successfully mitigated through a collaborative approach to both structure design and the development of construction methodology. The result is an upgraded structure that will meet the needs of the public for the next 100 years, installed without significantly inconveniencing them during construction.

The following figures show several highlights from the construction of the structure upgrades.

Figure 12. Substructure Rehabilitation & Strengthening

Figure 13. PBRP North Approach and Royal Avenue Underpass SPMT Staging Area (Looking South)

Source: FCP

Figure 14. Staging Area and Underpass After Removal of Original Superstructure

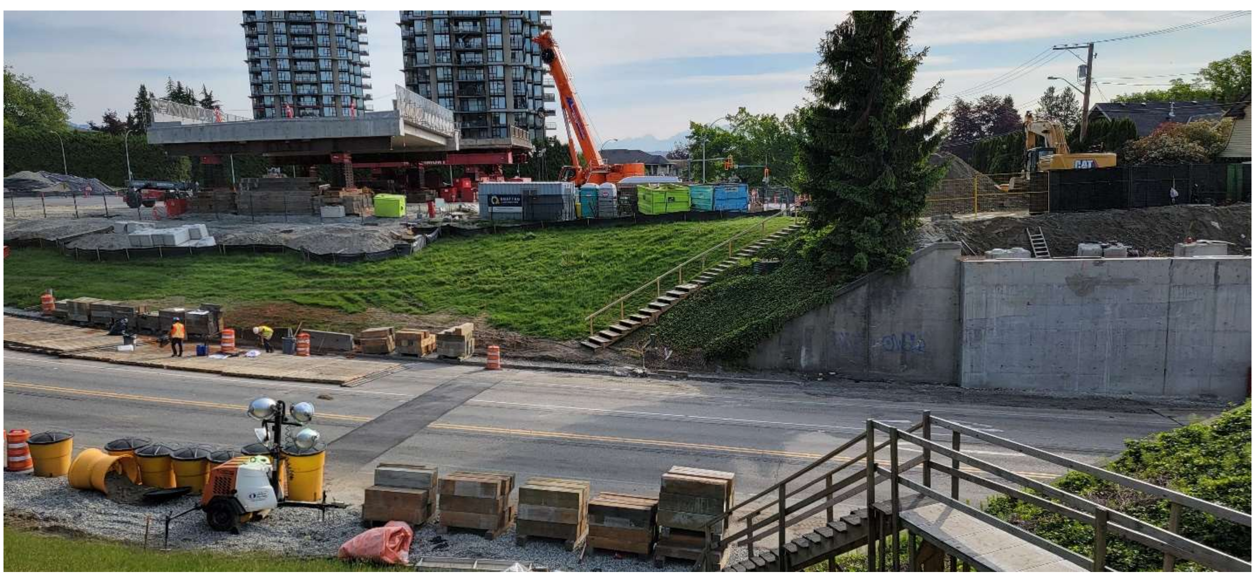


Figure 15. Installation of New Superstructure

Figure 16. New Superstructure Installed