Highway 99 Shoulder Bus Lane at BNR Overhead:

Complex Fast-Tracked Bridge Widening and Seismic Retrofit

to Provide Streamlined and Sustainable Commuter Option

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Paper prepared for presentation

at the Technical Paper Session

of the 2013 Conference of the

Transportation Association of Canada

Winnipeg, Manitoba

Abstract

The BNR Overhead structure is a 350-foot-long, five-span steel bridge that carries Highway 99 over the Burlington Northern Railway which connects Vancouver to the US Interstate network. To alleviate traffic congestion and encourage sustainable commuting, the Governments of BC and Canada provided stimulus funding for the addition of dedicated bus lane on this major artery. MMM was retained by the BC Ministry of Transportation and Infrastructure (BC MoT) to lead the widening design of this bridge.

Due to seismic deficiency of the existing bridge, an options analysis was added to the scope to compare short- and long-term solutions for accommodating the dedicated bus lane and the seismic upgrading of the bridge.

Challenges in this project included poor soils in the footprint of the bridge and its approaches, the lightweight construction of the original structure, the compressed design and construction schedule to meet stimulus funding deadlines, and the requirements for uninterrupted movement of the highway and the railway traffic.

The final design entailed widening of the existing bridge on both sides and utilizing helical mini-piles to allow piling to occur beneath the bridge deck. To accommodate the anticipated excessive earthquake displacements and to prevent potential collapse due to soil liquefaction, a “catcher” system was used. This structurally independent system, in addition to the use of seismic ties at deck joints, provides the required supports to the superstructure in the event of design earthquakes.

The project was completed on time and received the 2011 Deputy Minister’s Award of Merit from BC MoT.

1.0 Description of Project

The Burlington Northern Railway (BNR) overhead structure, originally named the Great Northern Railway (GNR) Overpass, was built during the initial double carriage highway widening of Highway 99 in 1960s. It is a 107 m (350 ft) long, five-span steel bridge that carries Highway 99 over the Burlington Northern Railway line which connects Vancouver to the US Interstate network. To alleviate traffic congestion and to provide an efficient bus transit option for commuters, the Governments of BC and Canada provided stimulus funding for the addition of a dedicated bus lane on this major artery. MMM was retained by the BC Ministry of Transportation and Infrastructure (BC MoT) to lead the widening design of this bridge. Figure 1 shows the location of

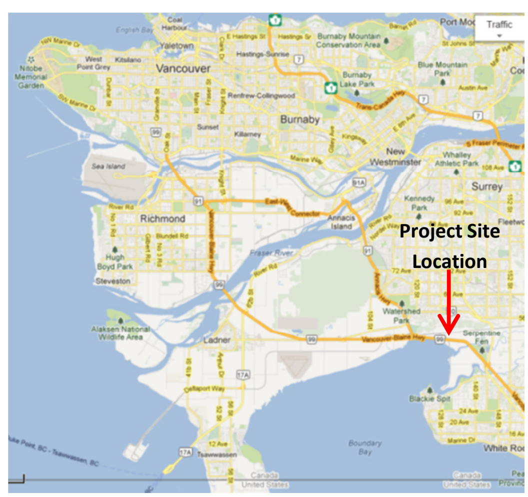

Figure 1 – Project Site Location

the project site in south Surrey, British Columbia.

Two parallel, independent structures cross a single railway track at this location, one carrying two lanes for northbound traffic and one carrying two lanes for southbound traffic along Highway 99. The twin bridges are typically about 4 m apart and have a skew angle of about 35°. This project deals with the northbound bridge only. Figure 2 shows a general view of the existing bridges looking northeast.

Figure 2 – Existing Bridge Structure

This existing northbound bridge consists of a 178-millimeter-thick (7 in) reinforced lightweight concrete deck with a 50-millimeter-thick (2 in) concrete overlay, supported by six rolled steel wide flange girders. The bridge has five equal spans of 21.34 m (70 ft) but was specially articulated with frames and drop-in spans to accommodate anticipated large differential settlements between supports, as illustrated in Figure 3 showing the general arrangement of the structure. The superstructure was constructed of two 27-metre-long (90 ft) and two 18-meter-long (60 ft) segments of 914-millimeter-deep (3 ft) steel girders from abutments to central piers, and a 15-meter-long (50 ft) central drop-in segment of 610-millimetere-deep (2 ft) steel girders over the railway track.

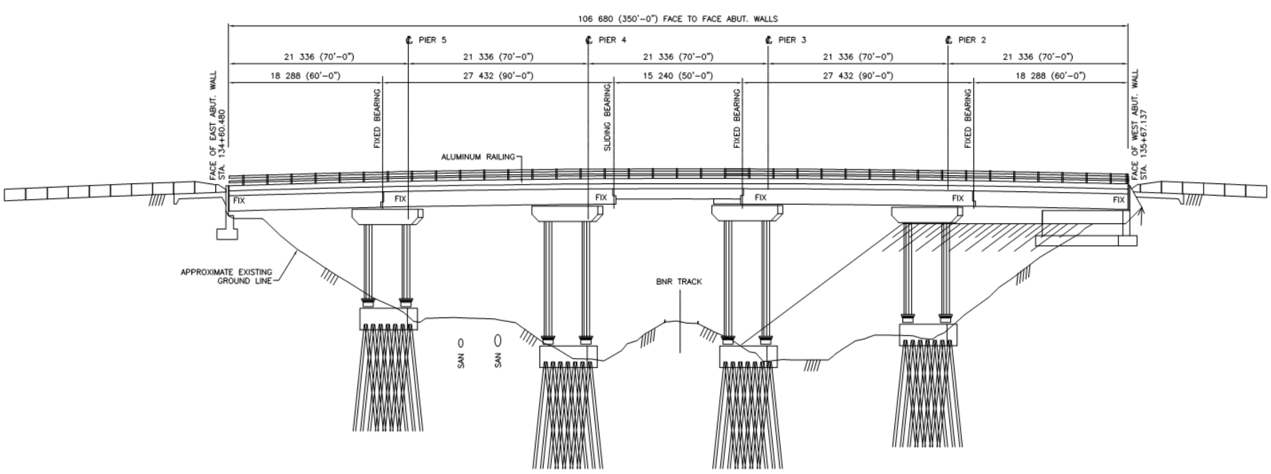

Figure 3 – General Arrangement of the Existing Bridge

Sliding bearings were installed on its eastern end of the central drop-in span, while all other bearings are fixed. Expansion joints were provided at the sliding bearing location and at the abutment locations. The expansion joint at the drop-in span originally was a steel finger joint and was replaced with an Acmaseal K-600 compression seal in 1980 as part of the deck resurfacing. The expansion joints at the abutments used Acmaseal J-300 compression seals. The existing bridge traffic barriers were aluminum posts-and-rails system supported on concrete curbs.

The piers were constructed as steel moment frames with a pair of columns pinned at their bases. A minimum vertical clearance of 6.86 m above the railway track is provided as per record drawings. The piers also incorporate three concrete shims (about 340 mm thick in total) placed at the bottom of each pier leg. These concrete shims were provided to allow future lowering of the pier legs to accommodate differential settlement between piers and/or between piers and abutments.

The pier foundations used battered timber piles embedded into a narrow concrete pile cap. The piles are creosote treated with a typical diameter of 175 mm and 350 mm at the toe and head, respectively. Each timber pile is about 23 m (75 ft) long. The abutments are supported on spread footings seated on 8-metere-high embankments with side slopes of approximately 2H:1V. The footings are 13.41 m (44 ft) long and 2.44 m (8 ft) wide. The wingwalls were extended out parallel to the abutments. Approach / settlement slabs were placed on top of the back wall and extended into the approach approximately 4.5 m at each end, topped by an asphalt wearing course.

The soil conditions at the bridge site are generally poor and comprise of layers of variable granular fill over silt, organic silt, and peat underlain by a thick silt deposit. The additional geotechnical investigation conducted at the onset of the assignment confirmed that the original soil information is valid. In general, the granular fill, comprising sand with variable silt and gravel content, was encountered to a depth of about 2.5 m. Below the fill, native silt and/or organic silt with some clay underlain by a thin peat layer was encountered to a depth of about 3.3 m. Below the peat, a thick silt layer was encountered to a depth of about 50 m depth, where silty sand was encountered to a depth of 53 m, where the geotechnical investigation was terminated. From the liquefaction triggering analyses, it was found that the silt to clayey silt are susceptible to liquefaction. The very soft silt with organics and portions of the upper OC silt to clayey silt deposit may experience cyclic mobility under the lowest design earthquake due to its over-consolidated stress state and sensitivity. The thickness of the zones susceptible to cyclic mobility and/or strain softening slightly increases with the magnitude of the design earthquake.

2.0 Conceptual Design and Options Analysis

Various feasible options for the addition of a northbound shoulder bus lane were investigated in order to identify an optimal solution by comparing a number of key parameters including costs, impacts and constraints. Several options (ranging from modification to the original bridge, construction of a new bridge, to the use of a temporary bridge) were developed to evaluate the long term and short term costs and benefits of each option. The options investigated included:

- Option 1: Widening the existing northbound bridge, including both:
    - Bridge deck widening to accommodate the new bus lane, and
    - Seismic retrofit to prevent the collapse of the bridge structure.
- Option 2: A short-term, single-lane ACROW bridge adjacent to the existing structure
- Option 3: Replacement of the existing northbound bridge, exploring two scenarios:
    - (A) The shortest possible bridge structure combined with long lightweight fill embankments. Expanded polystyrene (EPS) was assumed to be used under this scenario.
    - (B) A sufficiently long bridge structure to eliminate the use of EPS fill embankments.
- Option 4: A new purpose-built bus-lane bridge adjacent to the existing structure, exploring two alternatives outlined in Option 3 above.

  In addition, both alternatives of Option 4 above had to allow for future widening into a full three-lane bridge as described in Option 3 above.

The advantages, disadvantages, and high level cost estimates were compared amongst the various options. Option 1, the widening of the existing bridge with "Safety 1" seismic retrofit, is a competitive solution from the perspective of cost and schedule. However, the main objective of "Safety 1" level of seismic retrofit as defined by BC MoT is to prevent the collapse of the bridge only. One of the inherent drawbacks of this option is that it does not renew the service life of the existing bridge.

Option 2, the ACROW bridge, while feasible, is not economically competitive. This option does not involve any seismic retrofit on the existing structure to prevent collapse and even if BC MoT was prepared to accept the risk of low probability that a seismic event would occur during its limited intended service life, the cost of this option, including potential salvage value to some components, would still be too high to justify recommendation.

Of all the options considered, Option 3, the replacement of the existing northbound bridge, is the option that would provide the most comprehensive and lasting solution. The new bridge would meet the current seismic design requirements and provide a 75 year design life. Although it has the highest capital cost, Option 3 provides the best return on investment considering its life cycle cost. Of the two variations considered, Option 3A (the short bridge with EPS fill embankments) offers a better value than Option 3B (the long bridge without ground improvement).

Option 4, the new single-lane structure designed to accommodate a future widening, is not recommended, as this option carries a high cost for the value it provides.

The option of widening of the existing northbound bridge together with "Safety 1" seismic retrofit (Option 1) was selected by the BC MoT to be carried forward to detailed design.

3.0 Design Challenges

Widening the existing BNR overhead structure converts it from a two-lane configuration into a three-lane-wide bridge. The overall bridge deck after widening is 330 mm wider than the previously existing deck, and is designed to provide an updated and safer bridge crossing. It provides two 3.6-metre-wide traffic lanes, 1-meter-wide shoulder and a 4-meter-wide shoulder bus lane. The traffic barriers were also improved by replacing the original curb and aluminum railings with new standard concrete parapet-type barriers. Figure 4 shows the typical cross-section of both the previously existing and the widened bridge structures.

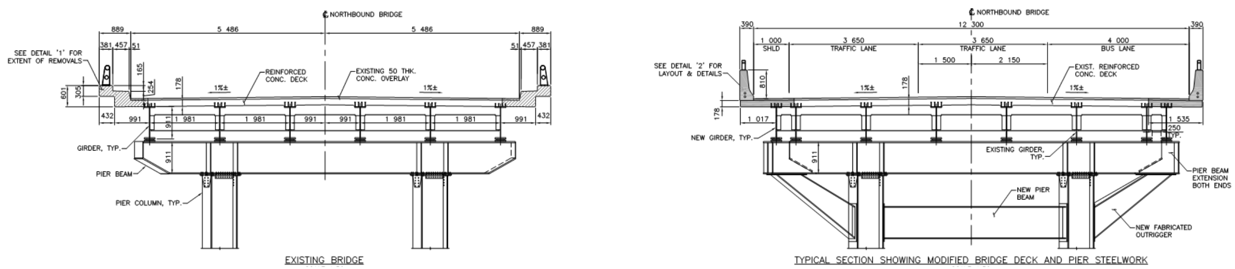

Figure 4 – Typical Section of the Existing (left) and Widened (right) Bridge Structure

Although the widening appears structurally simple, there are a number of design challenges including: (i) assessment of the existing structure for the added live load; (ii) poor soil condition and associating lightweight design; (iii) design to accommodate staged construction for uninterrupted traffic during construction; and (iv) limited headroom for foundation upgrade. Additionally, the schedule and the cost of the widening were very critical in order to qualify for federal stimulus funds available through the infrastructure improvement program. Each of these challenges is discussed next.

CONDITION ASSESSMENT: Prior to detailed design of the bridge widening, a thorough assessment of the existing structure was needed to evaluate its capacity for the added live load. Detailed inspection of the structure was carried out to validate the condition of major component, together with load rating and fatigue life assessment. It was found that the existing girders and deck cantilever did not have the required capacity for the widened deck and improved railing system. The existing timber piles were inspected and confirmed of their condition and capacity.

LIGHTWEIGHT CONSTRUCTION: Due to poor soil conditions in this area of the Mud Bay foreshore, the existing structures were designed using structural steel for the superstructure and piers to achieve a very light and efficient bridge structure. It is of interest to note that the construction records indicate that, during the construction of the original highway, large settlements were observed at the embankments leading to the bridge. Some records indicated settlements of up to 2 meters. Hence, the bridge was designed to be able to accommodate anticipated differential settlements and incorporated adjustable pier column supports with built-in shims to adjust the bridge deck profile in case of unexpected settlements along the length of the bridge. In order to minimize the amount of structural strengthening, intimate coordination with highway designer was required to achieve the narrowest possible deck configuration to accommodate three lanes of traffic and two new improved bridge parapets.

BRIDGE WIDENING DESIGN: The superstructure was widened on both sides of the bridge deck to maintain the symmetry of the bridge deck and allowed for the installation of new bridge barriers to improve vehicle safety. An additional line of steel girders was required along each side of the bridge deck to support the widened deck. The new girders were designed to replicate the mechanical properties of the existing girders in order to minimize undesirable changes to the stiffness and behavior of the existing structural system. The widening of the bridge superstructure required the strengthening of the existing steel frame piers. The existing steel pier bents are built in a typical rigid frame configuration with overhangs of bent cap beam to support the exterior lines of steel girders of the bridge superstructure. In order to minimize additional weight, a scheme using fabricated steel outriggers and strut was adopted to strengthen the existing piers. The outrigger strut supports the lengthened cantilever of the bent cap beam and a spreader beam spans between vertical legs (columns) of the pier frame where the outrigger struts were framed into (see Figure 4). Along with the widening, two bridge deck expansion joints were eliminated over the supports with fixed bearings by constructing a new link slab to improve the overall integrity of the superstructure and to reduce future maintenance of the deck.

FOUNDATION UPGRADE: The existing pier foundations which comprise 14 timber piles each, although are in good condition, are required to be augmented due to the added dead load from the widened superstructure. The available headroom between the underside of the bridge girder and the ground is only 6 meters; this headroom limitation prohibits the use of conventional pile driving technique. This is an area where new technology and modern equipment comes to play an important role. Helical piles, as shown in Figure 5, which can be installed using a torque convertor mounted on an excavator under the limited headroom, were selected. This new type of deep foundation system transfers loads down a shaft onto helical bearing plates and into load bearing soil. Four helical piles were installed per pier in close proximity to the four corners of the existing pile caps and extended to the same soil bearing strata as the existing timber piles. The pile cap had to be enlarged to tie the new piles into the group of existing timber piles. A static load test was performed to confirm the capacity and performance of the helical pile. The abutments, which used spread footings on top of the approach embankments, were widened to support the new additional steel girders.

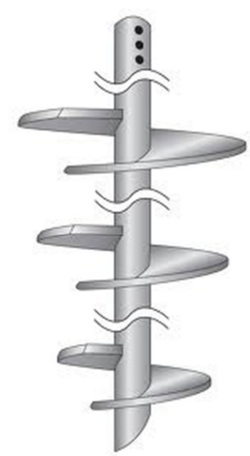

Figure 5 – Helical Pile

In order to meet governmental stimulus funding requirements, the additional steel rocker bearings supporting the new girders, matching that of the existing bearings, were designed and tendered separately prior to the tendering of the main works in order to prevent delays of the project. The timely input, reviews and consultations with BC MoT were instrumental in preparation of the tender documents in a short period of time.

SEISMIC RETROFIT: A review of the seismic behavior of the existing bridge structure identified serious deficiencies that would require extensive work not only on the overpass structure above the ground, but also on the foundations and embankments leading to the bridge. The underlying soils are susceptible to liquefaction under moderate seismic event. This would cause loss of lateral load carrying capacity for the pier piles and large ground movement of the embankment fills. The cost of seismically retrofitting the existing bridge and mitigating excessive ground movement of the embankments was estimated and found to be higher than that of constructing a new, modern crossing designed to the latest seismic requirements of the Bridge Code. In view of this finding and with the understanding that this overpass will need to be replaced at some future date, we were requested to develop a retrofit scheme that would prevent the collapse of the bridge and would be able to provide immediate access for emergency vehicles within a short period after a 475-year return period event.

The proposed "catcher" beam system was designed to prevent the collapse by providing completely independent supports ("catchers") to the bridge superstructure in the event that the load bearing capacity of the existing timber piles augmented by new helical piles is lost due to liquefaction of the soil strata underlying the bridge site. The "catcher" beam system uses larger diameter ductile steel pipe piles driven beyond the liquefiable layers to the competent soil strata to form the primary vertical supporting members of the "catcher" frame and a pre-fabricated steel girder under slung below the existing bridge superstructure and structurally connected to the steel pipe piles to become the required "catcher" beam. A nominal gap of 100 mm was provided between the top of the "catcher" beam and the underside of the bridge superstructure such that under normal service conditions, the "catcher" frames have no contact with the superstructure. The "catcher" frames will only be engaged when the superstructure has lost its original supports caused by the design earthquake. Once in contact, the bridge superstructure will be carried by the stiff "catcher" frames, thus preventing the collapse of the structure.

All steel pipe piles of the "catcher" frames were driven into the non-liquefiable soil strata to an approximate depth of 50 m (160 ft). The "catcher" frames were installed in a close proximity to the existing bridge piers and painted to match the color of the existing steelwork of the bridge. Figure 7 shows sketch of the "catcher" frame system.

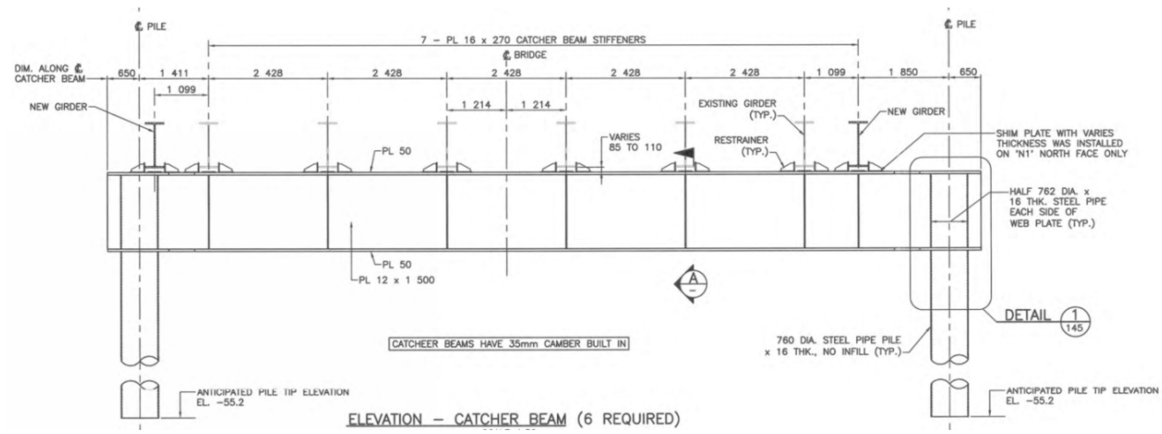

Figure 7 – Drawing of Catcher Frame

In addition, transverse restrainers were provided at either side of the steel girders to prevent lateral movement of the superstructure. To further protect the integrity of the dapped-end supports within the spans of steel girders, longitudinal restrainers using Dywidag bars were installed to tie the girders together. The ground improvement for the embankments is yet to be completed at a later stage. In the interim, if there is any substantial damage to the approach embankments by earthquakes, a temporary repair or partial re-build will likely be required to provide access for emergency vehicles. Figure 6 is a photo of the completed “catcher” frame system.

Figure 6 – Photo of the “Catcher” frame system

4.0 Construction Challenges

Geotechnical and environmental factors played a very significant role in the design and preparation of the tender document for this project. As discussed, helical piles were used for pier foundation strengthening. This technology is well suited for the site conditions encountered and, in the futher, will likely be used more frequently by the BC MoT. From an environmental point of view, all in-ground construction endeavored to maintain and improve the condition of drainage channels present along each side of the railway track. Particular attention was given to the aging underground sewer lines running under service road passing through the eastern side span of the bridge. A monitoring plan for these buried utilities was developed and implemented during construction. An emergency plan was also put in place in case of any damage suffered as a result of the piling operations.

The following summarizes the key challenges encountered during construction.

<u>TRAFFIC MANAGEMENT</u>: As a major highway corridor connecting Vancouver and the US border crossing, any closures on Highway 99 would result in significant traffic congestion and economic losses, neither of which is not desirable nor permitted. Therefore, the BC MoT mandated that two traffic lanes be open in each direction between 5:30 am to 8:00 pm from Monday to Sunday. Closing any lanes or work adjacent to the traffic lanes during those hours was not allowed.

A detailed traffic management plan was developed, and, together with well-staged construction sequences, the widening and seismic retrofit work was accomplished while maintaining an uninterrupted flow of traffic. A two-stage construction approach was used for the widening: with one side of the bridge being worked on behind temporary concrete barriers while maintaining two lanes of traffic with a reduced lane width on the other side of the barriers (see Figure 8). The staged construction was also used for the widening work on the piers and abutments.

Figure 8 – Traffic Management During Construction

<u>WORKING NEAR A RAILWAY</u>: As mentioned earlier, the BNR overhead structure crosses over the Burlington North Railway Line, which is a major railway corridor connecting Washington State and BC. The construction work had to be carefully planned to maintain the railway clearance envelope and to minimize interference with railway operation. Construction work adjacent to or above the railway line had to be scheduled to be done between all train traffic. In general, a railway flagging person is required whenever work is done over the railway track, within 10 m of the railway track, or when equipment crosses the railway track. All equipment within 10 m of the nearest railway track have to stop working on the approach of a train and remain stopped until the train has passed. With careful planning, the construction was successfully carried out with no delays and/or interruptions for the train operation.

<u>PILE DRIVING</u>: The “catcher” frames, which are constructed to prevent collapse of the structure under a major earthquake, consist of steel pipe piles and pre-fabricated steel beams. The steel pipe piles are typically located along edges of the deck, and the traditional pile driving method by Diesel hammer was used. However, the access area was limited by the close proximity of the adjacent southbound structure and pile driving was prohibited from the bridge deck. The solution was to install the piles immediately after the demolition of the overhang of the existing deck but prior to the construction of the new widened deck and the new bridge barriers. It was a significant challenge for the Contractor to move the pile driving equipment in position and to drive piles between the northbound and southbound bridges and to keep the operation outside the railway clearance envelope. Figure 9 is a photo showing the pile driving during night time.

Figure 9 – Pile Driving at Night

Each pile had to be driven in relatively short sections and spliced. This generally suited well to the construction shifts that the pile driving was done during short night time closure window available and splicing the piles done during long day time shift.

HELICAL PILE INSTALLATION: Due to the additional loads from the bridge widening, four helical piles with 810 mm diameter helices and a 273 mm dia. x 9.27 thick steel shaft were required. These piles were installed using an excavator with a torque convertor to the same pile tip elevation as the existing timber piles in order to transfer the pile loads to the same bearing strata. Piles were installed in short 2 m segments as dictated by the limited headroom available. Figure 10 depicts the installation and location details. This was the first BC MoT bridge project to use helical piles.

Figure 10 – Driving of the Helical Piles

UTLITIES: There are two aging Metro Vancouver sanitary lines under the existing east service road between the first two piers adjacent to the east abutment (N5 and N4) of the BNR Overpass Structure. The potential effects of "catcher" and helical pile installation on these force mains (500 mm diameter FRP pipe and 750 mm diameter steel pipe) was a major cause of concern. The Contractor implemented a utility protection plan prior to the start of the piling operation. This included:

- A utility monitoring plan, which included
    - an assessment and report on the condition of the existing force mains with relevant parties;
    - minimum survey monitoring points,
    - the establishment of bench marks, limits and procedures on excessive ground movement;

  - and measurement of peak particle velocities during piling operations.
- A contingency plan to provide a working knowledge of the locations of shut-off valves and the requirements for an emergency sewer bypass in case of sewer line damage.

WIDENING OF THE EXISTING STEEL PIERS: The widening of the bridge superstructure required widening of the existing piers to support one additional steel girder along each side of the bridge deck. The widening scheme adopted an outrigger strut supporting the lengthened cantilever of the top beam and a spreader beam between vertical legs of the pier frame where the outrigger struts framed into. Figure 11 shows the completed steel pier widening.

Figure 11 – Retrofit of Existing Pier Support

Although the structural solution described above is easy to understand and relatively simple to design, the construction proved to be quite challenging. The initial field fit-up, in particular, required more time than expected and the field welding also experienced some difficulties and caused time loss. However, these construction problems were resolved in time to proceed with the widening of the bridge superstructure and the completed pier widening blend well with the existing structural system of this 50-year-old bridge.

5.0 Conclusion

To alleviate traffic congestion and encourage sustainable commuting, a shoulder bus lane was added to this 50-year-old, 107-meter-long (35 ft) steel bridge crossing the Burlington Northern Railway on Highway 99. As part of the widening project, the existing bridge was also seismically assessed and an options analysis was carried out to compare various short- and long-term solutions for accommodating the dedicated bus lane and seismically upgrading of the bridge.

The added bus lane was accommodated by additional lines of steel girders along each side of the deck to support the widened deck and by lengthening and strengthening the existing steel piers, while maintaining the symmetry of the structure and upgrading the bridge traffic barriers to the new PL2 system. Because of the limited headroom underneath the structure, helical piles were selected and used to strengthen the foundation for the addition loads. In addition to installing longitudinal Dywidag bar restrainers at the dapped-end supports of the steel girders to prevent unseating, an independent “catcher” frame system was adopted to provide a cost effective and efficient system to prevent the collapse of the bridge structure during an earthquake.

The various construction challenges including traffic management, working near a railway, protecting existing utilities, and pile driving challenges were overcome by careful planning and close collaboration among the design team, the Owner, and the Contractors. The project was successfully delivered to meet deadline requirements for governmental stimulus funding and received the 2011 Deputy Minister’s Award of Merit from the BC MoT.