Design challenges to accommodate operations, maintenance, and construction considerations of the Neptune Cargill Overpass Extension Project

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Abstract

As Canada's largest multi-product bulk terminal, Neptune Bulk Terminals in North Vancouver plays an integral role in connecting the Canadian economy with overseas markets through handling commodities for export. The Neptune Cargill Overpass Extension forms part of the scope of a massive expansion initiative, termed the Allison Project, which would see terminal capacities increased to the order of 20 million tonnes of product handled annually. The Neptune Cargill Overpass Extension aims to improve access to a growing port terminal in the North Shore Trade Area. Stantec provided engineering design and construction support for this new overpass extension which was completed in 2019. This grade separation offers a direct route into the terminal steelmaking coal storage yard from Low Level Road and the existing Neptune/Cargill Overpass, improving terminal operations, efficiency in goods movement, and site safety via improved emergency access. The new bridge spans approximately 64.8 m on a curved alignment over a maintenance road entrance to an existing settlement pond, terminal access road, and multiple freight rail tracks. This paper discusses the challenges our team faced to accommodate rail operations, maintenance, seismic hazards, girder erection, and traffic management.

From the early stages in our design process, integration of operations played an important role. This overpass extension project was actually envisaged at the time of the Low Level Road Project and Neptune/Cargill Overpass original construction in 2013-2014 as part of the next phase in development. Our multi-disciplinary design team was intimately aware of the community impacts, port operations and site constraints given our previous involvement having worked in the area, and this was valuable to developing an innovative design solution that met the project objectives. Minimizing and avoiding rail operation disruption was a key consideration for the new grade separation, in addition to the adverse soil conditions that included areas of lateral spreading and liquefaction hazards.

During design development, fabrication and shipment of the superstructure girders required careful consideration of rail logistics and structure element sizing. The resulting bridge solution was streamlined for ease of construction through meticulous detailing and modular design. The steel components of the superstructure were fabricated and transported to site where it was fully assembled on the ground before being erected via self-propelled modular transporter (SPMT) units. With close coordination of the designer, terminal operator, railways, and contractor, Accelerated Bridge Construction (ABC) techniques were used to save project costs, minimize disruption to rail activities and enhance safety with respect to carrying out overhead works above the live rail envelope. The result is a more efficient link from the local arterial road network to the terminal site within the railway loop.

1 Introduction

The Neptune Cargill Overpass Extension project represents one of the most recent additions to the infrastructure of the Neptune Bulk Terminals Ltd. (NBT). NBT, owned by Canpotex Bulk Terminals Limited and Teck Coal Partnership (owner), integrates Canadian economy with overseas markets by providing commodities handling operations for products such as steelmaking coal and potash.

With over 57.5 m in clear span, the overpass structure crosses 7 lines of active rail tracks, various maintenance and access roads, and future alignments for 2 additional rail tracks. The bridge connects the existing overpass to the north with the steelmaking coal stockpile to the south. As with the Neptune/Cargill Overpass, also designed by Stantec Consulting Ltd. (Stantec), the Neptune Cargill Overpass Extension was to provide further improvements to the efficiency, integrity, and safety of the terminal's operations. The bridge allows for the uninterrupted movement of railway cars at grade while providing vehicles with a protected, direct access route to the main terminal operations. The Client's priorities were not only to build a connection from "A to B" but also to maximize efficiencies in design and construction by harnessing innovation, resiliency, and sustainability.

The unique features of this project include:

- its highly optimized, minimal footprint which integrates with existing infrastructure while addressing the geometric constraints imposed by geometry of the existing MSE wall at the north end, entrance requirements to the settlement pond, existing road and rail movement and limited space within the steelmaking coal stockpile;
- a short varying span length in concrete that required a partial demolish and rebuild of the existing MSE wall to accommodate the span without the need for bearings;
- a varying skew combined with a tightly curved horizontal alignment on the long steel girder span;
- multiple clearance requirements for railway and roadway right of ways;
- detailing, assembly and erection of girder components using accelerated bridge construction techniques; and
- the management of the construction process to effectively minimize disruptions to terminal operations.

The design and construction challenges encountered with the delivery of this project represent the core part of this paper and are described in the sections that follow.

2 Background

Since 1968, NBT has handled potash, steelmaking coal, bulk vegetable oils, fertilizers and agricultural products to be shipped to markets around the world. This facility is the largest multi-product bulk terminal in North America, and currently maintains operations from a leased portion of the Port of Vancouver terminal on the northern shores of the Burrard Inlet. The terminal covers a total area of 29 hectares, plus adjacent water lots. In 2011, NBT conducted a feasibility study which proposed the addition of two terminal components to increase the steelmaking coal export capacity. The feasibility study considered infrastructure upgrades to railcar dumper buildings, conveyor systems, ship loaders, and rail alignments. Access improvements throughout the site were also considered, including vehicular access from Low Level Road to the stockpile in the southern extents of the terminal. In 2013, the design and construction of the Low Level Project was underway through an initiative led by the Vancouver Fraser Port Authority (VFPA) to improve municipal infrastructure for rail and terminal operations, and enhance the safety and multi-modal connectivity of the Low Level Road corridor. The scope of the project included the construction of the Neptune Cargill Overpass, a new vehicular overpass that would replace an at-grade crossing and service industrial traffic from Low Level Road directly to the port terminal sites shared by NBT and Cargill Canada Inc. (Cargill). Through stakeholder consultation with NBT, the design criteria for the Neptune/Cargill Overpass were refined to include considerations for a future span that would extend from its south abutment, over the rail tracks and towards the stockpile. This future span would later become known as the Neptune Cargill Overpass Extension.

By 2017, the construction of the Neptune Cargill Overpass Extension would officially form part of the scope of the Allison Project, an extensive expansion of NBT's steelmaking coal export facilities as originally envisioned in the 2011 study. After completion of the Allison Project, it is expected that the capacity of the NBT facilities will increase to the order of 30 million tonnes of product handled annually. Given Stantec's involvement as Engineer of Record for the Neptune/Cargill Overpass and intimate knowledge of the terminal site, Teck Resources Ltd. retained Stantec for design and construction support services of the Neptune Cargill Overpass Extension. Fluor Canada Ltd. (Fluor) acted as the agent to the Owner (NBT), i.e., owner's engineer, providing commercial management and contract administration services. General contracting services were provided by B&B Heavy Civil Construction Ltd. (B&B). Steel components of the superstructure were fabricated by Capitol Steel. Nilex Inc. (Nilex) provided proprietary design of the Mechanically Stabilized Earth (MSE) ramp at south side of the bridge structure. Foundation and pavement design were developed by Golder Associates Inc. (Golder) who closely cooperated with our team at Stantec.

3 The Bridge

The Neptune Cargill Overpass Extension is a two-span bridge located at Neptune Bulk Terminals in North Vancouver, British Columbia, approximately 2.0 km west of the Ironworkers Memorial Second Narrows Bridge as shown in Figure 1. The bridge spans seven existing rail tracks a maintenance road, with provisions to span two future rail alignments, and provides connectivity from Low Level Road to the steelmaking coal loading facilities on the south side of the NBT site.

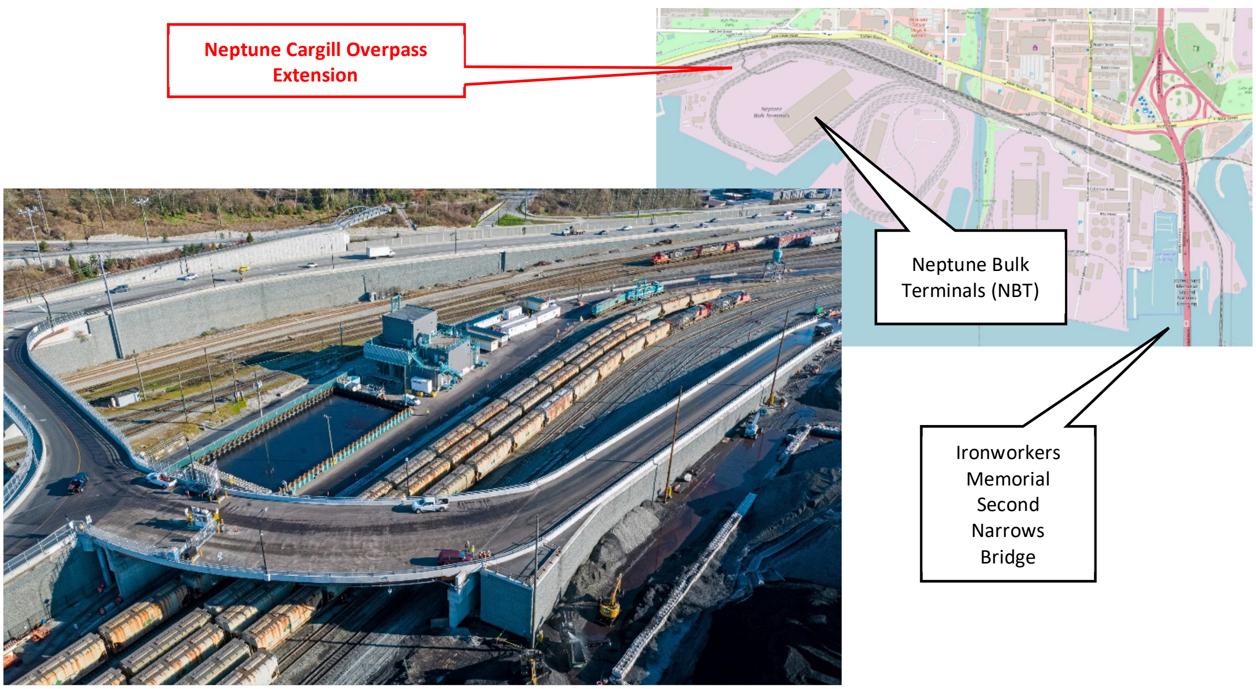

Figure 1: Aerial view of the Neptune Cargill Overpass Extension Project and vicinity map [Ref 3]

There were four alignment options developed in the conceptual design stage. The options explored various bridge superstructure types including a curved girder, a straight girder, a highly skewed deck girder, and a flared girder. The curved girder was ultimately selected as the preferred option due to the following advantages:

- Lowest impact on the existing facility given limited access points;
- Reduced construction footprint, resulting in minimal disruption to ongoing operations;

- Shallower and lighter steel sections as shorter spans met the required minimum clearances;
- Continuous and consistent turning movements achieved by the road alignment;
- Overbuilding of cantilever deck not required when using curved rather than straight girders to accommodate a small radius roadway curve;
- More aesthetically pleasing by eliminating the steel framing normally required to support a large cantilever deck; and
- North span configuration provides cost-effective solution reducing modifications to existing overpass.

The final structure consists of a 57.5 m long steel box girder main span and a 7.3 m long cast-in-place (CIP) concrete solid slab at the north end of the structure. The total bridge length is 64.8 m, measured from abutment centerlines along the roadway alignment control line. The vertical profile of the roadway alignment has a 1% downward slope toward the south abutment. At the south approach, a mechanically stabilized earth (MSE) retaining wall provides a smooth transition from the bridge deck down to grade. A CIP concrete approach slab is provided between the south abutment ballast wall and the south approach ramp MSE wall.

Due to the bridge's skewed and curved alignment, the total deck width varies along the span from 19.04 m to 19.98 m, inclusive of traffic barriers. The traffic barriers consist of British Columbia Ministry of Transportation and Infrastructure (BC MoTI) standard bridge parapets and steel bicycle railings. The deck accommodates two traffic lanes of varying and unequal widths, with a minimum 6.66 m clear lane width provided. Modular security kiosk and gate components were also installed on the deck surface and designed to allow for future modifications by the Client. An elevation view of the structure is shown in Figure 2.

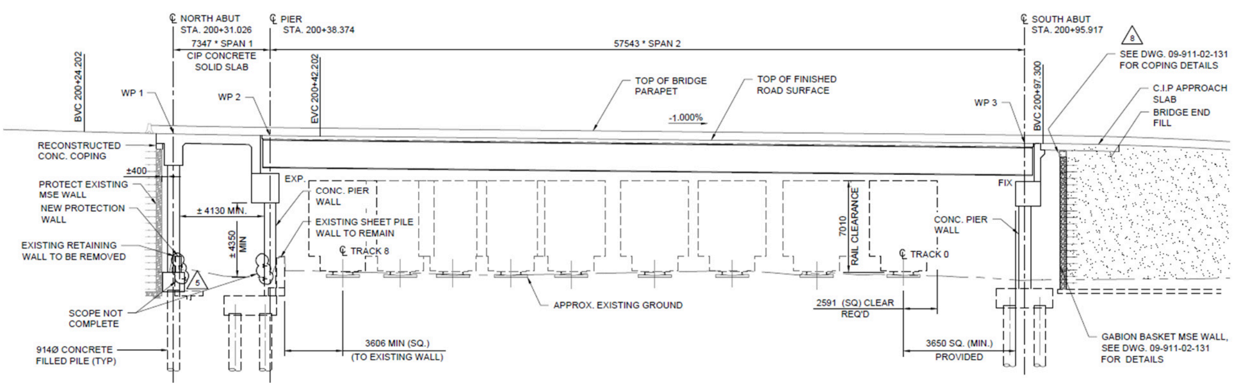

Figure 2: Elevation view of the bridge

The main span superstructure is comprised of three weathering steel curved tub girders made composite with a 240 mm thick CIP concrete deck. A protective coating was applied to the weathering steel girders for a 3 m section from girder ends to provide further corrosion protection due to the proximity of deck joints. Bearing articulation for the main span consists of fixed bearings at the south abutment and expansion bearings at the pier. A combination of multi-directional and uni-directional pot bearings at the expansion-end accommodate longitudinal movements as well as translational movements generated due to its asymmetrical configuration. Bearings have been designed to accommodate axial loads upwards of 7,700 kN, horizontal loads of 2,000 kN, rotations in the order of 20-40 mRAD as well as uplift forces on the central and inner girders. A typical cross-section of the bridge superstructure is depicted in Figure 3.

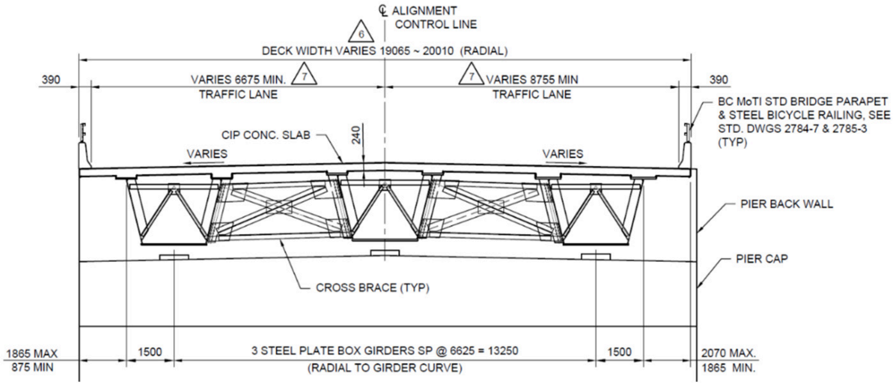

Figure 3: Typical cross-section of the bridge superstructure

The box girders comprised of welded flange and web plates with shear studs welded to the top flange to achieve composite action with the concrete deck. Each of the three girders features unique cambers and horizontal curvatures to achieve the desired roadway alignment. Two field splices were provided along each girder's length. Weathering steel K-bracing was provided inside each box girder at a typical spacing of approximately 3.0 m on centre and external X-bracing was at intervals of approximately 6.0 m on centre. The external bracing units were comprised of top, bottom, and diagonal chords which have been shop welded to form a single bracing assembly that can then be rapidly bolted onto girder stiffener plates on site. At the abutment and pier supports, a bolted plate diaphragms were provided with shear studs on the top flange to achieve composite action with the concrete deck. The diaphragm helps to distribute traffic loads as they transition from the stiff approach slab (MSE ramp end) and stiff concrete span (north end) into the relatively flexible, by comparison, concrete deck spanning between girder flanges. The diaphragm also helps stabilize the highly skewed girders ends under the heavy wet concrete load before the system becomes composite. The CIP concrete deck was placed in three stages beginning with the central section between field splices, followed by the south and north sections, respectively, as shown in Figure 4.

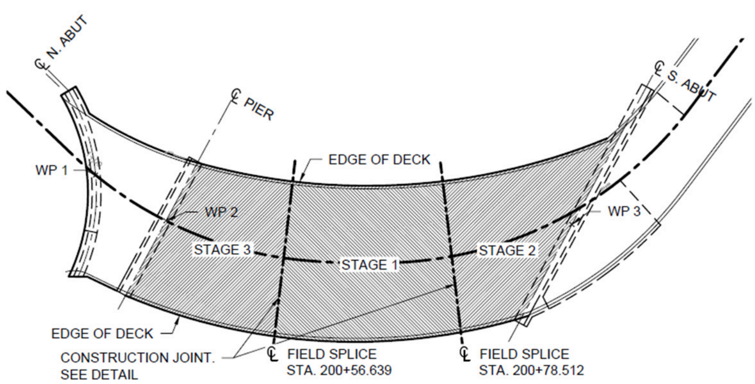

Figure 4: Plan View of Deck - Pour Sequence

The north span superstructure is comprised of a 700 mm thick concrete slab integral with the central pier and the north abutment cap and therefore considered to be fixed at both ends. A solid slab superstructure type was chosen for this span as it interfaces seamlessly with the existing curved MSE retaining wall Neptune/Cargill Overpass without the need for complex detailing or formwork. The solid slab also provides the shallowest profile, thereby maximizing the vertical clearance beneath this span needed for access to the adjacent settlement pond. Partial demolition of the existing MSE wall and coping was required along with tie-in details for the existing and new bridge parapets.

The substructure consists of a CIP concrete cap and wall at the south abutment and pier. At the north abutment, a CIP concrete cap is provided with five 900 mm diameter CIP concrete columns. The foundation at each substructure location was comprised of CIP concrete pile caps on steel pipe piles. The piles consisted of 914 mm O.D. open-ended piles with a concrete plug infill provided for the top 15.0 m. The piles were designed with respect to both static and seismic load cases, with the potential for soil liquefaction governing the design of the piles. As described further in Section 4.4, sophisticated iterative analyses were developed to characterize the soil-structure interaction of the piles. Maximum factored axial compression loads were in the order of 7,400 kN and significant uplift forces were also identified.

The south approach ramp is an MSE wall with a vertical wire basket facing and provides approximately a negative 6% grade from the south abutment of the overpass. The MSE ramp incorporated proprietary design details developed by Nilex.

4 Design challenges

The sections below describe some of the challenges encountered by the Project team during the design and construction of the overpass, which required close collaboration with the Client's representative, the general contractor, and their subcontractors. The design of the Neptune Cargill Overpass Extension was completed in accordance with number of codes and standards, the key documents are referenced in Section 8 [Ref 5 to 13]. A typical design life of 75 years was considered, and 100 years was assumed for any time dependent design calculations.

4.1 Minimizing Disruptions of Facility Operations

Minimizing interruptions to ongoing terminal operations throughout construction of the Neptune Cargill Overpass Extension was one of the key challenges faced by the Project team. It was important to minimize disruption to terminal operations in order to maintain the flow of goods movement for this important terminal in the Asia Pacific Gateway supply chain network. The site was highly constrained from all sides by existing port infrastructure, including an active steelmaking coal stockpile along the southern extents of the project, seven active rail tracks and vehicular access beneath the bridge main span, and a settlement pond encroaching onto the future location of the north abutment and central pier. Overview of the site is shown in Figure 5.

Figure 5: Overview of Site, looking west (after completion of overpass construction)

As the port maintains operations 24 hours of the day, seven days a week, the site was heavily trafficked by industrial activity throughout the construction period. Traffic detours and accommodations were managed through a combination of traffic control personnel and traffic light signalization to accommodate alternating traffic through narrow access corridors. Construction activities were planned around terminal shift schedules to minimize wait times and avoid the accumulation of traffic at entry points. Material laydown areas and staging areas were strategically placed to minimize conflicts with existing operations.

Work zones were limited in size and sometimes irregularly shaped, which limited the equipment that could be utilized for construction. The clear distance between the MSE wall of the existing overpass and the sheet pile walls of the settlement pond measured less than 900 mm, demonstrating how tightly congested this area was. One of the early works consisted of reconfiguring the settlement pond to accommodate the construction of the north span of the overpass. The existing sheet pile and concrete was partially demolished, and a temporary wall was erected to establish the work zone. Modifications were required to accommodate staging areas for pile driving equipment while maintaining full access and operation of the settlement pond during overpass construction. The original configuration of the settlement pond, prior to modifications, is depicted in Figure 6.

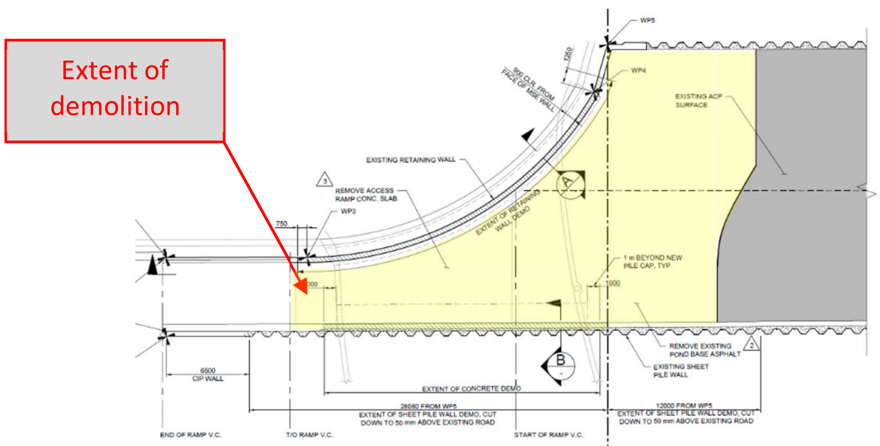

Figure 6: Existing Conditions and Settlement Pond Demolition Extents

To maximize the limited footprint area for the overpass, the north abutment and the pier were designed to integrate directly into the settlement pond retaining wall system while also providing adequate lateral clearance for the future construction of a ramp to improve access to the settlement pond.

It was required that all existing rail tracks remained operational, and delays or interruptions to port operations were avoided wherever possible. With the main span directly over the rail tracks, the steel box girder erection had the greatest potential for disruption to NBT's operations. Stantec worked together with the Contractor to develop a construction scheme to maximize the use of staging areas and minimize rail closure times. Construction staging scenarios proposed by the Contractor were verified using multiple 3D finite element analysis models to verify girder stability during assembly and erection. Steel connection detailing and haunch calculations were developed to allow the girders to be almost fully assembled on the ground, including the bracing, deck formwork and one layer of deck reinforcing steel. The assembled superstructure was then lifted off the ground from the assembly yard and lowered into position using self-propelled modular transporter (SPMT) units, all within a 90-minute rail closure interval, as further described in Section 4.5.3.

Existing and future utilities, including water mains, sanitary lines, and effluent lines in close vicinity to the bridge abutments were addressed to avoid disruption of utility services throughout the terminal site. At the south end of the MSE approach ramp, attention had to be paid to existing water/storm sewer lines passing through the facility from the adjacent the Greater Vancouver Regional District (GVRD).

4.2 Future Maintenance

Based on unique Client needs, the design of the overpass prioritized details which would minimize the frequency and extent of future maintenance in the long term. Specific circumstances had to be taken into account, such as: the structure's location spanning multiple railway tracks and tightly constrained by other infrastructure; necessity to accommodate a curved path; proximity to the steelmaking coal stockpile lending to dust and contaminant levels in the environment; and access to the existing adjacent settlement pond.

4.2.1 Structural Condition Inspections and Maintenance

The structural system conceived during concept stage and further refined during the design process incorporated details which would facilitate future inspection and maintenance activities. Considerations included load path redundancies, fatigue resistant details, materials selection, adequate protection from environmental factors and unobtrusive access to critical bridge components.

The three-girder system lends itself to load path redundancy and avoids the introduction of fracture critical elements, which typically require extensive inspections by highly trained inspectors. For similar reasons, fatigue prone details were avoided wherever possible by minimizing abrupt section changes and utilizing bolted connections. Figure 7 depicts the typical girder section and access hatch elevations as described above.

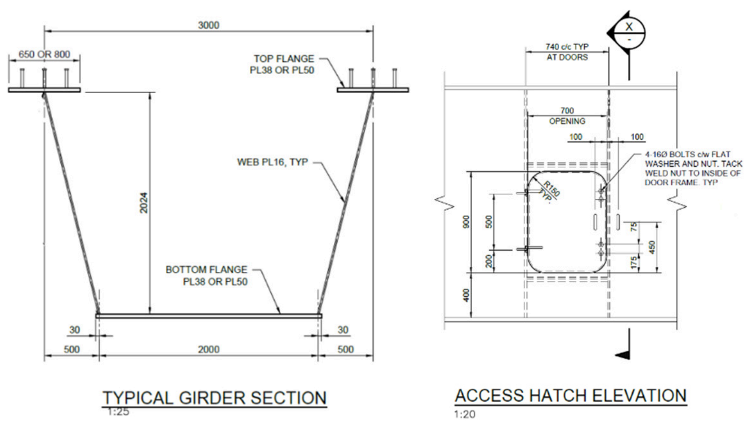

Figure 7: Typical Girder Section and Access Hatch – Clearance Dimensions for Inspection Access

A closed box section was selected for the main span of the structure as it provided excellent versatility to accommodate curved alignments and high torsional demands. However, for ease of inspection and maintenance, a box girder is generally less desirable when compared to a typical I-girder as interior surfaces are not readily accessible. Nevertheless, with proper detailing, access concerns can be effectively mitigated. The low-profile design of the railings facilitates inspections via snooper truck from the bridge deck. The increased arm reach provides access to all exterior superstructure surfaces and the deck soffit with minimal disruptions to railway operations beneath the bridge.

Inspection of the interior surfaces of the box girder can be completed by personnel using confined space entry techniques. The trapezoidal shape of the box girder lends itself well to inspection, as it provides a more generous lateral clearance, as compared to a straight box section. The girder section's interior vertical clearance at 2,024 mm provides adequate headroom to accommodate the height of an average inspector with room for maneuvering any necessary equipment. Access hatches measuring 700 mm wide and 800 mm tall allow for entry and emergency egress at both girder ends. These provisions are in accordance with CSA S6-14 Canadian Highway Bridge Design Code (CHBDC), Clause 1.8.3.1.5 which specifies minimum vertical clearances and access hatch openings in primary cellular girders. Maintenance access considerations are similar to those for inspection of I-girders. In addition, tub girder sections selected are advantageous for this specific site due to the proximity to the stockpile and heavily trafficked industrial facilities. With outwardly sloping webs and negligible horizontal surfaces, opportunities for detrimental substances to collect on the girder surface is minimized, along with bird-roosting opportunities. Combined with the use of weathering steel components, this superstructure type provides excellent resistance to corrosive activity and eliminates expensive maintenance costs associated with steel recoating. The northern span over the sediment pond access road utilizes a solid concrete slab superstructure integral with the pier and north abutment. As expansion joints are typically a major factor in long-term maintenance costs, therefore, having no joints at this span significantly reduces maintenance efforts and the corresponding impacts on access to the settlement pond.

4.2.2 Terminal Infrastructure Maintenance Access

The overpass design also took into account future maintenance of the adjacent terminal infrastructure, particularly of the settlement pond and rail tracks. The bridge spans seven lanes of active railway tracks (with an additional two future alignments planned), requiring a total lateral clearance of over 45 m. In addition, the northern bridge span was prepared to accommodate a separate vehicular ramp which would provide maintenance access for the settlement pond. These considerations governed the conceptual design and eventually configuration of the pier wall, the superstructure type selected for the north span, and protection elements required for the structure. Figure 8 presents a plan and section view of the north span as described.

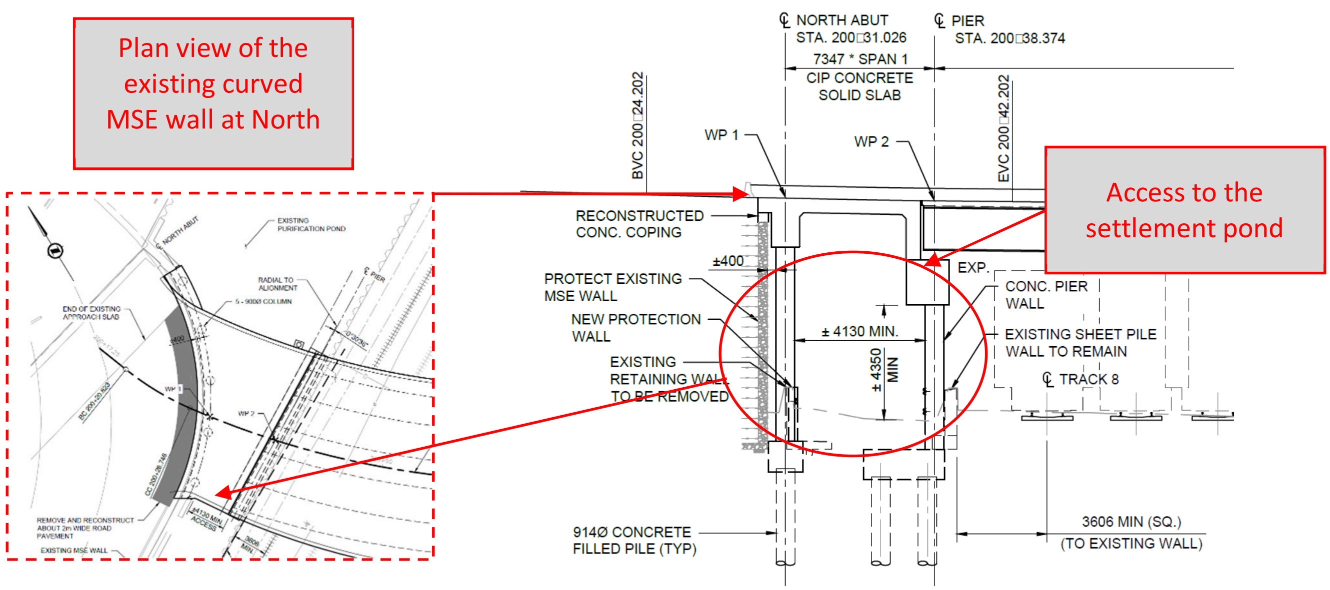

Figure 8: Access to the settlement pond at north abutment of the bridge

The pier could not have been placed within the tracks as it would have disrupted the railway operations, and therefore, it was decided to locate it in vicinity of the existing MSE wall at the north while still providing the adequate clearance for vehicular access to the settlement pond. It should be noted that the existing MSE wall at the north is curved in plan (see Section 3 for additional details), and therefore, lateral clearance under the span varies, but a minimum lateral clearance at the entrance to the span of 4,130 mm was achieved.

4.3 Improving Vehicular Access

One of the main objectives of the overpass was to provide enhanced operations of the overall terminal facility to firstly, enable the remaining scope of the Allison Project (see Section 2 for additional details) and secondly, provide a safe and reliable access route for terminal traffic into the future. The structure is intended to carry industrial traffic from the Low Level Road from the north to the stockpile at the south. As such, various configurations were examined during the development of the roadway alignment to address a diverse range of vehicles while maintaining an efficient structural footprint. The bridge was widened slightly from its original concept design in order to accommodate the curved path and the characteristics of the design vehicles, i.e., turning radii and overall design vehicle lengths. As apparent from Figure 9, these changes resulted in a noticeable difference between the widths of the southern approach roadway and the bridge deck.

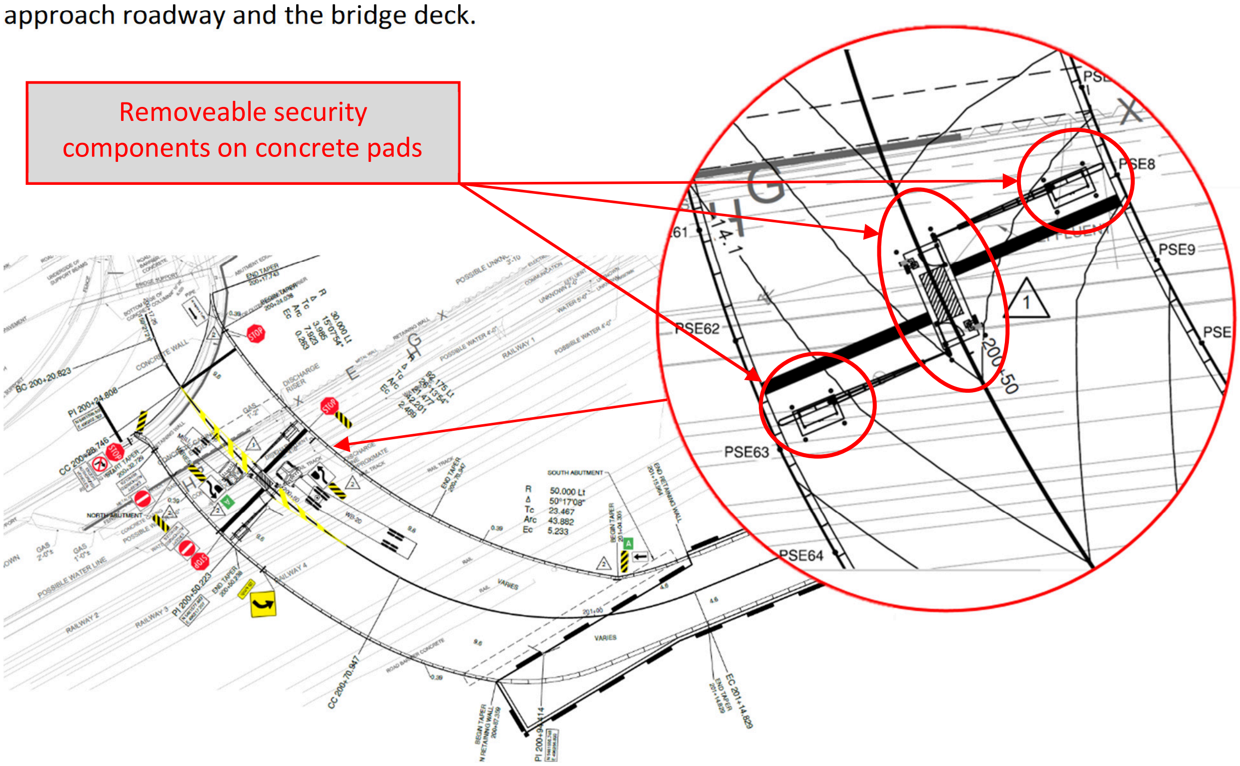

Figure 9: Plan view of overpass deck, depicting removeable security components

Vehicle counts and relevant traffic analyses were conducted to determine turning maneuvers. In the final design, also notable from Figure 9, right turns were prohibited for northbound traffic from the original overpass to the Neptune Cargill Overpass Extension, to avoid potential traffic conflicts at this location. To provide additional accommodations for wide vehicles in the future, security kiosk and gates were designed to be modular and removable. These components were proprietary systems and were mounted on concrete pads which allow for quick removal if the need arises.

Optimization of the bridge width was a complex assignment, involving iterative procedures for each truck type. Variables included bridge curvature limits, minimum turning radii at critical points such as at the interface of the MSE wall and south abutment, and the requirement to streamline the alignment close to rail tracks while maintaining clearance envelopes. Sophisticated roadway models, employing AutoTURN software (a third-party platform released for the AutoCAD), were developed to evaluate and determine necessary bridge width. The governing truck was identified to be Truck W-20. The truck configurations analyzed as part of the geometric design development are presented in Figure 10.

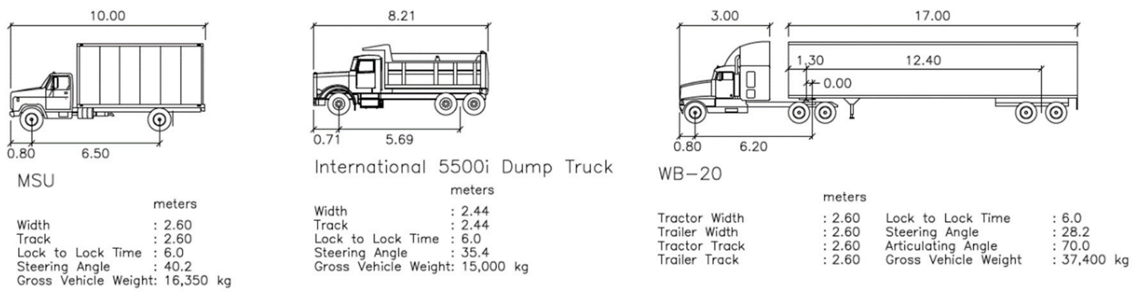

Figure 10: Trucks considered during the Geometric Design

4.4 Seismic Design

The designs of structures within the Lower Mainland of British Columbia are subject to stringent seismic considerations due to the proximity of plate tectonic environments that have the capability to produce three different types of earthquakes with different magnitudes, duration, and intensity and vulnerable geological formations. Furthermore, the project site is situated close to the Burrard Inlet shoreline and therefore is characterized by strata of various compositions susceptible to liquefaction.

The bridge was given a designation of “Other Bridges” which necessitated use of the force-based method of seismic analysis in accordance with CAN/CSA S6-14 CHBDC requirements. The structure was designed to sustain “repairable damage” and “probable replacement” following a 475-year and 2475-year seismic ground motion event, respectively. Resulting pile lengths ranged between 25 m to 35 m. Layout of the foundation piles is further elaborated on in Section 4.5.2. Due to significant design requirements, a complex geotechnical analysis to properly characterize soil-structure interaction was developed and informed subsequent Response Spectrum Analysis (RSA) as well as push-over analyses within the structural model. As later mentioned in Section 4.5.2, non-linear P-Y springs were employed to reflect the plastic behavior of soils acting under liquefied conditions.

The soil strata comprised layers of loose and compact sands, silts, and gravels, forming potentially liquefiable soils. Liquefaction of the subsurface soils was expected to occur in the layers above the till. Fine-grained clayed silt to silty clay layer contained a significant amount of organic material at depths 3.0 to 4.5 m at the southern extents of the bridge. Dense to very dense silt and sand (inferred till-like) was reached at approximately 11 m depth below the ground surface. The dense till-like layer underlining the site was encountered at approximate depth of 31 m.

While the soils were identified as Class F, concerning their susceptibility to liquefaction, it was established to use Class D response design spectrum. Such an assumption is correct in cases when site-specific ground motions are not available and response design spectrum representing Class D can be used to assess inertial loads. With the onset of liquefaction, kinematic loads were imposed on the foundation [Ref 2]. To mitigate impact of liquefiable soils, ground densification was recommended for the MSE ramp located south of the bridge structure. Similarly to the existing Neptune Cargill overpass, Rapid Impact Compaction (RIC) improvements were proposed for the extension of this project. Ground densification was required in depth of 8 m below the surface and 8 m extending horizontally beyond footprint of the MSE ramp.

Despite the bridge being located away from a major road network and inaccessible to the public, design criteria were adopted from the requirements for a typical BC MoTI highway structure. In the case of foundation piles, ASTM 252 standard was imposed as per typical highway project.

The natural period of the structure, being a function of its stiffness and mass, is dependent on the bridge configuration. Given the strength requirements to be met by the substructure, there was only limited room to adjust stiffness of the pier wall and abutment columns. Therefore, the natural period of the structure landed in a range between 0.5 to 0.9 seconds. While being function of the modal shape, the resulting inertial forces were affected by the acceleration of the design spectrum in order of magnitude ranging between 0.55g to 0.75g as shown in Figure 11.

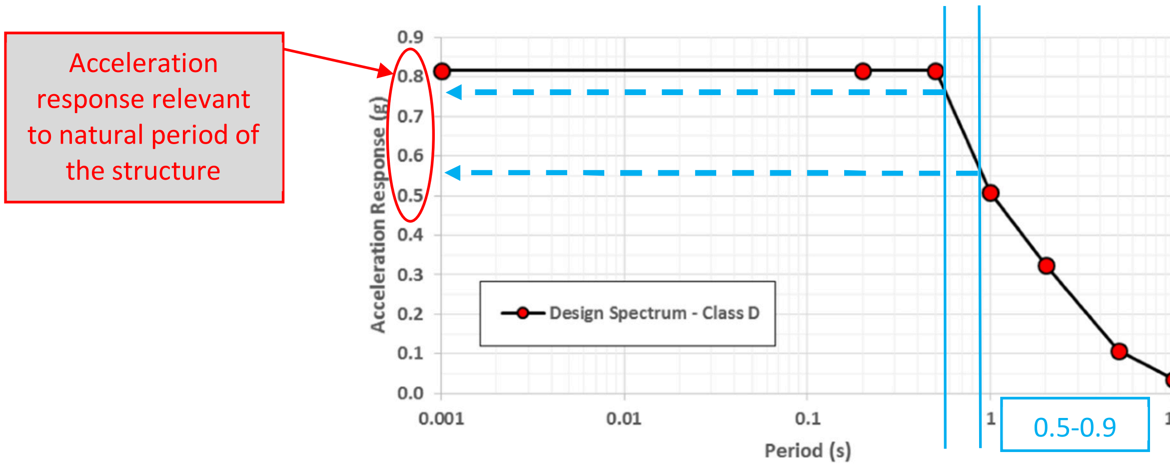

Figure 11: Design response spectrum for Class D soils, depicting acceleration response impacting the inertial forces action upon the structure
(Adapted from a Geotechnical memorandum [Ref 1])

Abutment and pier substructure components were designed assuming that a plastic hinge would form in close vicinity to the underside of the pile cap. In the case of the pier wall, reinforcement in the plastic hinge region was designed and incorporated directly into the slab reinforcement of the deck. Seismic detailing was completed for the steel reinforcement in components through the provision of sufficient development lengths and definition of "no splice zones" at critical locations. A section depicting reinforcement detailing in the pier-wall is shown in Figure 12 as an example.

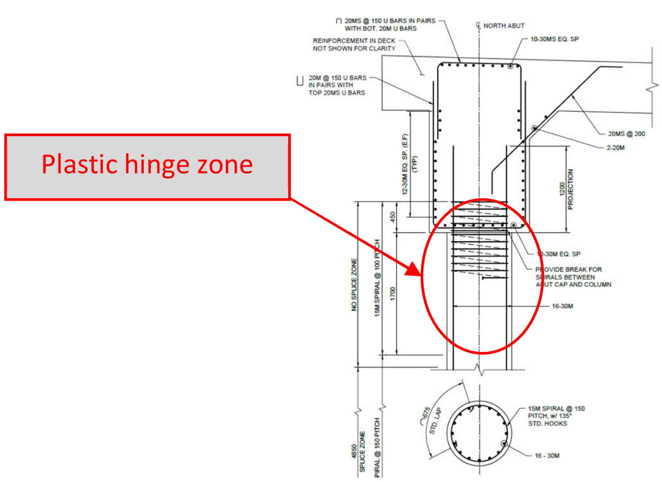

Figure 12: Assumed plastic hinge zone and reinforcement detailing in the pier wall below the pier cap

4.5 Construction

Constructability of the overpass was given high priority during the design development. From the early stages of conceptual design, fabrication limitations, operation of the facility, and specific site constraints were considered. A practical, efficient solution would address the tight footprint of the bridge location and the need to avoid any disruption to railway operations. Close coordination with the client and the contractor for the resolution of design issues was critical. During the construction phase, Stantec teams including structural, roadway, drainage, and electrical engineering personnel cooperated closely with the contractor to resolving issues and meet the proposed schedule.

4.5.1 Fabrication

Fabrication of the steel components took place in Ontario, Canada, which introduced the challenge of transporting the oversized bridge components over 4000 km across the country to the site location in North Vancouver, British Columbia. Delivery of the steelwork, largely via rail, required significant traffic management planning and permitting efforts. Shop drawings for the steel components were prepared by the fabricators and confirmed with the design team to balance transportation logistics with an economical and structurally sound design.

Partial depth diaphragms were used to accommodate the thickened armor joint at girder ends. The stress distribution at the top flange, which is affected by large lateral forces caused by the curvature, was addressed by sloping a section of the top flange. In order develop this transition, the top flange was extended, as shown in Figure 13. Analyses considering distribution of local stresses were carried out to confirm the length of the extended top flange.

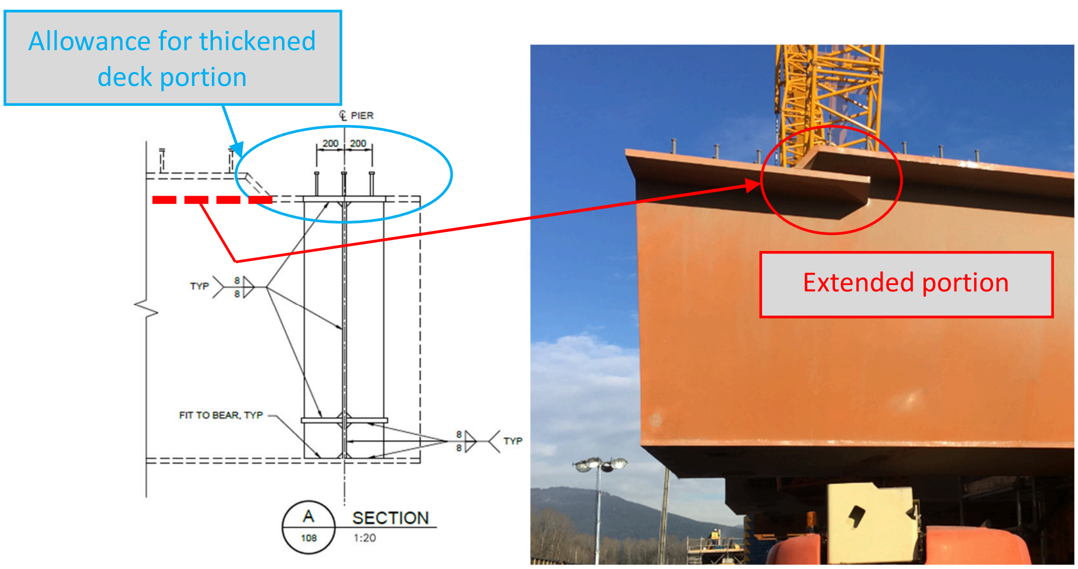

Figure 13: Extended top flange to address partial depth of the end diaphragms

The curvature of the girders in plan (horizontal plane) combined with a vertical profile reflecting the imposed camber (vertical plane) required the development of a sophisticated 3D model prepared by the fabricator. The model was used to accurately lay out each of the three girders, which had unique overall lengths, varying skews at either end, varying profiles to reflect the required deck geometry and camber. To address complexity of this task, we provided the fabricator coordinates of the chord – a projected line ran between webs of the girder along its length at elevation of the top flange. Prepared data were verified with the roadway team who had developed the deck surface using Civil 3D software.

Before shipping to site, lifting lugs were welded to designated points along the girder length to allow for placement of girders while minimizing the induced stresses. The lifting lugs were cut off after assembly of the girders of site. To assure minimum residual stresses in the top flanges, a controlled process of removal was required.

To reduce the field assembly efforts, particularly field welding, fabrication shop time was used to pre-assemble several sub-components. The girder flange and web plates, along with stiffeners and interior diaphragms were welded together at the shop. The exterior bracing components were also welded together to form a single bracing assembly in order to limit assembly time on the site. The superstructure components were assembled on site with bolted connections at girder splices and connections between the bracing units and diaphragms with the girders. An example of a diaphragm including both the welded and bolted connection is shown in Figure 14.

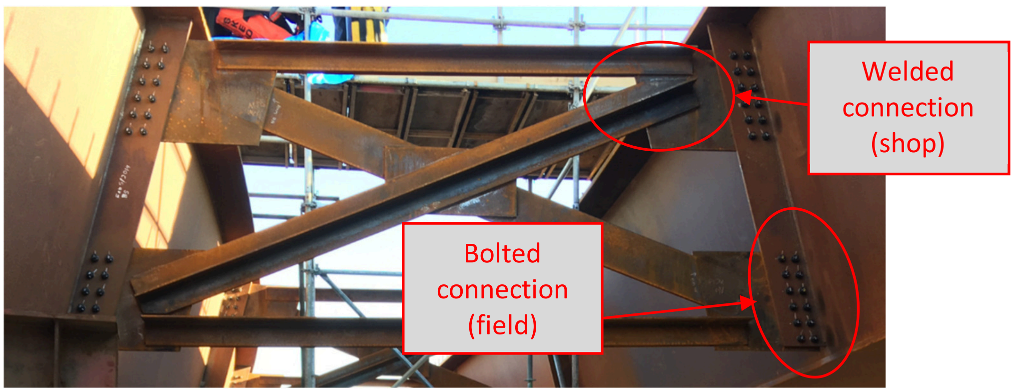

Figure 14: Example of a diaphragm including both the welded and bolted connection, enhancing efficiency of the assembly process on site

4.5.2 Pile Foundations at the Tie-in to Existing MSE Wall

The tie-in with the existing MSE at the north abutment was challenging due to its close proximity with the settlement pond (see Section 4.2.2 for additional details). The numerous constraints in this area gave way to challenges in the design of the piled foundations at both the north abutment and pier wall, compounded by the presence of the existing settlement pond sheet-pile retaining wall, railway tracks, and the curved MSE wall of the existing Neptune/Cargill Overpass. Close coordination between structural and geotechnical engineering disciplines was required. The foundation is comprised of CIP concrete pile caps supported on steel piles filled with reinforced concrete. Layout of the foundation piles depicting the final arrangement is shown in Figure 15.

Sizing of the piles was crucial. This process had to consider liquifiable character of soils, combined with high groundwater tables located only 1.5 m below the current ground surface. Stability of the MSE wall during construction was of great concern, as there was a potential of undermining the wall as a result of piling activities. To address this, iterative analyses were conducted to assess varying excavation depths and account for non-linear soil-structure interaction behaviors. Non-linear P-Y springs were developed by the Geotechnical engineering team and validated through an iterative process with the structural design and analysis model. Pile lengths ranging between 25 to 35 m were obtained as function of the soil properties and overall stiffness of the foundation assembly. Both displacement and moment distribution of the piles, as shown in Figure 16, were evaluated to achieve an optimal solution. The maximum moments occur at similar depth for all three load cases and the magnitude of displacement correlates with those, confirming anticipated soil-structure interaction.

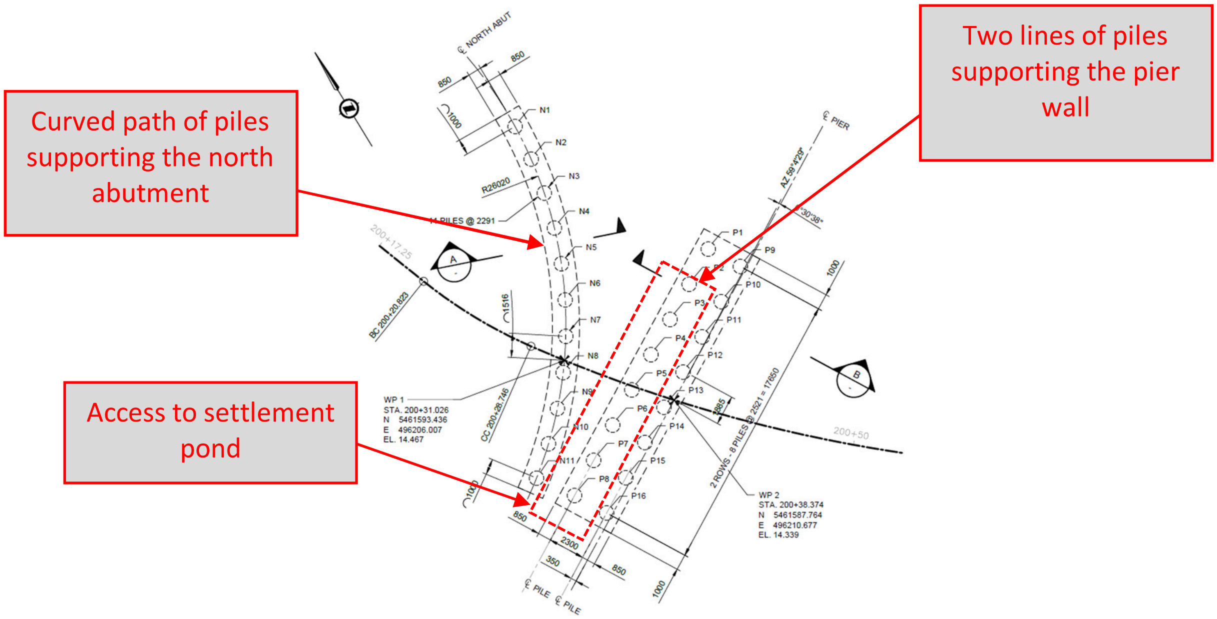

Figure 15: Layout of the foundation piles at north abutment of the bridge

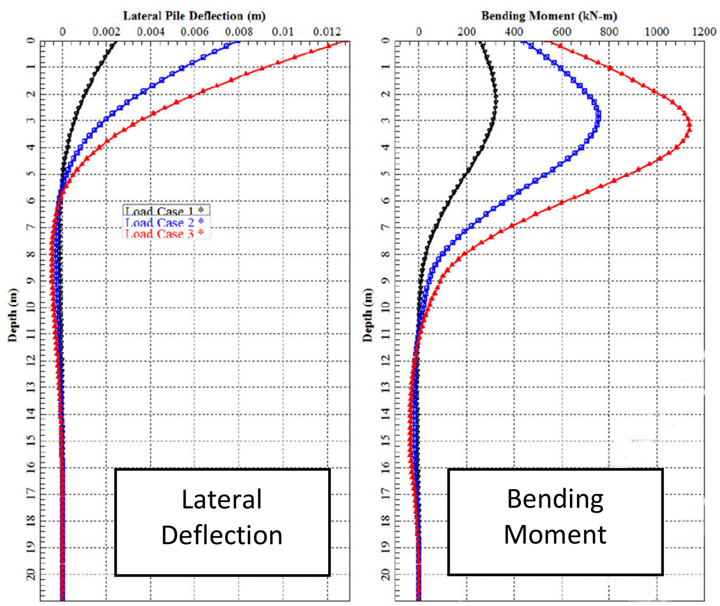

Figure 16: Typical displacement and bending moment distributions for foundation piles at the north abutment, considering non-linear soil-structure interaction during application of static loads only.

(Adapted from a Geotechnical memorandum [Ref 1])

In the final design, 914 mm diameter x 19 mm thick steel pipe piles filled with reinforced concrete and arranged as show earlier in Figure 15. Stantec inspectors carried out visual and nondestructive testing at the fabricator yard and during installation and splicing of the piles at the construction site for quality assurance purposes. While efficiency of material use was kept in mind, a limit of 3.0 m was imposed for minimum pile lengths that could be spliced. Weld checks were conducted in accordance with CAN/CSA

W59 Clause 11, Statically Loaded Structures — Design and Construction. At the pier location, two rows of piles were required. Providing sufficient foundation capacity at the pier location was governed by the clearance limitations on either side: the future settlement pond access ramp to the north and the rail track alignments to the south. In the completed stage, the access ramp covers the pier wall pile cap, surrounded with sheet-pile wall on its other side as shown earlier in Figure 8.

To mitigate impacts of pile driving on the stability of the existing MSE wall, vibrations were closely monitored during the installation process. Settlement of the wall was also tracked for potential serviceability issues such as cracking and drainage complications that could arise due to excessive vibrations.

Additional analyses were conducted during installation to reassess design demands and optimize the foundation design by incorporating actual soil conditions encountered on site. By doing so, pile lengths at several locations could be reduced, thereby avoiding unnecessary pile driving and mitigating the associated risks.

4.5.3 Accelerated Bridge Construction: Superstructure Assembly and Erection

One of the key objectives of the design of the overpass was to maximize the number of components assembled on the ground and reduce the time required for superstructure erection. In conventional design, single girder units are typically erected, secured at the bearings and stabilized through installation of bracing. Formwork and deck components would then follow. However, in the case of the Neptune Cargill Overpass Extension, all three girders were assembled on the ground, together with all bracing components, deck formwork and the first layer of deck reinforcing. Self-propelled modular transporters (SPMTs) were employed to maneuver the assembly to its final location. Stability of the superstructure assembly during the move was addressed through the development of additional structural analyses models. The models confirmed stability of the assembly while being fully supported by the SPMTs without its composite decking system. The layout of the SPMTs, supporting each girder at defined bearing location is shown in Figure 17.

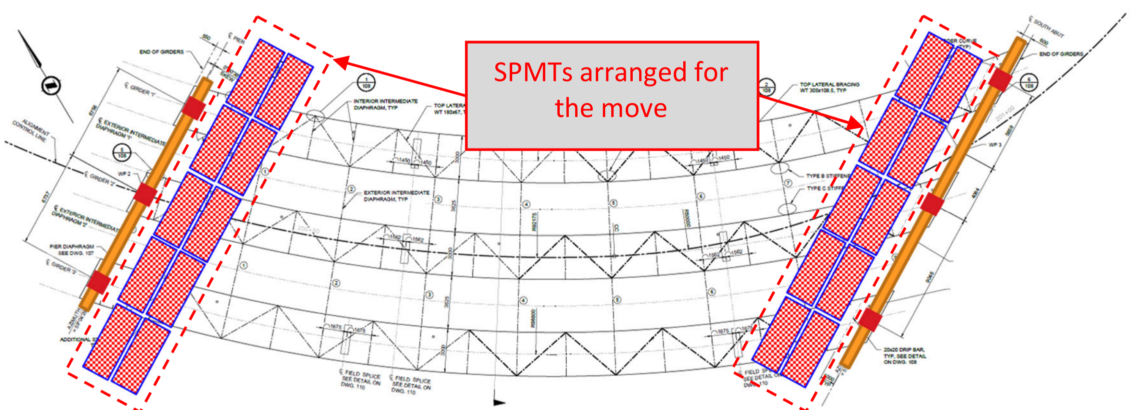

Figure 17: Layout of the SPMTs, supporting each girder at defined bearing location

The full girder installation process was allocated a three-day window during which the operation of the railway was temporarily suspended to allow for encroachment of equipment and personnel beneath the bridge span. The girder erection using the SPMTs to move the girders assembly from the staging area onto temporary bearing supports was successfully completed within an interval of 90 minutes. A sequence of the move is captured in Figure 18. Girders were placed on temporary supports and jacked up to allow installation of bearings, as shown in Figure 19. The remaining scheduled time was used to confirm measurements and make any adjustments prior to setting the bearings.

Figure 18: Girder erection completed with the use of Self-propelled modular transporters (SPMTs), Girders moved from staging area to final position above bearings

Figure 19: Temporary jacks and bearing assembly

After girder erection, additional formwork and reinforcing steel was installed to facilitate the deck placement which would be completed in three stages, as described in Section 3. Superplasticizers were proposed by the contractor and accepted for use, which greatly aided in the efficiency of the concrete pour by improving workability of the mix design.

4.6 Roadway design

As with the structural design previously discussed, the tie-in with the existing MSE at north abutment also proved challenging for the design of the roadway alignment. The Neptune Cargill Overpass Extension was developed with a longitudinal slope of approximately 1% but had to integrate with the existing structure resulting in a relatively steep slope of 2.8 %. A solution had to be found to accommodate the roadway profile and superelevation impacted by design speed and the angle of turning. A typical crown was maintained over a portion of the bridge deck; however, was altered to address the transition with the MSE wall on a crest curve. A detailed Civil 3D model was developed to confirm geometric constraints as well as drainage requirements. The final design solution is shown in Figure 20.

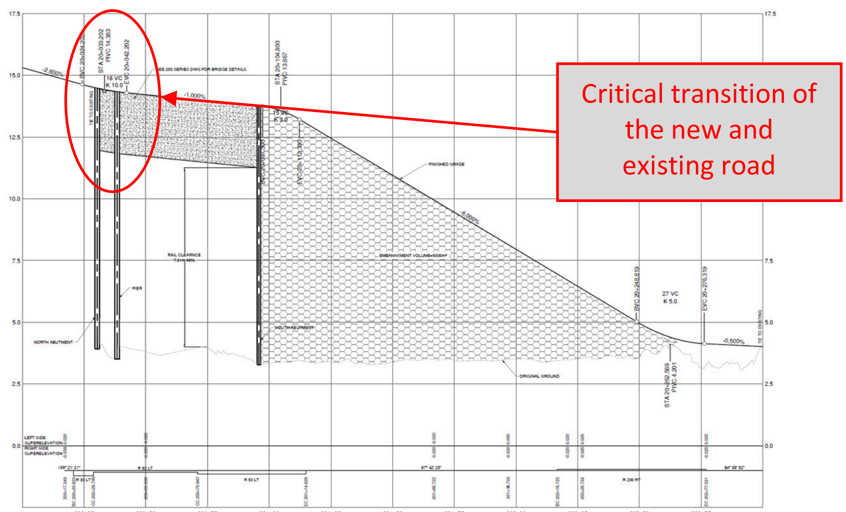

Figure 20: Final roadway design depicting transition of the new roadway design on the bridge with a steeper slope at the existing MSE wall at North

5 Benefits of the Enhanced Infrastructure

Stantec teams designed and helped to construct the overpass bridge structure overcoming the challenges presented above. The benefits of the achievement are described in the sections that follow.

5.1 Socio-economic benefits

While the original Neptune/Cargill Overpass provided general access from Low Level Road to the terminal site entrance, the Neptune Cargill Overpass Extension provides a safer, more direct connection to the main working areas south of the rail tracks, specifically to support increased steelmaking coal handling operations. This overpass is the first phase of the Allison Project, a major initiative to upgrade the steelmaking coal exports facilities within NBT's terminal. The completion of the overpass provides critical roadway access for the transport of equipment and materials to be used for the remaining infrastructure upgrades. With respect to the long-term horizon, the structure will continue to provide an alternative route for heavy trucks and terminal employees to bypass congested corridors thereby contributing to safer and more efficient transport of resources within the terminal. The Neptune Cargill Overpass Extension, together with the other infrastructure upgrades realized through the Allison Project, is expected to foster a sustained, economic growth for the local Lower Mainland region, across

Canada and around the world. Upon completion of the Allison Project, NBT's terminal will be capable of exporting over 20 million tonnes of steelmaking coal per year with the same land footprint, compared to 10 million tonnes currently being exported per year [Ref 4]. NBT is responsible for approximately 5% of Canada's offshore export goods, and its railway transport system provides a highly efficient link from product sources across Canada to offshore destinations. Neptune Cargill Overpass Extension spans seven existing rail tracks, plus two future rail alignments, allowing the uninhibited movement of railcars and improving the efficiency of loading and unloading activities. The increase to the terminal's capacity will indirectly benefit the nation's Gross Domestic Product (GDP) and spur the creation of new jobs within supporting industries. Economic benefits were also realized during the construction of the overpass. The project engaged a locally based Contractor, which resulted in increased employment opportunities and resource utilization within the community. The project's overall carbon footprint also benefitted from the use of local labor by reducing commute times and transport of construction materials to the site.

5.2 Environmental and Community Benefits

Stantec's Environmental Services team has been involved throughout the terminal expansion effort, including during the construction of the Neptune Cargill Overpass Extension. Work conducted included one year of in-water assessments and monitoring to study marine life and vegetation in the surrounding Burrard Inlet. The team monitored marine mammals and salmon movements, evaluated marine noise, and dived to establish the marine life living underwater. The information collected informed the design of a bubble curtain which was later used during pile driving operations to mitigate impacts to fish.

A comprehensive Construction Environmental Management Plan (EMP) was developed and included an archaeological team on site during ground disturbing works for areas with archaeological potential. Stormwater treatment on the terminal is very complex as all surface water runoff on the overpass requires careful treatment due to bulk material handling. Specific dust management protocols were deployed and monitored to ensure dust from raw materials was not being tracked offsite. For example, all vehicles, including all construction vehicles, were required to pass through a high-pressure washing facility upon entering or exiting the terminal. An earthworks tracking system was deployed during construction to monitor and confirm that vehicle loads being removed offsite disposed of waste material at an appropriate facility. A non-road diesel machinery emissions program was implemented which included frequent sampling of equipment emissions to determine if the opacity was within the accepted thresholds. To confirm successful implementation of the EMP, construction was monitored by a collaborative team of local First Nations and technical specialists.

Mitigation of impacts to the surrounding community were also considered. A comprehensive noise study was conducted as part of the design process to establish baseline noise levels within adjacent residential neighborhoods. Noise monitors were set up around the construction site and the collected data was compared with 24-hour noise sampling locations set up throughout the community to ensure they remain within the prescribed City of North Vancouver (CNV) bylaws. Pile driving noise was mitigated with the preferred use of a vibratory hammer and scheduling of all piling activities during daytime construction hours only in accordance with CNV noise bylaws and the Port Authority permit. Any directional LED lights used for construction were positioned to minimize light pollution to residential areas. Permanent lighting fixtures were designed to have no impact on receptors such as the water to the southeast and the residences to the north. Lighting would be directed towards the roadway surface, producing no light above 90 degrees and photocell controlled for energy efficiency.

6 Conclusions

This paper discussed design challenges and innovations implemented for the construction of the Neptune Cargill Overpass Extension, a 64.8 m long overpass spanning road and rail infrastructure within the Neptune Bulk Terminals site in North Vancouver, British Columbia. The bridge enhances operations of the terminal, providing safe and uninterrupted traffic flow over the railway tracks into the steelmaking coal stockpile at the south side of the terminal. The following challenges were presented in this paper: future maintenance and operations of the facility; optimization of the structural design to meet the requirements of fabrication and construction; enhancement of roadway design tying-in with the existing curved MSE wall; combined with tight footprint; presence of current facility components; and seismically active zone supported on liquefiable soils. Accelerated construction techniques, employing SPMTs, were part of the advanced construction sequence and were discussed as well. In addition to the design challenges and solutions, benefits of the new overpass structure to economy, environment, and community were highlighted.

7 Acknowledgements

The Stantec team would like to express gratitude to the client, Teck Resources Ltd., who supported preparation of this technical paper. We would also like to acknowledge the dedicated work of B&B Contracting, Nilex Inc., Golder Associates Inc., Capitol Steel, Sarens, and Fluor all of whom were pivotal in the successful completion of this ambitious project.

8 Reference

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