Superstructure Replacement and Substructure Modifications to the Fort Nelson River Bridge in Northern BC

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Abstract: The existing eight span, 430 m long single-lane Fort Nelson River Bridge on Hwy 77 was constructed in 1984 and is one of world's longest ACROW bridges. The British Columbia Ministry of Transportation and Infrastructure (MoTI), the owner of the bridge, due to increasing traffic demands in the region, is pursuing the replacement of the narrow single lane superstructure with a new two lane superstructure utilizing the existing piers and abutments. McElhanney Consulting Services Limited (McElhanney) has undertaken the initial foundation evaluation, condition inspection, conceptual and detailed design of the new superstructure and rehabilitation of existing abutments and piers to accommodate the heavier and wider superstructure. The existing bridge has spans of 34 m – 37 m – 58 m – 70 m – 70 m – 70 m – 58 m – 32 m with the longer spans using a double height ACROW section while the shorter spans have a single height section. The new superstructure consists of a full depth precast concrete composite deck with an out to out width of 10.0 m and three continuous lines of steel girders that vary in depth from 1.1 m to 3.0 m. The girders have been designed to be launched into place from the north end of the bridge. The abutments require additional piles and modified seats and backwalls to accommodate the wider structure. The land piers also require new steel pipe piles cast into new wider pile caps that support the existing pier shafts. As the bridge is to be constructed in extreme northern conditions, a significant amount of the bridge is shop fabricated for faster assembly on site.

1 BACKGROUND

The Fort Nelson River Bridge is located on Liard Highway No. 77 approximately 68 km northwest of Fort Nelson and approximately 43 km north of the Alaska Highway junction. The Liard Highway No. 77 is a primary route to the western Northwest Territories and in particular Fort Liard, Nahanni Park and Fort Simpson. It also provides an alternative route to the Northwest Territories other than using Highway 35 through Alberta. As such, it provides vital access for goods transportation, health and safety, tourism and emergency access.

The existing Fort Nelson River Bridge was designed and constructed by the British Columbia Ministry of Transportation and Infrastructure (MoTI) in 1984 utilizing a temporary 430 m long single-lane wood deck ACROW bridge supported on seven (7) permanent piers and two (2) permanent concrete abutments. The superstructure consists of eight (8) continuous spans of 34 m – 37 m – 58 m – 70 m – 70 m – 70 m – 58m – 32.1 m and includes a 4.4 m clear-width wood deck connected to ACROW truss floor beams. The bridge is pile supported on 1067 mm diameter pipe piles at the river piers, 508 mm diameter pipe piles at the land piers and 356 mm diameter pipe piles at the abutments. The existing piles were driven approximately 20 m below streambed through hard clay into dense sand and the new piles are proposed to be driven to the same depths. The Fort Nelson River flows under the bridge and the existing superstructure provides a 1.9 m freeboard above the anticipated 200-year flood level. The maximum anticipated local scour is anticipated to occur to a depth 3.0 m below existing riverbed and was found to have minimal impact to the pier piles. The river typically ices over in winter and with strengthening the ice surface can be used for temporary vehicular travel or construction activities. Refer to Figure 1 on the next page for the new bridge General Arrangement Drawing.

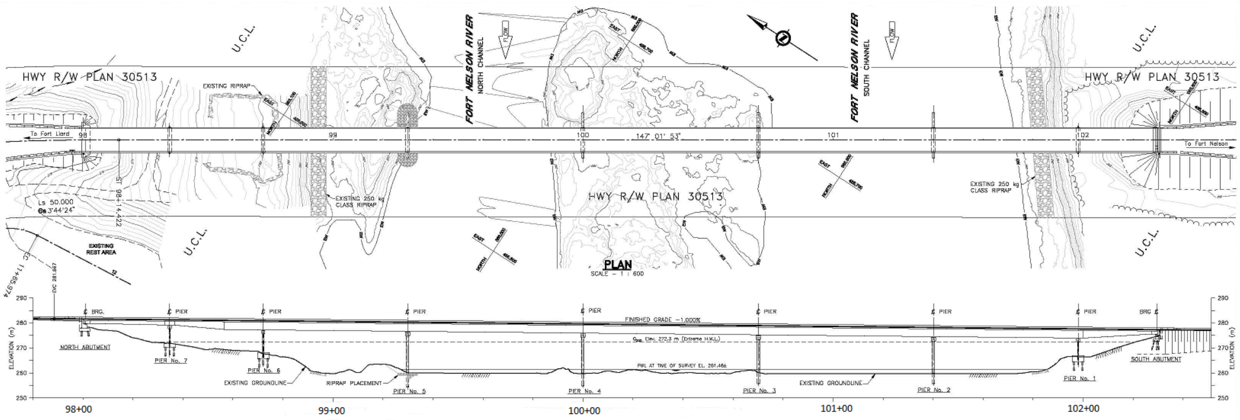

Figure 1: General Arrangement Drawing

The Fort Nelson River Bridge was originally designed as a single-lane structure using the American Association of State Highway Transportation Officials (AASHTO) 1977 bridge design code. MoTI requested that the existing substructures be evaluated and strengthened based on the Canadian Standards Association CAN/CSA-S6-06 Canadian Bridge Design Code and Supplement No.1 of May 2010. The proposed new 9.2 m wide two-lane superstructure was also designed to this code.

The existing 4.4 m wide bridge currently carries alternating northbound and southbound traffic. Due to the length of the bridge and the typical vehicle speed of only 15 to 20 km per hour it takes approximately three to four minutes for traffic to clear the bridge in one direction before opposing traffic can make their way across in the other direction. Queues build up consistently at the ends of the bridge and it is anticipated that this situation will get worse when traffic volumes increase due to increased resource development activity in the region. Most of the traffic is industrial in nature and includes a very high percentage of heavy trucks with some overloads and a significant number of oversize loads. As such, providing a Fort Nelson River Bridge with two lanes of traffic with a roadway design speed of 80 km per hour will dramatically improve the traffic flow along Highway 77. Figure 2 shows a small convoy of vehicles crossing the bridge and Figure 3 provided a view of the existing bridge from river level.

Figure 2: Vehicle Convoy Crossing Bridge

Figure 3: View of Bridge from River Level

2 CONDITION INSPECTION

McElhanney performed a bridge condition inspection on the Fort Nelson River Bridge in the fall of 2012. The inspection team closed the highway and inspected the bridge from the deck level and also used a MoTI snooper truck to gain access to the sides and underside of the superstructure, pier bearings, pier caps and the top portion of the pier shafts.

Our inspection confirmed that the approach spans at both ends of the bridge are a 300 series double single reinforced construction Acrow superstructure. The interior six (6) spans of the Acrow superstructure is of double double reinforced construction. The inside width between top chord members is 5.23 m and is referred to as Mode "B" in the Acrow (Canada) Limited "Canadian Deck System" Brochure. The deck width between wheel guards is approximately 4.4 m and the out to out width of the deck outside of wheel guards is roughly 4.8 m.

The Acrow truss panels, transoms, sway braces, rakers, stringer assemblies, jacking beams, bearings, timber cross ties, decking and timber curbs for all eight (8) spans were all thoroughly inspected as were the seven (7) piers and two (2) abutments.

Typically the Acrow superstructure was found to be in good shape with only a few local issues with missing bolts, loose bracing and bearing components. There is an ongoing problem with breakage of top chord reinforcing bolts with a number having broken in the past and an on-going replacement regime was being performed by the bridge maintenance contractor. It appeared that the bolts failed at the tapered end where the threads began probably from overtightening resulting in a fatigue tensile failure. The existing timber deck and cross ties were found to be deteriorating and required replacing in 2 to 3 years. The pier caps, pipe piles, concrete infill diaphragms and abutments were all noted to be in good condition with no signs of cracking or distress.

The condition assessment report recommended that non-destructive testing be performed at the male and female ends of the span junctions between the double single and double double trusses at spans 1 and 7. These are fracture critical connections that have been in service for more than 30 years. The bearing welds were also recommended to be magnetic particle checked as a crack was noted at one of the bearing at Pier 2. It was also recommended that if the bridge remains in operation for more than 5 years that all of the bearings be retrofitted to perform more reliably.

Figure 4: Bridge Inspection Using Snooper Truck

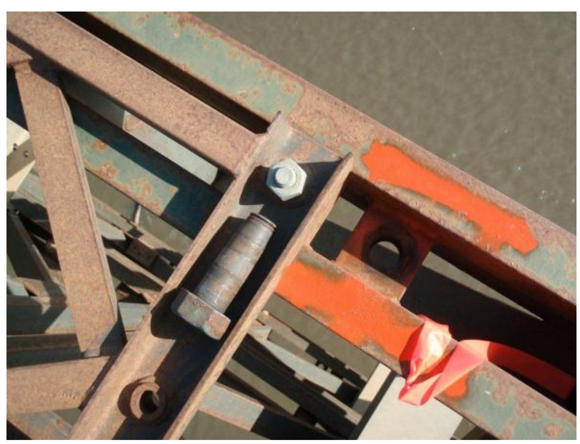

Figure 5: Failed Chord Reinforcing Bolt

3 CONCEPTUAL DESIGN

A number of substructure rehabilitation and superstructure replacement options were assessed during the conceptual design phase of the project using the following five (5) key criteria used to determine the optimal design for the project:

- Cost, Lower cost solutions considered to be more favourable.
- Constructability, Solutions using more prefabricated components, thus requiring less local on-site labour considered to be more favourable.
- Northern climate, Solutions that allow construction to continue through the winter or are more flexible vis-à-vis weather conditions considered to be more favourable.
- Durability, Solutions requiring less maintenance and more robustness are more favourable.
- Risk, Conventional solutions with less inherent design and construction risk considered to be more favourable.

3.1 SUBSTRUCTURE REHABILITATION

Preliminary dead and live loads calculated for the new two-lane superstructure were compared to pile capacities provided in previous substructure assessment reports and reviewed by GeoNorth Engineering Ltd. and MoTI geotechnical staff. Based on the existing foundation capacities it was determined that the north and south abutments and land piers 1, 6 and 7 required additional piling to carry the increased superstructure loads. River piers 2, 3, 4 and 5 are currently being reviewed by MoTI to determine if additional piles are required.

The rehabilitation options for the abutments included modifications to the existing abutments and complete abutment replacement. For the north abutment the existing pile capacity was significantly less than the calculated design load for the two-lane bridge and as such it was determined that the optimal solution was to drive two new lines of piles and construct a new abutment. At the south abutment the existing piles were minimally overloaded and it was determined that only two additional piles were required, resulting in the decision to modify the existing abutment to incorporate the new piles.

At Piers 1, 6 and 7 the existing pile capacity was also significantly less the calculated design load for the two-lane bridge and as such it was determined that the optimal solution was to drive two new lines of piles besides the existing pier and construct a new pile cap to connect the new strengthened foundation with the existing pier shaft. The existing pier caps for all of the piers were determined to be sized adequately such that only new bearing seats and anchor bolts needed to be incorporated into the pier caps, with no widening or lengthening required.

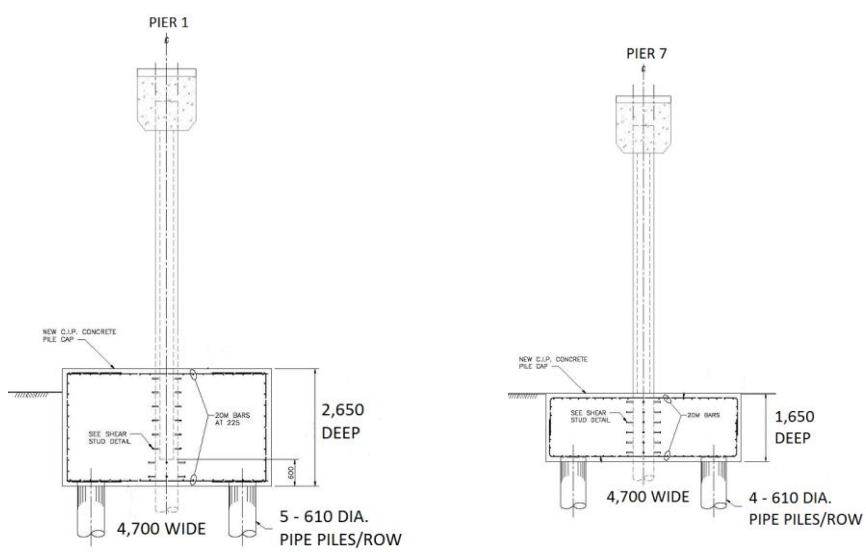

Figure 6: Pier 1 and Pier 6 Foundation Strengthening

3.2 SUPERSTRUCTURE REPLACEMENT

The superstructure options considered for the Fort Nelson River Bridge included girder types, number of girder lines and deck types. The options were evaluated for the five key criteria outlined at the beginning of Section 3.

Concrete girders were found to be not as cost effective compared to steel girders for this particular span arrangement and site location. Being significantly heavier than steel they would be challenging to handle, erect and transport in full 70 m long segments. Shorter segments would require post-tensioning of the drop in segments including stick-build construction either from the frozen river or a work bridge ruling out the possibility of girder erection through incremental launching. On the other hand, steel girders are expected to be much easier to handle and transport in 40 m sections either by road or rail. Additionally, they offer the flexibility of erection through either crane operations or launching.

As incremental launching was considered to be the preferred erection method, steel plate girders with constant depth or steadily changing depth to accommodate existing pier elevations provide the best weight and cost efficiency for the site.

Options for number of girder lines were evaluated to determine the most optimal arrangement. A two girder arrangement is a fracture critical situation without redundancy as collapse of one girder would lead to a catastrophic failure of the entire span. Additionally, spacing for two girder lines results in increased demands on the deck requiring a thicker and heavier slab (one-way action) or additional floor beams that act compositely with the deck (two-way action).

Three girder lines while adding redundancy against collapse was determined to be the optimal arrangement in terms of structural steel efficiency. The resulting girder spacing provides comfortable room for inspections and maintenance, a high priority aspect for bridges northern remote locations. Finally, a four girder option results in shallower girders but requires approximately 25% more steel compared to three girder lines. The shallower steel segments are also a bit easier to handle, transport and erect. However, the major disadvantage was the need for greater camber for relatively slender superstructure subjected to larger live load deflections, especially in combination with a full width precast deck panels as camber variances are less forgiving (four support lines instead of three).

The three girder line arrangement was favored for cost effectiveness due to the greater girder efficiency and the reduction in the number of support lines for the full width precast deck panels.

Cast-in-Place (CIP), partial depth precast and full depth precast deck options were reviewed and all were considered to be viable options for the Fort Nelson River Bridge. A CIP deck is relatively thin, has been proven to be durable and can adapt to girder line variability through the use of haunched formwork. However, they require intensive on-site labour activities for installation of formwork over almost the entire deck area, placing of rebar and casting operations. Casting being temperature sensitive there are greater limitations on the timing of these operations in northern regions.

A partial depth precast deck is also relatively thin, has been proven to be durable, reduce the amount of formwork and cast-in-place concrete required. The disadvantages of the partial depth precast deck include the need for formwork and CIP concrete for the deck overhangs, on-site placement of the top layer of rebar and overall more reinforcement steel than full-depth CIP deck. Thin partial depth precast panels are also not able to be driven on prior to the topping being placed and the concrete cured. Overall this deck system was deemed as the least cost-effective.

The full depth precast concrete deck proposed for this project is modeled after the Deh Cho Bridge deck that utilizes precast concrete panels with approximately 400 mm space between each panel for CIP joints. The space is utilized for the provision of interlocking hooked bars projecting from each panel and accommodates transverse reinforcing steel. The advantages of the full depth precast deck is increased quality due to fabrication in a certified plant environment. High quality control allows for a reduction in concrete cover and therefore reduced weight. Modular construction increases installation speed and significantly reduces on-site labour requirements. The major benefit to using full depth precast concrete deck panels is that they can be economically installed year round as compared to the other options.

3.3 SELECTION OF FINAL DESIGN CONCEPT

Four (4) bridge concepts were developed based on our evaluation of the girder types, the girder arrangements and deck arrangements for the Fort Nelson River Bridge. The four bridge concepts considered for in our evaluation were:

- Concept 1: Three steel girder lines with CIP concrete deck.
- Concept 2: Four steel girder lines with CIP concrete deck.
- Concept 3: Three steel girder lines with full-depth precast concrete deck.
- Concept 4: Four steel girder lines with full-depth precast concrete deck.

Each option was rated against the other options on a scale of 0 to 2 with 0 being the least favourable and 2 being the most favourable. As full depth precast decks have not been used by the ministry to date they were considered to have additional design risk over conventional cast-in-place decks.

Criteria	Concept 1 3-Girders CIP Deck	Concept 2 4-Girders CIP Deck	Concept 3 3-Girders Precast Deck	Concept 4 4-Girders Precast Deck
Cost	1	0	2	0
Constructability	0	0	1	2
Northern Climate	0	0	2	2
Life-Cycle Cost & Durability	2	2	1	1
Design Risk	1	1	0	0
Total	**4**	**3**	**6**	**5**

Figure 7: Ranking Table for Bridge Options

Based on ranking of the four bridge concepts, Concept 3 was recommended to MoTI for advancement to the detailed design stage. This decision was accepted by MoTI in December 2013 and detailed design commenced in January 2014.

4 SUPERSTRUCTURE DETAILED DESIGN

4.1 DESIGN PHILOSOPHY

The Fort Nelson River Bridge site in remote Northern BC poses unique challenges that require specialized knowledge and innovative engineering. The remoteness of the site and the climatic conditions of the North permit reasonable construction conditions for a relatively short duration in the year compared to warmer and more accessible locations.

Therefore, the design approach adopted minimizes field activities and their duration through maximum shop prefabrication. The components were designed with repetitive details for relative ease of assembly and installation on-site. A high degree of prefabrication required careful consideration of transportation aspects. The site location relative to potential fabrication shops as well as possible access routes, transportation limitations and traffic restrictions were considered in the proportioning and selection of the bridge components.

The extreme site conditions have a major influence on the life cycle cost, as maintenance demands are generally higher in remote locations. While paying emphasis on detailing components for enhanced durability, care was exercised to configure the bridge for comfortable access to critical components for inspection and replacement.

4.2 NEW GIRDER LAUNCH

The design incorporates a feasible and economical construction scheme that effectively addresses the site constraints. Given the relatively long multi-span bridge and limited in-stream access conditions, the girders were designed and detailed for an incremental launch method of erection. In this construction method, the girders and diaphragms are assembled in a launching bed at one end of the bridge and progressively pushed, or launched, over the piers to the opposite bank. Although there are a few options available to launch this steel superstructure including using a launch nose and/or temporary intermediate piers, the method considered for the Ft Nelson Bridge makes use of a relatively long launching nose only. It is anticipated that a tapered launching nose will be assembled at the tip of the first girder segment to minimize the cantilever deflection, reduce construction stresses on the permanent girders, and provide clearance for the cantilever tip to land on top of the rollers atop each pier. The maximum deflection anticipated at the leading end of the first permanent girder (at the connection to the launching nose) is 900 mm.

Since the new bridge will follow the same alignment as the existing bridge, a solution was developed to avoid having to dig up a large section of the roadway to accommodate a launching bed. Given that the northern two spans are located over land instead of water, enabling crane access, it was determined that the most feasible solution was to use these two spans as the launching bed. It is expected that additional temporary bents will be constructed within the northern most span to support the girder segments as they are assembled.

The two northern most spans and the one southernmost span were designed with varying depth girders to accommodate the raised height at Pier 7 and abutments where the shallower single height Acrow truss was supported. The varying depth girders are relatively challenging to launch and it is expected that these end spans, which are above land, will be installed using conventional crane erection. The raised height of Pier 7 at the north end of the bridge also requires a unique vertical jacking sequence when the girders are launched over the first two piers.

4.3 GIRDER DESIGN

The three steel plate girders have a constant depth of 3.0 m over the majority of the bridge with the end spans transitioning down to 1.1 m to match up with the top of existing abutment seats and top of the Pier 7 pier cap. The change in substructure elevations is due to the existing ACROW bridge switching from a double depth truss on the long interior spans to a single depth truss at the end spans. The three plate girders have a constant spacing of 3.33 m over the entire length of the bridge.

Launching requires that the underside of the bottom flange is level for the full length of the bridge. The use of precast deck panels requires that the top flange is level for the full length. This eliminates the need to vary the haunch height in the field but does require more effort fabricating the webs and flange to web welds in the fabrication shop. Given the northern location of this bridge, our preference was to simplify things on site, even if this meant putting in more effort in the shop.

It is important to consider the method of construction during the design phase of a bridge, particularly when a non-conventional erection method such as a launch is anticipated. Several unique details were incorporated into the design to simplify temporary equipment and allow the superstructure to be launched without overstressing the permanent components.

Design details included, a constant width bottom flange to simplify guide roller designs, a gap in the bottom flange splice plate to allow the rollers to pass through, a relatively stocky bottom flange that can accommodate the high compressive stresses during the launch, and a constant depth girder are examples of a few details that were incorporated to accommodate an incremental launch.

To tie in with the existing roadway alignment at the north end of the bridge while increasing the design speed, it was necessary to begin the roadway spiral on the bridge. This required a varying super-elevation for a small portion of the bridge deck on an otherwise constant deck profile. To simplify both precast panel fabrication and girder fabrication, the super-elevation was accommodated by providing a vertical kink in the upstream girder at the start of the super-elevation change and casting a higher bearing pedestal at pier 7 and the north abutment.

This enabled all three girders to have similar haunch heights with no need to build special formwork for thicker precast deck panels or form excessively high haunches that could become unstable during construction.

4.4 DECK DESIGN

In keeping with the design philosophy of minimizing on-site labor intensive activities such as concrete casting, the modular deck consists of full-depth precast deck panels. The entire deck is mild-steel reinforced without any pre-stressed or post-tensioned steel similar to the system provided for the Deh Cho Bridge in the Northwest Territories. A water proofing membrane with two lifts of asphalt are provide as corrosion protection barriers. Additionally, the top mat of rebar is stainless steel. This will be the first application of such a deck system for a highway bridge in the province of BC. The full depth precast panel deck has a typical constant thickness of 240 mm with thicker haunches at each girder line. Figure 7 shows a typical deck section.

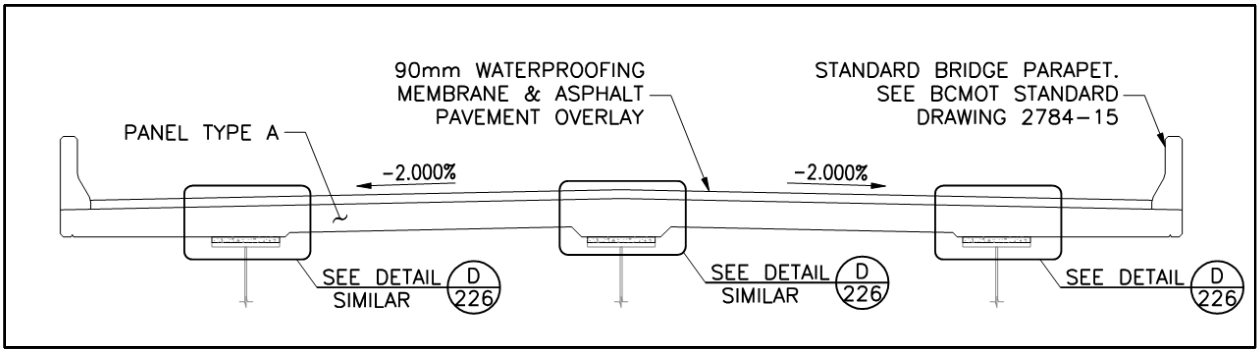

Figure 8: Typical Deck Section

The typical precast panels are the full width of the bridge and are supported on strips of compressible styrofoam at the edge of each girder top flange. After the girders are erected, a survey will be done and the styrofoam will be cut to the required depth to ensure the panels are fully supported by all three girders. At the north end of the bridge where the super-elevation varies, the full width panels are cut into two. See Figure 8. The panels have been designed so that the same formwork used for the typical panel can be used for the split panels by inserting a bulk head at the center. The downstream half of the panels is supported the same way as the typical panel. The upstream half of the panels is supported by leveling screws at each corner to ensure that the panels are properly seated on the at-grade center girder and the vertically kinked upstream girder. Levelling screws were used instead of varying the depth/profile of the underside of the panel to simplify both fabrication and erection.

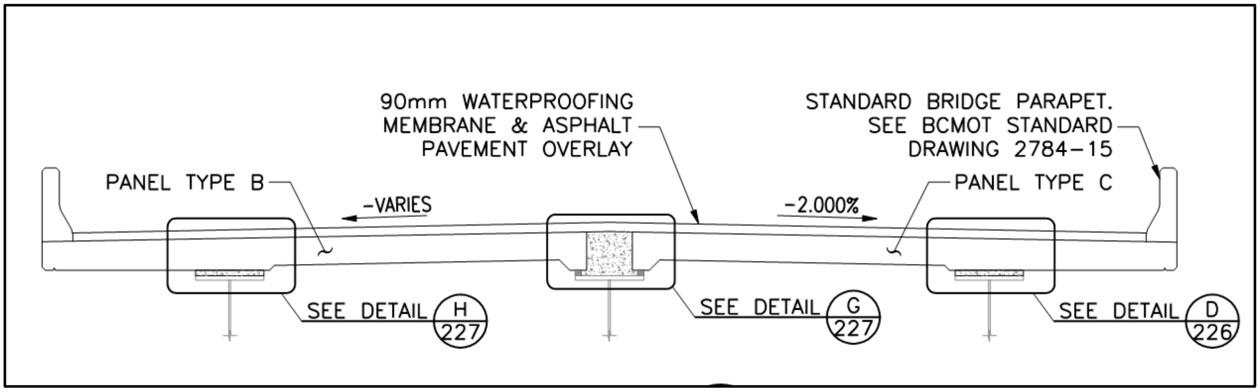

Figure 9: Split Deck Panel Section

Three grout pockets per girder line contain shear studs to make the precast deck composite with the steel girders. A 400 mm wide joint between each precast panel contains reinforcing loops projecting out of each panel to provide longitudinal continuity. These joints are filled with cast-in-place concrete of the same strength as the precast panels after the deck panels are installed.

4.5 BRIDGE ARTICULATION

The bridge superstructure including the deck is continuous over the entire length of the bridge with expansion joint at the abutments only. Continuity of the deck shields the girder system from the weather elements and improves the durability performance of the bridge while enhancing user comfort. Minimizing of joints further reduces the maintenance effort and thereby the life cycle cost of the bridge. Disc bearings were deemed the most feasible bearing type for the Fort Nelson Bridge because of their compact size, simplicity and relative lack of maintenance requirements, and ease and cost of replacement. The articulation scheme was developed to minimize longitudinal pier deflection under braking loads, minimize restraining forces arising from expansion and contraction during temperature changes and simplify bearing replacement.

Piers 2, 3, 4 and 5 are fixed in the longitudinal direction, meaning the point of fixity for longitudinal expansion and contraction is offset slightly towards the South causing slightly larger displacements at the north abutment than the south abutment. The existing piers are extremely flexible in the longitudinal direction, requiring the engagement four piers instead of only two piers to resist external longitudinal loads. Due to the flexibility of the piers, the expected longitudinal displacement at piers 2 and 5 due to the extreme temperature differential is easily accommodated with minimal stress in the pier piles.

The superstructure is restrained transversely at all piers by the upstream and downstream bearings. Guide bars are placed on the outer edge of the bearing only, meaning the upstream bearing only resists downstream forces and the downstream bearing only resists upstream forces. This was done to accommodate bearing replacement. The design incorporates a bridge jacking and a bearing replacement scheme. The scheme involves jacks to be placed in line with the girder centerlines for bearing replacement as opposed to jacking on the pier diaphragm. This requires the bearings to be slid upstream or downstream when being replaced.

Since there is not a lot of room on the existing piers outside of the exterior girders, the bearing design enables them to be removed towards the inside of the pier cap. The center girder is not restrained transversely at any of the piers.

4.6 BARRIERS

A standard cast-in-place MoTI PL-2 barrier has been designed for the Ft Nelson Bridge because of its reliability and simplicity. Starter reinforcing bars protrude from the top of the precast deck panels to connect the cast-in-place barriers to the precast deck. The top of the precast panels at the barrier interface is roughened to achieve a proper cold joint.

4.7 DECK PROTECTION SYSTEM

To protect the most critical asset of our bridge and the roof over our steel superstructure, a waterproof membrane system and two layers of asphalt wearing surface will be placed on top of the precast deck. The total thickness of the Hot Applied Rubberized Asphalt Membrane System is 90 mm and it consists of a rubber membrane, layer of protection board, two lifts of asphalt and additional layers of rubber membrane and fabric reinforcing at the cast-in-place infill joints. A wick drain will be installed beneath the asphalt wearing surface along the face of the barriers to allow any water that penetrates through the asphalt to drain via the small drain pipes embedded in the precast panels. Standards circular deck drains are placed along both traffic barriers to limit the drain water encroachment onto the roadway.

5 CONCLUSION

The design process considered the site extreme conditions in developing a cost effective solution that incorporates an advantageous erection scheme for this bridge located in a remote northern location. The maximum use of shop manufactured modular components for faster on-site installation will result in higher quality bridge with improved durability and reduced maintenance. The bridge utilizes an innovative mild steel reinforced full depth precast deck continuous over its entire length of 430 m for the first time in the province of British Columbia.

The detailed design of the Fort Nelson River Bridge superstructure is now complete with a final determination on the river pier strengthening requirements to be finalized shortly. The drawings and tender documents are planned to go out for tender in the spring or early summer of 2015. It is anticipated that the substructure strengthening and superstructure strengthening work will take approximately two years to complete. Once completed, the new two-lane bridge will allow traffic to travel unimpeded along the Liard Highway No. 77 and greatly improve current traffic flow.

6 ACKNOWLEDGEMENTS

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