ABC REPLACEMENT OF THE SKAGIT RIVER COLLAPSED SPAN

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ABSTRACT

Following the collapse of the Skagit River span 8 on May 23, 2013 the procurement and construction of the permanent bridge span replacement required complex accelerated bridge construction materials and techniques. The I-5 Skagit River Bridge Crossing is vital route linking Vancouver to Seattle transporting 71,000 vehicles per day. To restore the critical economic link an accelerated procurement and construction was performed within a three month timeline. To meet the project constraints, including aggressive schedule and geometric limitations such as vertical clearance and span weight limitations, an integral concrete deck girder system was enhanced with the introduction of an innovative full flexural-shear connection and the utilization of the state's first lightweight concrete in the girders and diaphragms. This system was constructed on a parallel temporary steel support structure while maintaining all lanes of traffic on I-5. Once completed the temporary steel bridge structure was moved out of place and the 1.8 million pound permanent concrete deck girder system was placed under a full overnight closure using a skidding system on rails located twenty feet from the beam ends. This paper will outline the accelerated bridge design and construction methods employed for the application of the lightweight concrete replacement.

Keywords: Lightweight Concrete, Design-Build, Accelerated Construction, Connections, Creative/Innovative Solutions to Structures

INTRODUCTION

On May 23, 2013, the evening commute was wrapping up in the four-lane stretch of the Interstate 5 (I-5) corridor between the Canadian border and Seattle. At roughly 7 p.m., a semi-truck in the outside southbound lane carrying a permitted oversized-load hit the first portal frame section and several subsequent overhead sway members along the steel truss section of the I-5 Skagit River Bridge. A 160-foot-long section of the truss span carrying both northbound and southbound traffic collapsed into the Skagit River. While the semi-truck made it across, several trailing vehicles didn't and the occupants had to be rescued. Three people in two different vehicles fell with the span; they were rescued by boat and did not sustain serious injury and fortunately, no one was killed in the collapse. This accident forced the immediate closure of the interstate and detour routes both east and west of bridge through the city streets of Burlington and Mount Vernon were set up causing significant traffic. As the main north-south interstate highway for the U.S. West Coast, I-5 links cities from the U.S.-Mexico border to Canada providing an essential corridor for international trade and commerce. In Washington State, I-5 is the only north-south interstate and the primary travel artery between Seattle and Vancouver, B.C. The longer the bridge remained closed, the greater the economic impact, not only on local communities and the state, but for trade between the United States and Canada.

Figure 1: View from the South Bank of the Skagit River Bridge Collapse

For Washington, the trade aspect is a vital portion of commerce. Canada is one of the state's largest trade partners and a majority of the goods imported from Canada stay in the state. In addition, many Washington State communities depend on business from Canadian customers traveling the I-5 corridor from British Columbia. The Border Policy Research Institute published a report in August 2013 showing a 51-percent decline in Canadian shoppers south of Burlington during the period of May through June 2013.

The collapse of the Skagit River span occurred just before Memorial Day weekend and the unofficial beginning of the summer traveling season, prompting the WSDOT officials to consider a short term immediate replacement to restore traffic. Within 24 hours WSDOT hired a contractor under an emergency contract to concurrently install two prefabricated bridges during the National Transportation Safety Board (NTSB) investigation. The temporary repair was intended to be a short term solution with a restricted speed limit and all overweight vehicles were detoured into the local city streets. As work was being done for the construction of the temporary access bridges, WSDOT began assembling contract documents and invited a select number of pre-qualified contractors for a two-week procurement of a permanent replacement span.

BRIDGE TYPE PROCUREMENT

Immediately following the collapse, WSDOT officials discussed how to approach the replacement of the collapsed span. Given the high-profile nature of the accident and the significance of I-5 for travel and commerce, WSDOT's main goal was to build a safe, long-term solution as quickly as possible that could be constructed while posing minimal disruption to the traveling public. The Primary factors in the design of the permanent span replacement included minimizing traffic disruptions, maintaining vertical clearance requirements, and superstructure dead load limitations. For navigational purposes, vertical clearance above the Skagit River had to be equivalent to that provided by the original truss span. And, most importantly, the weight of the bridge had to be within the dead load of the original truss by no more than 5% in order to prevent any seismic upgrades to the 50 year old timber foundations. WSDOT selected the design-build method (D-B) with the goal of rapid construction. Within 11 days of the the collapse of bridge a Request for Proposal (RFP) was issued for the five pre-qualified teams selected.

During the very limited two-week procurement period, an abundant amount of design and construction considerations were to be developed and considered. The D-B team consisted of Max J. Kuney (MJK) Construction Company as the contractor, Parsons Brinckerhoff (PB) as the design engineer and Omega Morgan (OM) as the specialized heavy lift contractor. The D-B team collaborated to prepare a design and construction scheme that could satisfy the WSDOT maximum dead load requirements, minimize impacts to I-5 traffic, be constructible within the 103-day permitted schedule, and provide the best value for the agency. To promote minimal disruption to the traffic, heavy financial penalties of $50k per day for delayed delivery and $660k per day for I-5 closures were imposed on the D-B team's cost proposals at selection. The RFP also set dates for equally heavy liquidated damages to commence if the D-B team was unable to achieve the commitments made in the proposal.

CONSTRUCTION METHODOLOGY

Due to the large liquidated damages, the development of a construction strategy that reduced the closure time of I-5 while limiting the potential risk was emphasized during the design process. To minimize I-5 closures, it was identified early in the design process the structure would have to be built alongside the I-5 alignment and then placed during a single closure. This process required the temporary bridge to be moved out of the way and the new bridge to be put in place within a 24 hour period. To accomplish the narrow span-switchover timeframe several options were developed including constructing the span on land or water and placing the span through the use of either a push-pull skidding system, barge mounted hydraulic lifting system or a self-propelled modular transport (SPMT). A marine based operation was initially selected as the most preferred option and an initial scheme of switching the spans over would utilize floating the bridge on barge and the use of a hydraulic lifting system. As the floating option was developed, several risk factors were exposed. Data gathered on the fluctuation in water level on the Skagit River proved that accurately predicting the draft and current to be difficult along with the intricate maneuvering required of massive barges and the significant amount of infrastructure on the barge extended the estimated I-5 closure time and raised potential risk. This method was estimated to require a I-5 closure from 24-48hours which reduced the viability of this construction method. Following this development it was decided to switch the switchover scheme to the skidding system. The skidding operation required the use of large amount of infrastructure including temporary bents and massive skidding beams to facilitate the construction and moving operations. The infrastructure was to be constructed alongside the existing temporary bridge span in a parallel alignment. The temporary bridge was to be slid up stream onto a network of temporary towers for disassembly, and the new permanent bridge would be slid into place from its construction platform. This alternative produced the most favorable combination of cost and risk reduction by reducing the estimated closure of I-5 to 12 to 24 hours.

Figure 2: Rendering of Floating Alternative (Left) and Skidding Alternative (Right)

DESIGN METHODOLOGY

To accommodate the accelerated bridge construction methods and meet the geometric requirements including span weight, vertical clearance and an aggressive construction schedule a number of structural systems were considered. A key concern during the design developments was meeting the maximum dead load limit for the new span (918 tons), in order to use the existing bridge piers, which had not been affected by the accident. This restriction along with a reduced construction timeframe restricted the materials that could be considered for the replacement. To facilitate the overnight switchover the structural system needed to accommodate the large concrete pedestals placed during the installation of the temporary bridge as shown in Figure 3. Removal of the existing pedestals would not permit the limited closure proposed. Finally the structural system needed to accommodate the proposed construction technique of lifting and skidding the bridge inside the conventional bearing locations for the switchover.

To accomplish the design restrictions the D-B team evaluated several steel alternatives that easily maintained the original span weight requirements, but the availability of fabricating the structural steel girders and risk of late delivery resulted in increased risk and a later switchover schedule. On the other hand, traditional concrete alternatives were inherently heavier, but materials and fabrication were readily attainable in the timeline required. The main concern was meeting the original truss span weight while satisfying all of the current design code requirements. This pushed the D-B team to consider a structural system composed of eight integral decked bulb tee girders utilizing lightweight concrete aggregate. WSDOT had limited decked girders to off-system bridges with low truck traffic volumes however the D-B team introduced a full flexural-shear connection between the flanges to permit the use of the system. Lightweight concrete aggregate was required for the girders, diaphragms, and barriers to stay within the stipulated span dead load limitations. The concrete girder system proved to be the most favorable combination of schedule and risk reduction. The Construction and Design Methodology outlined led to the D-B Team's concept to reconstruct the Span in 90 days with a switchover of the span with a single I-5 closure of less than 24hrs.

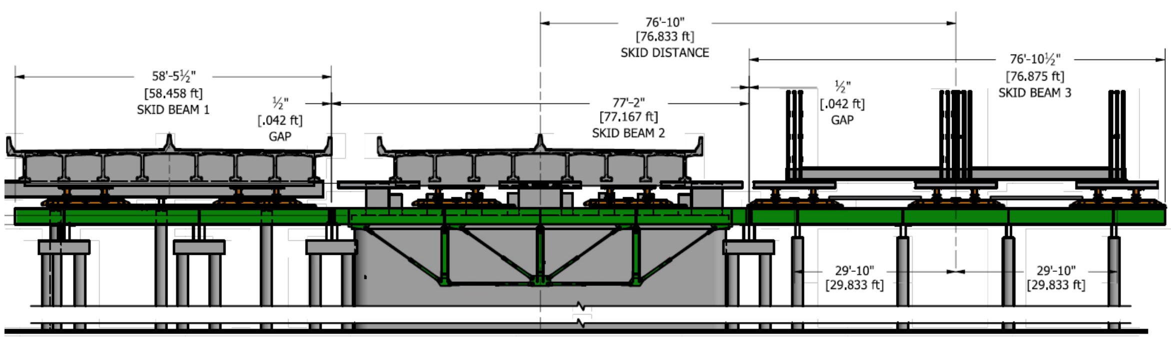


Figure 3: Skidding Sequence of Temporary Bridge and Permanent Bridge with Superstructure Arrangement

PROPOSAL SELECTON

A total of four D-B teams submitted proposals for the permanent span replacement. Of those four teams the proposals included two steel girder and two prestressed concrete girder systems. WSDOT selected the MJK-PB D-B Team concrete girder proposal which offered the best apparent value through a competitive initial cost and the shortest closure time among all proposals required to replace the temporary span with the permanent span.

PEARMANENT SPAN DESIGN

DESIGN PROCESS

Following the notice-to-proceed, the D-B team had less than 4 months to replace the temporary steel truss bridge with a new bridge. To expedite the review process and accelerate the approval process the design team met with WSDOT officials to conduct over the shoulder reviews. The critical element in the design process was to complete the lightweight concrete deck girder design and detailing to enable the fabrication to commence. To expedite the production of the critical concrete girders the precastor simultaneously conducted shop drawing production during the plan review process. The fabricator was provided daily updates to the design and detailing as plans were developed. This coordination enabled the precastor to start procurement of the long lead materials required for the fabrication and allowed the stressing beds to be prepared for the intricate and detailed girder requirements. While the design was being reviewed and developed for the service life under vehicular traffic coordination with the specialty heavy lifting contractor was also conducted. The design of the bridge structure also required consideration of the lateral slide operations. This required incorporating the design of the lifting diaphragms, locations of the temporary towers and maintaining the weight restrictions of the bridge. Additionally during this time survey was collected on the existing bridge to ensure the tight tolerance requirements of the bridge would fit with the existing pier geometry. The entire design process of the superstructure design was approved within 20 days of notice-to-proceed and the first girder was fabricated within two days of approval.

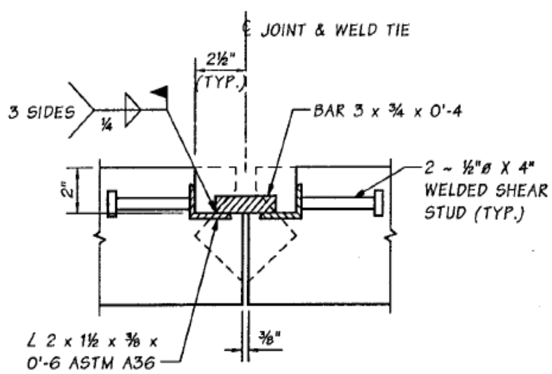
During the fabrication of the precast girders the contractor started construction of the temporary steel pile supported infrastructure to support the bridge construction and skidding operations. Careful consideration of the layout and elevation of the pile foundation was required to satisfy the equipment being utilized and the existing and permanent bridge geometry. The temporary span had limited jacking locations and the skidding system had limited stroke in the hydraulic rams. The temporary steel pipe pile foundations were being constructed within 24 days from the notice-to-proceed while the final design of the steel bracing and bent caps were completed. The entire construction set was released the first week of August, just five weeks after notice-to-proceed.

SUPERSTRUCTURE ELEMENTS

The D-B team solution for the new permanent span involved the use of accelerated bridge construction techniques utilizing a lightweight concrete deck bulb tee girder design. Traditionally the use of long span decked precast, prestressed concrete girders have been limited to low AADT off system bridges because of concerns about the structural integrity of the bridge system. According to NCHRP 12-69[1] “These issues include connections between adjacent units, longitudinal joints, longitudinal camber, cross slope, live load distribution, continuity for live load, lateral load resistance, skew effects, maintenance, replaceability and other factors that influence constructability and performance”.

To alleviate the owner’s concern and eliminate the possibility of reflective cracking the standard welded tie connections used for decked bulb tee girders were replaced with a cast-in-place closure. The WSDOT standard decked bulb tee connection involved the use of a longitudinal continuously grouted shear key and welded connectors placed at four feet on-center. This connection is only capable of transferring the shear and preventing relative vertical displacements across the joints. The proposed connection was developed to effectively tie the deck flanges together to provide a full-flexural shear connection and promote a continuous transverse deck behavior based on the research conducted in NCHRP 12-69[1].

This innovative connection permitted the use of a concrete alternative by eliminating a girder line while promoting enhanced durability. The use of a full flexural-shear connection reduced the potential for reflective cracking through the micro-silica overlay from the large overweight permit vehicles that frequently travel the I-5 corridor. To provide the full transverse deck behavior the use of protruding headed bars out of the flange of the girders were employed to create a non-contact lap splice with adjacent staggering bars from adjoining girders once erected. To accomplish the intricate connection the fabricator was required to apply strict quality control of the tolerance of the protruding reinforcing bars.



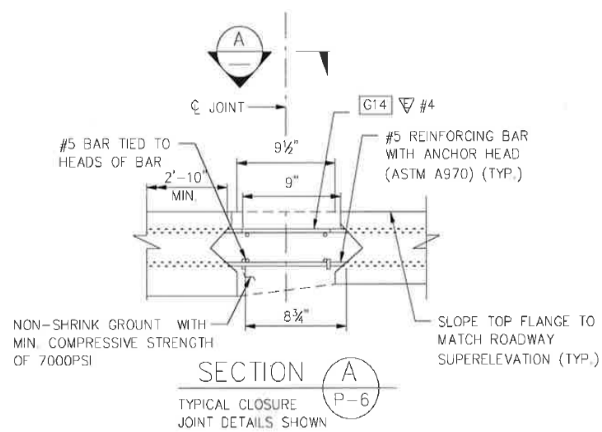


Figure 4: Standard Decked Bulb Tee Girder Connection (Left) Proposed Connection (Right)

The final superstructure section consisted of eight 65in decked bulb tee girders arranged in cross-section to fit the configuration of the existing piers. The girder spacing was set to 7.25ft nominally with the center girder spacing set to 10ft to accommodate the existing ACROW pedestals for seismic girder stops and eliminate the need to demolish the large pedestals during the span switchover. The girder design required the use of a 9ksi, 122pcf unit weight lightweight concrete in the bulb tee girders. The superstructure also required the use of a ksi lightweight concrete in the cast-in-place end and intermediate lifting diaphragms along with the cast-in-place barriers. To provide a smooth riding surface and prevent wear of the lightweight girder flanges a micro silica deck overlay was applied over the final roadway surface.

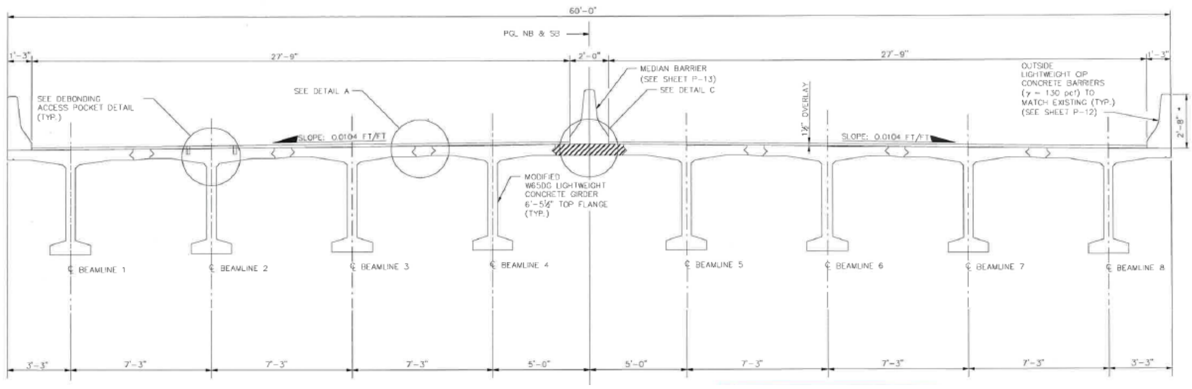


Figure 5: Final Superstructure Section Configuration

During the development of the concrete girder option mitigating additional dead load due to girder camber and cross slope was a primary concern. For the system to be capable of meeting the span weight requirements additional geometric control was identified early in the design process. The use of a long and slender lightweight concrete girder system with a span to depth ratio of 29.5 introduced an excessive camber of 6.5" due to the forty-eight 0.6" diameter strands utilized in the design. If the girder system was placed on the bridge profile the additional dead load would result in approximately 100 tons of additional concrete on the bridge deck. To mitigate the excessive amount of overbuild on the deck surface which would exceed the span weight limitations the girder forms were deflected approx. 4.375" to follow the profile grade line of the roadway. This technique traditionally performed only in steel girder bridges was employed through coordination with the concrete manufacturer on specific properties of the lightweight mixture. To mitigate overbuild due to the cross-slope of the bridge deck the top flange of the girders was sloped to match the existing 1% super elevation.

The final refinement required for the lightweight concrete girder system was the ability of the system to be compatible with the skidding operation. The slide-in-construction technique for the span swap-over placed the structure on temporary supports inside the traditional bearing areas. To support the girder system on the intermediate jacking diaphragms the prestressed girders required careful attention to the transient stresses that would develop. To mitigate excessive stresses in the top of the girder due to negative moment at the temporary supports, temporary post tensioning strands were added into the top flange of the girder along with additional non-prestressed reinforcing to reduce crack widths to acceptable levels. The temporary 0.6" strands were fully stressed to 75% of the ultimate strength and debonding access pockets were provided in the top flange of the girder through the micro-silica overlay. The contractor was required to de-tension the top strands following the move.

Figure 6: Installation of Temporary Post-Tensioning Strands in Girder Top Flange

The slide-in-construction operation employed the use of an unconventional location of lightweight intermediate diaphragms. The diaphragms were placed 20 ft in from the beam ends along the identical alignment of the skidding track used to lift the temporary steel bridge at the second panel node location. The bridge span was placed on four support points at each diaphragm by push pull hydraulic jacks that translated the bridge into place. To support the 1.8 million pound bridge the diaphragms dropped below the girders of the bridge span to permit the majority of the reinforcement in the diaphragm to be placed as effective as possible to minimize excessive weight as shown in Figure 7.

Figure 7: Intermediate Skidding Diaphragms during Construction

PERMANENT SPAN CONSTRUCTION

The construction of the permanent replacement span within a narrow two month construction timeline required a large group of contractors and fabricators. Following the notice-to–proceed the contractor was mobilizing onsite in preparation for the installation of the steel pipe pile foundations. To manufacture the concrete girders for the bridge the precastor was immediately procuring materials within two days of notice-to proceed. The lightweight concrete aggregate was procured from North Carolina and shipped to their local facility in Tacoma, Washington. The headed stud reinforcing bars were manufactured in two locations to meet the tight deadline. The precastor was conducting shop drawing production while the design was being finalized and the girder casting began only two days after final acceptance of the design by the owner. Once fabrication commenced the beds were turned over on a two day rotation due to the long set up time. Once the girders were fabricated the precastor monitored the girder camber on a daily basis and reported the findings. This process allowed the D-B team to ensure the structure would remain with the weight limitations imposed on the project and monitor the potential adjustment required for differential camber. Once the girders were trucked to the site the process of completing the bridge for traffic began.

DECK CONSTRUCTION

The girder erection occurred over three days in a carefully orchestrated process. The girder erection sequence involved the use of a 500-ton crane placed on land and a 200-ton crane on a barge to work in a detailed sequence with 19 specific moves. Each pick involved passing one end of the girder from the crane positioned on the dike to the barge crane, repositioning the crane on the barge while re-ballasting and finally placing the girder on the temporary bents. The permanent superstructure was constructed on steel piling and bents, just downstream of the temporary spans.

Figure 3: View Underneath Decked-Bulb Tee Girder Connection (Left) Casting of the Deck Closure between Girder Flanges to provide a Full Flexural-Shear Connection (Right)

Once the girders were erected the process of leveling the decked girders began as differential camber between the girders was surveyed up to 1”. The girder system was adjusted using a system of leveling beams and threaded inserts placed prior to casting concrete at the closures. Next, the closure pours between the flanges of the decked bulb tees were completed while leaving a small zone between each diaphragm. The closure pours were cast with a 7ksi normal weight pea gravel mixture to ensure proper development of the protruding headed bars. The girder spacing which accommodated the temporary bridge span pedestals facilitated the placement of the median barrier reinforcement bars in the closure while the exterior barrier reinforcing was cast in the flange of the deck girder. The barriers and diaphragms were then cast using a 4ksi Utelite lightweight concrete mix. The last step was the placement of the micro-silica overlay over the deck of the bridge span. The total construction of the superstructure lasted only two weeks after the girder delivery and was completed just three days before the span switch over.

SPAN SWITCHOVER

With the hydraulic vertical and horizontal jacking systems in place on top of the temporary piling and all of the concrete placed and cured the permanent bridge span was ready for its final voyage. Midway through the design of the new span a survey of the temporary bridge installation revealed the contractor had placed 1.75” thick expansion joint plates over the rear supports of the steel truss bridge span which had to be removed prior to the jacking operation. Once this process was completed the temporary bridge was relocated from the existing substructure and slid in approximately 30 minutes to a steel bent support upstream for disassembly later. The skid track system was composed of Teflon pads placed inside a steel dog push pull system lubricated using conventional liquid soap. The process then turned to moving the 1.8 million pound concrete bridge off its temporary support towers and into place. The installation of the permanent bridge required more precise movement and additional time due to the narrow 2” gap on each side of the bridge and a required translation of the bridge longitudinally. The skid track system allowed for the slight adjustment in the bridge due to the tolerances in placing the girders on the temporary bents. The gap was designed to be narrow enough to allow for the installation of a poured rubber expansion joint. The permanent bridge slide took approximately two hours.

Figure 4: View from Underneath Permanent Replacement Span during lateral slide-in.

The skid track jacking system could not lower the bridge the full amount required due to the clearance required over the concrete pedestals and therefore a two stage lowering process was employed. Once the bridge was in alignment the bridge was lowered and transferred onto a group of hydraulic jacks located at the end diaphragm. The skidding system was then removed from beneath the bridge and the bridge was lowered onto pedestals built on top of the existing piers. The arrangement of the girders allowed the pedestals to be constructed underneath the temporary steel truss bridge. Once lowered stainless steel shims were used to ensure all bearings had firm contact and the alignment of the road deck was measured within 1/8” to the existing roadway. The temporary strands were then cut and patched while the bridge received a set of striping for an opening within 19 hours of the closure.

CONCLUSION

The main advantage to utilizing a D-B approach for the I-5 Skagit River Bridge Replacement was its ability to tailor the extremely fast-paced schedule and construction techniques associated with the project to the contractor means and methods. Having just 3 months to design, build and remove the temporary bridge required involving the contractor and specialty moving contractor in the design process. The sharing of ideas assured that the owners concerns could be met while providing a cost effective solution that minimized the main goal of the WSDOT officials to limit disruption to traffic in this heavily traveled corridor.

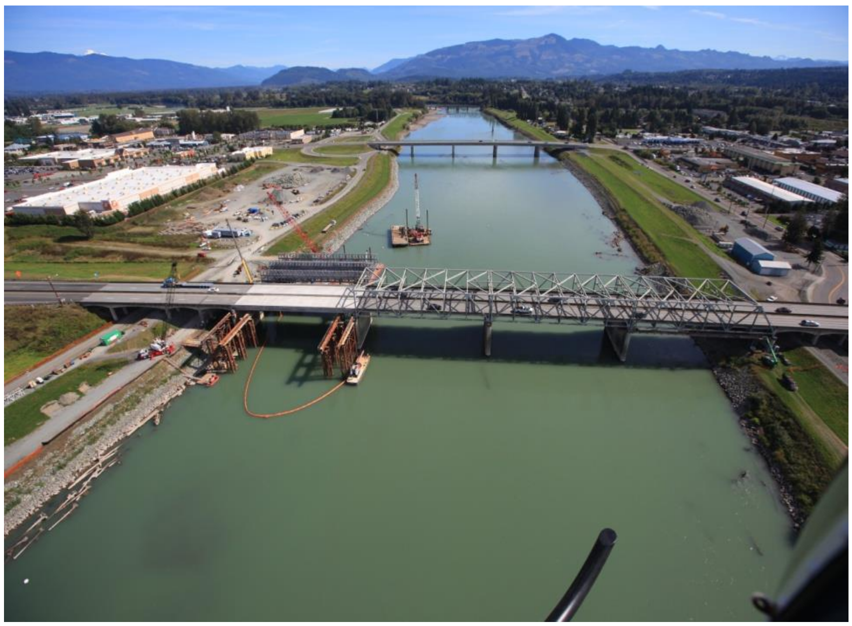


Figure 5: Completed Bridge Open to Traffic Immediately Following Span Switchover

The D-B team completed the project ahead of the client's original contractual deadline. The bridge opened to traffic on Sept. 15, 2013, following a single, 19-hour closure, 115 days from the initial bridge collapse and 88 days from the team's notice to proceed.

The collapse on the I-5 Skagit River Bridge, which connects Mt. Vernon and Burlington, represented a major disruption for a vital transportation artery and trade corridor. The importance of reestablishing this link became a top state and national priority. The innovative engineering solutions and the dedication of the construction crews was commemorated by Governor Jay Inslee at the opening of the bridge, "I want to acknowledge the tremendous work of the entire team who worked on this bridge. This is an effort we can all be very proud of."

REFERENCES

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