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Restoring a collapsed span over the Skagit River

- After the collapse of the north span of a bridge over the Skagit River between Burlington and Mount Vernon, Wash., severed Interstate 5, an emergency design-build contract provided for its rapid replacement.
- Prestressed sand-lightweight concrete decked bulb tees and diaphragms, along with an innovative full flexural-shear flange-to-flange connection, kept the weight of the superstructure within 5% of that of the steel bridge it replaced, allowing the existing undamaged substructure to be reused.
- The new permanent structure was opened to traffic 115 days after the collapse and 88 days after the contractor received notice to proceed.

On May 23, 2013, the evening commute was wrapping up in the four-lane stretch of Interstate 5 (I-5) between the Canadian border and Seattle, Wash. At roughly 7 p.m., a semitrailer in the outside southbound lane carrying a permitted oversized load hit the first portal frame section and several overhead sway members of the steel truss section of the I-5 Skagit River Bridge. Within seconds, a 160 ft (49 m) long section of the truss span carrying both northbound and southbound traffic collapsed into the Skagit River. While the semitrailer crossed safely, three people in two vehicles fell with the span. They were rescued by boat and did not sustain serious injury. The collapse forced the immediate closure of the interstate. Detour routes were set up through the streets of Burlington and Mount Vernon.

The main north-south highway for the West Coast of the United States, I-5 links cities from Mexico to Canada, providing an essential corridor for international trade and commerce. Seventy-one thousand vehicles per day cross the Skagit River on I-5, which is the only north-south interstate and the primary route between Seattle and Vancouver, BC, Canada. The longer the bridge remained closed, the more severe the effects on the local communities, the state, and international trade.

For Washington, trade is vital. Canada is one of the state's largest trading partners; a majority of the goods imported from Canada remain in the state. In addition, many Washington communities depend on business from Canadian customers traveling on I-5 from British

The Skagit River Bridge was originally constructed in 1955. The bridge was a statically determinate steel Warren through-truss structure having four simple spans with a total length of 1112 ft (339 m). Before the collapse, the most recent inspection of the bridge in August 2012 had found the condition of both substructure and superstructure to be fair but determined the bridge to be functionally obsolete. The north span collapsed in seconds when a semitrailer carrying an oversized load collided with several truss members on May 23, 2013. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

Columbia. The Border Policy Research Institute published a report in August 2013 showing a 51% decrease in the number of Canadian shoppers south of Burlington during May and June 2013.[1]

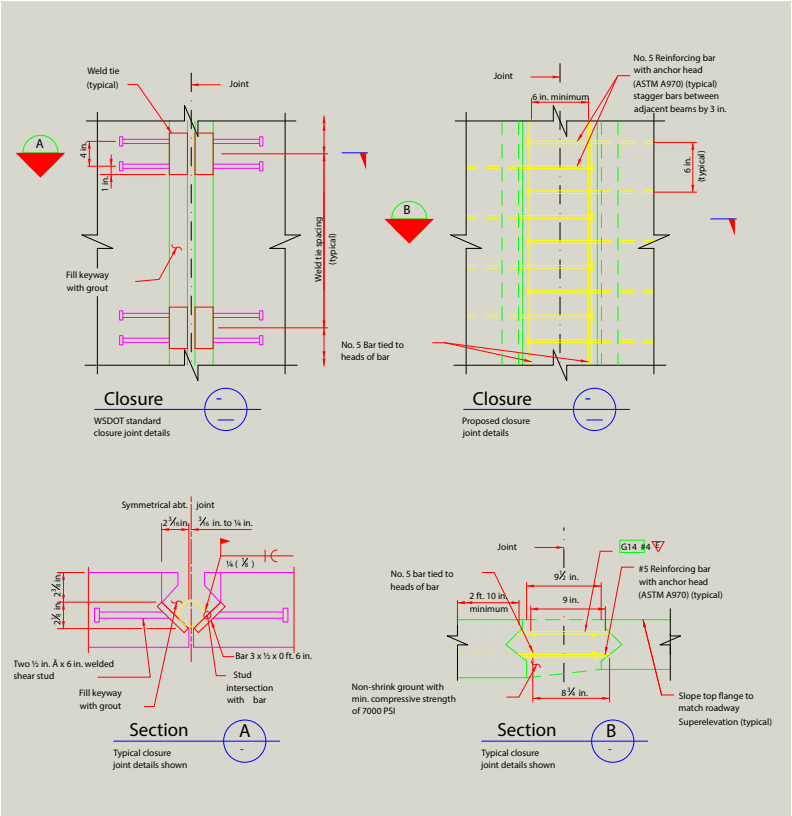
WSDOT responds to the collapse

The Washington State Patrol, Washington State Department of Transportation (WSDOT), and local agencies responded immediately, setting up and supervising detour routes east and west around the bridge. Traffic engineers worked through the night to refine detour routes through the streets of Burlington, and Mount Vernon, Wash.

The collapse of the Skagit River span occurred just before Memorial Day weekend, the unofficial beginning of the summer travel season, necessitating an immediate temporary replacement to restore traffic. While the temporary access bridges were being constructed, WSDOT began assembling contract documents for the permanent replacement span and a list of prequalified contractors for a two-week procurement period.

WSDOT bridge engineers assessed the damage and began plans for both emergency and permanent repairs while communication staff responded to the media, sending out updates and freight alerts throughout Washington, Oregon, and British Columbia.

Within 24 hours a contractor was hired under an emergency contract to remove the collapsed span and install two temporary prefabricated bridges while the National Transportation Safety Board conducted its investigation. Minimizing traffic disruptions dictated the installation of temporary side-by-side dual lane modular truss bridge spans (supplied by ACROW and subsequently replaced with the permanent span). The temporary replacement restored traffic at a restricted speed limit, and overweight vehicles were detoured onto local streets.



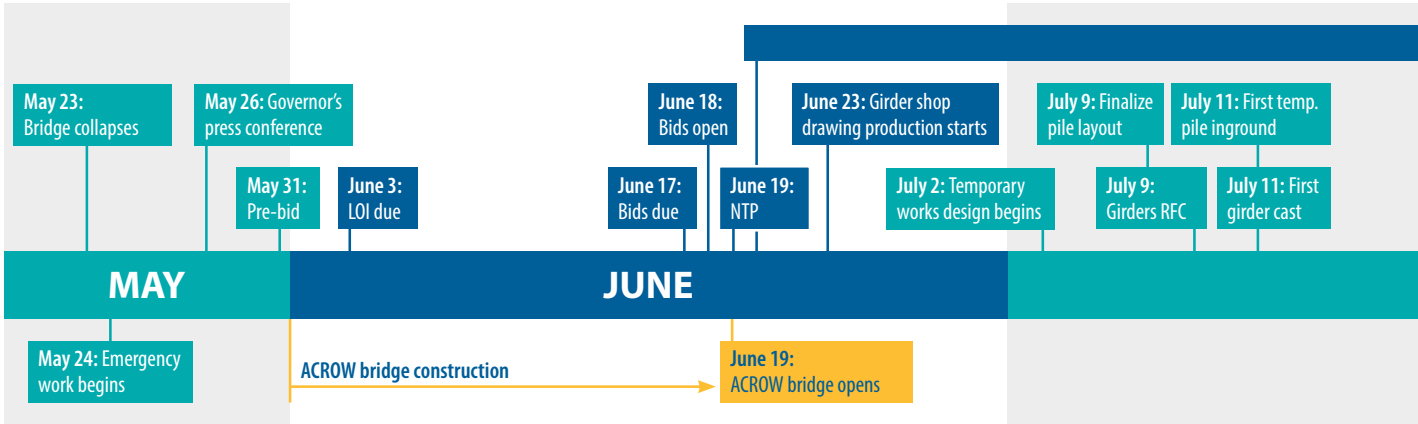
The standard flange connection (left) for decked bulb tees would have been acceptable for use in the replacement span, but the full flexure-shear connection (right) distributes live loads more effectively, allowing the elimination of one girder line. The consequent reduced weight of the superstructure made the prestressed concrete girder design competitive with the steel alternatives. Courtesy of Christopher Vanek, Parsons Brinckerhoff. Note: no. 4 = 13M; no. 5 = 16M; no. 6 = 19M; 1 in. = 25.4 mm; 1 ft = 0.305 m; 1 psi = 6.895 kPa.

Procurement

WSDOT's main goal was to build a safe, long-term solution as quickly as possible. The primary factors in the design of the permanent span replacement included minimizing traffic disruption, maintaining vertical clearance, and limiting the superstructure dead load. For navigational purposes, vertical clearance above the Skagit River had to be at least that provided by the original truss span. Most important, the weight of the new span had to be no more than 5% greater than the dead load of the original truss to obviate the need for seismic upgrades to the 50-year-old piers founded on timber piles.

WSDOT selected the design-build method to facilitate rapid construction. Within 11 days of the collapse a request for proposal was issued for the five prequalified teams selected. To minimize disruption to traffic, financial penalties of $50,000 per day for delayed delivery and $660,000 per day for closure of I-5 were imposed on the cost proposals at bid selection, with additional liquidated damages to be imposed if the proposed schedule was not met.

The design-build team comprised Max J. Kuney Construction Co. as the contractor, Parsons Brinckerhoff as the design engineer, and Omega Morgan as the specialized heavy lift contractor. During the limited two-week procurement period, the design team developed and considered numerous design and construction scenarios to satisfy WSDOT's requirements, including being constructable within the 103-day schedule, while providing the best value for the agency.



Due to the importance of Interstate 5 to the local and national economy, time was of the essence in providing a permanent replacement for the collapsed span. Close collaboration among the engineer, the contractor, the precast concrete fabricator, and the heavy-lift specialty contractor made it possible to complete the replacement slightly ahead of schedule. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

Construction methodology

Because of the large liquidated damages, the need to minimize the closure time of I-5 while limiting the potential contractor's risk of financial penalties was emphasized during the design process. To minimize closure time, it was recognized early in design that the structure would have to be built alongside the I-5 alignment and placed during a single closure. This process would require the temporary bridge to be removed and the new bridge put in place within 24 hours. Several options were developed, including constructing the span on land or water and placing it using a push-pull skidding system, a barge-mounted hydraulic lifting system, or a self-propelled modular transport.

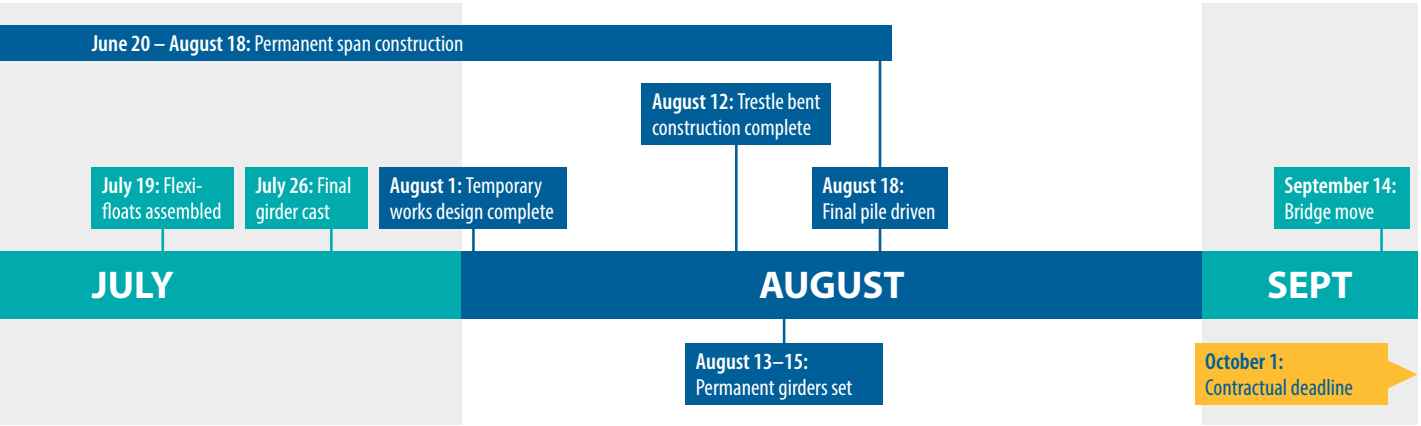
A water-based operation was initially selected, with a scheme of moving the spans by floating the bridge on a barge and using a hydraulic lifting system. However, several risk factors became apparent. Data gathered on fluctuations of the water level in the Skagit River showed that accurately predicting the draft and current, the intricate maneuvering of massive barges, and the amount of equipment on the barge would prolong the estimated closure time and increase the potential risk of delay. This method was estimated to require a closure time of 24 to 48 hours.

Accordingly, the team opted for the skidding system. Skidding required the use of temporary bents and massive skidding beams to facilitate construction and moving. The infrastructure was to be constructed parallel to the temporary bridge span. The temporary bridge was to be slid upstream onto a network of temporary towers for disassembly, and the new permanent bridge would be slid into place from its construction platform. This alternative resulted in the most favorable combination of cost and risk reduction by reducing the estimated closure of I-5 to 12 to 24 hours.

Evaluating the proposals

A key concern in design was the maximum dead load limit of 918 tons (833 tonnes) for the new span to permit use of the existing bridge piers, which had not been affected by the accident. This restriction, along with a compressed construction schedule, restricted the materials that could be considered for the replacement. This project was advertised for proposal with the assumption that the most likely structure types would be the steel or concrete girder options. To facilitate overnight replacement, the structural system needed to accommodate the large concrete pedestals that were placed during installation of the temporary bridge. Removal of these pedestals would extend the closure time beyond the proposed 12 to 24 hours. The structural system also needed to accommodate the proposed construction technique of lifting and skidding the bridge inside the conventional bearing locations.

Four design-build teams submitted proposals for the permanent span replacement. The design-build team evaluated two steel alternatives and two prestressed concrete girder span options. The proposals submitted included a steel through-truss (a near duplicate of the original span) that easily met the span weight requirements and was aesthetically consistent with the original bridge and a steel plate girder span with concrete deck, but the time restrictions for fabrication of the structural steel girders and risk of late delivery resulted in increased construction risk and delayed completion. On the other hand, traditional concrete alternatives would be heavier but could be obtained in time. The main concern was meeting the weight restriction and the design code requirements. This motivated the design team to consider a structural system comprising eight inte-



Temporary posttensioning strands in the top flange enabled the girders to withstand the stresses induced in transport, lifting, and skidding. These tendons were cut once the replacement span was in place. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

gral sand-lightweight prestressed concrete decked bulb-tee girders. WSDOT had previously limited the use of decked girders to off-system bridges with low truck traffic volumes due to concerns with the structural integrity of this system. However, the design-build team introduced a full flexural-shear connection between the flanges to permit its use. Lightweight 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.

WSDOT used the A+B+C best value approach, where A is the completion date, B is the shortest I-5 closure time, and C is the total cost. The proposal selected offered competitive initial costs, low overall life-cycle costs, the shortest girder procurement time, and the minimum closure time required to replace the temporary span with the permanent span. The construction and design methodology led to the proposal to reconstruct the span in 90 days, including moving the span into position within a single closure of I-5 of less than 24 hours.

Permanent span design

Design methodology

The scope of work included construction of the new span adjacent to the bridge's two temporary spans, then removal of the temporary spans and placement of the single permanent span. To minimize closure times, a new permanent span had to be constructed on piling and bents just downstream of the temporary spans. A series of tracks had to be installed 20 ft (6 m) from the ends of the girders. These tracks were installed on an inner set of pile bents under the permanent span, under the newly installed temporary span, and upriver of the temporary span. The temporary span had to be rolled sideways,

upriver from I-5, on completion of the permanent span. In the same operation, the permanent span had to be rolled upriver to replace the temporary span. All of the rolling was done on the inner tracks to roll out one bridge span and roll in another during a single road closure. After installation of the permanent span, the temporary span and all of the piling and tracks were removed.

The new permanent bridge was analyzed and designed using the *LRFD Bridge Design Specifications*[2] and the *WSDOT Bridge Design Manual*.[3] To limit the superstructure weight, the design-build team proposed a girder spacing of 7 ft 3 in. (2210 mm). This spacing eliminated one line of girders from the conceptual drawings advertised for bid. The total weight of the new superstructure, including the lightweight concrete traffic barriers and concrete overlay, was 915 tons (830 tonnes), below the maximum limit required by the contract.

Headed bars form the continuous flange-to-flange connection. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

Design process

Following notice to proceed, the design-build team had less than four months to replace the temporary steel truss span with a new span. The

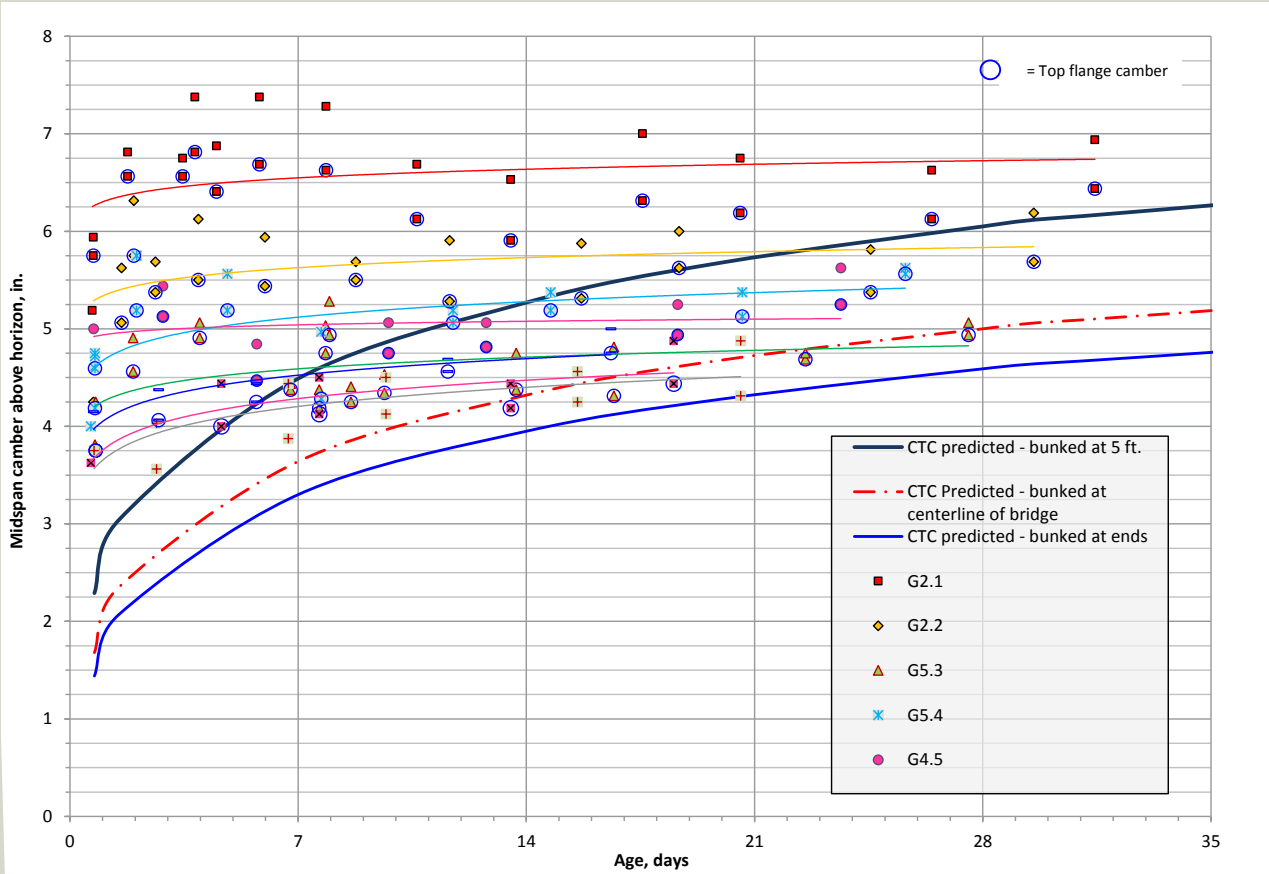
Each girder was placed on the temporary supports in a carefully choreographed sequence involving one crane on a barge and another crane on the north bank of the river. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

Differential camber

Differential camber and reflective cracking are the two performance challenges inherent in the use of decked bulb tees for long spans. The differential camber was adjusted using leveling beams before casting concrete at the closures. The predicted camber for the sand-lightweight decked bulb tee girders was 6.5 in. (165 mm), and the measured cambers were slightly above those predicted. The span-to-depth ratio of 29.5 met the LRFD bridge design criteria for deflection.

The design compressive strength of lightweight concrete used for the decked bulb tees was 9000 psi (62 MPa) with a concrete compressive strength at transfer of prestress of 7000 psi (48 MPa). The unit weight of the sand-lightweight concrete mixture was 122 lb/ft^3 (1950 kg/m^3); the unit weight of the girder was 133 lb/ft^3 (2130 kg/m^3) for design and dead load calculations. A total of forty-eight 0.6 in. (15 mm) diameter strands were used for the design of the girders in addition to the temporary posttensioning strands in the top flange to mitigate transient stresses during transport, lifting, and skidding into place.

—Bijan Khaleghi



Predicted and measured cambers. Camber values were measured from a horizontal datum. Add 4 3/8 in. (111 mm) to the bottom flange and 4 5/8 in. (117 mm) to the top flange to determine the total upward deflection due to prestress. Courtesy of David Chapman, Concrete Technology Corp. **Note: 1 in. = 25.4 mm.**

critical element in the design process was completing the sand-lightweight concrete decked girder design and detailing so that fabrication could begin. To expedite production of the critical concrete girders, the precaster produced shop drawings during the owner's design review. The fabricator also received daily updates on the design and detailing as plans were developed. This coordination enabled the precaster to procure the materials with long lead times and prepare the stressing beds for the intricate and detailed girder requirements.

While the design was being reviewed and developed for service under vehicular traffic, the designer also coordinated with the specialty heavy lifting contractor. The design of the bridge structure required consideration of the lateral slide operations to incorporate the design of the lifting diaphragms and locate the temporary towers while maintaining the weight restrictions. During this time the existing bridge was surveyed to ensure that the tight tolerance requirements of the replacement bridge would fit with the existing pier geometry. The design of the superstructure was approved within 20 days of notice to proceed, and the first girder was fabricated two days later.

During the fabrication of the precast concrete 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 for compatibility with the equipment being used and the existing and permanent bridge geometry. The temporary span had limited jacking locations, and the skidding system had limited stroke length in the hydraulic rams. The temporary steel pipe pile foundations were being constructed within 24 days of notice to proceed as the final design of the steel bracing and bent caps was being completed. Complete construction drawings were released the first week of August, five weeks after notice to proceed.

The closure pour completes the full flexural-shear connection between the flanges.
Courtesy of Christopher Vanek, Parsons Brinckerhoff.

Superstructure elements

The design-build team solution for the new permanent span involved the use of accelerated bridge construction techniques. The use of long-span decked precast, prestressed concrete girders had raised concerns with the structural integrity of the bridge system. According to Oesterle and Elremaily,[4] "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 mitigate the possibility of reflective cracking, the standard welded tie connections used for decked bulb-tee girders were replaced with overlapping bars and cast-in-place closures and the hot-mix asphalt topping was replaced with a 1 ½ in. (38 mm) high-strength concrete overlay. The WSDOT standard decked bulb-tee connection involved the use of longitudinal continuously grouted shear keys with welded connectors placed 4 ft (1.2 m) on center. This connection is only capable of transferring the shear and preventing rela-

The permanent replacement span was constructed alongside the temporary replacement span. Courtesy of Kurt Stiles, WSDOT.

tive vertical displacements across the joints. The new connection was developed to provide a full-flexural shear connection between the deck flanges and promote continuous transverse deck behavior based on the research conducted by Oesterle and Elremaily.[4]

This innovative connection more efficiently distributes live loads, eliminating a girder line (and the associated dead load) while enhancing durability. The full flexural-shear connection reduced the potential for reflective cracking through the silica-fume concrete overlay due to overweight vehicles that frequently travel I-5. To provide full transverse continuity of the deck, headed bars protruding from the girder flanges were employed to create a noncontact lap splice with adjacent staggered bars from adjoining girders. To accomplish the intricate connection the fabricator was required to apply strict tolerances of the protruding reinforcing bars.

The completed span was skidded into position during a single 19-hour closure of Interstate 5. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

The final superstructure section consisted of eight 65 in. (1650 mm) decked bulb-tee girders arranged to fit the configuration of the existing piers. The girder spacing was set to a nominal 7.25 ft (2.21 m) with a center girder spacing of 10 ft (3.0 m) to accommodate the existing pedestals reused as seismic girder stops for the temporary replacement span and eliminate the need to demolish them during the span replacement. The girder design required the use of a 9000 psi (62 MPa), 122 lb/ft^3

New technology implemented in this project: Precaster's view

This span replacement project provided the impetus to employ technologies that the Pacific Northwest PCI Producer Members had been discussing with WSDOT for quite some time.

Decked bulb tees have been popular with the State of Alaska and cities and counties in Washington State, but WSDOT had been reluctant to use them, particularly on high-volume roads. WSDOT developed standards for decked bulb tees but required a thick (5 ½ in. [140 mm]) cast-in-place deck in addition to the precast concrete deck, essentially negating the effectiveness of the section other than eliminating the need for cast-in-place deck formwork. It is believed that this was WSDOT's first use of these sections with only a thin leveling overlay. These sections allow the precaster to supply the deck as well as the girders. The owner gains an accelerated schedule by eliminating the need to form and place the deck in the field.

Due to the weight limitations, this project would have gone to steel girders without the use of controlled-density (sand-lightweight) concrete. WSDOT was reluctant to use this material because not enough data were available on the material properties. Previously, the city of Seattle had specified a controlled-density concrete mixture on a superstructure replacement for Airport Way, where the existing substructure was preserved and weight was a concern. Those specifications required what seemed at the time to be an inordinate amount of production testing of the mixture. However, the end result was a significant amount of data that could be used on the Skagit River project, enabling a reasonably accurate estimate of the girder camber.

WSDOT's standard connection between decked bulb-tee flanges consisted of welded plates at approximately 4 ft (1.2 m) on center in combination with a continuous grouted shear key. Although this detail had been used successfully on a multitude of projects, WSDOT was reluctant to employ it because of potential deterioration of the grout in the joint, reflective cracking in the overlay, and leakage through the deck. Relatively narrow joints with short projecting bars in combination with ultra-high-performance concrete had been tested and used in other states; however, ultra-high-performance concrete may not meet Buy America requirements because of the imported fibers in the material. Consequently, WSDOT elected to permit a combination of headed bars and higher-than-normal strength (7000 psi [48 MPa]) cast-in-place concrete for the connections. For a common decked bulb-tee bridge, this type of connection has some disadvantages. As with all prestressed concrete girders, there will be a certain amount of differential camber between girders. The typical procedure is to level the decked bulb tees with a push-pull system, then weld the flange plates. Once this is done, the push-pull system can be released and bridge construction can continue. With the headed bar joint, the leveling system must remain in place until the concrete in the diaphragms and closure pours between flanges reaches the required strength. However, this did not significantly affect the schedule on this project and allowed a girder line to be eliminated based on an improved live load distribution factor.

Precambering is a process Concrete Tech has used for the State of Alaska (and other clients) for many years. The formwork is either humped or sagged so that net camber is close to the required profile grade for the bridge. It was critical for the weight of the Skagit River superstructure to limit the thickness of the overlay to the minimum required for the full length while still matching the required profile grade. Although WSDOT was aware of this technology, it was reluctant to specify it because not all precast concrete fabricators in the area have demonstrated this capability. Concrete Tech had previously used this technology on a design-build project for WSDOT on a bridge just outside the right field entrance to Safeco Field (SR 519 intermodal access project phase 2) that required about an 18 in. (460 mm) camber to provide clearance to the railroad tracks below while still providing access to the adjacent Century Link Field parking structure that complied with the Americans with Disabilities Act. In essence, the camber for those girders had both upper- and lower-bound restrictions. That project was well thought out and successful, receiving the 2010 PCI Design Award for Bridges with Main Spans between 76 ft and 150 ft. The added complexity for the Skagit River project was the behavior of the controlled-density concrete. Although the initial cambers were higher than anticipated, in the end they were within the anticipated range.

These technologies, previously little used by WSDOT, were by necessity all combined to meet the requirements of this replacement span. Assuming the performance of this span meets expectations, this should add more options to WSDOT's toolbox. Some of these technologies may eventually become standard practice.

—Stephen J. Seguirant

Hydraulic jacks lower the replacement span into position. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

(1954 kg/m^3) sand-lightweight concrete. The superstructure also required the use of a 4000 psi (28 MPa) lightweight concrete in the cast-in-place concrete end diaphragms, the intermediate lifting diaphragms, and the cast-in-place concrete barriers. To provide a smooth riding surface and limit wear of the girder flanges, a silica-fume concrete overlay was applied to the final roadway surface.

With the concrete girders, mitigating additional dead load due to camber and cross slope was a primary concern. For the system to meet the span weight requirements, the need for precambering was identified early in design. The long, slender sand-lightweight concrete girders, with their span-to-depth ratios of 29.5 and forty-eight 0.6 in. (15 mm) diameter strands each, were estimated to exhibit an excessive camber of 6.5 in. (165 mm). To accommodate this estimated camber while matching the existing roadway profile, a thickened concrete overlay would result in approximately 100 tons (90 tonnes) of additional concrete in the bridge deck. To mitigate excessive overbuild on the deck surface, which would exceed the span weight limitations, the girder forms were deflected (sagged) approximately 4.5 in. (110 mm) so that after consideration of deflections due to prestress, self-weight, diaphragms, barriers, and a uniform thickness of overlay, the profile grade would match that of the existing roadway. This technique, traditionally performed only in steel girder bridges, was employed through coordination with the precast concrete manufacturer on specific properties of the sand-lightweight mixture. To mitigate overbuild due to cross slope of the bridge deck, the top flanges of the girders were sloped to match the existing 1% superelevation.

The final refinement required for the sand-lightweight concrete girder system was compatibility with the skidding operation. The slide-in construction technique placed the replacement span on temporary supports inside the traditional bearing areas. To support the girder system on the intermediate jacking diaphragms, the prestressed concrete 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, two temporary posttensioned strands in the top flange, along with additional mild reinforcement, maintained acceptable crack widths. The temporary 0.6 in. (15 mm) strands were stressed to 75% of the ultimate strength. Recessed pockets were provided in the top flange of the girder and through the silica-fume concrete overlay, which the contractor was required to access to de-tension the top strands after the move.

The slide-in construction operation used an unconventional location of lightweight concrete intermediate diaphragms. The diaphragms were placed 20 ft (6 m) from the beam ends along the 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 moved the span into place. To support the

span, the diaphragms extended below the girders to permit the majority of the reinforcement in the diaphragm to be placed as effectively as possible, minimizing the weight.

Permanent span construction

Construction of the permanent span began on July 12, 2013. To complete the permanent replacement span within two months required a large group of contractors and fabricators. Shortly after 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 precaster began procuring materials within two days of notice to proceed. The lightweight aggregate was procured from North Carolina and shipped to the precaster's facility in Tacoma, Wash. The headed stud reinforcing bars were manufactured in two locations to meet the deadline. The precaster produced shop drawings as the design was being finalized, and girder casting began two days after final acceptance of the design by the owner. Once fabrication commenced, the beds were turned over on a two-day rotation. The precaster monitored the girder camber frequently and reported the findings. This process allowed the design-build team to ensure that the structure would remain within the weight limit and monitor the potential adjustment required for differential camber. Once the girders were trucked to the site the process of completing the bridge began.

Superstructure construction

Girder erection occurred over three days in a carefully orchestrated process. The erection sequence involved a 500-ton (230-tonne) crane placed on land and a 200-ton (90-tonne) 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 reballasting, and finally placing the girder on the temporary bents. A time-lapse video of the girder setting can be found at https://www.youtube.com/watch?v=-IdUap4_IvY.

The permanent superstructure was constructed on a separate row of piling and bents just downstream from the temporary spans to support a rail system that would be used to slide the temporary spans out and the new span into place. A vertical and horizontal jacking system was concurrently installed using rails supported by temporary piling and bents.

Once the girders were erected, the process of leveling them began as differential camber between the girders was surveyed to the nearest 1 in. (25 mm). The girder system was

The alignment between the existing and replacement spans was checked to ensure a smooth transition. Courtesy of Christopher Vanek, Parsons Brinckerhoff.

The replacement span was opened to traffic on September 15, 2013, two days ahead of schedule. Courtesy of Kurt Stiles, WSDOT..

adjusted using leveling beams and threaded inserts placed in the top flange of the girders during fabrication. 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 7000 psi (48 MPa) normalweight pea gravel mixture to ensure proper development of the protruding headed bars. The girder spacing accommodated the temporary bridge span pedestals and facilitated the placement of the median barrier reinforcing 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 4000 psi (28 MPa) lightweight concrete. The last step was the placement of the silica-fume concrete overlay on the deck. The construction of the superstructure took two weeks after girder delivery and was completed three days before the span was slid into place.

Span placement

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 to be slid into position. Midway through the design of the new span, a survey of the temporary bridge showed that the contractor had placed 1.75 in. (44 mm) thick expansion joint plates over the rear supports of the steel truss bridge span, which had to be removed before jacking. The temporary bridge was then relocated from the existing substructure and slid in approximately 30 minutes to a steel bent support upstream for later disassembly. The skid track system was composed of Teflon pads placed inside a steel dog push-pull system lubricated with liquid soap. The process then turned to moving the 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 in. (50 mm) gap on each side of the bridge and a required longitudinal translation. 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.

The skid track jacking system could not lower the bridge the full amount necessary due to the clearance required over the concrete pedestals; therefore a two-stage process was employed. Once the bridge was in alignment, it was lowered onto hydraulic jacks at the end diaphragm. The skidding system was then removed from beneath the bridge, and the bridge was lowered onto pedestals on the existing piers. The arrangement of the girders had allowed the pedestals to be constructed underneath the temporary steel truss bridge. Once the bridge was lowered, stainless steel shims were used to ensure that all bearings had firm contact and the alignment of the road deck was measured within ⅛ in. (3.2 mm) of the existing roadway. The temporary strands were then cut and patched while the lanes were striped for an opening within 19 hours of closure.

Conclusion

The main advantage to the design-build approach for the I-5 Skagit River Bridge replacement was flexibility to tailor the compressed schedule and construction techniques to the contractor means and methods. Having just three months to design, build, and remove the temporary bridge required involving the contractor and specialty moving contractor in the design. The sharing of ideas ensured that the owner's concerns could be addressed while providing a cost-effective solution that minimized disruption to traffic in this heavily traveled corridor.

The design-build team completed the project ahead of the contractual deadline. The bridge opened to traffic on September 15, 2013, following a single 19-hour closure, 115 days from the initial bridge collapse and 88 days from notice to proceed.

The collapse of the I-5 Skagit River Bridge severed 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 at the opening of the bridge by Governor Jay Inslee, who said, "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."

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Increasing vertical clearance

As successful as the replacement of the collapsed bridge was (I-5 was closed for a total of only 28 days), the designers and contractors did not stop working on September 15. With the permanent replacement span in place, attention turned to the remaining three sway-frame truss sections and their vertical clearances.

A portal frame is the endmost lateral bracing frame on each independent span. Sway frames are the frames between the portal frames within a span. Constructability demanded some innovation.

Raising a portal and sway frame is not as simple as merely moving portions of the bridge up. The way this is done is to partially dismantle the bridge and reconstruct it in the new configuration. While the bridge is partially dismantled, its structural integrity is compromised until the portal or sway frame is reconstructed. Managing the volume of work performed at one time was essential in ensuring that the repair did not create another collapse. The restoration was successful.

Although truckers are responsible for their overheight loads, states would be prudent to examine impacts from overheight loads and mitigate them if possible. In this case, that meant removing and replacing the lowest-height elements of the trusses, increasing the vertical clearance across the two outside lanes, and helping to extend the already long life of the I-5 Skagit River Bridge.

—Bijan Khaleghi

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Abstract

A semitrailer hit several overhead steel truss members of the Interstate 5 (I-5) bridge over the Skagit River in Washington State, causing the north span to collapse. An emergency design-build contract required reopening of the permanent replacement span within 90 days of notice to proceed. Precast, prestressed concrete decked bulb tees of sand-lightweight concrete and full flexure-shear flange connections kept the weight of the superstructure within 5% of that of the original steel superstructure, allowing the undamaged substructure to be reused. Careful control of the girder geometry maintained vertical clearance over the Skagit River. Temporary posttensioning enabled the girders to resist construction-induced stresses. The replacement span was assembled alongside the existing bridge and skidded into place during a single 19-hour closure of I-5.

Keywords

Accelerated bridge construction, camber, connection, decked bulb tee, design-build, lightweight concrete, posttension, repair, silica-fume concrete.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

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