RAPID BRIDGE REPAIR / REHABILITATION IN WASHINGTON STATE

Jugesh Kapur[1]

Abstract

The Washington State Department of Transportation (WSDOT) used a very cost-effective technique using Carbon Fiber Reinforced Polymer (CFRP) to rehabilitate and strengthen a deteriorated precast concrete bridge. The beams on this bridge had experienced spalling of concrete and corrosion of reinforcement. WSDOT also replaced four, 122 cm movement steel modular joints on an Interstate 90 floating bridge due to fatigue cracking of the transverse center beams in the modular joint. In order to meet the new fatigue resistant design criteria, the new center beams are solid and 2.5cm wider than the center beams in the original modular expansion joint. Both projects were done very efficiently and rapidly without loss of quality.

US 2 Ebey Slough Viaduct – Repair with Carbon Fiber Reinforced Polymer (CFRP)

The Washington State Department of Transportation (WSDOT) has effectively used Carbon Fiber Reinforced Polymer (CFRP) to rehabilitate portions of a deteriorated precast concrete bridge located near Everett, Washington at beginning of highway US 2. Portions of the bridge were repaired in 1999 and 2007 with the final section due to be completed in 2010. CFRP strengthening of vertical load carrying elements is relatively new in the United States even though it is used extensively in Europe and Japan. CFRP strengthening can be a cost-effective alternative to replacement or posting of structurally deficient bridges. Despite its high cost, CFRP possesses high strength and is light in weight. It is also corrosion resistant, easily constructible and has a high fatigue resistance. These qualities make it a favorable material for the rehabilitation of our nation's transportation infrastructure.

Existing Bridge

The Ebey Slough Viaduct was constructed during the late 1960's and opened to traffic in 1968. The bridge carries nearly 35,000 vehicles per day and provides a vital link between western and eastern Washington. The bridge spans a river and slough area that floods every year. The bridge has several different superstructure types and is 11,909 feet (3630 meters) in length with a total of 256 spans.

EBEY SLOUGH VIADUCT

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[1] State Bridge Engineer, Washington State Dept. of Transportation, Olympia, WA

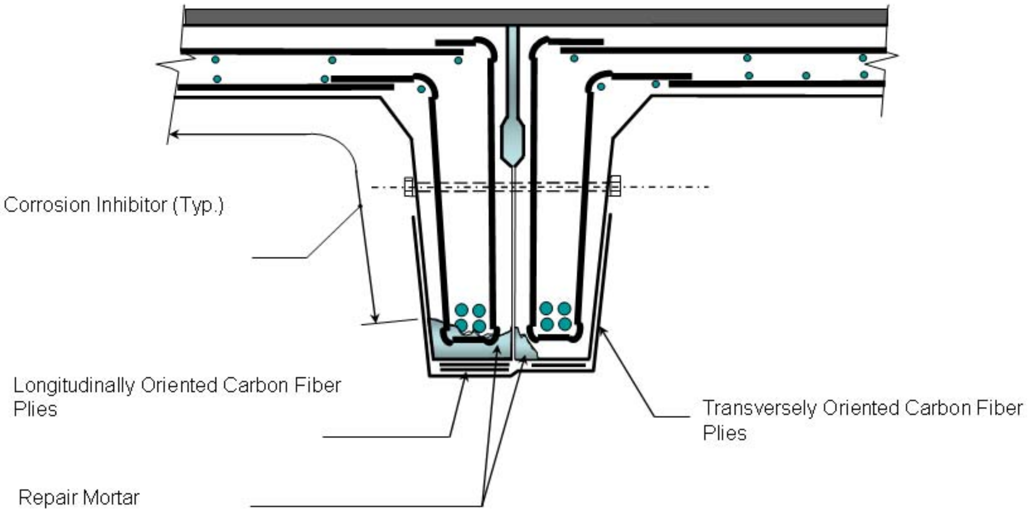
A significant portion of the bridge, 226 spans – 7,410 feet (2259 meters) has conventionally reinforced precast concrete double tee concrete units, also known as inverted tub units. The concrete unit spans approximately 38 feet (11.6 meters) between piers with each span composed of six superstructure units bolted together transversely through their webs.

Each individual unit has a bundle of four #11 reinforcing bars at the bottom of each web covered with 1 inch of concrete. The precast concrete units also have grouted keyways between them. Over the years the grout in the keyways had deteriorated allowing water and deicing salt to penetrate between the precast units which caused the main longitudinal steel reinforcing bars to corrode and spall off the concrete cover. Areas of exposed and corroded reinforcing steel are scattered, but mostly predominant in the exterior units.

WSDOT contracted with Construction Technology Laboratories to analyze several randomly obtained core samples with the objective of evaluating the technical feasibility of repairing this structure. An analysis of the concrete core samples determined that structural rehabilitation was feasible.

Repair and Rehabilitation Using CFRP

WSDOT bridge engineers reviewed different options and decided to repair the precast tub units using CFRP. Since the amount of section loss in the steel reinforcing was unknown, the CFRP would make up for the loss. CFRP material properties and applications methods differ from conventional bridge materials and how these realities affect typical civil structural engineering design philosophies. The carbon fiber has an elastic modulus comparable to that of steel and an ultimate strength that is much greater than that of steel. Carbon does not possess the same ductility. This is different with respect to the traditional ductile concrete and reinforcing steel design philosophy.



US 2 Ebey Island Bridge

CFRP composites have positive attributes including high strength-to-weight ratios. Additionally, the designer is afforded the flexibility of orienting stiffness and strength in the directions required. FRP composites have high resistance to fatigue and corrosion. Compared to other rehabilitation methods, FRP composites minimize handling difficulties and can be installed in limited access situations, often with minimal disruption to traffic.

In spite of these advantages, many perceived technical and institutional barriers still exist to FRP composite usage in the civil engineering arena such as, standardized/codified design criteria is limited and there is a lack of construction specifications available. Durability is another issue. The aerospace industry has conducted extensive durability tests on FRP composites relevant to their needs. Obviously, the applicability of some of these tests to civil engineering applications is somewhat contentious. Plausible durability tests include resistance to humidity, salt water immersion, alkali, dry heat, fuel, ultraviolet weathering, and freeze/thaw cycling. The questions which need to be definitively answered are: Which of these tests are pertinent and should be required? For what durations should such tests be conducted?

FRP composite costs are perceived to be high. In rationalizing material costs, other factors must be considered: life cycle costs, traffic disruptions, durability, worker safety, and real estate costs associated with wholesale bridge replacement. One important issue was the sequencing under which carbon fiber plies are bonded to load carrying elements. Manufacturers and suppliers of CFRP materials have asserted that the plies can be bonded to structural bending elements of a bridge while that structure is under full traffic. Structural engineers disagree on the effectiveness of strengthening performed under full live load.

The main concern is that imposed live load will subject both the resin bonding agent and the carbon fiber plies to micro-strain during the curing process. Assuming full development of bond to the substrate structural material, the carbon fiber plies will augment the ultimate capacity of the structural bending element. The carbon fiber plies will not participate in resisting future live loads that are less than those that were imposed during the resin curing process. This could have potential long-term durability implications depending upon the condition of the structure before rehabilitation, the live load levels anticipated during bond cure, and the future environment to which the structure will be subjected.

Prior to structural design of the Ebey Viaduct repairs, a field survey was conducted to estimate steel corrosion losses at various locations. Based upon these estimates, a stress-strain compatibility analyses was performed to establish the carbon fiber ply cross sectional area required to regain structural moment capacity. This was done for varying levels of steel reinforcement bar corrosion loss.

Carbon fiber ply application plans specifying carbon fiber ply tensile capacity requirements were developed for each span for the contract documents. Multiple longitudinal plies where required by the design calculations. In areas where very severe spalling had occurred, transversely oriented carbon fiber plies were specified to resist horizontal shear across the existing concrete-to-repair mortar interface.

Epoxy injection of all cracks greater than 0.02" (0.51 mm) wide was required. Concrete surface preparation follows. In addition to removal of spalling concrete, this includes application of passive grout to all exposed steel reinforcement following its sandblasting to a white metal finish.

All existing sharp edges/corners in the concrete are ground smooth. Repair mortar placement follows. Once the repair mortar cures, a primer is applied to the bottoms of all concrete webs to prepare the surfaces for carbon fiber ply bonding. Putty is then used to fill all surface concavities. A resin undercoat is then applied to which the carbon fiber plies are immediately bonded. After the plies are bonded and rolled smooth, a resin overcoat is applied. Sand was broadcast onto the resin overcoat for aesthetic reasons and to provide some level of resistance to ultraviolet degradation.

Performing either repair mortar placement or carbon fiber bonding work under full traffic conditions was ruled out due to the high amount of truck traffic on the structure. A compromise was reached by electing to perform these repairs during either full traffic closure or under restricted traffic conditions. Restricted traffic was defined as only vehicles under 5 tons (4546 kg) at speeds below 25 miles (40 km) per hour. This gave four different combinations that determined how to perform the work on the remainder of the bridge.

Pilot Project on eight spans

WSDOT bridge engineers selected a 304 feet (92.7 meters) long eight span section of the bridge for a pilot project. The objective of this pilot project was to assess the feasibility of rehabilitating all the precast concrete tub units on the entire bridge using advanced composite CFRP materials, both from an economic and a durability perspective. The use of CFRP would provide a way to repair and strengthen the bridge with minimal disruptions to traffic.

The work began in June 1999 and was completed by August 1999. The contract was awarded to Concrete Barrier Incorporated for nearly $970,000 with 40 days to complete the work. Mitsubishi Chemical supplied the carbon fiber system.

The overall scope of work included setting up a containment and work platform. Removal of the existing ACP overlay to allow repair of deck delaminations and to inspect and repair the longitudinal keyway joints between adjacent concrete units. To repair the grouted keyways, the contractor sawcut 9 inches (23 cm) deep to the mid-depth of the keyways and cleaned and filled the resulting 1 inch wide gap with low modulus epoxy. A new deck membrane and ACP overlay was then placed on the roadway deck side of these eight spans. Upon completion of the overlay repairs, the spalled concrete web surfaces were prepared for placement of repair mortar. After repair mortar placement, carbon fiber plies were bonded to the web bottoms.

Corrosion inhibitor was applied to all exposed surfaces of the precast concrete units to enhance durability. The overall rehabilitation strategy involved the removal of deteriorated concrete adjacent to spalls, blast cleaning of all exposed corroded steel to a white metal condition, epoxy injection of cracks wider than 0.02", repair mortar placement, miscellaneous concrete surface preparation, and bonding of CFRP strips to the web bottoms. Structural design calculations were set up in an automated electronic format to establish the cross sectional CFRP requirements for varying levels of longitudinal steel reinforcement corrosion loss.

The carbon fiber supplier's willingness to be on the jobsite to provide technical guidance and train to the contractor was directly related to the success of the project. The supplier and contractor's work crew had a meeting prior to the carbon fiber application. Previous projects nationally have demonstrated that CFRP can be bonded under full traffic conditions to strengthen bridge superstructures. In order to evaluate several construction staging options, span-specific traffic control requirements with respect to placement of repair mortar and CFRP strip bonding were specified. Two traffic control conditions were imposed during construction: full traffic closure and a restricted traffic condition with vehicle weights limited to five tons at a maximum speed of 25 miles (40 km) per hour. Durability and performance of spans repaired under the two different traffic control scenarios will be examined and taken into consideration in developing a long-term repair strategy for the entire bridge.

Total cost of this initial pilot project was about \$970,000 which equates to about \$106/SF (\$1141/m^2) of bridge deck area. This cost is 10% or less of the cost of bridge replacement. A breakdown of seven bid items representing approximately 80% of the contract cost shows the removal and replacement of concrete accounted for about 40% of the total with the CFRP application accounted for about 8% of the total cost.

Ten years following construction, all CFRP repaired concrete areas have been inspected with the longitudinal joint repairs and carbon fiber reinforcement performing as originally designed with no visible deterioration. It is anticipated that this repair will provide 25 years or more of service.

Phase 2 Project - Rehabilitate 128 spans

WSDOT bridge engineers identified 136 spans of the tub units for the second phase of the Ebey Slough Viaduct rehabilitation. The project followed the same design as specified in the 1999 pilot project. The contract was awarded to Wilder Construction Company for nearly $7.9 million with 97 days to complete the work. The work began in April 2007 and was completed by November 2007.

The contract plans specified that all traffic be restricted during the application of the carbon fiber which required the use of the parallel bridge at times to carry both directions of traffic. The contractor was allowed to determine the number of layers of carbon fiber to apply based on the amount of corrosion of the steel reinforcing bars. This provision became a problem during the project since WSDOT review of assumptions made by the contractor did not justify the number of layers of carbon fiber the contractor applied. The total cost of the carbon fiber material was nearly $1.5 million or 19% of the total project cost.

Two years following construction, all CFRP repaired concrete areas have been inspected with the carbon fiber reinforcement performing as originally designed with no visible deterioration. It is anticipated that this repair will provide 25 years or more of service.

Phase 3 Final Project - Rehabilitate 82 spans

The final 75 spans of the precast concrete tub units for the Ebey Slough Viaduct are scheduled to be rehabilitated in 2010. The project will follow the same design as specified in the 1999 and 2007 projects. This project has a budget of nearly $31 million. It is anticipated that the actual cost will be substantially less that what is currently budgeted.

The traffic control and construction access will be more difficult than the previous two phases. These bridge spans are over water so the contractor must install work platforms from the existing bridge deck requiring additional lane closures. Connections to the parallel bridge are also more difficult in this area thus the traffic control options will be more complicated.

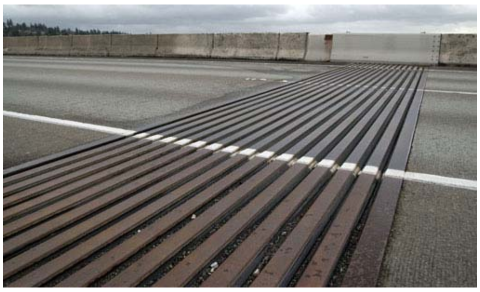
I-90 Homer Hadley Floating Bridge – Replacement of Modular Expansion Joints

The Interstate 90 "Homer M. Hadley" bridge is the third floating bridge to be constructed across Lake Washington between Mercer Island and Seattle and carries five lanes of traffic (three for westbound and two reversible). This bridge was officially opened on June 4, 1989 and is 5,811 feet (1771 meters) in length with eighteen floating

pontoons. The three westbound lanes have an Average Daily Traffic (ADT) of 60,000 and the two reversible lanes have an ADT of 12,000.

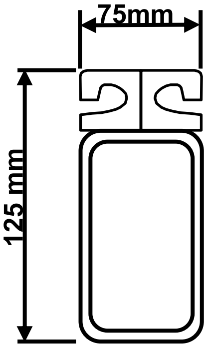
The bridge has transition spans at both ends that allow traffic to move from the approaches to the floating sections and to allow boats to go under the bridge. The longitudinal movement, which represents a combination of wind and wave loading, seasonal water level fluctuations, and thermal variations in the bridge are accomplished through the steel modular expansion joints.

ORIGINAL MODULAR EXPANSION JOINTS



The section of the bridge with the three westbound lanes has two large movement modular joints (48 inch, 122 cm) that are 63 feet ((19.2 meters) in length and the section with two reversible lanes has two large movement modular joints (48 inch, 122 cm) that are 40 feet (12.2 meters) in length. Thus there are a total of four of these sizes of joints on the bridge.

The original modular joints were designed, fabricated, and installed prior to the advent of fatigue-based design and manufacturing criteria for modular expansion joints. The joint manufacturer chose to use a hollow tube shape for the main transverse center beams.



Fatigue cracking initiated in the hollow tube and the welded support bar connection within 18 months after the Homer Hadley Bridge opened to traffic.

WSDOT developed some research projects with the University of Washington to investigate the cause of the cracking. The university performed field measurements of the dynamic wheel loads. The location and extent of the cracks were also carefully monitored. Repairs were made in several instances by welding the cracks but nearly all of these locations cracked again.

Fatigue Design of New Modular Expansion Joints

In November 1990, the pontoons in the parallel original I-90 Lacey V. Murrow floating bridge, which was being rehabilitated at the time, sunk. WSDOT recognized the need to improve on the design of the large movement modular joints during the design of the I-90 Lacey V Murrow replacement.

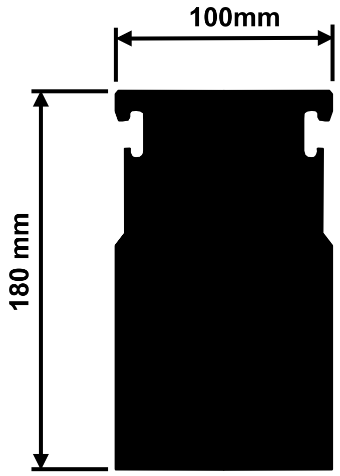
As part of that effort, WSDOT worked with D.S. Brown, the joints' manufacturer, the German-based Maurer Sohne Company, and University of Innsbruck (Austria) to develop the first generation fatigue resistant design specification for WSDOT. This new design was used on the new Lacey V. Murrow Bridge replacement.

Following the work by WSDOT, there was a substantial amount of interest throughout the United States to improve the fatigue resistance of steel modular expansion joints. The Transportation Research Board (TRB) subsequently funded NCHRP Project 12-40. This project culminated in the publication and release of NCHRP Report 402, which provided comprehensive fatigue-based test and design specifications for modular expansion joints.

To date, all of the modular expansion joints designed and installed based on this new fatigue design criteria are performing well.

Project Planning and Design

A decision was made in 2007 that all four of the 48 inch (122 cm) movement steel modular joints needed to be replaced due to the amount of fatigue cracking in the transverse center beams and the high risk associated with a potential failure. In order to meet the fatigue resistant design criteria, the new center beams are solid and one inch wider than the center beams in the original modular expansion joint.



The replacement of the joints required WSDOT to determine the best way for the joints to be manufactured, delivered and installed. WSDOT developed an initial estimate and plan then had a meeting with the Association of General Contractors (AGC) to review the details.

At the meeting, the AGC and WSDOT discussed some of these details:

1. The amount of time to replace the joints – three weeks for the westbound lanes and 3 weeks for the reversible lanes.
2. The joints should be replaced in two separate closures, one for the westbound lanes and one for the reversible lanes.
3. WSDOT should purchase the joints and advertise the replacement/installation project separately.
4. Make sure the liability issues and warranty issues are understood and addressed.

WSDOT decided to purchase the joints directly from the manufacture and have them shipped to Washington State. These joints would be handed over to the contractor that was given the joint replacement contract. WSDOT supplying the joints would speed up the manufacture and delivery time, eliminate contractor mark-up, reduce contractor risk for acceptance of the joint. Having the joint design prior to the bid will allow WSDOT to fully design the replacement reinforcement and dowels into the block out area. The contractor would then have a better idea of the actual removal-installation details.

Project Construction

The expansion joint contract was awarded to the General Construction Company for $5.7 million with the final construction cost being $5.85 million. The 4 modular expansion joints were replaced in two stages.

Stage 1 replaced the two 40 foot long joints located in the reversible lane roadway. All traffic used only the three westbound lanes. The first closure began on May 4, 2009 and was completed on May 16, 2009. The contract allowed 19 days with the contractor completing the work in 12 days. For the first closure, the contract had a provision to pay the contractor an extra $40,000 for each 24 hour period completed early. Total was not to exceed $160,000.

The first closure and replacement of the two 40 foot (12.2 meters) long joints allowed the contractor to better understand the work. We thought that the lessons learned during the May work would enhance the contractor's productivity during the more complicated stage 2 closure.

Stage 2 replaced the 63 foot (19.2 meters) long joints located in the westbound lane roadway. All traffic had to use the two reversible lanes. The second closure began on July 5, 2009 and was completed on July 17, 2009. The contract allowed 21 days with the contractor completing the work in 12 days. For the first closure, the contract had a provision to pay the contractor an extra $80,000 for each 24 hour period completed early. Total not to exceed $320,000.

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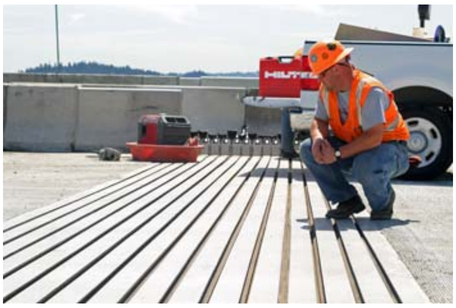
Our Special Provisions required that the contractor submit structural analyses verifying the load carrying capacity of the bridge for the specific cranes that would be used. Given the weight of each joint being installed and the boom radii that would be required to position these joints in their respective blockouts, we realized that the contractor would need some pretty substantial lifting equipment. Additionally, we required that the contractor operate all cranes on a separate pad and load distribution system designed in accordance with AASHTO LRFD Bridge Design Specifications.

The contractor used a 250-ton (228,000 kg) and a 300-ton (272,000 kg) crane operating on the respective transition spans to install joints on the reversible lane roadway. The contractor used a barge-mounted crane to install the two modular joints on the westbound lane roadway.

The contractor developed a good method to remove the concrete in the header area on both sides of the existing expansion joint and removal of the existing joint. A large concrete saw was used to cut a line across the bridge at the removal limits. Workers then used chipping hammers to remove the concrete.

The first of the technical issues was the fact that the overall width of the replacement modular joints was greater than that of the originally installed joints. This created some issues with the traffic barriers. When a new bridge is constructed, blockouts are formed in the concrete deck or edge beam to accommodate the modular expansion joint later on. After the modular joint is installed, the concrete barriers are constructed up to the outside limits of the modular joint with steel embedment for attaching steel sliding cover plates.

Removing and reconstructing the ends of each concrete barrier would have added at least three days to the total construction duration. In lieu of demolishing the ends of the existing concrete barrier it was decided to install all four joints in contracted configurations before expanding them prior to anchorage and concrete placement. The bottoms of the concrete barriers were chipped out to accommodate the edge beam upturns beyond the curb line.



The next technical issue was the gap to set the replacement modular expansion joint in place. The cumulative gap setting is primarily a function of wind and wave motion and water level, not the temperature of the bridge, the floating portion of which is moderated by the temperature of the lake water. It was decided to set reference pins in the roadway slab prior to removal of the existing joints, then to install the replacement joints so that they would have the same cumulative gap setting as the original joints.

The overall project was considered a success. It is anticipated that the lessons learned on this project will be used when WSDOT replaces other large movement bridge expansion joints in the future.