Red Lillooet River Bridge Deck Renewal

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Abstract

The Red Lillooet River Bridge is located east of Village of Pemberton in the province of British Columbia. It is along Highway 99 (Sea-to-Sky Highway), which is a popular tourism route connected to the Whistler ski resort and popular provincial parks. The bridge crosses the Lillooet River and connects Pemberton to the Lil'wat Nation and Mount Currie. Built in 1987, the 117-m-long two-lane bridge deck has deteriorated and was rated in poor condition. The deck top surface was extensively patched, which significantly reduced rideability. The objective of the Red Lillooet River Bridge Deck Renewal Project was to resurface the deck and to improve travel experience.

The deck renewal design had the following challenges and site constraints:

- The design solution needed to provide the best valued benefit: improve rideability and travel experience with lower cost.
- Full closure of the bridge and Highway 99 was not an option. The design solution needed to allow construction to take place in two phases and half width of the deck be replaced in each phase so that the other half can remain open to traffic.
- The navigable channel underneath needed to remain unobstructed and protected from contamination due to construction activities.

Given that the top surface showed extensive deterioration, two repairing schemes were developed based on the condition of the soffit. For deck area with evidence of bottom mat reinforcement corrosion, full depth replacement was recommended. For deck area with no deterioration visible on the soffit, partial depth repair was recommended. Most of the deck overhang was in good condition; therefore, only localized partial depth repair was required. This cost-effective solution minimized risks related to the environment, nearby utilities, and public safety.

The deck renewal design was developed collaboratively with the owner during the design stage and the project was successfully completed in August 2023. The finished product is a more durable bridge deck that matches seamlessly with the existing road at either end. The renewed deck consists of new corrosion prohibiting measures such as stainless-steel reinforcement and galvanic anodes. The replacement of the existing deck joints with reinforced concrete link slab improves rideability and requires less maintenance effort in the long term.

This presentation will be a case study describing the design and construction features of the project and the collaborative efforts from BC Ministry of Transportation and Infrastructure (the owner), designers, contractor, and stakeholders to ensure the success of the project.

Introduction

The Red Lillooet River Bridge is located east of the Village of Pemberton on Highway 99 (Sea-to-Sky Highway) in the province of British Columbia. Highway 99 is an important travel route that connects to Whistler, a popular tourism resort, and other popular provincial parks. The bridge crosses the Lillooet River and connects the Village of Pemberton to the Lil'wat Nation and Mount Currie. Built in 1987, the 117-m-long bridge comprises four 29-m-span superstructures with 11.22 m wide deck that carries 2 travel lanes. In each span, there are four precast I girders spaced at 2.95 m and transversely connected by concrete diaphragms. Two water / sewer pipes are attached under the North overhang. *Figure 1* and *Figure 2* show the elevation view and deck cross section of the bridge respectively.

Figure 1 - Elevation of existing bridge

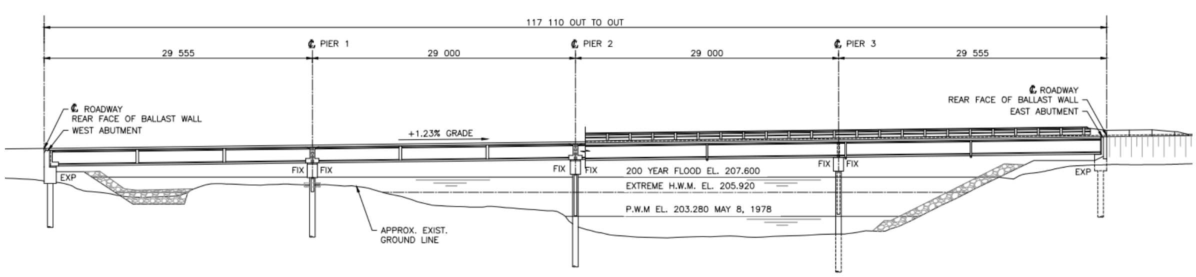
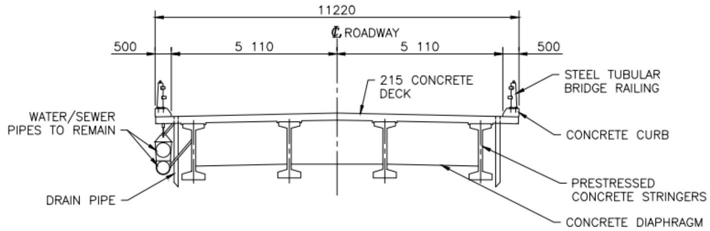


Figure 2 – Cross section of existing bridge superstructure



The bridge deck has deteriorated over the years, and the deck top surface was extensively patched, which significantly reduced rideability. BC Ministry of Transportation and Infrastructure (BC MoTI) had previously engaged consultants to conduct bridge deck condition survey in 2014 and 2020. The 2014 condition survey found that the concrete deck was in poor condition with significant amounts of corrosion-related deterioration, deck patching, and cracking throughout three of the four spans. Approximately 6% of the total area of the deck has been patched, and approximately 41% of the patched areas have subsequently delaminated. The 2020 deck condition survey found that the area of delamination or patch had grown to approximately 55% of the deck area, indicating the deck condition declined considerably since the 2014 condition survey.

The deteriorated and extensively patched deck surface significantly reduced rideability. Furthermore, deterioration of the deck was highly visible, which attracted the public's concern for safety. The objective of the Red Lillooet River Bridge Deck Renewal Project was to resurface the deck and to improve rideability and travel experience.

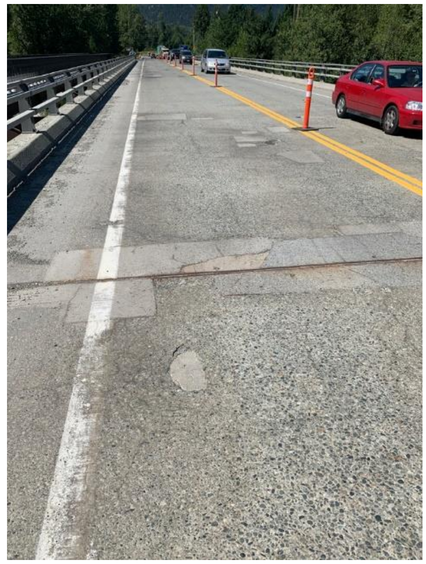
Deck Condition Assessment

Prior to the detailed design, a detailed visual inspection was performed to assess the latest deck condition and to determine a cost-effective solution for the deck renewal. The visual inspection covers the full area of the deck from the top surface and the deck soffit utilizing a snooper truck. The condition of the deck was recorded at each bay of the deck bounded by the girders and transverse diaphragms. The condition of the deck was found to vary significantly, with some areas of the deck with visible deterioration of the concrete, while others were in good condition.

Deck Top Surface

The top of the deck had been extensively patched and was in poor condition. The varying condition, size, shape, and material of the patches, and the areas of spalling lead to very poor rideability (see *Figure 3*). The deck overhang, however, was generally in good condition except for the south overhang along the entire span 2.

Figure 3 – (a) Deteriorated surface with patches *(b) Surface patches around deck joints*



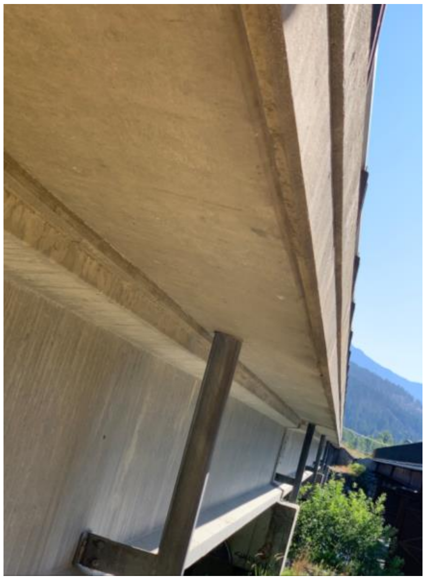
Deck Soffit

The deck soffit also had varied levels of visible deterioration. Spans 1, 2, and 4 were in poor condition with most of the soffit surface having visible deterioration that included map cracking, transverse cracks, efflorescence staining, rust staining from rebar corrosion, spalling, and delaminated concrete (see *Figure 4a* and *Figure 4b*). Despite the poor conditions in other area in the soffit, most of the soffit of Span 3 was in good condition (see *Figure 5*). Hammer sounding was used to check for areas and extent of delamination.

Figure 4 – (a) Area of deck soffit with deterioration *(b) Crack and delaminated concrete in deck soffit*

Figure 5 – Area of deck soffit with good condition

Figure 6 - Overhang soffit in good condition



Deck Overhang Soffit

Majority of the overhang / cantilever portion of the deck was in good condition (see *Figure 6*). Minor defects such as hairline cracks with some efflorescence staining were visible.

Deck Joints and Girder Ends

There are three armoured flexible sealant joints between deck spans, one over each pier. All three deck joints were corroded with pitted armour and the flexible seal appears to be leaking (see *Figure 7*). The leaking deck joints appeared to be contributing to concrete degradation of the girder ends at the piers (see *Figure 8*).

Figure 7 - Deteriorated deck joint and concrete

Figure 8 - Girder ends with spalling and corroded strands

Deck Renewal Strategy

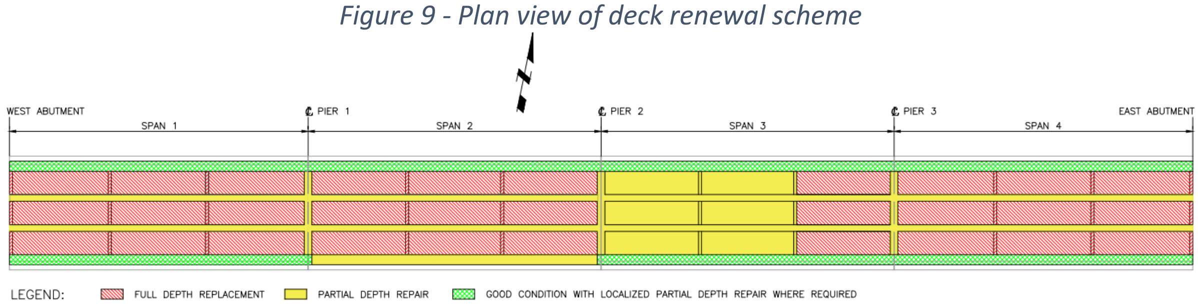
Several factors or constraints needed to be considered to develop the deck renewal design to achieve the project objectives. The design solution needed to provide the best valued benefit: improve rideability and travel experience with lower cost. Based on the inspection and condition assessment, some portion of the deck, especially the deck overhang, was generally in good condition with minimal deterioration, as such the same repair does not necessarily apply to the entire deck. Considering the bridge had already been in service for nearly 40 years, the most economical solution was to repair the deck area with deterioration so that the bridge continues to serve in good condition during its remaining service life and be replaced by a new bridge when the time comes.

The bridge is an important section of Highway 99 and an arterial gateway to the local communities. There is no alternate route for the local communities to commute within reasonable travel time and distance between Pemberton on the West and the Lil'wat Nation and Mount Currie on the East. Therefore, full closure of the bridge and Highway 99 during the deck construction was not an option. Because the bridge deck width accommodates only two traffic lanes (one lane each direction), a Traffic Control Plan incorporating single lane alternating traffic was accepted and adopted for this project.

Weather conditions at the bridge site, such as snowstorms and extreme temperatures, could impact construction flow. The favourable deck construction season in the area is from April to September. The climate and winter weather condition outside this period make construction challenging and costly. In addition, because the bridge is on a popular tourism route, prolonged traffic disruption would increase commuter travel costs and attract public criticism. Ideally, completing the deck construction within one construction season with a relatively short construction duration would lead to less impact to the public and less project costs. From the design perspective, developing good design details contributed to the ease of construction and a shorter construction schedule.

Based on the outcome of the inspection and condition assessment, we considered two deck renewal schemes: full depth repair and partial depth repair. *Figure 9* shows an overview of the deck renewal scheme: approximately 60% of the deck area required full depth replacement (red shade), 25 % required partial depth repair (yellow shade), and the remaining 15 % did not require repair (green shade).

Figure 9 - Plan view of deck renewal scheme



Full Depth Repair

Full depth repair was necessary for the deck area showing significant deterioration such as map cracking, rust staining caused by rebar corrosion, spalling, and delaminated concrete. This scheme required the full depth of the existing concrete deck along with the top mat reinforcements to be removed and replaced, and the bottom mats reinforcements to be cleaned or individually replaced when severely corroded or damaged.

Partial Depth Repair

Partial depth repair was suitable for the deck area that had little to no visible concrete deterioration and no observable rebar corrosion in the deck soffit. This scheme required only the top half of the existing concrete deck along with the top mat reinforcements to be removed and replaced. The bottom half of the existing concrete deck remained intact.

Deck Overhang (Partial Depth Repair)

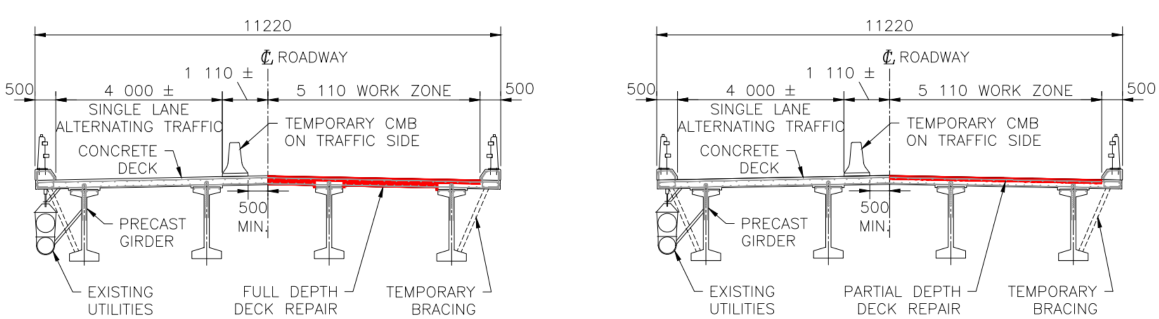
The deck overhang was generally in good condition; therefore, it required only localized partial depth repair as needed, except for the south overhang along the entire span 2 where partial depth repair was necessary because of significant deterioration on the top surface. Partial depth repair at the overhang simplified the construction activities, as the remaining lower half of the existing concrete overhang was used to support the deck construction equipment. The water/sewer pipes on the north overhang also remained in-place and unimpacted for the entire duration of construction. Compared to a full depth repair which would require utility relocation, forming the deck overhang and reconstruction of the railing, the partial depth repair had significant savings on cost and schedule.

Deck Renewal Detailed Design

Design for Two-Phase Construction

In general, the deck renewal detailed design was in accordance with the requirements of the Canadian Highway Bridge Design Code (CHBDC) CAN/CSA S6-19 and BC MoTI Supplement to S6. The deck renewal design was developed for both repair schemes. *Figure 10* shows typical deck section for each of the two repair schemes, respectively. As shown in the sections, the deck repair took place in two phases and half width of the deck was replaced in each phase so that at least one traffic lane remained opened during the entire construction period. A temporary precast barrier was required in the middle of the deck to protect the vehicles in the traffic lane. The bridge deck under the temporary barrier was checked as deck overhang for possible vehicle wheel loads. To accommodate the two-phase construction, rebar coupler was specified in the construction joint along the centre of the deck to splice the new transverse reinforcement of the two phases.

Figure 10 – (a) Section of full depth replacement *(b) Section of partial depth repair*



Stainless Reinforcement

All existing reinforcement in the deck are epoxy coated rebars. We expected the epoxy coating would be damaged or removed during the removal of the existing concrete deck. Both repair schemes required the top mat rebars to be removed and replaced, except for the transverse rebars projected from the deck overhang, approximately 1 m long projection remained for the purpose of lap splice with the new transverse rebars. Following the current BC MoTI supplement to S6-19, stainless steel reinforcement was specified to replace the existing top mat reinforcement for improved corrosion resistance. The new transverse stainless rebars were spliced with the remaining existing rebars projected from the deck overhang. Another corrosion prohibiting measure incorporated in the design was placing galvanic anodes along the interface of the new and old concrete to mitigate the corrosion of the existing reinforcement. See *Figure 11* and *Figure 12* for the reinforcement design of the two repair schemes.

Figure 11 – Reinforcement design for full depth replacement

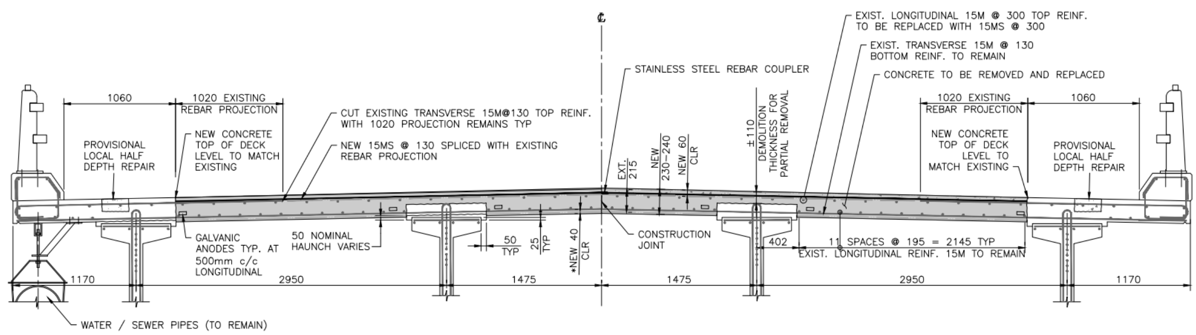
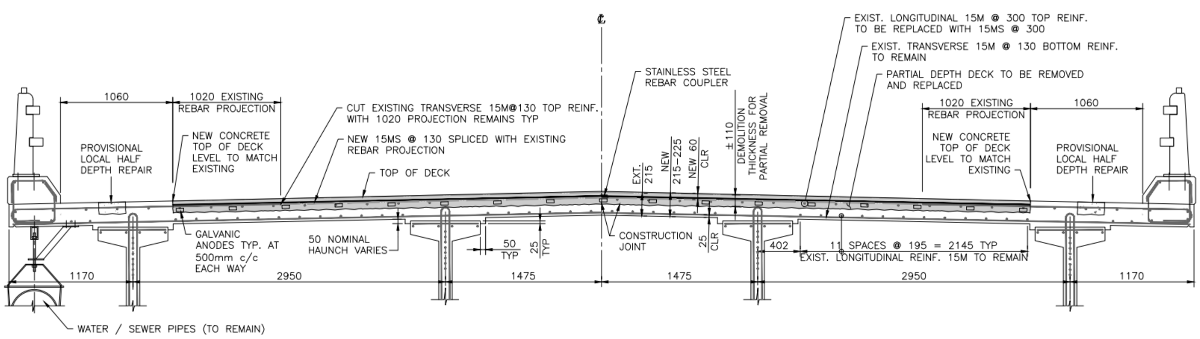


Figure 12 – Reinforcement design for partial depth repair



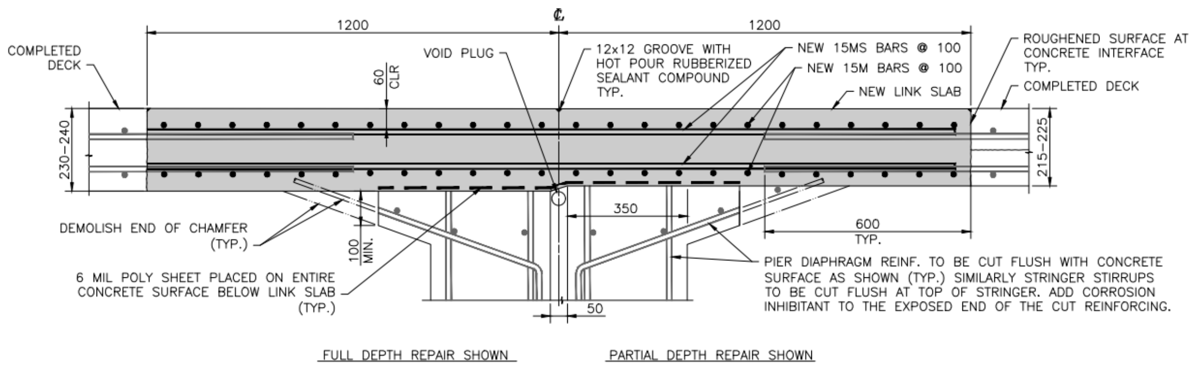
Concrete

The new concrete for the deck had a minimum specified 28-day strength of 35 MPa and Class C-1. Polypropylene fibre was specified to control the shrinkage cracking in the new concrete. The record drawing of the existing bridge deck indicates the concrete cover being 25 mm at the deck soffit and 50 mm at the top surface, which were less than current standard. In the design of the new deck, the deck thickness increases gradually from the boundary of demolition at the overhang towards the crown of the deck with the intention to achieve up to 25 mm more concrete cover (60 mm cover at crown of new deck and 40 mm cover at the soffit of full depth repair) while not significantly increase the dead load on the girder. The deck cross fall was slightly increased, and the deck surface drain pattern remains the same as the existing.

Link Slab

The seals of the existing deck joints over the piers were degraded and the leakage from the joints contributed to the concrete deterioration and reinforcement corrosion in the girder ends and pier caps. To reduce the need for future maintenance, the deck joints were replaced by reinforced link slab with a poly sheet for debonding. The link slab was designed for the girder end rotation induced by the service live load on the bridge spans, in accordance with the Caner and Zia's method[1]. In general, link slab will greatly improve rideability and user comfort compare to deck joints. *Figure 13Figure 11* shows the design details of the link slab.

Figure 13 – Reinforcement design for link slab



Construction over Water

The project required that an unobstructed navigable channel in the Red Lillooet River be maintained throughout the construction period. The required height clearance under the bridge was calculated based on Transport Canada guidance and possible vessel/boat travelling in the river as a guidance for the contractor to plan for the falsework. Stringent specifications were developed for environmental protections such that no construction debris fall into the river.

Deck Construction

The contractor arrived at the construction site in March 2023. After 6 months of consecutive construction, the bridge opened to full traffic at the end of August 2023. As planned, the deck construction was completed in two phases, starting from westbound half of the deck (northside of the bridge), then shifted to the eastbound half of the deck (southside of the bridge). The removal of old concrete was completed by combined methods of milling, hydro demolition, and hand tool demolition. The construction cost was approximately $5 million.

Because of stringent specifications for environmental protections, suspended scaffolding with enclosed containment was installed below the bridge superstructure to catch concrete waste from the deck removal. The suspended scaffolding also provided an unobstructed navigable channel in the Red Lillooet River as required by the project. The water/sewer pipes on the northside of the bridge overhang remained in-place and were not affected during the entire construction period. *Figure 14* to *Figure 20* show the progress of deck construction.

Figure 14 - Exposed rebar after partial deck removal

Figure 15 - Severely corroded rebar

Figure 16 - Full depth concrete removed

Figure 17 - Installation of new rebar

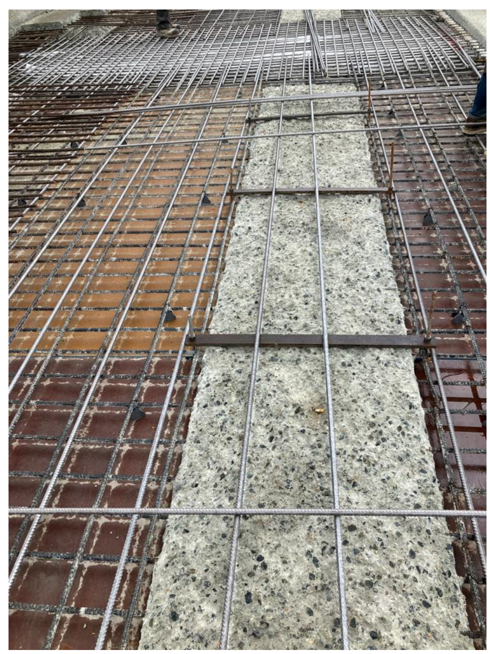


Figure 18 – Suspended scaffolding over water (orange sign showing vertical clearance)

Figure 19 – Completed new deck

Figure 20 – Elevation view of bridge with completed new deck

Conclusion

The engineering design for the Red Lillooet River Bridge Deck Renewal Project was developed collaboratively with the BC MoTI during the early design stage. This enabled informed decisions to be made in a timely manner, avoiding efforts on rework or repetitive rounds of communications. During the construction, the structural engineering team actively supported the contractor in addressing site queries to avoid construction stoppage or delays.

The new concrete deck is a more durable product that is essential to extend the service life of the bridge. The replacement of the existing deck joints with reinforced concrete link slab requires less maintenance effort in the long term and provides a smooth riding surface for drivers. This project greatly improved the rideability and promoted a positive travel experience for local commuters and tourists.

References

[1] A. Caner and P. Zia. "Behavior and Design of Link Slabs for Jointless Bridge Deck." *PCI Journal.* Chicago, IL: PCI. p. 68-80. (1998)