

## **PIER REPAIR/RETROFIT USING UHPC EXAMPLES OF COMPLETED PROJECTS IN NORTH AMERICA**

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### **Abstract**

The infrastructure sector is under tremendous pressure to find reliable and durable solutions to tackle maintenance and upgrade existing structures to meet our ever changing needs. Owners and designers need to select repairs and retrofits solutions that are proven and which will perform as intended for the remaining life of the structure. Ultra-High Performance Concrete (UHPC) sold under the brand name Ductal<sup>®</sup> by Lafarge North America Inc. (a member of LafargeHolcim) has been used throughout North America for over 15 years. The design community is increasingly familiar with the UHPC closure pour solutions for precast deck panels. This is now leading consultants to push the envelope and explore avenues where the durability of UHPC can be applied to other types of bridge repairs. This paper will provide a brief overview of four North American pier repair/retrofit projects. The CN Rail, Montreal, QC jacketing project; the Mission Bridge, Abbotsford, BC seismic pier retrofit; the Hooper Rd., Town of Union, NY connection of a new precast pier cap to existing columns; and the Hagwilget Bridge, New Hazelton, BC steel bent legs encasements will be reviewed. These “new” projects are now becoming references to guide owners and designers facing similar challenges where viable, durable and maintenance free solutions are required.

**Keywords:** column, connection, Ductal, encasement, jacket, Lafarge, pier, pier cap, repair, retrofit, ultra-high performance concrete, UHPC

### **1. Introduction**

Enhanced durability and extended infrastructure life is achievable by using advanced construction materials with properties not found in traditional materials. UHPC is one of those materials. This paper presents remedial options for consultants who are seeking ways to extend the life of pier/column elements and limit or greatly reduce the need for frequent maintenance.

Ductal<sup>®</sup> was used in all four highlighted projects. The Ductal<sup>®</sup> formulations were tailored to the specific application. Characteristics of the material will not be discussed in this paper. Numerous documents have been published and various references are available (Lafarge, 2016 and FHWA, 2016). The components for the premix and the steel fibers are sourced in North America.

## 2. CN Rail Bridge Pier Jacketing, Montreal, QC

The Canadian National Railway (CN) and their consultant for this project, AECOM, were looking for an innovative and durable solution for the repair of an existing rail bridge pier in Montreal, Quebec. The site conditions were challenging, as shown in Figures 1 and 2.



Figure 1. Existing surface before repair



Figure 2. CN rail bridge site layout

The railway bridge crosses over a 2 lane access ramp to the Victoria Bridge and the lanes are quite narrow; hence the concrete repair cover had to be as thin as possible in order to maintain adequate clearances. The pier is approximately 800 mm wide x 7 m long x 3.3 m high (32 in. x 23 ft. x 11 ft.). Its cross section is a parallelogram. In this case, the existing pier is able to sustain the gravity and train loads; the repair to the column is required to provide protection against chloride and freeze/thaw. The owner was looking for a repair solution which would last at least twice as long as a retrofit with normal concrete.

The contractor, DJL Construction, had to work under challenging conditions. One lane of traffic had to remain open during the construction and train traffic would have to continue without interruption.

The existing concrete condition showed considerable degradation (Figure 1). Work was staged to maintain one lane of traffic. A galvanized rebar cage was added after removal of the deteriorated layer and forms set to allow for approximately 100 mm (4 in.) thick of new concrete (Figure 3).



Figure 3. Formwork ready for casting



Figure 4. Final repair

A fluid, self leveling UHPC formulation was used for this repair. In this case, hydrostatic pressure is a very important factor to consider in the design of the formwork. The forms need to be watertight and able to support the pressure until the material initial's cure. Ductal<sup>®</sup> was batched on site using a pair of high shear mixers to batch bulk bags of material with an output of 0.5 m<sup>3</sup> (0.65 yd<sup>3</sup>) per load. The project was completed in mid-October 2013 (Figure 4) and used approximately 11 m<sup>3</sup> (14.4 yd<sup>3</sup>) of material.

### 3. Mission Bridge Seismic retrofit, Abbotsford, BC

The Mission Bridge, opened to traffic in 1973, is a 1,126 m (3,690 ft.) long bridge on Hwy 11 that crosses the Fraser River between Mission and Abbotsford, British Columbia. One of the nineteen V-shaped concrete piers (Pier S4) was retrofitted by using Ductal<sup>®</sup> jackets for 2 existing concrete columns. This retrofit was the last step in a series of seismic upgrades performed over several years to ensure the integrity of this vital link in this high seismic zone.

The soil in this area is liquefiable sands and the lightly reinforced rectangular concrete columns of Pier S4 could be subject to high displacement and possible collapse under earthquake loading. The bridge is a critical asset. Associated Engineering after evaluating many options including traditional thick reinforced concrete jackets, elliptical steel shells or soil consolidation proposed the use of Ductal<sup>®</sup> jackets. A detailed explanation of the problem statement and design rationale is available in a paper prepared by the design team of Associated Engineering (Kennedy, D. et al. 2015). The other methods were technically viable but proved visually obtrusive at this prominent site, and offered no cost advantages over a Ductal<sup>®</sup> jacket. Compared to traditional piles compaction techniques, using a Ductal<sup>®</sup> jacket provided savings of \$1.5 million (CDN), and would allow for a high seismic deformation capacity using a thin jacket, eliminating below-ground costs and risks from piling, while also demonstrating a new application for Ductal<sup>®</sup>.



Figure 5. Existing prior to final retrofit



Figure 6. Completed retrofit



Figure 7. Batching / delivery to site by ready-mix trucks



Figure 8. Placing via top of the form

As can be seen on Figure 5, the columns had already been strengthened in past retrofit. The existing fiber-reinforced polymer (FRP) wrap was removed and the surface was roughened. The pedestal was widened with traditional concrete to force the plastic hinge at this location under seismic load. Additional steel dowels were imbedded in the existing column. A reinforcing rebar cage was secured to the dowels and new 225 mm (9 in.) thick Ductal<sup>®</sup> jackets were used to increase and stiffen confinement up to a height of approximately 3 m (10 ft).

In this case, the formulation JS1000 with 2% steel fibers was used. A total of four truck loads were used for this project (Figure 7). The trucks were loaded at a nearby Lafarge plant. 100% ice was used instead of water to facilitate the batching in the drum and to keep the material at a proper temperature. Once on site, flow tests were performed to ensure the mix had the required consistency before placing. A large concrete bucket was used to fill the forms from the top (Figure 8).

The project was completed in June 2014 and required approx. 18 m<sup>3</sup> (23.5 yd<sup>3</sup>) of material (Figure 6). Inspected one year after installation, the confined Ductal<sup>®</sup> jackets, supplemented with mild steel reinforcing retains an excellent appearance. This retrofit project received the 2015 ACI Excellence in Concrete Award, Repair & Restoration category.

#### 4. Hooper Rd, Town of Union, NY

In this specific application, the existing piers' columns were to remain while the whole superstructure was replaced, including the pier caps. The 3-span bridge is located on Hooper Rd. over Route 17C east of Binghamton, NY. Precast was used for the deck, approach slabs and new pier caps. On the tender documents, UHPC was specified for the closure pours and link slabs. The contractor, Economy Paving Company had used UHPC before on another bridge deck project. This current project called for a very aggressive construction schedule. Once the contract was concluded, the contractor turned its attention to the specified connection for the new precast pier caps to the existing pier columns (Figure 9).

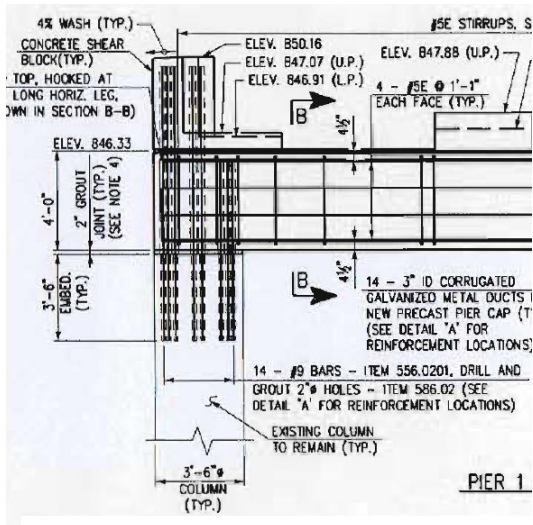


Figure 9. Original details for the pier cap to column connection

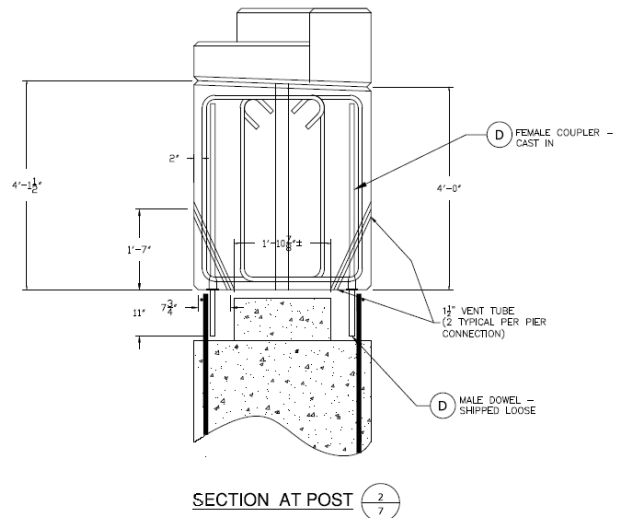


Figure 10. Final connection details

The specified method called for a precast pier cap with fourteen 3 in. (75 mm) ducts for each column. These ducts would have to match new 2 in. (50 mm) diameter holes to be drilled to a depth of 3 ft 6 in. (1.07 m) in the existing columns. A total of 84 holes would be required. There was little chance that the existing rebar cage was exactly where it was specified on the original drawings. Finding a way to locate the existing rebar to avoid conflict when drilling the new holes and match these locations with the ducts cast in the new precast pier caps seemed quite challenging. Because Ductal® was already specified for other portions of this project, the contractor saw an opportunity to specify it for the connections of the precast pier caps to existing columns. Rebar from the existing columns could be exposed to create continuity with new dowels extending from the underside of the new precast pier caps (Figures 10). The connection concept was reviewed by the FHWA, NYSDOT, project engineering firm McFarland Johnson and the UHPC supplier, Lafarge. Ductal® allowed for a very short development depth with #9 (nominal area 1 in.<sup>2</sup> or 654 mm<sup>2</sup>) dowels, it was determined that an 11 in. (280 mm) depth was sufficient to achieve the required load transfer. For the contractor, it was estimated that using a UHPC connection detail would save two days on the schedule. This was a huge time savings and allowed easy adjustments to set the elevation and place the new precast pier caps. It also eliminated the uncertainty of misalignments and the individual grouting of 84 ducts. The whole replacement project was completed in 21 days in September 2014.



Figure 10. Existing rebar and new dowels



Figure 11. Completed



The existing rebar on the outer edge of the existing columns were exposed and cut to allow the 11 in. (280 mm) splice. A concrete pedestal was left at the center of the existing columns. Enough concrete was removed around the rebar to allow room for the dowels at the bottom of the precast pier cap. The dowels in the precast elements were set on a smaller radius compared to the existing rebar on the columns, hence no issues of interference or misalignments. By leaving a portion of concrete at the middle of the column, this allowed the use of steel shims for final height adjustments. For the pier cap, long dowels with a female coupler were cast in the pier cap. Once the new pier cap was lowered on the existing columns, dowels were extended by threading the remaining length into the embedded coupler. One 3 in. (75 mm) diameter grouting duct was required for each column location along with 2 small bleeding ducts. The grouting duct was used to fill the joint area with UHPC. Ductal<sup>®</sup> flowed between the gap provided by the steel shims and top of the column. The contractor used the same standard steel forms, the same size used to cast the similar concrete columns to form this 11 in. (280 mm) gap. For the UHPC, the JS1212 formulation which has an accelerator component was used (Figure 11). Thermo couplers were used to monitor curing time. Insulating blankets were used to keep the area as warm as possible. This helped speed up curing times and allowed the project to continue without delays.

This is the perfect example of exploiting the characteristics and properties of UHPC to allow faster and simpler details. In this case, an experienced contractor brought to the table an idea and concept that allowed time saving and simpler details.

## 5. Hagwilget Bridge, New Hazelton, BC

The British Columbia Ministry of Transportation and Infrastructure is the owner of this single lane suspension bridge with a main span of 140 m (459 ft.) and is 75 m (250 ft.) above the water. It is the only practical route to the local regional hospital and the community of Old Hazelton in central British Columbia. To keep this lifeline functioning it has been upgraded and modified several times over the years. The main span was built in 1931 (Figure 12).



Figure 12. Hagwilget Bridge

Buckland & Taylor / COWI has been providing evaluation, design and supervision services to upgrade this structure since 1987. Numerous modifications were made to the original structure to increase its truck-carrying capacity and structural integrity, along with modifications to better resist lateral winds and earthquake loads. In 2015, the latest modification to date, Buckland & Taylor / COWI used Ductal<sup>®</sup> to encase the steel bent legs.



Figure 13. Corrosion at the base of a bent leg. Figure 14. Bents with formwork for encasement.

The bent legs of the bridge approaches had developed local corrosion at their base (Figure 13) and a solution was required to strengthen these weakened zones and at the same time mitigate future corrosion.

Because of access limitations, congestion and a small zone available to transfer concentrated load from the bent leg to its concrete pedestal, the solution demanded a very high strength concrete with excellent flow-ability during placement, virtually no shrinkage, virtually no permeability and good tensile capacity. The obvious choice that fit those characteristics was Ductal<sup>®</sup>. The design demanded a minimum compressive strength of 100 MPa (14,500 psi).

The load transfer is facilitated by the use of steel plates bolted to the flanges of the bent leg (Figure 15). This helps distribute the vertical load to the top of the Ductal<sup>®</sup> encasement.

In total the rehabilitation involved 32 bent leg bases (Figure 14, 16 and 17) and will provide excellent corrosion protection and load transfer for many years to come.



Figure 15. Reinforcing rebar cage and steel bolted to the flange leg

Figure 16. Ductal<sup>®</sup> encasement of the bent plates bases prior to capping



Figure 17. Ductal<sup>®</sup> encasement capped for drainage with zero slump mortar

## 6. Discussion on future needs

Owners, designers, consultants and contractors will continue to be faced with challenges and UHPC is another tool at their disposal to repair, retrofit or rehabilitate infrastructure. The goal of this article was to bring to the forefront some recent examples to showcase the diverse array of situations where UHPC was used successfully in North America (Perry, V.H. et al. 2013 and Doiron, G., et al. 2014). Many other projects have been completed around the world and the engineering community is becoming more receptive and aware of the benefits linked to UHPC for repairs/retrofits applications. Moving forward the industry will continue to address areas such as codes and life cost analysis. When there are clear design guidelines and codes in place, the use of UHPC will certainly become more prevalent. Currently, if a designer is not familiar with this product, it is time consuming to develop the expertise and be confident that UHPC will perform as intended. We naturally tend to gravitate to proven, known solutions, even if these solutions are not the best ones. To be able to justify a new approach takes time because the construction community needs tangible examples. Owners are increasingly paying attention to the number of interventions required to maintain a structure. This is where UHPC has a huge advantage over traditional repairs. Because the use of UHPC is still relatively recent; the oldest UHPC structure in North America (and in the world) is a pedestrian bridge built in Sherbrooke, Quebec 19 years ago (Blais, P.Y. et al), it may be difficult for some owners or designers to rely heavily on research results and extrapolations. Numerous studies point to durability of 100 years and beyond, depending on the specific parameter studied. Research and development continue to explore alternatives. The applications highlighted in this paper were cast-in-place. In some situations it might make more sense to use UHPC precast elements and grout them to the existing structure. The use of a UHPC spray or shotcrete might be best in other applications where access or shape of the elements would make formwork difficult or time consuming. As usual, the problems and challenges provide incentives for the development of new techniques.



## 7. Conclusion

The examples provided highlight the fact that there is not one specific reason why UHPC is being used for the repair and retrofit of pier/columns. For the CN Rail project, freeze-thaw and resistance to chloride were the main drivers. Ductility, aesthetics and cost savings were important for the Mission Bridge project. For the Hooper Rd project, speed of execution and simpler details were major factors. Finally for the Hagwilget Bridge, confinement and high compressive strength were key components for the selection of UHPC.

The implementation of UHPC solutions requires collaboration of all parties and each mobilization brings its own challenges because formulations, batching and placement will need to be adjusted to deal with each specific situations.

With the growing awareness of life cycle costs, UHPC is well positioned to provide alternative ways to minimize the on-going maintenance costs. This is becoming a key driver for many owners who need to find ways to tackle repairs and avoid future mobilizations and disruption to traffic.

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