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

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Abstract

Consultants and owners of infrastructure projects are seeking more durable, cost effective solutions using alternative materials and processes. Customized UHPC solutions, designed to address specific challenges, provide enhanced durability and reduce maintenance needs. This paper highlights four North American projects where custom UHPC solutions were selected for very different reasons. “Ductal®” is the UHPC brand used on each of these projects: (1) a pier jacketing project, where durability was the key driver; (2) a seismic retrofit solution with an esthetically pleasing UHPC element on an existing bridge pier; (3) an innovative solution to connect a new precast pier cap to existing columns (simpler connection details also reduced on-site construction time); and (4) a unique encasement solution, applied to the bottom portion of corroded steel bent legs. Overall, these innovative projects validate alternative construction methods using highly durable UHPC solutions for challenging repair and retrofit issues, ultimately extending the life of infrastructures with reduced need for maintenance.

Résumé

Les ingénieurs et propriétaires d’ouvrages de génie civil recherchent des solutions durables et économiques faisant appel à de nouveaux matériaux et procédés. A ce titre les solutions BFUP sur mesure, adaptées aux besoins spécifiques, fournissent une durabilité améliorée et réduisent les besoins de maintenance. L’article présente quatre réalisations en Amérique du Nord où une solution BFUP spécialement étudiée a été sélectionnée pour des raisons différentes. Le BFUP de marque Ductal® a été utilisé pour chacun de ces projets : (1) le chemisage d’une pile, où la durabilité a été la raison principale du choix; (2) une réhabilitation sismique où un élément BFUP à caractère esthétique a été rapporté sur l’ouvrage existant; (3) une solution innovante de connexion d’un nouveau chevêtre préfabriqué aux fûts de pile existants (détails de connexion simplifiés permettant une réalisation plus rapide sur chantier) ; (4) et une solution originale d’enrobage de la partie inférieure corrodée de béquilles en acier. Au total, ces projets innovants valident de nouvelles méthodes utilisant un BFUP extrêmement durable pour des problèmes de réparation et réhabilitation délicats, permettant de prolonger la durée de vie de ces ouvrages avec un besoin réduit de maintenance.

1. INTRODUCTION

Enhanced durability and extended infrastructure life is achievable by using advanced construction materials with properties not found in traditional materials. Ultra-High Performance Concrete (UHPC) is one of those materials. This paper presents remedial options for consultants and owners who are seeking new, alternative methods and materials that will extend the life of pier/column elements and limit or greatly reduce the need for frequent maintenance.

Ductal®, the UHPC fabricated by LafargeHolcim was used in four projects presented on the following pages. The UHPC formulations were tailored for each specific application. All components for the premix and steel fibers were sourced in North America. Material characteristics will not be discussed. Numerous papers and articles on similar, related topics have been published in recent years and provide further validated references [1].

2. CN RAIL BRIDGE PIER JACKETING, MONTREAL, QC, CANADA

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

Figure 1: Existing surface before repair

Figure 2: CN rail bridge site layout

The railway bridge crosses over a two-lane access ramp to Victoria Bridge. The lanes are quite narrow, therefore 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. Its cross section is a parallelogram. In this case, the existing pier is able to sustain the gravity and train loads but repair to the column was required to provide added protection against chloride and freeze/thaw. The owner wanted a repair solution that would last at least twice as long as a retrofit with normal concrete.

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

The existing concrete condition showed considerable degradation (Fig. 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 application of new concrete, approximately 100 mm thick (Fig. 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 must be watertight and able to support the pressure until the material's initial cure. Using a pair of high-shear mixers, the UHPC material was batched in bulk bags on site with an output of 0.5 m^3 per load. The project used approximately 11 m^3 of material and was completed in October, 2013 (Fig. 4).

3. MISSION BRIDGE SEISMIC RETROFIT, ABBOTSFORD, BC, CANADA

The Mission Bridge, opened to traffic in 1973, is a 1,126 m 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 with UHPC jackets for two existing concrete columns. This retrofit was the final step in a series of seismic upgrades performed over several years, to ensure the integrity of this vital link in a 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 in the range of 400 mm and possible collapse under earthquake loading. The bridge is a critical asset in this area. The engineering consultant, Associated Engineering, after evaluating numerous options including traditional, thick reinforced concrete jackets, elliptical steel shells or soil consolidation, proposed the use of UHPC jackets to the owner.

A detailed explanation of the problem statement and design rational is available in a paper prepared by the design team of Associated Engineering [2]. The other methods were technically viable but proved visually obtrusive at this prominent site, and offered no cost advantages over a UHPC jacket. Compared to traditional piles compaction techniques, using a UHPC jacket provided substantial savings 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 UHPC.

Figure 5: Existing prior to retrofit

Figure 6: Completed retrofit

Figure 7: Batching & delivery to site by ready-mix trucks

Figure 8: Placing via top of the form

As shown in Figure 5, the columns had been previously strengthened during a past retrofit. The existing fiber-reinforced plastic (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. A gap was left between the jacket base and pile cap to allow the column to hinge plastically. Additional 16 mm diameter steel dowels with plate washers were imbedded in the existing column; spaced 230 mm in each direction. A reinforcing rebar cage was secured to the dowels and new 225 mm thick UHPC jackets were used to increase and stiffen confinement up to a height of approximately 3 m.

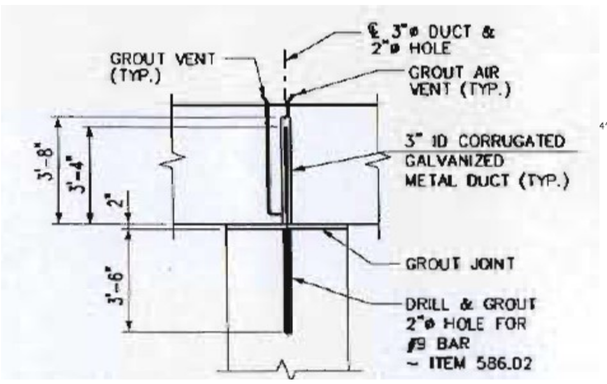
It is believed that, at the time of construction, this was the first time UHPC was used as a seismic retrofit solution for large rectangular concrete columns. Consequently, the consultant wanted to proceed with caution and specified dowels and a rebar cage. Hence; the design did not consider the full tensile capacity and stiffness of the UHPC. The reinforcement may not have been required but it was an easy way to improve crack distribution, post-cracking stiffness, and resistance to cracking from jacket restraint. This also allowed lower steel fibre content. (In this case, Lafarge's "JS1000" UHPC formulation was used with 2% steel fibers per volume).

A total of four truck loads were used for this project (Fig. 7), loaded at a nearby ready mix plant. To facilitate batching in the drum and to keep the material at a proper temperature, 100% ice was used instead of water. 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 (Fig. 8).

The project required approximately 18 m^3 of material and was completed in June 2014. (Fig. 6). Inspected one year after installation, the confined UHPC jackets, supplemented with mild steel reinforcing, retains an excellent appearance. In 2015, it won an "ACI Excellence in Concrete Award" in the Repair & Restoration category.

4. HOOPER ROAD, TOWN OF UNION, NEW YORK STATE, USA

In this application, the existing piers' columns had to remain intact, while the entire superstructure was replaced, including pier caps. The three-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. In the tender documents, UHPC was specified for the closure pours and link slabs. The contractor, Economy Paving Company, had used UHPC once before, on another bridge deck project. This project called for a very aggressive, accelerated construction schedule and once awarded, the contractor turned his attention to the specified connection for the new precast piers to the existing pier columns (Fig. 9).



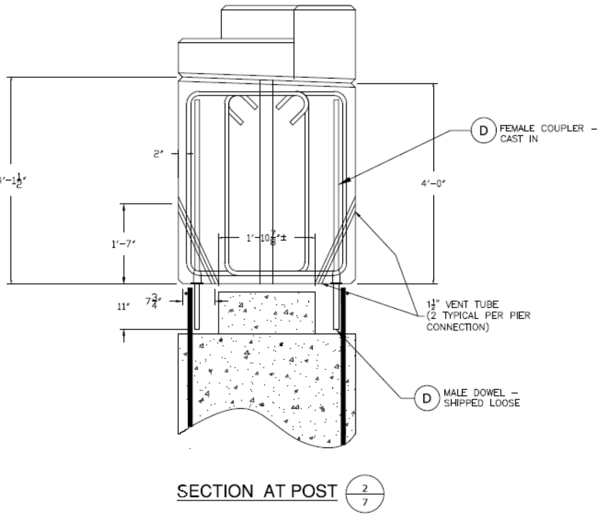


Figure 9: Original details for the pier cap to column connection

Figure 10: Final connection details

The specified method required casting of fourteen 75 mm ducts in the new precast pier caps and the need to match new 50 mm diameter holes, to be drilled on a depth of 1,070 mm in the existing columns. A total of 84 holes would be required. There was little chance that the existing rebar cage would be 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 piers seemed overwhelming.

Because UHPC was already specified for other sections of this project, the contractor saw an opportunity to specify the material for connections of the new precast pier 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 (Fig. 10 and 11). The connection concept was reviewed by the FHWA, NYSDOT, project engineering firm, McFarland Johnson, and the UHPC supplier, LafargeHolcim. UHPC allowed for a very short development length with 29 mm diameter dowels. It was determined that a 280 mm depth was sufficient to achieve the required load transfer. It was also estimated that UHPC connections 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 piers. It also eliminated the uncertainty of misalignments and the individual grouting of 84 ducts. The entire replacement project was completed in 21 days in September, 2014.

Figure 11: Existing rebar and new dowels

Figure 12: Completed

The existing rebar on the outer edge of the existing columns were exposed and cut to allow the 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, with no interference or misalignment issues. By leaving a portion of concrete in the middle of the column, this allowed the use of steel shims for final height adjustments. Long dowels with a female coupler were cast in the pier cap.

Once the new pier cap was lowered onto the existing columns, dowels were extended by threading the remaining length into the embedded coupler. One 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. The material flowed between the gap provided by the steel shims and top of the column. The contractor used the same size standard steel forms as those used to cast the similar concrete columns to form this 280 mm gap.

For the UHPC, the JS1212 formulation with an accelerator component was used (Fig. 12). Thermo couplers were used to monitor curing time. Insulating blankets were used to warm the area, which helped to speed up curing times and allowed the project to continue without delays.

This project is a perfect example of how the characteristics and properties of UHPC may be exploited, to allow faster and simpler details. In this case, an experienced contractor also recognized an opportunity for a UHPC solution with simpler details that resulted in accelerated construction and earlier project completion.

5. HAGWILGET BRIDGE, NEW HAZELTON, BC, CANADA

The British Columbia Ministry of Transportation and Infrastructure is the owner of this single lane suspension bridge with a main span of 140 m and 75 m above water. It is the only practical route to the local regional hospital and community of Old Hazelton in central British Columbia. The main span was built in 1931 and, to keep this lifeline functioning, it has been upgraded and modified several times over the years. (Fig. 13)

Figure 13: Hagwilget Bridge

Buckland & Taylor / COWI has been providing evaluation, design and supervision services to upgrade this structure since 1987. Numerous modifications have been 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, on the most recent modification (to date), the consultant specified UHPC to encase the steel bent legs.

The bent legs of the bridge approaches had developed local corrosion at their base (Fig. 14), therefore a solution was required to strengthen these weakened zones while, at the same time, mitigate future corrosion.

Because of access limitations, congestion and a small zone available to transfer concentrated loads from the bent leg to its concrete pedestal, the solution demanded a very high strength concrete with excellent flowability during placement, virtually no shrinkage, virtually no permeability and good tensile capacity. UHPC fulfilled those requirements and the design assumed a minimum compressive strength of 100 MPa.

Figure 14: Corrosion at the base of a bent leg

Figure 15: Bent legs with formwork for encasement

The load transfer is facilitated by the use of steel plates bolted on each side of the flanges (Fig. 15). This helps distribute the vertical load to the top of the UHPC encasement.

The work on the bases proceeded while traffic was maintained on the bridge. Batching was done on site, using small portable mixers. Access was challenging because the approach is built on a very steep slope. A small, motorized front loader was used to carry the UHPC material to each form. In total, the rehabilitation involved 32 bent leg bases (Fig. 16 and 17) and the UHPC solution will provide excellent corrosion protection and load transfer for many years to come.

Figure 16: Reinforcing rebar cage and steel bolted to the flange leg

Figure 17: UHPC encasement of the bent leg bases after capping with non-shrink grout

6. DISCUSSION ON FUTURE NEEDS

Owners, designers, consultants and contractors will continue to be faced with challenges on infrastructure projects. UHPC repair and retrofit (R&R) solutions can provide cost-effective, highly durable and innovative methods to effectively address these challenges and help to protect, rebuild and/or repair their structures for years to come.

The project examples presented on the previous pages demonstrate how very different UHPC R&R solutions have been successfully applied in North America in recent years. Many other R&R projects have been completed around the world and the engineering community is becoming more receptive and aware of the benefits linked to UHPC these applications.

Going forward, the industry will continue to address and define 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 the designer is not familiar with the product, it is time consuming to develop the expertise and confidence; that UHPC will perform as intended. We naturally tend to gravitate to proven, known solutions, even if they 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 solutions offer significant advantages compared to traditional/conventional repair materials.

Historically, the use of UHPC is still relatively recent. The oldest known UHPC structure in North America (and possibly in the world) is a pedestrian bridge in Sherbrooke, Quebec, erected 20 years ago [3] and performing well to date. 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 and/or time consuming. As usual, the problems and challenges provide incentives for the development of new techniques.

7. CONCLUSION

The project 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. As with many projects where UHPC is specified, there is usually a set of unique attributes that the material brings to the solution. For the CN Rail project, resistance to freeze-thaw and chloride were the main drivers. Ductility, aesthetics and cost savings were important for the Mission Bridge project. For the Hooper Road project, speed of execution and simpler details were major factors. Finally, for the Hagwilget Bridge, confinement and the need for high compressive strength were key components for the selection of UHPC.

The implementation of UHPC solutions requires collaboration and commitment of all parties. Each mobilization brings its own set of challenges because formulations, batching and placement techniques typically need to be adjusted and tested, to deal with each specific situation.

With the growing awareness of life cycle costs, UHPC is well positioned to provide alternative ways to minimize ongoing maintenance costs. This is becoming a key driver for many owners who have to find ways to repair and replace structural elements while ensuring that it is done correctly (often quickly) and that the repair will last, at least for the remaining life of the structure.

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