STRUCTURAL STRENGTHENING OF GIRDERS WITH CFRP ON THE CHAMPLAIN BRIDGE

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Due to the aging of structures and an expanding population, the need for infrastructure safety, maintenance, and efficiency has become more pressing and requires creative solutions. The Champlain Bridge is such a solution, joining the island of Montreal to Brossard on its south shore as well as spanning the Saint Lawrence River and seaway shipping lanes.

The bridge first opened to traffic in 1962 and spans 3.7 miles (6 km). It is a steel truss cantilever bridge with approach viaducts constructed of prestressed concrete beams that support a prestressed concrete deck paved with asphalt (Fig. 1). Approximately 160,000 vehicles cross the bridge daily—of which about 10% are trucks—making this the busiest bridge in Canada.

Deicing salts, freezing-and-thawing cycles, and larger/heavier trucks coupled with increasing volumes of traffic have placed supplementary demands on the bridge that it was not originally designed to handle.

Specifically, much of the damage to the edge girders and post-tensioning strands was caused by deicing salts. However, the degree of corrosion was difficult to assess due to the design of the girders. Maintenance work to ensure security for bridge users has been ongoing since the bridge's opening. More importantly, since 1986, other strengthening methods have been used to deal with increased demands.

Fig. 1: Champlain Bridge

Jacques Cartier Champlain Bridge Incorporated (JCCBI), which owns the bridge, announced that a new bridge will replace the Champlain Bridge by 2024, at which point the existing structure will be decommissioned. To maintain the existing bridge and ensure safe passage for users until a new bridge is operational, various repairs were recommended in September 2013, including a carbon fiber-reinforced polymer (CFRP) solution. Because the work was of a temporary nature, it was decided to replace concrete in delaminated areas, inject cracks with epoxy, and wrap CFRP around portions of the edge girders to increase shear strength.

As a composite material using polymeric resins combined with carbon fiber material, CFRP yields a high strength-to-weight ratio. The main load-carrying capacity is provided by the carbon fibers, while the polymeric resins bind to the fiber and substrate offering structural benefits. Low-viscosity epoxy resins are used primarily as primers and saturants for carbon fiber fabric. Higher-viscosity resins in the form of pastes are used to correct out-of-plane defects as well as to fill in depressions and honeycombs. Among CFRP's many valuable qualities for structural strengthening are a high tensile strength, high strength-to-weight ratio, non-corrosive nature, cost-effective installation, and thin profile.

BRIDGE REPAIRS

CFRP use on the bridge was intended to increase shear strength for certain edge girders. Years of abundant runoff of deicing salts from the traffic deck onto the edge girders had accelerated the aging process.

In this particular case, two layers of unidirectional carbon fiber fabric measuring 15.75 in. (400 mm) wide were used for both the vertical strips and the horizontal anchoring strips.

Fig. 2: Application of primer

Fig. 3: Application of epoxy paste

The installation of CFRP required repair methods similar to those used for traditional concrete repair. Therefore, unsound concrete, cracks, and corrosion-induced damage were repaired prior to CFRP installation to ensure longevity of the strengthening repair procedure.

The following steps were performed during the CFRP installation process.

SURFACE PREPARATION

The contractor used abrasive blasting to prepare the concrete surface and achieve a concrete surface profile of CSP 3 to 4 according to ICRI Technical Guideline No. 310.2R.[1] This method of preparation was particularly effective for CFRP installation because it removes the concrete laitance, opens the pores, and minimizes microfracturing of the concrete, thereby providing an adequate substrate for this type of bond-critical application.

Other important considerations for surface preparation were the removal of obstructions that may damage the fiber and the rounding off of any corners to achieve a 0.5 in. (12 mm) radius. In both cases, the use of mechanical grinders equipped with diamond blades were quite effective and used before abrasive blasting.

PRIMER APPLICATION

This step consisted of the installation of a two-component, epoxy-based consolidating primer on all areas that would receive the CFRP (Fig. 2). The primer was a specifically formulated low-viscosity (<500 cps) liquid, making it suitable for consolidating and priming concrete for CFRP installations. The work area had to be tented and kept as clean and dust-free as possible to avoid contamination of the primer. The installation area was also kept acclimated according to the manufacturer's recommendations, between 50 and 86°F (10 and 30°C), to facilitate the proper curing of the epoxy resin.

PASTE APPLICATION

This step consisted of using a two-component, epoxy-based thixotropic paste to fill all honeycombs as well as to correct out-of-plane areas such as concrete form lines and deviations (Fig. 3). This paste was used to provide a plane surface for installing the saturating resin and carbon fiber wrap.

SATURATING RESIN AND CARBON FIBER WRAP PROCEDURE

Once the paste was installed and cured for 1 to 3 hours, a "dry layup" procedure (Fig. 4) was used to install the saturating resin and unidirectional carbon fiber fabric measuring 15.75 in. (400 mm) wide and weighing 18 oz./yd^2 (600 g/m^2). Two strips or layers of carbon fiber wrap were installed vertically and then anchored with two more layers.

The "dry layup" installation procedure consisted of applying the epoxy saturant by roller at the manufacturer's recommended thickness. Immediately after, a spatula and worm roller were used to embed carbon fiber wrap to the point of complete saturation, removing any air pockets that might have been trapped within the composite. The steps were repeated until all layers of vertical and horizontal carbon fiber wrap strips were installed within the same day.

At the end of the day, another coat of medium-viscosity saturating resin was installed and clean,

Fig. 4: Installation of saturating resin and carbon fiber wrap

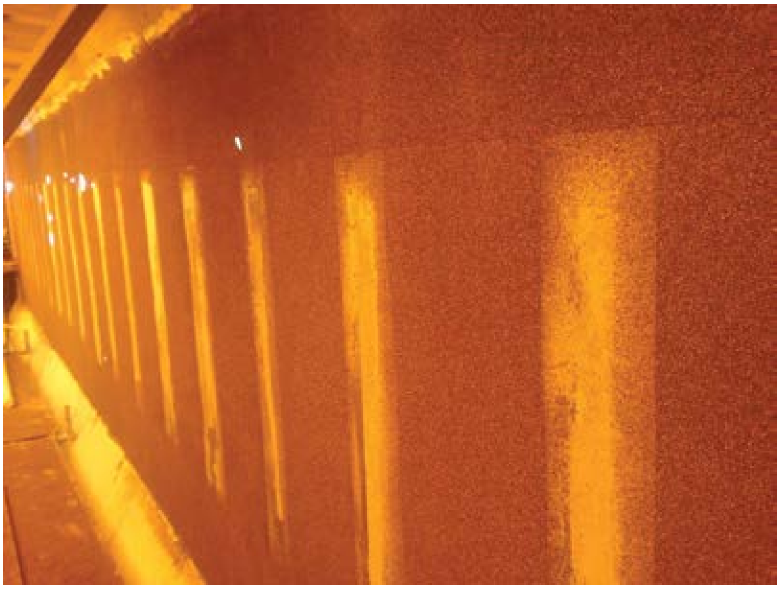

Fig. 5: CFRP with sand broadcast

Fig. 6: View of the suspended scaffolding setup

dry silica sand was broadcasted into the wet surface (Fig. 5). This step provided a mechanical bond for the final cementitious coating. That final finish coat was installed for protection against exposure to ultraviolet (UV) rays, carbonation, and deicing salts, as well as rendering a more uniform final appearance to the project.

All of the steps, from the primer to the sand broadcast application, had to be completed within the same work day in accordance with the manufacturer's recommendations. Therefore, it was important to estimate as closely as possible the amount of area that the crew could finish within the same day, which would consequently define the amount of primer that the crew would install.

CONCLUSIONS

The speed at which the repair work was completed was greatly impacted by the lightweight and easy-to-handle characteristics of the CFRP materials, as no cranes, special barges, or heavy equipment were needed to lift these materials. The only heavy equipment necessary was the crane used for the installation of the suspended scaffolding (Fig. 6) as well as the initial setup and takedown of these scaffolds and installations, such as the workers' trailer, compressors, generators, and toolboxes needed during the course of the work.

The strengthening performed on this bridge project is an example of the many types of repairs that can be achieved with CFRP. The formats of carbon fiber products are varied: carbon fiber wrap is available in one-, two-, and four-directional weaves; carbon plates come in different widths and strengths; and carbon rods and anchor systems are available in various sizes. This flexibility offers great versatility to design professionals for structural strengthening projects.

REFERENCES

1. ICRI Technical Guideline 310.2R, "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair," International Concrete Repair Institute, Rosemont, IL, 2013, 48 pp.

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