

HIGHWAY BRIDGE PIER CAPS STRENGTHENED WITH FIBER-REINFORCED POLYMER

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The transportation infrastructure, specifically bridges, plays a vital role in the well being and economic growth of America's business community. According to the American Association of State Highway and Transportation Officials (AASHTO), in the next 30 years, domestic freight volume is forecasted to double and international freight volume entering U.S. ports may quadruple.

The recent collapse of the I-35W Mississippi River Bridge in Minneapolis is a potent reminder of something we know all too well: America's infrastructure is crumbling. Evidence of the need for comprehensive bridge rehabilitation programs is compelling: since 1966, 1500 bridges have actually collapsed. According to the National Bridge Inventory, one-quarter of our nation's current bridges are structurally deficient or functionally obsolete, which threatens our economy. In addition to deterioration, over the past decades, standard truck weights and traffic volumes have increased. As a result, many older bridges that are still in good condition are not adequate to support today's traffic needs.

In its July 2008 report, *Bridging the Gap*, AASHTO stated that approximately \$140 billion is needed to rehabilitate bridges in the U.S. To address this need, cities and states must find new technologies and solutions to restore older bridges to meet increasing traffic volumes that are practical, durable, and cost-effective.

Budget constraints due to a shortage of available funds have forced many agencies to post load restrictions on deficient bridges until more funds become available. Load restrictions typically result in detours with increased travel time and distances for heavier trucks such as those used to transport goods or provide emergency services such as ambulances and fire trucks. Posted bridges may have marginal overstress conditions and experience has shown that when load tested, many of these bridges often exhibit strength and stiffness characteristics beyond those analytically predicted using traditional load rating procedures. As a result, design professionals are now using more sophisticated methods of analysis to "squeeze out" a higher load rating of existing bridges. In addition,

the use of full-scale diagnostic load testing for the purpose of load rating has become an accepted practice for evaluating these bridges.

Economically, it is not feasible to replace every deficient bridge. The construction of a new bridge involves tedious planning and design processes that take a long time to complete and typically causes inconvenient traffic disturbances. A more economical and rapid solution is to strengthen bridges using techniques that cause minimal or no disturbance to daily operations. Strength deficiencies can be resolved using conventional structural strengthening techniques such as the installation of monolithic reinforced concrete enlargement or the use of post-tensioning systems.

One repair material that is gaining popularity for the repair and rehabilitation of bridges is fiber-reinforced polymer (FRP)—composite materials made of a polymer matrix reinforced with high-strength carbon or glass fibers. FRP materials have been demonstrated to provide a good alternative to conventional strengthening techniques. FRP materials provide an excellent and economical solution for the structural upgrade of bridge components due to their lightweight, corrosion-resistant, and high tensile strength properties. FRP's most important characteristics for bridge repair and strengthening applications are its speed and ease of installation. The higher material cost is typically offset by reduced labor, minimal use of heavy machinery, and no shut-down costs, making FRP strengthening systems a very competitive strengthening technique for bridge rehabilitation.

CASE STUDY

The building officials for a local county determined that the existing bridge pier caps on two roads required structural strengthening to ensure the pier caps could support the current traffic loads. Analysis of the existing bridge piers revealed that the piers required an increase in shear capacity as well as an increase in bending capacity. The first bridge crosses over a major U.S. highway and a freight railway. The four-span bridge is supported on three sets of piers. The second bridge crosses over one of the nation's busiest passenger rail lines.

Several options were evaluated for upgrading the pier caps, including enlargement and externally bonded FRP composites. The enlargement solution involved placing additional bonded reinforced concrete to the existing piers in the form of a jacket. With section enlargement, the load-carrying capacity of the piers could be increased to the desired level. A typical enlargement for the pier caps would be approximately 4 to 6 in. (100 to 150 mm) thick and would require a significant amount of shoring, surface preparation, and possible shut downs. For this project, enlargement was not a viable option because of the cost, access, time required to complete construction, and the logistics of working so close to a freight railway.

The bridges had to stay in operation during the course of the repair project, which made using FRP a more viable strengthening strategy. FRP was also selected for several other reasons, one of the most important being that it would cause little or no disruption in the day-to-day use of the bridge for train, pedestrian, and automobile traffic. In addition, due to the layout of each bridge, the construction site had minimal space, which did not allow for

storage of large quantities of materials and large equipment. By using FRP, there was no need for storage areas or space typically needed to manage heavy equipment or bulk material.

The bridge pier caps had positive bending, negative bending, and shear deficiencies. The positive moment deficiency was resolved by installing FRP strips at the underside of the pier cap, extending from face to face of the columns. To resolve the negative bending deficiencies, two strips of carbon FRP (CFRP) were applied at the topside of the pier cap (one on each side of the existing bearing pads). Shear deficiency was addressed by wrapping the piers with three plies of CFRP that extended on the sides and soffit of the pier cap.

A challenge for working on the first bridge was access to the piers. The two outside piers could only be accessed from the embankments next to the bridge, which were covered mostly with rocks. Crews had to build wood access ladders on the embankment to allow for climbing up the steep slope. For the middle pier, the only way to access the work platform was to climb a 30 ft (9.1 m) tall ladder. Work platforms were constructed of wood frames suspended by steel cables clamped to the underside of the bridge. Corrugated metal decking was placed on top of the frame to form the work deck. To construct the work deck, crews first hung the support cables using a rough-terrain man lift. Then, the wooden frame was built and the metal decking was installed. Because all of the work decks were suspended from the underside of the bridges, minimal work was done from the ground. Crews accessed the work deck from the sides. This ensured that the installation crew was not near traffic and needed minimal access to the railroad property.

To comply with the repair specialty contractor's stringent safety requirements, several additional safety measures were enacted in addition to 100% fall protection. The construction crew members had to be tied-off 100% of the time while on the work platforms, including while climbing the access ladder. Double lanyards were used to ensure 100% tie-off. Safety was of critical importance because both the railway and highway were active with freight train and vehicular traffic during the entire repair. A spotter, equipped with an air horn and two-way radio, was stationed along the railroad for the duration of the project. The spotter would inform the crews of any approaching trains via the radio. Since one side track was close to the work platform, if a train was headed down that track, crews had to get down from the platform and wait for the train to pass. Occasionally, a train would need to be parked on this track. This would be communicated to the spotter via the train conductor. The spotter would then radio the crew on the platform that they needed to clear the platform until the train was parked.



Elevated work deck allowed for access around entire work area



Surface preparation of concrete



Application of surface primer



Saturated carbon fiber sheets are placed onto the primed surface



Smoothing of surface using putty filler for holes and cracks



Saturated carbon fiber sheets are rolled onto the structure



Application and quality control of tack coat prior to placement of carbon sheets



Carbon sheet material is pressed with a ribbed roller to ensure no air bubbles are trapped beneath the fabric

To begin the work, construction crews prepared the surface of the piers with electric grinders to open the pores of the concrete, smooth form lines, and remove dirt and grime buildup so that the FRP would achieve the required bond with the concrete substrate. Several quality control measures were employed, including a series of pulloff tests to evaluate the quality of bond. These tests were used to measure the strength of the bond between the FRP reinforcement and the concrete substrate and also between subsequent layers of FRP reinforcement.



Application of topcoat for aesthetics and improved durability



Completed installation

All of the pulloff tests conducted on the surface-applied FRP confirmed that the surface preparation was done properly and that the carbon fiber was fully bonded to the concrete substrate. All pulloff tests resulted in a failure in the concrete substrate, indicating the bond between the carbon fiber and concrete is stronger than the tensile capacity of the concrete itself. The strengthened pier caps were then painted with a breathable acrylic coating to maintain a uniform appearance. The same process was performed for all three piers.

Because of the busy high-speed, passenger-train railway, all work had to be conducted on the second bridge without any disruption to railway traffic. Before crews could begin working on this bridge, all personnel who would work on the project had to attend a day-long safety class led by the passenger rail company. In addition, a preconstruction meeting was held to discuss the work that was to be performed as well as the hazards that surround the job site. For example, the high-speed passenger trains reach speeds of 120 mi/hour (193 km/hour) and would be racing by while work was occurring. Further, the

trains were powered by overhead electric lines that would be live during the project.

Once all of the training was complete and the logistical concerns were addressed, the weather had become cold, which is not ideal for installation of CFRP. Therefore, the project was put on hold until the weather warmed up a few months later. For the two piers on the second bridge, crews applied two strips of CFRP on the top, one strip on the bottom, and three strips on each side of each pier cap. Once FRP installation was completed, the breathable acrylic coating was applied as a final step to improve the aesthetics and durability of the FRP system. The same safety procedures, including 100% tie-off, were also performed on this portion of the project.

Externally bonded CFRP composites provided the most economical solution for the flexure and shear upgrade of the two highway bridges. This upgrade strategy was the most cost-effective solution due to speed and ease of the composite system application. The two bridges remained operational during the entire repair process with no disruption to traffic. Because of its light weight, installation of the CFRP system was achieved by a crew of four to six men and did not involve the use of any heavy machinery. The design/build approach that was used in this project and the quality control of the specialized contractor was essential to achieving a successful upgrade using externally bonded FRP reinforcement.



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