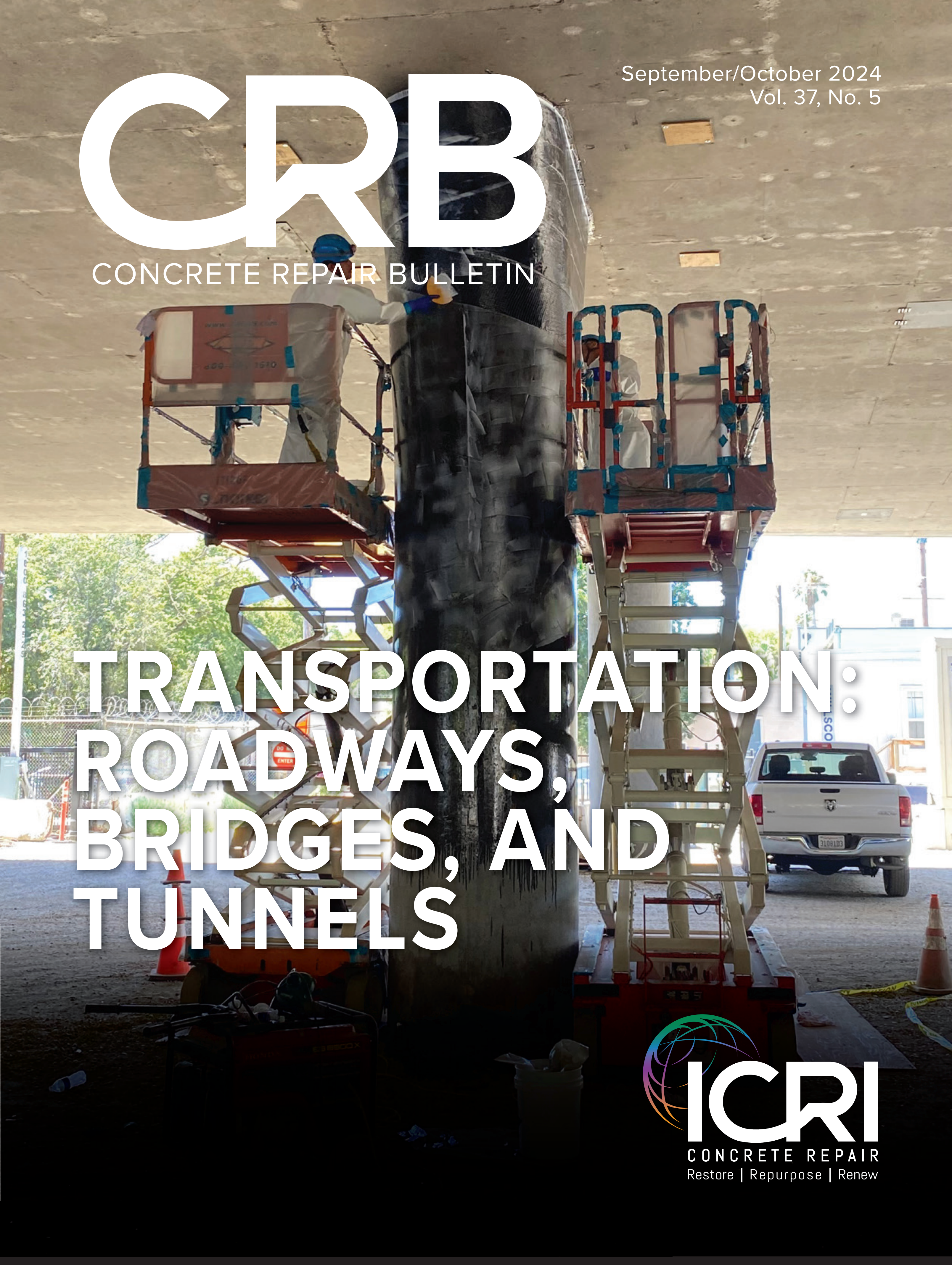

September/October 2024
Vol. 37, No. 5

CRB
CONCRETE REPAIR BULLETIN

TRANSPORTATION: ROADWAYS, BRIDGES, AND TUNNELS

ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

Seismic Strengthening of Bridge Columns with FRP Value Engineered to Replace Steel Jackets

by Sarah Outzen, PE

Aging transportation infrastructure in the US highlights the increasing need for critical repairs and improvements. Among this aging infrastructure is a segment of US-50 in Sacramento, California, a major east-west route stretching 3,019 miles (4858 km) from West Sacramento, California, to Ocean City, Maryland. Originally constructed in the 1960s, this section needed extensive improvements to meet the current code.

The project included the widening of 11 bridges, the addition of seven miles (11.3 km) of High Occupancy Vehicle (HOV) lanes, replacement of all lanes with 100-year pavements and asphalts, and seismic repair and strengthening of over seventy flared bridge columns with round bases. A common technique for improving the seismic behavior of columns when retrofitting is steel jacketing. In this article, I will share how we value-engineered the originally specified steel jackets with fiber-reinforced polymer (FRP).

STEEL VERSUS FRP JACKET

The original US-50 column retrofit design showed steel jackets to strengthen the columns, a standard and popular choice for many years. Although there are many structural advantages to steel jacketing, there are also disadvantages. For example, the fabrication of special steel shapes to match existing column geometry, the use of multiple steel pieces to create the jacket, full-depth Complete Joint Penetration (CJP) groove welding, jacket modification to accommodate existing conditions, and grouting of the annular space between the steel jacket and the column.

FRP is an externally bonded reinforcement system made of a high-strength, fabric sheet saturated in epoxy resin and surface-applied to a structural element. FRP composites provide a variety of advantages over the traditional steel jacketing method. It is lightweight and corrosion-resistant, offering a lengthier duty life than steel. Installation is performed by hand, eliminating the use of cranes, providing cost savings, and simplifying site logistics. Moreover, unlike steel jacketing, FRP can be cut and shaped on-site, and the design can be easily modified for the varying demands of different regions of the columns.

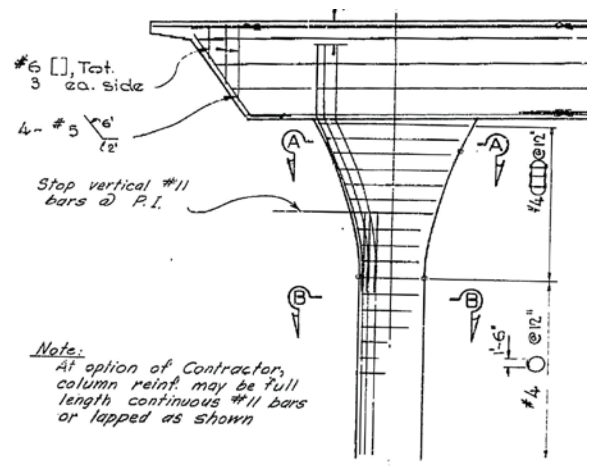

Fig. 1: Original column detailing

FRP JACKET DESIGN

The columns at US-50 have a hyperbolic flare at the upper portion and a circular section at the bottom portion. FRP provided an ideal solution for seismic retrofitting of the existing columns considering their non-uniform geometries. A performance-based approach was used for the design. The project Engineer of Record provided our design team with the target drift demands in longitudinal and transverse directions. Adding another area of structural concern, as you can see in the original detail in Figure 1, the geometric plastic hinge occurs at the same place as the vertical reinforcing bar splice region.

Our engineering team developed analytical models to identify the location and length of plastic hinges to calculate the required plastic rotation capacity to withstand target drifts. The location of the plastic hinge did not correspond to the location of the maximum moment, see Figure 2.

Fig. 2: Non-linear analysis model

What this means for the FRP jacket design is that by using a nuanced, performance-based approach, the engineering team could optimize layering

Fig. 3: Optimized FRP jacket along the column height

over the height of the column. A greater number of layers of FRP is applied at the plastic hinge region, compared to the top and bottom. This provides added strength and ductility where needed. However, the number of FRP layers is reduced outside the plastic hinge zone, meeting project design criteria while lessening the overall material and labor costs, see Figure 3.

The FRP jacket solution was presented to the project design team's staff and ownership. After addressing technical comments related to FRP detailing, the proposed FRP jacket solution was approved to improve the seismic performance of the concrete bridge columns.

FRP JACKET INSTALLATION

The existing columns extend 4-feet (1.2m) below grade; therefore, excavation was required to access the below grade portion of the columns and the FRP installation process ended up being broken into two phases. In Phase 1, the FRP jacket was installed on the upper portion of columns ahead of the excavation, and in Phase 2, the FRP jacket was installed on the column segment below grade; see the former in Figure 4.

The following steps were used by the FRP contractor to install the FRP jacket:

1. Concrete surface preparation was achieved using mechanical grinding to open up the concrete pores and grind down existing concrete form lines. The target surface profile is CSP-3 per ICRI Guideline 310.2R-2013.[1]
2. Applying epoxy primer coat to the prepared substrate and then using epoxy putty to smooth the surface and fill bug holes.
3. Impregnating dry FRP sheets with epoxy using mechanical saturators to control the amount of epoxy applied to the fiber sheets and avoid under or over-saturation of the sheets which can lead to dry fiber or sagging.
4. Installation of FRP sheets.
5. Using rib rollers to remove air bubbles after the installation of each FRP layer.
6. After cure of the FRP jacket, apply a topcoat for long-term protection of the jacket.

Fig. 4: Applied FRP jacket on the site

INNOVATIVE IMPROVEMENTS

The use of conventional construction materials or procedures does not always produce the most technically viable or cost-effective solutions. The US-50 project illustrates how advanced FRP composites can improve the seismic performance of concrete structures and provided a cost-effective alternative to conventional solutions. Material and labor costs were reduced over the traditional method. The elimination of welding reduced the overall quality assurance costs, as verification testing of the welds was no longer needed. The non-corrosive nature of the FRP also eliminates the ongoing need for periodic maintenance, as repairs should only be required in case of actual damage to the column itself. Overall project timelines with the FRP method can be reduced significantly compared to the steel jacketing method, as fabrication lead times can be four times as long. Figure 5 shows a comparison of steel jackets versus FRP, highlighting the benefits of using FRP jacketing.

Performance Factors	Steel Jacket	FRP Wrapping
Installed Cost (includes labor)	Base Price	Saved over $3,000 / col x 72 columns
Quality Assurance	Verify Welds ($$)	Direct Tension Tests ($)
Durability	Periodic Maintenance	Corrosion Resistant
Flexibility for Odd Shapes	Moderate	High
Materials Lead Time	12-16 Weeks	2-3 Weeks

Fig. 5: Comparison between steel jackets and FRP jackets

REFERENCES

1. ICRI 310.2R, Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair, International Concrete Repair Institute, Minneapolis, MN, 2013

Sarah Outzen, P.E., has been a Composite Strengthening Systems™ (CSS) field engineer at Simpson Strong-Tie since 2020. Before joining Simpson, she worked as a consulting engineer for nearly a decade, focusing on both new construction and retrofit of existing structures, primarily in concrete and steel. Sarah received her undergraduate degree from Cornell University, and a Master of Science from San Francisco State University, with a research concentration on recycled aggregate in concrete.