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Repair of Timber Piles and Pile Caps on the Canadian Rail Bridges with FRP

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ABSTRACT: Timber bridges remain a prevalent component of the railroad infrastructure across North America. Many of these aging structures are nearing or have exceeded their original design life and now exhibit significant signs of decay. Their frequent location in remote and difficult-to-access areas makes them ideal candidates for repair techniques that require minimal equipment and labor.
For deteriorated pile repairs, a 1.1-mm-thick Glass Fiber Reinforced Polymer (GFRP) laminate is utilized. These high-strength laminates are produced using proprietary equipment that applies heat and pressure to resin-impregnated glass fabrics, resulting in thin, impervious rolls up to 1200 mm wide and over 100 meters in length. In the field, a piece of laminate—typically cut to twice the pile circumference plus 200 mm—is coated with epoxy paste and wrapped around the pile to form a two-ply structural shell with a 1–2 mm annular gap. This space is filled with low-viscosity resin, which penetrates cracks and voids in the damaged timber, forming a strong bond between the FRP shell and the pile. The technique restores both axial and flexural capacity of the pile and can be implemented underwater without the need for cofferdams.
Similarly, deteriorated pile caps and stringers can be repaired using resin-saturated biaxial CFRP or GFRP fabrics. These flexible fabrics conform to complex geometries, with longitudinal fibers enhancing flexural strength and transverse fibers improving shear capacity.
Both repair methods have been successfully applied to hundreds of piles and pile caps throughout Canada. Their lightweight nature, field adaptability, and minimal equipment requirements make them particularly well-suited for remote railroad bridge rehabilitation projects.

1 INTRODUCTION

Timber bridges have served the rail industry in Canada and elsewhere for well over a century. Many short-span and medium-span rail bridges, particularly those located in rural and remote regions, continue to rely on timber piles, caps, beams, and stringers as primary structural elements. The widespread historical use of timber was driven by its availability, low cost, and ease of construction. In many cases these bridges remain in service today because replacement costs are substantial and their locations make major reconstruction difficult.

Over time, however, timber members are subject to deterioration caused by decay, checking, splitting, moisture intrusion, freeze-thaw exposure, and, in marine or brackish environments, attack by marine borers such as shipworms and gribbles. Earlier generations of timber piles were often treated with creosote to improve durability, but environmental concerns have significantly restricted the use of such preservatives, particularly in water crossings. As a result, many timber substructure elements are now more vulnerable to deterioration. In superstructure elements such as beams and girders, years of cyclic loading and environmental exposure can also lead to section loss, reduced stiffness, and localized damage.

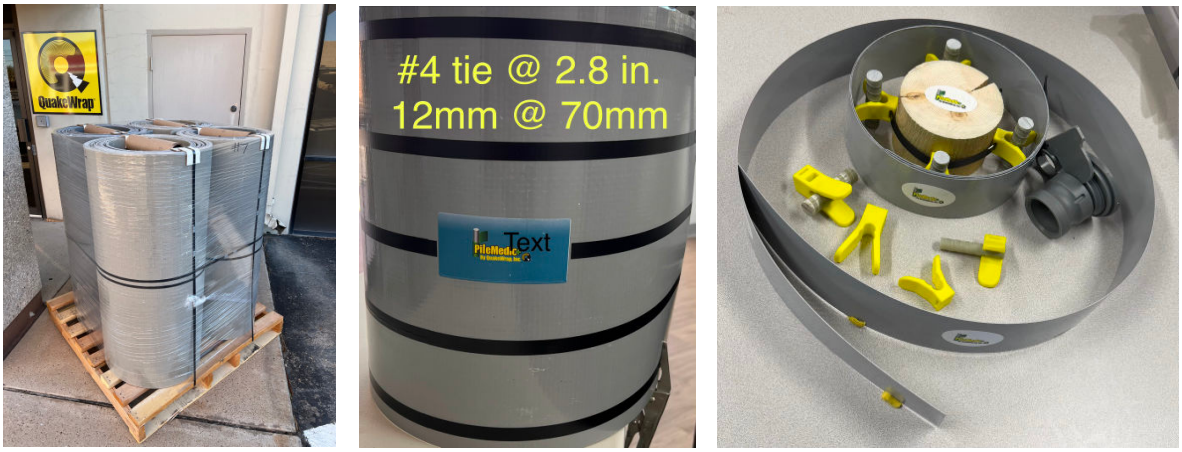
For railroad bridges, these challenges are compounded by access constraints. Many bridges are located in remote regions where mobilizing heavy equipment is difficult and costly. Repair methods that require custom-fabricated jackets, extensive falsework, or prolonged service interruption are therefore less attractive. In addition, timber members often vary in size and geometry - even within the same structure - making rigid prefabricated repair systems difficult to apply efficiently.

This paper presents a proprietary FRP-based approach for the rehabilitation of timber rail bridges, with emphasis on field applications in Canada. The technique uses thin, flexible FRP laminates to create structural shells around deteriorated timber piles, with the annular space filled using a high-strength low-viscosity (LV) resin (Ehsani 2016). The paper also introduces a related method for strengthening deteriorated timber beams and girders using resin-saturated FRP fabrics wrapped around the member, combined where appropriate with LV resin injection to fill internal voids and improve composite action. Together, these techniques provide a lightweight, durable, and highly adaptable solution for extending the service life of timber rail bridges with minimal disruption to operations.

2 FRP REPAIR SYSTEM FOR TIMBER BRIDGE ELEMENTS

The author and his associates introduced fiber-reinforced polymer (FRP) systems for repair of bridge girders more than three decades ago (Ehsani and Saadatmanesh 1990). Within a few years, these techniques were extended to increase the strength and ductility of concrete columns (Saadatmanesh et al. 1994). The original wet layup system consisted of carbon or glass fabrics saturated with resin in the field and bonded to the surface of the structural member. Once cured, these materials develop tensile strengths significantly greater than that of steel on a weight basis. Wet layup systems have been used successfully on thousands of projects worldwide, particularly for strengthening concrete beams, slabs, and columns.

For timber bridge repair, two related FRP techniques are particularly effective. The first uses thin prefabricated FRP laminates to form a shell around deteriorated piles. The second uses resin-saturated FRP fabrics wrapped directly around timber beams, girders, or stringers. In both cases, low-viscosity resin can penetrate cracks and voids in the timber, improving bond and restoring continuity in deteriorated regions.



(a) (b) (c)

Figure 1. Components of PileMedic®: (a) Rolls of laminates; (b) comparison of strength of the jacket with steel ties, and (c) spacers and rebar holders.

2.1 Repair of timber piles with flexible FRP laminates

The pile repair system described in this paper is based on a patented FRP laminate system commonly known as PileMedic®. These laminates are manufactured by saturating reinforcing fabrics with resin under heat and pressure, producing a thin, flexible laminate typically less than 0.05 in. (1.2 mm) thick. The laminates can be supplied in rolls up to several meters wide and more than 400 ft (120 m) long (Fig. 1a), allowing them to be transported and handled easily in remote locations.

For pile repair, a laminate approximately 4 ft (1200 mm) wide is convenient for field handling. Once cut to the required length, the laminate is wrapped tightly around the pile, typically for two full revolutions plus an overlap, forming a seamless two-ply structural shell. Epoxy paste is applied between the layers to bond the shell closed. Because of the small thickness and flexibility of the laminate, the shell can be formed around piles of varying diameter without the need for custom-fabricated jackets. This is a major practical advantage for timber bridge rehabilitation, where pile dimensions often vary from one location to another. Figure 2 shows a typical repair detail utilizing this technique.

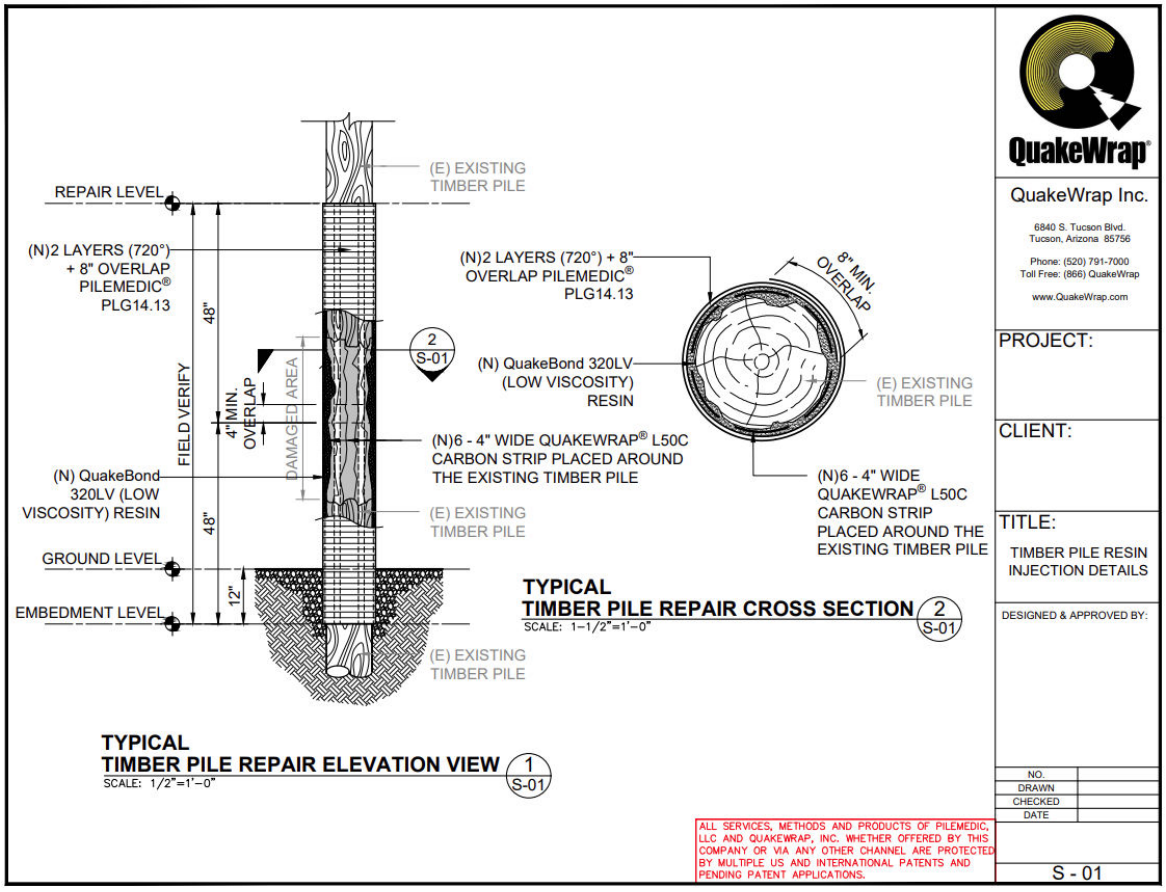


Figure 2. Typical repair details for timber piles.

The completed shell is then injected with a high-strength low-viscosity resin. This resin bonds the shell to the timber substrate, fills cracks and internal voids, penetrates cavities created by decay or marine borer attack, and creates a composite section in which the original timber and outer FRP shell act together. Because the shell is seamless, leakage of resin is minimized, making the system particularly effective for underwater and splash-zone applications.

2.2 Testing

The effectiveness of the proposed technique has been demonstrated through several research studies. One study funded by the Nebraska Department of Roads investigated strengthening of timber piles with significant section loss. The lost area was filled with cementitious grout and aggregate, after which the pile was wrapped with FRP laminates and injected with low-viscosity resin. The strength of the repaired piles was significantly higher than that of the original undamaged pile (Gull et al. 2015).

Another major investigation was conducted by the U.S. Army Corps of Engineers. Six products were submitted for evaluation, and within the first few weeks five products were eliminated from further consideration. PileMedic® was the only system extensively tested over a three-year period. As a result, this system is currently the only approved product used by the U.S. military for pile repair projects worldwide (Hammons et al. 2018).

2.3 Structural performance and durability

The FRP shell provides circumferential confinement and longitudinal strength. Depending on the fiber architecture and material type, the laminates can be designed to provide substantial strength in both the hoop and axial directions. When the annular space is filled with LV resin, the shell becomes well bonded to the timber, allowing the FRP to contribute to axial and flexural resistance. This is particularly important in piles with localized damage where the original timber section may have been significantly compromised.

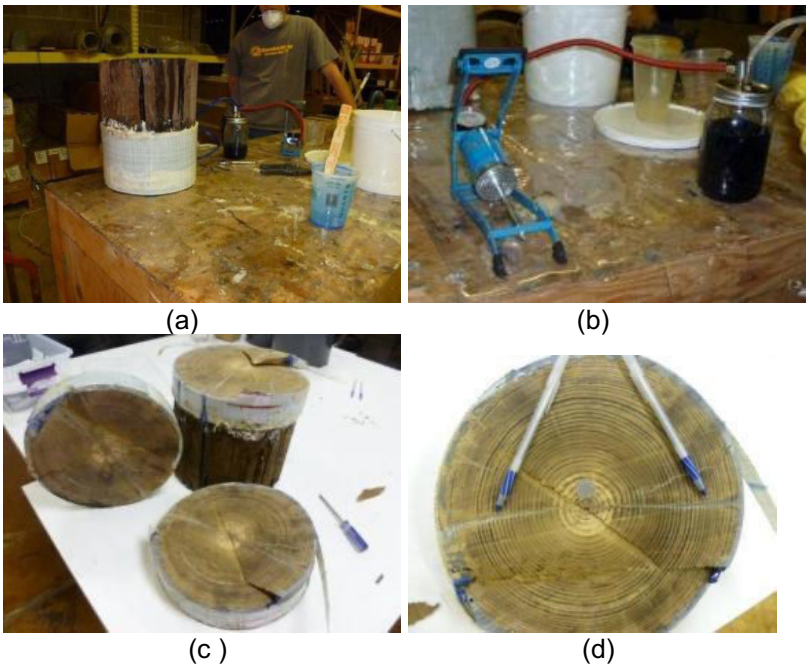


Figure 3: A timber pile (a) wrapped, (b) injected with Low Viscosity (LV) resin with a simple pressure pot, (c) cut into slices, and (d) section of s timber pile showing the penetration of LV into invisible cracks.

The LV resin also fills internal defects that are often not visible from the surface. In piles damaged by marine borers, for example, the outer shell of the timber may appear relatively intact while the interior has been hollowed out. By penetrating these internal cavities, the resin restores continuity and supports stress transfer between the timber core and the FRP shell. Figure 3 shows a cut section of a timber pile that was injected with LV resin; the dark lines indicate cracks that were filled with the resin.

The compressive strength of most timber piles is typically less than 3000 psi (21 MPa), whereas the compressive strength of the LV resin is nearly four times higher. Consequently, filling voids within the timber pile with this resin can significantly improve the axial load-carrying capacity of the repaired pile.

Another benefit of the laminate is the lateral confinement that it provides. As shown in Fig. 1b, when wrapped in two plies, the jacket provides the equivalent of #4 ties at a spacing of 2.8 in. (12mm Ø @ 70mm) along the height of the pile. Thus, the laminates eliminate the need for lateral ties.

From a durability standpoint, the seamless FRP shell acts as a barrier against moisture ingress and oxygen exposure, thereby slowing further deterioration of the repaired timber. FRP materials do not corrode, and unlike rigid multi-piece jackets, the absence of longitudinal seams reduces the likelihood of water intrusion. This makes the system particularly attractive for long-term rehabilitation of piles in harsh environments.

2.3 Repair of timber beams, girders, and stringers

In addition to pile repair, FRP can also be used to rehabilitate deteriorated timber beams, girders, and stringers in rail bridges. Many such members develop longitudinal splitting, checking, localized decay, and reduction in effective section due to prolonged moisture exposure and repeated loading. Where the member remains generally stable but has suffered moderate deterioration, a wet layup FRP system can provide an effective strengthening solution.

In this approach, resin-saturated FRP fabrics are wrapped around the timber member, typically in a U-wrap or full wrap configuration depending on access and geometry. The wrap provides confinement, enhances shear resistance, and helps hold together cracked or split sections of timber. In some cases, the member may contain internal voids or deep cracks; these can be injected or filled with low-viscosity resin prior to or in conjunction with wrapping. The resin penetrates the damaged timber, restores integrity in the weakened zone, and improves bond between the timber substrate and the external FRP reinforcement.

For beams and girders, the FRP wrap can be designed to address specific structural deficiencies. Longitudinal FRP reinforcement may be added to improve flexural capacity, while transverse wrapping helps confine the member and resist splitting. The resulting system is lightweight, rapidly installed, and well suited to sites where replacement of large timber members would be difficult or disruptive.

Earlier studies have demonstrated that Carbon Fiber Reinforced Polymer (CFRP), can be used to strengthen and retrofit timber beams and bridge girders. A total of 10 solid-sawn Douglas Fir timber beams were taken from a timber stringer bridge that was replaced in 1999; some of these beams had been treated with creosote. The research concluded that bonding FRP to timber can significantly increase strength, stiffness, and ductility while altering failure modes to be less brittle (Buell and Saadatmanesh 2005).

In another study, glue-laminated beams were strengthened by bonding carbon strips to the tension face and wrapping the bottom and side faces with a bidirectional carbon fabric saturated with resin. These tests also showed significant increase in flexural strength of the beams. The presence of the fibers on the side faces of the beam prevented delamination of the laminates in the tension zone and the beams exhibited significant ductility prior to failure (Ehsani, et al. 2004)

3 FIELD APPLICATIONS IN CANADA

The FRP techniques described above have been used successfully on timber bridge rehabilitation projects in Canada since 2020. The applications presented here focus primarily on pile and beam repair for rail bridges.

3.2 Rail bridges in remote regions of northern Canada

Some 300 timber piles have been repaired by Western Infrastructure Renewal Inc. to date on rail bridges in remote regions of northern Canada. These bridges were located throughout northern Manitoba, where construction is challenged by cold temperatures, snow, and limited access. The piles generally ranged from 400 to 500 mm (16 to 20 in.) in diameter. Damage was typically concentrated near or just above the waterline, although several piles required repair over their full height.

For these projects, the deteriorated portion of each pile was wrapped with a two-ply laminate shell formed directly in the field (Figs. 6 & 7).

Access to the bridges was often difficult. Crews used rafts and floats that were transported by high-rail trucks and lowered into the water beneath the bridge (Fig. 6a). Because epoxies must be stored and mixed above a minimum temperature, heated enclosures were created on the rafts using insulated tarps, with warm air supplied through flexible ducts from heaters mounted on the rail vehicles. This enabled repairs to continue even under harsh late-season conditions (Fig. 6b).

The flexibility of the laminates also proved beneficial in congested areas where piles were adjacent to diagonal braces or other framing elements (Fig. 6c). Each shell or jacket covers a height of 4 feet (1.2m) of



(a) (b) (c)

Figure 6: Some of the job site challenges: (a) high rail trucks helping with lowering a raft for mobilization and (b) providing heat to keep the crew and resin warm on a snowy day; (c) wrapping a pile in a tight space.



(a) (b) (c)

Figure 7: Installing the laminates to create a (a) partial or (b) full height repair of a pile; (c) placement of low viscosity resin in the annular space.

the pile (Fig. 7a). When the required repair height is taller, additional shells can be installed with a 4 inch (100 mm) overlap over the previous shell (Fig. 7b).

The slight deformations on the surface of a timber pile create a small annular space between the pile and the shell. The annular space was then filled with high-strength low viscosity (LV) resin. An alternative is to cut three 0.5-in. (13mm) deep grooves with a chain saw at roughly 120 degrees into the surface of the pile. Perforated tubing can be embedded in these grooves and the tubes can be connected at the top with a manifold; the LV can be introduced into all these pipes through the manifold. A pressure pot used in painting is an easy way to force feed the LV into the manifold. Because the shell could be fabricated onsite to match the actual pile dimensions, there is no need to order or transport custom-sized jackets. This greatly simplified logistics across multiple remote bridge locations. It is also a significant advantage in post disaster, e.g. hurricane, repairs when there is little time to plan and order for custom-sized jackets or shells.

In some cases, existing brace bolts were temporarily removed and replaced with wooden pegs (Fig. 8). After the shell was wrapped, openings were made through the laminate to reinstall the brace using the original bolt holes, after which the annular space was filled with LV resin.



Figure 8: Reinstalling the bolt to connect the bracing element.

The field productivity of the system was noteworthy. Crews were typically able to complete repairs to two or three piles per day. Given the remoteness of the sites and the time required for travel and setup, this represented a highly efficient repair method. Several of these bridges had been considered candidates for replacement at costs exceeding several million dollars; the FRP repair program provided a means of extending service life for decades at a fraction of replacement cost and with minimal disruption to rail operations. Figure 9 shows one site where multiple piles were repaired on a bridge.



Figure 9: One of the rail bridge sites where dozens of piles were repaired.

3.3 Extension of FRP techniques to timber superstructure members

In addition to pile repairs, bridge owners and contractors involved in these projects have expressed growing interest in applying FRP systems to deteriorated timber beams, pile caps, girders, and stringers. In many cases, these members exhibit longitudinal checks, localized rot, or splitting near supports and connection points. Full replacement of such members is often difficult because it requires track closures, heavy lifting equipment, or extensive shoring.

A wet layup FRP system offers an attractive alternative. After removal of unsound material and preparation of the timber surface, resin-saturated fabrics can be wrapped around the member to provide confinement and strengthening. Where internal voids or deep cracks are present, low-viscosity resin can be injected beforehand to fill the damaged zones and improve overall continuity. This combined approach can restore capacity, reduce further splitting, and provide a protective outer layer that helps shield the timber from future moisture ingress.

Figure 10 shows one of three municipal bridges in Saskatchewan where damaged pile caps were repaired in situ. These pile caps had horizontal splitting cracks that ran along the length of the span. A biaxial glass fabric weighing 24 oz/yd^2 or (610 g/m^2) was saturated with a two-part structural epoxy resin and wrapped around the pile cap in the areas between the piles. The slab above prevented wrapping the beam on all 4 sides. However, the timber panels on the abutment wall were temporarily removed to allow access to the back face of the beam. Thus the 4-ft (1.2m) wide bands of fabric were wrapped in a U-shape configuration around the beam. The next 4-ft wide band of fabric was installed similarly, overlapping the previous band by 12 in. (300mm). The portions of the beam directly above the piles could not be wrapped. The repair

system provides additional flexural and shear strength for the wrapped portions. In addition, the fabric protects the beam from exposure to the elements.



Figure 10: One of three municipal bridges in Saskatchewan where pile caps were repaired with resin-saturated FRP fabric



Figure 11: The pile cap being repaired in the shop and after installation

In another case, the 14-in. X 16-in. (356 mm X 406 mm) pile cap shown in Fig. 11 was damaged by rot. Due to the unusual size of the beam, a replacement beam could not be easily obtained. The bridge was on a remote site with limited traffic. Using a 200 Ton crane, the superstructure was lifted and placed on the adjacent ground. The pile cap was removed and transported to the contractor's shop. The rotted sections

were replaced with new timber pieces, bringing the cross-sectional dimension of the beam to its original size. The beam was then wrapped all around with 4-ft (1.2 m) wide bands of the same glass fabric described earlier. The wrapped beam was transported back to the site and installed on top of the piles. Steel pins were used to reconnect the piles to the pile cap. Finally, the superstructure was lifted and placed back on the substructure, allowing the bridge to be opened to traffic. The complete wrapping of the beam will protect it from the elements, providing the pile cap decades of additional maintenance-free life.

4 COST CONSIDERATIONS

The FRP laminate system used for pile repair offers a cost-effective alternative to conventional replacement or heavy civil rehabilitation methods. The PileMedic® laminates used on these projects cost approximately US$120 per square meter, while the epoxies used in the system cost roughly US$35 per liter. For a typical 12 -in (300 mm) diameter pile, the cost of the FRP shell including the epoxy paste used to form the shell is around $120/ft (US$380/m) of repaired height.

To minimize resin consumption, the laminate should be wrapped tightly around the pile. Some piles contain hidden internal cavities or severe deterioration that increase the resin volume required; assuming approximately 4 liters of LV resin per meter of pile height, the total direct material cost of the repair system is on the order of US$500 per meter. Since installation requires no custom-fabricated jackets, no heavy lifting equipment, and minimal interruption to bridge service, the overall installed cost remains highly competitive.

For timber beams and girders, costs will depend on the size of the member, extent of deterioration, amount of resin injection required, and the quantity and orientation of FRP fabric needed for strengthening. Even so, the method remains attractive where replacement would require lengthy outages, large cranes, or difficult access.

5 SUMMARY AND CONCLUSIONS

This paper presents an FRP-based approach for rehabilitation of timber rail bridges, with emphasis on applications in Canada where remote access, harsh climate, and aging infrastructure create significant maintenance challenges. The primary repair technique uses thin flexible FRP laminates to form a seamless shell around deteriorated timber piles, with the annular space filled using a high-strength low-viscosity resin. This method eliminates the need for custom-manufactured jackets and allows the repair to be tailored in the field to timber elements of varying size and geometry.

Field applications on the Selkirk Trestle in British Columbia and on multiple remote rail bridges in northern Manitoba demonstrate the practicality and efficiency of the system. The repair can be performed with limited equipment, in tight spaces, and with minimal disruption to service. The low-viscosity resin fills cracks, voids, and internal cavities in the timber, while the FRP shell provides confinement, strengthening, and long-term environmental protection.

The paper also outlines the extension of similar FRP concepts to timber beams, girders, and stringers. In these members, resin-saturated FRP fabric wraps, used in conjunction with low-viscosity resin filling of internal defects, offer a promising technique for restoring structural integrity and extending service life without full member replacement.

Overall, FRP repair systems provide bridge owners with a durable, lightweight, and economical solution for prolonging the life of timber rail bridges. Their adaptability, rapid installation, and suitability for remote locations make them particularly valuable for short-span and medium-span rail structures where conventional replacement is costly and disruptive.

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