Repair of timber piles in rail bridges – A Canadian perspective

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ABSTRACT: Timber piles are used in many railroad and secondary highway bridges throughout North America. Many of these structures are reaching the end of their design life and the piles are showing signs of deterioration. These structures are often located in remote sites where limited access favors repair techniques that require minimal equipment. This paper describes two such techniques that have been successfully used in Canada to repair and extend the operation life of those aging structures.

Both techniques use 1.1-mm thick laminates made of Glass Fiber Reinforced Polymer (GFRP) products. The high-strength laminates are supplied in 1200-mm wide rolls that are over 100 m long. In the field, a length of laminate, typically twice the circumference of the pile plus 200 mm is cut. The laminate is coated with an epoxy paste and wrapped around the pile to create a doubly ply structural shell at a desired standoff distance from the pile. In one case, the annular space between the pile and the shell is only 1-2 mm wide. This space is filled with a low viscosity resin that penetrates through the cracks and crevices of the deteriorated pile. The FRP shell bonds to the host pile and the strength of the original pile is easily restored.

In another case, longitudinal reinforcing bars are positioned around the pile. The laminate is wrapped around these bars to create an annular space up to 75 mm wide. The annular space is filled with concrete, creating a new reinforced concrete column around the deteriorated timber pile. The GFRP laminate provides significant confinement pressure and eliminates the need for ties. Both techniques have been successfully implemented on several projects throughout Canada that will be presented. Installations in inclement weather and icy conditions will also be discussed.

1 INTRODUCTION

For nearly a century, timber piles have been used on railways and secondary highway and county bridges. The availability and low cost of timber has contributed to the popularity of this system. In earlier years, the piles were treated with creosote to improve their life expectancy. However, in recent years, environmental concerns have limited or banned the use of such treated wood, especially in water crossings. This has made the piles more susceptible to decay.

At the same time, recent environmental successes in cleaning the inland waterways have led to a resurgence of marine pests such as shipworms and gribbles. Together, they attack wood pilings; the gribbles, which are tiny crustaceans, chew from the outside, while shipworms, larger mollusks, bore tunnels within. In NY City, for example, a few years ago, over $100 million was spent on one project to repair damaged piles with concrete and steel that are immune to such attacks (Hu 2019).

The loss of cross-sectional area results in loss of axial capacity of timber piles, requiring strengthening of these elements. In the case of railroad bridges, the sites are often located in remote locations where access by road may be limited. This makes repairs with solutions that require heavy lifting equipment difficult and costly. The dimensions of timber piles also may vary on a single bridge. This makes it difficult for solutions that require pre-manufactured jackets as these jackets will most likely be too small or too large for some of the piles on any project, leading to construction delays. Furthermore, the transportation and storage of such bulky jackets add cost and delays in projects.

This paper presents a new technique for repairing timber piles that overcomes all of the above shortcomings. Two variations of the repair are described in detail including some of the construction challenges that are unique to colder climates in Canada.

2 REPAIR SYSTEM

Fiber Reinforced Polymer (FRP) products were introduced in the late 1980s for repair of structural members. The original system consisted of fabrics of carbon or glass that would get saturated with epoxy in the field and bonded to the exterior surface of the structural element. By the next day when the epoxy cures, FRP reaches a tensile strength 2-3 times that of steel. While that technique known as wet layup has been successfully used on thousands of projects worldwide, the flexible fabric must be bonded to a flat, smooth surface such as that of a concrete beam or slab; it is not suitable for repair of timber piles with uneven exterior surfaces.

The patented solution presented here for repair of piles uses a special type of FRP laminate developed by the author over a decade ago (Ehsani 2016) commonly known as PileMedic®. These laminates are made in a special process where one or more layers of reinforcing fabric are saturated with resin and subjected to heat and pressure to produce a very thin laminate. The laminates can be supplied in rolls that are up to 3m wide by over 100m long. However, for repair of piles, a 1200mm (4 ft) wide roll is most convenient for handling in the field (Figure 1a). The system has been tested extensively by various agencies (Gull et al. 2015; Hammons, et al. 2018) Various attributes of this product are presented below.

2.1 *Shape and size*

Conventional fiberglass jackets used to date for repair of piles must be specially ordered to size for each project. This could result in construction delays, if the jackets are manufactured too big or too small. In contrast, the small thickness of these laminates, which is typically less than 1.5 mm makes them flexible enough to be wrapped around piles of any shape and size. Standard detail requires wrapping the laminate twice (i.e. 720 degrees), plus a 200mm extension around the pile (Figure 2). Once the right length of laminate is cut from a roll in the field, the second half of the laminate is coated with an epoxy paste, and it is wrapped around the pile and bonded to the first layer, creating a two-ply structural shell around the pile. This eliminates the need for custom ordering the jackets, saving significant time, and shipping and storage cost. Each of the 120m long rolls shown in Figure 1a, for example, can repair 75m of 250mm diameter piles, or 63m of 300mm diameter piles, etc.

(a) (b) (c)

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

In repair of badly deteriorated piles, it is necessary to add supplemental reinforcing bars to increase the flexural capacity of the pile. Placement of these bars and maintaining their position during the placement of grout is a challenging task. We have developed plastic spacers in a variety of shapes and sizes. These serve multiple purposes. A zip tie can be passed through several spacers and fastened around the pile. When needed, the longitudinal reinforcing bars (typically made of glass FRP that will not corrode) can be snapped into these spacers (Figure 1c). This allows the engineer to know the precise location of each bar and the width of the annular space that are needed for strength calculations. As discussed later, the annular space between the jacket and the pile will be filled with grout, concrete or epoxy later.

2.2 *Reinforcement and confinement*

Depending on the type of fiber that is used, that is carbon or glass, the FRP laminates have tensile strength ranging between 200-1050 MPa. Furthermore, by selecting the orientation of the fibers within the fabrics the strength of the laminate in the longitudinal and transverse directions can be adjusted to meet the specific project requirements. The jacket creates a uniform confining pressure (i.e. 360 degrees) around the pile and it eliminates the need for hoop reinforcement. This allows divers to install the vertical reinforcing bars individually (when needed) and the lateral reinforcement or tie is provided by the jacket itself. The elimination of handling assembled reinforcing cages that requires two divers, results in significant dive time and savings for the project. As shown in Figure 1b, the most common laminate (PLG14.13) is equivalent to 12mm ties placed at a spacing of 70mm along the height of the pile. The confining pressure of the jacket also increases the compressive strength of the original pile and any grout that is placed in the annular space. This results in a larger axial load-carrying capacity of these piles compared to a pile repaired with conventional FRP jackets of the same size.

The jackets also have significant strength along the axis of the pile that could contribute to the axial and flexural capacity of the repaired pile. However, to fully engage the jacket, it must be bonded to the pile. The use of an epoxy as the filler material achieves this. But, when a cementitious material is used to fill the annular space, it is conservative to ignore the contribution of the jacket in flexure. A more economical way to increase the flexural strength of the pile is to introduce GFRP rebars in the annular space and fill the space with a non-shrink grout or concrete.

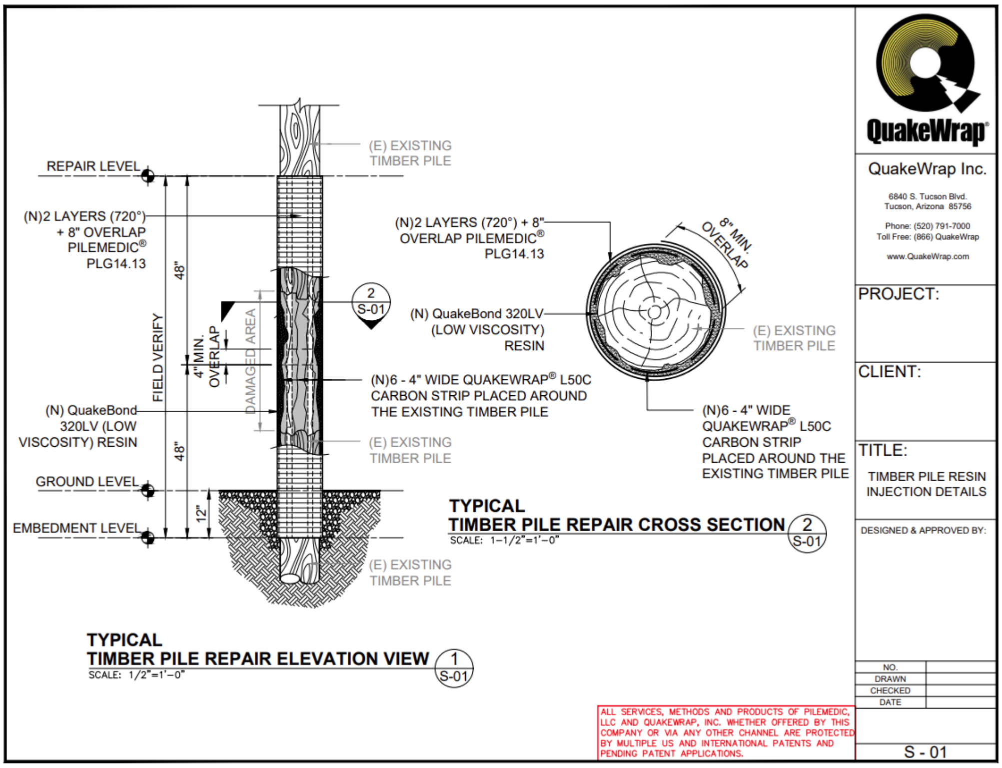

Figure 2. Typical repair details for timber piles.

2.3 *Corrosion protection*

It is well recognized that the oxygen present in water is the fuel for the corrosion process. The laminates create a seamless shell around the pile, preventing any moisture or oxygen ingress. In the same way that paint is used to protect steel structures from corrosion, FRP products can be used with longer lasting results. FRP materials do not corrode and offer a very long service life. Unlike paints that crack and peel off after several years, the fibers in these laminates prevent them from cracking, giving them an extended service life. This will drastically reduce the corrosion rate in the pile. In contrast, most jackets on the market are comprised of two pieces that are bolted together in the field; these seams will allow for passage of some moisture and oxygen and the corrosion process will continue after the repair is completed. While in this paper the focus is on strengthening piles, other similar systems are available for repair of bulkheads and abutment walls.

A further benefit of the seamless shell is that it allows the use of a low viscosity resin as the filler material without any concern about leaking of the epoxy from the seams.

2.4 *Filler material*

The filler material can be either resin-based or a cementitious material. The examples presented in this paper use a low viscosity resin that not only bonds the jacket to the pile, but it also fills all the voids, cracks and cavities inside the pile. In this case, it is best to keep a minimal annular space to keep the repair cost down.

Alternatively, a non-shrink anti-washout concrete or grout can be used. These are often accompanied by GFRP reinforcing bars placed in the annular space. The annular space for these applications is 40mm or larger to allow the concrete to flow freely and fill the annular space.

In some cases, the repair portion of the pile extends to the mud line and the soil provides a seal at the bottom of the jacket for placement of the grout. However, there are many applications where the length of the repair is limited to the splash zone, requiring the creation of a seal at a point along the height of the pile where the bottom of the jacket will be positioned. The skirt pin shown in the foreground of Figure 1c allows the creation of that seal.

3 FIELD APPLICATIONS

The system presented above has been used successfully to repair some 200 piles in Canada recently. The cases described below highlight a few projects where two repair scheme variations were employed.

3.1 *The Selkirk Trestle*

The Selkirk Trestle is in Victoria BC and provides a link for pedestrians and cyclists between Victoria/ Saanich and Victoria West. The trestle was initially erected c. 1917 for the Canadian Northern Railway which subsequently became the Canadian National (CN) Railway. Use of the trestle for rail service terminated in the early 1980's and it was subsequently threatened by fire in the early 1990's. The structure was re-purposed in 1995 turning the trestle into a multi-use regional trail (part of the Galloping Goose trail system). The BC Ministry of Transportation and Infrastructure (MOTI), acting as the Province's agent, is the legal owner of the structure and the Capital Regional District (CRD) is the manager/operator of the structure.

The trestle is comprised of 61 timber bents, typically spaced at 4.5m and generally constructed with 6 piles each, and a 37m long steel Scherzer Rolling Lift Bridge commonly referred to as "the bascule". The overall structure length is 302 m. Detailed records of historic repairs are not available for the existing structure. It is known that ~1/3 of the piles were replaced in 1957 and it is probable that the remaining piles have also been replaced at some point in the 100+ year history of the structure. The bridge is located NW of Victoria BC, with the coordinates of 48.439343, -123.382491.

The Galloping Goose trail project and other projects that have expanded the Greater Victoria Cycling Network have been very successful, with use exceeding the original expectations of the project. According to Statistic Canada, the Victoria area has the greatest percentage of both walkers and cyclists in Canada, with more than 15% of workers over the age of 15 biking or walking to work daily. The Selkirk Trestle is a vital part of the Greater Victoria bike network. Annual ridership of this portion of the Galloping Goose trail is over 1 million trips per year (CRD - Regional Cyclist and Pedestrian Count Program available at eco-counter.com).

The original Selkirk trestle crossing was constructed to support rail loading which is significantly heavier than the current loading for the structure (multi-use trail with provision to support small maintenance/ emergency vehicle). The additional capacity of the original structure allowed the 1995 retrofit to be completed with no repairs or upgrades to the trestle sub-structure.

Stantec completed a detailed condition assessment of the trestle in 2021 and noted that the time is approaching where a substantial sub-structure upgrade project will be needed to keep the trestle in service. Stantec anticipates up to 60 of the existing 366 piles will need substantial repairs. As part of an eventual repair/ extensive of life project, the CRD is also considering widening the structure to accommodate the future demands of cyclists and pedestrians.

As part of the 2021 condition assessment, Stantec recommended using a fiber reinforced polymer (FRP) repair system for the damaged piles. This system was recommended for the Selkirk trestle primarily because it would allow the structure to remain in use during the repair construction.

The main deterioration method for the timber piles is marine borer attack. Marine borer is a collective term used to describe invertebrates that thrive in brackish water and burrow into and damage wood members. Preservative wood treatment systems such as creosote have traditionally been used to protect wood from this kind of damage. Typical marine borer damage often results from a small split or bolt hole whereby the invertebrates gain entry to the untreated heartwood of a pile. The treated shell of the pile often remains intact, while the invertebrates effectively hollow out the inside of the pile. This damage often goes unnoticed until it has progressed to the point where the shell of the pile starts to fail.

FRP repair was determined to be a good option to deal with this condition, as the marine borer damage is typically localized to the intertidal zone, with sound wood being found above and below the area of marine borer attack. This repair method is not common in British Columbia and Stantec and the CRD determined that it would be beneficial to complete a trial pile repair project to determine the cost and feasibility of this method of repair.

In the fall of 2022 Stantec prepared repair drawings and specification for a trial project which would repair four of the existing timber piles that had been recommended for repair. A local

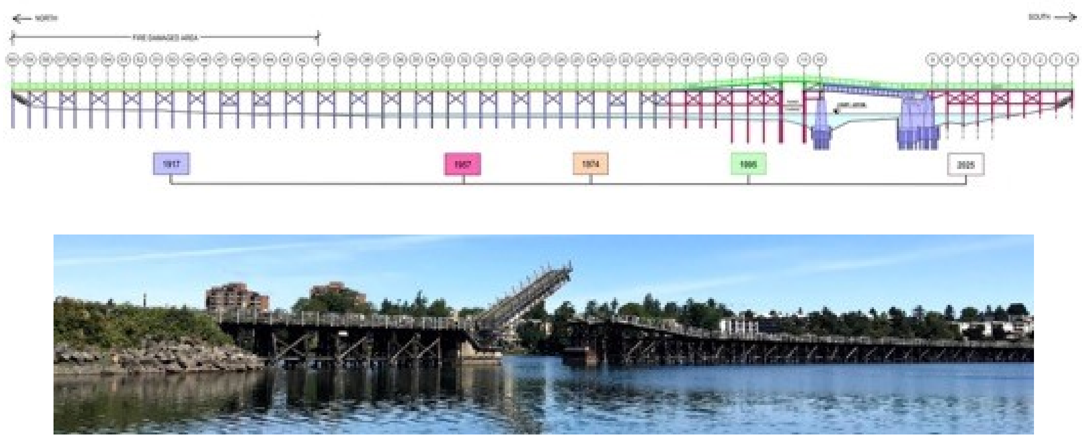

Figure 3. Selkirk Trestle elevation and view from southeast.

Figure 4. Progressive repair steps using the PileMedic® system.

marine contractor, Salish Seas Industrial Services (SSIS), was engaged to complete the repairs. Four 100mm (4 in.) wide carbon laminate strips with tensile strength of 2825 MPa (410 ksi) were placed around the pile in the damaged zone (Figures 2 and 4). PileMedic® laminate was wrapped around the pile and created a seamless shell that was filled with a low viscosity high compressive strength resin. This resin bonds the carbon strip, timber pile and the PileMedic® shell together to resist all imposed loads. The low viscosity resin also flows through all cracks and fills the voids formed by the marine borers, increasing the axial capacity of the pile. The carbon strips and the PileMedic® shell provide significant flexural capacity for the repaired pile.

Stantec provided environmental monitoring and structural review during the installation of the Pile Medic system. The trial project was successful, and we are hoping that a substantial repair/ life extension project can be completed in the near future incorporating the PileMedic® repair system.

3.2 *Railroad bridges in remote sites*

Northern Canada experiences extreme cold temperatures that can make any construction project challenging. Over the last four years, Western Infrastructure Renewal, Inc. has been repairing hundreds of bridge piles using the PileMedic® system described above. Many of these bridges belong to municipalities or are on rural roads and are used to transport people in addition to various freight. This paper will focus on about 135 piles on rail bridges that have been repaired by Western Infrastructure renewal Inc. in 2023.

The rural parts of Canada are served mostly by a number of smaller rail companies that operate within a relatively smaller region. Western Canadian Short Line Railway Association, for example, is an industry association representing 18 short line railways across Alberta, Saskatchewan, and Manitoba and rail supplier partners. Their work supports freight and passenger rail transportation, economic opportunities for rural communities, and rail innovation in Western Canada. This group of short lines are concentrated mostly in southern Saskatchewan and eastern Alberta, with one line running all the way to Hudson Bay in northern Manitoba for access to seaports.

Figure 5. Vicinity map where 135 piles were repaired in 2023.

The 135 piles repaired in 2023 were located on 8 bridges; they were scattered in the circled area shown in Figure 5 throughout northern Manitoba which experiences very cold temperatures and snowfall. The bridges had piles that varied in diameter between 400 to 500mm (16 to 20 in.). The repairs were completed over the period of April through late November 2023.

The repair of all timber piles followed the detail shown in Figure 2, except that there was no carbon strip added along the length of the piles. Many of the piles had rot and damage just above and below the water level elevation, although eight piles required encapsulation for their full height. Once the damaged portion of the piles were wrapped in a two-ply shell created on site with the PileMedic laminates, the annular space was filled with a high strength low viscosity resin.

The remote locations of these projects cause significant challenges in terms of mobilization and demobilization. Most of these sites were not easily accessible by cars. The crew used floats and rafts to access the piles. The railroads provided high rail trucks (Figure 6a) to carry these rafts and lower them in water below the bridges. They would subsequently lift the raft at the end of each project and move it and the other equipment and materials to the next repair site.

Epoxies in general have a temperature range for storage, mixing and application. The system being used here can be applied in temperatures higher than 7 °C (45 °F). In. most cases, the crew can keep the quantity of the resin needed for each shift inside the heated cab of a work truck. But this was not possible for the extreme conditions on these sites. A closed quarter was built on a raft using insulated tarp. A heater on the rail truck continuously provided hot air through a flexible duct to keep the crew and the resin inside the closed quarter warm (Figure 6b). As can be seen on this figure, some of these repairs continued even with snow on the ground.

One of the advantages of the PileMedic system is that the thin laminates can be wrapped around a pile in very tight spaces and small clearances. Figure 6c shows one such case, where there is little space between the pile and the diagonal brace.

(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.

Each laminate covers a length of 1200mm (4 ft) along the pile (Figure 7a). Additional laminates can be installed overlapping the previous one by 100mm (4 in.) to cover the desired height (Figure 7b). Once the required length of the pile is wrapped in the Pile-Medic® shell, the high strength low viscosity resin is mixed and gravity fed into the annular space (Figure 7c). This will fill all the cracks and voids in the pile and it will bond the shell to the pile.

All the epoxies that are a part of this repair system cure underwater. This is of particular significance because it eliminates the need for construction of any coffer dams and dewatering.

On many timber bridges diagonal braces are bolted to the piles. These bolts could be temporarily removed, and a wooden peg of the same size could be placed in the bolt hole. Once the jacket is wrapped, it can be pierced to allow the removal of the wooden peg and installation of the same diagonal brace or a new one using the same bolt hole as highlighted in Figure 8. As the last step, the annular space is filled with low viscosity resin.

In terms of productivity, this repair system can be installed very quickly. A main advantage is the fact that the laminates can be formed into a shell of any shape or size in the field, preventing delays from having the wrong size of jacket onsite. On this project each crew could finish between 2-3 piles a day. Even considering the long travel time from one site to the next and the time to set up, the 135 piles were repaired in about six months.

Prior to these repairs, several of these bridges were being considered for replacement at costs exceeding $10M. The repair system will extend the service life of these bridges for decades with virtually no disruption of service during the repairs. Considering the huge savings realized, the railroads are planning to increase the number of piles being repaired in 2024. They are also considering strengthening some of the deteriorated beams and stringers with wet layup FRP.

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

4 COST

The PileMedic® laminates used on these projects cost around US$120 per square meter. The epoxies used in this system cost roughly US$35/liter. As an example, the cost of a 300mm shell including the epoxy paste that is applied to the second half of the laminate is less than $350/m height of the shell. To minimize the volume of the injection resin, it is best to wrap the laminate tightly around the pile. Some piles may have excessive cracks and cavities in the middle that are not easily detected from the outside, making it difficult to calculate the volume of resin needed to fill those cavities. Assuming 4 liters of resin per meter of the pile, the total cost of the repair

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

system including the shell and the injection resin is about US$500 per meter. As shown in the above applications, the installation of the system is easy and does not require any heavy lifting equipment on site. All these result in an economical and durable solution for repairing such piles.

5 SUMMARY AND CONCLUSIONS

This paper summarizes the application of an innovative solution for strengthening deteriorated timber piles. The focus has been on rail bridges in remote locations where limited access make conventional repairs that require heavy equipment very costly. Repairs of nearly 140 piles in extreme cold conditions have been presented. These field applications demonstrate the versatility of the system that eliminates the need for ordering custom-sized jackets in advance and how this results in time and cost savings. Approximately two piles can be repaired each day, allowing many of these bridges that have been considered for demolition to be returned to service in a short time and at minimal investment. Repairs can be performed while the bridges remain open to traffic. All parties including the owners have been satisfied with the results and plan to expand their repair activities in the coming years.

6 REFERENCES

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