

# Assessment and Evaluation of Timber Piles Used in Nebraska for Retrofit and Rating



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16. Abstract <p>The cost of an effective retrofitting and rehabilitation of timber piles is less than cost of replacing the piles. However, some of the retrofit options used in Nebraska failed to result in the expected performance levels. Further, design and detailing of different retrofit schemes are not well defined. Therefore, the objective of this project was to develop a set of guidelines to retrofit damaged timber piles.</p> <p>Different types of damages, methods of assessment, and repair procedures of the timber piles were reviewed. Few repair methods were selected for detail investigation. Five full scale timber pile specimens with different level of damages were prepared. The damage in each specimen was repaired by using FRP wrap to capsule the damaged region and filling it with either resin or grout or resin and gravel. Guidelines are provided carry out the repair of timber piles in field using the selected repair methods. Ultimate load tests were carried out on the specimens to evaluate the effectiveness of the repair methods.</p> <p>Test results show that grout is more effective in repairing large cavity-type damages compared to resin. Resin might be more effective for repairing cracks and small cavities in timber piles. Further, the failure load of the repaired pile specimens was at least five times greater than the design load capacity of the timber pile.</p>			
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## **Executive Summary**

Timber piles are used in the substructure of many bridges throughout Nebraska with the majority being found on county bridges. These timber piles can deteriorate from different damages over an extended period of time. One obvious option to address the conditions created by damaged timber piles is to replace the piles; however, the cost of an effective rehabilitation of timber piles can be much less than the cost of replacing the piles. Different repair and rehabilitation options are available for the timber piles and some of the retrofit options used in Nebraska failed to result in the expected performance levels. Further, design and detailing of other retrofit schemes are not well defined.

Therefore, the main objective of this project was to develop a set of guidelines to retrofit damaged timber piles. This objective was achieved by reviewing the available retrofit options through a state DOT survey, selecting a few repair options for detailed investigation, and conducting experimental work to evaluate the effectiveness of the repair methods.

Different types of damages, methods of assessment, and repair procedures of the timber piles are reviewed. Select repair methods were investigated in this study. These repair methods use FRP wrap to capsule the damaged region of the pile, which is then filled with resin, grout, or resin and aggregate. Ultimate load tests were carried out on five full scale timber pile specimens with different levels of damage and repaired using different methods to evaluate the effectiveness of the repair methods.

Test results show that grout is more effective in repairing large cavity-type damages compared to resin. However, resin may be more effective for repairing cracks and small cavities. Further, test results indicate that the failure load of a repaired pile specimen was at least five times greater than the design load capacity of the pile.

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## Chapter 1 Introduction

Many timber piles used in the substructure of bridges throughout Nebraska have different types and extent of damage. The damaged area is typically located immediately beneath ground level or in the splash zone, which is defined as a boundary between the top surface of the water and the air. Below the water level there is water, but not enough oxygen. Above water level, there is oxygen, but not enough water. In the splash zone, partly due to changes in water levels, the sub-structure elements are subject to both water and oxygen, the two elements needed to cause deterioration. Figure 1.1 show some typical damages observed in Timber piles in Nebraska.



**Figure 1.1: Examples of observed damages in Timber Piles in Nebraska**

When only one timber pile is damaged, use of any retrofit technique may prove to be sufficient. However, problems arise when several timber piles in a given pier experience damage. In these situations a reliable engineering approach needs to be exercised. Further, field observations indicate that when one pile shows signs of damage it will only be a short time before the same level of damages are observed on other timber piles of the same pier.

In the past, the routine option to address the conditions create by damaged timber pile was complete replacement of the pile. The cost of an effective rehabilitation of a timber pile is less than cost of replacing the pile. Some of the past retrofit options used in Nebraska have failed to result in the expected performance levels. Further, design and detailing of other retrofit schemes are not well defined, mainly because of lack of test or research data. The retrofits options currently use in Nebraska are mainly developed based on engineering judgments. In some cases these alternatives have not achieved their expected performance levels.

There is no a comprehensive research on timber pile with eccentric compression load available. A study by [1] shows current rating method is not conservative while it only take account concentric compressive load, and the results could lead to an overestimate capacity while the pile strength was significantly reduced under eccentric load compared to concentric load. The current code provisions take into account only concentric compressive force on timber pile. This assumption that timber piles carrying out pure eccentric compressive load is not valid for simply supported super structure spans because if one span collapse the reaction of two other spans will lead to eccentric compressive load, increase the moment and decrease the capacity of timber pile. According to the current code, it was assumed that due to rigidity of concrete deck, timber pile is only under compressive load and no eccentricity is considered for compressive applied load. The Army and Navy considered the interaction of compression force and bending moment on wood elements in 1924. After that an interaction based on axial and bending stress equation was developed, that lead to accurate results for short, intermediate and long beam columns. Zahn tested Western Hemlock specimens 2in by 6in nominal size for a combination of different axial and bending load. In order to calibrate the results for a longer specimens, over 400 extra specimen 18in length tested. Most experimental available results are related to small sawn lumber and there is limited test results for timber pile with circular section. Totally, this report focused on test retrofitting of 6 timber piles along different materials for repair at the ultimate load level.

This report focused on repairing of bridge timber piles at the damaged section, and different materials take into account the effect of interaction of axial force and bending moment, resulting from the eccentricity of applied axial load. In this research a simple and reliable retrofit technique was developed by using resin, grout and combined resin and gravel to increase compression axial capacity of current timber piles in old bridges. In this research an experimental work conducted to explore the effect of retrofitting and loading eccentricity on the capacity of timber piles. Timber piles are not required to be designed for combined compression and flexure loading by current AASHTO design provisions although eccentricities are typically assigned to unsymmetrical loading of simply supported spans. Six pile specimens were considered for experimental testing. These specimens were tested under combined of compression and a small axial load eccentricity.

## **1.1 Objectives**

The main objective of this project is to develop a set of guidelines to retrofit damaged timber piles. Specific objectives of the project are as follows:

- Conduct survey to establish the current state of practice as related to retrofitting damaged timber piles in bridges.
- Review the available retrofit options and, in consultation with NDOR bridge engineers, select a few techniques worthy of considerations.
- Construct full scale test specimens and repair them with selected repair methods and describe different steps involved in the repair procedure.
- Conduct the ultimate load tests on the timber pile specimen and evaluate the effectiveness of the selected repair procedures.
- Summarize the results and comment about the effectiveness of the repair method.

## **1.2 Organization of the report**

This report is divided in five main chapters.

Chapter 2 describes different types of damages and methods to carry out inspection of the timber piles. The types of damages are divided into two main categories that are biological damages and physical damages. The type and extent of damages in timber piles can be evaluated by using different methods of assessment. A brief description of each method of assessment is provided in this chapter.

Chapter 3 states different repair and protection procedures that are generally used for the timber piles. The protection of timber pile is normally carried out by treating the wood with preservative. There is a wide variety of repair methods that have been used or investigated in literature. This chapter provides a brief summary of some of the repair methods.

Chapter 4 presents the details of the repair methods investigated as a part of this research project. Three repair methods were investigated. The repair procedure described in section 4.1 provides the general guidelines for implementing these repair procedures in the field. Jacketing and injection are the two main steps that are required for repairing the pile using the repair methods described in this chapter.

Chapter 5 describes the load tests carried out on full scale timber pile specimens with different levels of damages repaired by different repairing methods. Five full scale timber pile test specimen were tested evaluate the effectiveness of repair method. The specimens were subjected to both axial and lateral loads. Test results indicate that repaired pile specimens were able to carry at least five times of the design load capacity used in structural design of timber pile bridges.

## **Chapter 2       Damages and condition assessment**

It is difficult to estimate the remaining capacity of a damaged timber pile and the safety of the bridge containing a deteriorated timber pile foundation. However, it is important to detect the type and extent of damages in the piles so that appropriate repair can be carried out. A timely repair is essential in extending the life of the bridge using timber pile foundations. Repair methods often depend on the type and extent of damages. Different condition assessment techniques that can be used to assess the type and extent of damages in timber are described in this chapter.

### **2.1 Types of damages**

Damages in timber piles used as foundations of bridges can be categorized into biological damages and physical damages. Biological damages are generally caused by different organism and result in decay of the wood in piles. Physical damages are caused by different factors resulting in deterioration of the piles. Following section discuss the biological and physical damage in more detail.

#### **2.1.1 Biological damage**

Biological damage is caused by different organisms causing the wood to decay. Rate of biological damage depend on the environmental conditions and type of the organism. Following are the most common organism causing biological damage in timber piles:

- Fungi
- Termites
- Powderpost beetle
- Carpenter ants
- Bacteria and mold

Fungi are reported as the most destructive organism for timber pile used in bridges [2]. Rate of damage caused by fungi depends on the environmental conditions. Most of the fungi grow rapidly in warm and moist conditions. Termites are well known for causing damage to wood. The damage cause by termite is much more rapid compared to damage caused by fungi. Powderpost beetles, carpenter ants, bacteria and mold can also cause significant damage to wood depending on the prevailing conditions. Generally, cold and dry conditions restrain the biological damage.

### 2.1.2 Physical damage

Physical damages are caused by different factors and cause the deterioration of exterior treated wood cover. Damage of exterior protective cover provides biological mechanism access to interior untreated wood resulting in decay of the interior wood. Different types of physical damages are shown in Figure 2.1. The most common type of physical damage is caused by impact of objects floating in water. Physical damage is also caused by overloading due to heavy loads, failure of adjacent piles, and over-tightening of the fasteners. Fire can destroy and cause failure of timber pile bridges in a matter of hours. Partially burned timber pile can carry load depending on the remaining unburned cross section of the pile.



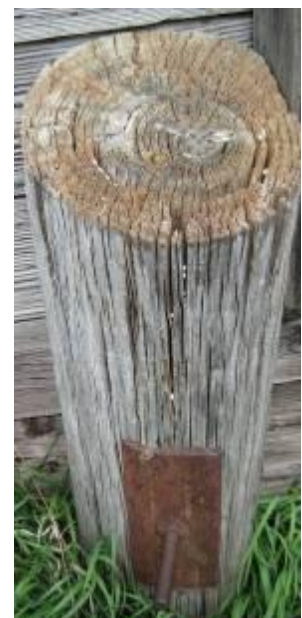
(a) Mechanical Damage



(b) Debris Damage



(c) Fire Damage



(d) Weathering/UV Damage

**Figure 2.1 Breaks in preservative barriers by exterior damage leads to premature decay [2]**

## 2.2 Methods of assessment

Different methods of inspecting the timber piles are discussed in detailed in a report by Iowa State [3]. A brief summary of each method followed by advantages and disadvantages is discussed in the following sections.

### 2.2.1 Visual inspection

Visual inspection involves going to the site and inspecting the piles visually. Color changes, presence of bleach, staining, corroded fasteners, splits, cracks, checks, crumbling and collapsed wood can be noticed visually. Different advantages and disadvantages are listed in the Table 2.1.

**Table 2.1: Summary of advantages and disadvantages of visual inspection**

Advantages	Disadvantages
<ul style="list-style-type: none"><li>• Quick inexpensive method that is readily applicable</li><li>• Checks, decay at fasteners, end grain decay, splitting, staining, surface decay, ultraviolet degradation can be inspected [2]</li></ul>	<ul style="list-style-type: none"><li>• Qualitative assessment of the piles can be done</li><li>• Small pockets of decay are difficult to catch</li><li>• No information regarding depth of decay can be obtained</li></ul>

### 2.2.2 Probing and pick test

Probing can be done by moving a sharp pointed tool such as awl on the wood surface of the timber piles. Generally the wood in good health is dense and difficult to penetrate with the pointed tool compared to decayed wood.

In pick test a pointed tool is inserted in the pile and then moved sideward to pick a small piece of wood out the pile. The sound and pattern of separation of the small piece picked from the wood pile gives an indication of the condition of the wood pile. Wood in good condition breaks off to one side of the pick away from the tool with a sharp sound. Decayed wood generally breaks above the pick's point with a dull sound.

**Table 2.2: Summary of advantages and disadvantages of probing and pick test**

Advantages	Disadvantages
<ul style="list-style-type: none"><li>• Quick inexpensive method that is readily applicable</li><li>• Probing test can locate pockets of decay near surface of wood [2]</li><li>• Pick test subjectively differential between the sound and decayed wood [2]</li></ul>	<ul style="list-style-type: none"><li>• Require some experience to reliably interpret the results [2]</li></ul>



### 2.2.3 Moisture measurement

Excessive moisture in timber pile indicates the possibility decay. Moisture in timber pile can be measure using a moisture meter that measures the electrical resistance between two points of the timber pile. This electrical resistance is converted to equivalent moisture content using calibration charts built into the moisture meter. A moisture greater than 20 percent indicates that decay is most likely to start and a thorough inspection of the pile is required.



**Figure 2.2 Electronic moisture meters for timber**

### 2.2.4 Sounding

In this technique a hammer is hit on the surface of timber pile to assess the quality of wood in the pile. Hitting hammer on different quality woods results in different sounds. An experienced person can differentiate between sounds from hollow wood and healthy wood. Since this technique largely depends on the judgment of inspector, it is generally used with other assessment techniques.



### **2.2.5 Mechanical wave tests**

In this technique, defects in the timber pile are detected based on the speed of the mechanical wave traveling through the pile. Speed of mechanical or stress wave in defected wood is slower compared to speed of the waves in healthy wood. Signal reliability, access to complete surface, magnitude of damage, and lack of differentiation between different defects are some of the challenges with this inspection method. More details about this method can be found in literature [4] [5] [6].

### **2.2.6 Drill resistance tests**

Healthy wood has more density and provide more resistance to drilling compared to decayed or defective wood. Drill resistance devices can measure the resistance of the wood to drilling indicated the quality of the wood. This method can be used with other inspection techniques.

### **2.2.7 Preservative retention analysis**

Preservative retention analysis is used for assessing the capability of the wood to retain different preservatives used for protecting the wood. Following are the different types of preservatives used for protecting the wood:

- Creosote
- Pentachlorophenol
- Copper Naphthenate
- Chromated Copper Arsenate (CCA)
- Acid Copper Chromate (ACC)
- Ammoniacal Copper Zinc Arsenate (ACZA)

The procedure to carry out preservative retention analysis for each preservative is different and is specified by American Wood Protection Association (AWPA) standards.

Creosote retention analysis can be carried out according to AWPA A6-09 that specifies the method for the determination of oil-type preservatives and water in wood.

Copper Naphthenate and Pentachlorophenol analysis can be carried out according to AWPA A5-05 that specifies the standard methods for analysis of oil-borne preservatives.

Metallic Elemental Analysis is used to determine the quantities of different metals in wood treated with CCA, ACC and ACZA. AWPA A21-00 and AWPA A9-01 can be used to carry out the analysis.

## **Chapter 3      Repair and protection**

### **3.1 Methods for Protection of Timber Piles**

Marine borers are the main cause of damage to timber piles. Preservative treatments can be used to protect the piles in marine environments. These preservatives prolong the service life of piles for many years. However, environmental issues regarding the use of these preservatives have restricted their use by far.

Creosote, one of the most common and effective preservatives used for the protection of timber piles has effectively been banned in marine environments. Another preservative is Chromate Copper Arsenate (CCA) which contains heavy metals and can be hazardous to human health. As a result the federal government has restricted its use in residential applications. Even some states have banned it for noncommercial applications entirely. Following is the list of other preservatives as described in section 2.2.7.

- Creosote
- Pentachlorophenol
- Copper Naphthenate
- Acid Copper Chromate (ACC)
- Ammoniacal Copper Zinc Arsenate (ACZA)

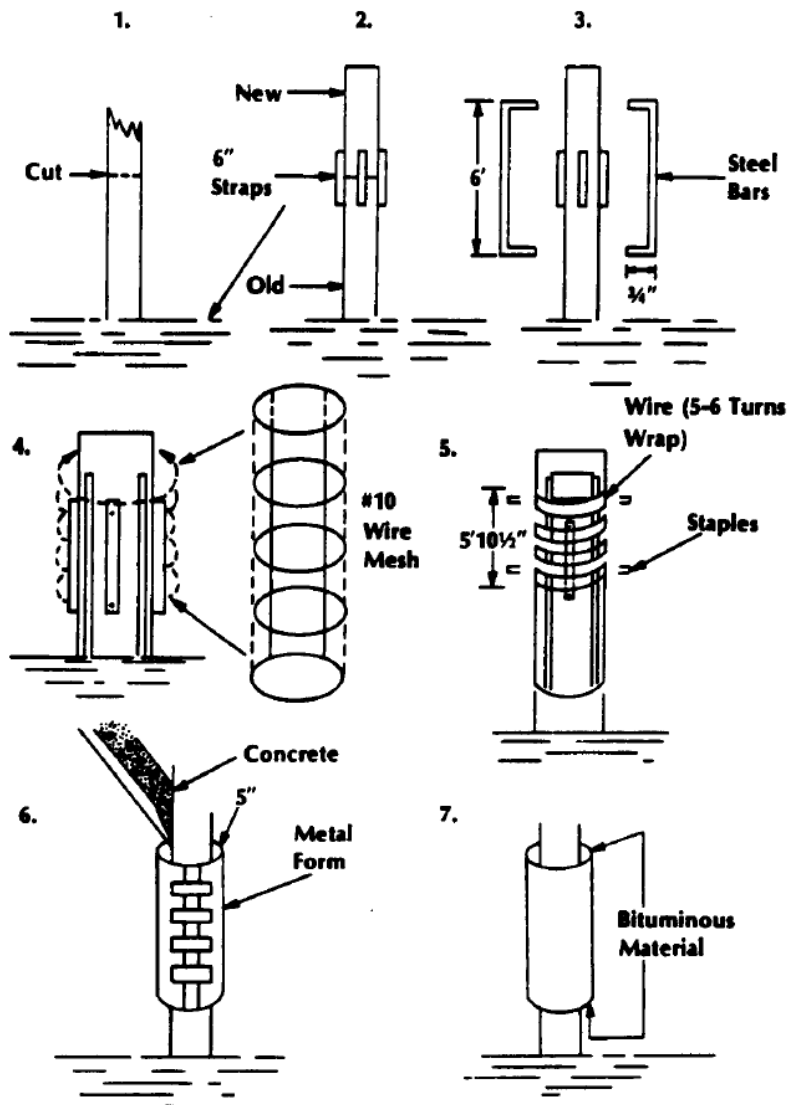
### **3.2 Method for Restoring Timber Piles**

Several parameters affect the selection of a repair method, including the strength and durability of the repaired pile, access to the damaged pile, and disruption of structure functions due to repair activities. In remote locations the main parameters are availability of craftsmen, material and equipment. Although repair cost overrides the selection of an appropriate method in many cases, strength and durability of the repaired pile is also an important factor.

#### **3.2.1 Splicing**

This method involves the addition of new material and connectors, such as attaching a new section of timber pile, bolting or splicing of steel, or adding steel or timber bracing. Figure 3.1 shows the steps in this repair method. If long unsupported timber piles are being spliced, the flexural capacity of the new section is usually less than the original pile. In this case, a reinforced concrete encasement can be used

as shown in Figure 3.1. However there are concerns about the complexity of the technique, the amount of required material, and the durability of the repair.

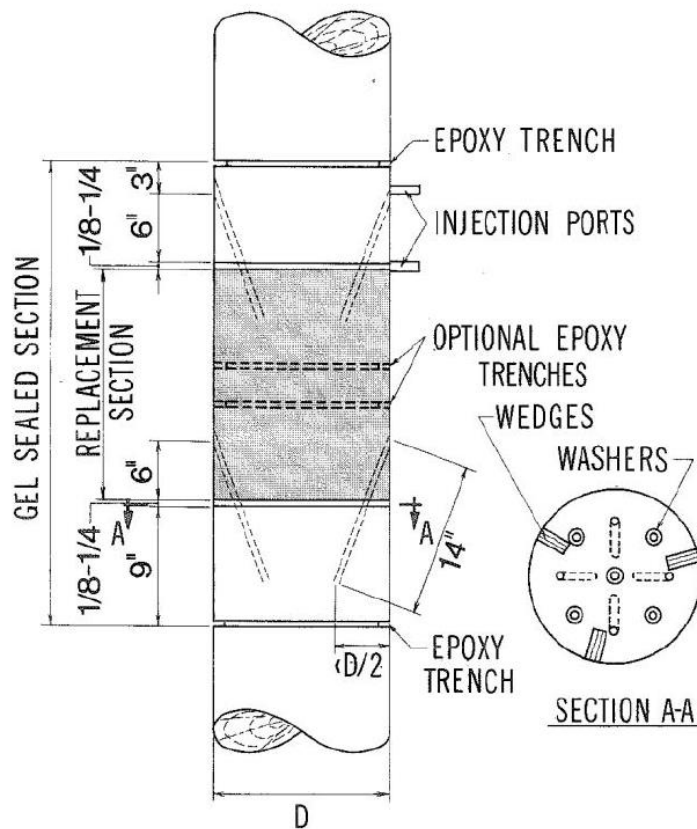


**Figure 3.1 Timber pile repair scheme by splicing using reinforced concrete after US Army FM 5-134 (1985)**

### 3.2.2 Cutting and Posting

This method is similar to pile splicing and involves cutting and replacing the damaged section of pile. The damaged portion of the pile is cut perpendicular to the piles longitudinal axis. The pile is supported on a jack and a new section with the same diameter is placed in the cut zone. The new section is spiked

or bolted to the existing portion and a relatively weak connection is formed. Then a low viscosity epoxy is injected through a predrilled port connecting the new piece to the existing pile (Figure 3.2).



**Figure 3.2 Cutting and posting of damaged timber piles [7]**

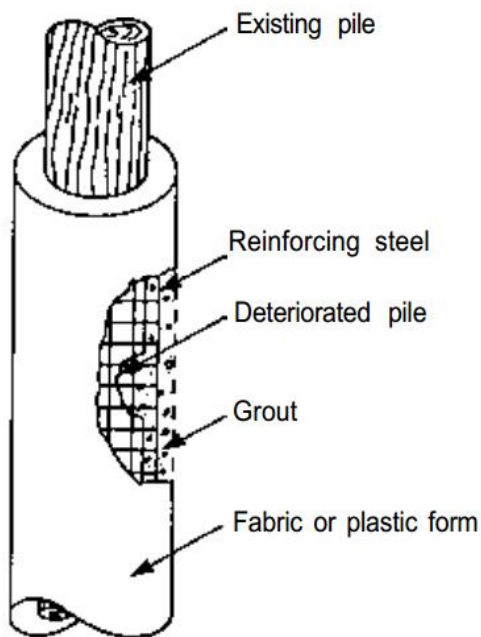
Effectiveness of this method is evaluated both experimentally and in a field application [7]. It is reported that the repair method can restore the axial strength of timber piles to their original value [7]. However, the flexural strength can be restored to only about half of the original capacity [7].

### 3.2.3 Grout Injection

Railway Track & Structures published a periodical [8] exploring a repair method that involved the injection of cementitious grout in decayed timber piles. The existing timber is first treated to prevent further decay, followed by drilling various holes and pumping the grout into the drilled holes. Based on the Railway Track and Structures, this method can increase the service life of the piles about 15-20 years. If the damage is not very severe, epoxy can be injected instead.

### 3.2.4 Concrete Jackets

In this method, reinforcement is first placed in the annular space between the deteriorated timber pile and the formwork, followed by concrete injection. These concrete jackets can also be formed using a 25-50 mm thick coating of shotcrete reinforced with a wire mesh. Precast concrete jackets have also been used. Figure 3.3 shows different of a deteriorated timber pile repaired by using reinforce concrete jacket.



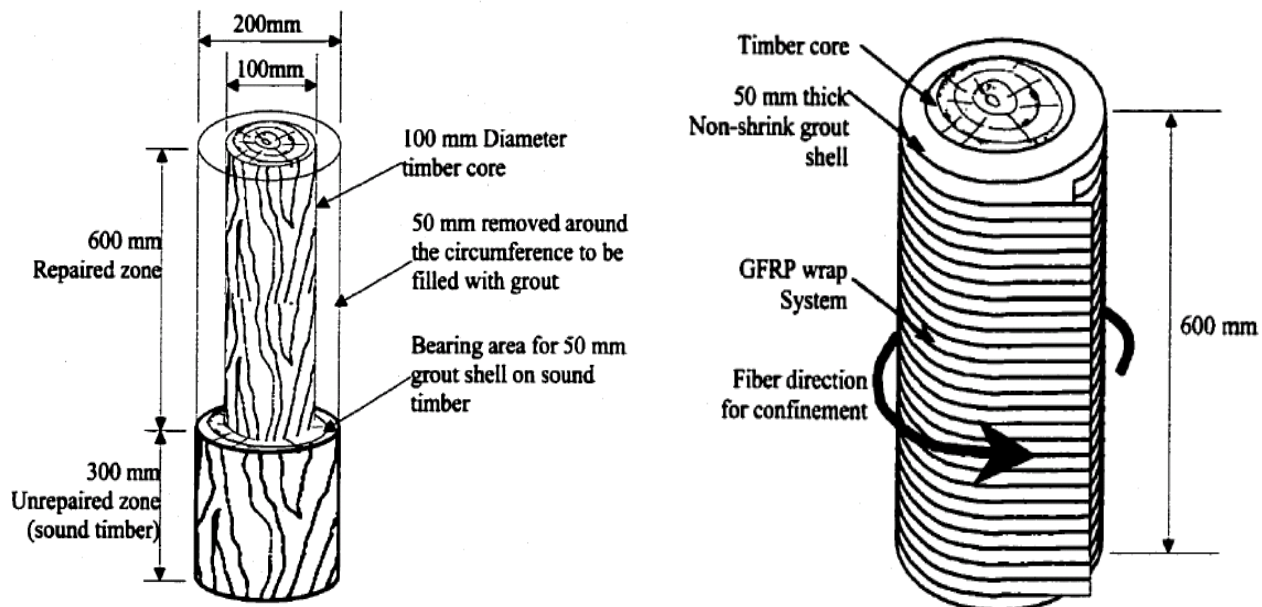
**Figure 3.3 Reinforced concrete jacketed timber pile [7]**

There is a concern regarding the durability of reinforced concrete jackets, since concrete is prone to deterioration from environmental effects such as acids, alkalies, or salt in ground water. Freeze and thaw can also cause cracking and spalling, which may lead to exposure and corrosion of reinforcing steel as well as cross section loss.

### 3.2.5 FRP Wraps

Typically fiber-Reinforced Polymers are composite materials. FRP material consists of a matrix and reinforcement. In FRP, carbon fiber is reinforcement, which provides the strength. Usually a polymer resin, such as epoxy plays as matrix, to bind the reinforcements together. In FRP property of materials depend on these two distinct elements. The strength and rigidity of FRP comes from reinforcement. These properties depend on the layouts of the carbon fiber and the proportion of the carbon fibers relative to the polymer. Another advantage of FRP is protecting the host timber pile and grout or resin

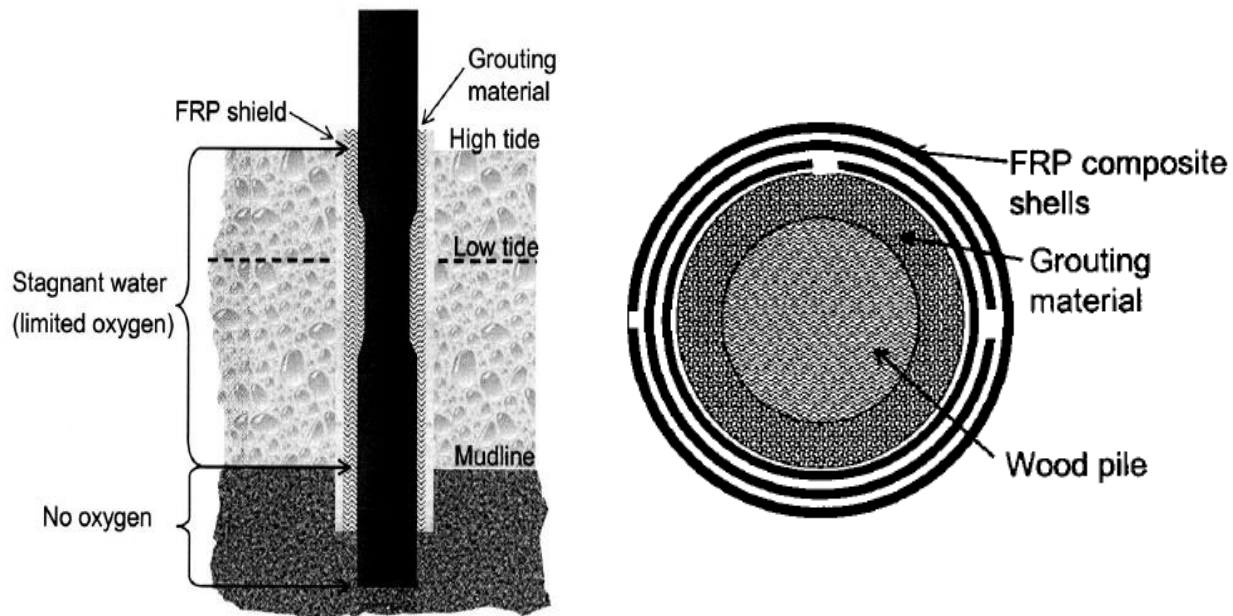
against future deterioration. Fibers and resin could make a composite material by blending with different manufacturing processes.



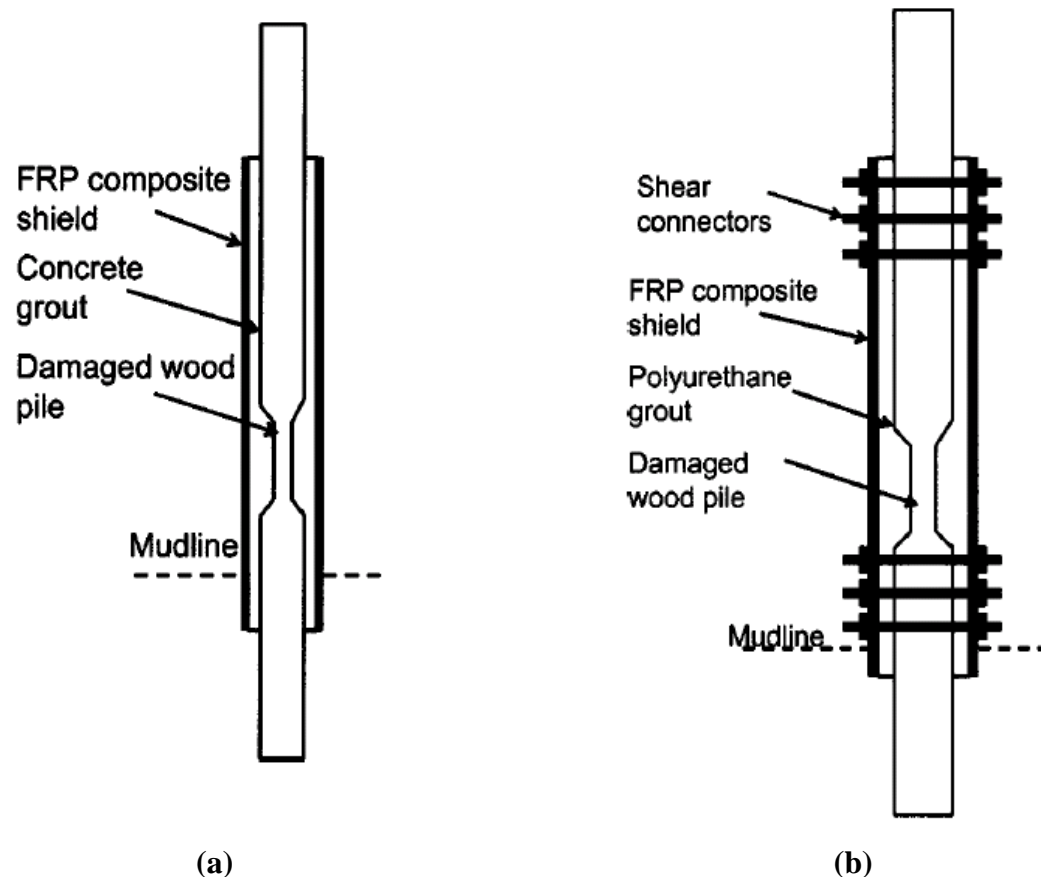
A similar method for repair of decayed timber piles was proposed in 2004 by Emerson [10] that involves three steps. First the decayed portion of the pile is removed and the remaining portion of the pile is treated to prevent further decay. Then, the removed portion is replaced with aggregate and epoxy to provide compression capacity. Finally, the pile is transversely wrapped in fiberglass to confine the repaired portion. In this study, some specimen were built and evaluated in the lab by compression

testing. It was concluded that providing transverse fiberglass reinforcement can improve and restore the axial strength of the repaired portion.

Earlier research [11] proposed a repair method for timber piles which utilizes bonded FRP composite shells that encapsulates and splices the deteriorated portion of the pile. These shells are fabricated in a quality-controlled composites manufacturing facility and have a slit or opening along their length which enables them to be opened and placed around the deteriorated pile. In this method the space between the timber pile and the FRP composite shield is filled with a grouting material that does not provide a structural bond with the wood pile, but provides interlocking between the other two components. Lopez-Anido (2005) [11] argued that their repair method has a dual function of marine borer protection and structural restoration. The repair methods used by Lopez-Anido are illustrated in Figure 3.5 and Figure 3.6.



**Figure 3.5 Repair method using FRP composite shells [11]**



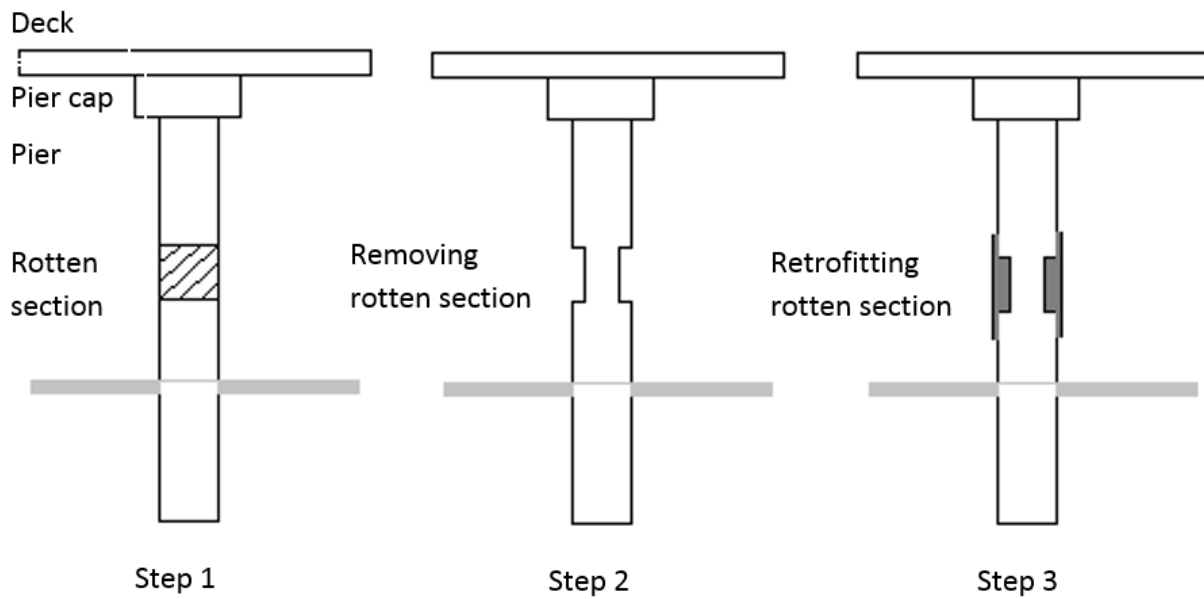
**Figure 3.6 FRP composite repair system with (a)cement-based grout (b)shear connectors and polyurethane grout [11]**

There are three main steps to repair timber piles using FRP wraps as follows:

- Evaluation of timber pile and finding the rotten section
- Removing rotten section

Figure 3.7 schematically shows the sequence of the retrofit procedure. The first step is finding the location and depth of damaged part on timber pile. The next is removing damaged part from timber pile, and the last step is covering the removed part by FRP shell and filling out the empty inside space by some desired resistance material through a hand lay-up process.





**Figure 3.7 Sequence of the proposed retrofit procedure**

The surface of repaired part cleaned and roughened. Then the FRP laminate wrapped around the repaired zone and compacted to ensure adhesion and saturation. The laminate wrapped two times around the timber pile and resin applied to make around the laminate seamless. At least three people were needed to wrap each specimen. A hole can be drilled in the surface of wrap to have access to damaged part and a syringe can be used to inject the grout inside of the empty region. During making the grout, the separate materials are mixed mechanically with a low speed drill. Grout is poured into wrapped empty region through a hose at injection void. The grout poured freely and all voids and edges filled completely. During the injection of grout, all the fibers of timber pile saturated by grout and all air bubbles removed from the composite and vibration was done by tapping the wrapped part at the repair zone. Repaired regions are covered by plastic wrapping to keep the FRP laminate fix at the place and bubbles pushed out from under the plastic wrap manually.

## **Chapter 4      Repair methods investigated**

This chapter describes the repair methods investigated as a part of this study. Following are different repair methods investigated:

- FRP wrap filled with resin
- FRP wrap filled with resin and aggregates
- FRP wrap filled with grout

All of these repair methods use a FRP sheet that wraps around the damage region. The difference in these methods comes from the filler material that is used to fill the damaged region after wrapping it with FRP sheet. The first method uses an epoxy resin as a filler material that is relatively expensive compared to aggregate and grout. If the size of the damage region is large, filling it with resin is not an economical option. Therefore, the second method uses aggregate to fill most of the space in the damaged region and the remaining space is filled out by resin, which also serves as a binder for aggregates. The third method uses grout as filler material in order to reduce the cost of repair. There are some differences in the repair procedure depending on the filler material used in the repair. Section 4.1 describes the details of the repair procedure for the different repair methods listed above.

### **4.1 Repair procedure**

The procedure described here was used to repair the pile for laboratory testing, however, with minor modifications the same procedure can be used to repair the real bridge piles. There are two main steps used in repair of timber piles as follows

- Jacketing the damage area with FRP wrap
- Injection of damaged area with resin or grout

Details of each step are provided in the following sections

#### **4.1.1 Jacketing**

For jacketing material, Glass-Fibre-Reinforced Polymer (GFRP) sheets with two way reinforcement were used. Detailed description of the GFRP material is given in appendix B. The size of the GFRP sheet used for jacketing depends on the size of pile and length of the damage to be repaired. Figure 4.1 provides some guidelines regarding size of the GFRP wrap. Length of the GFRP sheet the dimension that goes around the pile along the pile perimeter and can be estimated by the following formula

$$L = 2\pi D + 8$$

Where,

$D$  = Diameter of the pile in inches

$L$  = Length of GFRP sheet in inches

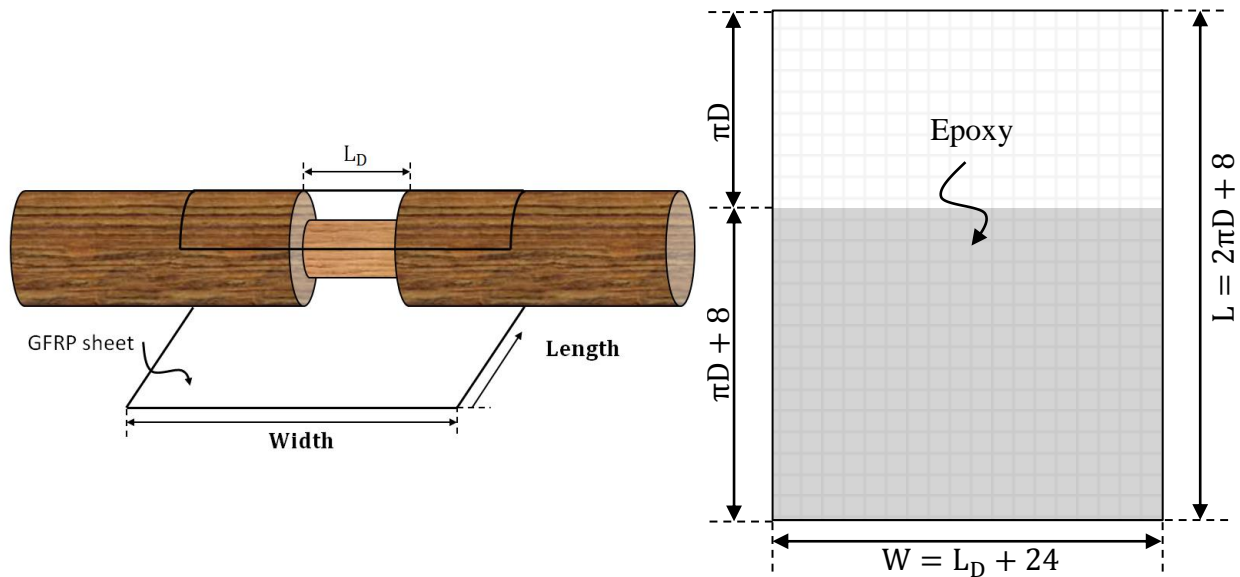
The width of GFRP sheet is the dimension that goes along the length of the damage in the timber pile and can be estimated by the following formula

$$W = L_D + 24$$

Where,

$L_D$  = Length of damage in the pile in inches

$W$  = Width of GFRP sheet in inches



**Figure 4.1: Guidelines for GFRP sheet sizing for jacketing**

Once a piece of GFRP sheet is obtained in proper dimension, it is cleaned and its surface is made rough by a 3M sand sponge. After that, the GFRP sheet is coated with a layer of epoxy in order to affix it to

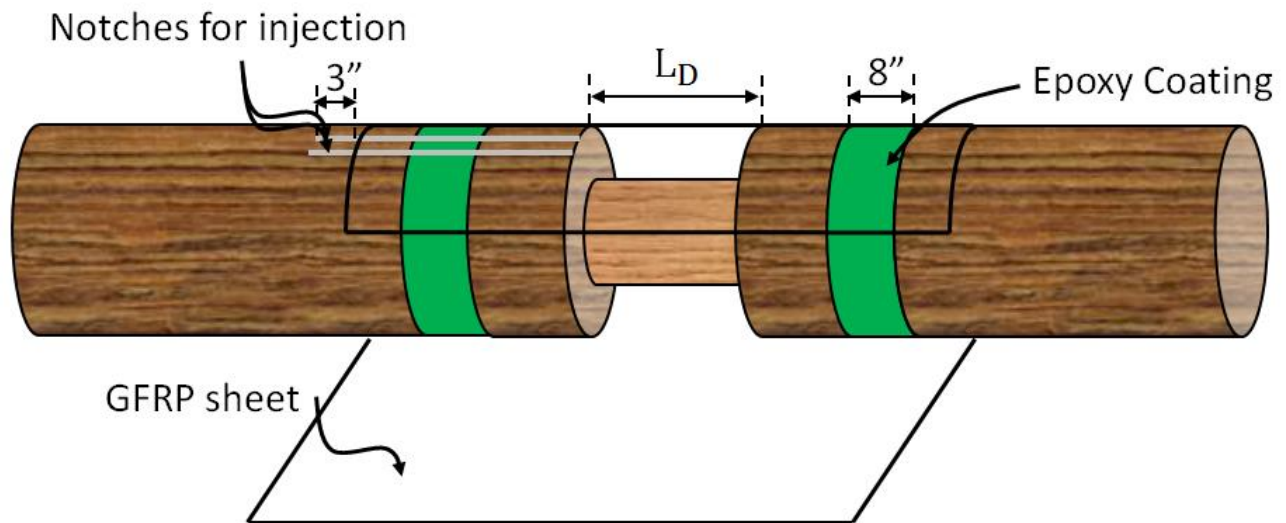
the pile. Figure 4.1 provides a guideline regarding the length of GFRP sheet to be coated with epoxy (detailed description of the epoxy material is given in appendix B).



**Figure 4.2: Surface roughening and application of epoxy to GFRP sheet**

Notches are cut in the timber piles with a chain saw to pass the grouting pipe to the damaged region of the pile. Notches should be long enough to have one end at the damaged region and other end about 3 inches outside the jacketing as shown in Figure 4.3. An approximately 8 inch wide band of epoxy coating is applied around the perimeter of the pile to establish the bond between GFRP sheet and pile. Notches can be clogged with the epoxy therefore care should be taken to avoid filling the notches with epoxy while applying epoxy coat around the perimeter of the pile.

The access to the damaged region of a timber pile can also be obtained by drilling small holes in the FRP jacket. These holes give an easy access to the damaged area for filling it with different materials. Since the size of these holes is small, it is expected that the effectiveness of repair is not reduced due to these holes. This is further confirmed by testing results of the specimens with small holes in the jacket. The result showed that these small holes in the jacket do not reduce the effectiveness of the repair method and the pile specimens failed outside the repaired area.



**Figure 4.3: Preparing pile for GFRP sheet**

In order to stretch and tighten the GFRP sheet around the timber pile, one end of the sheet may be nailed to the pile as shown in Figure 4.4. These nails might not be required for the real piles that are vertical; however, can be helpful in holding the GFRP sheet in place even in case of vertical piles.

The epoxy is difficult to remove if hardened on skin. In order to avoid skin contact with epoxy, it is recommended to wear disposable sleeves and gloves during application of epoxy and wrapping of the GFRP sheet.





**Figure 4.4: Wrapping GFRP sheet around the pile**

Once GFRP sheet is wrapped around the pile, plastic wrap can be used to hold the sheet into place as shown in Figure 4.5. Complete curing of epoxy takes 24 to 72 hours. There are different stages of curing of epoxy that can be checked by followings:

- Stage 1 in which a finger print can be imprinted on layer of epoxy
- Stage 2 in which a finger nail can be imprinted on the layer of epoxy
- Stage 3 in which epoxy is fully hardened and no impression can be made with hand

Once epoxy is fully hardened the jacketing is complete and next step of repair that is injection can be started. The injection procedure for different materials is described in the following section.



**Figure 4.5: Holding GFRP sheet around the pile by Saran<sup>TM</sup> plastic wrap**

Jacketing procedure is same for different repair methods. However, for repairing the timber pile using aggregate and resin there is one extra step that is carried out before the jacketing operation. In this step, wire mesh is wrapped around the damaged region. Nails can be used to keep the mesh in place as shown in Figure 4.6. Once the mesh is wrapped around the damaged region, an access is cut in the wire to insert aggregates. An attempt was made to fill the damaged region with as much aggregates as possible in order to reduce the quantity of resin required to fill the remaining space. The jacketing operation is carried out, as described above, after filling the damaged region with aggregates.



**Figure 4.6: Wire mesh for holding aggregate in damage region**

#### **4.1.2 Injection**

Different options can be used for injection of resin or grout into the damaged area after completion of jacketing. Some of these options are described in the following section.

**Pressure Pot** is one option that can be used to inject pre-mixed resin into the damage area after the completion of the GFRP jacketing and is the simplest means of dispensing a liquid resin into a cavity [12]. The pre-mixed resin is stored in the pressure pot and air pressure is applied to displace the resin from the pot and inject it into the damaged area.

The appropriate amounts of resin and hardening agent are measured and mixed in a bucket. Resin to hardening agent ratio of 2:1 by volume was used in the pile repair described here. Injection of resin was done in successions of injecting 48 ounce of the pre-mixed resin. Due to the rapid set nature of the epoxy, some of the pre-mixed resin might get hardened in the pressure pot and pressure pot needs to be cleaned after every 2 or 3 succession of injection.



A pressure of 30 psi was input into the pressure pot by an external air tank. Resin is generally a low viscosity material and seeps into the cracks under low pressure. Since the piles were horizontal in this experimental set-up, one end of the pile is made higher than the other end so that air bubbles can move up out of the damaged cavity. In a real situation, the pile would be vertical and bubbles can easily move up and find their way out of the jacketing.

It is important to know that resin has high heat of hydration and if a large cavity is filled with resin in a single step, temperature due to heat of hydration can be as high as 221°F. If the ambient environment is hot and dry the heat of hydration of resin may damage GFRP material used for jacketing. Generally real timber piles are close to water surface and that water can be used to dissipate the heat of hydration from the resin. Another way of curbing the heat of hydration from the resin is to inject the resin in successions.



**Figure 4.7: Injection of pre-mixed resin using a pressure pot**

*Pneumatic pumps* with mixing tips are generally used to inject the resin in repairing the timber piles under bridges. The main advantage of using pneumatic pumps over the pressure pots is that they do not require a pre-mixed resin to inject. Mixing of resin with hardening agent is done during injection process if pneumatic pumps are used.

A *plastic hose with piston* can be used to inject grout because grout is thicker than resin and may not pass through small openings of injection pot. In order to fill the damaged region with grout, a hole was drilled in the surface of wrap to have access to damaged region. A hose with nozzle was used for



injecting the grout inside of the empty region. During the injection of grout, all the fibers of timber pile saturated by grout and all air bubbles removed from the composite and vibration was done by tapping the FRP jacket.

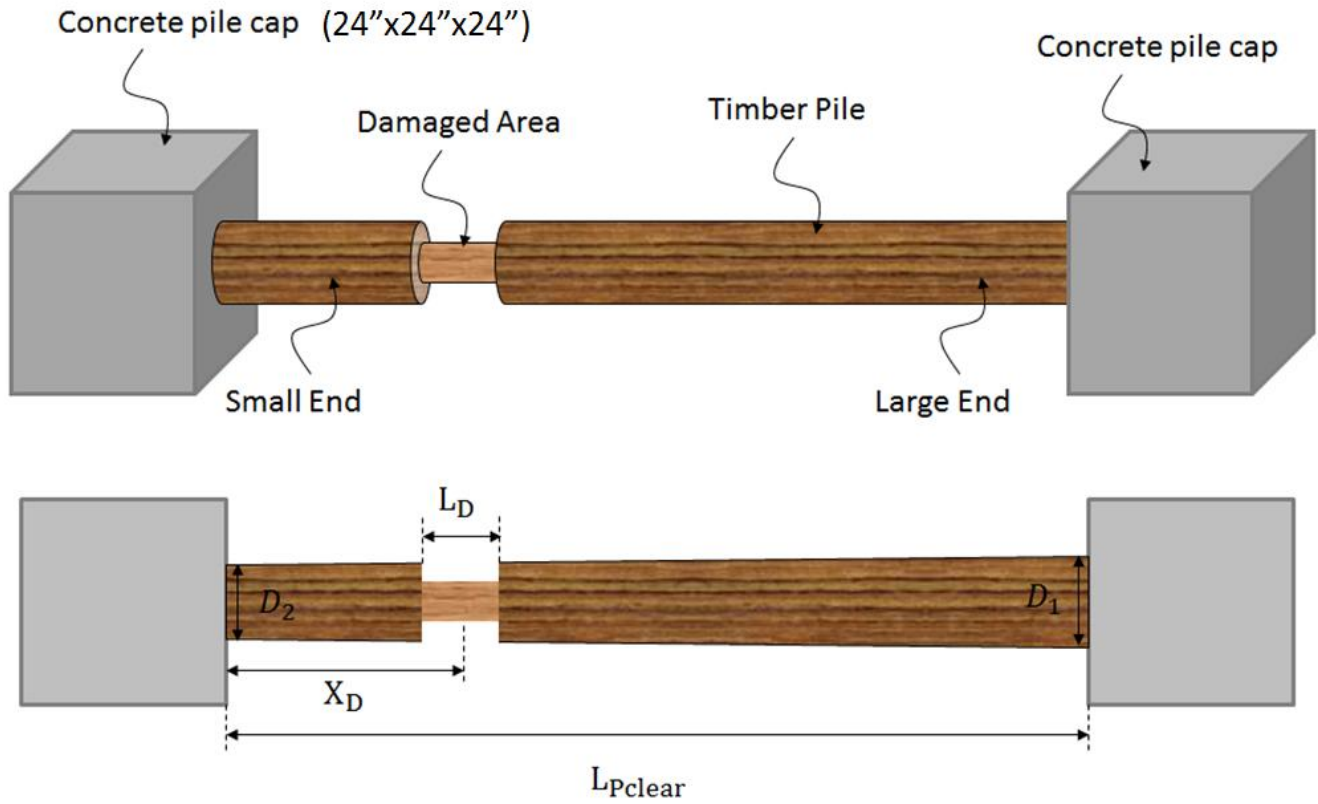
## Chapter 5      Testing

### 5.1 Test Specimens

Full scale SYP timber piles were obtained for the test specimens. Five full scale test specimens were prepared and tested. Each test specimen has a small end and a large end. A concrete cap (26"x26"x26") was cast at each end as shown in the Figure 5.2. The length of the pile embedded in the concrete pile cap is 22 inch. Each specimen has a damaged area that is offset at a distance,  $X_D$  from the face of concrete pile cap on small end, which varies between specimens.



**Figure 5.1: Full Scale timber pile test specimens**



**Figure 5.2: Description of test specimens**

Different details of the timber pile test specimens are provided in Table 5.1. The five test specimens have different levels and location of damages, and are repaired by different method as shown in Table 5.1. Three different damage levels were used in the test specimens. Specimen 2 and 3 have 1.0 inch and 1.5 inch deep damage respectively and specimen 4 through 6 have 2.0 inch deep damage. The length of damage is kept constant for all test specimens. Different levels of damage are shown in Figure 5.3.



**Figure 5.3: Different levels of damage in timber pile test specimens**

In order to evaluate the strength of damaged/repaired section, the location of the damaged/repaired section is located close to the section of expected failure. Theoretically, the pile section at the face of concrete pile cap on the small end is most likely to fail. However, due to heterogeneous timber material, non-uniform specimens, and accompanied loading eccentricities, it is difficult predict the precise location of the failure. Location of the center of damaged/repaired area is 28 inches from the face of concrete pile cap at small end in specimen 2, 3, and 4. Center of damaged/repaired area is located at 8 inches from the face of the concrete pile cap at the small end for specimen 5 and 6. Further, the section capacity of timber pile is very small at the location of damage. Since, the damage is located the fixed end, the pile is likely to fail at the damaged location, unless the retrofitting provide the enough strength to shift the failure to other location.

Specimen 2 and 3 that have 1 inch and 1.5 inch deep damage, are repaired by filling the damaged area with resin (detailed description of the resin material is given in appendix B). However, resin is an expensive material and depending on the size of damage, large quantities of resin might be required to fill the damaged area. Therefore, other three specimens are repaired using different materials to see the effectiveness of relatively cheap material in repairing the piles. Specimens 4 and 5, which have 2.0 inch deep damage, are repaired by filling the damaged area with SARKRETE<sup>®</sup> non-shrink construction grout

(see Appendix B for detailed material properties). Specimen 5 that has 2.0 inch deep damage is repaired by filling the damaged area with aggregate followed by injection of resin in the remaining space.

**Table 5.1: Details of timber pile test specimens**

Specimen	Large End Diameter, $D_1$	Small End Diameter, $D_2$	Clear Length, $L_{Pclear}$	Length of damage, $L_D$	Depth of Damage	Distance of damage from face, $X_D$	Injection material for repair
	(inch)	(inch)	(inch)	(inch)	(inch)	(inch)	
1	10.19	7.88	205	16	1.0	28	Resin
2	9.63	8.30	201.5	16	1.5	28	Resin
3	10.42	8.83	207.5	16	2.0	28	Grout
4	9.91	8.28	202.25	16	2.0	8	Grout
5	9.55	7.88	204	16	2.0	28	Resin + Aggregate

## 5.2 Test set up

Although timber piles are designed to carry only axial load, there are instances where timber piles in the bridge are subjected to both axial and bending loads. Following are the main sources of bending loads in the timber piles used in bridges

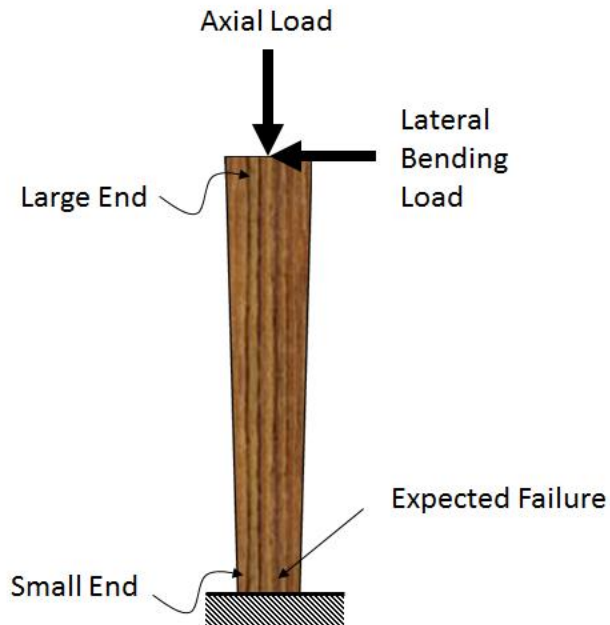
- Brake loads of traffic transferred from deck to the timber piles
- Eccentricities in the axial load arising from non-uniform cross section due to damage

Therefore, the test setup is designed to apply both axial and bending loads to the full scale timber pile test specimens.

The test set up consists of two concrete blocks, hydraulic rams, and post tensioning rods set to apply both axial and bending load to the full scale timber pile specimens. One of the concrete blocks was securely fixed to the ground and will be referred as the fixed block. The other concrete block is moveable, as shown in Figure 5.5.

The fixed block was intended to provide a fixed support at the small end of the pile. The moveable block was intended to transfer both axial and vertical load to the large end of the pile while keeping the

rotation free at the large end. With the large end of pile free to rotate and the small end fixed, the failure is expected in the pile section near the small fixed end of the pile as shown in Figure 5.4. However as discussed earlier, due to heterogeneous timber material, non-uniform specimens, and accompanied loading eccentricities, it is difficult predict precise location of the failure.

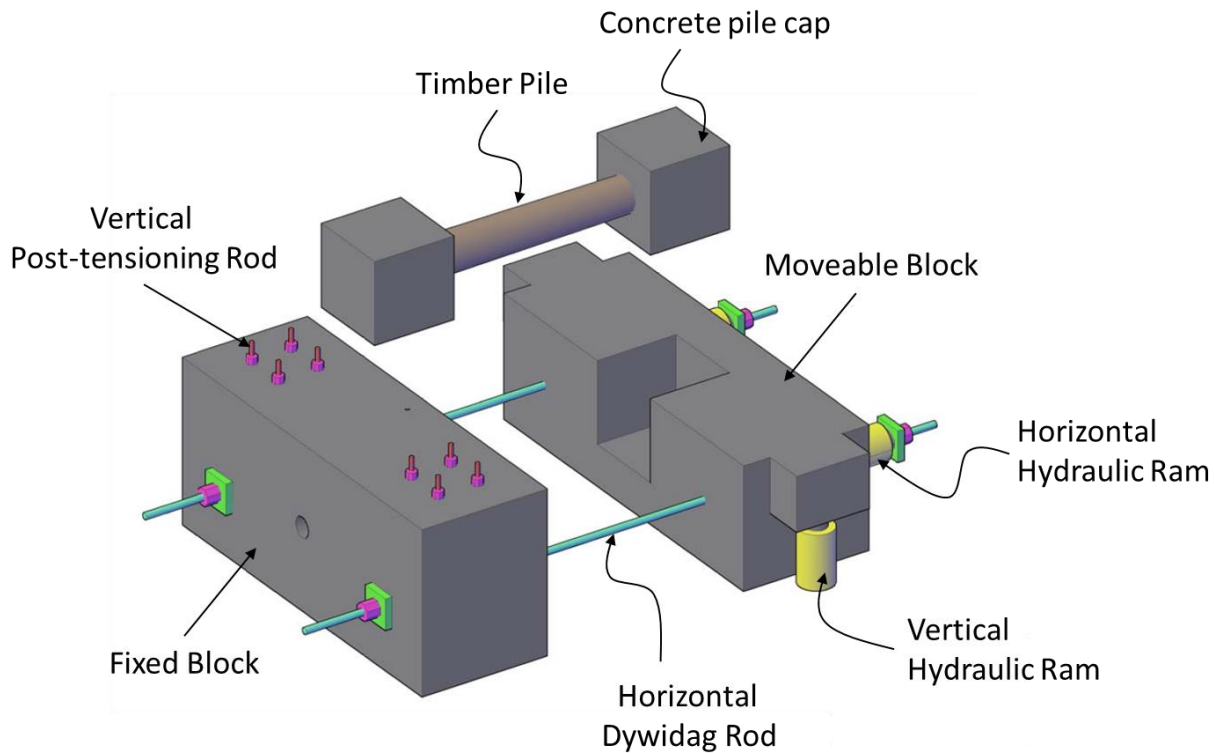


**Figure 5.4: Expected failure at the small fixed end of the pile**

The fixed block is connected to the strong floor with vertical post tensioning rods shown in Figure 5.5. Hydrostone was used in between the strong floor and bottom of fixed block to eliminate unevenness and provide absolute fixity.

Two vertical hydraulic rams ENERPAC RCH-606 with 60 ton capacity and 6 inch stroke were used on either side of the moveable block to apply the vertical/bending load on the pile. The vertical hydraulic rams (ENERPAC RRH-6010 with 90 ton capacity and 10 inch stroke) lift the movable concrete block by a certain displacement to apply the vertical load to the timber pile. PTFE stripes were placed under these hydraulic rams to reduce the friction between the strong floor and movable block and for vertical rams as well to allow their free horizontal movement.

Axial load is applied using two horizontal hydraulic rams acting on two horizontal dywidag rods. It should be noted that any imbalance in the load applied by the horizontal rams can result in twisting of the pile specimen about vertical axis. This will introduce biaxial bending in the test specimens. To avoid this biaxial bending the load imbalance was monitored and the applied loads adjusted as necessary to minimize bending during the test.



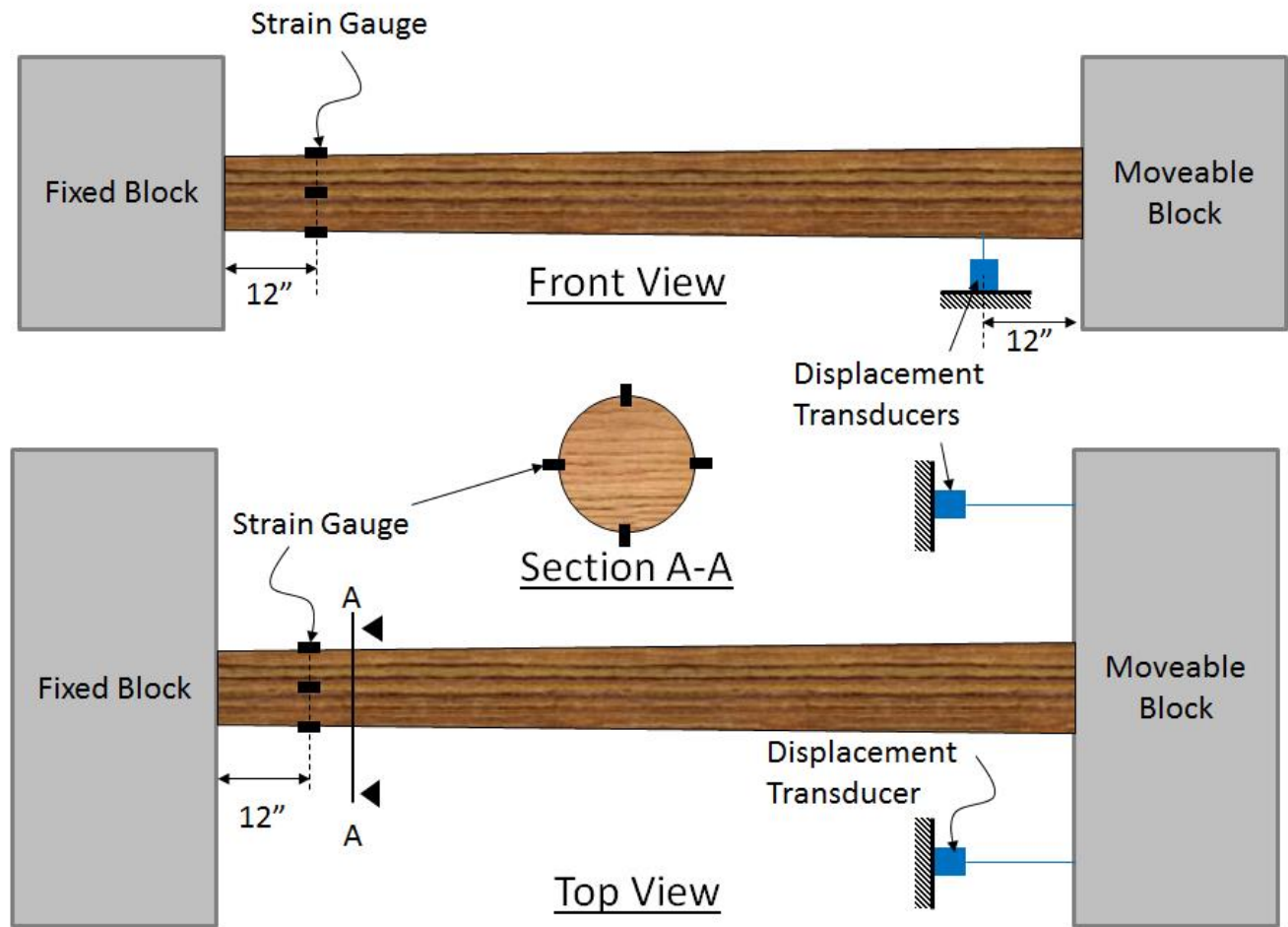
**Figure 5.5: Test setup for testing full scale timber pile specimens**

### 5.3 Instrumentation

Test specimens were instrumented to measure applied loads, deflection of free end, and bending and axial stress near the fixed end of the full scale timber pile specimens.

Four strain gauges were used at a distance of 12 inch from the face of the fixed block around the perimeter of the pile to measure both bending and axial stresses as shown in Figure 5.6. Two displacement transducers are attached to the moveable block on both sides of the pile to measure axial deformation. One displacement transducer was attached to the pile at a distance of 12 inches from the face of the moveable block to measure vertical deflection of the test specimen. Four pressure transducers are used to measure the load applied by each hydraulic ram.





**Figure 5.6: Instrumentation plan**

## 5.4 Testing procedure

After the specimen was completely installed, some initial axial load was applied to the specimen to remove any slack in the test setup. After application of the axial load, the lateral load was applied in the form of lateral displacement near the free end. The lateral displacement induced lateral moment in the pile specimen and made the axial load eccentric. Since the movable block is free to rotate, the lateral deflection results in maximum lateral moment near the fixed block. The lateral moment can be determined by the strains measured by strain gauges located near fixed block. Table 5.2 lists the lateral displacement and lateral moment applied to each specimen at the beginning of test. Applied



lateral displacement ranges from 2 to 2.2 inches resulting in lateral moment ranging from 14 kip-in to 22 kip-in.

**Table 5.2: Lateral displacement and moment applied to each specimen**

Specimen	Initial Axial Load (Kips)	Lateral Displacement (inch)	Lateral Moment (kip-in)
1	23.0	2.0	17.7
2	28.6	2.1	18.6
3	29.0	2.1	21.5
4	28.6	2.2	16.2
5	25.9	2.0	13.7

After application of lateral displacement, the axial load was increased until a sound of wood cracking was noticed. The axial load was put to hold after noticing the cracking sound in order to see if specimen fails by progressive cracking and failure of wood. The load was increased again if cracking stopped without failing the specimen until the next cracking sound or failure of the specimen.

It is worth mentioning that eccentricity of the axial load kept on changing during the test. The initial eccentricity was approximately 2 inch at the start of the test equal to the amount of applied lateral displacement at the free end of the pile. With the increase in axial load, the pile deflected in either one or two lateral directions changing the eccentricity of the applied axial load. The location and direction of maximum lateral deflection of the pile near the failure load is difficult to predict or measure due to inherent imperfections in material and geometry of timber piles. Therefore, the specimens were not instrumented to measure the lateral moment near the failure load.

## **5.5 Test results**

Specimen 1, with one inch deep damage filled by resin, showed the highest ultimate load capacity among the five specimens tested as part of this study. The specimen failed at approximately 177 kips axial load with rapid cracking. Major damage was observed at two locations after the failure of the specimen. Damage was observed near the fixed end where the pile had a big longitudinal crack splitting the pile into two halves. Damage was also observed at the repair location resulting in ripping and delamination of FRP jacket. Note these damages occurred at failure and were not progressive in nature.



**Figure 5.7: Failure of specimen 1 (1 inch deep damage filled with resin)**

Specimen 2, with 1.5 inch deep damage filled with resin, showed the lowest ultimate load capacity (95 kips) among the five specimens tested as part of this study. This specimen failed mainly due to large gradual deflection at the repair location. FRP jacket was damaged at the two ends of the 14 inch long damaged region. The test was continued even after the large downward deflection of the repaired region that resulted in cracking of the fixed end of the pile.



**Figure 5.8: Failure of specimen 2 (1.5 inch deep damage filled with resin)**

Specimen 3, with 2 inch deep damage filled with grout, took nearly 120 kips maximum axial load before failure. The specimen did not show any sign of damage in the repair region. The damage was observed at one end of the FRP wrap that is 12 inches away from boundary of damaged region. Inspection of

failed specimen indicated bending type failure resulting in crumpling top fibers and splintering bottom fibers. No damage of FRP wrap was observed during this test.



**Figure 5.9: Failure of specimen 3 (2 inch deep damage filled with grout)**

Specimen 4 also had 2 inch deep damage filled with grout similar to specimen 3 however; the location of damaged region was different from specimen 3. In specimen 4, the damaged region was placed at the most critical location (fixed end) in an attempt to fail the specimen in damaged region. The failure of this specimen however appeared away from the damaged region during the test. The specimen took approximately 170 kip maximum axial load before failure.



**Figure 5.10: Failure of specimen 4 (2 inch deep damage filled with grout)**



Specimen 5, with two inch deep damage filled with resin gravel, failed at approximately 115 kips axial load. The failure took place away from the repaired section. Insignificant damage was observed in the FRP jacket on the repaired section.

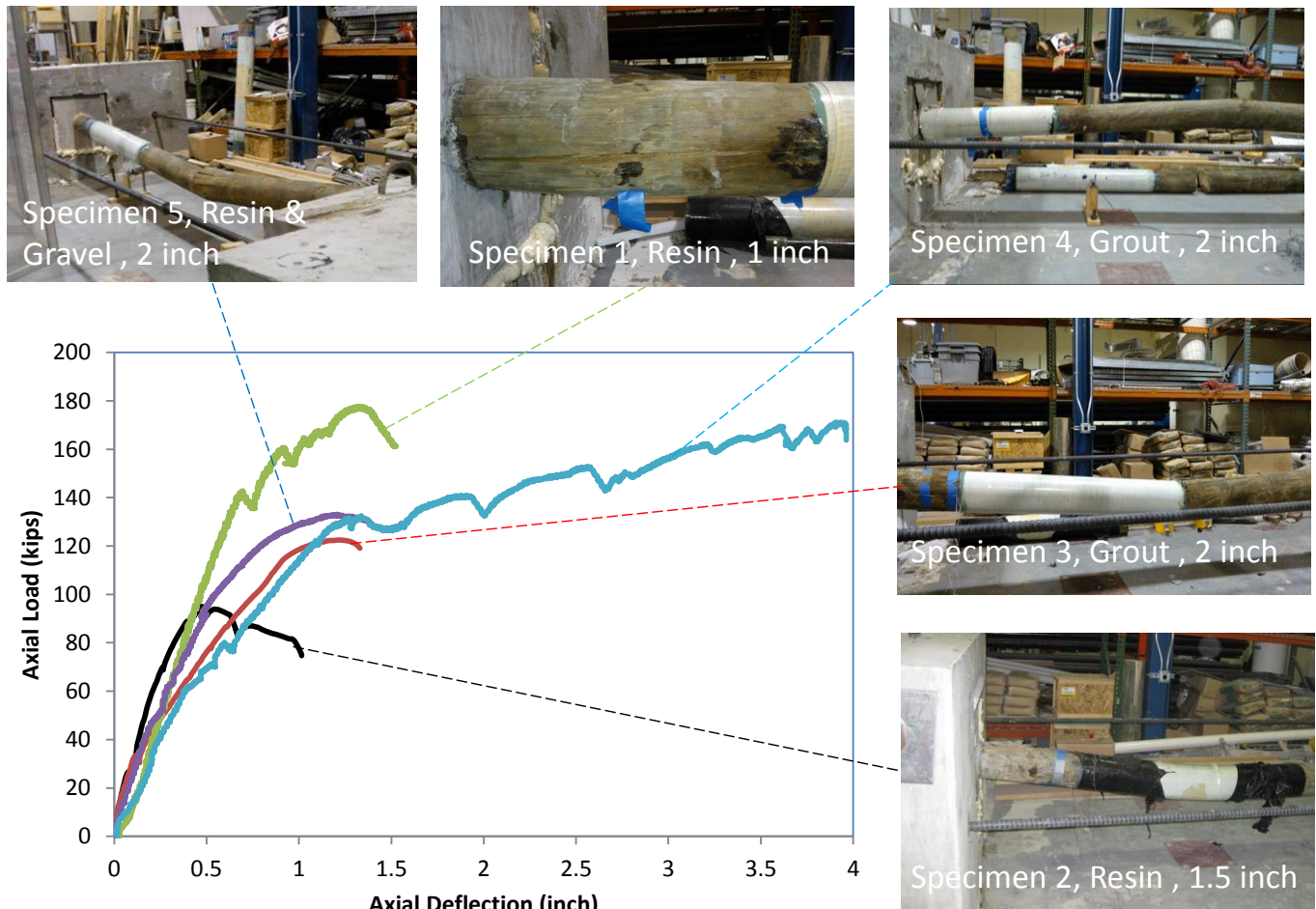


**Figure 5.11: Failure of specimen 5 (2 inch deep damage filled with resin + gravel)**

In summary, two timber pile specimens that were filled with resin (specimen 1 and 2) showed some damage of repaired area during the load test. The damage of the repaired section was insignificant for the specimen using resin and gravel as filler materials (Specimen 5). No sign of damage was observed in the repaired region for the grouted specimens (specimen 3 and 4). Further, for specimens 3, 4 and 5, a clear failure took place outside the repaired region. For specimens 1 and 2, partial or complete failure took place in the repaired region. These observations show that resin might not be very effective for filling large cavities of damage in timber piles. One reason this behavior might be the large heat of hydration from the bulk of resin affecting the quality of cured resin. The other can be the low modulus of elasticity of the resin material compared to modulus of elasticity of wood. In both cases stiffness of the cured resin would be less than the stiffness of wood. This will result in weak repaired section forcing the failure to happen in the repaired section. The resin worked very well when used with gravel that shows resin is good filling small cavities and cracks type damages. Further testing is required to make these conclusions for certain. However, from limited testing, it recommended to use grout to fill the large cavities type damages and resin to fill out crack type damages. Due to the relatively low viscosity compared to grout, resin can fill out the cracks and small cavities more effectively.

Load deflection curves and the failure mode of the five specimens tested as part of this study is shown in Figure 5.12. There are small drops in load-deflection curve of some of the specimens. For example, two

load drops can be observed in load deflection curve of specimen 1 at approximately 140 kips and 160 kips load. These load drops correspond to cracking of the wood during the test. Whenever wood cracking sound was heard, the load was put to hold to allow the failure to take place by progressive wood cracking. However, if the cracking sound stops and failure did not take place, the load was increased again until the next cracking sound or complete failure of the test specimen.



**Figure 5.12: Load deflection curve and failure mode of specimens**

Timber piles are made of heterogeneous material, however, effects of this heterogeneity on structural behavior of timber piles are not pronounced at small load levels. Therefore, timber pile specimens show similar initial axial stiffness as indicated by the load deflection curves in Figure 5.12. The variability is more pronounced in failure loads and maximum deflection before failure. The maximum axial load for the specimens ranged from 95 kips to 178 kips. Similar maximum axial deflection before failure ranges from 0.5 inch to 4 inches.

Due to inherent heterogeneity of timber piles' material and non-uniformity in timber piles' size, it is difficult to evaluate the effectiveness of a repair method by testing five specimens and comparing the results with each other or with the results of an undamaged control specimen. In order to compare the repair methods with each other or with control specimen, large number of test specimens need to be tested for control specimen and for each repair method to get the range of results due to inherent invariabilities in the timber pile. Therefore, failure load of repaired timber piles is compared to the design capacity of the piles used in structural design of timber pile bridges to see if the repaired piles meet the design requirements.

Table 5.3 shows the ratio of maximum axial load to design capacity of the timber piles. Maximum axial load is obtained from the tests carried out on the timber pile specimens described in section 5.1. The design capacity was obtained from the early ninety's design plans of timber pile bridges. The ratio of maximum axial load to design capacity in the last column of Table 5.3 is obtained by dividing the maximum axial load by the design capacity. This ratio has a minimum value of 5.3 for specimen 2 that indicates that specimen 2 was able to carry 5.3 of the design capacity load before failure. The average value of the ratio of maximum axial load to the design capacity is 7.8. This indicates that the repaired timber piles can carry the design load with a large factor of safety.

**Table 5.3: Maximum axial load and Design capacity of timber pile specimens**

Specimen	Average Diameter (inch)	Damage Depth (inch)	Repair Material	Maximum Axial Load (kips)	Design Capacity (kips)	Ratio of Maximum Axial Load to Design Capacity
1	9.0	1	Resin	177.7	18	9.9
2	9.0	1.5	Resin	95.0	18	5.3
3	9.6	2	Grout	122.5	18	6.8
4	9.1	2	Grout	171.2	18	9.5
5	8.7	2	Resin + Gravel	133.1	18	7.4
					<b>Average:</b>	<b>7.8</b>

## **Chapter 6      Summary and conclusions**

This report describes different types of damages of the timber piles and methods to assess these damages. The types of damages are divided into two main categories that are biological damages and physical damages. The type and extent of damages in timber piles can be evaluated by using different methods of assessment. A combination of two methods of assessment is generally recommended for the condition assessment of timber piles.

Different repairs and protection procedures that are generally used for the timber piles were reviewed. The protection of timber pile is normally achieved by treating the wood with preservative. There is a wide variety of repair methods described in the existing literature. Select repair methods were investigated in this study. Repair procedures are described in detail to provide guidelines for implementing these repair procedures in the field.

Ultimate load tests were carried out on full scale timber pile specimens with different levels of damages repaired by different repairing methods to evaluate the effectiveness of repair method. The specimens were subjected to both axial and lateral load in the load tests. Following observations and conclusion are made from the experimental work:

- Two timber pile specimens that were repaired using resin only showed some damage of the repaired area during the ultimate load test. Failure of these specimens was not concentrated at one location instead more than one section along the length of the specimen showed some damage. Damage in the repaired section indicates that partial or complete failure took place in the repaired region.
- Limited or no damage within the repaired section was observed in specimens that were repaired using grout or resin and aggregate. A clear failure took place outside the repaired region for these specimens.
- These observations show that resin might not be effective when repairing large cavity-type damage in timber piles. One reason this behavior might be the large heat of hydration from the bulk of resin affecting the quality of cured resin. The other can be the low modulus of elasticity of the resin material compared to modulus of elasticity of wood. The resin worked very well when used with aggregate, which shows that resin is good for filling small cavities and crack type damages. Further testing is required to make these conclusions for certain.

- From the limited testing, it recommended to use grout to fill the large cavity-type damages and resin to fill out crack-type damages. Due to the relatively low viscosity compared to grout, resin can fill out the cracks and small cavities more effectively.
- Due to inherent imperfections in material and geometry of timber piles, it was not feasible to compare the ultimate load capacity of the timber pile specimen with each other or with a control test specimen. Therefore, the ultimate load capacity obtained from the test result is compared to design load capacity of the timber piles. The test results indicate that the repaired pile specimens were able to carry at least five times of the design load capacity used in structural design of timber pile bridges.



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## **Appendix A: Survey of DOT practices**

The previously mentioned methods are merely a guideline to practical approaches. After contacting Departments of Transportation nationwide, more specific descriptions were obtained. Many states followed procedures outlined above, but some took a more inventive approach.

### **A.1 Oregon**

One of the more original methods, Oregon drives a new pile without having to remove the damaged material. They take steel pipe, or H-pile, depending on soil conditions, and use a hydraulic jack to drive the new pile to the desired depth. This is done using splicing pile sections together as well as a fitted and removable section that allows for the jack to have a flat surface to work against. When the pile is installed, they weld a ring of steel around the jack, leaving a small window. This way the new pile is a tight fit under the pier, and the jack can be salvaged. This method was reported to have great success.

### **A.2 Nebraska**

Nebraska uses a similar method to Oregon. After removing the damaged pile, a new pipe pile is installed in its place, using the remaining timber as a footing for the pipe. A tight fit is acquired using threaded rebar near the pile cap. By tightening nuts on the rebar, a tight fit is obtained, making sure the new pile is sufficiently reloaded.

### **A.3 Arkansas**

Arkansas uses more improvised approaches, both of which fall under the splicing category. The first method uses timber pieces to splice together the repair. The second involves mounting a large metal drum around the splice and filling it with concrete grout. Neither method appears to be long term nor successful.

### **A.4 Mississippi**

Mississippi also uses the concrete filled drum approach. Nothing differs from Arkansas' approach.

### **A.5 Iowa**

Continuing in the splicing category of repairs, Iowa also has two different approaches. First of which uses reinforced concrete. This involves replacing the damaged section of the pile, and installing a cylindrical RC shell around the cut section to protect and produce stability. The second method uses steel for the splice. Again, the damaged section is replaced, but the sections are bolted together with

steel plates, producing a rigid section. The shape of the steel plates may vary. Sometimes straight plates are used, but other times they may form a cylindrical steel shell once fully constructed.

## **A.6 Illinois**

Illinois is another state that uses steel and concrete splices. Their methods for an RC wrap and steel splice are essentially the same as Iowa's. But they have one additional method. That is to encase all of the piles in the row in one concrete footing or wall. The soil around the piles is excavated and the wall is constructed to the desired depth, with a wide, shallow footing at the bottom of this wall. This seems to be overdoing the job, unless the entire pile row has considerable damage.

## **A.7 Maine**

Maine takes a different approach to the RC wrap method. First, they install the new timber section and the RC wrap. But they also encase the RC wrap in a fiberglass shell, adding another level of protection.

## **A.8 Missouri**

Missouri also takes a different approach to RC wraps. After removing the damaged timber section, it is replaced with steel H-pile, not new timber. The rest of the process is similar to any other RC wrap method.

## **A.9 New Jersey**

New Jersey also utilizes cylindrical steel splices. However, their method is different in that instead of replacing the damaged timber with new timber, the section is replaced with a fiber-reinforced plastic pile.

## **A.10 North Dakota**

North Dakota uses steel splices to repair damaged piles. This process has been described above.

## **A.11 Virginia**

Virginia uses steel splices to repair damaged piles. This process has been described above.

## **A.12 West Virginia**

West Virginia makes use of the FRP wrap method. They first wrap the damaged timber section in a glass fiber reinforced polymer fabric, and then inject the cavity with an epoxy grout. In addition to damaged piles, West Virginia has also had success using this process on railroad ties and timber stringers as both retrofitting and preventative measure.

# Appendix B: Detailed Description of Materials Used in Repair

## B.1 GFRP



PileMedic, LLC  
2055 E. 17<sup>th</sup> Street  
Tucson, AZ 85719 U.S.A.  
Phone: (520) 791-7000  
Fax: (520) 791-0600  
www.PileMedic.com

### Product Data Sheet **PileMedic™ PLG60.60** For Structural Strengthening of Columns and Submerged Piles

#### DESCRIPTION

PileMedic™ PLG60.60 is a high-strength Fiber Reinforced Polymer (FRP) laminate constructed with bidirectional glass fabrics providing strength in both longitudinal and transverse directions. The laminate is wrapped around the column or pole and the overlapping portions are bonded together using QuakeBond™ 220UR (Underwater Resin) or QuakeBond™ J201TC (Tack Coat) to create a strong shell around the existing structure. PileMedic™ is unique in that it allows construction of a seamless structural shell around an existing column, utility pole or submerged pile. The annular space between PileMedic™ Jacket and the host pile can be filled with QuakeBond™ 320LV Low Viscosity epoxy resin or high-strength non-shrink grout.

#### USE.

- Repair of underwater piles
- Repair of bridge piers
- Repair & strengthening of corroded steel columns
- Repair & strengthening of timber utility poles & bridge piling
- Applicable to all materials: concrete, steel and timber

#### ADVANTAGES.

- One flat sheet can be used to construct a shell of *any size in the field*, eliminating the expense and delays of special order jackets.
- The jacket provides significant *lateral confining pressure* (in the hoop direction) that increases the axial compressive capacity of the pile or column.
- Provides *flexural (bending)* enhancement.
- The *seamless shell prevents migration of moisture and oxygen* into the column, significantly reducing future rate of corrosion and deterioration.
- Annular space can be adjusted in the field to *minimize the volume of grout or resin*.
- Eliminates or reduces the need for costly divers in underwater pile repairs
- *Corrosion-resistant* system can withstand various chemicals.
- *Non-toxic, odorless* resins are approved for potable water.
- Strength of the laminates can be verified *prior to installation in the field* (in contrast with wet layup FRP systems).
- Laminates can be installed as single shells with overlapping joints along the column height or as a continuous spiral shell.
- The laminates are manufactured in our plant with the highest quality control.

#### PACKAGING

Standard rolls are 50 in. X 150 feet (1.27 m X 45.7 m). PileMedic™ laminates can be custom manufactured in widths up to 60 inches (1.52 m).

#### SHELF LIFE

PileMedic™ laminates have unlimited shelf life when stored properly.

#### STORAGE CONDITIONS

Store in dry place at 30°-120° F (0°-50° C).

#### APPLICATION

- 1) Cut the required length of PileMedic™ considering the number of layers necessary and the overlap length beyond the starting point.
- 2) Wipe PileMedic™ with appropriate cleaner (e.g. acetone or MEK) using clean cloth.
- 3) Apply QuakeBond™ 220UR (Underwater Resin) or QuakeBond™ J201TC (Tack Coat) on the overlapping regions of the laminate sheet.
- 4) Wrap the laminate around the pile or column to create a multi-layer jacket as required. Spacers may be used to control the size of the annular space between the host pile and the PileMedic™ jacket.
- 5) Use ratchet straps to temporarily hold the jacket in the desired size.
- 6) Seal the bottom of the annular space.
- 7) Before the epoxy cures, fill the annular space with non-shrink grout or resin; the hydrostatic pressure from the weight of the grout will press the PileMedic™ laminate plies against each other for improved bonding. For underwater applications, the grout or resin must be compatible for such applications.
- 8) For longer piles, repeat the above steps for additional 4-ft wide bands of jacket along the height of the pile; insert the lower portion of the new jacket a minimum of 4 inches inside the previously installed jacket.
- 9) Leave the installation undisturbed for 24 hours before removing the ratchet straps.
- 10) Apply appropriate coating on the exterior of the jacket.

Installation of PileMedic™ products must be performed only by specially-trained and approved contractors.

Laminates can be cut to appropriate length using commercial quality heavy duty shears. Care must be taken to support both sides of the laminate during cutting to avoid splintering. Since dull or worn cutting tools can

PileMedic, LLC warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current technical data sheet if used as directed within shelf life. User determines suitability of product for intended use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product exclusive of labor or cost of labor. NO OTHER WARRANTIES EXPRESS OR IMPLIED SHALL APPLY INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. PILEMEDIC, LLC SHALL NOT BE LIABLE UNDER ANY LEGAL THEORY FOR SPECIAL OR CONSEQUENTIAL DAMAGES.

## B.2 Epoxy



### The FRP Retrofit Experts

QuakeWrap, Inc.  
2055 E. 17<sup>th</sup> Street  
Tucson, AZ 85719 U.S.A.  
Phone: (520) 791-7000  
Fax: (520) 791-0600  
Toll Free: (866) QuakeWrap [782-5397]  
www.QuakeWrap.com

## Product Data Sheet QuakeBond™ J201TC Tack Coat

### DESCRIPTION

QuakeBond™ J201TC (Tack Coat) is a two-component high-strength structural epoxy designed for vertical and overhead applications. J201-TC has an immediate high tack consistency, allowing it to hold heavy weight fabrics impregnated with J300-SR Saturating Resin in place during cure. QuakeBond™ J201TC trowels easily and has a long pot life for coverage of large areas. The convenient color-coded ("A" yellow and "B" blue) 2:1 volumetric mix ratio is user friendly. QuakeBond™ J201TC is a 100% solids formulation with low toxicity and low odor during cure.

### USE

- Adhesive for bonding external reinforcement to concrete, masonry, wood, stone, steel, etc.
- Structural bonding of carbon laminates, e.g. QuakeWrap™ DU50C.
- Structural bonding of fabrics saturated with QuakeBond™ J300SR resin on vertical and overhead surfaces.
- As a binder for epoxy mortar repairs.

### ADVANTAGES

- Long pot life.
- High strength, high modulus, structural paste adhesive.
- Fully compatible and excellent adhesion to QuakeWrap™ DU50C carbon laminate plates and glass or carbon fabrics saturated with QuakeBond™ J300SR resin.
- Paste consistency ideal for vertical and overhead applications.
- Convenient easy mix ratio, (2 volume parts of component "A" with 1 volume part of component "B").
- 100% solvent free.
- Color coded components (Yellow & Blue) to ensure proper mixing control.
- Nearly odor-free.
- Low toxicity during cure.

### COVERAGE

Applied at a thickness of 40 mil (1 mm) results in 40 square feet per gallon (1 liter per square meter). Rough and uneven surfaces result in lower yields.

### PACKAGING

Component "A" is supplied in 2-gallon (7.58L) containers and component "B" in 1-gallon (3.79L) containers, resulting in 3-gallon kits. Ships DOT non-regulated.

### MIXING

Proportion 2 parts component "A" to 1 part component "B" by volume into a clean container. Mix thoroughly for 3 minutes using a paddle at low speed (400-600 rpm) drill until uniform color is achieved. Mix only the quantities that can be used within pot life. **DO NOT THIN:** solvents will prevent proper cure.

### SHELF LIFE

2 years in original, unopened and properly stored containers.

### STORAGE CONDITIONS

Store at 55°-100°F (13°-38°C) Avoid freezing.

### CERTIFICATE OF COMPLIANCE

- Material Safety Data Sheet (MSDS) will be supplied upon request and is included with each shipment.
- Possesses 0% volatile content per EPA Test Method 24.

### SURFACE PREPARATION

Surface must be clean and sound. It may be dry or damp but free from standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles and other bond inhibiting materials from the surface. Existing uneven surfaces must be filled with an appropriate repair mortar. The adhesive strength of concrete must be verified after surface preparation by random pull-off testing (ACI 503R) at the discretion of the engineer. Minimum tensile strength of 200 psi (1.4 MPa) with concrete substrate failure is required. Blast clean, shot-blast, scarify or use other approved mechanical means to clean the substrate surface. Any sharp edges (i.e. fins, form-marks, etc.) must be ground smooth and flush. Sharp edges must be rounded to a minimum radius of 3/4 in. (19 mm).

### APPLICATION

Apply QuakeBond™ J201TC onto the substrate with a trowel or spatula to a nominal thickness of approximately 40 mil (1 mm). A notched trowel may be used for this application. Before the epoxy hardens, apply saturated fabric or DU50C strips to the epoxy-coated surface. The external reinforcement must not be disturbed for a minimum of 24 hours.

All epoxy components shall be preconditioned to a temperature between 65°F (18°C) and 85°F (29°C) prior to the time of mixing.

### LIMITATIONS

Minimum application temperature of the epoxy is 40° F (4°C). DO NOT THIN this epoxy with solvents.

### FIRST AID

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse. Consult MSDS for detailed information.

### CLEANUP

Collect with absorbent material, flush with water. Dispose of in accordance with local disposal regulations. Uncured materials can be removed with approved solvent. Cured materials can only be removed mechanically.

EPOXY PROPERTIES	
Color - Part "A" is yellow paste, Part "B" is blue paste	
Viscosity	Non-sagging thixotropic paste
Pot Life at 77° F (25° C)	90 minutes
Full cure time	48 hours
Density at 68° F (20° C)	Part A: 9.8 lbs/gal (1.18 kg/L) Part B: 9.4 lbs/gal (1.13 kg/L)
Tensile Strength (ASTM D-638)	4360 psi (30.06 MPa)
Tensile Modulus (ASTM D-638)	329,000 psi (2268.45 MPa)
Compressive Strength (ASTM D-695)	8006 psi (55.2 MPa)
Compressive Modulus (ASTM D-695)	278,900 psi (1923.02 MPa)
Flexural Strength (ASTM D-790)	8025 psi (55.33 MPa)
Flexural Modulus (ASTM D-790)	250,100 psi (1724.44 MPa)
Shear Strength (ASTM D-3165)	1453 psi (10.02 MPa)
Water absorption (% gain) in 24 hrs	< 1%
Expansion Coefficient [-40°-0° C]	61.21 *10 <sup>-6</sup> m/m °C
Expansion Coefficient [50° to 175° C]	210.58 *10 <sup>-6</sup> m/m °C

### CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION.

KEEP OUT OF REACH OF CHILDREN.  
NOT FOR INTERNAL CONSUMPTION.

FOR INDUSTRIAL USE ONLY.  
KEEP CONTAINER CLOSED TIGHTLY.

QuakeWrap, Inc. warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current technical data sheet if used as directed within shelf life. User determines suitability of product for intended use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product exclusive of labor or cost of labor. NO OTHER WARRANTIES EXPRESS OR IMPLIED SHALL APPLY INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. QUAKEWRAP, INC. SHALL NOT BE LIABLE UNDER ANY LEGAL THEORY FOR SPECIAL OR CONSEQUENTIAL DAMAGES.



## B.3 Resin



### The FRP Retrofit Experts

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Phone: (520) 791-7000  
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Toll Free: (866) QuakeWrap [782-5397]  
[www.QuakeWrap.com](http://www.QuakeWrap.com)

## Product Data Sheet QuakeBond™ 320LV Low Viscosity Resin

### DESCRIPTION

QuakeBond™ 320LV (Low Viscosity Resin) is a two-component, high-strength, low-viscosity structural epoxy. The low viscosity makes this an ideal product for crack injection, gravity feed or patching. It can be used as a liquid binder for sand, aggregate or other mineral fillers to form cost-effective material to fill the annular space around piles when PileMedic™ laminates are used. The resin cures underwater, making it suitable for repair of submerged piles. The high compressive and tensile strength of this epoxy provide structural strength for the pile or pole in repairs using PileMedic™ laminates. QuakeBond™ 320LV can be used in repair of concrete, masonry and wood structures. The resin also provides excellent durability and chemical resistance. The convenient 2:1 volumetric mix ratio is user friendly. QuakeBond™ 320LV is a 100% solids formulation with low toxicity and low odor during cure.

### USE

- Filling the annular space created between the PileMedic™ and concrete or timber pile or pole being repaired for both above-water and submerged conditions
- As a binder mixed with sand and small-size aggregates to form a resin-based grout to fill larger annular spaces in repair of piles and poles using PileMedic™
- Filling cracks in concrete by injection or gravity feed
- Crack repairs in masonry, wood and concrete structural members
- A moisture barrier (water-proofing) system in conjunction with PileMedic™ laminates

### ADVANTAGES

- High strength, high modulus, low-viscosity structural adhesive.
- Moisture insensitive – it cures under water
- Fully compatible and excellent adhesion to PileMedic™ carbon or glass laminates.
- Convenient easy mix ratio, 2:1 by volume.
- 100% solids, VOC free and Butyl Glycidyl Ether (BGE) free.
- Nearly odor-free.

### COVERAGE

Apply as a filler material to fill all cracks and voids in concrete, masonry and timber structures. Application rate varies greatly based on the porosity and the volume of voids present in the structural member being repaired. For wider annular spaces, the epoxy can be mixed with clean silica sand and pea gravel (3/8 inch and under) for improved yield.

### PACKAGING

Each of the components is supplied in 5-gallon (19L) containers or 55-gallon (208L) drums, resulting in 15-gallon or 165-gallon kits. Ships DOT non-regulated.

### MIXING

Mix 2 parts resin "A" to 1 part hardener "B" by volume into a clean container. Mix thoroughly for 3 minutes using a paddle at low speed (400-600 rpm) to avoid air entrainment. Mix only the quantities that can be used within pot life. REMEMBER – you will have less working time at higher temperatures. **DO NOT THIN**; solvents will prevent proper cure. If desired, silica sand and well-graded pea gravel (3/8 inch and under) can be added up to a maximum of 70 pounds sand and gravel per gallon of QuakeBond™ 320LV.

### SHELF LIFE

2 years in original, unopened and properly stored containers.

### STORAGE CONDITIONS

Store at 55°-100°F (13°-38°C)

### CERTIFICATE OF COMPLIANCE

- Material Safety Data Sheet (MSDS) will be supplied upon request and is included with each shipment.
- ASTM C 881 Compliant

### APPLICATION

Properly mixed QuakeBond™ 320LV can be used to fill the annular space between PileMedic™ jackets and the pile or pole being repaired. When introduced at the bottom of the annular space, the high density of the resin pushes the entrapped water to the top. The resin can be thickened with clean silica sand and pea gravel (3/8 inch and under) for filling larger annular spaces. All epoxy components shall be preconditioned to a temperature between 65°F (18°C) and 85°F (29°C) prior to the time of mixing.

### LIMITATIONS

Minimum application temperature of the epoxy is 45° F (7°C). **DO NOT THIN** this epoxy with solvents.

### CLEANUP

Uncured materials can be removed with approved solvent or warm soapy water. Cured materials can only be removed mechanically.

### SAFETY PRECAUTIONS

Avoid breathing of vapors. Forced local exhaust is recommended to effectively minimize exposure. NIOSH approved, organic vapor respirators and forced exhaust are recommended in confined areas, or when conditions may cause high vapor concentrations. Do not weld on, burn or torch any epoxy materials as this will cause release of hazardous vapors. Consult MSDS for detailed information.

EPOXY PROPERTIES:		
Color – Both Parts "A" and "B" are amber liquid		
Viscosity Mixed at 77° F (ASTM D-2196)		780 cps
Working Time at 77° F (25° C)		20 minutes
Gel Time		30 minutes
Weight (Mixed) lb/gallon		9.21
Density (Mixed) kg/liter		1.11
Tensile Strength (ASTM D-638)		7,900 psi (54.5 MPa)
Compressive Strength (ASTM D-695)		11,200 psi (77.2 MPa)
Elongation @ Break (ASTM D-638)		4.8%
Adhesion to Concrete		>800 psi (5.5 MPa); 100% failure in concrete
Hardness, Shore D (ASTM D-2240)		86

**CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION.**

KEEP OUT OF REACH OF CHILDREN.  
NOT FOR INTERNAL CONSUMPTION.

FOR INDUSTRIAL USE ONLY.  
KEEP CONTAINER CLOSED TIGHTLY.

## B.4 SARKRETE® non-shrink construction grout



Sarkrete® Non-Shrink Construction Grout is a non-shrink, non-metallic, structural hydraulic cement for high-strength grouting.

### FEATURES AND BENEFITS:

- Meets ASTM C 1107 Packaged Dry, Hydraulic-Cement Grout (Non-shrink)
- Non-corrosive, Will Not Attack Reinforcement
- Non-shrink, Per ASTM C 1107
- Non-metallic, Non-Staining, Gray Color
- Meets Corps of Engineers Specification CRD-C 621
- Plastic and Flowable Consistency
- Pumpable for Easy Placement
- Super Plasticized for Improved Strength

### USES: Grouting of

- Concrete - poured in place, precast, tilt-up and prestressed
- Heavy Machinery
- Sole Plates
- Anchor Bolts
- Steel Bearing Plates
- Dowel Rods
- Reinforcing Steel in Block Cells
- Concrete Columns

### SAFETY:

READ and UNDERSTAND the Material Safety Data Sheet (MSDS) before using this product. WARNING: Wear protective clothing and equipment. See HMIS block. For emergency information, call CHEMTREC at 800-424-9300 or 703-527-3887 (outside USA). KEEP OUT OF REACH OF CHILDREN.

### PREPARATION:

Remove all unsound concrete, grease, oil, paint, and any other foreign material that will inhibit performance. Prior to grout placement, all surfaces must be clean and saturated with water for 24 hours. Remove excess water before placing the grout. Provide air relief holes where necessary if grouting is beneath large plates.

Suggestions in Form Work: Wood form work or other absorbent forms should be coated with a form release oil to prevent grout adherence and water absorption. Design form work to facilitate rapid, continuous and complete filling of the space to be grouted. Use methods that will enable the grout to flow by gravity between the surfaces and keep the grout in full contact with these surfaces until it has hardened.

Refer to: ACI 351.R-99 Report on Grouting between Foundations and Bases for Support Equipment and Machinery for important information and recommendations.

### TECHNICAL DATA:

	<u>Plastic</u>	<u>Flowable</u>
<u>Consistency of Flow</u> ASTM C 942	115%	140%
24 hours	3,000 psi (21 MPa)	2,000 psi (14 MPa)
7 days	6,500 psi (45 MPa)	6,000 psi (43 MPa)
28 days	9,000 psi (62 MPa)	8,000 psi (55 MPa)

### MIXING:

Add only clean water. The water quantities shown are approximate and may vary slightly with type of equipment and application conditions. Water demand and mix temperature must be determined using standard test methods for consistency and temperature measurement at the time of application.

Desired Grout Consistency:

Flowable (Pumping Consistency), 50 lbs. (22.7kg) Grout, approximately 1.1 Gallons Water (4.2 L)

Plastic (Trowel Consistency), 50 lbs. (22.7 kg) Grout, approximately 1.0 Gallon Water (3.8 L)

### PLACEMENT:

Use a mixer large enough to permit continuous placement before any part of the grout has set. Place the grout quickly. Rodding the grout lightly will help move material. Avoid vibration which can cause bleeding and segregation. Shut down nearby machines.

The air, mix & substrate temperatures should all be between 40°F (4.4°C) and 90°F (32.2°C).

### CURING:

SARKRETE Construction Grout can be exposed under normal weathering conditions. Forms may be removed as soon as the grout reaches its final set. Protect from freezing for a minimum of 48 hours after placement. ACI 308-Standard Practice for Curing Concrete.

### STORAGE:

Store in a tightly closed container off the floor in a dry place.

### COVERAGE:

50 lbs. covers 0.45 cu. ft. (12.7 L)

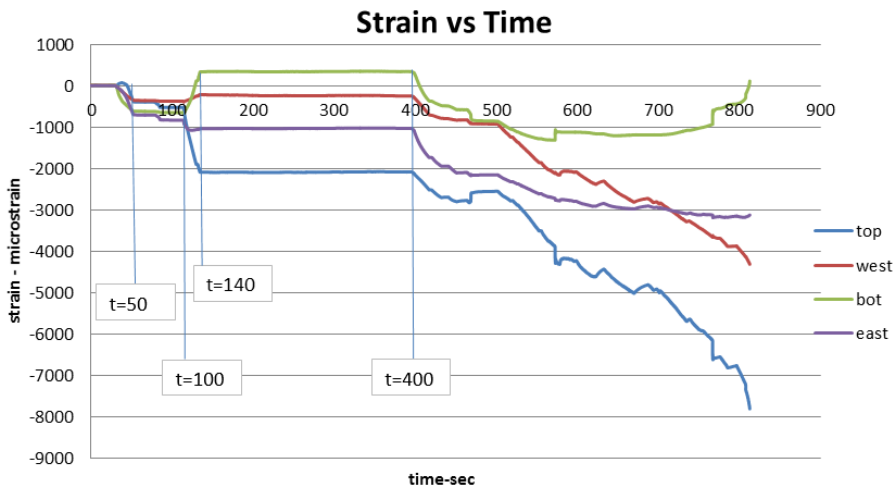
### PACKAGING:

50 lb. bag (22.7 kg) UPC: 7-64661-16350-3

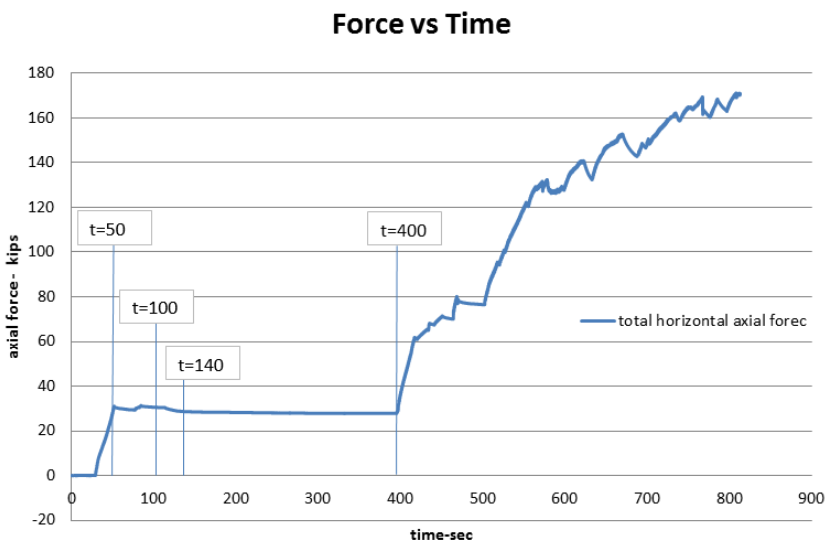


## Appendix C: Test sequence for one specimen

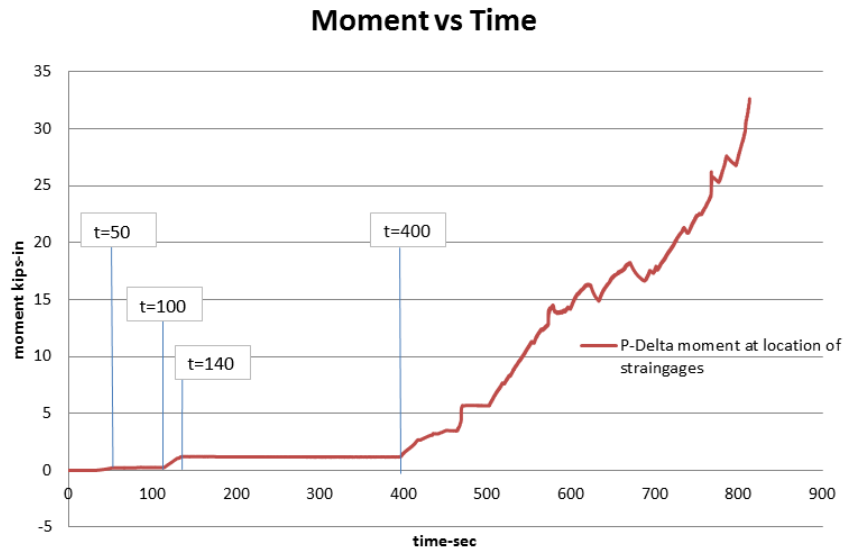
This appendix is describing sequence of applying vertical and horizontal load on one specimen. For all the other specimens the sequence of loading is approximately the same. The initial axial load applied to the specimen from time  $t=0$  sec to  $t=50$  sec to tight timber pile with two end concrete blocks. After 50 sec the research team control vertical hydraulic jacks for applying vertical load. During  $t=100$  sec to  $t=140$  sec the vertical load applied to the specimen for making eccentricity. As it has shown in Figure C.2 and Figure C.3, after  $t=100$  sec, while just vertical load at the location of unfixed support loads applied, timber pile doesn't carry out any axial force, but the amount of moment increased significantly. During this time the vertical load keep the axial force constant but make a jump in P-Delta affect from 0.5 kip-in to 1.2 kip-in that is approximately 0.05 of the total moment at collapse level. After  $t=140$  sec until  $t=400$  sec the research team were prepared to ready for the final step of test. At the final step of loading, after the  $t=400$  sec, axial load was increased until the collapse level. For instance, Figure C.1 and Figure C.2, show during the time  $t=0$  sec to  $t=50$  sec, increasing initial axial force to 30 kips increase the strain around 500. This axial load is approximately 18 percent of collapse load. The effect of this initial load is insignificant on bending moment at the location of damage. At the next step during increasing the vertical load, the strain for east, top and west of the section decrease while the strain for bottom section increase. At the final step of loading, after  $t=400$  sec, all fibers of the section is under compression and there is more compression at the top and east than the bottom and west side of the section (these results for each specimens is different). These graphs indicate there is a moment around two major axes of the section. Furthermore, because the strain at the top of the section is maximum, therefore in this specimen the first yielding fibers occurred at the top of the section. Figure C.4 is a compression between applying force by hydraulic jack at different points of unfixed support and total horizontal and vertical loads. Figure C.5 shows the horizontal deflection at the east, west and middle of the unfixed support and middle of timber pile length.



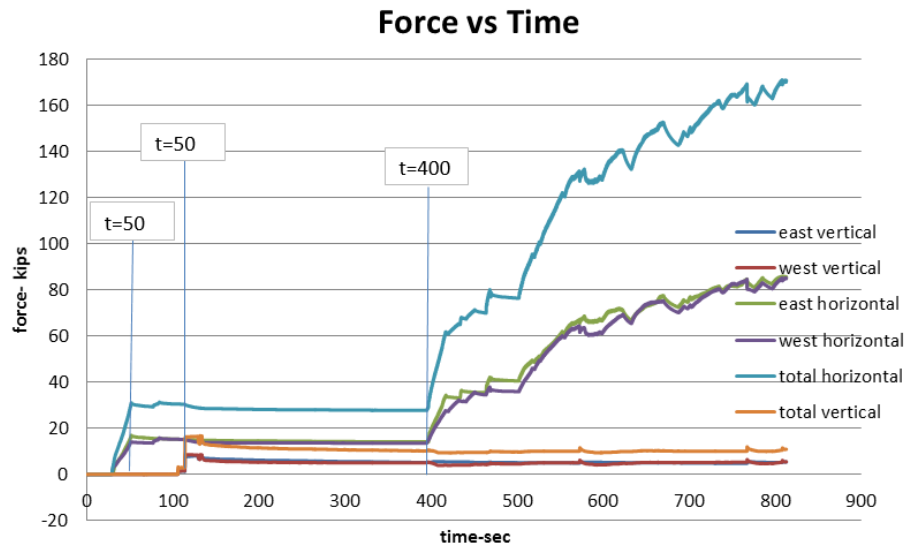
**Figure C.1 Strain versus time at different stages of loading**



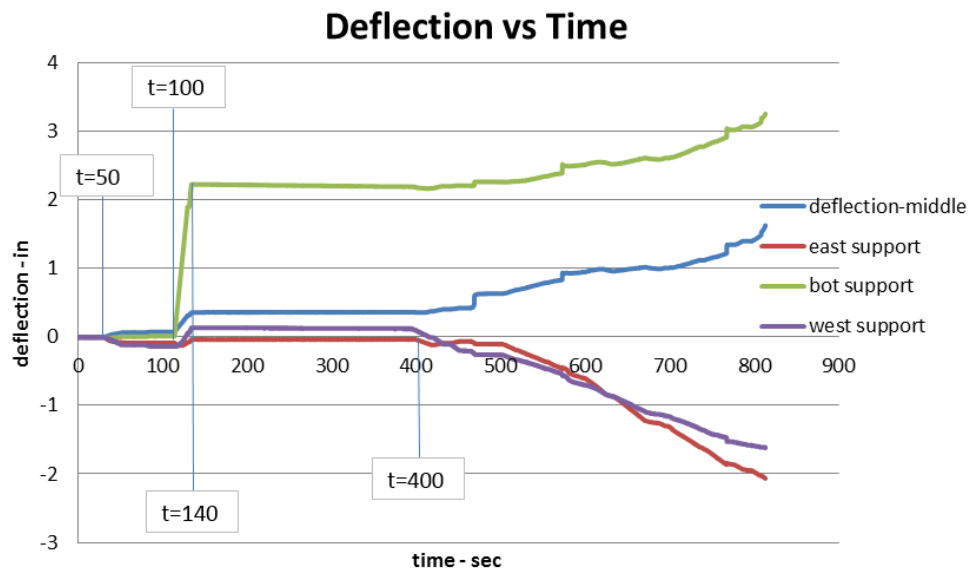
**Figure C.2 Axial force versus time at different stages of loading**



**Figure C.3 Moment versus time at different stages of loading**



**Figure C.4 Forces applied by each jack through the whole steps of loading protocol**



**Figure C.5 Measured deflection at different locations along the timber pile length**