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Rehabilitation of timber bridge piles using a wrapping system

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ABSTRACT: The majority of the thousands of timber bridges around Australia are more than 50 years old and strengthening and rehabilitation of deteriorated timber bridges is a strong financial commitment. Therefore it is a timely concern to investigate the rehabilitation process involved. The maintenance cost of timber bridges are affected significantly by a number of deterioration mechanisms, which require a systematic approach for diagnosis and treatment. The techniques used to rehabilitate timber bridges vary depending on the deterioration mechanism and location. This research aims at investigating the techniques used in timber pile rehabilitation. The main deterioration mechanism studied in this research is the splitting. An experimental program was carried out to investigate the strength enhancement due to a FRP wrapping system combined with two types of filler material, Crane Rail Grout (CRG) and Underwater Cementitious Grout (UCG). Hardwood timber of grade F27 with 150 mm diameter and 300 mm high samples were used in the testing program. Three levels of damage were introduced to the total height, samples were wrapped with FRP system and tested for compression. Load and displacement curves were developed based on the experimental results.

1 INTRODUCTION

Current timber bridge stock in Australian roads are definitely having timber piles as its primary structural support. Road authorities are making every effort to maintain these aging bridges. Dismantling older timber bridges and replacing them with concrete or any other material may not be the best option for most of the timber bridges. Therefore, rehabilitation techniques are being researched, commercialized and implemented on bridges around Australia. Eccentric and concentric loads on timber piles were analysed experimentally and analytically in the past (Borello 2009; Borello et al. 2010).

Fibre composites such Fibre Reinforced Polymer (FRP) laminates with their inherent properties which offer great tensile strength benefits than those of steel, timber and concrete in vast varieties of environmental conditions. These conditions can range from tidal/splash waves, high moisture environments and fluctuating thermal conditions. The combination of FRP laminate with an infill annulus material offers deteriorated timber sections greater lateral confinement, resulting in larger axial load capacities. Not only does the FRP laminate offer high tensile strength, but also offers a protection from biological attack for submerged timber pile cases.

This research paper focuses on a repair method for decayed timber piles, for bridges, boardwalks and jetties using FRP jacketing technology. Due to durability, pumpability, workability and compressive strength requirements, Crane Rail Grout (CRG) and Underwater Cementitious Grout (UCG) were selected as the filler materials in this study. The combination of material offers an all-round (360 degree) confining pressure. This significantly increases the strength of the pile. Therefore, this repair method will be tested and validated throughout this paper.

Currently information about splitting due to thermal expansion is lacking and in dire need of research and testing. New piles can be cut and posted onto the old piles but this solution can often be costly. Therefore, a new technique currently on the market offer a helpful solution. Wrapping the deteriorated pile while still under axial load reduces time and cost of the project. This solution consists of a GFRP wrap spaced approximately 20 mm with corner bar spacers that are attached to the existing pile. The wrap is sealed with an underwater resin that will eliminate any moisture from entering the fill material and ultimately to the existing pile. Usually an underwater cementitious grout is used to fill the 20-mm annular space as its material properties are extremely high. After 7 days the fill material will reach approximately 90% of its maximum 28 days strength. After 7 days the compressive strength should be approximately 100 MPa. This is just one example of rehabilitation that can be seen dominating the market for its ease of use, strength benefits and cost effectiveness.

2 TIMBER PILE DETERIORATION

There are many ways that can initiate a timber bridge deterioration. Once started it will spread due to many other reasons as well.

2.1 *Main deterioration methods*

Weathering is the main cause of timber pile deterioration as moisture can inhibit the pile causing thermal expansion to occur. The result of this is cracking along the fibres, opening the timber for fungal decay to start breeding.The principal cause of weathering is the excessive exposure of moisture content. When wood is unprotected from external factors, moisture can be absorbed in both the cell walls and the cell cavities of the timber. Some researchers (Mohammadi et al. 2014) suggested that a moisture content greater than 20% decay will start taking place whereby Austroads guide to bridge technology (Austroads 2009) believes that decay will start taking place at 15% moisture content.

Austroads (2009) reported that decay is the rotting of timber because of fungal attacks. Timber piles are subjected to weathering conditions such as water and temperature. As a result, the nature of the pile is to shrink. This shrinkage results in large internal stresses. The outcome of this action causes splits to form in the timber pile. These splits are a pathway for fungal decay to take effect. The fungal decay will make its way to the centre of the untreated timber pile.

Termites is another means that a pile can deteriorate rapidly. Termites are generally found in the northern tropical belt of Australia (Austroads 2009). The Damage caused by termites is much more rapid growing than that of fungi ((Mohammadi et al. 2014). It is less common to see termite attack to occur in durable hardwoods without some sort of preexisting fungal decay. This is due to the fact moisture is present which is excellent conditions for termite growth (Mainroads 2014). There are many marine borer species, and each species has a different habit and ability to attack timber piles in different coastal regions (Cookson 1986).

Timber piles that are submerged beneath the water surface can be inhabited by marine organisms. It has been noted that these organisms become more severe in subtropical waters than in colder waters (Bootle 1983).

Austroads (2009) defines a split as separation along the grain extending right through the member. Splitting is caused by thermal expansion, fluctuations of moisture content and overloading. Most splitting is due too wet and dry cycles. It can be noted that Austroads (2009) agree that moisture content and thermal expansion are the main causes for splitting or checking along the grain of the timber pile. Overloading is another contributing factor for the cracking or splitting of timber piles. Queensland timber bridge maintenance manual (MainRoads-Queensland 2004) stipulates that cracks may be aggravated by overloading vehicular collision. Overloading cause splitting to start from the bearing area and travels upwards to the timber girder. Once again, the splitting can be seen to run along the grain.

2.2 *Rehabilitation techniques*

From previous studies, it is evident that rehabilitation of timber piles around Australia is a necessity in maintaining the structural integrity of timber bridges. There is approximately 12,075 timber bridges that currently or in future need maintaining for the given defects outlined above. There are several timber pile rehabilitation methods available around Australia.

2.2.1 *Posting repair method*

This procedure meant the deteriorated affected pile was removed completely and replaced with a new surface treated pile to stop weathering or decaying issues. Epoxy grouting is used to join the new section to that of the old section. In some cases, the repair methodology required shoring to support the pile from becoming weak or unstable. This method of repair was tested under axial compression loading. The results were credible with maintaining ultimate strength and axial stiffness after the repair had taken place. These tests did not evaluate combined axial and lateral loads on the repair procedure.

2.2.2 *Splicing*

Splicing is a simple and cost-effective solution for the rehabilitation of deteriorated timber piles. This process entails cutting and posting a new section replacing the old deteriorated pile. The material used in splicing can either be timber or steel straps approximately 15 cm in length (Mohammadi et al. 2014). This section is connected by long metal screws. Lap splicing is extremely low cost, effective but will not last the test of time. This is a short-term fix with the intentions of implementing a better repair technique in the coming years. Austroads (2009) and Mohammadi et al (2014) agree that lap splicing should be avoided where possible. In addition, it is stated (Kim & Andrawes 2016) that this method will have catastrophic consequences if the pile is subjected to a bending moment. This was evident in a bridge collapse in Illinois, USA.

2.2.3 *Grout/ epoxy injection*

Another effective low cost and durable repair is grout or epoxy injection. This technique leaves a proportion of the timber exposed. When using epoxy injection some sort of confinement needs to be incorporated (Emerson 2004). For example, using a FRP wrap in conjunction with an epoxy will suffice. According to railway and track structures, grout injection has the strength capabilities to increase the service life of the timber piles to approximately 15 – 20 years. Epoxy injection requires approximately 30 min to 5 hours drying time (Avent et al. 1978). Then the injection ports can be sanded smooth then painted for aesthetics purposes. This injection method can be used for both structural and semi structural components of timber bridges.

2.2.4 *Concrete jackets*

Concrete jackets are another method of rehabilitating a deteriorated timber piles. A steel cage is placed around effected area of the existing timber pile. Jackets can be formed using 25 – 50 mm (Mohammadi et al. 2014) thick coat shotcrete reinforced with steel caging. This method has its downfall as concrete is likely be subjected to external factors such as acids, alkalize or salt in ground water. This may cause drastic effects such as cracking and spalling (Mohammadi. et al. 2014). This will cause exposure of the steel cage resulting in corrosion and loss of cross sectional area. If cross sectional area is reduced then strength and durability will be reduced. Austroads (2009) also suggests concrete jacketing as a repair method but does not go into detail about how the repair should be carried out or implemented.

2.2.5 *FRP wrapping*

Fibre-Reinforced Polymer is another method of rehabilitating defected or decayed timber piles. Polymer resins plays as the matrix which helps bind fibre reinforcements together. Another advantage of using the FRP wrapping technique is that the resin used to bind the material can eliminate future deterioration. One matrix combination study conducted at the University of Manitoba used Glass Fibre-Reinforcement Polymers (GFRP) and grout shells to restore axial loads. This technique places a grout shell approximately 50 mm thick around the affected area. Then the GFRP is wrapped around the grout to create a seal. When tested the pile showed positive results restoring and in some cases increasing the compressive strength.

Cut and post is another technique (Caiza et al. 2012) where the rotten or deteriorated section is cut and reposted with a new timber section. A FRP wrap and grout shell completes the retrofit when the old timber section meets the new. Results shows that this technique will increase the compressive strength of the timber pile.

Recent technology such as FRP wrapping is becoming more and more frequent because of its strength improvements. Alongside this, FRP can be easily installed/fitted on site without and need for machinery. Therefore, this method seems to be the best method of rehabilitating timber piles.

Previous attempts and testing has been achieved in this field but more data is required to gain a defined method of procedure. Results vary in what percentage axial compression will increase when using the FRP wrapping method. Therefore, further testing is essential in accurately proving how FRP wrapping can increase the structural integrity to that of a normalized defected pile.

3 EXPERIMENTAL PROGRAM

The experimental program was designed to test short timber columns with FRP wrapping and a filler. Total number of samples tested in this project is 16. Testing of one control sample (no damage), 3 unwrapped samples with 3 damage levels, 3 samples strengthened using underground cementitious grout (duplicate) and 3 samples strengthened using crane rail grout (duplicate) comprised the experimental program.

3.1 *Materials*

The timber samples were sourced by University of Southern Queensland while the filler and FRP wrapping were provided by Quakewrap Australia. Material quantities used are summarized in Table 1.

Table 1. Material quantities

Material	Quantity
F27 timber (150 mm diameter)	4.8 m
Cementitious Grout	50 L
Crane rail grout	50 L
FRP laminate	7.5 m^2
Underwater Resin 220UR	2.2 L

3.1.1 *Timber*

Grade F27 cylindrical timber samples having approximate dimensions of 150 mm diameter and 300 mm length were used in this experimental program.

3.1.2 *Filler*

The two filler materials used were crane rail grout and underwater cementitious grout. Both filler materials will reach approximately 90% of its compressive strength after 7 days (Figure 1).

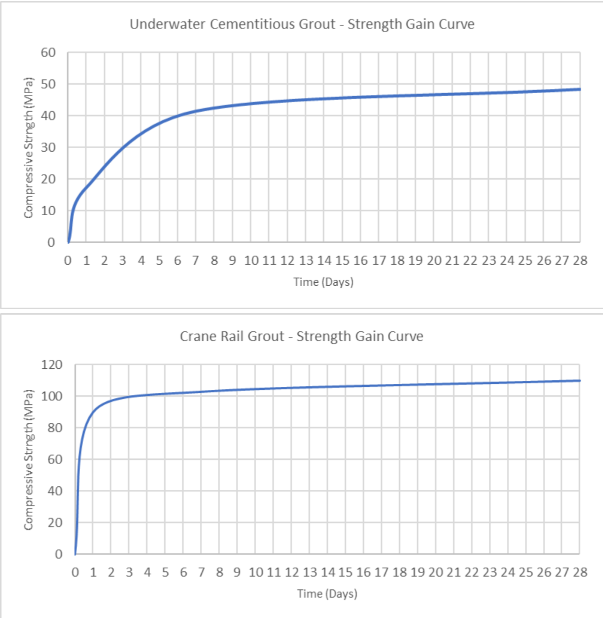

Figure 1. Strength development of filler

3.1.3 *FRP wrapping system*

PileMedic™ PLG60.60 is the FRP laminate used in the wrapping system. It has bidirectional fibres providing strength in both longitudinal and transverse directions. Properties of FRP are shown in Table 2.

Table 2. Material properties

Material	Max strength MPa
Underwater cementitious grout	48.3 (compression)
Crane rail grout	110 (compression)
Fibre Reinforced Polymer (FRP)	3.8 (tension)
Underwater Resin 220UR	418 (tension)

3.2 *Sample preparation*

All the samples were cut into approximately 300 mm lengths, weighed and the dimensions were recorded. Splitting was introduced into all the samples except the control sample.

3.2.1 *Damage levels*

Timber Bridge Detail Inspection Guidelines (Mainroads 2014) from Main Roads Western Australia states a severe vertical split would be greater than 5 mm in width and extending more than a meter in length. Some splits may be wider than 5 mm but have shorter length or vice versa. This was the only information found about the splitting measurements through inspection of deteriorated timber piles. The length of split gained from inspection extends greater than 1 m. Therefore, the split used in this research runs the entire length of the sample (≈300 mm). These two parameters will be maintained throughout experimental procedure. Split depth will be adopted at depths of full radius, 2/3 radius and 1/3 radius Figure 2.

Figure 2. Defect induced samples

Samples were then wrapped by the FRP laminate (Figure 3) and the filler was introduced into the annulus (Table 3)

Figure 3. FRP wrapping process

Table 3. Annulus details

Material	Annulus thickness mm
Underwater cementitious grout	20
Crane rail grout	20
Fibre Reinforced Polymer (FRP)	3
Underwater Resin 220UR	2

3.3 *Testing*

All the samples ready to be tested are shown in Figure 4 and they are to be tested using the SANS compression testing machine to find the maximum load/stress of the timber piles. Samples were attached with the strain gauges too to get the strain values in addition to the strains getting from the machine. A sample ready to be tested in the machine is shown in Figure 5.

Figure 4. Samples ready for testing

Figure 5. Sample in the compression-testing machine

Recorded data included the load and the displacement from the testing machine and the strain values from the data acquisition system 5000.

4 RESULTS AND DISCUSSION

Figure 6 shows the load deformation curves for the control sample, and the samples with defects. All these samples are unwrapped. The machine has the capacity of 2000 kN and it was calibrated to be used only for 1800 kN. Hence, the sample without any defect (control) could not reach its maximum capacity.

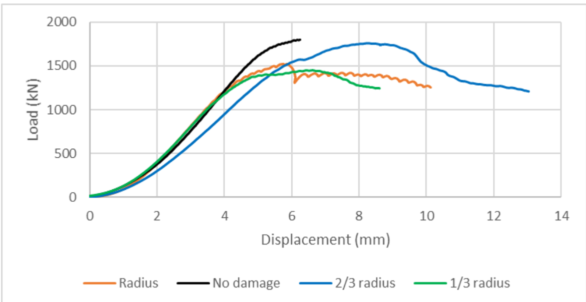

Figure 6. Load deformation for control samples

Figure 7 shows the load deformations curves for underwater cementitious grout (samples did not reach their capacity). However it is clear from Figures 6 and 7 that the deformation with FRP wrapping and cementitious filler is less than the deformation observed for unwrapped samples.

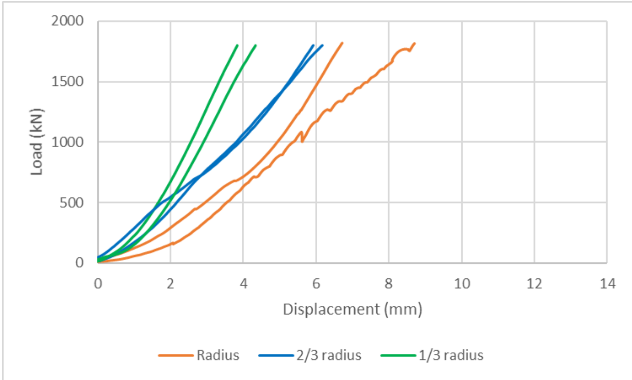

Figure 7. Load deformation curves for cementitious grout

Figure 8 shows the load deformation curves for the samples wrapped with FRP and crane rail grout as the filler. Comparing with Figure 7, it can be observed that samples with crane rail filler will reach a higher ultimate deformation than the samples with cementitious grout filler.

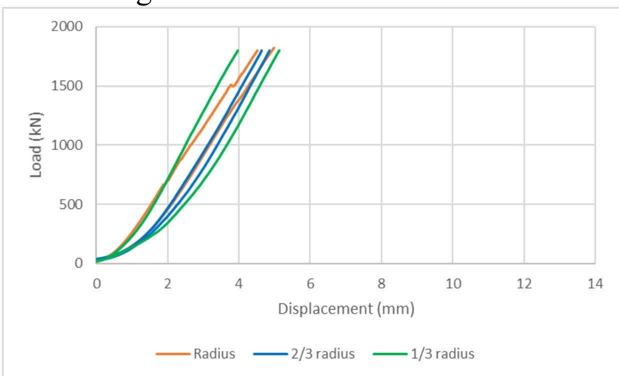

Figure 8. Load deformation curves for crane rail

5 CONCLUSIONS

Several conclusions can be drawn from this study. All defected control samples produced a failure and showed higher axial deformation. Due to the limitation of the capacity of the compression testing machine, no conclusions can be made regarding the failure load of the wrapped samples. However the observed curves show that the timber short columns can effectively be confined using the proposed FRP wrapping system and the 2 fillers (cementitious grout and crane rail grout). This is shown by the much higher expected failure load and the increased anticipated deformation from the observed curves. Further work is planned to test similar samples using a higher capacity-testing machine.

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