WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH & INNOVATION PROGRAM

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Advanced Epoxy Timber Pile Repair – Stage 1 and Stage 2

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Summary

Under the WARRIP program, Main Roads Western Australia (Main Roads) engaged the Australian Road Research Board (ARRB) to undertake a multi-year project with the aim of developing a commercially available and fit-for-purpose design and rehabilitation solution that will facilitate the life extension of existing timber bridges in Western Australia.

Main Roads has been utilising epoxy fill injection solutions in timber piles as a semi-structural solution since it was initiated approximately 20 years ago. The epoxy fill injection is used to mitigate further localised deterioration. This repair method is currently only utilised for piles that have been identified as having an adequate cross-section area intact. An opportunity was identified for using epoxy resin as a method to increase the structural capacity of timber piles.

The current project stage comprises design development and epoxy resin investigation through field trials, and development of a draft technical specification for on-site rehabilitation works. The field trials have improved and refined the repair method, particularly the evaluation of epoxy resins to be used and the development of methodology for the repair works.

A total of 4 field trials were undertaken at bridge sites selected by Main Roads using the recommended epoxy materials, which were selected based on product suitability for Main Roads' requirements through a product selection process. The selection criteria were based on Main Roads' experiences with Epigen 0301MRD, which has been utilised by Main Roads in timber piles repair. The decision was made to trial the 'Technirez' brand of epoxy resins – Technirez R1025 and Technirez R1510 – in addition to Epigen 0301MRD. Flow testing of epoxies was also undertaken as part of the trials to evaluate the viscosity of the epoxy material, which was identified as the most important characteristic to consider when choosing an epoxy material for timber pile repairs'.

Main Roads advised that they were pleased with Technirez R1510 for its faster processing time, relative to Technirez R1025, and its excellent penetration. As Technirez R1510 is not ultraviolet (UV) stabilised, a high–density polyethylene (HDPE) formwork was utilised. It was found to be sufficiently flexible to suit the required application, and its UV stabilised property provided better longevity for a permanent solution.

Several process improvements were identified throughout the field trials. It was concluded that the approach and method developed are satisfactory with opportunities for a number of process improvements including the epoxy resin system, pile preparation and possible training sessions with new contractors or new installers prior to works being undertaken.

The information gathered from the investigations and field trials has led to the delivery of updated technical guidance documentations, including Main Roads Specification 850 Timber Bridges Specification and Timber Bridge Preventative Maintenance Manual (Document No. 6707/02/2226). The field trial outcomes and the proposed changes to these documents were discussed in a virtual workshop with key stakeholders in Main Roads. Valuable feedback was provided from this workshop with refinements made to the document to ensure they are fit for purpose.

In addition to the field trials and workshop, the project stage also included an assessment of the feasibility of extending the use of epoxy resins to piles as a strengthening solution. The aim was to identify key parameters and performance properties of epoxy materials that are required to undertake a detailed structural analysis and provide AECOM, a design stakeholder engaged by Main Roads, with sufficient information to assess the suitability of epoxy as a strengthening solution for decaying timber piles. Further testing to validate the limitations identified and to confirm the shear strength values were suggested.

The next proposed stage of the project will evaluate through laboratory testing the mechanical and structural performance improvements on piles that have received epoxy repair. The project will focus on on-site field trials, laboratory testing and the development of a specification based on shear strength testing and modification of a design solution and construction methodology.

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1 Introduction

Main Roads Western Australian (Main Roads) is responsible for many bridges with timber piles which were originally constructed 60 to 80 years ago from Jarrah or Wandoo hardwood. Many of these bridges are of significant age. Main Roads has diligently monitored and identified a common defect pattern amongst these structures, with pile decay becoming an increasingly prevalent issue.

The common decay pattern has been internal pipe rot, which is detectable by drilling into the timber pile. The majority of the pile's length is typically in a sound condition apart from a short section at the waterline or groundline. This location of the pile is known as the 'rot zone' – a section of the pile that is exposed to both water and air creating a region of accelerated timber degradation. Within the rot zone, approximately 1 m of the pile shows signs of splitting, segmenting, finning and necking. These defects lead to a reduced localised diameter of the pile, resulting in a reduction of section and member load capacity.

Main Roads initiated epoxy resin injection solutions approximately 20 years ago as a semi-structural solution to mitigate further localised deterioration, and this repair method has been successful across many applications. Currently, this method is only utilised for piles that have been identified as having an adequate cross-sectional area intact to ensure continued support of the design loads. Main Roads has in the past assumed that the epoxy used does not contribute any load capacity to the member. Piles that have decayed as such that the remaining cross-sectional area doesn't provide adequate load capacity, require more extensive maintenance and refurbishment works to rectify, such as replacing the timber members with steel members or concrete potting.

Based on the method's past successes and its relative ease of use, a value opportunity has been identified to use epoxy resin as a method to increase the structural capacity of the pile. The aim of this report was to evaluate the current use of epoxy resin as a pile protection method and assess the applicability of extending its use to deteriorated piles to restore structural performance. The overall project was divided into a 3-stage process. This report addresses Stage 1 and outlines the initial scoping of Stage 2.

Stage 1: Protect and preserve

The repair preserves the pile in its current state. The pile has the same structural capacity as it did prior to repair with the advantage that it will not decay further. This stage was conducted by the Australian Road Research Board (ARRB).

Stage 2: Provide composite action only

The repair preserves the pile in its current state and enhances structural capacity. The materials injected into the pile provide sufficient adhesion and mechanical interlock to allow the segregated timber sections to perform as one composite section. This stage will be conducted by AECOM and ARRB.

Stage 3: Increase section capacity

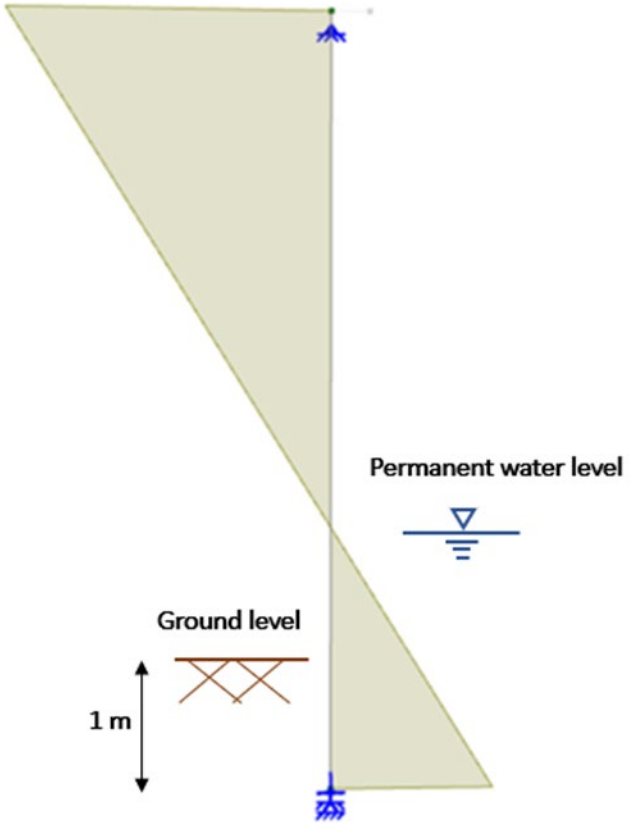
The repair preserves the pile in its current state and significantly enhances structural capacity. Additional actions are undertaken on the pile that results in an overall increase in section capacity from its initial, pre-repaired state. This stage is subject to future engagements and will consider the results of previous stages.

2 Background

2.1 Pile Modelling in Western Australia

Piles in Western Australia (WA) are often modelled structurally as propped cantilever columns. That is, moment fixity is below ground provided by the soil, and lateral restraint is at the top of pile by the deck. Moment is applied by eccentric loading at the top of the pile due to the timber half-cap sitting on one side of the pile. Due to the propped cantilever model, the bending moment diagram (BMD) is linear but is twice as large in magnitude at the top versus below ground. This creates a point of contraflexure roughly coinciding with the the rot zone, which in many cases may be advantageous for rehabilitation as it suggests a zone of weakness is occurring at the least critical point in the section for bending capacity. Refer to Figure 2.1 for the relevant pile BMD as generated by the Space Gass software.

Figure 2.1: Space Gass model of typical pile moment diagram

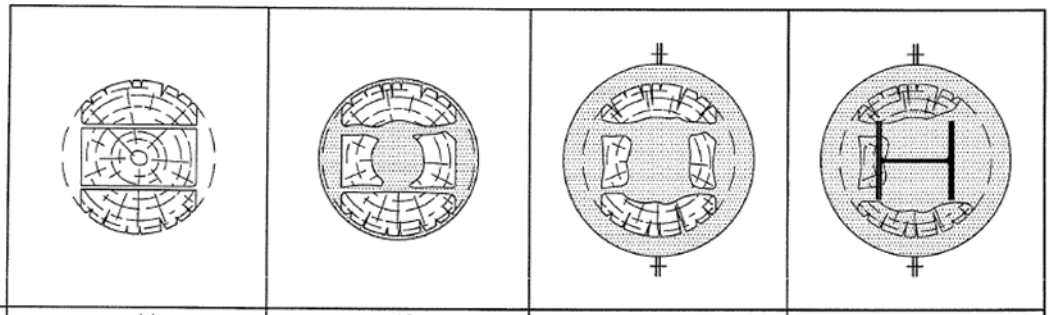


2.2 Current Specification and Methodology

The current Timber Pile Repair Methodology utilised by Main Roads is covered in Specification 850 – *Timber Bridges* (Main Roads 2019) and *Structures Practice Notes – Structures Engineering Document No: 6702/02/221* (Main Roads 2010). These documents provide guidance for a series of timber pile repair procedures, separating maintenance into 4 typical methods. The latest version of Specification 850 suggests only 3 of these methods are current (types 2, 3 and 4). Types 2 and 3 correspond with the potting of defective piles, and type 4 corresponds with piles presenting a loss in cross-sectional area.

Figure 2.2 provides a visual guide for type 4 repairs and suggests the relevant repair procedure based on a given timber pile condition.

Figure 2.2: Detailed repair options for sectional loss in piles



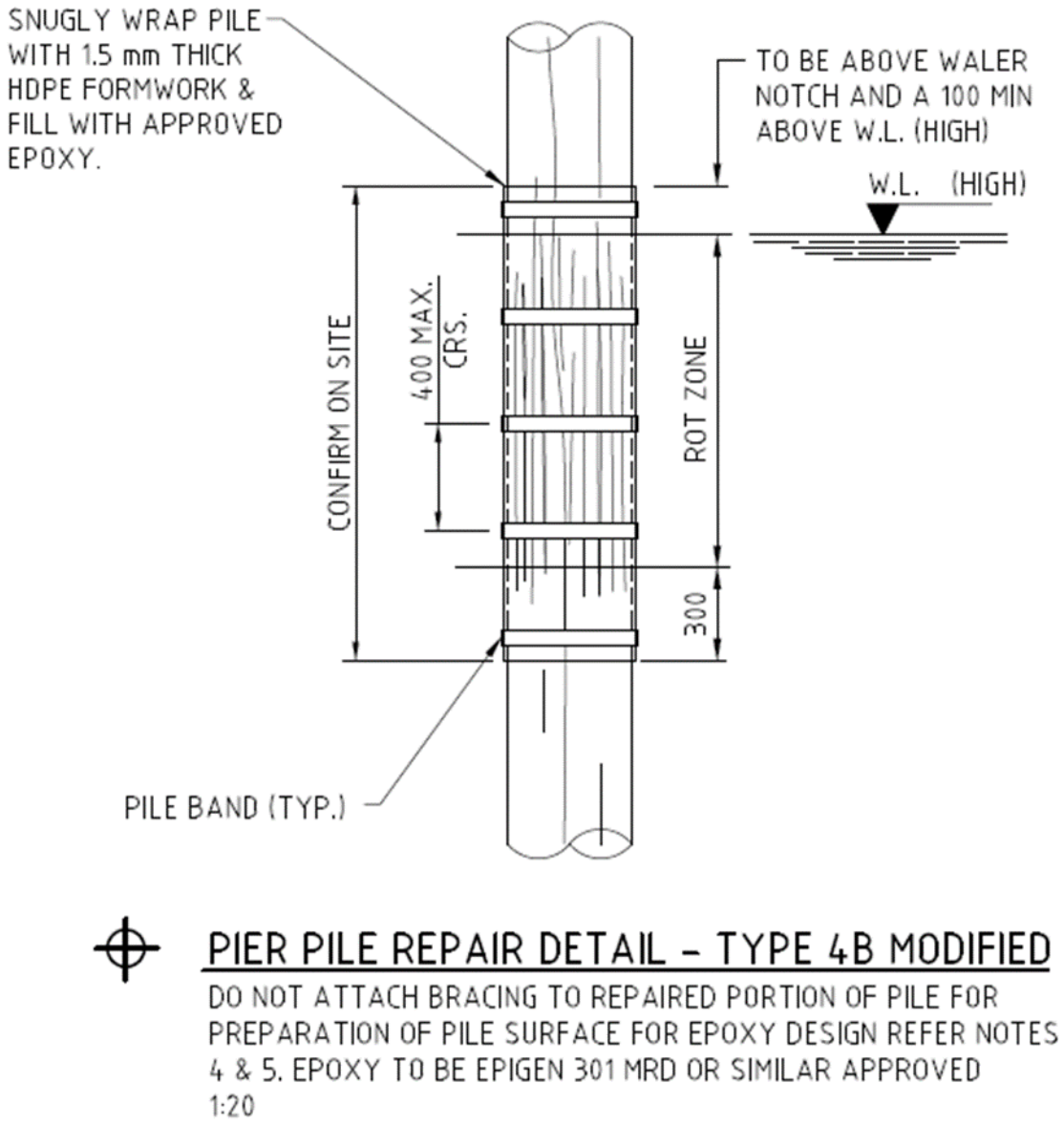
TYPE	4A	4B	4C	4D
EXISTING TIMBER CONDITION	PILE TIMBER IN GOOD CONDITION. NUMEROUS SURFACE SPLITS. WIDTH AT FACE TYPICALLY 5mm TO 15mm AND REDUCING QUICKLY WITH DEPTH. SPLITS NOT INTERCONNECTING.	SIMILAR TO '4A' BUT MORE SIGNIFICANT LOSS OF SECTION AT WALER BOLT LOCATIONS ø50 HOLES AND CENTRAL PIPE. TIMBER ANNULUS >90mm.	SIMILAR TO '4B'. EVEN GREATER LOSS OF SECTION AT WALER BOLT LOCATIONS, SOME INTERCONNECTED. LARGER CENTRAL PIPE. SOME SPLITS JOIN WITH PIPE VOID. TIMBER ANNULUS <80mm.	SIMILAR TO '4C'. SIGNIFICANT LOSS OF SECTION AND OR NON-SYMMETRY OF TIMBER RETAINED.
TIMBER CROSS SECTIONAL AREA	90% ORIGINAL CROSS SECTIONAL AREA OF TIMBER CAPABLE OF CARRYING LOADING.	70% ORIGINAL CROSS SECTIONAL AREA OF TIMBER CAPABLE OF CARRYING LOADING.	CAPABLE OF CARRYING AXIAL DEAD LOAD ONLY DURING REPAIR PROCEDURE. NEED FOR STEEL SLEEVE TO SUPPLEMENT TIMBER STRENGTH. MINIMUM AREA OF GOOD TIMBER AVAILABLE SHALL BE EQUIVALENT TO 250 x 250mm SYMMETRICALLY LOCATED ABOUT THE PILE.	INCAPABLE OF CARRYING DEAD LOADS IN AXIAL COMPRESSION. AREA OF GOOD TIMBER AVAILABLE LESS THAN 250 x 250mm AND/OR NOT SYMMETRICALLY LOCATED ABOUT PILE.
TIMBER SECTION STABILITY	GOOD	ADEQUATE	CONSIDERATION FOR PILE STABILITY DURING THE WORKS, i.e. REMOVAL OF UNACCEPTABLE MATERIAL MAY REVEAL THE CONDITION '4D'.	ALTERNATIVE SUPPORT FOR PILE LOAD DURING THE WORK IS REQUIRED.
WORK REQUIRED	HIGH PRESSURE WATER JET PREPARATION. PLUG ONE END OF EXISTING BOLT HOLES AND FILL HOLE WITH EPIGEN 301 MRD EPOXY OR SIMILAR APPROVED. SEAL INDIVIDUAL SPLITS >10mm WIDTH WITH EPIGEN 1614 OR SIMILAR APPROVED.	HIGH PRESSURE WATER JET PREPARATION THEN WRAP WITH 0.8 mm THICK CLEAR ACRYLIC BEFORE APPLYING EPIGEN 301 MRD EPOXY OR SIMILAR APPROVED.	HIGH PRESSURE WATER JET CLEAN, THEN FIT STEEL SLEEVE AND FILL WITH CONBEXTRA UW GROUT OR SIMILAR APPROVED.	HIGH PRESSURE WATER JET PREPARATION CUT AWAY DETERIORATION ZONE AND ADD UC SECTION, THEN FIT STEEL SLEEVE AND FILL WITH CONBEXTRA UW GROUT OR SIMILAR APPROVED.

Source: Main Roads (2010).

The type 4B is of particular interest to this investigation, as it represents the current Main Roads procedure for repair of piles with presence on internal pipe defect mechanism detailed in Section 1. Since inception of this document further adjustments have been made to the repair methods based on feedback and lessons learned in field trials, leading to modified details on drawings

Further detail on a modified type 4B repair method is provided in Drawing No: 1930-0332-1, which shows the repair methodology for the timber piles on Main Roads' Bridge 0681 over Moore River. An excerpt of this drawing is shown in Figure 2.3 (AECOM 2019).

Figure 2.3: Typical type 4B pile repair methodology



Source: Drawing No: 1930-0332-1, AECOM (2019).

The current methodology for pile repair is outlined in Specification 850 as follows:

i. All piles nominated as requiring splinting or epoxy repair shall have all bolts and loose rotten material thoroughly cleaned with a high-pressure water jet and compressed air. This process shall continue until a quality of wood is exposed that when drilled produces timber particles of 2–3 mm length.
ii. The newly exposed section shall then be sterilised in Boracol 200RH.
iii. Piles classified as type B shall be wrapped with a 3 mm[1] clear acrylic which extends a minimum of 200 mm and a maximum of 300 mm below the deteriorated zone and a minimum of 200 mm and a maximum of 300 mm above the deteriorated zone.
iv. The bottom of the acrylic wrap shall be fastened as shown on the Drawings.
v. The wrap shall then be filled with Epigen MRD epoxy or similar approved by the Superintendent.
vi. The epoxy shall be used in accordance with the manufacturer's published recommendations.

[1] This thickness is inconsistent throughout Main Roads literature. Three millimetres has been confirmed as the thickness currently used in practice.

2.3 Historical Use

The following sections presents cases of pile repairs on bridges using either epoxy resin or cementitious grout.

2.3.1 Bridge 0950

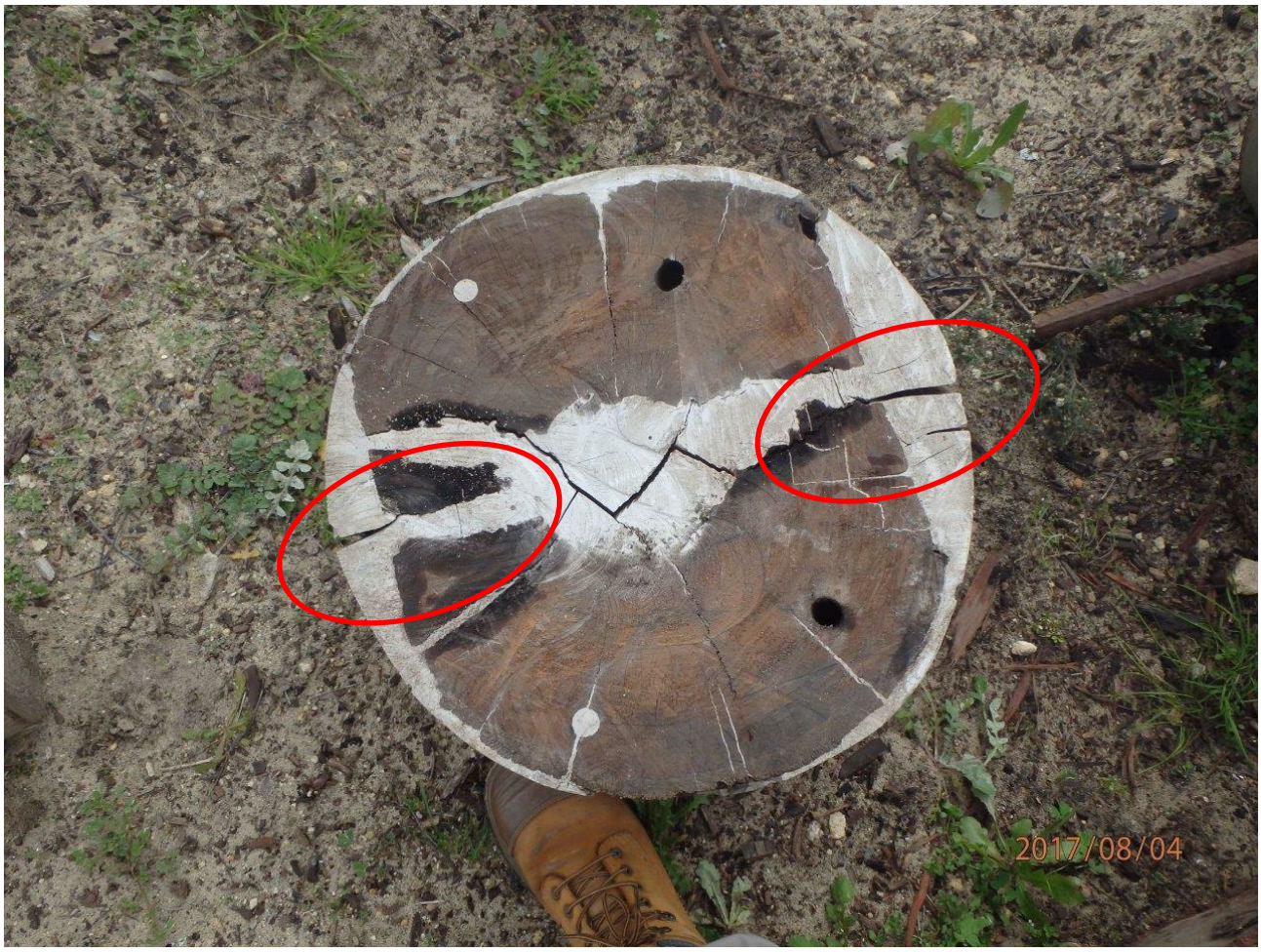
The first recorded use of epoxy resin as a design solution was on Main Roads Bridge 0950, Garratt Road, in the 1990s. Main Roads observed significant section loss in the pile at the rot zone, similar in nature to Figure 2.4. As the pile's loss of section was not yet severe enough to warrant structural replacement, Main Roads made the decision to attempt a less intrusive preservation solution, wrapping the pile in acrylic sheet and coating it in epoxy resin. The epoxy resin utilised is unknown.

Figure 2.4: Loss in section of pile in rot zone taken from Bridge 0950

Source: Main Roads.

Bridge 0950 recently underwent further asset management works, at which point Main Roads had the opportunity to remove a resin cast section of pile, shown in Figure 2.5. The timber pile shows lack of decay, with epoxy penetration into both large and minor cross-sectional cracks. Cracks formed in the outer annulus of the epoxy resin have not extended throughout the cross-section as indicated in red in Figure 2.5

Figure 2.5: Section of repaired pile taken from Bridge 0950



Source: Main Roads.

2.3.2 Bridge 0752

Following the successful use of epoxy resin on Bridge 0950, Main Roads progressed to further refine the methodology of its use on Bridge 0752, a bridge over the Mortlock River in Northam. By adjusting the viscosity, colour and material of the formwork Main Roads is preparing updated technical drawings for the repair method. This epoxy was labelled Epigen 0301MRD.

Main Roads observed that the external resin annulus appeared to crack along pre-existing splits shortly after the repairs had been undertaken. As the cracks terminated close to the surface of the annulus and did not propagate throughout the pile, The cracks were deemed to have no effect on performance; however, it does appear aesthetically unpleasant as shown in Figure 2.5 and Figure 2.6

Figure 2.6: Resin coated pile on Bridge 752

Source: Main Roads.

While experimenting on Bridge 0752, Main Roads observed the behaviour of the acrylic formwork left in situ. The acrylic became brittle and cracked and was aesthetically unpleasant as it aged.

2.3.3 Bridge 0782

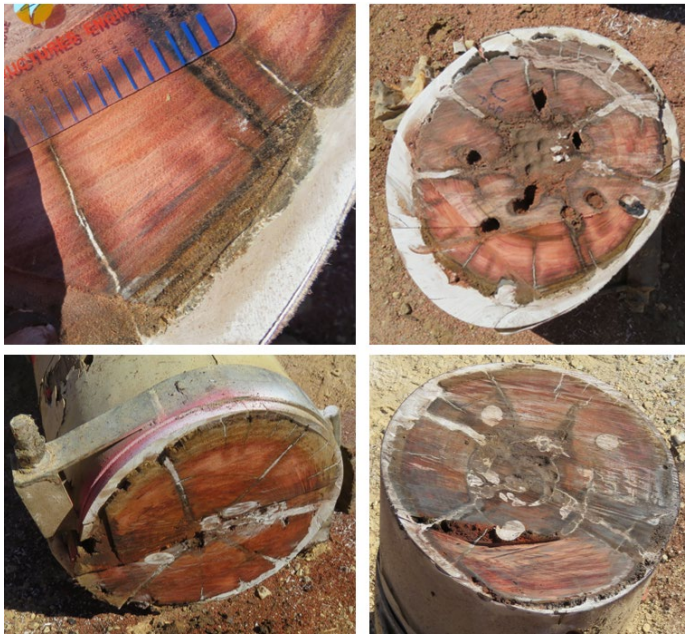
Main Roads utilised the developed practice note as referred to in Section 2.3.2 to repair the piles on Bridge 0782. One pile featured a diagonal strut resulting in an excessively thick annulus that presented severe cracking shortly after the repairs. (Figure 2.7)

Figure 2.7: Thick annulus cracking apart on Bridge 0782.

Source: Main Roads.

Main Roads recently removed the treated piles on Bridge 0782 and cut slices in the timber to inspect the internal condition (Figure 2.8). The timber inside was preserved in excellent condition, with epoxy penetration to cracks as thin as 0.2 mm.

Figure 2.8: Removed piles with cut sections on Bridge 0782



Source: Main Roads.

2.3.4 Use of Cementitious Grouts

Prior to using epoxy resins, Main Roads repaired piles utilising a cementitious grout product. It was observed that the flowability of the grout posed issues when penetrating the internal pipe. When pile sections were cut, it was noted that the grout had encased the pile rather than flown through it. This raised concerns about the overall durability of the system should this outcome occur.

These concerns were confirmed on Bridge 0672, where Main Roads observed that if there was significant internal pipe that the grout had failed to penetrate and the pipe continued above the top of the rot, moisture and oxygen levels within the pipe remained sufficient for rotting to continue within the repaired zone (Figure 2.9). Notably, if the timber pile was solid at the top of the encasement, insufficient oxygen was present for the piles to rot.

Figure 2.9: Removed piles on Bridge 0672

Source: Main Roads.

3 Epoxy Resin Investigation

The epoxy resin investigation evaluated the current Main Roads repair method 4B and identified process improvements. Based on this investigation, this report provides the framework for future trials and highlights materials that may warrant investigation for future use.

When scoping this project, ARRB and Main Roads identified that epoxy resins were the obvious choice for investigation, as their structural and chemical properties make them inherently suited for this application. It is noted, however, that there may be merit in conducting trials with non-epoxy-based materials as industry continues to innovate.

3.1 Stakeholder Design Considerations and Prerequisites

3.1.1 Main Roads Considerations

Main Roads indicated that an ideal pile repair solution would take the following into consideration:

- It would be as simple as possible for small periodic maintenance crews to undertake installation to ensure repeatable outcomes are achieved amongst all who perform the works.
- Process complexities would be kept to a minimum. Given the location of the works conducted, it is impractical to require equipment such as pumps, vacuums and heating to conduct the works.
- It would be suitable for inexperienced subcontractors. Due to the size and sparseness of WA, the installation process must not rely heavily on past knowledge and experience and must be well documented to avoid ambiguity.
- It should be low cost. For a method to be a viable option, it must be more economic than equivalent large scale works that would significantly improve the design life.
- It would be a solution that involved permanent formwork, saving time at the end of installation where a contractor would typically need to return to site and strip the piles.
- To be a viable solution, the lifetime extension to the pile must be a minimum of 20 years before replacement is required, preferably 40 years.
- As it has been previously observed that the external annulus does not provide tangible strength benefit, it is desirable to minimise this to the smallest practical thickness.
- It should be able to be set up in water a) with the formwork reaching the riverbed or b) where the repair area is suspended partly up the pile.

3.1.2 Contractor Considerations

In discussions with a contractor with experience undertaking Main Roads' repair method type 4B, it was identified that an ideal repair solution would take the following into consideration:

- Mixing of the resin on-site needs to be a very simple process, and should ideally be achievable using a battery-operated mixing drill.
- Fillers that increase thixotropic properties of the net mixture are undesirable as they will slow the installation process.
- The material required varies per pile, depending on the depth of the damaged section, and the loss of the section observed.
- The current repair method does not detail a seal at the base of the pour, which often leads to an excessive resin volume and a high amount of waste.

3.2 Existing Literature

A literature search on the use of epoxy resin as a method of repairing timber piles showed that this solution has been conceptualised by multiple researchers and road authorities around the world.

In the USA, the Nebraska Department of Transport (DoT), Iowa DoT, Oklahoma DoT and Minnesota DoT have conducted research and field investigations on the suitability of epoxy resins as a repair tool for timber piles on their extensive timber bridge network. The following sections detail the methods that are similar to the Main Roads approach.

3.2.1 Oklahoma DoT Method

The Oklahoma DoT has developed an in situ repair technique for decaying timber piles that utilises a combination of in-fill aggregate and epoxy resin. The methodology is as follows:

1. Holes are drilled throughout the outer shell and spaced to allow for cleaning and placement of fill material.
2. The exterior void is cleaned by vacuuming, flushing and sawing, and the timber is then allowed to dry.
3. Holes are drilled above and below the affected region and treated with borate rods to prevent further decay. These holes are then plugged with dowels.
4. The void space is filled with aggregate, and the pile is transversely wrapped with fibre material and set with resin.
5. Holes are then drilled once again to inject epoxy resin. The injection port holes are drilled to allow the resin to travel upwards through the pile.
6. The injection ports are sealed and, finally, coated with an ultraviolet resistance coating.

A cross-section of a pile that was treated through the Oklahoma DoT method is shown in Figure 3.1 (Emerson 2004). Oklahoma DoT proceeded to test the piles repaired with this method under axial compression. The piles failed with timber splitting from the central core and collapsing in compression. Added strength could not be quantified, and it was noted that the piles failed below design axial strength.

Figure 3.1: Cross-sections of repaired piles utilising the Oklahoma DoT method

Source: Emerson (2004).

3.2.2 St. Louis – San Francisco Railway Company Mortar Injection Method

In 1973, the St. Louis – San Francisco Railway Company developed a method for pile repair by injecting cementitious grout under pressure to fill the voids of defective piles (Dahlberg et al. 2012). The following method was used:

1. Pile voids were drilled with 32 mm diameter holes with 2 or 3 10 mm air holes drilled above.
2. Voids were then flushed with water and blown out with air to remove loose particles.
3. Depending on the condition of the pile, nails with washers were driven in to provide a shear interaction with the external grout.
4. A grout based on standard Portland cement was then injected into the pile at pressure, with any leakage zones quickly sealed using a quick set grout.
5. All holes were then plugged, and the pile was left in situ.

While not utilising an epoxy resin, this method was considered relevant as it represents an example where an infill material was the primary preservation mechanism.

3.2.3 Utilisation with Fibre Reinforced Polymer (FRP)

The most predominant usage of epoxy resins found in the literature review and anecdotal findings was in conjunction with a fibre reinforced polymer (FRP) shell, which is intended to provide local shear and axial strength to the pile in the repaired region. As this method of repair is intended to restore performance in the pile, it was considered outside the scope of Stages 1 and 2 of the project. Main Roads' experience with this material has been problematic as the sheet tends to rupture when the timber pile swell as a result of trapped moisture, causing induced hoop stress in the sheet..

3.3 Epigen 0301MRD (Main Roads' Current Solution)

The current product utilised by Main Roads in timber pile repairs is Epigen 0301MRD, which is manufactured by Peerless Industrial Systems. Main Roads originally selected this epoxy resin due to its flowability and high strength setting characteristics. Epigen 0301MRD is currently advertised as a pile encapsulating resin; however, it is unknown if this was the case at the time of early trials.

The technical staff at Peerless Industrial Systems commented that the primary problem faced in the field when using Epigen 0301MRD was avoiding uncontrolled exotherm, an event in which the chemical reaction of the epoxy resin setting creates excess heat which compromises the quality of the casting. Uncontrolled exotherm in epoxies is characterised by a surface yellowing and crazing. Main Roads noted this phenomenon was observed in piles extracted from a structure treated with Epigen 0301MRD approximately 20 years ago, as shown in Figure 3.2.

Figure 3.2: Epoxy resin with noted yellowing and surface crazing

Source: Main Roads.

Although excessive internal cracking was not observed throughout these samples, Peerless Industrial Systems warned that this cracking can often be representative throughout an entire sectional area, leading to a reduced life of the repair.

The proposed solution to this issue is the addition of sand to the mix as a filler material, with the sand slowing the rate of reaction and limiting the exothermic effects. However, this results in a significant trade-off on viscosity and penetration of small splits, which has previously been identified as a key factor in the quality of installation.

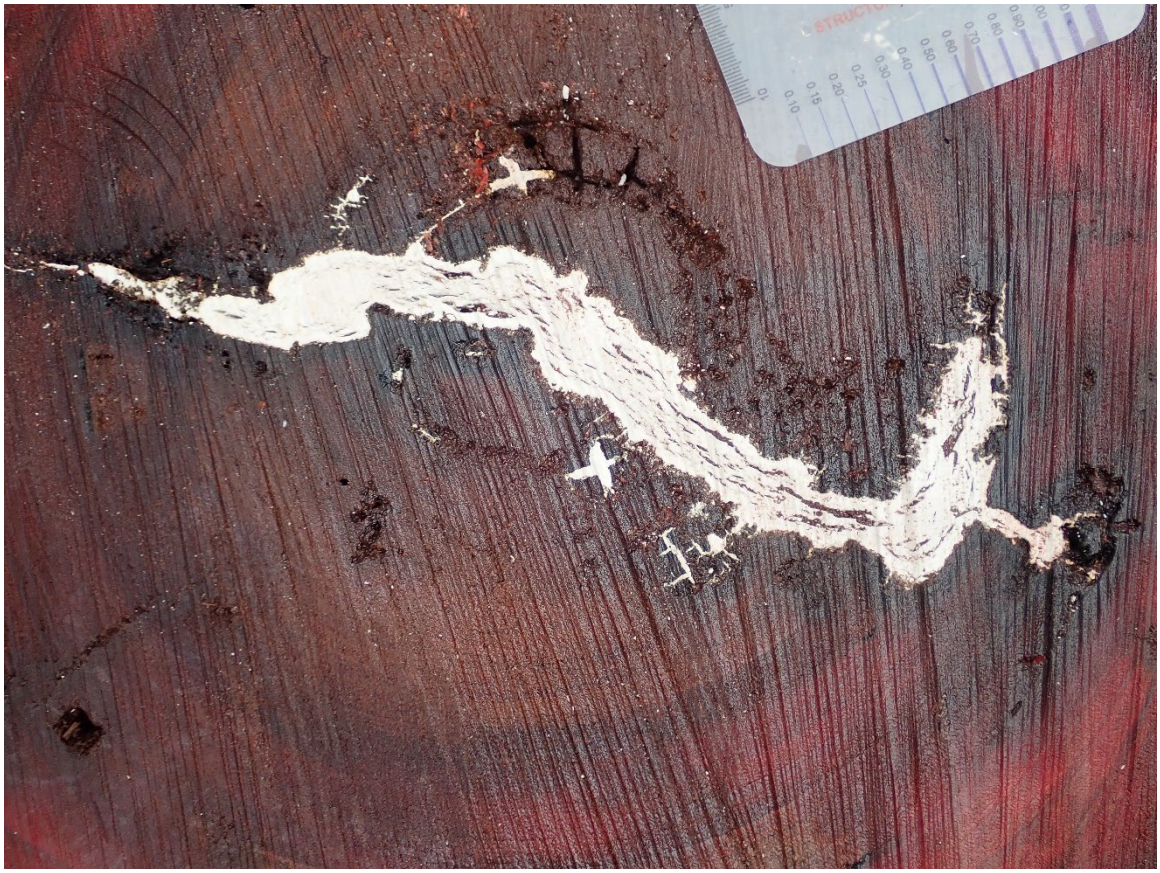
Piles removed from Scott Street Bridge and assessed by Main Roads did not show any evidence that sand filler had previously been used, likely because the risk of the uncontrolled epoxy exotherm outweighed the risks of reduced penetration through the section due to higher viscosity and reduced epoxy flowability.

Further cross-sections taken from these piles, treated 20-years ago, show good overall penetration (Figure 3.3) of the epoxy into the hollow pipe region, although not without areas of voids where the epoxy did not flow due to debris or decayed matter that was not removed in the preparation process (Figure 3.4).

Figure 3.3: Cross section of Epigen 0301MRD repaired pile

Source: Main Roads.

Figure 3.4: Typical minor sections where epoxy has not flowed



Source: Main Roads.

3.3.1 Moisture Swelling and Epoxy Shrinkage

Main Roads observed that encased timber piles appear to show a higher moisture content than timber piles that is not encased. It is believed this is a result of the pile wicking up moisture from the surrounding groundwater. The increased moisture build-up creates swelling of the timber within the pile. It is noted that moisture present in Figure 3.3 and Figure 3.4 is not representative of this, as the surface of the slices were washed prior to photos.

In contrast to this swelling action, as the poured epoxy resin cures it undergoes shrinkage. The compounding of these 2 effects creates internal stresses within the timber-epoxy matrix leading to cracking of the outer epoxy annulus. This often coincides with the natural pre-existing splits within the pile.

3.3.2 Outer Annulus Cracking

Cracking of the outer annulus does not indicate a failure of the system but is a by-product of the above-mentioned swelling and shrinkage effects the pile experiences. Main Roads has observed that in instances where external annulus cracking occurs, these cracks do not propagate past the surface of the pile, as represented in Figure 2.5. Misinterpretation of this phenomenon may lead to the conclusion that the repair method has failed, which is not the case.

Main Roads has noted that, in severe instances, the annulus will have cracked to such an extent that the timber had become re-exposed. In these locations the external section of the affected zone showed weathering effects consistent with the surrounding exposed solid sections; however, the internal epoxy remained in good condition and stalled further internal rotting.

3.4 Availability of Epoxy Resins on the Australian Market

Since their invention in 1946, epoxy resins have gained popularity across a variety of industries where they are utilised in structural applications such as laminates, composites, tooling, moulding, casting, construction, bonding and adhesives (Gannon 1986).

Due to their widespread popularity and range of uses, there is no shortage of options available on the Australian market, with chemical manufacturers offering a range of different product options and suggested use applications.

While it is beneficial to have such a broad variety available, it creates difficulty in specification. Typical prerequisite characteristics of epoxies vary significantly depending on their intended use. In fact, properties of epoxy resins can vary significantly.

3.4.1 Epoxy Requirements

Based on Main Roads' previous experiences with Epigen 0301MRD, the criteria included in Table 3.1 were identified as requirements to set the framework of any systems that are to be considered alternatives within this report.

Table 3.1: Properties required to installation

Property	Requirement	Commentary
Viscosity	As low as possible	Viscosity is the most important characteristic for consideration, as flowability of the epoxy is critical for filling internal voids within the pile. Main Roads has previously trialled using more viscous options, such as cementitious mortars, with low levels of success due to the inability of the mortar to flow through the pile.

Property	Requirement	Commentary
Permeability	Impermeable	The epoxy resin must halt further degradation within the rot zone of the pile. This is accomplished by isolation from the combination of water and oxygen. As such, the epoxy resin must be impermeable once set.
Bond characteristics	Sufficient interlock to dissimilar materials	The epoxy resin must form a strong bond with dissimilar materials, specifically wood. The presence of water needs to be observed so the material interlocking is not compromised. Epoxies that do not bond well to dissimilar substrates are not considered suitable.
Shrinkage	1–3% max	As previously discussed, shrinkage must be mitigated as the timber swells because of encapsulation. Excessive shrinkage may create significant internal stresses and lead to crack formation.
Pot life	Higher preferred	Due to the flowability requirements of the resin, a high pot life is desired to ensure the material does not increase in viscosity significantly throughout the duration of the pour. It is noted that this does not apply to the plug mix(1), whereby a shorter pot life is desirable.
Cure time	Lower preferred	A low cure time is desirable for the initial plug mix, as this sets the base layer for which the main mix is poured over.
Characteristic strength	Negligible	The preserve and protect solution assumes that the pile is still entirely load bearing through the existing section of timber i.e. the epoxy is not performing any structural work other than preservation. As such, while relative strength will be noted, it is not a priority in Stage 1.

1. Plug mix corresponds to an initial layer of material featuring additives that accelerate the cure time. This approach was identified as being beneficial in the second trial, and further information and discussion can be found in Section 4.5.

3.4.2 Review of Suitable Epoxy Resins

Engagement of suppliers and utilisation of expert knowledge was found to be the most efficient method of retrieving information on epoxies that fit Main Roads' desired criteria. Providing a usage case and indication of the required properties gave suppliers a satisfactory level of information to make relevant suggestions. All suppliers who were approached were cooperative and willing to make recommendations and appropriate disclaimers for the application described. A summary of suggested epoxies is presented in Table 3.2.

Table 3.2: Alternative epoxy resins for consideration

Product	Viscosity (mPas^{-1})	Pot life (minutes@^{o}C)	Tensile/ compressive strength (MPa)	Cure time (Hours)
Epigen 0301MRD	–	30@24	21/100	6
Technirez R1025	4,000–5,000	40–50@25	28/65	24–36
Technirez R1510	180	720@25	–/–	72
QuakeBond 320 LV	780	20@25	54/77	–*
MasterEmaco 2525	–	–	60/95	168
MasterBrace 1446	–	30@23	14/70	168
Master bond 88FL	800–1,200	20–30@24	3–8/–	24–48

*QuakeBond 320LV was advertised as able to cure underwater.

Sources: Peerless Industrial Systems, ATL Composites, Master Builders, Master Bond.

Feedback from the suppliers throughout the research process was often cautionary that the performance of the suggested epoxy resins could not be guaranteed without conducting field trials. In further discussions with the suppliers this was understood to be due to the niche usage and the uncertainty of adhesion to in situ timber.

Furthermore, the quantitative information provided by the epoxy manufacturers often fall short with information such as viscosity, permeability and shrinkage either completely omitted or represented by unclear commentary.

Based on this feedback, it was deduced that a field trial stage would add significant benefit to the overall report findings, as it would serve the dual purpose of addressing the above uncertainties and ensuring due diligence was undertaken as per the suppliers' recommendations.

4 Field Trials

4.1 Field Trials Arrangements

Two field trials of selected epoxy materials were planned. ARRB coordinated several meetings to discuss Main Roads' requirements, the availability of the epoxy materials and their properties. Through collaboration with industry, 2 products (Technirez brand) were shipped from Queensland. After the initial two field trails, a third trail was performed to further refine the repair methodology. The third trail is presented in section 4.6

ARRB's scope was to:

- identify appropriate products based on the literature review and market survey
- discuss the product selection process and make recommendations based on the products' suitability for Main Roads' requirements
- ensure supply of the selected products for the field trials
- coordinate with Main Roads and attend the field trials
- provide on-going technical support during the trials

Main Roads' scope was to:

- select bridge sites for the field trials
- arrange logistics for the field trials – crew and equipment
- manage product preparation as per manufacturer recommendations
- execute field trials at the nominated sites.

4.2 Epoxy Selection

Based on the epoxies listed in Table 3.2, the decision was made to trial the Technirez brand of epoxy resins listed because:

- The 2 different products recommended presented considerably different viscosities, allowing for the deduction of an optimal value or range.
- Adhesive Technologies, Southport Qld, (the supplier) was enthusiastic to support the trial, citing a high level of technical support and national product availability.

4.3 Trial 1 – Technirez R1025/H26 Slow Epoxy and Epigen 0301MRD

4.3.1 Background

Trial 1 was conducted on timber piles at WA Bridge 4512 over the Helena River at Scott Street, Helena Valley, WA (Figure 4.1). The trial consisted of 2 epoxy pours: Epigen 0301MRD on 28 August 2020 and Technirez R1025 on 2 September 2020. The aim of this trial was to compare the performance of the existing procedure utilising Epigen with the new Technirez epoxy.

Technirez R1025 is a medium viscosity resin system that is designed to perform well in higher volume casting applications. The longer pot life makes it a suitable option for use in warmer periods of the year without risk of premature flashing. Technirez R1025 cures to a very high surface hardness, offering excellent resilience to the external environment.

This site was selected as there were 2 neighbouring piles in the river channel with identical environmental exposures. Over 20 years ago, one pile was in worse condition and treated with epoxy. The other pile was left untreated. At the time of the trial, the untreated pile was now in visibly worse condition and planned for

potting. This created an opportunity to apply different epoxies to the untreated pile. Then both piles were removed and sliced for comparison.

Figure 4.1: Trial 1 site – Bridge 4512

4.3.2 Construction Method

The following was the construction method used for the trial:

1. Debris was cleaned from the pile by waterblast.
2. The base of the formwork was sealed with foam.
3. Nails were used as spacers for the formwork at the top, middle and bottom of the wrap. Nails sat around 10 to 20 mm proud of timber.
4. Plastic formwork sheet was wrapped around the pile and secured with straps where the sheet laid on nails.
5. Epoxy parts were combined and mixed.
6. Epoxy was poured into the formwork via a funnel.
7. Three units of Epigen was used to fill pile defect.

4.3.3 Flow Testing

As part of the trial, flow testing of the epoxies was undertaken shortly after mixing to evaluate the rate at which the material ran into the casting. As shown in Figure 4.2, a standard funnel was filled to the brim with the selected epoxies and water was used as a control fluid. The time to empty was then recorded for each material using a stopwatch. Results of these tests, as well as the measured ambient temperatures, are presented in Table 4.1.

Figure 4.2: Flow time testing of Epigen 0301MRD

Source: Main Roads.

Table 4.1: Initial flow and temperature recordings

Material	Item	Time of day	Temperature (°C)	Flow time (s)
Water (control)	**Water**			**2.5**
Epigen 0301MRD	Ambient temperature	9:15 am	16.8	
	Epoxy temperature after mixing	**9:21 am**	**18.2**	**25**
Technirez R1025	Ambient temperature	8:28 am	13.8	
	Epoxy temperature after mixing (first batch)	8:28 am	17.4	
	Epoxy temperature after mixing (second batch)	**9:25 am**	**17.5**	**52**

Source: Main Roads.

A unit of Epigen was also set aside for testing, with flow time progressively measured as the material began to set. Unfortunately, the data provided was not complete; however, what can be deduced is the epoxy remained acceptably flowable for 27 minutes after mixing, which aligns with advertised pot life. Additional comments from Main Roads acknowledged that, past this point, the epoxy set rapidly. Refer toTable 4.1 andTable 4.2 for initial and subsequent set times.

Table 4.2: Epigen flow time vs temperature

Time since mixed (minutes)	Temperature (°C)	Flow time (s)
0		25
7	25	24.5
10	28	24.75
18	34	24.5
24	41	28
27	51	33
	60	59
	64	Set – unflowable

Source: Main Roads.

4.3.4 Discussion

Throughout the installation process, it was observed that the higher viscosity of the Technirez created issues with the funnel and pipe arrangement that was being utilised for installation (Figure 4.3). To improve performance, the pipe section was later removed, and the epoxy resin was poured directly into the casting via a funnel.

Figure 4.3: Technirez R1025 flowing into wrapped pile

Source: Main Roads.

4.4 Trial 1 Results

Approximately 2 weeks after the initial pours, the epoxy-wrapped sections of pile were cut and moved aside to be cut into sections. The moisture content at the base of the pile prior to cutting was noted to be 26%, greater than the 22% below which decay was observed to commence.

Main Roads observed that the Technirez R1025 set hard and brittle with a glassy appearance, in contrast to the Epigen, which was more ductile.

Epigen 0301MRD

The Epigen section was cut with a chainsaw, and water was sprayed throughout for cooling and dust suppression. The moisture content at the fresh cut was 45%, which was notably high due to the water sprayed at the interface. Once dried out, the moisture content was remeasured at 35%. Filings of Epigen were observed to be like sawdust, with shards presenting a level of flexibility.

Overall, the Epigen appeared to have flowed well, penetrating all notable cracks in the section (Figure 4.4). Minor voids remained in the section where the formwork had not been fully sealed, or where debris had not beenadequately consumed.

Figure 4.4: Section of pile treated with Epigen 0301MRD

Source: Main Roads.

While these new trials were being undertaken, Main Roads took the opportunity to remove a pile that had previously been treated with Epigen 0301MRD on the same bridge 20 years prior. This would allow a direct comparison between old and new works and show the longevity of existing works on piles exposed to equivalent conditions. Figure 4.5 shows the 20-year-old slice and reaffirms previous findings that if good penetration of epoxy has been achieved, further decay of the pile will effectively halt. Therefore, it is expected that had the current treated pile been left in situ, it would have achieved similar performance for an extended period.

Figure 4.5: Section of 20-year-old pile treated with Epigen 0301MRD

Source: Main Roads.

Technirez R1025

The Technirez section was observed to be so hard that it could not be cut with a chainsaw, damaging the blade when attempted. As a result, the pile was split into wedges (Figure 4.6), making it difficult to assess internal crack penetration. It was, however, observed from a cut at the top of the pile that the Technirez product within the internal pipe was level with the outer annulus, suggesting that internal flowability was achieved.

Figure 4.6: Section of pile treated with Technirez R1025

Source: Main Roads.

Overall, Main Roads was satisfied with the result achieved utilising the Technirez R1025; however, the viscosity unfortunately rendered it unsuitable for practical constructability. Concerns were raised regarding the hardness and perceived brittleness of the Technirez epoxy, with the potential to crack apart as the pile swells. Main Roads did not note any advantages of using Technirez R1025 over the existing Epigen system, with the exception that the increased hardness may provide additional strength if used in a situation where the epoxy is required to improve section capacity.

4.5 Trial 2 – Technirez R1510/H510 Slow Epoxy

4.5.1 Background

Trial 2 was conducted on timber piles at WA Bridge 0235 at Bussell Highway, Capel, WA (Figure 4.7). The trial consisted of a single epoxy pour using Technirez R1510 on 15 February 2021. The aim of this trial was to evaluate the performance of a low viscosity option, relative to the epoxies used in trial 1.

Figure 4.7: Trial site 2 – Bridge 0235

Technirez R1510is a low viscosity resin system that offers a very long pot life relative to other epoxies investigated. As a result, this epoxy offers significant advantages in a gravity pour application, and penetration is expected to be excellent.

4.5.2 Construction Method

The following was the construction method used for trial 2:

1. Waterblast was used to clean debris from the pile, and holes were drilled into the pile horizontally to drain water.
2. An Ableflex layer was wrapped around the base of pile.
3. The pile was wrapped with HDPE formwork at a gap of approximately 10 mm and was held from the pile using deck spikes and fastened with a combination of silicon, tek screws and ratchet straps.
4. A quick-dry cement layer was applied at the base of pile.
5. Epoxy parts were combined and mixed, with resin installed in 2 separate layers – an initial layer (plug mix) with an accelerated hardener and a secondary layer without.

6. Epoxy was poured into the formwork via a funnel.

In trial 2 a greater focus was placed on adjusting the methodology and observing the effects on the overall process. The pile selected for repair had pre-existing holes that had been previously drilled for fungicide installation and capped with a plastic cap. The caps were removed to allow use as an inflow hole for water blasting, and an additional horizontal hole was drilled at the base of the repair to act as a drainage hole for central muck build-up.

Figure 4.8 shows that the base of the epoxy appeared ‘milkier’ than the upper section. This phenomenon is the by-product of a hardener additive mixed in with the initial batches of epoxy to reduce the chance of leakage. A strip of Ableflex foam was placed as an initial stopper seal at the base. Ableflex was selected as it appears sufficiently flexible to absorb local variances in the section profile of the timber, while also providing enough of a seal to withstand the hydrostatic pressure of the epoxy pour.

Below the Ableflex, an air gap was left and a foam backing rod wrapped below to prevent the external cement mix from entering. The intent of this arrangement was to determine whether the Ableflex alone would be satisfactory in sealing the base of the formwork.

Figure 4.8: Section of pile treated with Technirez R1510

Source: Main Roads.

4.5.3 Flow Testing

Flow testing was conducted as part of trial 2 in a manner consistent with trial 1 (Table 4.3). However, ambient temperature was not recorded on the day.

Table 4.3: Initial flow and temperature recordings

Material	Item	Time of day	Temperature (°C)	Flow time (s)
Water (control)	Water			2.5
Technirez R1510 (Sample 1)	Epoxy temperature at time of flow test	11:50 am	31.5	2.5
Technirez R1510 (Sample 2)	Epoxy temperature at time of flow test	12:15 pm	31.1	2.8
Technirez R1510 (Remains)	Remaining temperature test	2:40 pm	45	

4.5.4 Discussion

The additional holes drilled as part of the pile preparation were successful, with a flow path observed through the pile as water was blasted and water continuing to flow until clear. The water blaster was then inserted into the lower horizontal drainage hole and observed to flow up through the pile. While the hollow section pile has not been examined, it is expected that these minor process improvements reduced the quantity of internal debris left over pre-installation.

The pile was stripped approximately 7 days after the pour process. At that time, a 10 mm horizontal hole was drilled approximately 100 mm below the top of the repair. The drilled epoxy had a similar resistance as the solid timber. Water flowed from the hole at this time, suggesting typical moisture swelling had already occurred. Heavy rain was also noted in the days prior, which may be a contributing factor.

The pile was subsequently removed from the bridge and cut very close to the epoxy section. It was observed that the epoxy penetrated as expected based on the findings of a subsequent trial 3a (refer Section 4.6), designed to further refine the processes and methodology utilising WA Bridge 0238 at Busselton, i.e the epoxy penetrated into the small segments and appeared to perform the same as at Bridge 0238. It should be noted that the annulus of the epoxy at Bridge 0235 was larger than required and the seal at the base of the repair leaked into the surrounding ground due to the butt joint of the Ableflex foam seal.

The Ableflex implementation also proved successful, and when the pile was eventually stripped of formwork it was observed that the epoxy did not penetrate past this point, suggesting that, in future, cement curing will not be required, and Ableflex can be utilised as a sole sealing mechanism. Main Roads noted that the use of a success of a single layer of Ableflex may have been good fortune in this instance, and a more comprehensive method would need to be established for further trials.

A hardener was implemented to assist with a faster curing of the lower layer, which was highly effective in sealing the base of the pile. Future trials will further investigate optimisation by tweaking cure time, viscosity and consideration of fillers that may provide advantageous material properties.

At the time of testing, it was noted that unlike the epoxies utilised in trial 1, Technirez R1510 did not appear to significantly increase in temperature as it set. This is attributed to its higher advertised pot life, which leads to a slow reaction and less exothermic energy produced over a time delta.

Overall, Main Roads advised that they were pleased with the Technirez R1510, citing noticeably faster processing time relative to Technirez R1025 and excellent penetration. One drawback of the Technirez R1510 is that it is not ultraviolet (UV) stabilised, and as such, an external barrier will need to be implemented. High density polyethylene (HDPE) formwork was utilised in trial 2 and was found to be sufficiently flexible to suit the required application. Furthermore, HDPE is UV stabilised, providing better longevity for a permanent solution.

4.6 Trial 3a – Technirez R1510/H510 Slow Epoxy in Submerged Conditions

4.6.1 Background

Following the valuable information and lessons learned in field trials 1 and 2, it was agreed with Main Roads that a third trial would be scoped into the project, with the intention of further refining the processes and methodology.

Trial 3a was conducted on timber piles on WA Bridge 0238 at Busselton, WA and consisted of multiple epoxy pours using Technirez R1510 on 2 August 2021. The aim of this trial was to investigate the constructability and suitability of various formwork sealing options as well as epoxy 'plug' variants. Furthermore, the trials were to explore the feasibility of the developed approach in an environment where the repair area was at an equivalent level to the water line. Additional steps to isolate the pile from the surrounding water level were necessary, combined with a sound methodology for creating a water-tight seal at the base of the works.

Bridge 0238 was scheduled for demolition shortly after trials were conducted, making it an ideal candidate to undertake this approach with no major risk of recourse should the experimental method not successfully rectify the pile.

4.6.2 Construction Method

Following the successes of the second trial, the steps that were undertaken in that trial were documented with greater detail for use on future applications. As such, the planned construction method for trial 3a featured a much greater level of detail than prior trials, as follows:

1. A large steel drum was placed around the pile to full depth (Figure 4.9).
2. A hose was inserted and connected to a water pump to lower the water level within the steel drum.
3. Three 20-mm diameter holes were drilled at the top, bottom and below the existing pile defect.
4. Existing preventative maintenance plugs were removed.
5. The surface and inside of the pile were water jet blasted (by inserting a water blast lance in all holes repetitively to assist in flushing) to remove all debris and decomposed timber.
6. A formwork sealing layer was wrapped around the base of pile.
7. Three millimetres of HDPE formwork was wrapped around the pile as tightly as possible, with an 8 mm deck spike utilised to create space for the epoxy pour.
8. The pile was de-watered and the initial epoxy plug mix was poured and allowed to set.
9. A water-tightness test was undertaken to ensure the plug could withstand the hydrostatic pressure.
10. The remaining epoxy mix was to be poured into the formwork.

In line with the aim of this trial, several materials were reviewed for suitability. These are presented in Table 4.4 below.

Table 4.4: Scope of materials utilised in trial 3a

Formwork seal variants	Epoxy plug variants	Formwork wrapping	Main epoxy
Ableflex backing rod (25 mm)	Filler with 20-minute pot life (ATL2878)	3 mm HDPE sheeting	ATL Technirez R1510
EPDM sponge rubber (19 mm)	Filler with 15-minute pot life (ATL2877)	3 mm EPDM Rubber	
Silicon sponge chord (12 mm)	Filler with 300% typical viscosity (ATL2859)	1.5 mm EPDM Rubber	
Close cell neoprene foam			

4.6.3 Discussion

Unfortunately, trial 3a was abandoned prior to epoxy being poured into the pile. While the works crew made every attempt on the day, substantial difficulties were created by the volume of water present. Despite the efforts in creating a works zone around the pile (Figure 4.9), the base of the repair zone remained submerged, creating visibility issues. Furthermore, the Ableflex could not be efficiently held in place nor adhesively attached to the pile.

Figure 4.9: Pile isolation technique

Source: Main Roads.

Eventually the works crew were able to set up the pile for the works; however, a water tightness test soon found leakage occurring. At this point the attempt was aborted, with the decision made to wait until such time that the water level lowered and the base of the pile became more readily accessible.

Main Roads held a debriefing session following trial 3a. The following are the lessons learned:

- It is essential that repairs are undertaken when the surrounding water level is at or near its lowest point.
- Sound timber below the rot zone must be accessible for sealing the base of the pile effectively.
- There is a vulnerability to the base formwork seal if it is in a region of timber splitting.
- The base formwork detail must be re-evaluated to ensure it is robust enough to allow installation in a submerged environment.

4.7 Trial 3b – Technirez R1510/H510 Slow Epoxy in Submerged Conditions

4.7.1 Background

Following the unsuccessful attempt on WA Bridge 0238 at Busselton, trial 3b was scheduled to re-attempt the planned scope of works in a low water level environment. Main Roads continued to monitor the conditions at Bridge 0238, eventually identifying an opportunity to conduct the repairs on the 24 August 2021.

4.7.2 Construction Method

Following the events of trial 3a, adjustments were made to the methodology for trial 3b, specifically, the installation of the formwork sealing layer, to ensure a greater chance of success. Furthermore, as the water level was now below the base of the repair zone, isolation of the pile was no longer necessary. The updated methodology consists of:

1. Three 20-mm diameter holes were drilled at the top, bottom and below the existing pile defect.
2. Existing preventive maintenance plugs were removed.
3. The surface and inside of the pile were water jet blasted (by inserting a water blast lance in all holes repetitively to assist in flushing) to remove all debris and decomposed timber.
4. The formwork sealing layer was installed (refer Section 4.7.3).
5. Three millimetres of HDPE formwork was wrapped around the pile as tightly as possible, with 8-mm deck spike utilised to create space for the epoxy pour. HDPE formwork overlapped at the joint interface by a minimum of 200 mm and feature gasket (refer Section 4.7.4). HDPE was secured at the joint using stainless steel tek along the length of the pile at no greater than 50 mm centres.
6. The pile was de-watered and the initial epoxy plug mix was poured and allowed to set.
7. A water-tightness test was undertaken to ensure the plug could withstand hydrostatic pressure.
8. The remaining epoxy mix was poured into the formwork.

4.7.3 Formwork Seal Investigation

The various formwork base seals investigated were assessed for robustness, constructability underwater and effectiveness at sealing the formwork. The technique used to install the seal was as follows:

1. The lower end of the seal material (in good timber region) was located with a broad head nail, ensuring the nail was embedded sufficiently to allow the seal to be compressed by the formwork.
2. The seal was wrapped around the pile, forming tight, closely spaced loops, from the bottom up.
3. The top end of the seal was located with another nail, ensuring the nail was embedded sufficiently to allow the seal to be compressed by the formwork.
4. The formwork could then be installed on top of the seal by wrapping the HDPE sheeting around the pile (and over the seal). The formwork could be temporarily located with ratchet straps and/or tek screws as required.
5. The HDPE formwork was tightened from the bottom up, ensuring a ratchet strap was located directly on the seal material and tek screws were installed along the seam.

The following formwork base seals were assessed.

Closed cell Ableflex backing rod (25 mm)

A closed cell Ableflex backing rod (Figure 4.10) was found to be practical, with the above installation method achievable when utilising a 25 mm variant. Furthermore, the feedback on system constructability suggested this approach may be suitable for a submerged installation. Main Roads noted approximately 10 mm compression when the HDPE formwork was wrapped, resulting in an annulus of 15 mm. Seepage was observed between the layers of Ableflex, which was rectified through a caulked silicone at routine intervals around the installation. Overall, this approach proved the most cost effective of the materials trialled, with the Ableflex backing rod costing approximately $1.00 per metre.

Figure 4.10: Closed cell Ableflex backing rod installation

Source: Main Roads.

A closed cell Ableflex backing rod was concluded to be a suitable seal material when following the updated methodology and taking into consideration the comments outlined above.

EPDM sponge rubber (19 mm)

Installation of the EPDM sponge rubber(Industrial Gaskets n.d.) was easy, which was attributed to the elasticity of the material, which could be tensioned when wrapped around the pile (Figure 4.11). However, unlike the Ableflex backing rod, the material appeared to lack compressibility, making it difficult to achieve a tight seal between the formwork wrapping and HDPE sheeting. This material was also not cost effective relative to other products trialled, costing approximately 10 times the price of the Ableflex rod.

Figure 4.11: EPDM sponge rubber installation

Source: Main Roads.

The EPDM sponge rubber was concluded to be unfeasible due to its cost and lower relative compressibility relative to the other options trialled.

Silicon sponge chord (12 mm)

Installation of the silicon sponge chord was difficult due to the smaller diameter of the material. Furthermore, the material was not cost effective relative to the other products trialled, costing approximately 24 times the price of the Ableflex rod. Main Roads did not progress the silicon sponge chord to a full formwork set-up and trial, as the installation difficulties outlined above rendered it notably inferior.

Closed cell neoprene/Ableflex square foam

The close cell neoprene/Ableflex square foam was used in trials 1, 2 and 3a. While it proved effective in the original trials, trial 3a identified shortcomings when it came to an underwater set-up. The shape of the seal was vulnerable to installation error, which was attributed to the requirement to create a butt joint between the 2 ends. This approach relied on perfect alignment, which was simply not achievable in the submerged environment.

For this reason, a round 'looped' seal was preferred moving forward.

4.7.4 Vertical Seam

A vertical seam arrangement (Figure 4.12) was utilised in trial 3b. Insertion of a 12.7-mm thick strip of closed cell neoprene foam tape was used to seal the HDPE sheeting vertical joint. Compression was applied to the area through stainless steel tek screws at 50 mm centres.

Figure 4.12: View of vertical seam

Source: Main Roads.

4.7.5 Epoxy Plug Investigation

First utilised in trial 2 in the form of a hardener, the purpose of the epoxy plug was to create a watertight seal to prevent the main epoxy pour from leaking prior to curing. Given the successful outcomes realised in trial 2, Main Roads identified an opportunity to further investigate and experiment with various mixtures. The results of the trials of various mixtures are presented in Table 4.5.

Table 4.5: Epoxy plug investigation results

Epoxy Plug	ATL2878	ATL2877	ATL2859
Flow time (s)	68	24	8
Suitable for water-filled environment	Yes	Yes	No
Pot life (minutes)	20	15	Unknown
Self-levelling from single flow point	Yes	Yes	Yes
Temperature at base of form (°C)	41	38	Unknown

It is noted that flow time was measured in the same manner as in the earlier trials (see Sections 4.3.3 and 4.5.3) to allow a direct comparison. The suitability of the water-filled environment was assessed by observing the mixture's ability to displace water present between the pile and the formwork as it was poured into the pile. This is of particular importance in submerged environments where the mixture would need to flow through water to seal the base. Main Roads identified ATL2877 as the preferred variant for a plug mix based on flowability, pot life and water displacing characteristics.

4.7.6 Discussion

Main Roads was satisfied with the information obtained throughout this trial and was able to identify several process improvements. The combined installation method and associated materials identified above performed adequately for underwater installation, full height test and overall constructability. It is expected that with further minor modifications, this repair detail will be suitable for a range of applications and is sufficiently robust for specification as a standard repair detail.

4.8 Trial 3b Results

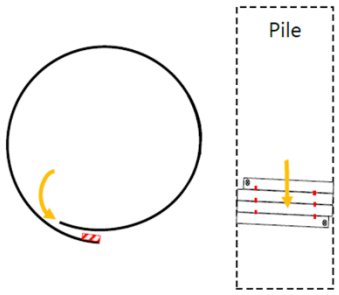
4.8.1 Post Repair Site Inspection

On 1 September 2021, Main Roads returned to the trial 3b site and removed the HDPE formwork from the trial repairs completed. In general, the performance of all epoxy-plug variants trialled was acceptable. This reaffirmed Main Roads' position that ATL2877 is the preferred variant due to its viscosity and fast curing time. Furthermore, the Ableflex sealing method performed well and was effective at forming a seal at the base of the repair zone. It is expected the diameter of material could be further reduced to 20 mm to produce a more economic result.

All piles exhibited mixing of main epoxy and water, evidenced by the presence of white, milky areas of the epoxy. This highlights the need to remove as much water from the pile as possible prior to pouring the epoxy. This includes draining water from the HDPE formwork if the plug mix has cured at a height above the water level. This would be achievable through drilling a small drain hole in the formwork that can be patched once standing water has been allowed to drain.

Slow epoxy leakage was observed around the 'loop channel' (area between Ableflex layers), which is believed to be a result of the interaction between the vertical seal and Ableflex base layer (refer to Figure 4.13). This observation should be addressed by future adjustment of the formwork overlap/seal detail.

Figure 4.13: Sketch of vertical seal and base layer interaction



Source: Main Roads.

The following subsections outline the observations for the 3b trial site where various methods were used.

Pier 3 Pile 1

Pier 3 Pile 1 was repaired utilising the Ableflex base seal approach and ATL2878 plug mixture. Observations were as follows:

- No vertical seal was used between the HDPE sheet lapping, leading to leakage of epoxy with minimal resistance. This highlights the necessity and effectiveness of the vertical seal approach developed.
- The plug mix utilised worked effectively; however, viscosity was higher than desired. The plug mix did not equally disperse around the pile, measuring 110 mm height below the pour location and 85 mm on the opposite side. Main Roads considered this to be acceptable.
- 25 mm Ableflex was wrapped around the base of the pile to create four layers to create a cumulative height of approximately 100 mm.
- Leakage occurred through pile splits in the region of the Ableflex. The plug mix was able to slow and eventually stop this leakage, an added advantage of plug mix curing underwater.

Pier 3 Pile 2

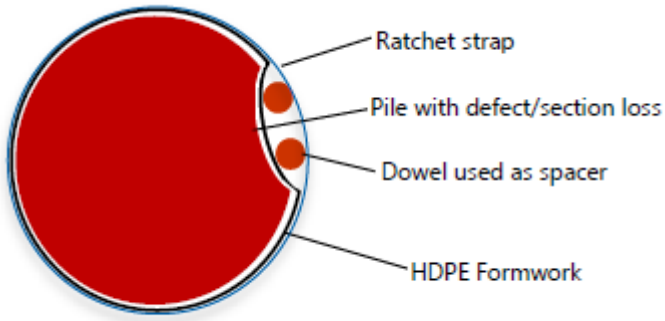
Pier 3 Pile 2 was repaired utilising the Ableflex base seal approach and ATL2877 plug mixture. Observations were as follows:

- The vertical seal/seam detail was constructed better than Pier 3 Pile 1; however, leakage still occurred through the loop channel.
- The plug mix dispersed in a similar manner to Pier 3 Pile 1, measuring 115 mm in height below the funnel and 90 mm at the opposite side.
- The main epoxy level dropped as the epoxy cured. This is possibly a result of epoxy penetrating the internal splits of the pile.
- Moisture wicking occurred and was observed above the level of the epoxy installation height.
- The Ableflex base seal approach appeared to be highly effective.

Pier 4 Pile 1

Pier 4 Pile 1 was repaired utilising a small pour specifically targeting the defect zone. This pile was purposely selected as it featured a scallop defect, which required insertion of a dowel spacer in the region of section loss to ensure effective formwork engagement. This is visualised in Figure 4.14.

Figure 4.14: Sketch of pile featuring scallop defect



Source: Main Roads.

Observations were as follows:

- The vertical seam had some leakage through the loop channel; however, silicone dobs applied through the Ableflex appeared to effectively block the leakage path.
- Three layers of Ableflex at the base of the pile was adequate.
- The use of tek screws worked well to locate and seal the formwork.
- The formwork was intentionally installed in a region of pile splitting to further investigate the effectiveness of the plug. Leakage was observed to slow adequately as the mixture cured, minimising any loss of materials.
- The plug mix exhibited signs of brittleness compared to the main epoxy mix.
- From an aesthetic point of view, the repair detail appeared neater when the formwork was left in place.

4.8.2 Pile Slicing and Cross-section Review

On 7 October 2021, 2 piles (Pier 3 Pile 1 and Pier 3 Pile 2) were removed from the bridge, relocated offsite and cut into sections. This process was undertaken to evaluate the effectiveness of the repair at penetrating the internal splitting and to allow direct comparison with previous trials.

The main epoxy penetrated the splits in both piles very effectively, with epoxy observed in regions of initial piping even though no splits were present in the pile. Notably, some regions of epoxy were observed to have not set. In these areas the epoxy was soft or spongey and white in colour, which may indicate the presence of water has inhibited curing (see Figure 4.15).

Figure 4.15: Main epoxy section Pier 3 Pile 1 showing soft white epoxy through the pipe

Source: Main Roads.

Thicker sections of the external annulus appeared to have cracking in areas corresponding to internal splitting. However, this cracking did not propagate into pile splits, consistent with historic results (see Figure 4.16).

Figure 4.16: Epoxy cracking

Source: Main Roads.

The plug epoxy of both variants penetrated most splits effectively; however, it did not capture all of them. The bottom section of the repair (the plug mix) was also notably harder than the pure epoxy mixture in the upper section and was more difficult to cut through. The Ableflex seal and plug epoxy interaction of Pier 3 Pile 2 performed well and allowed for visualisation of the epoxy slowing as it cured travelling through the Ableflex loops (see Figure 4.17).

Figure 4.17: Ableflex interaction

Source: Main Roads.

The moisture content of both piles was consistent and no shrinkage of timber away from the epoxy was observed. The epoxy had effectively sealed the pile between cutting and removing.

4.9 Discussion and Recommendations

It was concluded that the approach Main Roads is taking is satisfactory with opportunity for a number of process improvements, which are discussed in the following sections.

4.9.1 Epoxy Resin System

Of the epoxy resins tested, Technirez R1510 appeared to provide a good all-round epoxy system, providing improvements over both the Epigen 0301 MRD and Technirez R1025. In particular, the system's low viscosity and long cure time make it highly flowable and allows for both installation into a narrow annulus and the ability to 'forward prepare' multiple batches on site, increasing its overall efficiency. Furthermore, the properties of the epoxy suggest it would perform consistently in damp ground conditions and throughout hot, wet and dry cyclic seasonal changes.

The supplier has proven cooperative throughout, offering to package material kits in sizes nominated by Main Roads and in correct ratios, allowing for bulk batches without the need to decant and measure, removing the need for work crews to accurately measure and decant on site.

Unfortunately, as observed in the trial 3b pile sections, the miscibility in water was shown to be problematic, as material in zones of trapped water did not appear to harden and gain strength. This further raises environmental concerns in the event of a spillage into a wet creek. This limits the use of R1510 to installations in a dry environment, where water is not present at the time of the works.

Further environmental testing and monitoring is required to validate any proposed lifetime extension ability; however, based on the properties and past experiences with Epigen 0301 MRD, it is reasonable to expect a design life of 20 years or greater, ideally 40. As mentioned in the epoxy resin investigation, Technirez R1510 is not UV stabilised, and as such, this method would need to consider UV painting or implementation of permanent formwork.

Moving forward, additional constructability trials targeting a product that is suitable for installation into a wet environment are required to close out the functionality and environmental concerns raised above. Main

Roads has identified that the ideal product will be a similar system to R1510, with the ability to set firm in the presence of water. While low viscosity has been a priority item to date, it has been sufficiently identified through previous trials of Epigen 0301MRD and R1510, that below a certain value, the quality of penetration is not impacted, and a material that features a viscosity within this range would be satisfactory.

4.9.2 Pile Preparation

Pile sections cut as part of trials 1 and 2 showed that while the current cleaning process (Figure 4.18) is successful in removing the majority of trapped debris, it does not remove the complete quantity. Following the successful outcomes of trial 3, size and quantity of preparation holes are now stipulated as part of the pile preparation methodology.

Lessons learned throughout undertaking the third trial have highlighted the need to prioritise maintenance around times where the water level is likely to be low, such as the summer months and periods of low tide. While trial 3a ultimately had to be abandoned, there is still potential feasibility in conducting works in a flood environment through the implementation of processes developed in trial 3b, and as discussed in Section 4.9.3.

Figure 4.18: Timber pile cleaning with high pressure water

Source: Main Roads.

4.9.3 Installation method

Several process improvements were identified throughout the trials. Trial 3 focused on formwork and refining the methodology, which led to a greater understanding of the mechanisms contributing to installation quality. This has generated a number of learnings and recommendations, as described in the following subsections.

Formwork base seal

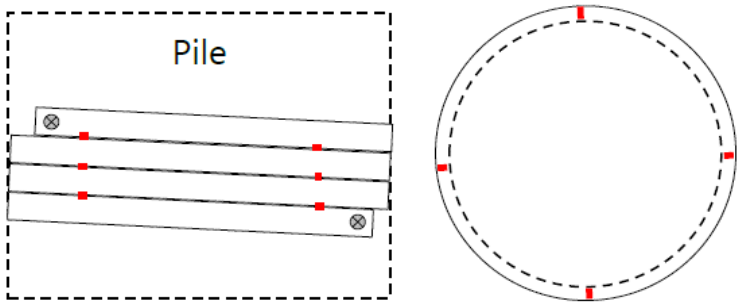
Main Roads identified substantial benefits associated with creating a seal at the base of the formwork, especially one that could be done quickly and cost effectively on site. This is not a process that was documented in the previous installation guidance.

Ableflex was identified to be a highly effective material for this application, which is attributed to its availability in multiple sizes, its flexibility, its closed cell nature and its compression properties. Various sizes and arrangements were trialled, including Ableflex with double sided tape, with the intention that it would adhere to the timber. However, a strong bond was not formed due to the surface saturation created when debris was washed from the pile.

Early trials were undertaken utilising a single rectangular strip of Ableflex around the base of the pile. While effective in dry installation, this method had limitations when used for a wet or flooded environment as it was difficult to ensure the Ableflex aligned, which is a requirement for creating a tight seal with this method. For later trials, a circular Ableflex rod was instead wrapped around the base of the pile multiple times and sealed with a silicone that is suitable for use in a caulking gun. This method proved to be effective, with the flow of epoxy slowing as it navigated the wrapping.

The Ableflex backing rod should be located with a single nail at each end and wrapped tightly around the pile 3 times to avoid any gaps. The backing rod should be wrapped around the pile in such a manner that the start and end are offset vertically. Silicone should be applied at 4 equally spaced locations between each loop, as per Figure 4.19. Any noted splits in the timber around the sealing area should also be caulked with silicone.

Figure 4.19: Sketch of recommended base seal arrangement



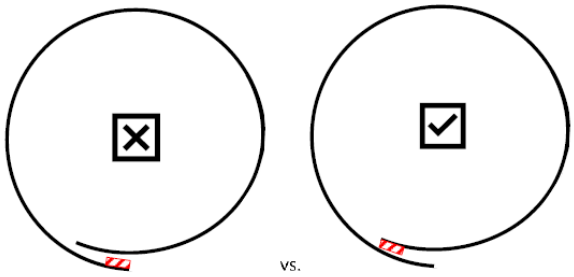
Source: Main Roads.

Vertical seal

Following trial 3b, Main Roads suggested the incorporation of a vertical seal moving forward. The intention of this seal is to create a vertical barrier preventing any seepage of epoxy between the layers of HDPE sheeting.

The vertical seal is suggested to be a closed cell neoprene sponge 12.7-mm thick with tape to allow bonding to the HDPE sheeting. This should be installed as per Figure 4.20 below. While Main Roads adopted stainless steel tek screws at 50 mm spacing throughout the trial, they have recommended increasing this to 100 mm spacing as the smaller spacing appeared overly conservative.

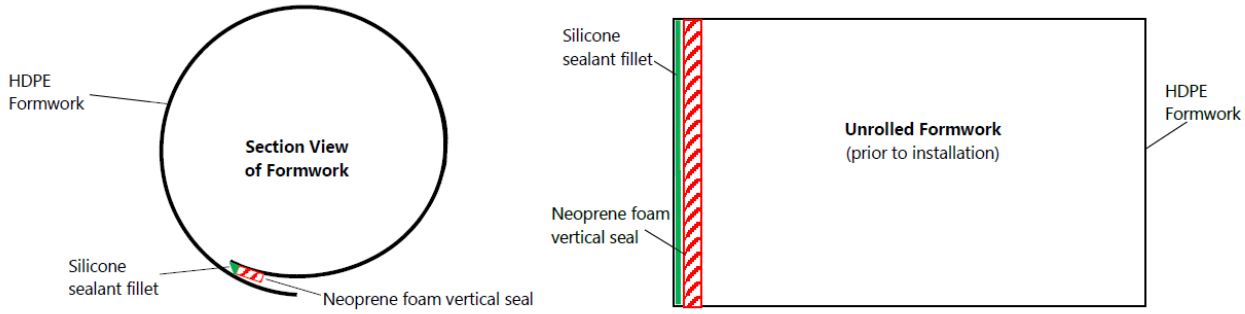
Figure 4.20: Sketch of recommended base seal arrangement



Source: Main Roads.

Furthermore, to reduce the spillage occurring at the interface between the vertical seal and the Ableflex layer, additional silicone caulking is suggested directly adjacent to the neoprene vertical seal. This is shown below in Figure 4.21.

Figure 4.21: Sketch of silicon sealant addition to formwork installation



Source: Main Roads.

Casting formwork

A 3-mm thick HDPE formwork was utilised throughout all trials to date, because of its flexibility and lightweight properties making it easy for crews to secure around piles. Furthermore, HDPE is UV stabilised and chemically inert, providing an additional layer of protection from the elements.

Concerns were raised, however, regarding the resilience of HDPE to fire events. As timber structures are particularly vulnerable in bushfire events, the addition of materials that may accelerate or worsen the likelihood of serious fire damage are undesirable. A Material Safety Datasheet reviewed for HDPE identified that under fire conditions, the product will readily burn and emit a heavy, irritating black smoke. Anecdotally, a high concentration of airborne powders or dust may form an explosive mixture with air. To verify this comment, further research was undertaken, which indicated polyethylene is a flammable in temperatures above its ignition point of 340 °C. Furthermore, as it drips when burning, anecdotally there is potential for accelerated fire spread; therefore, it is suggested to explore options that are inherently less flammable in future works, as this will be a prerequisite of the final methodology.

As a result of the outcomes observed in the field trials, a revised reference drawing has been completed for the repair method, including detailed construction staging instructions. This drawing will available from Main Roads.

4.9.4 Contractor Training

Given the substantial developments made in the methodology throughout the field trials and the sensitivity of the installation process, it may be necessary to require a training session with contractors prior to works being undertaken. This would provide Main Roads with an opportunity to assist in the learning process of

new installers and to share the lessons learned from these trials. This may be realised through a contract clause or outlined on future project drawings.

5 Definition of Parameters and Quality Assurance for Structural Analysis

In previous sections of this report, it has been an assumption of works conducted that the epoxy resins used for timber pile refurbishment did not provide structural enhancement. As a result, the epoxy repairs were limited to piles that were in the early stages of decay only and were otherwise capable of achieving the required capacities through the surviving timber section. This section assesses the feasibility of extending the use of epoxy resins to piles that have progressed beyond early decay and would otherwise require a form of strengthening such as potting or replacement with a steel column.

This section identifies epoxies that performed favourably throughout the Stage 1 field trials, outlining key parameters and performance properties that are required to undertake a detailed structural analysis. The intention of this deliverable was to provide AECOM, a design stakeholder engaged by Main Roads, with sufficient information to assess the suitability of epoxy as a strengthening solution for decaying timber piles.

5.1 Epoxy Properties

Throughout the field trials, Main Roads and ARRB worked closely with an epoxy resin manufacturer, ATL Composites (ATL). ATL assisted with the selection of suitable trial products and provided technical knowledge and support throughout the process. They also remained resourceful during the evaluation of material properties.

Of the products trialled, 2 were identified as favourable - Technirez R1510 and Technirez R1025. R1510 is a clear epoxy with low viscosity ensuring optimal flow through voids within the pile, and was observed to have excellent adhesion to the timber. R1025 is a black epoxy with medium viscosity that sets with a high hardness, notably breaking a chainsaw when pile slicing was undertaken.

5.1.1 Technirez R1510/H1510

The technical properties for Technirez R1510/H1510 have not previously been quantified. ATL clarified that this is due to the epoxy resin not being mechanically characterised within their product range as it was not intended to carry load and is effectively a cosmetic encapsulation. However, having recently undertaken testing on a similar system, Technirez R1332, they were able to offer the results of these tests as an indication of what R1510 may be..

The properties provided for R1332 (Table 5.1) are intended to be an estimate of R1510, provided by ATL based on similarity in material and chemical composition.

Table 5.1: Cured properties for Technirez R1332

Cured properties	Value
Tensile strength	38 MPa
Elongation at break (tension)	23.97%
Flexural strength	41 MPa
Flexural modulus	1,008 MPa

5.1.2 Technirez R1025/H1026

Through consultation with ATL, the following mechanical properties of Technirez R1025/H1026 (Table 5.2) were established.

Table 5.2: Cured properties for Technirez R1025/H1026

Cured properties	Value
Tensile strength	28 MPa
Compressive strength	65 MPa
Compressive modulus	2,000 MPa
Flexural strength	18 MPa
Flexural modulus	2,000 MPa

5.2 Shear strength

Shear strength testing is not typically undertaken on epoxy resins. Rather, as it is commonly used as a bonding agent or adhesive, the lap shear strength (i.e. the ability to resist forces in the plane of bonding) is assessed. As a result, the shear strength has not been previously evaluated by ATL for either epoxy.

AECOM has identified that the shear strength (experienced through the pile when bending occurs) is a required value for analysis. Therefore, if shear strength is to be evaluated, it is necessary to make an approximation based on the material properties of the epoxy. As Technirez R1025 is the only epoxy of the 2 where properties have been determined through testing, it was the sole focus of this evaluation.

ATL indicated the following:

- Epoxy resins are an isotropic material when cured. That is, epoxy resins do not cure to have strong or weak directions.
- Technirez R1025 is a linear elastic material.
- When undertaking tensile testing, Technirez R1025 does not fracture in a brittle manner; however, it will yield shortly after necking commences. It is therefore most appropriately classified as semi-ductile.

To ensure a conservative approach, shear strength approximates based on both brittle and ductile outcomes were reviewed.

Isotropic, brittle materials typically feature shear strengths that are comparable to tensile strength and, in some cases, exceeding it. This is because typical shear failure mechanisms in these materials are a result of tensile strength limits. Based on comments by Norton (2020), it is reasonable to assume a brittle material featuring a tensile strength of 28 MPa will have a shear strength of approximately 28 MPa, significantly exceeding 1.5 Mpa, which is the expected longitudinal shear force experienced by a timber pile in ultimate limit state (ULS) conditions.

For isotropic materials that fail in a ductile manner, it is possible to approximate shear strength through Tresca Criterion, which states shear strength can be estimated as half the evaluated tensile strength (Christensen 2019). This would equate to a characteristic shear strength of approximately 14 MPa. ATL confirmed that this method is the preferred approach within industry, as it is sufficiently conservative and appears to align with testing values where undertaken.

From the above, it is suggested to adopt the lower value, resulting in an estimated shear strength of 14 MPa.

5.3 Limitations

As the properties of R1332 were provided for indicative purpose only, further testing and evaluation of R1025 is recommended to determine its true material values. ATL remains co-operative, and should more valid

representation be required, they are willing to work with ARRB and Main Roads to develop a suitable testing proposition.

This document considered the epoxy material only and did not evaluate composite section behaviour. Should stiffness between in situ timber and epoxy resins vary, this may result in uneven load sharing. Due to the age and variety of timber in the various bridges in WA, this may be difficult to quantify, and as such, consideration should be given to a worst-case scenario i.e. if the timber component has failed and the epoxy takes all loading.

Furthermore, the bonding strength of epoxy to timber is not known; however, it has shown historically to present a high level of adhesion. For greater certainty, it is suggested that load testing of an entire pile should be undertaken or representative lap shear testing should be conducted.

To conclude, the material properties within this report are satisfactory for AECOM to progress with structural analysis and further evaluation. However, further testing is required to validate the limitations identified above and to confirm the approximate shear strength values ahead of further site-based trials.

6 Virtual Workshop

A virtual workshop was held on 5 May 2022 to discuss the findings of the epoxy resins investigation and field trials and to allow for feedback on draft specification from the timber pile repair practitioners, Main Roads and ARRB.

6.1 Arrangements

A list of the potential workshop attendees was prepared jointly by the Main Roads project manager and the ARRB project leader. An invitation was sent to the invitees on 5 April 2022.

A workshop handout was circulated to all workshop invitees a week prior to the workshop in order to allow the attendees to familiarise themselves with the project background, field trials procedure, draft specification development and key findings of the project to date.

6.2 Structure of the Workshop

The workshop included a 45-minute presentation followed by 1 hour of discussion. The presentation was delivered by Nigel Powers (ARRB National Leader – Asset Performance and Quality Manager for this project) and Wayne Spencer (Main Roads Senior Engineer Bridge Maintenance). The workshop covered the following areas:

- project background
- field trials – materials and procedures
- desired epoxy characteristics
- trialled epoxy systems
- documented processes and learnings
- specifications updates.

6.3 Workshop Discussion and Key Findings

The main points discussed during the workshop included:

- the trial aim and objectives
- solution priorities including simplicity, minimal process complexities, low cost, design life i.e. minimum extension of 20 years, ideally 40 years
- the desired epoxy characteristics including low viscosity, impermeable, low shrinkage, high pot life and low cure time
- the three epoxy systems trialled as part of 3 field trials including:
  - Epigen 0301MRD
  - Technirez R1025
  - Technirez R1510
- field trials findings
- specification updates including pile preparation (drilling and cleaning), formwork preparation (sealing the base, HDPE wrapping, creating a seal), hydro testing, epoxy pouring (initial plug mixture, dewatering and second hydro testing and epoxy pouring) and equipment requirements
  The documents that required updating included:
  - Main Roads Specification 850
  - Main Roads Preventative Maintenance Standards.
- training needs regarding the methodology
  It was highlighted by Main Roads that training needs depend on the nature of the project. It can be a

demonstration at site prior to the commencement of the work. Main Roads may need a smart bidding/tendering process. Issues discussed are as follows:

  - If a contractor is not familiar with the process, they may price it higher; on the other hand, if Main Roads makes the contractor familiar with the process, they can reduce their risk and cost it effectively.
  - Main Roads faced similar issues on other projects where a contractor was not familiar with the process. This resulted in quite a thick annulus, leading to wastage of material and, consequently, higher cost.
  - A trial can be conducted with the contractor before they complete the rest of the piles for a cost-effective solution.
  - Other potential solutions include provision of daywork rates in the schedule to optimise cost and considering the whole project as a provisional sum. In the future, Main Roads could convert to a lump sum or schedule of rates, as appropriate, when the contractors are familiar with the work procedure.
  - It was highlighted that although it seems like a great idea to do a trial before the commencement of the work, a clear procedure is required to procure in a single stage process (consisting of both a trail and the remediation work). It may be more practical to do a trial upfront and quote after that to ensure more certainty and better pricing.
  - It should be noted that the contractor who has done a similar job previously could bid lower and it may not be fair for the other contractors who have not completed a similar job. Their rates would be higher to accommodate the risk. Therefore, a formal assessment process or trial would be fair for the industry.

- the need for a method statement, procedure or guideline for this kind of work to explain the installation and procedure to repair timber piles with epoxy. Prepared guidelines could be attached to the standard to give contractors an opportunity to familiarise themselves with the process.
- the requirement for sterilisation of the newly exposed section of the pile with Boracol 200RH, as specified in Clause 1 of 850.31.02 of Specification 850, should be deleted
- proposed changes to the draft repair manual for the Preventative Maintenance Standards, including:
  - in step 3, change statement from watertight to epoxy tight
  - in step 5, provide an image of the wrong way to fill with a large cross over to highlight this is the incorrect method
  - in step 6, amend to 300 mm net water head pressure
- the importance of neoprene foam and silicone sealant filler inserted in the HDPE formwork on the outside of the inner layer as a critical element to prevent potential seepage
- how to document that the process regarding the epoxy pour as outlined in steps 10 and 11 of the draft repair manual for the Preventative Maintenance Standards has been followed correctly
  There may be no surveillance to watch the contractor to ensure that the process has been followed and the treatment is correct. It was proposed to include a clause in Main Roads Specification 850 or the guidelines that the contractor seeks the superintendent's approval by providing evidence that the procedure has been followed and implemented correctly. It should be ensured that this requirement is included in the contract as well.
- a new clause to be included in Main Roads Specification 850 stating that if the contractor is using another product or a new epoxy type (not mentioned in the Main Roads products list) based on its value for Main Roads, they need to submit to the superintendent for approval before using the alternative product
- a clause to be included to cover what happens after the epoxy has set, including removing ratchet straps and applying steel bands to make sure the epoxy stays in place
  Also, include adhesive foam tape in the material list.
- regarding health and safety, additional Personal Protective Equipment (PPE) requirements should be mentioned in addition to complying with product-specific safety requirements as a part of MSDS. These requirements include eye protection (safety glasses) and face shield.

The updated Main Roads Specification 850 (Draft) and repair manual (Draft) for the Timber Bridge Preventative Maintenance Standards are included in Appendix A and Appendix B, respectively.

6.4 Discussions

The workshop discussion concluded that, overall, there is positive support across Main Roads for the method being proposed. There were several good points of feedback which will be addressed in the final version of the specification and guidelines and which will enhance the documents. A number of pertinent points were raised regarding procurement of epoxy timber pile repairs. Main Roads will need to consider the best approach to procure the works with the initial projects to ensure fair tendering and that tenders are fully aware of the scope.

7 Conclusion

The findings of the epoxy resin investigation identified that the methodology utilised by Main Roads in the repair of timber piles is practically exclusive, with few other references of this approach by other road authorities globally. The process is unique in that it encourages a proactive approach to pile maintenance (before excessive loss of section) allowing for long-term preservation and it stalls the need to undertake more extensive rehabilitation works for an additional 20 to 40 years.

However, being a unique solution has made it a niche usage case for epoxy resin and created difficulty establishing suppliers willing to endorse products. As a result, the field trial process has proven to be an invaluable resource and has allowed for a substantial improvement in the understanding of the mechanisms and process upon which the repair method relies. Trial scoping was also critical, with the initial trials utilised to understand epoxy flowability and material interaction and the third trial utilised to refine elements of the installation process. These trials have allowed for improvement and refinement in the method in a number of ways, including but not limited to:

- evaluation of multiple epoxy resins, leading to discovery of a product that offers improved flowability and ease of installation relative to the present solution
- realisation of the value of incorporation of a ‘quickset’ plug mix at the base of the pile
- improvements to the installation process that create better economy, reducing the volume of material required to achieve the same result
- evaluation of the most effective approach to formwork set out, improving the overall likelihood of success to the method, and reducing leakages
- methodology for conducting repair works in an environment where the water level is encroaching the repair zone.

The field trial outcomes and the proposed changes to Main Roads Specification 850 (Draft) and repair manual (Draft) for the Timber Bridge Preventative Maintenance Standards were discussed in a virtual workshop with key stakeholders in Main Roads. Valuable feedback was provided from this workshop with refinements made to the document to ensure they are fit for purpose. This feedback has already been incorporated into project drawings and documents, such as those shown in Appendix A and Appendix B.

Overall, the learnings outlined in the report have satisfied the project aim and provided added benefits through improvement of the existing process and development of guidance literature that provides information to maintenance contractors. It is suggested that any future process improvements be trialled in a similar nature to those within the report, including documentation of unsuccessful trials and associated lessons learned.

8 Future Project Stages

The project stages 1 and 2 were based on field trials, undertaking an epoxy resin investigation to determine what products are available and the development of a draft technical specification for on-site rehabilitation works.

The proposed stage 3 will test and evaluate the mechanical and structural performance improvements on piles that have undergone the epoxy repair method. A focus will be on design critical characteristics such as pile bending and longitudinal shear. Main Roads' extensive relevant experience for other forms of pile rehabilitation will be utilised in stage 3 of the project.

The outputs of stage 3 of the project should include:

- scoping of testing, including a determination of the test method, arrangement with the lab and a report documenting the process and decision-making background
- a technical report to document the investigations, field trials, laboratory testing and development of a specification based on shear strength testing and modification of a design solution and construction methodology.

The proposed methodology of stage 3 of the project will be:

- Conduct on-site field trials of the design solution to test constructability and refinement of specification requirements.
- Perform laboratory testing related to the evaluated bending/longitudinal shear on a combination of unrepaired and repaired pile samples.
- Analyse and interpret the test result data for application of the design solution, construction methodology and specification based on the results of the off-site testing.
- Perform a cost-benefit analysis.
- Reporting including a presentation and dissemination of the activities of stage 3.R

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Appendix A Draft Main Roads Specification 850 Timber Bridges

SPECIFICATION 850

TIMBER BRIDGES

REVISION REGISTER			
Clause Number	**Description of Revision**	**Authorised By**	**Issue Date**
850.02	Title Change for MRWA Specification Nos 204 and 301	SCO	29/10/2019
850.02 850.27 850.28, 850.29 850.31 850.33 850.41 850.93	Specification 820 added to Clause Additional information added regarding schedule of maintenance activities Clauses deleted. Information is covered by in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges. Clause split into Type 2/3 and Type 4 pile repair sections for clarity, product name amended. Product name amended Methodology of treatment of timber decking removed. Information is covered by in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges. Timber End Grain Sealing and Outside Stringer maintenance removed. Treatment tables for stringers, bedlogs, bearers and decking removed. Information is covered by in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.	SDSE	18/06/2018
Whole document	Reformatted	SCO	09/05/2017
Annexure 850A	Coloured plastic plug system added for Borocol treatment	SDSE	26/03/2010
850.27 (3)	Minor change to Main Roads' Website address	SDSE	02/06/2009
850.33.04	Replaced reference to Fibremesh C 50 with EMACO S88C Grout	SDSE	08/01/2008
850.27.3 Guidance Notes	Reference to Annexure 850A added. Clause numbers updated in Table 850.1 and table transferred to Annexure 850A New note 1 - "Clause Numbering" added and subsequent notes re-numbered	SO	16/08/2006
Whole document	Complete revision of Issue 1.4 to new format	MCP	01/08/2006

Table of Contents

SPECIFICATION 850

TIMBER BRIDGES

GENERAL

850.01 SCOPE

1. The work under this specification consists of the technical requirements for maintenance and refurbishment of bridge timber.

850.02 REFERENCES

1. Australian Standards, MAIN ROADS Western Australia Standards and MAIN ROADS Western Australia Test Methods are referred to in abbreviated form (e.g. AS 1234, MRS 67-08-43 or WA 123). For convenience, the full titles are given below:

Australian Standards

AS 1214	Hot Dipped Galvanised Coatings on Threaded Fasteners
AS 1720	Timber Structures
AS 2082	Timber – Hardwood - Visually Stress-graded for Structural Purposes
AS 3660	Termite Management
AS 3730.10	Guide to the Properties of Paints for Buildings – Latex – Exterior - Gloss
AS 3730.13	Guide to the Properties of Paints for Buildings – Primer – Wood – Solver-borne – Interior/Exterior

Australian/New Zealand Standards

A/NZS 2311	Guide to the Painting of Buildings
A/NZS 4671	Steel Reinforcing Materials

Other Standards

MRWA	Document No. 6706-02-2226, Preventative Maintenance Standard for Timber Bridges
MRWA	Document No. 67-08-62, Roadways
MRWA	Drawing No. 9530-0072 Pile Bands & Curved Washer Fabrication Details

MAIN ROADS Specifications

Specification 204 ENVIRONMENTAL MANAGEMENT

Specification 301 VEGETATION CLEARING AND DEMOLITION

Specification 819 FALSEWORK

Specification 820 CONCRETE FOR STRUCTURES

Specification 821 FORMWORK

Specification 830 STRUCTURAL STEELWORK

Specification 831 MINOR STEEL ITEMS

Specification 835 PROTECTIVE TREATMENT OF STEELWORK

850.03 – 850.05 NOT USED

PRODUCTS AND MATERIALS

850.06 SPECIES

1. All sawn timber used in the works shall be Western Australian Jarrah Eucalyptus Marginata.

850.07 QUALITY

1. Sawn timber shall be Structural Grade Number 3, in accordance with AS 2082 and AS 1720 and shall be back sawn.

850.08 TOLERANCES FOR ALLOWABLE DEFECTS IN SAWN TIMBER

850.08.01 INSECT HOLES

1. Clean holes which are isolated and not in groups, free from insect life and decay, and less than 6mm in diameter will be tolerated provided the density of the timber is not unduly affected.

850.08.02 GUM VEINS

1. These will be accepted provided they are clean tight gum veins as distinct from gum pockets or cavities, free from decayed tissue, and are not closer together than 40mm.

850.08.03 WANEY EDGES

1. Sapwood on the corner of a piece of sawn timber shall not be cause for rejection unless it exceeds 12mm on either face of the piece.

850.08.04 SHRINKAGE

1. The sizes shown on the Drawings are nominal sizes, and the timber shall have excess size to the extent of 1mm per 15mm on both transverse directions. No shrinkage allowance is required on the longitudinal direction.

850.09 STACKING OF SAWN TIMBER

1. Immediately on delivery, sawn timber shall be stacked off the ground on suitable bedlogs which shall be spaced such as to prevent permanent warping.

2. Sawn timber shall be stacked so that there is a minimum clear air space of 25mm between pieces of timber to allow for proper ventilation and seasoning.

850.10 PROPRIETARY TIMBER PRESERVATION PRODUCTS

1. This Specification nominates specific proprietary products for suggested use. These products have a history of satisfactory performance for the relevant activities. However, where such proprietary timber preservation products are listed, it shall read “or similar approved” throughout.

2. **Any alternative products shall be submitted to the Superintendent for consideration for approval, with the Contractor giving at least 2 week written notice of intended use.** ***HOLD POINT***

3. Suitable epoxy as referenced throughout this Specification shall be one with high SG and low rate cure with low exothermic heat output with good bond to saturated timber.

850.11 – 850.25 NOT USED

OPERATIONS

850.26 CARPENTRY

1. The whole of the timber work shall be executed to the best standard of workmanship for bridge carpentry. No round timber shall be dressed except as shown on the Drawings or as specified.

2. All joints, facing, checking, scarfing, birdsmouthing and shouldering shall be accurately made in order to obtain tightly fitted joints requiring no wedging or packing.

3. Unless otherwise specified or shown on the Drawings, each piece of timber shall be without joints for its full length and shall have the ends sawn square and wrought perfectly true at all contact surfaces.

4. The holes for bolts and spikes and other fasteners shall be drilled accurately and all mortises, holes and tenons and scarfs and joints shall be cut so as to fit accurately and tightly.

5. The holes for bolts shall be bored with augers 2mm larger in diameter than the bolts. Holes for spikes and drift bolts shall be 2mm smaller in diameter than the spike or drift bolt.

6. Where slotted holes are shown on the Drawings, the holes shall be positioned such that the bolts are free to move in the direction of shrinkage.

7. Squared timber shall be so fixed that the surface which was further from the heart of the tree will be the outer surface of the work. The heart side of all squared timber shall be placed downwards except in the case of bracing and similarly situated members when it shall be placed next to the timber to which it is fastened. The Contractor's attention is specifically drawn to the importance of this requirement when fixing decking planks.

850.27 BRIDGE TIMBER PRESERVATION AND GENERAL MAINTENANCE

1. Bridge timber preservation treatment and general maintenance shall be undertaken in accordance with the requirements detailed below.

2. The specific timber maintenance activities required for the bridge shall be as specified on the Drawings.

3. Preventative maintenance activities shall occur shall occur in a 5 yearly cycle. Routine maintenance activities shall occur as required.

4. Table 850.1 at Annexure 850A describes all standard preservation treatment and routine maintenance activities and the corresponding Activity Code Number referenced in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges, available for information only. Copies of this document are available from the Main Roads website at www.mainroads.wa.gov.au under Standards and Technical, Structures Engineering Design (Note: All downloaded copies are uncontrolled).

5. All work shall be carried out in accordance with Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

6. Residual pesticides must not be allowed to enter the water body or environment other than that being treated. Drop sheets or similar method of containment must be used. Chemical toxicity and application risk information from the manufacturer's published recommendations and material safety data sheets shall be observed.

850.28 – 850.29 NOT USED

850.30 INSTALLATION OF BOLTED AND THREADED ROD CONNECTIONS

1. In addition to the original bolts, stringers and corbels shall be bolted as scheduled on the Drawings. ***Install***

2. All new and replacement bolts, nuts, washers and spikes shall be of mild steel and be galvanised to AS 1214. Bolts shall have well forged square or hexagonal or cup heads as appropriate, or shown on the Drawings, and square or hexagonal nuts with threads accurately cut for a minimum length of 100mm or five times the diameter of the bolt, whichever is the greater.

3. The Contractor shall determine accurately the lengths of all bolts and make allowance for shrinkage of the timbers. Ends of bolts shall be cut off not more than one half of the diameter beyond the nut.

4. Single square washers shall be used against timber behind all nuts and bolt heads with the exception where the bolt bears against round timber, then, curved washers shall be used as detailed in Drawing No. 9530-0072. The minimum size of washers shall be as shown below. In the case of bolt heads sunk flush with the surfaces of the timbers, then the heads shall be tightly fitted into round countersunk holes without washers. All such countersinks shall be tightly packed with Denso paste to prevent lodgement of water. Nuts or bolt heads shall not be packed out with wood or any other packing material.

Diameter of Bolt	24mm	20mm	16mm
Washer	65 x 65 x 5	60 x 60 x 5	50 x 50 x 3

5. Prior to the installation of all new or replacement connectors into the timber, the inside of each hole shall be sterilised with Boracol 200RH and each bolt shall be coated, and each hole filled with Denso paste.

6. Bolts and threaded rods shall be tightened to the tightness achievable with an ordinary spanner without crushing the timber under the washer. Following tightening the exposed ends of all bolts and threaded rods shall be coated in Denso paste to facilitate tightening in the future. Further tightening may be required to accommodate creep in the timber.

850.31 PILE REPAIR

1. Piles shall be assed to determine the appropriate pile repair type (Type 2, Type 3 or Type 4). Repair details are referenced in MRWA Document No 6702-02-221, Structures Engineering Practice Notes.

850.31.01 TYPE 2 AND TYPE 3 PILE REPAIRS

Piles

1. Defective piles shall be potted as detailed on the Drawings. Piles that are required to be pottedshall be exposed by excavating below ground level to the depths shown on the Drawings. Working room shall be kept to a minimum.

2. During pile repair work the bridge superstructure shall be adequately supported in accordance with the requirements of Specification 819 FALSEWORK. Temporary props shall be located on stable ground unaffected by excavations.

3. Before cutting the timber piles, the location and extent of the deterioration shall be determined by drilling, using 8mm diameter augers. Piles to be repaired, as shown on the Drawings, shall be cut off not less than a minimum of 100mm beyond the location where a 100mm annulus of solid timber is first encountered and any pipe encountered is less than one third of the diameter of the pile. Cuts shall be made square and true to the axis of the pile to ensure steel replacement sections will be located concentric and square to the cut surfaces.

4. The cut surface at the top of the timber pile shall be given a heavy brushing with the diffusible fungicide Boracol 400RH. Following the fungicide treatment the top surface shall be sealed using Elastoseal Heavy Duty reinforced with Crommlein Polyfabric.

5. For potted piles, temporary shimming of the suspended section of the pile will be required until the bearing angles at the base of the suspended section are fully installed. This is to ensure full load transfer without deflection of the superstructure. Permanent shimming may be required to ensure full load transfer capacity, as approved by the Superintendent. Shimming shall be undertaken in a manner that does not damage the water proof membrane.

850.31.02 TYPE 4 PILE REPAIRS

1. All pier piles nominated as requiring splinting or epoxy repair shall have all bolts and loose rotten material removed from the area of penetration. These piles shall be thoroughly cleaned with a high-pressure water jet and compressed air. This process shall continue until a quality of wood is exposed that when drilled produces timber particles of 2-3mm length. ~~The newly exposed section shall then be sterilised with Boracol 200RH~~. At this stage a final assessment shall be made of the pile condition as the removal of unacceptable material on a pile classed as a type C may reveal a type D

2. **The pile classification shall be agreed with the Superintendent prior to commencing corrective action.** ***HOLD POINT***

3. Piles classified as type A require no further treatment.

4. Piles classified as type B shall be repaired in accordance with section __ of the Timber Bridge Preventative Maintenance standards.

5. **For piles classified as type B undergoing repair, prior to placement of any epoxy, the Contractor shall certify to the superintendent that all falsework and formwork has been installed correctly and hydro-tests have been performed in accordance with guidance outlined in the Preventative Maintenance standards. The Contractor shall seek the Superintendent's approval by providing evidence that the procedure is followed and implemented correctly. If an epoxy product other than those approved is used, the Contractor shall submit to the Superintendent for approval.** ***HOLD POINT***

6. Piles classified as types C and D shall be splinted as shown on the Drawings. The suspended section of pile in a type D repair will require shimming off to ensure full load transfer without deflection of the superstructure.

7. The splint shall be positioned vertically on the pile with the clearances specified on the Drawings. A non-shrink cementitious grout, Conbextra UW by Fozroc, or similar approved, shall be used to fill the void inside the steel splint for the full height of the splint. The grout shall be used in accordance with the manufacturer's published recommendations.

850.32 HALFCAP REPAIR AND REPLACEMENT

Halfcaps

1. Halfcaps shall be repaired as detailed on the Drawings. During halfcap repair and replacement works, the bridge superstructure shall be adequately supported in accordance with the requirements of Specification 819 FALSEWORK.

2. An accurate survey shall be made of the seating and alignment of the existing halfcaps.

3. PFC halfcaps shall be installed straight without distortion and halfcap seating shall be cut accurately to provide the minimum seating specified without distorting the steel halfcaps. Existing halfcaps not adequately seated on pile checkouts shall have brackets or shimming plates installed as detailed on the Drawings.

4. Packing between timber and steel halfcap strengthening shall be in accordance with the Drawings. Only new seasoned Jarrah timber packers shall be used as detailed on the Drawings.

5. Packing shall be such that a continuous support is provided to the existing timber halfcap. The existing timber may need to be shaped to ensure continuous support.

6. PFC halfcaps shall be fabricated in accordance with Specification 830 STRUCTURAL STEELWORK and surface treated in accordance with Specification 835 PROTECTIVE TREATMENT OF STEELWORK.

7. All pile end grain exposed as a result of any halfcap works shall be sterilised with Boracol 200RH in accordance with Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges

850.33 STRINGER AND CORBEL REPLACEMENT

Stringers and Corbels

1. Stringers and corbels shall be replaced as detailed on the Drawings. During stringer and corbel replacement works, the bridge superstructure shall be adequately supported in accordance with the requirements of Specification 819 FALSEWORK.

2. New steel stringers and corbels shall be fabricated in accordance with Specification 830 STRUCTURAL STEELWORK and surface treated in accordance with Specification 835 PROTECTIVE TREATMENT OF STEELWORK.

3. New steel stringers and corbels shall be installed into final position in such a manner that ensures the stringers accept dead load from the deck. Jacking may be required to ensure full contact with the underside of the deck planks to allow full transfer of dead load.

4. Where gaps between the deck planks and the top flange of the stringer still exist after jacking, they shall be packed using steel shims or MasterEmaco S488, or similar approved by the Superintendent, to ensure that a minimum of 50% of each deck plank is bearing on the top flange of the stringer.

850.34 FASTENER MAINTENANCE

1. All existing threaded fastenings within 1.5 metres of groundline or waterline shall be removed for checking. Fused nuts may be released by application of heat and applying a good quality penetrating oil. Application of force by jacking may be required to remove the bolt from the member. ***Maintenance***

2. The condition of each fastening shall be checked. If the thread condition is considered acceptable and corrosion of bolt and rod is minimal to allow reuse of the fastener, the fastener may be reinstalled. (Note: It is rare for an old bolt or fastener near the groundline or waterline to be in good enough condition for reuse).

3. **Re-use of fasteners shall be proposed to the Superintendent for consideration for approval prior to any reuse.** ***HOLD POINT***

4. If the thread condition has deteriorated such that nuts can no longer be screwed on and tightened or if any of the shaft section has been lost due to corrosion, the fasteners shall be replaced with equivalent sized galvanised threaded rods in accordance with the Clause 850.30 of this specification.

5. The condition of the hole through the timber element shall be checked for enlargement or extension into areas of dry rot surrounding the hole.

6. If the hole enlargement is minimal (less than 20mm larger than the fastener diameter), the inside of the hole shall be thoroughly cleansed and treated with diffusible fungicide and the hole packed with Denso paste.

7. If the hole enlargement is large (greater than or equal to 20mm larger than the fastener diameter), the hole shall be reinstated by sleeving and filling the remaining void with a suitable epoxy filler, once the hole has been cleansed and all deteriorated material has been removed.

8. Alternatively, in the cases of timber braces or walers, the braces or walers may be relocated above the old pile holes with new holes drilled into piles and filled with Denso paste.

9. In severely deteriorated situations, sleeving or other pile repairs shall be installed in accordance with the Clause 850.31 of this Specification, where nominated on the Drawings.

10. Prior to installing fasteners, all fastener holes shall be filled with Denso paste.

11. All new or reused fasteners shall be coated with Denso paste before being installed in accordance with Clause 850.30 of this specification.

850.35 BOLT TIGHTENING

Tightening

1. All existing bolts greater than 1.5 metres from the groundline or waterline shall be tightened. If the thread condition has deteriorated such that nuts can no longer be screwed on and tightened, they shall be replaced with the equivalent sized galvanised threaded rods in accordance with the Installation of Bolted and threaded Rod Connections Clause of this specification.

850.36 WALINGS AND BRACES

Walings and Bracing

1. All existing timber walings and braces shall be checked for condition of timber, in particular splitting of ends and deterioration around connectors.

2. Where shown on the Drawings timber walings and braces requiring relocation shall have new holes drilled for new connectors. The new holes shall be away from existing holes which shall be cleaned out to remove all deteriorated timber and then filled with epoxy. The minimum offset of holes shall be three connector diameters clear from sound timber surrounding the existing holes.

3. Wherever possible existing braces to be relocated which have splits or deteriorated ends or with deterioration around end connections should be reused by cutting off deteriorated ends and then rotating the braces upwards at the bottom connection and re-drilling to suit new connectors.

4. All existing walings within 300 millimetres of groundline (as measured from the underside of the waling) shall be removed from piers to prevent deterioration of the timber piles at the groundline.

5. All existing walings subject to inundation within the usual water splash zone as indicated on the piles by water splash zone shall be raised by 300mm above water splash zone markings on piles (as measured from the underside of the waling).

6. All holes left in timber piles following the removal or relocation of walings and braces shall be cleaned out to remove all deteriorated timber and then filled with epoxy.

7. Holes that have increased in size by more than 20 millimetres larger than the original connector diameter shall be treated in accordance with Clause 850.29 of this Specification. Where cut outs in timber piles for walings have exceeded 50mm in depth, type B repairs shall be mandatory.

8. More severe deterioration and larger cut outs for walings shall be repaired using either type C or D repairs as detailed on the Drawings.

850.37 - 850.40 NOT USED

CONCRETE OVERLAYS

850.41 PREPARATION OF TIMBER DECKING FOR A CONCRETE OVERLAY

850.41.01 GENERAL

1. The timber decking shall be prepared in the order of the Clauses shown below.

850.41.02 REMOVAL OF EXISTING DECK OVERLAY

1. The existing road pavement or concrete deck overlay shall be removed from one half of the bridge at a time. The section to be removed shall be separated by saw cutting to give a uniform line. The material shall be removed in such a manner that does not cause damage or excessive loading to the bridge and in particular the timber decking.

2. The Contractor shall ensure that any plant used to strip the material over the deck planks do not overload exposed deck planks. The proposed plant shall be checked for load effects on the deck planks and stringers. Tracked vehicles shall not be permitted.

3. **Details of the machine proposed to strip the existing road pavement or concrete overlay and all structural checks shall be submitted to the Superintendent for approval at least 2 weeks prior to intended use.** ***HOLD POINT***

4. The removed material shall be disposed of in accordance with local government requirements for the disposal of waste material.

850.41.03 CLEANING OF TIMBER DECKING

1. The upper surfaces of the deck planks shall be cleaned, by removing all gravel and other loose timber and foreign material with a water jet spray.

850.41.04 REPLACEMENT OF TIMBER DECKING

1. Timber deck planks found to have a minimum thickness of sound timber less than 75mm shall be replaced.

2. When it is required to replace individual deck planks, the deck planks shall be replaced using either 125mm x 225mm seasoned Jarrah or concrete on permanent formwork. Where two or more adjacent deck planks require replacement, the deck planks shall be replaced with permanent formwork and a layer of SL81 reinforcement fabric in accordance with AS/NZS 4671. The SL81 fabric shall be in addition to the reinforcement shown on the Drawings. The SL81 fabric shall be placed with 40mm cover. The concrete shall be poured in the same pour as the concrete overlay. The concrete shall comply with Specification 820 CONCRETE FOR STRUCTURES. The concrete shall be formed in accordance with Specification 821 FORMWORK.

3. **The Superintendent shall inspect the timber deck planks prior to replacement of any timber decking.** ***HOLD POINT***

850.41.05 TIGHTENING OF TIMBER DECKING

1. All connections between deck planks and stringers or spiking rails shall be decked for tightness and continuous bearing.

2. The tightness shall be checked by placing a bar between the decking planks. If vertical movement or more than 3mm of horizontal movement occurs then the connection shall be tightened.

3. Continuous bearing between the deck planks and the top of the seating surface of the stringers or spiking rails shall be checked. If there is less than 50% bearing then the connection shall be tightened.

4. Loose deck planks shall be tightened by firstly driving the existing spikes at the connection until they are flush with the top surface of the decking. Then if the connection is not tight, additional spikes shall be driven adjacent to the existing spikes.

850.41.06 LAYER OF HESSIAN

1. A layer of hessian fabric, as detailed on the Drawings, shall be placed on the timber decking in preparation of placing the concrete. The hessian shall be lapped and nailed down as required to ensure that all decking remains covered during the placement of overlay concrete.

850.41.07 PRESERVATION TREATMENT OF TIMBER DECKING

1. Timber decking shall be treated prior to placement of the overlay concrete. Treatment of timber deck shall comply with the requirement with Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

850.42 ADJUSTMENT TO ROAD SURFACE LEVELS AT APPROACH SLABS AND EXPANSION JOINTS

1. The Contractor shall arrange the adjustment of the road surface levels at the approach slabs and expansion joints prior to opening each half of the overlay to traffic.

2. A minimum 3m length of transition shall be applied beyond each end of the bridge as required to transition between the finished overlay or approach slab levels and existing road pavement levels. Maximum and minimum grades shall be in accordance with Main Roads Document No. 67-08-62 “Roadways” but generally shall be between 0.3% and 4%. Make up of road level shall made good by use of road pavement material similar to existing.

850.43 SITE CLEAN-UP

Clean-up

1. At the completion of the required works the Contractor shall ensure that the site is cleaned up to a standard at least equal to its condition prior to commencing the works, with all rubbish, debris and excess building materials removed from site. Rubbish and debris shall be taken to the relevant Local Authority rubbish tip and all fees and charges shall be paid by the Contractor.

850.44 – 850.80 NOT USED

AS BUILT AND HANDOVER REQUIREMENTS

850.81 – 850.90 NOT USED

CONTRACT SPECIFIC REQUIREMENTS

850.91 – 850.99 NOT USED

ANNEXURE 850A

TABLE 850.1 SCHEDULE OF TIMBER PRESERVATION AND GENERAL MAINTENANCE

Clause No.	Preservation Treatment Activity	Activity Code No.*	Activity Required?
-	Timber End-grain Sealing	011	
850.32 850.33	Bolt Tightening and Fastener Maintenance	012	
850.93.02	Groundline Treatment of Piles	013	
850.93.02	Waterline Treatment of Piles in Permanent Water	013a	
850.41.07	Fungicide Treatment of Timber Decking Planks	014	
850.93.01	Fungicide Treatment of Timber Stringers	015	
-	Routine Maintenance of Outside Timber Stringers	016	
-	Treat Abutment End of Wandoo Stringers (End Spans Only)	017	
850.93.05	Fungicide Treatment of Abutment Bedlogs and Bearers	018	
850.93.06	Fungicide Treatment of Halfcaps	-	
-	Fungicide Treatment of Timber Bearers and Pier Bedlogs (Off Ground)	019	
-	Repair of Split Piles	021	
-	Repair of Split Stringers (Scarf Splits less than 800mm Long)	022	
-	Treatment (Fungicide) of Gravel Pavement	023	
850.93.09	Timber Handrail Maintenance	031	
850.93.05	Deck Drainage Maintenance	032	
-	Removal of Deck Vegetation	033	
850.93.06	Vegetation and Debris Clearing Under Bridges	034	
-	Regulatory and Warning Signs	035	
-	Marine Organism Protection	041	
850.93.07	Termite Inspection and Treatment	042	

* Activity Code Numbers refer to the activities listed in the Preventive Maintenance Standard for Timber Bridges, Document No. 6706-02-2226 which is available ***for information only***.

Note 1: Insert “Yes” or “No” under “Activity Required” against each Activity Code No.
Note 2: If required, include Document 6706-02-2226 in the “Information for Tenderers”.
Note 3: Complete separate table for each Bridge No.
Note 4: Delete these notes.

GUIDANCE NOTES

FOR REFERENCE ONLY – DELETE GUIDANCE NOTES FROM FINAL DOCUMENT

1. All edits to downloaded Specifications shall be made using *Track Changes*, to clearly show added/deleted text.

2. If **all** information relating to a clause is deleted, the clause number should be retained and the words **"NOT USED"** should be inserted.

3. The proposed documents with tracked changes shall be submitted to the Project Manager for review, prior to printing the final batch of documents. When this final printing is carried out, the tracked changes option is to be turned off.

4. Before printing accept all changes in the document, turn off *Track Changes* and refresh the Table of Contents.

5. The Custodian of this specification is the Structures Design and Standards Engineer.

1. CLAUSE NUMBERING

1.1 Any proposed changes to specification clause numbers must be communicated to Structures Information and Standards Manager for comparable changes to Document No 6706-02-2223, Structures Engineering Practice Notes and Standard Drawings, as cross-references from these documents to specification clause numbers exist.

1.2 If clauses are not required for a particular project the preferred method is to retain the clause number but delete the clause text and mark the clause number as "NOT USED".

2. CONCRETE OVERLAYS (Clause 850.41)

2.1 Concrete work for new concrete overlays must be appropriately specified by including Specifications 819, 820, 821, 822 etc. as required.

3. NAVIGATION PIERS PROTECTIVE SYSTEMS (Clause 850.91)

3.1 Where modifications or repairs are required to bridge navigation piers, insert Clause 850.91 (or a suitable variation) to ensure pier protection systems are reinstated at the completion of repairs to at least their original condition.

4. ADJUSTMENT OF ROAD LEVELS

4.1 Where the adjustment of levels is to form part of the contract (for example, where a new concrete overlay requires the road level at each end of the bridge to be raised over a suitable transition length), either Clause 850.42 will need to be extended/modified, or alternatively a more detailed description inserted in CONTRACT SPECIFIC REQUIREMENTS to include a specific road specification. Such a specification could be inserted as Clause 850.92 using the headings shown.

5. ADDITIONAL ROUTINE MAINTENANCE WORKS (Clause 850.93)

5.1 If the contract includes additional routine maintenance works, such as fungicide treatment or other needs, a selection of such needs should be made from the clauses in CONTRACT SPECIFIC REQUIREMENTS.

5.2 If necessary, ensure a copy of Document 6706-02-2226 is included as part of the “Information for Tenderers”.

5.3 If any fungicide treatment is included in the contract and the treatment reservoir holes are required to be capped with plastic plugs, the colour of the plugs shall be specified as per Document 6706-02-2226

CONTRACT SPECIFIC REQUIREMENTS

The following clauses are to be placed under the CONTRACT SPECIFIC REQUIREMENTS, as required. After inserting the clause, change the clause number and heading to style “H2 SP” so it appears in the Table of Contents.

850.91 MODIFICATIONS TO NAVIGATION PIER PROTECTIVE SYSTEMS

1. The Contractor shall allow for removing the rubber tyre and timber fendering system from the navigation pier piles that require repair.

2. The location of the navigation pier piles requiring repair are shown on the Drawings.

3. Tyres shall be modified to encase the new steel splints and reinstalled to their original position on completion of the splinting operation. The timber fendering shall be reinstalled using cleats attached to the equal angles of the pile splints as shown on the Drawings. Tyres and timber damaged during the removal, modification and reinstatement process shall be replaced by the Contractor at no cost to the Principal.

850.92 ADJUSTMENT OF ROAD LEVELS

1. Survey

2. Earthworks (if any)

3. Pavement

4. Re-surfacing

850.93 ADDITIONAL ROUTINE MAINTENANCE WORKS

850.93.01 FUNGICIDE TREATMENT OF TIMBER STRINGERS

Fungicide Stringers

1. All timber stringers requiring fungicide treatment shall be treated by injection of diffusible Borate fungicide (Timbor or Polybor powder or slurry) or Boracol 400RH.

2. The dosage rate shall be determined using the average stringer diameter calculated for each stringer measured at midspan and at both supports.

3. The entire volume of each stringer nominated for treatment shall be treated with diffusible Boron based fungicide powder to achieve a Boric Acid Equivalent (BAE) of at least 4.5kg/m³ or with Boracol 400RH to achieve a BAE of at least 3.0kg/m³. The amount of Borate powder or Boracol required to treat each stringer to meet this requirement shall be calculated from the design charts in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

4. The minimum application locations shall be drilled reservoirs at supports and at midspan, where no existing pipes, holes or splits exist.

850.93.02 FUNGICIDE TREATMENT OF TIMBER PILES

Fungicide Piles

1. All timber piles requiring fungicide treatment shall firstly be treated with sufficient diffusible boron based fungicide in treatment reservoirs within the piles in the groundline zone to achieve a Boric Acid Equivalent (BAE) in the timber of at least 5 kg/m³ of timber. The amount of Borate powder or Boracol required to treat each stringer to meet this requirement shall be calculated from the design charts in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

2. Where piles have previously been treated at the groundline, the number and location of existing treatment reservoirs shall be checked to determine whether they conform to this requirement and modified as required to suit if they have not been.

3. Where piles have not previously been treated, treatment reservoirs 20mm in diameter shall be drilled at groundline and at 300mm above groundline. Holes shall be drilled downwards into the piles at an angle of approximately 15 degrees to the vertical and be evenly spaced around the perimeter with ground level holes staggered relative to the holes at 300mm above. The maximum practical length of hole that can be drilled in most piles is 500mm, limited by intersection with adjacent holes and drill bit lengths.

4. The number of reservoirs required shall be calculated for each pile based on their measured diameter and the information in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges. A maximum of 12 treatment holes total shall be drilled in any pile at or around the groundline. For 20mm diameter standard reservoir drill bits the treatment volume is 32ml / 100mm length of hole. Where the required treatment volume cannot be fitted into the available drilled reservoirs during the initial visit, a subsequent treatment shall be carried out by topping up the reservoirs between one and three months after the initial visit.

5. Treatment reservoirs shall only be drilled through sound timber, away from checks and splits. Each reservoir shall be filled with liquid fungicide and if the fluid level drops quickly in a hole due to leakage, the treatment in that hole shall be supplemented with 4 No. 14mm diameter ‘Polesaver’ rods.

6. After treatment each reservoir hole shall be capped with a plastic plug of the same colour as specified in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

7. The Contractor shall record the treatment (or re-treatment) date for the bridge to enable scheduling for the next treatment. Fungicide usage and batch number of chemical applied shall also be recorded for each pile.

8. Piles in permanent water shall be treated to the waterline zone of each pile, carried out in accordance with Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

9. Potted piles shall all be scheduled for standard treatment in the zone above the level of the concrete collar, carried out in accordance with the treatment required at ground level.

850.93.03 FUNGICIDE TREATMENT OF BEDLOGS AND BEARERS

1. All timber bedlogs and bearers requiring fungicide treatment shall be drilled using 20mm drill bits, with holes drilled at as steep an angle as possible to pass through the centre and pass through into rot zones, typically at the far faces of the bedlog or bearer.

2. The bedlogs and bearers shall be treated with a slurry consisting of 5.0kg of Solubor powder to 2.90 litres of water or Boracol 400RH pumped into the drilled holes to achieve the dosage rates as shown in Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

3. Hole spacings shall be 0.5m to 1.0m along bedlogs or bearers, located specifically in the vicinity of the areas of dry rot occurring in the bedlogs or bearers.

4. Sufficient holes and repeat dosages shall be applied to achieve an application rate of 4.5kg of Boric Acid Equivalent (BAE) per cubic metre of timber, based on the actual slurry mixture strength used, hole lengths drilled and actual diameters. If Boracol 400RH is used, the application rate shall be at least 3.0kg/m^3 BAE.

850.93.04 FUNGICIDE TREATMENT OF HALFCAPS

Fungicide Halfcaps

1. The halfcap shall be saturated with water one day prior to proposed fungicide treatment to encourage 'take up' of hygroscopic Boracol in the treatment to follow.

2. The diffusible boron-based fungicide, Boracol 400RH shall then be applied in brush form to the halfcap, with repeat doses as necessary until a level of Boric Acid Equivalent (BAE) of 3.0 kg/m^3 of timber has been achieved in the halfcap. Repeat doses shall be delayed by at least an hour to allow full absorption of each application.

3. Normally 2 or 3 repeat doses will be required to achieve this BAE level. The actual number of applications required to achieve the required BAE level is a function of the timber thickness and the absorption rate of the halfcap. For halfcaps 170mm x 340mm, the total application rate required of absorbed Boracol 400RH to achieve 3.0kg/m^3 of BAE has been calculated at 0.31 litres/m.

4. The amount of Boracol 400RH to be applied to the halfcap to achieve the absorbed level of BAE required shall take into account all losses.

850.93.05 DECK DRAINAGE MAINTENANCE

Deck Drainage

1. Bridges noted as requiring deck drainage maintenance and not requiring construction of a concrete overlay shall have all existing drainage outlets, whether through horizontal holes in timber kerbs or vertically through decks (both known as Scuppers) cleaned out to remove all debris and to allow the continued free flow of drainage water through them.

2. Scupper flashing as detailed shall be installed under all side discharge scuppers, mounted on the outside stringers to minimise the discharge of water onto them. Where scuppers are located over piers the scupper flashing shall be shaped to discharge water from the scuppers away from the halfcaps below. Where this is not practical scuppers shall be sealed by packing with suitable jarrah timber blocks.

3. Where vertical scuppers discharge onto stringers, scupper flashing shall also be mounted on the affected stringers.

850.93.06 VEGETATION AND DEBRIS CLEARING UNDER BRIDGES

Clearing

1. Refer to Specifications 301 VEGETATION CLEARING AND DEMOLITION and 204 ENVIRONMENAL MANAGEMENT for clearing permissions and limit of clearing.

2. All clearing works are to comply with Document No. 67-02-2226, Preventative Maintenance Standard for Timber Bridges.

3. The area of land under each bridge from 10 metres beyond each Abutment and extending to 10 metres past the bridge edge or to the road reserve boundaries (whichever is the greater) is designated to be the control area for the bridge.

4. Under certain circumstances where vegetation does not pose a fire hazard or affect the free flow of water under the bridge and it is considered to be of special significance or of special aesthetic value, it may be retained, subject to the approval of the Superintendent.

5. Bridges that are located within water catchment areas or are in areas of special control (such as the Avon Valley, Swan River Trust, etc.) may be controlled by specific regulations for vegetation clearance and their Acts which prevail over the Main Roads Act and the Local Government Act. In such circumstances, vegetation clearing shall be carried out in accordance with the prevailing Act and regulations.

850.93.07 TERMITE TREATMENT AND ERADICATION

Termite Treatment

1. The Contractor shall carry out a detailed inspection of the bridge and surrounding area up to 10m from the bridge for any evidence of termite activity.

2. Termite eradication measures shall be initiated for all affected areas with a report produced by the Contractor detailing treatment method and application rates. It is recommended that Termidor Termiticide or a similar alternative approved by the Superintendent be used. The proposed application technique shall be specified in the tender submission.

3. Permanent aluminium tags shall be fixed to the bridge at Abutment 1 so as to be clearly visible by others. The tag shall contain the following information by metal stamping: Bridge number; Name of treating company; Date of treatment; Chemical used; Licence number of pest control operator and Date for reinspection.

4. All treatment sites shall be marked with coloured paint for identification and monitoring.

5. The Contractor shall prepare a report and submit it to the Superintendent within 2 weeks of initial treatment, outlining details of initial detailed inspection, exact location of termite activity and treatment methods.

6. The Contractor shall reinspect the bridge after a period of 3 months. If active termites are found they shall be eradicated at no cost to the Principal.

7. The Contractor shall prepare a follow-up report and submit it to the Superintendent within 2 weeks of reinspection, outlining details of current termite activity and treatment. The report shall be specific with regards to exact locations of treatment site accompanied by sketches.

850.93.08 EMBANKMENT WIDENING

1. Any embankment widening required for pathways, traffic safety barrier terminations and the like, shall be constructed to similar standards to the existing adjacent embankment if not detailed on the Drawings.

850.93.09 TIMBER HANDRAIL MAINTENANCE

1. The existing handrail to the footpath on the bridge is to receive maintenance work (for information only refer Activity Code No. 031 of Document No. 6706-02-2226, Preventive Maintenance Standard for Timber Bridges), followed by repainting. The entire surface of the handrail, both posts and rails shall be repainted.

2. Prior to painting, all surfaces shall be prepared by removal of the existing paint system to a sound surface then washing, scraping, sanding and filling as appropriate and in accordance with AS/NZS 2311 Section 7.

3. Damaged or unserviceable railings, spacer blocks and posts shall be removed.

4. New posts, spacer blocks, railings and delineators, where necessary and as indicated on the Drawings, shall be installed, ensuring good general rail alignment.

5. All structural fixings and anchorages shall be tightened, except at expansion joints on steel flex beam railing.

6. All surfaces shall receive a minimum of three coats of paint as follows:

   - One coat of Primer to AS 3730.13

   - Two coats of Gloss to AS 3730.10

   Rails shall be painted white, and posts white above the deck and black below, in accordance with the existing colour scheme. All paint shall be applied in accordance with the manufacturer's published recommendations unless specified otherwise in this Specification.

7. During all preparation and painting operations the Contractor shall ensure that no material falls into the river.

AMENDMENT CHECKLIST

Specification No. **850** Title: **TIMBER BRIDGES** Revision No:_____

Project Manager:_____ Signature:_____ Date:_____

Checked by:_____ Signature:_____ Date:_____

Contract No:_____ Contract Description:_____

ITEM	DESCRIPTION	SIGN OFF
Note: All changes/amendments must be shown in Tracked Changes mode until approved.		
1.	Project Manager has reviewed Specification and identified Additions and Amendments.	
2.	**CONTRACT SPECIFIC REQUIREMENTS** addressed? Contract specific materials, products, clauses added? (Refer Specification Guidance Notes for guidance).	
3.	Any unlisted materials/products proposed and approved by the Project Manager? If "Yes" provide details at 16.	
4.	Standard clauses amended? **MUST SEEK** approval from Manager Contracts.	
5.	Clause deletes shows as **"NOT USED"**.	
6.	Appropriate **INSPECTION AND TESTING** parameters included in Spec 201 (Text Methods, Minimum Testing Frequencies verified).	
7.	**ANNEXURES** completed (refer Specification Guidance Notes).	
8.	**HANDOVER** and **AS BUILT** requirements addressed.	
9.	Main Roads QS has approved changes to **SMM**.	
10.	Project Manager certifies completed Specification reflects intent of the design.	
11.	Completed Specification – independent verification arranged by Project Manager.	
12.	Project Manager's review completed.	
13.	**SPECIFICATION GUIDANCE NOTES** deleted.	
14.	**TABLE OF CONTENTS** updated.	
15.	**FOOTER** updated with Document No., Contract No. and Contract Name.	
16.	Supporting information prepared and submitted to Project Manager.	
Further action necessary:		

Signed:_____ *(Project Manager)* Date:_____

Appendix B Draft Repair Manual for Timber Bridge Preventative Maintenance Standards

General Description

Penetration of timber pile rot zone in epoxy resin to halt further deterioration and extend usable life.

Quality Standard

After repair method has been undertaken, timber pile region subject to rotting will have been completely sealed with epoxy resin. Internal penetration of epoxy will have occurred throughout majority of pipe rot and splits, halting further deterioration. The intended extension of pile usable life is a minimum of 20 years, ideally 40.

Unit of Measure

Per treated pile.

Steps

1. Drill three 20 diameter holes at top, bottom and below existing pile defect and remove existing preventative maintenance plugs (if present), to improve flowability through the pile.
2. Water jet blast surface and inside (by inserting water blast lance in all holes repetitively to assist in flushing) of pile until all debris has been removed and water runs clear.
3. Wrap 20mm Ableflex Rod continuously around the base of the pile three times in a location below the repair zone, on clean sound timber below the rot zone. Hold Ableflex in place through use of locating nails installed at each end of the rod. Apply a caulk silicone in 4 equally spaced intervals between each layer of Ableflex. Ensure rod is wrapped tightly and has no gaps present. The intention of this is to create a epoxy tight seal at the base of the repair zone.
4. Wrap the pile in 3mm thick HDPE sheet. Select a size of HDPE that will wrap around the pile tightly and create an overlay of approximately 200mm. the top of the HDPE formwork should extend a minimum 200mm clear of the rot zone and reside above the existing water level. The base of the HDPE should be located below the bottom layer of Ableflex.
5. Between the HDPE overlap (on the outside of the inner HDPE layer) insert a layer of 6.4mm x 48mm closed cell neoprene sponge with self-adhesive tape offset from edge by 10mm. This shall be installed as per Image 1 below. At the top of the HDPE insert a single 8mm deck spike as a spacer to ensure enough of a gap is left for epoxy pouring. Hold this arrangement in place on the pile by using 3x ratchet straps located at the top, middle and base of the works. Secure the HDPE to the pile utilising stainless steel Tek Screws at 50mm centres starting from the base of the pile working upwards. The screws should be installed in the overlap region, passing through all layers of HDPE and closed cell neoprene sponge. A silicone sealant shall be caulked between the edge of the closed cell sponge and HDPE to create a seal at the interface.

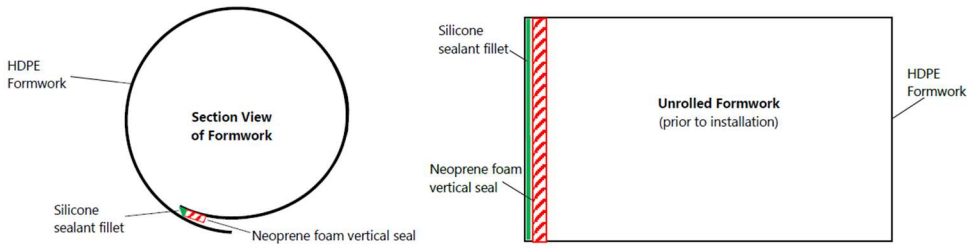


Image 1: Silicone sealant and vertical seal arrangement in formwork installation

6. Prior to progressing further, a hydro test shall be undertaken by filling the form work with 300mm of net water head pressure to ensure the formwork is sufficiently watertight and will not leak when plug mix is installed. Observe the water level and ensure it drops by no greater than 50mm in 30 seconds. Should the hydro test fail to maintain a satisfactory water level, the superintendent shall be consulted prior to further progression. At the discretion of the superintendent with consideration of site conditions (flowing water below or dry creek bed), the contractor may be approved to commence pouring of initial plug mix whilst monitoring for leakage.
7. Place absorbent sock or similar around pile to capture any overspill.
8. Remove standing water from formwork by dewatering. Once clear of water install epoxy plug mix consisting of ATL 2875 Resin + ATL 2877 Hardener. Alternative products shall be submitted to Main Roads Structures Engineering for approval. Allow plug mix to set. The purpose of this mix is to seal the pile at base of formwork across its entire cross section.
9. After plug mix has fully set, dewater pile and capture any contaminated water. Insert water to the full height of the repair works and observe for any water level drop over a period of one hour. There should be no observable loss in height of the plug mix epoxy over the duration. Should water loss be observed, add an additional layer of plug mix and retest. Subsequent failures should be addressed by identifying points of water loss and sealing with an injectable silicone.
10. After successful hydrotest has occurred and the hold point surrounding this step has been released, dewater the pile and install epoxy mix of Epigen 301 MRD or ATL 1510. ATL 1510 not for use where repairs are undertaken in water. Alternative products shall be submitted to Main Road Structures Engineering for approval. The Pouring of epoxy is to be controlled via. hose, use of a funnel or bucket to pour directly into the formwork is not permitted.
11. Return to pile after a period of 7 days and observe status of repair, if necessary, top up with further epoxy to the level of formwork.
12. Remove ratchet straps and apply steel bands to ensure the epoxy stays in place.

Suggested Personnel

1 Supervisory Staff
2 Construction worker

Suggested plant

High-pressure water cleaning unit

Drill/ paddle mixer
Battery operated handheld drill & 20 diameter drill head

Materials

6.4mm thick Closed Cell Neoprene Sponge with self-adhesive foam tape one side
ATL 2875 Resin and ATL 2877 Hardener or approved equivalent
Epoxy Resin (Epigen 301 MRD/ ATL 1510 or approved similar)
3mm thick HDPE sheet
8mm deck spike
Funnel and hose
20mm diameter Ableflex foam rod
Caulking Silicone
Stainless Steel Tek Screws
Ratchet straps
Clout head nails
Mixing buckets
Absorbent sock/ spill kit

Planning Notes

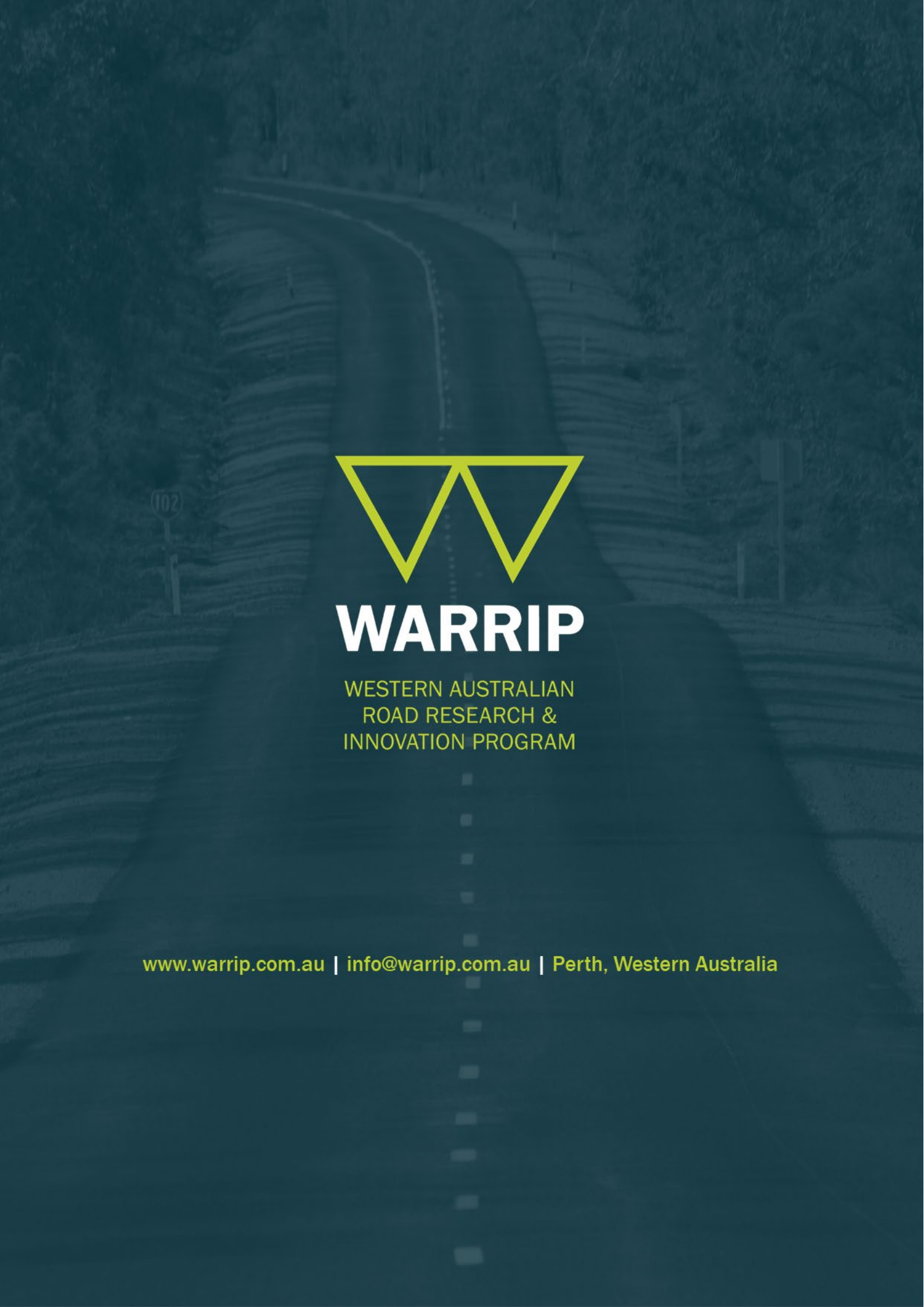
1. Pre-inspection essential for this Activity. Existing pile condition to be assessed for severity of internal piping present in piles. This activity only applies to piles that are still structurally adequate to support the required loads. For scenarios that do not meet this prerequisite it is suggested to review the Main Roads Structures Practice Notes.
2. This repair method cannot be undertaken in a flood environment, or where the water level is invasive/ substantially higher than the rot zone. It is suggested where possible to prioritise works for summer months and periods of low tide when the water level in the river and creek network is likely to be lower. Repair must be undertaken at lowest possible water level.

Average Daily Production

(To be determined.)

Works Classification

Specific Maintenance



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