TRIAL OF GROUND PENETRATING RADAR TO LOCATE DEFECTS IN TIMBER BRIDGE GIRDERS

Wayne Muller
Engineer (Concrete Technology),
Structures Division, RS&E Group, Queensland Department of Main Roads

Abstract

Termite and fungal attack can result in large internal defects within timber bridge girders[1]. In extreme cases this can lead to a severe reduction of bridge load capacity and has the potential to result in bridge collapse under heavy loads.

As these defects typically show few outwards signs of their presence, current inspection methods such as visual inspection and test drilling[1] are 'hit and miss' at best.

In March-April 2002 a trial was undertaken using non-destructive techniques to locate internal defects in timber girders. Ground penetrating radar (GPR), gamma ray transmission and ultrasound techniques were used to investigate timber girders from a demolished bridge and girders in an existing four span bridge. Defect predictions were assessed by cutting up and inspecting the girders from the demolished bridge, and by conducting a drilling investigation of the existing bridge.

Of the techniques trialled, GPR was found to be the most reliable method for locating internal defects. Various defect types were successfully located using this method, including piping, rot and cracking. Overall there was an excellent correlation between the GPR defect predictions and verification testing.

This paper gives an overview of each of the techniques trialled before focusing on the performance and potential applications for GPR in timber bridge inspection.

Key Words: Timber bridges, Timber Girders, Non Destructive Testing, NDT, Ground Penetrating Radar, GPR.

Introduction

In March-April 2002 a trial was undertaken using various non-destructive testing (NDT) techniques to locate defects in timber bridge girders.

The NDT techniques used were Ground Penetrating Radar (GPR), gamma ray transmission and ultrasound.

The trial involved the inspection of timber girders from two locations:

- *Purga Creek Bridge:* GPR, gamma ray and ultrasound techniques were used on four girders salvaged from this recently demolished four span bridge. Defect predictions were assessed by cutting up the girders, locating defects and comparing their location and size with the predictions.
- *Redbank Creek Bridge:* GPR was used to locate defects in all 20 girders of this existing four span bridge. Gamma ray techniques were used to locate defects in 6 selected girders. Defect predictions were assessed by comparison with test drilling results at selected locations.

The following section gives an overview of the non-destructive techniques used during the trial. The remainder of the paper focuses on the performance of the most successful of the techniques trialled: Ground Penetrating Radar (GPR).

Overview of techniques used

Method 1: Ground Penetrating Radar (GPR)

Principles of operation

GPR is a non-destructive technique that uses electromagnetic (EM) waves to "look" into a material. GPR systems operate in a similar manner to sonar – i.e. by emitting a series of brief pulses and estimating distance to objects from the time it takes to detect reflections.

Figure 1 shows a schematic of a GPR system in operation. Transmitting and receiving antennas are used to emit the EM pulse and detect the reflections.

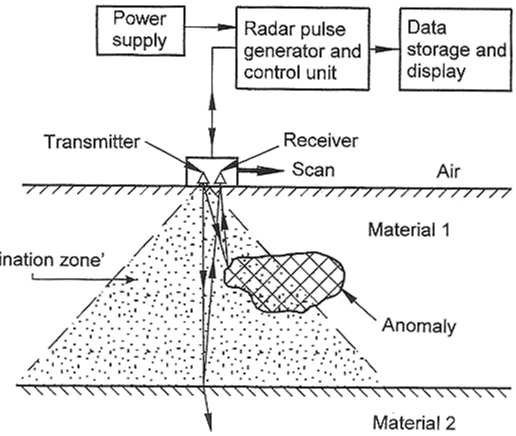


Figure 1 - Schematic of GPR operation(2)

Reflections occur when the EM wave passes from one material into another material with contrasting electrical properties. The strength of the reflection depends on the electrical contrast between materials (i.e. a strong contrast produces a strong reflection).

The GPR records the strength of reflections detected for a set duration after each pulse. A plot of this data is called a 'trace'. Figure 2 shows a typical trace and illustrates how the EM reflections correspond to the material boundaries.

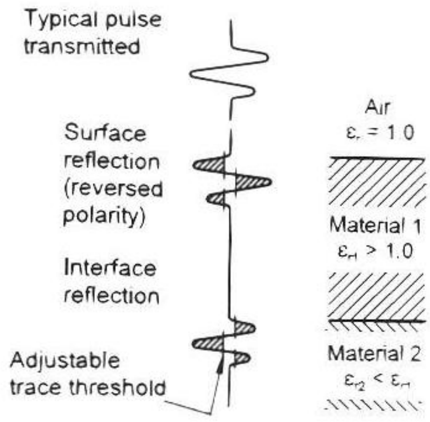


Figure 2 - GPR "trace" and corresponding material boundaries(2)

As the EM waves travel very quickly, the time duration the GPR 'listens' for after each pulse is very brief. The trace signal is usually plotted against a time scale measured in nanoseconds. (i.e. billionths of a second).

GPR systems generate a rapid succession of traces, which are displayed as a “radargram”. A radargram is simply a display of one trace after another with the intensity of the reflected signal represented by different colours or shades of grey. Figure 3 shows an unprocessed radargram of the end of a girder shown with a grey scale palette.

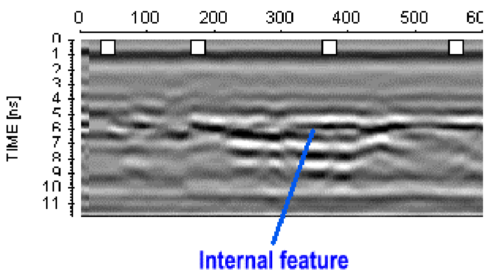


Figure 3 – Unprocessed radargram

In Figure 3 the black line near the top is the near side of the girder and the far side of the girder is around 9ns (somewhat difficult to see). The location of an internal feature has been highlighted. The white squares near the top are markers that were entered at metre intervals.

The depth to the feature can be estimated as follows:

$$D = v_r \,.\, t_r / 2 \qquad \text{Eqn. 1}$$ [2]

Where v_r = velocity of the EM wave
t_r = time to detect reflection
d = depth to feature

The velocity (v_r) of the EM wave is dependant on the material properties, but is fairly constant in sound timber. As the thickness of the girder is known from site observation, the average velocity can be calculated from the time it takes for the signal to reflect from the far side of the girder.

The appearance of the radargram can often be improved by signal processing of the raw data. Figure 4 shows the same radargram shown in Figure 3 after basic signal processing, including corrections for distance along the girder, zero depth and with the depth scale shown.

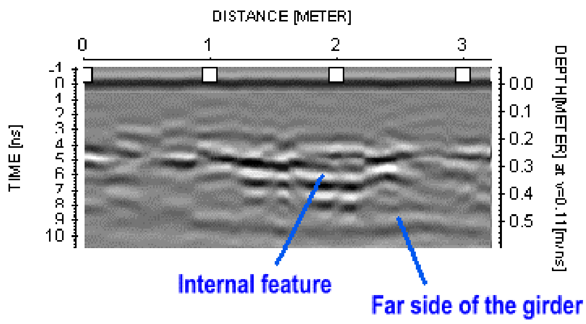


Figure 4 - Processed radargram

After signal processing it is now easier to see the far side of the girder, which was previously obscured because of signal artefacts.

Performance and Other Considerations

The performance of GPR is discussed in greater detail later in this report.

GPR surveys, signal processing and interpretation of the results should be undertaken by personnel experienced in using these techniques. Poorly configured systems will lead to poor results.

Interpretation of the results is often an involved process (even for the initiated!). Successful interpretation requires a good understanding of the underlying principles and limitations of these techniques.

GPR is suitable for investigating relatively non-conductive materials such as concrete, timber and road pavements. It is not suitable for investigating materials with high conductivities such as metals, or materials with high moisture contents.

As GPR uses very weak non-ionising radiation there are no particular safety issues for site personnel (i.e. similar but much weaker than a mobile phone).

Method 2: Gamma ray transmission

Principles of operation

A gamma ray probe called a Lixi Profiler was used during the timber bridge trial.

This device operates by placing a radioactive source on one side of a girder and measuring the strength of gamma rays passing through to the far side of the girder. From the intensity of gamma rays passing through the girder the thickness of sound timber is predicted. The size of internal defects is inferred as being the difference between the total diameter of the girder and the thickness of sound timber reported by the probe.

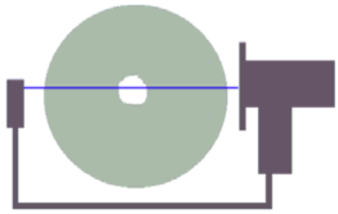


Figure 5 - Schematic of Lixi profiler in use on a timber girder

The profiler's output is a plot of the total predicted thickness of sound timber. For example if the profiler predicts 300mm of timber in a girder, which is 450mm in diameter, then a 150mm void is inferred.

Performance and Other considerations

A problem with this approach is that it does not account for the effects of non-hollow defects such as rot and termites nests. The density of these defects will reduce the intensity of gamma rays passing through the girder leading to an overestimate of sound timber thickness.

This effect was found to be significant during this trial. In half of the girders surveyed in the Redbank Creek bridge the profiler significantly overestimated the amount of sound timber, and as a result underestimated the size of defects. In these locations defects 40-60mm in size were predicted but were found to be 150-250mm in size from test drilling.

As the profiler has no way of distinguishing which defects are hollow and which are not it does not appear this limitation can be avoided.

As the isotope is continually degrading regular calibration is essential. The isotope used for this trial was at the end of its usable life (2 years 4 months old), which made the survey quite slow. The equipment is heavier than the GPR (~4.5kg v's ~2kg), more awkward and relies on the line of sight between source and detector aligning with the defect, which may overlook some defect types (e.g. v-rot at the top).

It was concluded that caution should be exercised using this method as it may significantly underestimate the size of non-hollow defects.

Method 3: Ultrasound

A Pundit ultrasound system was also used for the trial. This system consisted of a pair of transducers attached to a control unit. The unit generates a compression wave on one side of the girder and measures the time for the wave to travel to the transducer on the opposite side. It was hoped that an increase in travel time would indicate the presence of a large defect as the wave travels around the defect.

Performance and Other considerations

Unfortunately it was difficult to achieve proper coupling of the flat transducers to the round girder. As a consequence the readings fluctuated widely and in many cases it was not possible to record a proper reading at all. Small splits and cracks in the timber are also believed to have contributed to the poor performance of the ultrasound equipment.

It was concluded that this type of ultrasound investigation was not suitable for locating internal timber girder defects.

GPR trial: Purga Creek Girders

Introduction

Four girders from Purga Creek Bridge were salvaged during bridge demolition and transported to a MR depot for testing.

Prior to testing the four girders had defective ends cut off. The ends were then covered and they were placed with their spiking faces down. This was to ensure that internal defects were not visible during testing.

The GPR system used was a GSSI SIR 2000 with a 1.2GHz ground coupled dipole antenna. The system was powered in the field by a car battery. The SIR2000 control unit is shown in Figure 6.

Figure 6 - SIR2000 control unit powered by a car battery

Survey runs consisted of sliding the antenna along the length of the girder – see Figure 7. Each survey run was completed in around a minute with around 30 seconds to set up for the next run.

Figure 7 - GPR investigation of Purga Creek Girders

The output was displayed in real time on the SIR2000 monitor. Larger features could be identified straight away, however the average screen quality and colour palette used made site interpretation of subtle features more difficult.

Passes were undertaken on each girder in the “2 o’clock” and “10 o’clock” orientations, as these would avoid bolts on an insitu girder. Runs were first undertaken in 8-bit format and later repeated using 16-bit format data. These results were very similar indicating a high level of repeatability.

Predictions and Findings

The location of internal features was predicted based on the post-processed GPR data.

To assess the validity of these predictions the girders were cut with a chainsaw at one-metre marks and the defects were located. Where the GPR data indicated features lay between the metre marks additional cuts were made. The dissected girders are shown in Figure 8.

Figure 8 - Purga Creek Girders are cut up

Overall there was an excellent correlation between the location and size of defects predicted and those found after dissecting the girders. A variety of defect types were detected including piping, cracking and rot.

Some of the internal defects located by the GPR investigation are shown in Figure 9. An example of the processed GPR data, defect predictions and corresponding photographs for one of the girders is shown in Appendix A.

Figure 9 – Purga Creek Girder defects

GPR trial: Redbank Creek Girders

Introduction

The same GPR system used for the Purga Creek investigation was also used for the Redbank Creek investigation. To reach the girders the GPR antenna was mounted on a fibreglass pole – see Figure 10.

Figure 10 - GPR investigation of Redbank Creek (Crossing #3) Bridge

Horizontal and vertical passes were undertaken on each internal girder. As bolts get in the way, only one pass was undertaken on each external girder, aligned in between the rows of bolts. Each run took around a minute to complete and 30 seconds to set up for the next run.

As with the Purga Creek girders, the SIR2000 monitor displayed internal features in real time but the output was sometimes difficult to interpret. When the same data was shown on a laptop screen the results were much easier to interpret. Appendix B shows an example of a raw output shown on a SIR2000 monitor and the same data shown on PC screen for comparison.

Predictions and Findings

The GPR data was analysed offsite by the Author and defect predictions were made. Post processing of each radargram took around 3 to 5 minutes. The data was most effective when all radargrams for a span were presented on a single page. The contrast between sound and defective girders allowed trouble spots to be quickly identified.

The defect predictions were assessed by comparison with a site drilling investigation. The investigation was undertaken by the Main Roads Southern District timber bridge crew.

Drill locations were selected onsite by the Author based on the radargram output. The defect predictions were read aloud before each drill hole was undertaken. Areas predicted to contain large defects, small defects and no defects were drilled to test the predictions. Figure 11 shows the drilling investigation underway.

Figure 11 - Drilling investigation of Redbank Creek (Crossing #3) Bridge

In general there was an excellent correlation between the GPR predictions and the drilling survey findings.

Every location where a major feature was predicted one was found, and every location predicted to be sound was confirmed by the drilling. The majority of smaller defects predicted by the GPR were also found by drilling. In total 35 drill holes were undertaken.

The GPR correctly located voids and rot defects ranging from 50mm to 350mm in size. The relative size of defects predicted correlated well with the GPR predictions.

From the vertical and horizontal GPR runs the defects could also be located in the girder cross section. For example if a if a medium size defect was noted after 200mm of sound timber in a vertical scan then the defect is at the top of the cross section (i.e. near the deck). Predictions such as these were confirmed by vertical and horizontal drilling.

Appendix C shows a summary of GPR output, GPR predictions and drilling survey findings for Span 4 of the Redbank Creek bridge. The yellow arrows indicate the locations of drill holes.

Applications

It is envisaged that these techniques could be used as a first pass to locate defects and to target drilling investigations. Once the use of these techniques is established it may be possible to significantly reduce the amount of drilling necessary. These techniques could also be applied to other timber bridge components such as piles and headstocks. The high repeatability of results in this trial indicates these techniques could also be used over longer periods to monitor rates of deterioration.

GPR techniques are also useful for a variety of other applications including road pavement, concrete and subgrade investigations*. This additional utility may improve the economy of hiring such equipment.

Conclusion

A trial was undertaken using various non-destructive techniques to locate internal defects in timber girders.

Of the techniques trialled, Ground Penetrating Radar (GPR) was found to be the most reliable method of locating internal defects such as piping and rot. Overall there was an excellent correlation between the GPR defect predictions, test drilling and inspection after cutting up of girders.

The GPR system used was quick, lightweight, mobile, safe for personnel and well suited to field conditions. Interpretation and post-processing of the GPR data was complicated at times and requires experienced personnel.

The results of this trial on timber girders have certainly been promising, and have demonstrated that GPR has a number of significant advantages over existing timber girder inspection methods.

References

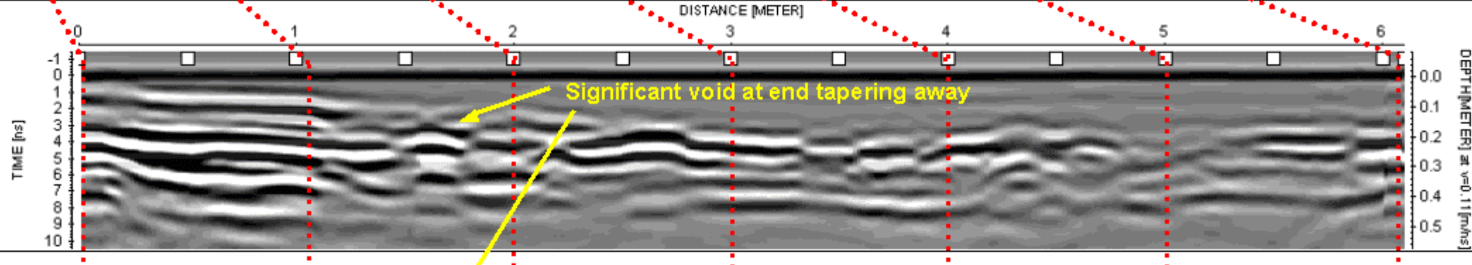
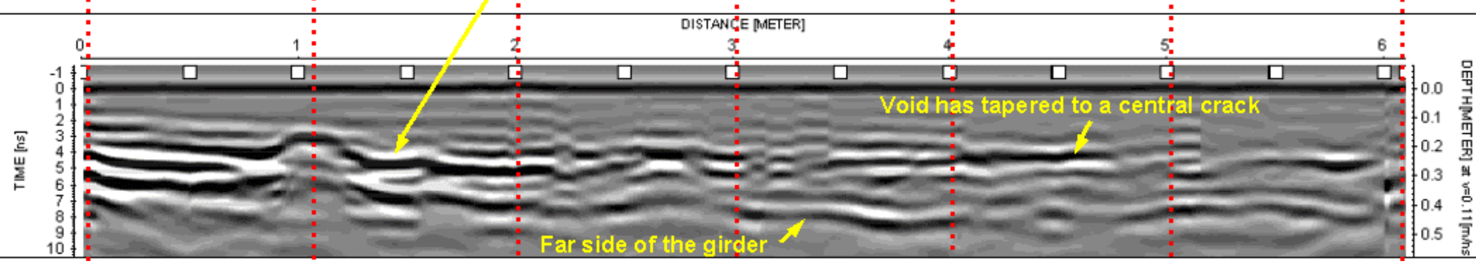
1. Queensland Department of Main Roads (2000) – '**Bridge Inspection Manual'**; Version 1, Brisbane, 1.2-1.12; 2.14-2.16; 2.30-2.31

2. The Concrete Society (1997) – '**Technical Report No 48 - Guidance on Radar Testing of Concrete Structures'**, Slough, United Kingdom, 8-9, 73.

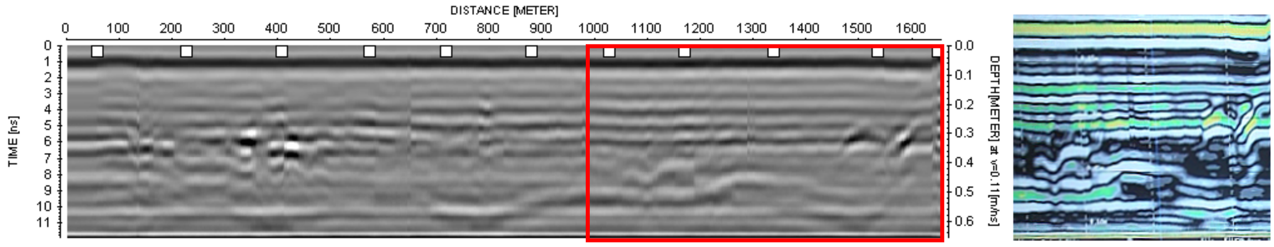
** Note: different antennas and GPR set-up is required for some other applications.*

Appendix A

GPR investigation of Purga Creek Girders - Trial at Brassall Depot March-May 2002 — Wayne Muller, Structures Division, Main Roads

Girder X15	**Photos:**									
	Distance	0.0 metres	1.1 metres	2.0 metres	3.0 metres	4.0 metres	5.0 metres	6.0 metres (end)		
	Comments / Onsite observations	210mm dia. hole. Approx 70mm LHS and 130mm RHS	210mm dia. hole. At top. Approx. 50mm LHS and 130mm RHS is sound	Hole at top 100-120mm wide, 180mm deep.	Hole at top 100-120mm wide, 200mm deep.	V-crack 110mm wide at top extending 160mm down.	3 cracks at top (total 150mm wide) – extending 70mm deep.	Vertical split 10-20mm.		
	Orientation	**Radargrams**								
	File 74 8-bit data									
	File 75 8-bit data									

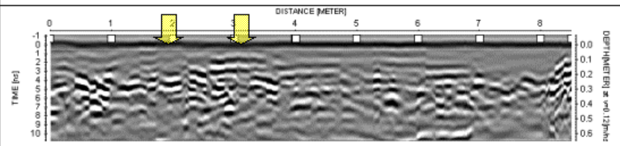
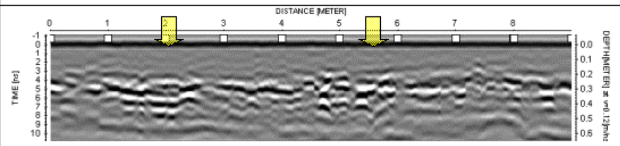
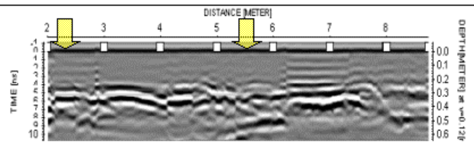
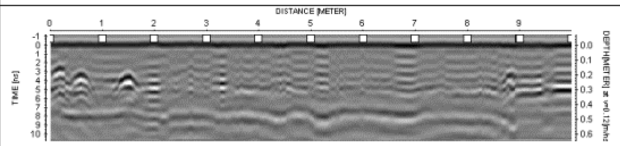
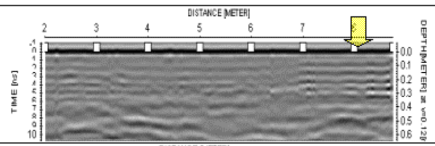
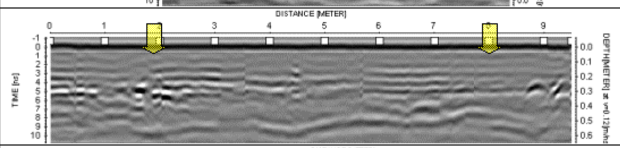
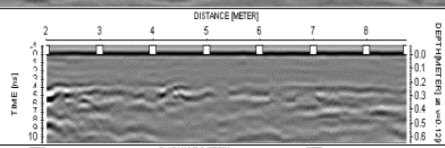
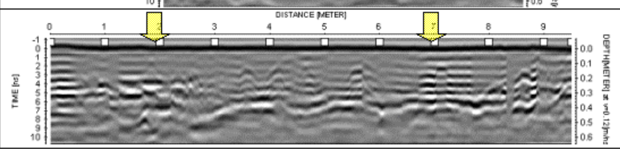
Appendix B



Raw radargram shown on a PC screen (in the red box, left) and on the GPR monitor (right)

Appendix C

Redbank Creek Crossing No. 3 Bridge - Span 4

	Orientation	Radargram	Offset	Revised GPR interpretation	Drill survey findings
Span 4 Girder1	File 25		2.0m (45°)	Med-large pipe. Approx. 180mm of timber before the hole, but possibly soft to within 60mm of surface.	200mm dia. hole noted after 50mm sound timber
			3.0m (45°)	Large pipe. Approx. 40-60mm of sound timber nearest the surface.	250mm hole (50 mm sound + 50mm soft + 250mm hole)
Span 4 Girder 2	File 26		2.0m (H)	Medium pipe. Approx. 200mm of sound timber to the nearest defect.	100mm soft material, 50mm dia. hole
			5.5m (H)	Medium size localised void. Approx. 180mm of sound timber to the nearest defect. Girder is holding water.	100mm void.
	File 31		2.2m (V)	Void, approx. 240mm of sound timber to the nearest defect.	Vertical drilling confirmed this was a V-shaped defect
			5.5m (V)	Void, approx. 220mm of sound timber to the nearest defect.	V-crack. 150-200mm sound timber at nearest face.
Span 4 Girder 3	File 27		NA	NA Girder is holding water.	NA
	File 32		8.0m (H)	Generally sound but girder is holding water.	Sound
Span 4 Girder 4	File 28		2.0m (H)	Small-medium central void /soft or crack. Approx. 150-200mm of rel. sound timber to the nearest defect. Girder is holding water.	75mm soft
			8.0m (H)	Sound	Sound
	File 33		NA	NA Girder is holding water.	NA
Span 4 Girder 5	File 29		2.0m (45°)	Small central void, approx. 160mm of sound timber to the nearest defect.	50mm soft, 75mm hole.
			7.0m (45°)	Sound	Sound

Author Biography

Wayne Muller is a Civil Engineer who works for the Queensland Department of Main Roads. Wayne has been with Main Roads for over 6 years and has worked in a number of roles including District work, onsite bridge and road construction and most recently working in MR's Structures Division.

For the last 3 years he has worked in the Concrete Technology section of Structures Division, providing advice to Districts on the construction and maintenance of concrete bridges. During this time he has developed a particular interest in the use of non-destructive investigation techniques.

Postal Address: c/- Queensland Department of Main Roads, GPO Box 1412, Brisbane Q 4001

E-mail: wayne.b.muller@mainroads.qld.gov.au