Appendix D Non-Destructive Testing

Queensland Government
Department of Main Roads

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1 Background

The current method of identification and quantification of defects in timber components as detailed in the Bridge Inspection Manual (BIM) is visual inspection and drilling investigation of principal components.

Inspectors carry out conventional drilling investigations using a 12-16mm diameter bit to bore holes in timber components at critical and suspect locations. The extent and severity of any piping or rot within the component is assessed by the inspector based on the resistance to drilling as "felt". This method relies on the experience and subjective judgement of the inspector and provides information only at the selected drill location.

The BIM defines the locations of maximum stress and/or those most susceptible to decay, where drilling tests should be carried out. It also highlights the issue that test holes can expose the member to more rapid decay and regular drilling can result in significant strength reduction, even if no decay is found. It states that all test holes shall be plugged with wooden dowels, which have been treated with an approved preservative, to reduce the potential for accelerated deterioration following the survey. Although it is generally accepted practice within the Department to conduct initial drilling tests on a bridge at the locations detailed in the BIM and probe these locations at subsequent inspections, recent inspections of the bridges have identified that some members have had significant numbers of holes drilled in them, which can expose the member to more rapid decay or strength reduction.

Bridge Asset Management section (BAM) have found that supplementary drilling in addition to the Level 2 inspection is often required to locate and quantify defects to the required level of detail when conducting bridge capacity assessments, thus highlighting deficiencies in the current inspection practices. The need for supplementary drilling is costly in terms of re-establishment, diversion of resources from other tasks and is detrimental to bridge members. Despite supplementary drilling, there has not been a marked improvement in confidence in testing results being representative of member condition.

In response to the identified need to improve the accuracy and reliability in identification and quantification of defects within timber components, BAM have assessed and validated two non-destructive testing (NDT) methods, namely the "Lixi Profiler" (nuclear densometer) and the "Resistograph" (drill resistance testing). The following sections summarise the assessment and validation of the NDT methods and detail corporate guidelines for the implementation of the NDT and conventional drilling methods.

Non-destructive identification and quantification of defects in timber components as detailed in the following sections should be conducted in conjunction with Level 2 Bridge Condition Inspections as defined in the BIM for the Timber Drilling Survey. In addition it is recommended that material species and stress grading be determined as part of the Level 2 Bridge Condition Inspection. An advice note will be released in January 2004 detailing the requirements for species identification and visual stress grading. At this time Main Roads have engaged either the Department of Primary Industries or a Consultant to conduct all inspection and testing required.

Appendix D

1.1 Timber Structure

As a natural building material, timber has evolved unique material properties which dictate and influence use and also maintenance strategies. In the growing tree, the trunk acts as a structural member, anchored by the root system, to support the leaf and branch system. This ability to support both tree mass and wind induced loads makes timber a practical material for our structural component requirement such as for girders, piles and decking.

The structure of timber is essentially a collection of longitudinally oriented cellulose cells, cemented together by lignin, a complex polymer compound which also strengthens the cell walls. Figure 1 shows magnified structures for hardwood and softwood timbers and is included to show the general assemblage of wood cells. The structure of hardwoods is more complex than those of softwoods.

Because timber is essentially composed of longitudinal cells, its properties are anisotropic, ie strength and stiffness properties are much higher along the grain than across the grain. Another property that varies between tangential, radial and longitudinal directions in a log is shrinkage, which occurs as timber moisture content gradually reduces. Shrinkage is greatest in the tangential direction and results in the formation of longitudinal checks or oracles in the timber due to its weakness in tension across the grain.

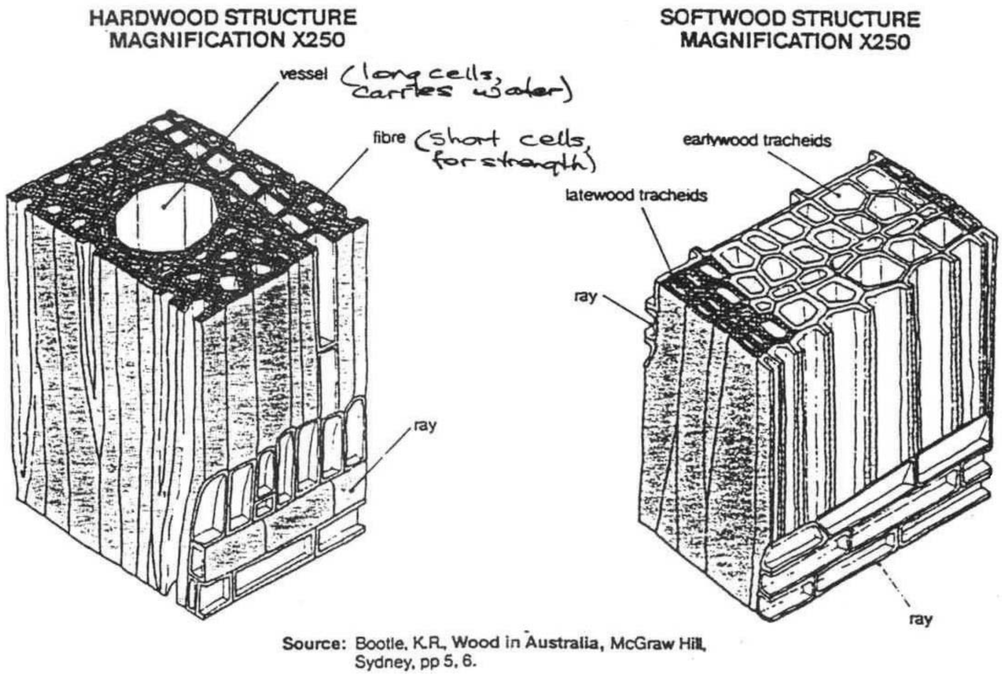


Figure 1 - Wood Structure

1.2 Timber Deterioration

The major causes of deterioration in timber bridges, as described in part 2, section 1.4 of the BIM include: Fungal (rotting); Termites; Marine organisms; Corrosion of Fasteners; Shrinkage and Splitting; Fire damage; and Weathering. Fungal and termite attack, and shrinkage and splitting are the causes of deterioration which are of particular interest with regard to the investigations detailed in this advice note. The sketches shown below in Figure 2 illustrate typical deterioration of girder members. It should be noted that visual inspection of the member may not identify the presence of internal deterioration.

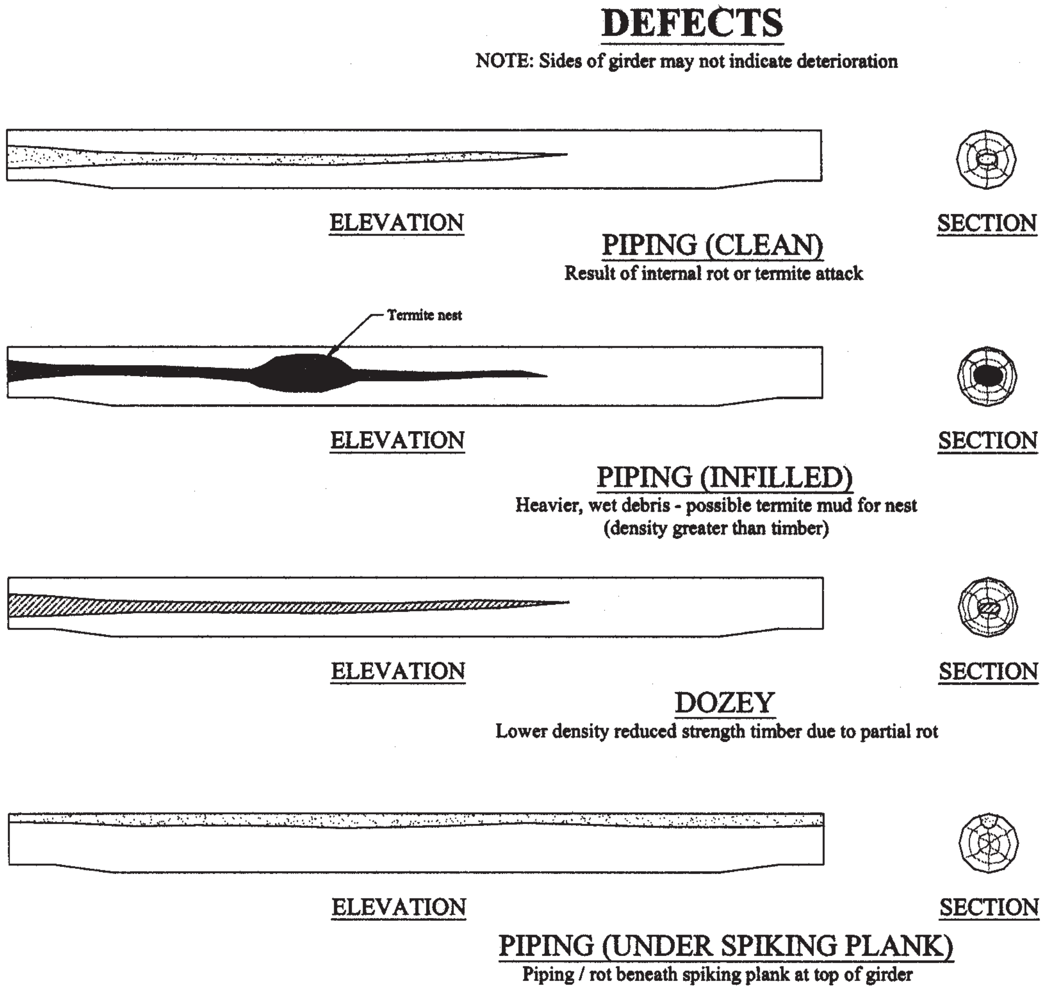


Figure 2 – Typical deterioration of timber girder members

2 Guidelines for Timber Drilling

The guidelines for timber drilling tests currently documented in the BIM provide a general standard for investigation. However, several additional requirements documented below should improve the reliability and consistency of the reporting and determination of condition states, and thus improve the accuracy of capacity assessments.

The requirements for conducting the timber drilling survey are detailed in part 3, section 3.10 (BIM). The key points are included in the following extract from the manual.

> *The purpose of the survey is to determine the residual amount of sound timber by drilling a hole in a member. The respective extent of any pipe, rotted and solid portions is determined by gauging the resistance to drilling supplemented by examination of wood shavings.*

Drilling is carried out at the locations of maximum stress and/or for those areas most susceptible to decay, namely:

- *Midspan and end of girders.*
- *Ends of corbels.*
- *Ends of headstocks.*
- *Base and top of end posts.*
- *Ground level, normal water level or around connections in piles.*
- *Around bolted connections in general.*

All test holes shall be plugged with wooden dowels which have been treated with an approved preservative, to reduce the potential for accelerated deterioration following the survey.

Accepted practice within the Department is to conduct initial drilling tests on a bridge at the recommended locations with a 12mm drill bit and probe these locations at subsequent inspections. Where internal deterioration is evident at the test location additional drilling tests are conducted at locations along the member (typically 500mm intervals) until a solid section is identified.

Typical deterioration mechanisms in standard timber bridge components and guidance on the inspection of these members is detailed in part 2, section 2.3 of the BIM. For example an extract from the section on timber girders states.

Timber girders should be inspected for pipe or external rot at their maximum stress location at midspan. Inspection of the girder ends should also be carried out as pipe rotting is generally more severe at these locations. Girder ends are prone to crushing failure when excessive loss of section has occurred.

The following guidelines for drilling tests are provided in addition to the current guidelines detailed in the BIM, and should be read in conjunction with Figure 3. These guidelines have been developed by BAM based on typical deterioration of timber bridge members, critical locations for assessment of member capacity and guidelines developed by Road Traffic Authority of New South Wales (RTA) and Western Australia Department of Main Roads.

- At the initial inspection the drilling test holes should be made at the locations illustrated in Figure 3 and these holes should be plugged and probed at subsequent inspections to monitor and quantify progressive deterioration.
- Test holes should be plugged with wooden dowels, which have been treated with an approved preservative to reduce the potential for accelerated deterioration.
- Care should be taken to avoid drilling completely though the members, and horizontal drills should be inclined slightly upwards to allow drainage.
- It is recommended that drill holes be made perpendicular to the face of the member such that the recorded deterioration is relative to the section size.
- Two test holes are required to be made through the cross section of girder and corbel members to identify deterioration in the centre of the section and also v-shaped deterioration in the top of member.

- Where deterioration is identified in the girders from the drilling tests at the locations illustrated in Figure 3, then additional drilling tests should be carried out at 500mm intervals along the member until a sound section is identified.
- Where deterioration is recorded in the drilling test at the pile/headstock connection, an additional drill should be made approximately 500mm along the headstock from the centreline of the pile.
- It is recommended that material samples be taken and submitted to BAM for species identification as detailed in an Advice Note on Timber Species Identification and Visual Grading, to be released by BAM in January 2004.

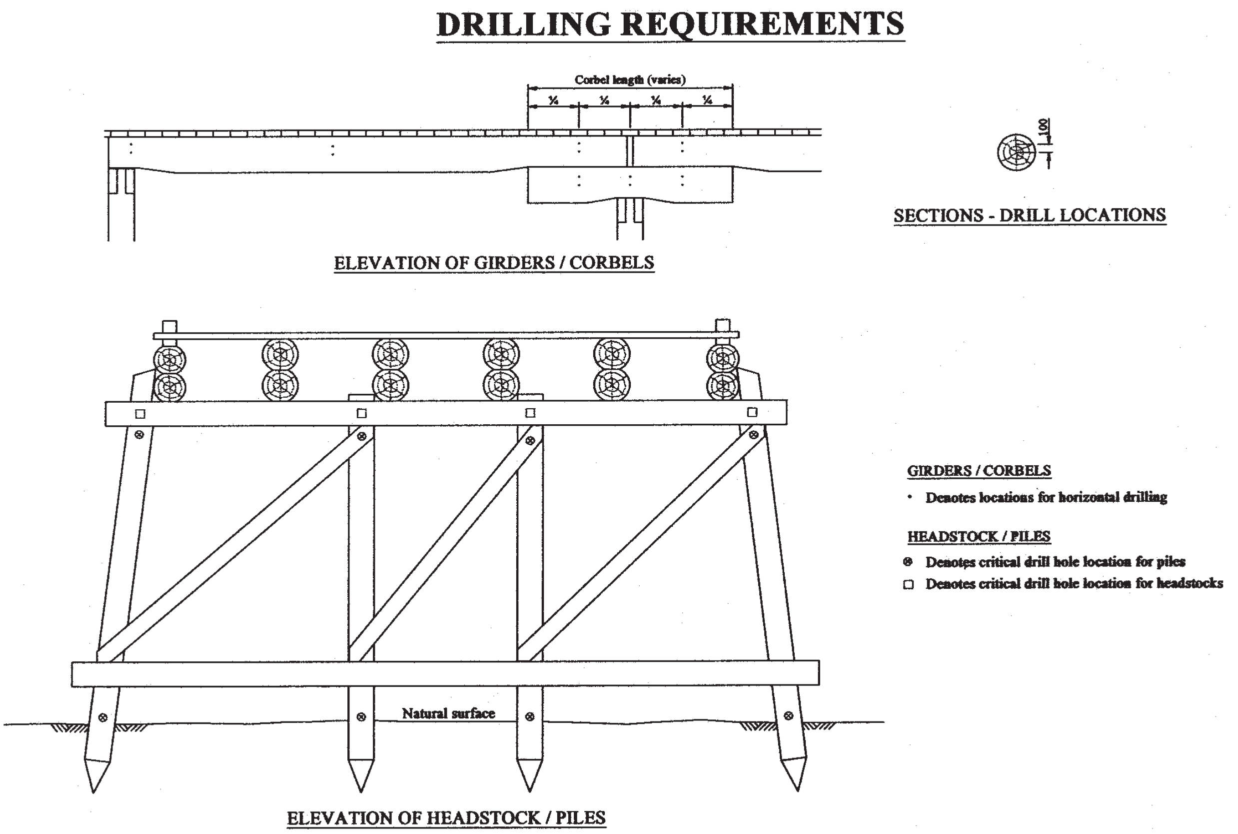


Figure 3 – Guidelines for Drilling Timber Members

3 Investigation of the "Lixi Profiler" (nuclear densometer) NDT Method

3.1 Background

The "Lixi Profiler" is a real time density measuring system, which produces a graph showing the net thickness of the timber section. The "Lixi Profiler" is illustrated in Figure 4 below. It uses a radioactive isotope, Gadolinium-153 (Gd-153) and generates a highly collimated beam of radiation that penetrates through the timber section. The amount of radiation that reaches the detector opposite the source is proportional to the total thickness and average density of the material it passes through. The "Lixi Profiler" is calibrated against a solid section of girder timber and thus calculates and reports the thickness of the timber.

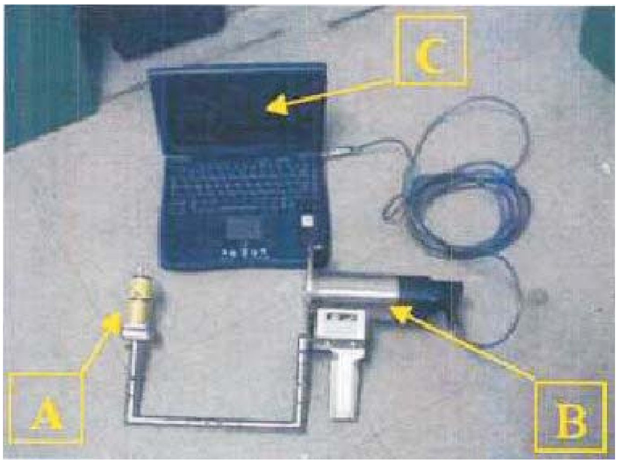


Figure 4a: "Lixi Profiler" Inspection system, consisting of an isotope (A), a micro channel-plate (MCP) detector (B), a laptop computer (C) running MS windows based proprietary software (Intico Pty Ltd)

Figure 4b : "Lixi Profiler" in operation

Intico Pty Ltd was engaged by BAM to provide inspection and assessment services for trials using the "Lixi Profiler". Intico Pty Ltd is the sole importer of the "Lixi Profiler" into Australia. Lixi Inc of Illinois USA manufactures the "Lixi Profiler". "Intico" have two "Lixi Profiler" units and provide an inspection service which includes the "Lixi Profiler" and a trained technician and a report of the condition of the members. Intico's head office is in Melbourne, and they also have an office in Brisbane. All trials with the "Lixi Profiler" conducted to date have been provided from the Melbourne office on a cost plus basis.

The "Lixi Profiler" was developed as an inspection tool to assess the condition of steel piping systems, in response to the problem of examining insulated piping for blockage and corrosion. The objective was to provide a method which could quickly scan along the length of the insulated pipe to locate areas of poor condition without having to take the pipes out of service. The difference with the application of the "Lixi Profiler" to the inspection and assessment of timber members is the material and deterioration characteristics of timber compared to steel.

Intico's standard operating procedure for "Lixi Profiler" scanning is attached for reference and several points are highlighted below.

- *Applicable codes and specifications are: Code of Practice for the Safe Use of Radiation Gauges (1982); and Intico Procedure TP1 RT 17.*
- *Personal performing scanning covered by the Procedure shall be the holder of current radiation license and have relevant experience as specified in AS 3998 and other relevant Specifications which may apply to the specific project.*

- Equipment shall be registered as a Radiation Gauge as per Code of Practice for Safety Use of Radiation Gauges (1982).
- Source of radiations shall be collimated 90-110 keV activity Gadolinium – 153 (Gd-153) isotope, housed in stainless steel / tungsten source head.
- Safe operating instruction detailed in the procedure should be adhered to.
- The "Lixi Profiler" shall be calibrated using a range of thickness using sample material of the same density of the item under test.

As detailed in Intico's standard operating procedure the operator is also required to be the holder of a current radiation license and have relevant experience as specified in AS 3998 and other relevant Specifications which may apply to the specific project.

"Intico" have been engaged to provide testing and data analysis services for the trials using the "Lixi Profiler" conducted to date. Based on the unit rates "Intico" have provided and BAM's experience with regard to the time taken to complete inspections conducted to date, BAM provide the following cost estimates for inspections using the "Lixi Profiler". "Intico" have indicated that they intend to mobilize from Brisbane for work requested by Main Roads, however if "Intico" are required to mobilize from Melbourne the associated air fares and accommodation costs will be charged at cost+10%.

- Inspection of all members on a typical 4 span timber bridge which is easily accessible, should take approximately 8 hours. The cost for the inspection is estimated at $4700 which includes the "Lixi Profiler", 1 technician, 1 assistant technician and associated reporting. It is possible that the District or RoadTek provide an assistant which would reduce the estimated cost to $4000. Additional costs are dependant on the location of the bridge and any associated travel and accommodation costs incurred by "Intico", these costs will be charged as follows :
  - $80 / night for each member of crew (living away from home including meals and other inconveniences)
  - accommodation at cost + 10%
  - car hire at cost + 10%
  - consumables (such as fuel, etc) at cost

- Inspection of all members on a typical 4 span timber which requires access equipment such as the UBIU and where access is also limited due to requirements on duration of traffic disruptions, should take approximately 2 days (16 hours). The cost for the inspection is estimated at $8400 which includes the "Lixi Profiler", 1 technician, 1 assistant technician and associated reporting. It is possible that the District or RoadTek provide an assistant which would reduce the estimated cost to $7000. Additional costs are dependant on the location of the bridge and any associated travel and accommodation costs incurred by "Intico", these costs will be charged as detailed above.

It is noted that the cost of any access equipment such as the UBIU and any associated traffic control is additional to the costs detailed above.

3.2 Assessment & Validation

The "Lixi Profiler" can scan the length of the member and identify the locations of deterioration. This is considered a significant advantage over conventional drilling and "Resistograph" methods, which provide information at a specific location only. Typical deterioration mechanisms in timber members as illustrated in section 1, indicate that the deterioration is not generally evident from a visual inspection of the member. Thus the location of drilling investigations as detailed in section 2 is typically determined based on expected deterioration and critical locations identified by structural capacity assessments. Accordingly defective zones within the member may be missed entirely.

BAM have conducted two trials in June 2002 and March 2003 to investigate the application of the "Lixi Profiler" to the inspection of timber bridge members following an initial demonstration of the equipment in April 2002.

3.2.1 Typical Investigation and Results

The "Lixi Profiler" is required to be calibrated for the inspection of each member section. Calibration of the "Lixi Profiler" is dependant on the outside dimension of the member and density of the section. The "Lixi Profiler" may be calibrated against a sample section of material in the laboratory or based on material densities stated in the Australian Standard for Timber Structures AS1720.1 if the member species is known. Alternatively the "Lixi Profiler" may be calibrated in the field on members where the thickness of the section can be measured and the internal condition can be verified, such as at the ends of corbels and headstocks. This calibration is essential for the thickness measurement to be considered valid as an absolute measure of sound material in the member. It is also possible to utilise the results from investigations with the "Lixi Profiler" to provide a relative measure of the deterioration within the section by reviewing the percentage loss. The percentage loss of material is illustrated on the records of the scans reported by "Intico" and can be determined on site by reviewing the real-time scan record.

For the purpose of the trials conducted to date the "Lixi Profiler" has been mounted in a U-shaped bracket and in some cases an extension arm has been attached to provide access to the girders from the ground level as illustrated in Figures 4b and 5a.

Figure 5a – General view of scanning with the"Lixi Profiler" (Intico Pty Ltd)

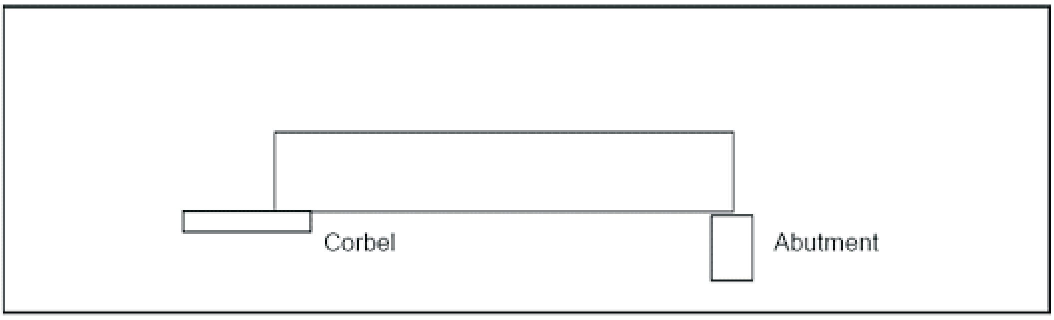
Figure 5b - Real-time results of the scan

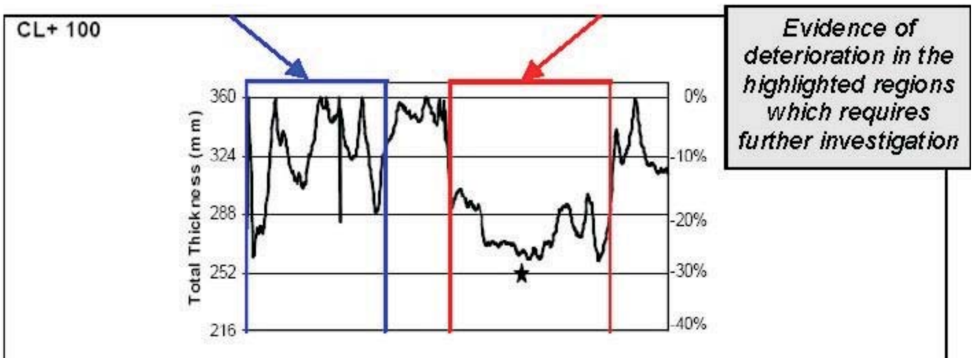
Initially the member is scanned longitudinally along the centreline of the cross section, to identify locations of deterioration in the centre of the member. Additional longitudinal scans at 50-100mm above the centreline of girders are also carried out to identify any deterioration in the top of the girder.

In the field the real-time results of the scans are shown on the screen of the laptop computer as a determined material thickness in millimetres as illustrated in Figure 5b. In the trials conducted to date the thickness measurements have been recorded against the time of the scan. The real-time record of the scan allows areas of identified deterioration to be marked on the member for further investigation.

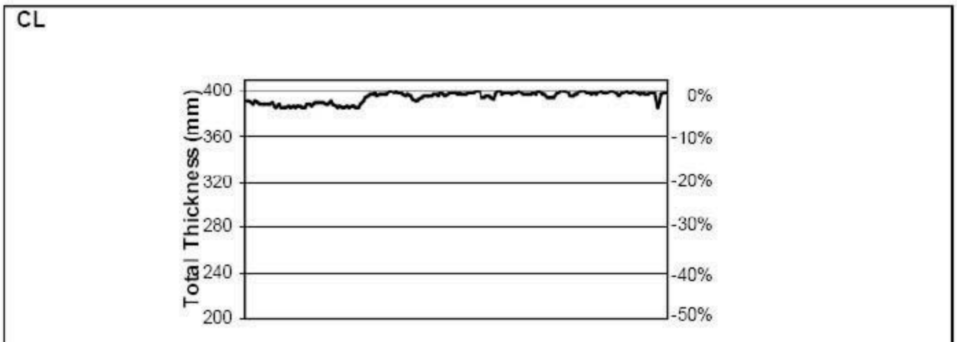
The services provided by "Intico" for the trials conducted to date have included production of a report of the test scans. The records of the scans have indicated the determined material thickness and corresponding percentage loss of thickness against the time taken to complete the scan as illustrated in Figure 6. It has therefore been necessary to mark the location of deterioration on the member when it is identified. If the record of the scan is to be referenced at future inspections the location of deterioration needs to be adequately detailed on the record, thus it would be beneficial if the equipment was modified to provide a distance based record of the scan.

BRIDGE:	Bremer River
COMPONENT:	Girder 1
LOCATION:	Span 4





Comment ★-Evidence of loss 1275mm from Abutment 2; Min thickness 260mm
Recorded thickness 340 – 360mm

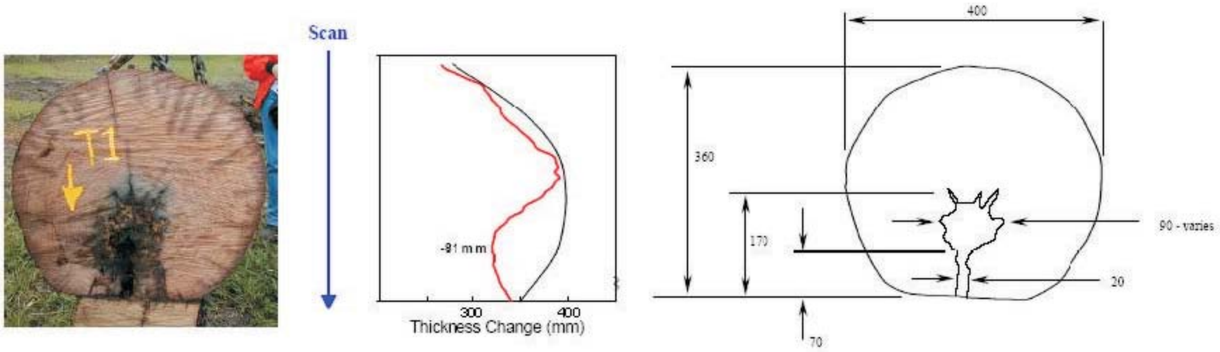


Comment Recorded thickness 370 – 400mm

Figure 6 – Typical record illustrating the results of scans along a timber girder plotted against time and actual deterioration within the girder

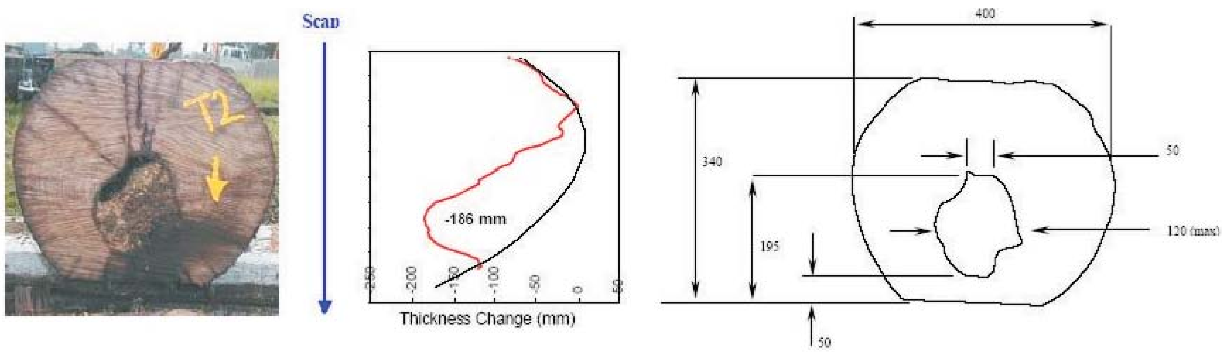
Additional testing is required to provide more detailed information of the deterioration identified in the longitudinal scans or to verify the condition of areas which appear suspect in the visual inspection. This additional testing may include a transverse scan with the "Lixi Profiler" and/or drilling with the "Resistograph" or conventional drilling.

The results of a transverse scan with the "Lixi Profiler" are illustrated below in Figure 8. It is important that the outer dimensions of the member at the scan location are recorded and plotted (black line). The plot of the scan (red line) shows the recorded thickness through the member. Thus the change in thickness due to deterioration can be measured through the section and the location of the deterioration within the section identified.



	Thickness Loss
Initial Longitudinal Scan	-60 mm
Transverse Scan (greatest loss)	-71 mm
Actual	- 90 mm max

Figure G1-2: Details of Section T1 – Measurements and Appearance
Note – transverse scan shown is overlaid with approximate thickness indication for solid timber – this is an estimate only.



	Thickness Loss
Initial Longitudinal Scan	-80 mm
Initial Transverse Scan (before cut)	-80 mm
Transverse Scan after cut and cleaned	-110 mm
Actual	-120 mm max

Figure G1-3: Details of Section T2 – Measurements and Appearance
Note – transverse scan shown is overlaid with approximate thickness indication for solid timber – this is an estimate only.

Figure 7 - Transverse scans showing recorded deterioration and actual member cross section.

3.2.2 Investigations in June 2002

Analysis of the results from the trials conducted on the 7th June 2002 concluded that, in the case of deterioration in the girders where the cavities were filled with rotted material and debris, the severity of the loss of section identified by the "Lixi Profiler" was reduced by up to 30%. However, loosely packed debris in the cavity had a minimal effect on the loss of thickness recorded by the "Lixi Profiler".

In addition to identifying pipe defects in timber components it is believed that a member which is dozey through the entire cross section can also be identified using the "Lixi Profiler". Where the "Lixi Profiler" reading shows a constant thickness which is less than the thickness of the solid girder, a transverse scan should allow the determination as to whether the girder is dozey. If the girder is dozey the reduction in recorded thickness compared to that of a solid girder should be constant for the entire transverse scan. The accuracy of this methodology relies on the calibration of the "Lixi Profiler" to the actual material and the control of the orientation of the scan.

3.2.3 Investigations in March 2003

Review of the results from investigations at Bremer River bridge highlighted the following:

- The importance of calibrating the "Lixi Profiler" for the specific members being investigated.
- The need for distance based measurement and recording of the investigations to provide an accurate record of the location of any defects for analysis and future reference.
- The importance of aligning the source with the centreline of the member and square to the face of the member, or at 100mm above the centreline of the member as required and as close to the surface as possible.
- The "Lixi Profiler" underestimates the size of deterioration within a member when the member is filled with material, such as rot, because the reported thickness is based on the measurement of the density of the material scanned.
- The size variation along the length of the member.

3.2.4 Discussion

There is some variability, typically in the order of 5% to 10% in recorded thickness on a longitudinal scan of a member with no significant defects. The main reasons for this variation are likely to be due to, variation in size of the member and the effect of surface imperfections such as small splits. The condition state limits for girders as detailed in the BIM are CS 3 £35% piping at ends or £50% piping at midspan and CS 4 £50% piping and £70% piping at midspan. Based on the deterioration limits for the various condition states as detailed in the BIM and noted above for girders, the variation of 5% to 10% is not considered to be of concern with regard to identifying defective components in condition state 3 or 4.

The present arrangement of moving the "Lixi Profiler" manually, and presenting the data on a time scale (approximating a distance) limits its accuracy in mapping out areas of piping or dozey deterioration, as the location of defects must be manually recorded on site. In addition to errors which may occur in the manual location of the defect, the speed of recording along the member is not automated and does not provide a record of deterioration which can be used for future reference. "Intico" is presently developing an alternative system of data recording that will allow a more accurate position-based assessment of the longitudinal and transverse scans. It is noted that this sophistication is only required to provide a permanent record of the deterioration along the length of the member. It is acceptable to scan the member, mark the location of defects as they are identified during the scan, record the location of the deterioration by measuring along the member and conducting further investigations such as a transverse scan or drilling to quantify the deterioration.

It is recommended that a centralizing jig is developed to ensure that the centre of the source is aligned with the centre of the member and as close to the surface as possible. It is noted that the use of a centralising jig is a requirement for testing pipes in Intico's Testing Procedure for the "Lixi Profiler". The current bracket arrangement the "Lixi Profiler" is mounted on limits the access along the girder to approximately 300mm from the end of the corbel. "Intico" are aware of the issues associated with the current arrangement of the equipment and have indicated that they would modify the mounting bracket should the "Lixi Profiler" be included as an inspection method within Main Roads inspection regime, however the modifications were not considered economic in the evaluation phase.

Extracts from reports provided by "Intico" are included to illustrate the information provided. The report is concise and provides the results of all scans. The percentage loss is included on the vertical axis of the plots produced in addition to the recorded material thickness, and the condition state criteria defined in the BIM can then be applied to the results to determine the condition of the member. It is noted that the girder sizes are required to be measured and the measurements shown on the record of the scan to illustrate the percentage loss of section.

The time taken to investigate a timber bridge member using the "Lixi Profiler" is typically 2 minutes per longitudinal scan of a member such as a girder or pile. Inspection of bridges less than 3m high and over dry waterways, can be conducted from the ground as illustrated in section 3.2.1. However, if the bridge is higher and/or there is water under the bridge, then the under bridge inspection unit (UBIU) or similar equipment is required as for a conventional drilling inspection and the time and cost of the inspection is increased accordingly.

3.2.5 Health and Safety

As noted above, the "Lixi Profiler" technology utilizes low-level gamma radiation and therefore the health and safety of staff must be considered with regard to any recommendation for the use of such equipment within the Departments inspection regime. Documentation provided by "Intico" states the following. *"The technology utilizes low-level gamma radiation, which has been approved by the QLD Health Department. It is safe for the operators as well as for the members of public. There are no safety requirements to restrict access to the area while scanning is in progress."*

3.3 Recommendations

The accuracy of the "Lixi Profiler" is considered appropriate for determining the deterioration of timber bridge members, based on the results of investigations conducted to date and the condition state levels defined in the Bridge Inspection Manual.

Based on the health and safety information obtained on the "Lixi Profiler", the equipment is considered to be safe. However, BAM will continue to monitor research, developments and requirements associated with the health and safety issues of the equipment.

BAM recommends that the "Lixi Profiler" is used in conjunction with either conventional drilling or "Resistograph" inspection methods, however the "Lixi Profiler" may be used as the sole NDT method if additional investigations are conducted as detailed in section 5.1.3.

It is recommended that modifications be made to the "Lixi Profiler" equipment to ensure that the centre of the source is aligned with the centre of the member and as close to the surface as possible and the thickness of the member along the scan is recorded against distance.

Where "Intico" are engaged by Districts or RoadTek to conduct investigations using the "Lixi Profiler", it is recommended that BAM are informed to monitor the performance, service, implementation and cost of the inspections. The contacts at "Intico" are listed below.

- "Intico" Melbourne, Wolfgang Mika, Manager, Power Generation Division and Vladimir Kurbalija, "Lixi Profiler" Technician, phone 03 9350 4366.
- "Intico" Brisbane, Keith Langdon, Manager Queensland, phone 07 3216 7771.

4 Investigation of the "Resistograph" (resistance drilling), NDT method

4.1 Background

The "Resistograph" is a quasi non-destructive testing method, which measures the resistance of the timber to the advancement of a small 1.4mm diameter drill bit. The "Resistograph" is illustrated in Figure 2 below. The drill is advanced at a constant speed through the timber and the recorded resistance provides a measure of the density of the material through the sample. The "Resistograph" produces a real-time graph of the relative magnitude of the torque required by the drill to keep the bit moving at a constant speed, against the depth of penetration. This graph is also stored in the onboard computer.

Tree Testing Australia (TTA) was engaged by BAM to inspection and assessment services for trials using the "Resistograph". The "Resistograph" is made in Germany by IML. "TTA" is division of IML Australia and are the sole distributor of the "Resistograph" in Australia and New Zealand. TTA's office is located near Toowoomba.

Information provided by "TTA" also states that, *"Resistograph assessments have the advantage of being less invasive (the 2mm hole is self sealing on withdrawal of the probe) and more accurate than core sampling and ultra-sound."* The back sealing of the test hole, limits the opportunity for moisture ingress or the initiation of decay and the effect of the drilling on the overall structural system.

The inspections conducted to date have been at a contract rate of $550 per day. "TTA" have indicated that there are several options available to Main Roads including purchase or lease of equipment, or an inspection service contract. The F300S "Resistograph" unit costs $10,550 plus GST, and additional costs for training. A lease plan is also available at a cost of $650 per month for a F300S "Resistograph" unit over a 24 month period, including full warranty and training.

The investigations at Bremer River Bridge included drilling 37 test holes using the "Resistograph" and took 1 day to complete in the field and 1½ days to prepare the report at a cost of $1375 plus GST. The testing at Bremer River Bridge drilled only defective locations identified by the "Lixi Profiler" and the time taken was increased due access limitations which required the use of the UBIU while minimising traffic delays to 15 minutes on a single lane bridge.

Investigations using the "Resistograph" take approximately 5 minutes, which allows for changing of batteries, paper indicators, computer identification codes and drill bits. Based on the rates provided by "TTA" and BAM's experience with regard to the time taken to complete inspections conducted to date, BAM provide the following cost estimate for inspections using the "Resistograph".

- Inspection of all members on a typical 4 span bridge with 4 girders per span and 3 piles per pier group will require approximately 126 drill holes using the "Resistograph" to drill at the locations illustrated in Figure 14. For a bridge which is easily accessible, it is estimated that it will take 2 days in the field to complete the inspection and cost approximately $2000+GST. This cost includes the "Resistograph", 1 technician and associated reporting, and assumes that the District or RoadTek provide an assistant.
- Inspection of all members on a typical 4 span bridge which requires access equipment such as the UBIU and where access is also limited due to requirements on duration of traffic disruptions, is estimated to take 3½ days. The cost for the inspection is estimated at $3000+GST. This cost includes the "Resistograph", 1 technician and associated reporting, and assumes that the District or RoadTek provide an assistant.

It is noted that the cost of any access equipment such as the UBIU and any associated traffic control is additional to the costs detailed above.

4.2 Assessment & Validation

BAM have conducted two trials to investigate the application of the "Resistograph" to the inspection of timber bridge members following initial testing conducted by Southern Region in August 2002. The trials conducted by BAM included investigation of individual girders in conjunction with laboratory testing and the investigation of the Bremer River timber bridge.

4.2.1 Typical Investigation and Results

Initial investigations with the "Resistograph" were carried out using the 500mm model, however it was found that the 300mm model was more appropriate for timber bridge inspections. "Resistograph" investigations conducted by BAM in the laboratory and at Bremer River were completed using the 300mm model. Standard timber bridge members are less than 600mm in diameter and therefore the 300mm "Resistograph" penetrates more than half the thickness of the member as required.

The "Resistograph" drilling produces a real time print out and also stores the test results electronically. "TTA" processes the electronic data to highlight the deteriorated regions and provide comments on the assessment of the test.

Figure 8- The "Resistograph" being loaded with paper to record the test.

Each drill test is identified by a unique code, which is programmed into the "Resistograph". This code is in a number in the format ## / ##, and the corresponding span and girder number, drill location along the member and the orientation of the "Resistograph" were recorded for each drill test.

The "Resistograph" was aligned with the girder in accordance with the timber drilling guidelines.

Figure 9a - Horizontal test using the "Resistograph" ***Figure 9b - Vertical test using the "Resistograph"***

At the end of each test the unique code was written on the paper printout. Any comments regarding possible problems with the reading were recorded on the printout. At the end of each day the electronic file was downloaded to a computer for storage of the data.

Analysis of the drilling data was undertaken by "TTA" and electronic records of the tests were provided. The electronic record includes a summary of the section and test details and highlights the areas of deterioration identified by the test.

Several test members were cut into sections to verify the section properties. The correlation of the "Resistograph" test printout to the timber section is illustrated in Figures 10 and 11.

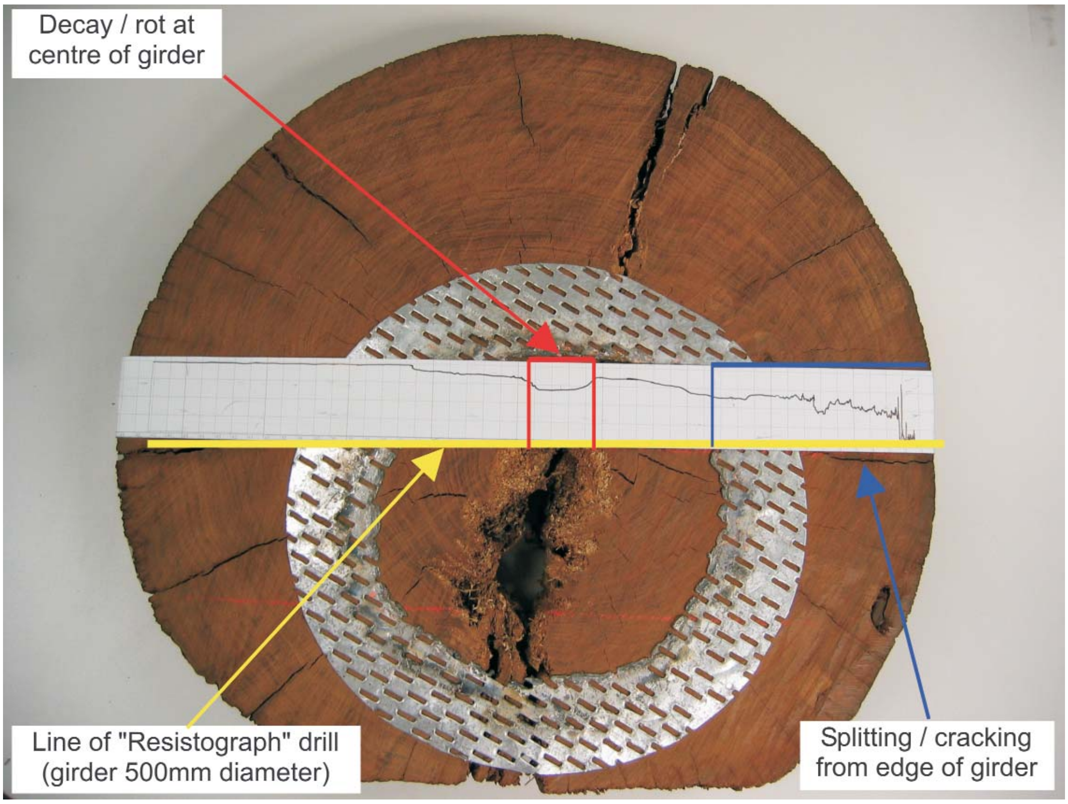


Figure 10 –Correlation between reduction in resistance and deterioration of section, in particular splitting/cracking from edge of girder and decay/rot in the centre of the section.

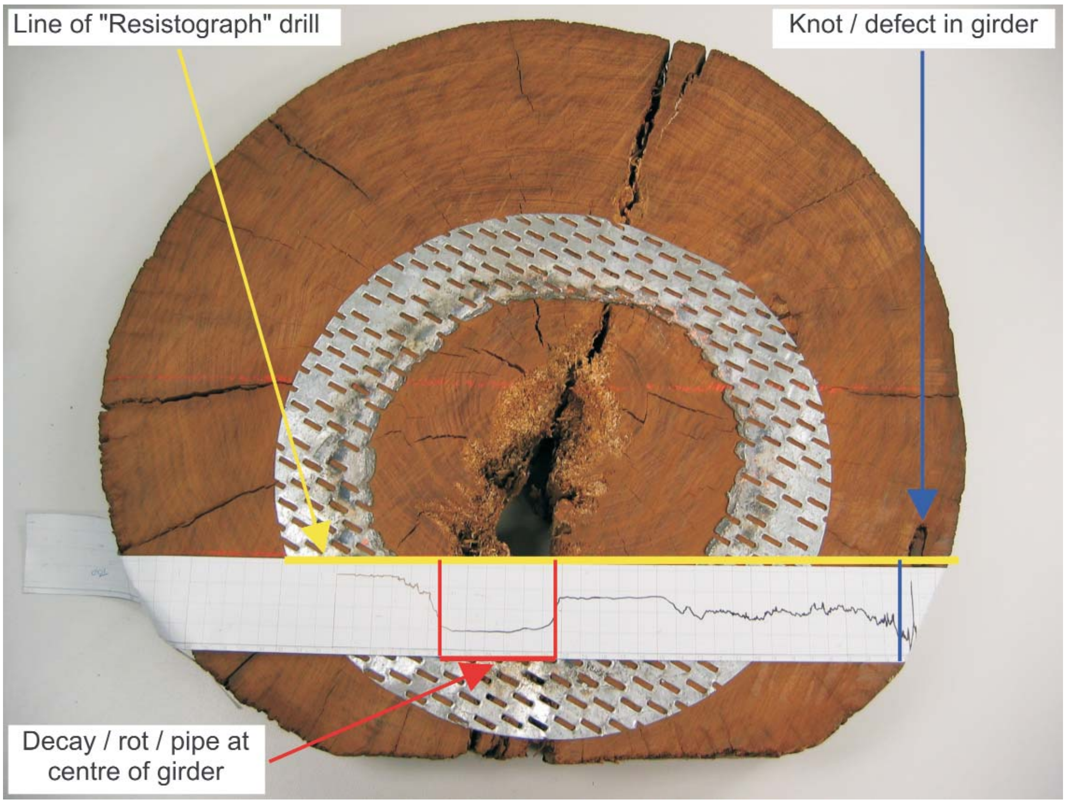


Figure 11 – Correlation between reduction in resistance and deterioration of section, in particular identification of knots/defects and decay/rot/pipe in the centre of the section.

A typical processed drill report is shown in Figure 12. In general the results are presented clearly with both a visual and numerical interpretation of the degree of piping in the member. The use of this colour coding system provides the client with a detailed understanding of the state of the member.

Figure 12 - "Resistograph" processed drill record

4.2.2 Discussion

The "Resistograph" provides significant advantages over traditional drilling methods. The 1.4mm drill bit is smaller than the standard 12mm drill bit and has a negligible effect on the overall structural system. The drill is advanced at a constant speed through the timber and the density of the material is determined from the recorded resistance and therefore does not rely on the operators experience or judgement. A real-time graph is produced which illustrates resistance against depth of penetration, hence the location of deterioration within the member is evident from the printout.

Initial tests conducted using the "Resistograph" identified problems with the drill bits breaking, however there have been no such problems with the more recent testing conducted at Bremer River bridge. Two drill bits were broken during the laboratory testing conducted by BAM, however these occurred when the "Resistograph" battery failed and the drilling had to be restarted with the drill embedded in the member. There were no problems with the "Resistograph" battery during the testing conducted at Bremer River bridge.

Testing conducted in the laboratory on members with significant cracking defects, identified the importance of ensuring that the drill is not positioned directly on a crack or within 20mm of the crack to reduce the likelihood of the "Resistograph" following the path of least resistance, along the crack. This also highlighted the importance of conducting a visual inspection of the girder at the drill location and recording this information for use in conjunction with the "Resistograph" results, to ensure that cracks are correctly identified and not misinterpreted as pipe or rot defects within the member.

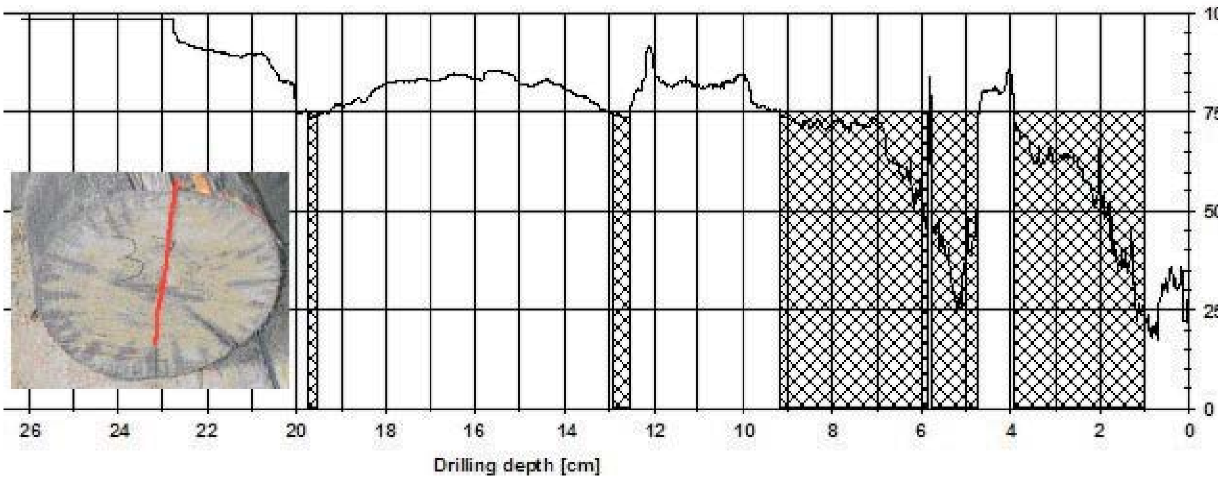


Figure 13 – Processed "Resistograph" test result with cracking in the outer 90mm of the section.

The red line on the picture of the girder in Figure 13 indicates the approximate "Resistograph" test path. Examination of the photo indicated that there are no voids in the first 1-9cm of the girder which were initially predicted from the "Resistograph" tests record. However, further examination of the cross-section revealed cracking extending towards the heart of the girder. Hence it was concluded that due to the timber being softer in the location around the cracks that the resistance is lower in the outer region of the girder.

The recorded depth of penetration of the "Resistograph" was 210mm to 280mm through girders 355mm to 435mm in diameter, which is over half the section thickness but did not penetrate completely through the section. Where the initial horizontal drill identified defects a second drill perpendicular to the first was completed to provide further information on the size and location of the defect. The West Australian Main Roads Department specify three drill holes at any timber section one vertically and two horizontally from each side of the member, to enable the size and location of the deterioration to be accurately determined. It is also considered necessary to include at least one additional horizontal drill at a location 100mm above the girder centreline to ensure v-shaped rot deterioration in the top of the girder can be identified or quantify the deterioration if identified by the "Lixi Profiler".

The "Resistograph" has a small contact area and no anchoring system. Since the girder surfaces are curved the stability of the equipment during drilling may be compromised. It is recommended that a mounting bracket similar to that used on concrete coring units be adapted for the "Resistograph" to lock the unit into location for the drilling test.

A benefit of determining the material properties of members investigated using the "Resistograph" is that the information may be used to assess the correlation between the measured resistance and the various material species. This knowledge may enable material species to be determined from the "Resistograph" tests in the future.

4.3 Recommendations

The accuracy of the "Resistograph" is considered appropriate for determining the deterioration of timber bridge members, based on the results of investigations conducted to date and the condition state levels defined in the Bridge Inspection Manual.

BAM recommend that the "Resistograph" is used in conjunction with the "Lixi Profiler", however the "Resistograph" may be used as the sole NDT method as detailed in section 5.

It is recommended that a mounting bracket similar to that used on concrete coring units be adapted for the "Resistograph" to lock the unit into location for the drilling test to improve the stability during drilling.

It is recommended that the 300mm long drill bit recommended for testing of timber bridge members, to reduce the likelihood of the drill bit breaking during the investigations.

An adequate power source for the "Resistograph" is required to be provided for all investigations to reduce the likelihood of problems during testing. "TTA" can provide guidance on the appropriate power source required.

Where "Tree Testing Australia" is engaged by Districts or RoadTek to conduct investigations using the "Resistograph", it is recommended that BAM are informed to monitor the performance, service, implementation and cost of the inspections.

The contact at "TTA" is Peter Blank, phone 0418 709 846.

5 Recommendations for Implementation of the "Lixi Profiler" and "Resistograph" NDT methods

BAM recommend that the "Lixi Profiler" and "Resistograph" NDT methods be used in conjunction to produce consistent and reliable condition data on the condition of timber bridge members. This information in conjunction with member species and stress grade can then be applied to determine accurate bridge capacities based on generic code values and assist in the efficient management of heavy vehicle movements.

Where "Intico" or "Tree Testing Australia" are engaged by Districts or RoadTek to conduct investigations using the "Lixi Profiler" or "Resistograph", it is recommended that BAM are informed to monitor the performance, service, implementation and cost of the inspections.

Guidelines for the implementation of the "Lixi Profiler" and "Resistograph" non-destructive testing methods provided in the following sections and guidelines for conventional drilling are provided in section 2.

In addition to the requirements for Level 2 inspection detailed in the BIM, the information listed below is required to provide a comprehensive record for capacity assessment of timber members.

- All bridge components are to be numbered in accordance with the requirements of the BIM.
- It is recommended that the material species and stress grading of all members be determined. The requirements for these investigations will be detailed in an Advice Note to be released January 2004.
- The thicknesses of the members at the end and middle and test locations along the member are required to be measured and recorded.
- Locations of all NDT and conventional drilling investigations are to be recorded and numbered for reference.

5.1 Application of the "Lixi Profiler" and the "Resistograph" or Conventional Drilling

- The "Lixi Profiler" is required to be calibrated if the thickness measurement is to be used as an absolute measure of sound material in the member. Alternatively the results from the investigations with the "Lixi Profiler" may be used as a relative measure of the deterioration within the section by reviewing the percentage loss.
  - The "Lixi Profiler" may be calibrated against a sample section of material in the laboratory or based on the material densities stated in the Australian Standard for Timber Structures AS1720.1 if the member species is known; or
  - The "Lixi Profiler" may be calibrated in the field on members where the thickness of the section can be measured and the internal condition can be verified, such as the ends of corbels and headstocks.
- The thickness of the members at end and middle locations along the line of the scan should be measured using callipers or similar measuring device to verify the calibration of the equipment and assist in identification of any dozey areas within the member.
- The "Lixi Profiler" is required to be mounted in a centralizing jig/bracket and it is recommended that the record of the scan is distance-based.
- The recommended investigations using the "Lixi Profiler" and the "Resistograph" are described below and illustrated in Figure 14.
- It is recommended that the "Lixi Profiler" be used to carryout longitudinal scans along the centreline of the section of all components in the bridge including girders, corbels, headstocks and piles to determine defective regions. Additional longitudinal scans at 100mm above centreline of girders are also required to identify any deterioration in the top of the girder.
- Additional testing is required to quantify the size and location of the deterioration identified by the longitudinal scans using either the "Resistograph" or Conventional Drilling methods.

- Additional testing is also recommended at critical locations as illustrated in Figure 14 and at locations which appear suspect from visual inspection but were recorded as sound by the longitudinal scan, or any locations which were inaccessible with the "Lixi Profiler".
- All drilling should be conducted in accordance with the relevant guidelines for either the "Resistograph" or Conventional Drilling methods as detailed within this document.

5.2 Application of the "Resistograph" only

- The thickness of the members at end and middle locations along the members is required to be recorded.
- It is recommended that the 300mm long drill bit recommended for testing of timber bridge members, to reduce the likelihood of the drill bit breaking during the investigations.
- An adequate power source for the "Resistograph" is required to be provided for all investigations to reduce the likelihood of problems during testing.
- The recommended investigations using the "Resistograph" are described below and illustrated in Figure 14.
- Drilling tests with the "Resistograph" should be carried out at critical locations described in the BIM in addition to any areas which appear suspect.
  - Care should be taken to avoid drilling completely though the members, and horizontal drills should be inclined slightly upwards to allow drainage.
  - "Resistograph" drills should be made from both faces of girder and corbel members at each cross section to quantify the location and extent of the deterioration in the member, as the 300mm long drill bit will only provide information just past the centre of a typical timber bridge member.
  - It is recommended that drill holes be made perpendicular to the face of the member such that the recorded deterioration is relative to the section size.
  - Four test holes are required to be made through each cross section of girder and corbel members to identify deterioration in the centre of the section and also v-shaped deterioration in the top of member. These test holes should be located along the centreline of the section and at 50 to 100mm above the centreline of the section as illustrated in Figure 14 and the "Resistograph" drills should be made from both faces of the member at each cross section as noted above.
  - Where deterioration is identified in the girders from the drilling tests at the locations illustrated in Figure 3, then additional drilling tests should be carried out at 500mm intervals along the member until a sound section is identified.
  - Where deterioration is recorded in the drilling test at the pile/headstock connection, an additional drill should be made approximately 500mm along the headstock from the centreline of the pile.
- It is recommended that the "Resistograph" is not positioned directly on a crack or within 20mm of a crack to reduce the likelihood of the "Resistograph" following the path of least resistance along the crack.

- It is recommended that a mounting bracket similar to that used on concrete coring units be adapted for the "Resistograph" to lock the unit into location for the drilling test to improve the stability during drilling.

5.3 Application of "Lixi Profiler" only

- The "Lixi Profiler" is required to be calibrated if the thickness measurement is to be used as an absolute measure of sound material in the member. Alternatively the results from the investigations with the "Lixi Profiler" may be used as a relative measure of the deterioration within the section by reviewing the percentage loss.
  - The "Lixi Profiler" may be calibrated against a sample section of material in the laboratory or based on the material densities stated in the Australian Standard for Timber Structures AS1720.1 if the member species is known; or
  - The "Lixi Profiler" may be calibrated in the field on members where the thickness of the section can be measured and the internal condition can be verified, such as the ends of corbels and headstocks.
- The thickness of the members at end and middle locations along the line of the scan should be measured using callipers or similar measuring device to verify the calibration of the equipment and assist in identification of any dozey areas within the member.
- The "Lixi Profiler" is required to be mounted in a centralizing jig/bracket and it is recommended that the record of the scan is distance-based.
- The recommended investigations using the "Lixi Profiler" are described below and illustrated in Figure 14.
- The "Lixi Profiler" should be used to carryout longitudinal scans as detailed above in section 5.1.1.
- Additional testing required to quantify the size and location of the deterioration identified by the longitudinal scans may include transverse scans with the "Lixi Profiler".
  - Additional testing is also recommended at critical locations as illustrated in Figure 14 and at locations which appear suspect from visual inspection but were recorded as sound by the longitudinal scan.
  - The limitation of using the "Lixi Profiler" to conduct the transverse scans compared to a drilling method is that no information can be obtained for locations which are inaccessible with the "Lixi Profiler".

Appendix D

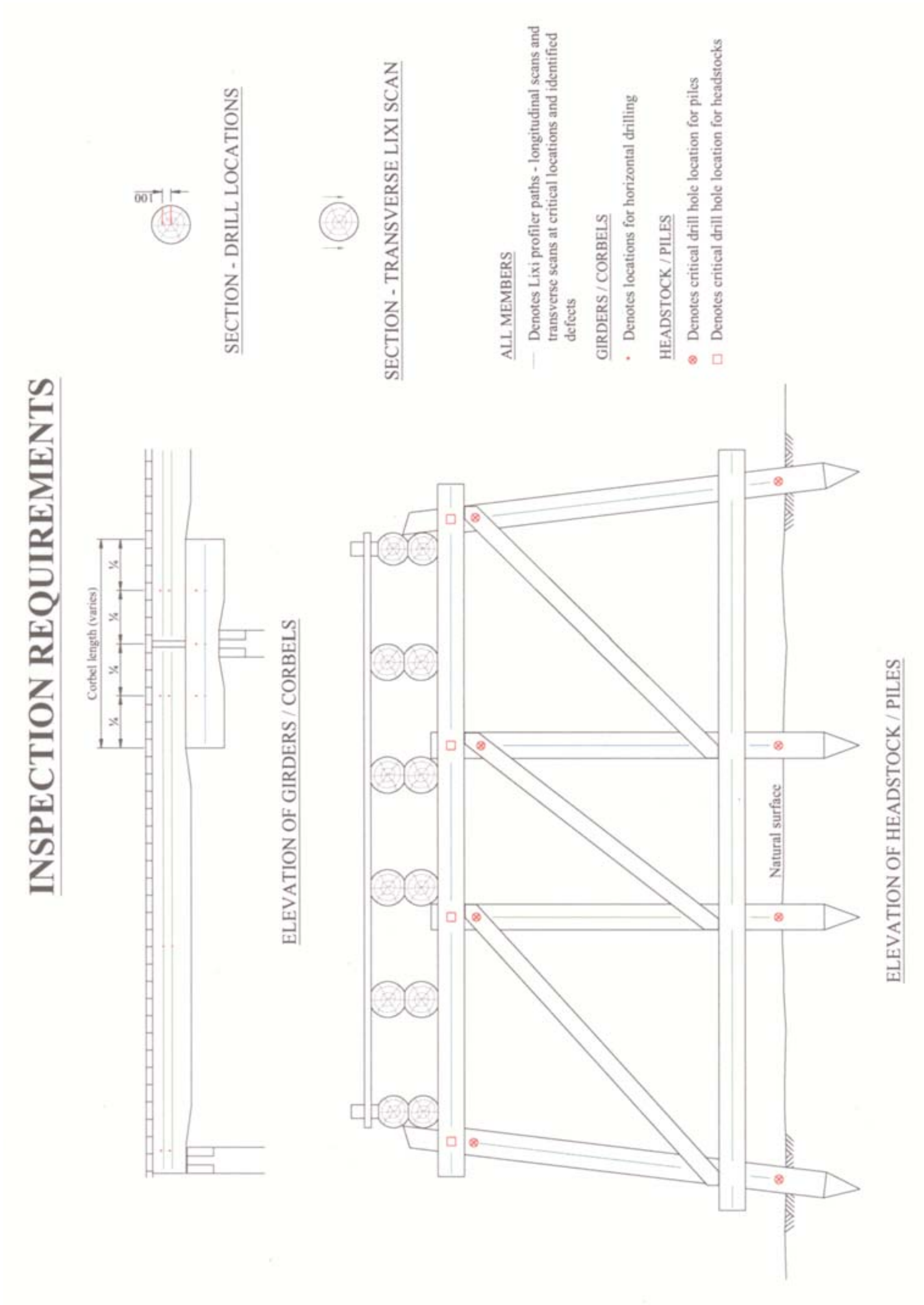


Figure 14 – Inspection Requirement