THE BRITE PROJECT

Innovation
Case Study
No 6

Ground Penetrating Radar Finds Defects in Bridge Beams

This series of innovation case studies has been developed by the BRITE Project of the Cooperative Research Centre for Construction Innovation. The case studies demonstrate the benefits of innovation and successful implementation strategies in the Australian Building and Construction Industry. Many highlight the strengths of small and medium-sized businesses in regional areas.

Who should read this? Participants in the building and construction industry, particularly bridge engineers and government road and traffic authorities.

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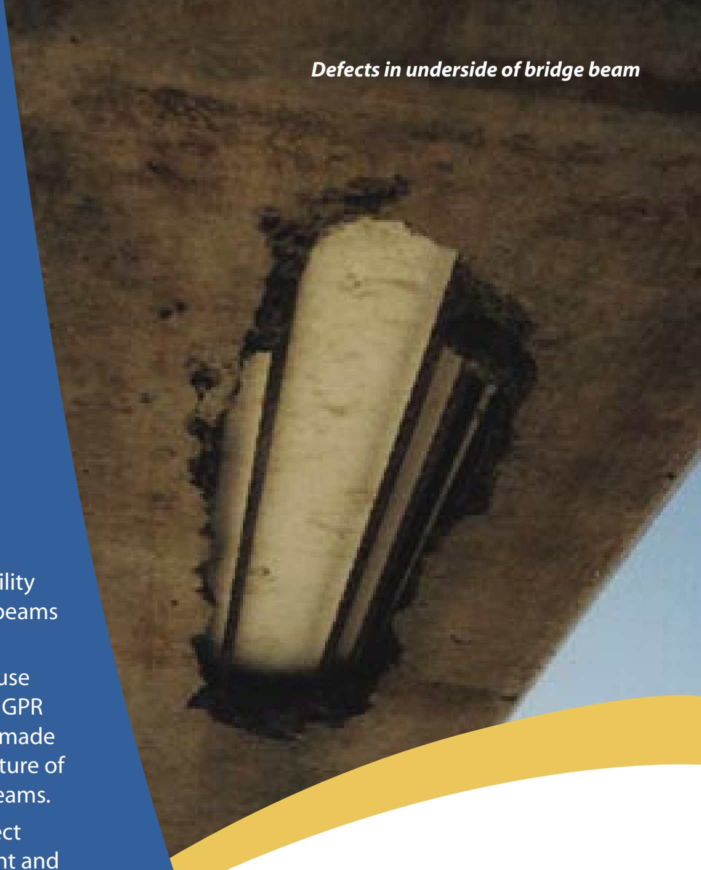
Ground Penetrating Radar Finds Defects in Bridge Beams

Use of Ground Penetrating Radar (GPR) has reaped significant savings in redressing problems with defective bridge beams on the Cattle Creek Bridge project located in Mackay, north Queensland. Fifty per cent of the cost of completely replacing the defective beams was saved because GPR provided the ability to reliably locate the defects in the beams and repair them *in-situ*.

This is believed to be a world first – use of latest generation high-frequency GPR to identify if movement of purpose-made voids had occurred during manufacture of prestressed concrete bridge deck beams.

Perhaps more importantly, the project created the conditions for refinement and demonstration of advanced technology that more efficiently allows for rapid, non-destructive, and non-invasive inspection of the internal structure of concrete.



Defects in underside of bridge beam

The Project

The original timber bridge over Cattle Creek was constructed in 1941. It was replaced in 1999 by a concrete bridge, which was constructed by a private sector contractor under a Schedule of Rates agreement. The bridge opened in May 2000, following the cooperative and innovative resolution of problems with defective concrete bridge beams, using GPR.

Selected Project Participants

Client	Queensland Department of Main Roads (QDMR)
Head Contractor	Abigroup
GPR consultant	Georadar Research Pty Ltd

Organisations consulted in preparing this report: QDMR and Georadar.

Cover photo: *Cattle Creek Bridge*

The Achievement

In 1999, at a very late stage in the construction of the Cattle Creek Bridge, when the last of the prestressed concrete bridge beams were being installed, the suppliers of the bridge beams discovered that some of them were defective. The supplier alerted QDMR to the problem, but was not able to identify the extent or precise location of the defects.

QDMR was faced with the choice of completely reconstructing the bridge on the assumption that all the beams were defective, or finding a way to identify the defective beams for selective repair and replacement. At that time, there was no accepted method for identifying or analysing defective beams without damaging them further.

An 'innovation champion' at QDMR's Central Queensland Regional Office who was active in knowledge networks suggested that GPR may be an option. Consequently, QDMR commissioned a private consulting firm, Georadar Research Pty Ltd (Georadar), to undertake initial testing. The results were good, with Georadar proving that GPR could efficiently solve the problem. Georadar was then commissioned by the supplier of the concrete beams to inspect all the beams on the bridge deck and jointly develop a solution for repair of the defective beams.

The Innovation

GPR is an imaging technology that uses electromagnetic waves with frequencies typically from 25 MHz to 2 GHz to obtain information on the structure of sub-surfaces. Since the introduction of the first commercial system in the 1970s, which measured the thickness of ice, GPR has been successfully applied to a wide range of tasks. GPR was introduced to Australia by Georadar in 1984 and has since been used in mining, civil engineering, geology, archaeology, telecommunications, and gas and water industries.

The innovation on the Cattle Creek Bridge project was in using high-frequency GPR to investigate the interior of prestressed concrete beams in a precisely calibrated way. This latest generation of GPR technology is only just beginning to be used globally for structural applications, and the Cattle Creek Bridge application was a very early, and successful, test of the technology in this field.

Richard Yelf, Georadar Research:

'I am very curious and keen to look inside things - especially concrete!'

The improvement in image accuracy obtained by the latest generation GPR represents a quantum leap in clarity. GPR was able to provide accurate images of internal defects in the Cattle Creek Bridge beams to within five millimetres. This accuracy was confirmed by drilling small percussion holes in selected beams and using a wirehook test to check that the thickness of concrete around the voids corresponded to the GPR images. Blind tests gave a mean difference of 1.6 millimetres between GPR measurements and core hole measurements. The technology is now earning the trust of engineers, which earlier more blurry GPR results had failed to do.

Georadar was a key international player in recognising the advantages and facilitating the development of the latest generation GPR antennae and control units. The company has also developed unique software for transforming radar results into accessible engineering images. The software was custom built for the Cattle Creek Bridge project and has been applied to a number of subsequent road and bridge projects.

GPR was used to image 180 prestressed concrete bridge beams on the Cattle Creek Bridge. The beams analysed are of a standard design used throughout Queensland. In this design, large polystyrene blocks (called 'voids') are cast internally within the deck beams to reduce the weight of the beams. At Cattle Creek, GPR was used to determine the final location of these voids within the beams and identify any defects caused by movement of the voids during their construction.

The results indicated that over 90 per cent of the beams were 'out of tolerance' due to significant movement of the voids, creating thin top or bottom flanges and air cavities between the lower steel stressing strands, resulting in soffit cracking.

Instead of entirely replacing every beam, with very high associated removal and transportation costs, the defective beams were repaired by cutting a narrow slit into the underside of the beams and pumping grout into selected locations.

The Benefits

Had GPR not been used, it is unlikely that QDMR or the suppliers of the beams would have been able to identify the location, or the extent, of the defects in the beams. Drilling and coring was not a feasible option as it would have been necessary to drill every part of each beam to obtain, with sufficient certainty, an understanding of the nature of the defects, while causing significant damage in the process. The only other solution was to rebuild the bridge deck units, which QDMR estimated would have cost about $2 million (probably borne by the supplier).

In contrast, the cost of GPR analysis, and repair and replacement of defective bridge beams, cost $1 million (primarily borne by the supplier), roughly half the cost of a total rebuild. Because this was the first time GPR had been used for such a problem and extensive validation trials were required, the costs to validate the method were higher at Cattle Creek Bridge than they will be for similar projects in the future.

Unquantified benefits have also flowed to QDMR as a result of using GPR on the Cattle Creek Bridge project. For example, the technology has been successfully used to identify termite damage in a timber bridge and was recently applied to examine historical scour events (caused by debris during flooding) at the Cattle Creek bridge.

Further, QDMR believes that GPR can be used more widely to identify defects in concrete structures in Queensland, estimated to be worth about $15 billion. Already, GPR has been used by Georadar in 2000 in an audit of bridge decks and to assess portions of new concrete road pavements on the Pacific Motorway Construction Project. The results indicated that some sections of the concrete road pavements contained defects. These were remedied by the project contractors during the warranty period, probably saving significant maintenance costs.

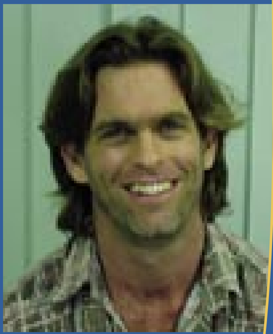
The Implementation Process

'…luck favours the well-prepared mind'

The decision to use GPR to identify the location and number of defects in the beams of the Cattle Creek Bridge involved a commitment to trial the technology for this type of application. Georadar was willing to spend research and development funds to demonstrate the benefits of the technology before project stakeholders committed to a more comprehensive testing of the beams.

Since its establishment, Georadar has internationally pioneered many surface and underground applications of GPR. As noted above, an 'innovation champion' at QDMR's Central Queensland Regional Office persuaded his colleagues to consider using GPR and Georadar to identify the defects in the Cattle Creek Bridge project. This champion had become interested in radar technology after his involvement in addressing the problem of collapsed trenches at Rockhampton Airport in 1975. The solution was to drill at 750 millimetre intervals along the length of the runway to identify the location of the sub-surface collapse zones. The inefficiencies of the approach encouraged his interest in non-invasive, non-destructive methods of identifying hidden defects. He began to read widely across scientific literature and later encountered Georadar, commissioning them to perform several survey projects using low-frequency GPR to investigate deep geological targets.

Georadar had been working to develop the more challenging high-frequency GPR technology for over nine years before the Cattle Creek Bridge project. They consider the Cattle Creek Bridge a fortuitous opportunity for real-world application and testing of new technology, noting however, that 'luck favours the well-prepared mind'. They first used pre-cursors of the high-frequency GPR technology to test the concrete shell structures of the Opera House in 1992. They realised then the need for significantly improved resolution to increase the accuracy of defect identification. Over subsequent years, several individuals and organisations, including international scientists and antennae manufacturers, worked with Georadar to develop the technology.



Tony Elgar, Principal Engineer (Contracts) Mackay, DMR:

'there was a high level of cooperation between the parties, which was critical to the success of the project'

Lex Van Der Staay, Regional Advisor, Technical Services, Central Queensland Regional Office, DMR:

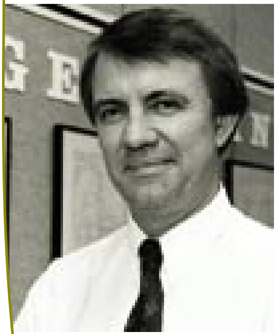
'This was a world first for the application'

The Cattle Creek Bridge problem presented a timely opportunity for testing and refining Georadar's latest advances. All parties committed to a cooperative approach to the problem. Georadar deployed their technology under an Intellectual Property (IP) agreement with QDMR. In turn, QDMR's willingness to commit funds to trial the technology facilitated their access to the benefits of GPR for the Cattle Creek Bridge, and to subsequent testing work, subject to an IP agreement. Significant funds were also committed by the supplier of the bridge beams, which was keen to arrive at a cooperative and efficient solution to the defect problem. Additionally, the experience led quickly to improvements in the supplier's manufacturing processes.

Overcoming Difficulties

The most important difficulty associated with the use of GPR to audit the Cattle Creek Bridge beams was the risk of failure, because the technology had not previously been used that way. All key stakeholders – the client, consultant, contractor and supplier – agreed to trials of the new technology because they accepted the need for judicious risk taking. They championed the innovation: QDMR Head Office was very keen to find an efficient solution to the beams problem and created the organisational conditions for innovation to succeed; QDMR Central Queensland Regional Office had networks in place that pointed to the potential value of GPR; and Georadar was the technical expert, with an international reputation for championing developments in GPR.

Having decided to test GPR, the parties needed to cooperate during the trial and investigation period. This was assisted by a history of good relationships, which were maintained throughout the project's uncertainties. The networking of key individuals had previously built the inter-business relationships upon which an efficient solution to the Cattle Creek Bridge problem depended. QDMR believes that without these good relationships, a more costly solution would have been necessary. In particular, QDMR and Georadar have independently noted that the positive attitude of the supplier was crucial in ensuring the positive outcome.



Alan Carse, Principal Engineer (Concrete Technology), DMR:

'We've been able to take what we learned on Cattle Creek Bridge and apply it elsewhere'

Lessons Learned

- Problems are strong innovation drivers.
- Problems can create opportunities for learning and future benefit.
- Investment in problem-solving on a particular project/application often reaps flow-on/spill-over benefits across a number of projects/applications.
- Fine-tuning of new technology to suit specific applications depends on opportunities for testing in real-world situations.
- The presence of 'innovation champions' is often crucial to the adoption and development of innovative technologies.
- Organisations willing to invest in research and development can reap significant benefits over time.
- A culture of cooperation is often necessary for identification of innovative solutions to problems.
- Innovation is not a short-term endeavour – persistence is required.
- Involvement in knowledge networks is a good insurance policy against uncertainties of the future.

Conducting GPR survey on Cattle Creek Bridge deck

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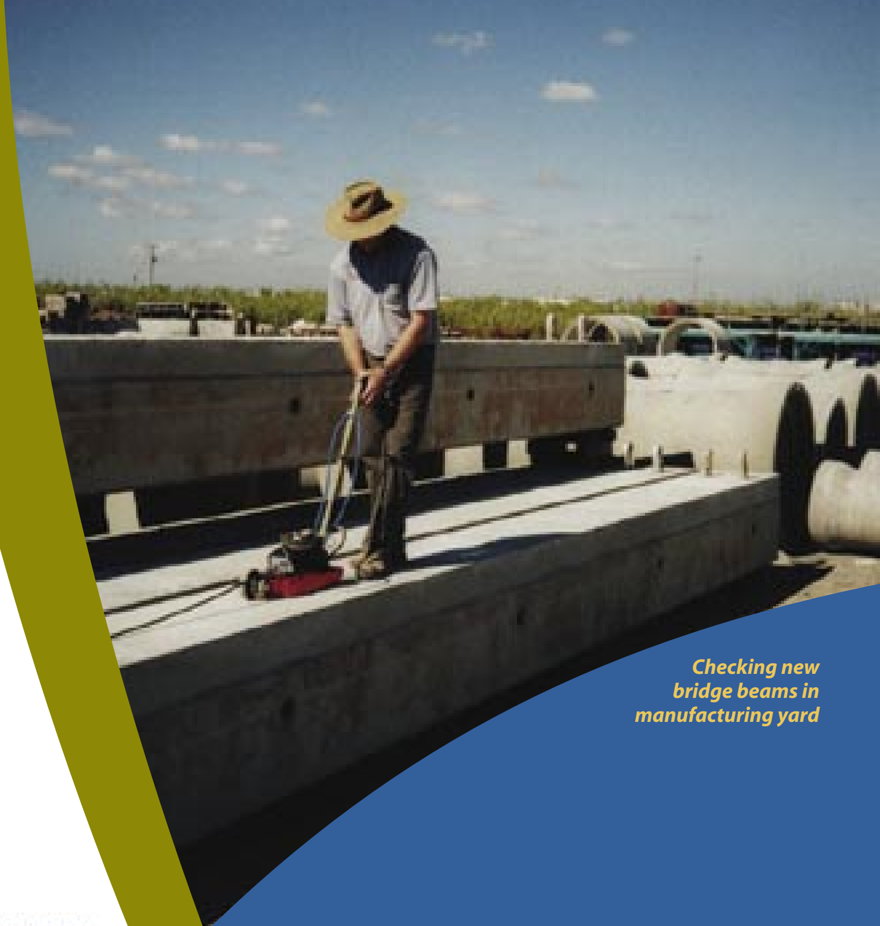

Checking new bridge beams in manufacturing yard

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CRC Construction Innovation Vision
… 'to lead the Australian property and construction industry in collaboration and innovation'

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