TECHBRIEF

Nondestructive Inspection Protocol for Reinforced Concrete Barriers

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This document is a technical summary of the unpublished Federal Highway Administration (FHWA) report *Nondestructive Inspection Protocol for Reinforced Concrete Barriers,* available through the National Technical Information Service at www.ntis.gov

Introduction

The National Transportation Safety Board (NTSB) investigation of the accident that occurred on August 10, 2008, on the William Preston Lane, Jr., Memorial Bridge, which crosses the Chesapeake Bay near Annapolis, MD, identified significant corrosion of the anchor bolts attaching the bridge railing to the bridge deck. A subsequent NTSB recommendation stemming from that investigation, H-10-18, was to "expand the research and development of nondestructive evaluation technologies to develop bridge inspection methods that augment visual inspections; offer reliable measurement techniques; and are practical, both in terms of time and cost, for field inspection work; and promote the use of these technologies by bridge owners."[1] This document summarizes a response to that recommendation.

Reinforced concrete barriers are generally anchored to the deck of a bridge or retaining wall using reinforcing steel protruding from the main structure or by anchored bars or bolts added during retrofits. Corrosion of steel bars or bolts can weaken this attachment and reduce the capacity of the barrier. The most direct damage resulting from corrosion is the reduction of steel diameter and cross-sectional area. Steel corrosion in concrete is caused primarily by chloride- or carbonation-induced corrosion. Barriers are generally located at or very near the gutter-line of a roadway and may have significant long-term exposure to corrosive

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deicing materials and other corrosion-inducing environments.

Anchorages and adjacent voids are typically embedded in concrete structural elements and consequently cannot be fully inspected visually. Research has been done on non-destructive evaluation (NDE) methods to evaluate reinforced concrete and embedded steel reinforcement.[2,3] Four NDE technologies were examined and tested in this project, and the results of those test are reviewed and summarized in this document.

NDE Technologies

The four NDE technologies considered in this project were ground-penetrating radar (GPR), low-frequency ultrasonic tomography, infrared (IR) thermography, and digital radiography.

GPR

GPR is a high-resolution electromagnetic technique designed primarily to investigate the shallow subsurface of the earth, building materials, roads, and bridges. GPR is routinely used to locate and map reinforcing steel in concrete structures. Detecting damage to embedded reinforcing steel, however, is a difficult challenge.

The general principle of GPR is illustrated in figure 1. The electromagnetic wave is radiated from a transmitting antenna and travels through the material being tested at a velocity determined primarily by the material's dielectric permittivity. When the wave encounters an object having different dielectric properties than the surrounding medium, it produces a scattered pulse that is detected by a receiving antenna. The resulting output voltage signal is amplified, processed using different filters, and displayed on a computer monitor.

For a single scan of the antenna, a standard GPR display is referred to as a B-scan or radargram image (figure 2).[4] The horizontal axis indicates the antenna position, and the vertical axis displays either signal arrival time or inferred penetration depth. The gray-scale image depicts echo strength, with white depicting a strong positive voltage value and black depicting a strong negative voltage.

Figure 1. GPR principle.

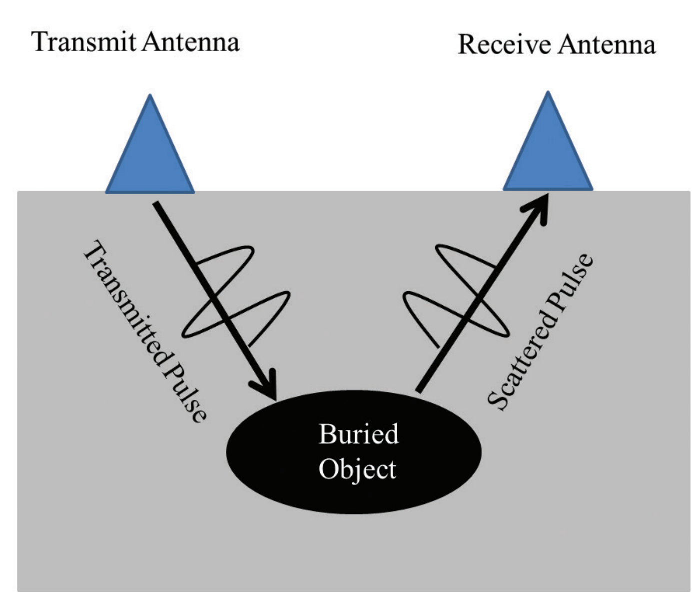
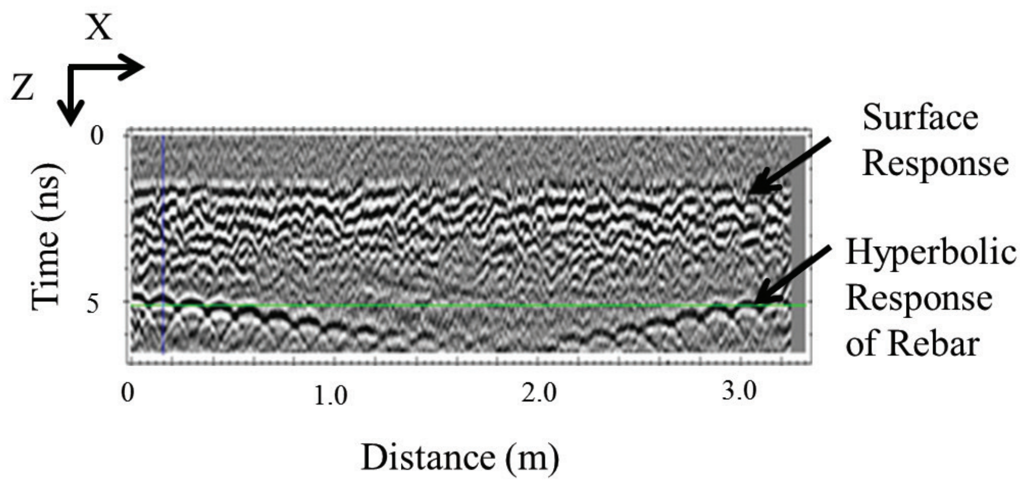


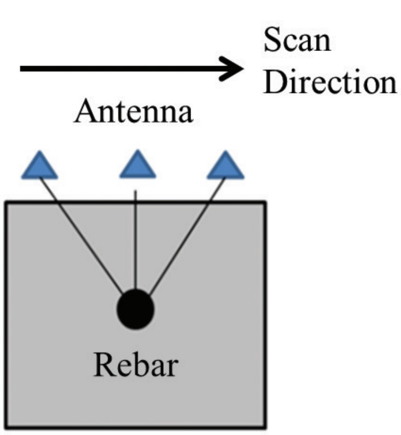
Figure 2. Standard GPR display.



1 m = 3.3 ft

When the antenna is scanned across a concrete fixture containing reinforcing steel, the reinforcing steel is sensed at many different antenna positions (figure 3). The arrival time of the reinforcing steel echo depends on the distance between the antenna and the reinforcing steel. (The arrival time is shortest when the antenna is directly above the reinforcing steel.) Because of the dependence of echo arrival time on antenna position, regions of high reflected amplitude in B-scans have a hyperbola-like shape, as illustrated in figure 2.

Figure 3. Scan direction.



Low-Frequency Ultrasonic Tomography

The low-frequency ultrasonic tomographer creates a three-dimensional (3-D) representation (tomogram) of internal defects that may be present in a concrete structure. The instrument is based on the ultrasonic pitch-catch method and uses an antenna composed of an array of dry point contact transducers. The transducers emit shear waves into the concrete. One transducer sends out a stress-wave pulse, and a second transducer receives the reflected pulse (figure 4). The time from the start of the pulse until the arrival of the echo is measured. If the wave speed C is known, then the depth d of the reflecting interface can be calculated.

Once data are acquired in the explore-and-scan mode, a signal processing technique called synthetic aperture focusing technique (SAFT) is used to reconstruct a 3-D tomographic image of the interior of the concrete member.

Using SAFT, the pulse-echo measurements made at a multitude of transmitter-receiver locations are combined to form a map of the ultrasonic reflectivity of the region of interest. The method takes advantage of both spatial and temporal correlations to enhance the resolution and the signal-to-noise ratio of the reconstructed 3-D image. The reconstructed 3-D image is stored in the computer, and the user can view a 3-D picture of the locations of all detected interfaces, or the user can view the projection of the interfaces on three orthogonal planes with specialized software supplied by the manufacturer.

The views of the three orthogonal planes in figure 5 have formal names. A C-scan shows the reflecting interfaces projected on a plane parallel to the test surface; that is, a C-scan is a "plan view." A B-scan shows the reflecting interfaces projected on a plane perpendicular to the test surface and perpendicular to the scan direction; that is, a B-scan provides an "end view." A D-scan shows the reflecting interfaces projected on a plane perpendicular to the test surface but parallel to the scan direction; that is, a D-scan provides an "elevation view." The user can also look at specific "slices" through the object in each of the three directions by defining the Z-coordinate for a C-scan image, the X-coordinate for a B-scan image, and the Y-coordinate for a D-scan image.

Figure 4. Low-frequency tomography principle.

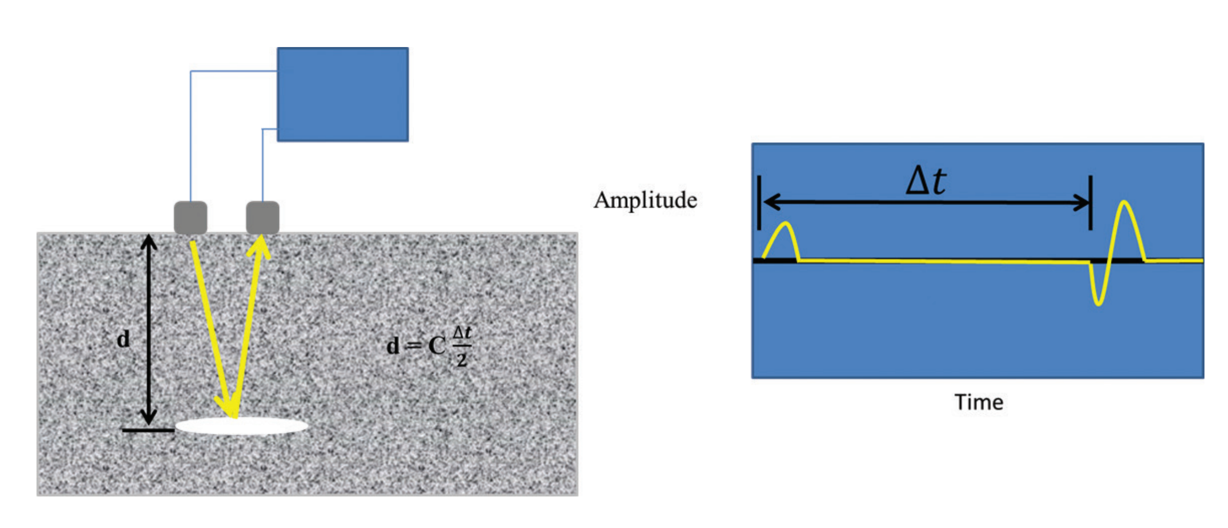
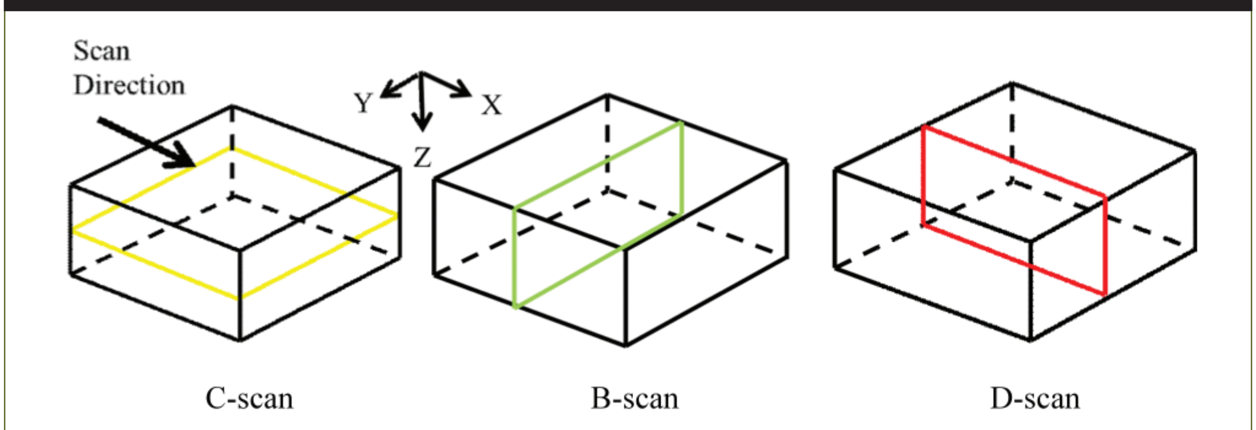


Figure 5. SAFT-reconstructed orthogonal planes.



IR Thermography

IR thermography is a non-contact method for detecting the difference in temperature between a problem area and its surroundings. Depending on the underlying cause, the problem area may be warmer or colder than its surroundings. This temperature difference is clearly visible in the camera's image display. A trained operator can immediately hone in on the source of the problem and its cause without having to cut into walls or disassemble equipment.

Digital Radiography

Because of isotopic sources such as Caesium (Cs) 137, Cobalt (Co) 60, and Iridium (Ir) 192, conventional radiography applied in the field is typically considered hazardous.[5] The physical size of these sources makes them very convenient for remote location inspection. Because the sources are not collimated, however, they require a large area to be cordoned off to prevent radiation exposure to personnel in the area. In addition, these source types in the past have been used with films (as the detector) that can take minutes of exposure to get the correct radiographic image.

Advances in both the source and the detector technology in recent years have led to radiographic images that can be obtained in much less time and with lower exposure. These advances are primarily due to the development of a pulsed X-ray source. Pulsed X-ray sources produce radiation only when the source is activated and the X-rays are highly directional. Furthermore, the sources are man-portable and can be operated using batteries equivalent to those used in handheld electric tools.

Testing and Results

Laboratory testing was conducted on two concrete barrier configurations used in the Washington, DC, metropolitan area: the F-shape bolt down barrier and the New Jersey free standing portable barrier. The testing was of barrier connections—bolt connections in the case of the F-shape bolt down barrier, and embedded reinforcing steel connections in the case of the New Jersey barrier. Additional tests are proposed on reinforcing steel rebars within barriers to quantify damage. A third type of barrier—the F-shape free standing portable barrier—would be added for these tests. A mockup bridge deck was constructed for the testing, and connecting rebars and bolts were altered by machining away steel to produce varying levels of cross-section losses. Future testing should include the placement of hollow balls, loose gravel, and foam in barriers to simulate voids and delamination and to quantify their effects. Future testing should also be conducted on specimens where true sectional loss due to corrosion of steel reinforcement has occurred. Specimens for this testing can be prepared by inducing electrical current to speed up the corrosion process.

In the completed testing of barrier connections, the four selected NDE technologies were applied to the barrier connections. GPR provided images of the response of rebars in concrete for the F-shape bolt down barrier at all cross-section loss levels. The thicker concrete cover of the New Jersey barrier, however, prevented penetration from the output of the high-frequency antenna. Consequently, the GPR images showed no indication of a response. Although the low frequency ultrasonic tomographer detected reinforcing steel in concrete, it was difficult to differentiate between different cross-section losses in the rebars without prior knowledge. The responses from 0 and 10 percent cross-section losses were clear for both rebar sizes used, but the larger cross-section losses of 25 and 50 percent were not evident. IR thermography was not successful in locating rebars in either type of concrete barrier, mainly because of thick concrete cover. Lastly, digital radiography with a low power pulsed X-ray system also did not penetrate deep enough into the thick concrete to produce images of the rebars. Figure 6 and figure 7 are examples of the GPR images and the ultrasonic tomographer images at different cross-section loss levels in the F-shape bolt down barrier, respectively.

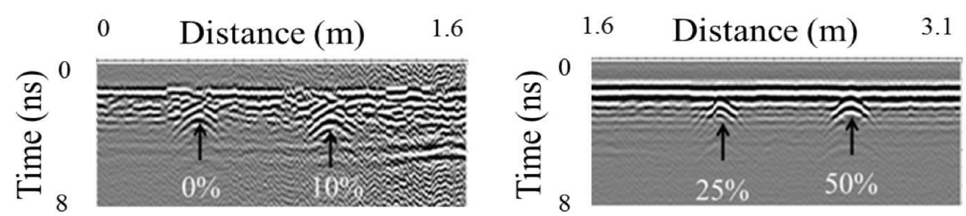
Capacity Protocol

To understand the current capacity protocols for determining deterioration thresholds that should trigger advanced inspection and possibly rehabilitation of concrete barriers, a short survey was developed and distributed among FHWA Division Bridge Engineers. The survey results collected are listed in table 1. The table indicates that there is currently little or no guidance available on acceptable and unacceptable deterioration levels in concrete barriers, or at what point NDE methods should be used for assessment of barrier conditions.

Recommendations

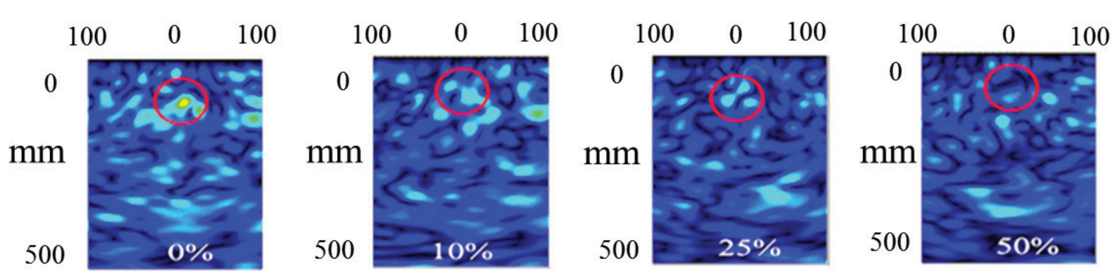
The limited scope of the testing and the paucity of positive results preclude the drawing of definitive conclusions about the usefulness of the reviewed NDE technologies for barrier inspections. Further investigation is warranted. The thickness of the concrete in barriers appeared to affect all four of the technologies, although GPR and low frequency ultrasonic tomography somewhat less so than IR thermography or digital radiography. Among the many avenues for additional effort, the fusion of GPR and the low frequency ultrasonic tomography should be considered. Such a fusion might provide complementary information regarding the condition assessment of concrete barriers. Future research about such a fusion could include the quantification of measurements made in the tomographer and GPR tests already completed. Future work should include image processing techniques to quantify voids and cross-section loss.

Figure 6. GPR images of cross-section losses at four levels in an F-shape bolt down barrier.



1 m = 3.3 ft

Figure 7. Ultrasonic tomography images of cross-section losses at four levels in an F-shape bolt down barrier.



1 mm = 0.04 inches

Table 1. Deterioration threshold and guidance survey.				
State	**Type of Barrier**	**Anchorage System**	**Inspection Protocol**	**Guidance on Deterioration Threshold**
Colorado	F-Shape	Rebar During Construction	Not Available	Not Available
Hawaii	Jersey	Rebar During Construction	National Bridge Inspection Standards	Not Available
Illinois	F-Shape	Rebar During Construction	Visual, Cores	Not Available
Indiana	F-Shape	Rebar During Construction	Visual, Hammering	Not Available
Kansas	F-Shape	Rebar During Construction	CoRE Guide (AASHTO)	Not Available
Michigan	Type 4	Rebar During Construction	Visual	Not Available
Minnesota	J-Shape, F-Shape	Rebar During Construction	Bridge Inspection Manual (MnDOT)	Not Available
Montana	F-Shape	Rebar During Construction	Visual	Not Available
New Jersey	F-Shape	Not Available	Not Available	Not Available
New York	Not Available	Not Available	Visual	Not Available
North Carolina	Jersey and F-Shape	Rebar During Construction	National Bridge Inspection Standards	Not Available
Ohio	Jersey, Single Slope	Rebar During Construction	National Bridge Inspection Standards, Visual	ODOT, Bridge Inspection Manual
Pennsylvania	F-Shape	Rebar During Construction	Visual	Not Available
Tennessee	Jersey, Constant Slope	Rebar During Construction	Visual, Hammering	Not Available
Texas	Single Slope, F-Shape	Rebar During Construction	National Bridge Inspection Standards	Not Available

AASHTO = American Association of State Highway and Transportation Officials.
CoRE = Commonly Recognized Elements.
MnDOT = Minnesota Department of Transportation.
ODOT = Ohio Department of Transportation.

References

1. National Transportation Safety Board, *Safety Recommendations H-10-17 and H-10-18,* Washington, DC, 2010.
2. Clemena, G., Lane, S., Freeman, T., and Lozev, M., *Evaluation of Nondestructive Evaluation Methods for Application in Early Detection of Deterioration in Concrete Pavements,* VTRC–R13, Virginia Transportation Research Council, 2000.
3. Al-Qadi, I.L., Lahouar, S., and Loulizi, A., *Ground-Penetrating Radar Calibration at Virginia Smart Road and Signal Analysis to Improve Prediction of Flexible Pavement Layer Thicknesses,* FHWA/VTRC 05-CR7, Virginia Department of Transportation, 2005.
4. Jensen, T., Wendt, S., Gray, J., Eisenmann, D., Margetan, F., Lo, C., Nakagawa, N., and Brasche, L., *Feasibility Study for Detection and Quantification of Corrosion in Bridge Barrier Rails,* InTrans Project 11-413, Center for Nondestructive Evaluation, Iowa State University, Ames, IA, 2013.
5. Cobb, A., *Feasibility Study for the Inspection of Hidden Corrosion Damage in Multi-Layer Gusset Plates,* SWRI Project No. 18.17643, Sensor Systems and Nondestructive Evaluation (NDE) Technology Department, Southwest Research Institute, San Antonio, TX, 2013.

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