CONCRETE BRIDGE DECK CONDITION ASSESSMENT USING ROBOTIC SYSTEM RABIT

Nenad Gucunski[1], Ali Maher[2] and Hamid Ghasemi[3]

Abstract

Development and implementation of RABIT (Robotics Assisted Bridge Inspection Tool) in condition assessment concrete bridge decks is described. The system uses multiple nondestructive evaluation (NDE) technologies in characterization of three most common deterioration types: rebar corrosion, delamination, and concrete degradation. The system implements four NDE technologies: electrical resistivity (ER), impact echo (IE), ground-penetrating radar (GPR), and ultrasonic surface waves (USW), and advanced vision to complement traditional visual inspection. The associated platform for the enhanced interpretation of condition assessment in concrete bridge decks is comprised of data integration, fusion, and deterioration and defect visualization. The data visualization platform facilitates intuitive presentation of the main deterioration and defects.

Introduction

The Federal Highway Administration's (FHWA's) Long Term Bridge Performance (LTBP) Program initiated development of a robotic system for condition assessment of concrete bridge decks named RABIT (Robotics Assisted Bridge Inspection Tool). Based on the discussions with State Departments of Transportation (DOTs) and bridge expert groups, the Program included the concrete bridge deck performance as one of the key bridge performance issues. To create knowledge about the deck performance, the LTBPP team has been conducting periodical manual data collection using multiple NDE technologies (Gucunski et al., 2012 and 2013), visual inspection and physical sampling and testing. While the manual NDE data collection provided high quality information, it was also a labor intensive, expensive and a relatively slow process. As the Program is entering a new phase, with the need to assess the condition of decks on hundreds of bridges, a data collection that is rapid, economical and consistent became an imperative for the success of the LTBP Program. In addition, to fully benefit from the application of multiple NDE technologies, there was a need for interpretation techniques that can effectively integrate data from different NDE technologies and perform inferences that may not be possible from a single technology. While the development of the RABIT system was triggered by the needs of the LTBPP, potential benefits to State DOTs were also considered.

[1] Professor and Chair, Department of Civil and Environmental Eng., Rutgers University
[2] Director, Center for Advanced Infrastructure and Transportation, Rutgers University
[3] Team Leader, Turner-Fairbank Highway Research Center, Federal Highway Administration

From the technical point, the RABIT system was designed with two main objectives in mind. The first objective was to develop a system that would enable automated NDE data collection. The NDE technologies included those already implemented and proven within the LTBP Program, in particular: impact echo (IE), ultrasonic surface waves (USW), electrical resistivity (ER) and ground penetrating radar (GPR). The operation of the robotic platform was designed to collect data at rates four or more times faster than the current manual data collection that requires a team of five or more people, as for example it is illustrated in Figure 1. The second objective was to create a platform for enhanced interpretation of condition assessment in concrete bridge decks through data fusion, and deterioration and defect visualization. While the system provides a near real-time preliminary condition assessment of the bridge deck, the interpretation and visualization platform specifically addresses data integration and fusion from the four NDE technologies. It integrates survey results and facilitates intuitive presentation of the main deterioration caused by corrosion, delamination, and concrete degradation. The following sections describe the main components of the robotic platform and the control system for data collection monitoring and analysis.

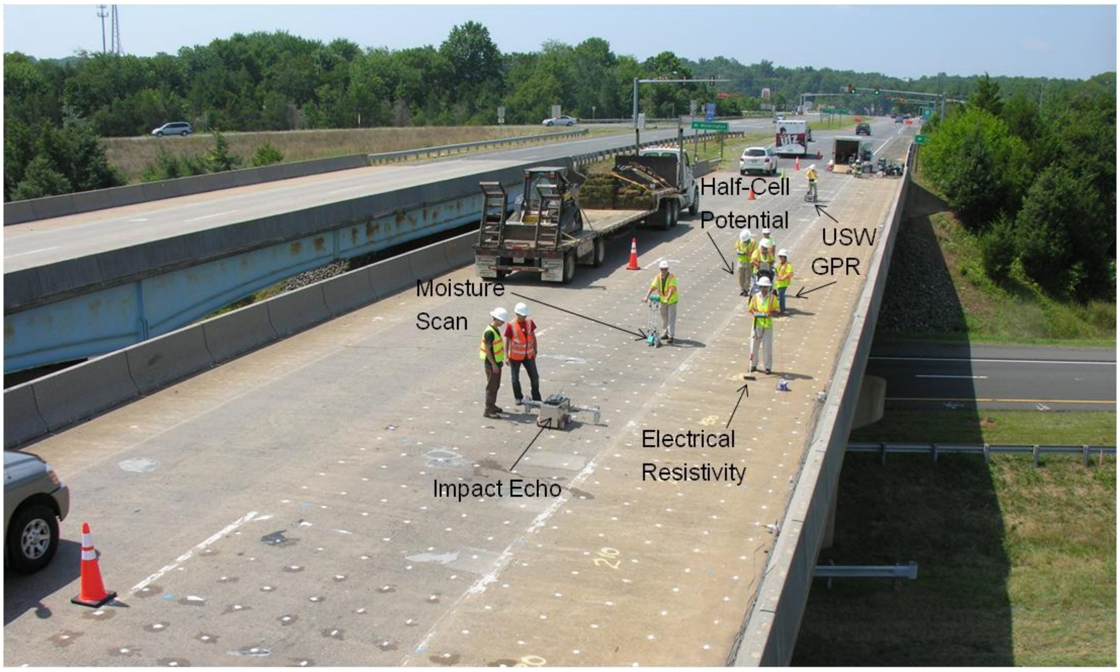

Figure 1. Condition surveys of a bridge deck using multiple NDE technologies.

Benefits of Condition Assessment Using NDE

The primary benefits from the condition assessment using NDE technologies stem from the quantitative nature of the information collected. That information can be described in terms of condition maps, describing the location and severity of deterioration, and calculated condition indices, describing the overall condition of the deck of a bridge or a section of a bridge. As an illustration, a set of typical results of the NDE based condition assessment of deck using four NDE technologies is shown in Figure 2. In all maps the areas marked in hot colors describe progressed deterioration or condition favorable for fast progression of deterioration. On the other side of the spectrum are zones plotted in cold colors, describing good conditions.

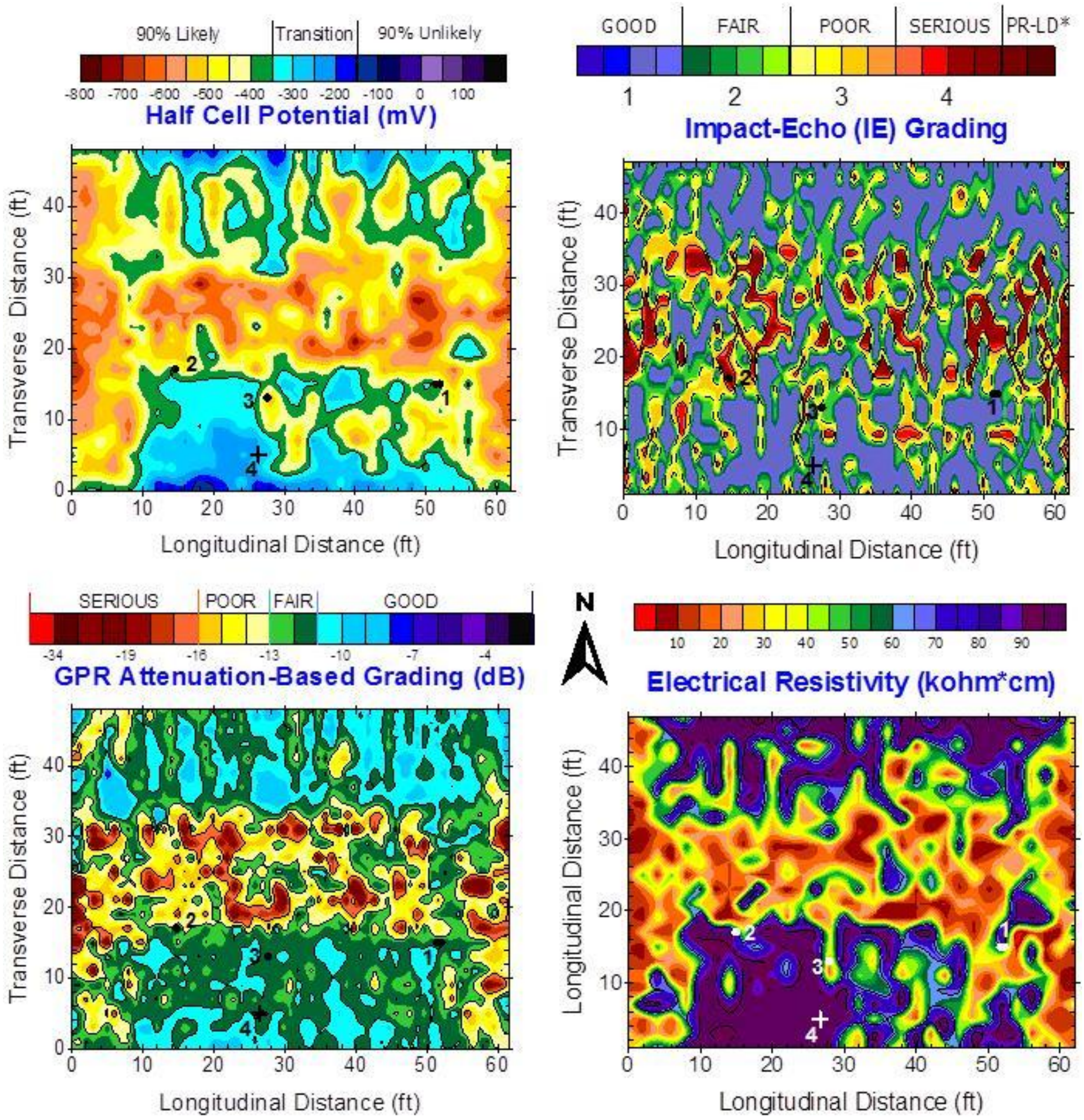

Figure 2. Conditions maps from half-cell potential, impact echo, GPR and electrical resistivity surveys.

The condition maps shown in Figure 2 demonstrate the ability of different technologies to detect and define the boundaries of deterioration, and to describe their severity. It was also demonstrated during the first phase of the LTBP Program that the NDE technologies have ability to monitor deterioration progression. As an illustration, condition maps from ER surveys conducted in 2009 and 2011 are shown in Figure 3. The maps clearly describe progression of the aggressiveness of the corrosive environment during the two year period in both the extent and severity level. Similar ability of other NDE technologies was demonstrated.

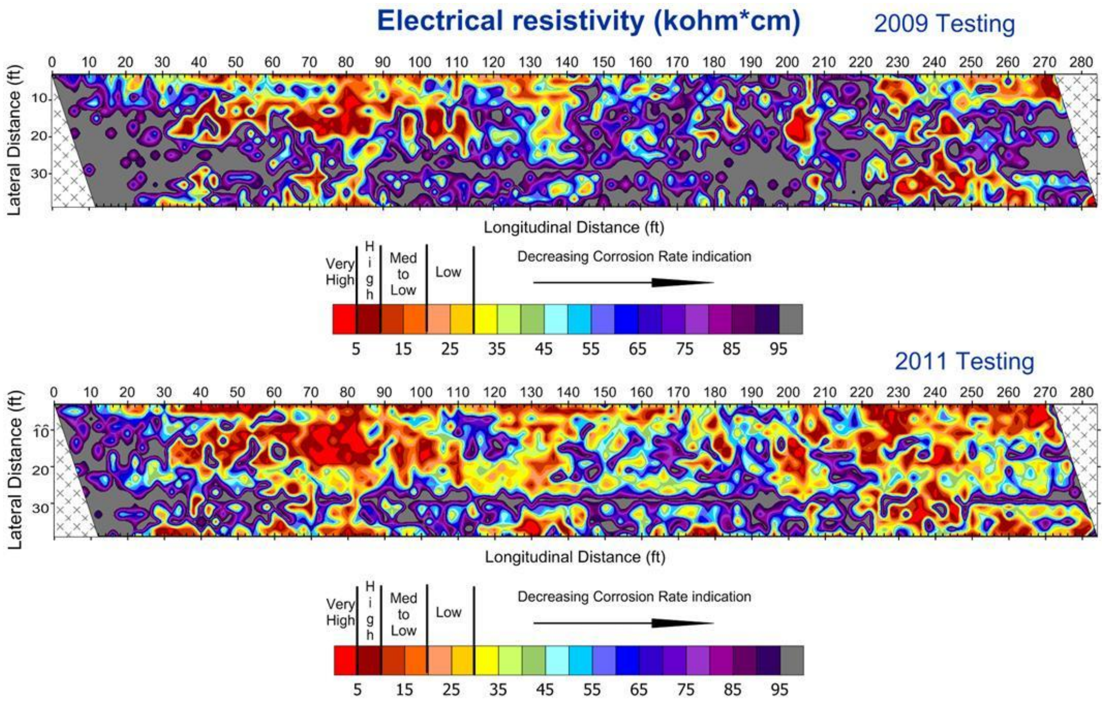

Figure 3. Assessment of progression of aggressiveness of corrosive environment using electrical resistivity.

The quantitative nature of NDE data can be also exploited for a more objective condition rating of deck and to more precisely quantify deterioration progression. It can be also used, in combination with bridge deck segmentation, to identify bridge sections with higher deterioration. Condition rating with respect to each of the deterioration or defect types is calculated using a weighted area approach. For example, the rating with respect to delamination, on a scale of 0 (worst) to 100 (best), is calculated from a weighted average of percentages of the areas falling into the three delamination conditions. The area described as sound (no delamination) is assigned a weight factor of 100. The area described in the state of initial delamination (fair to poor grade) is assigned a factor 50, and the area in the state of severe delamination a factor 0. Condition ratings with respect to delamination, corrosion and concrete degradation for a bridge are illustrated in Table 1. The progression of deterioration in all three cases can be observed. Condition ratings on the network level or sections of larger bridges can be utilized to identify the areas of faster deterioration progression and or the ones that should have priority in maintenance or rehabilitation.

Table 1. Condition Ratings for a Bridge Deck

	2009	2011
Active Corrosion	39.4	28.1
Delamination Assessment	70.0	57.2
Concrete Degradation	48.1	35.3
Combined Rating	52.5	40.2

Description of the Robotic Platform

The robotic system for condition assessment of bridge decks, with its main components marked, is shown in Figure 4. The robotic platform is a Seekur robot from Adept Mobile Robot Inc. The robot itself is approximately 1.4 m long, 1.2 m wide and 1.1 m tall. It has four omni-directional wheels. which enable the robot to move laterally and to turn at a zero radius. These wheels also allow fast movement from one test location to the next one in any direction. The primary navigation system is a differential GPS, for which the robot uses two Novatel antennas mounted on the robot, and the third one on a tripod, the base station. The information from the GPS systems is fused with the information from an on board inertial measurement unit (IMU) and a wheel encoder using Kalman filter. It is sufficient to take GPS coordinates at three points on the deck to fully define the robot movement path. The sensor arrays are 1.8 m wide, enabling the robot to assess half of a lane width in a single pass.

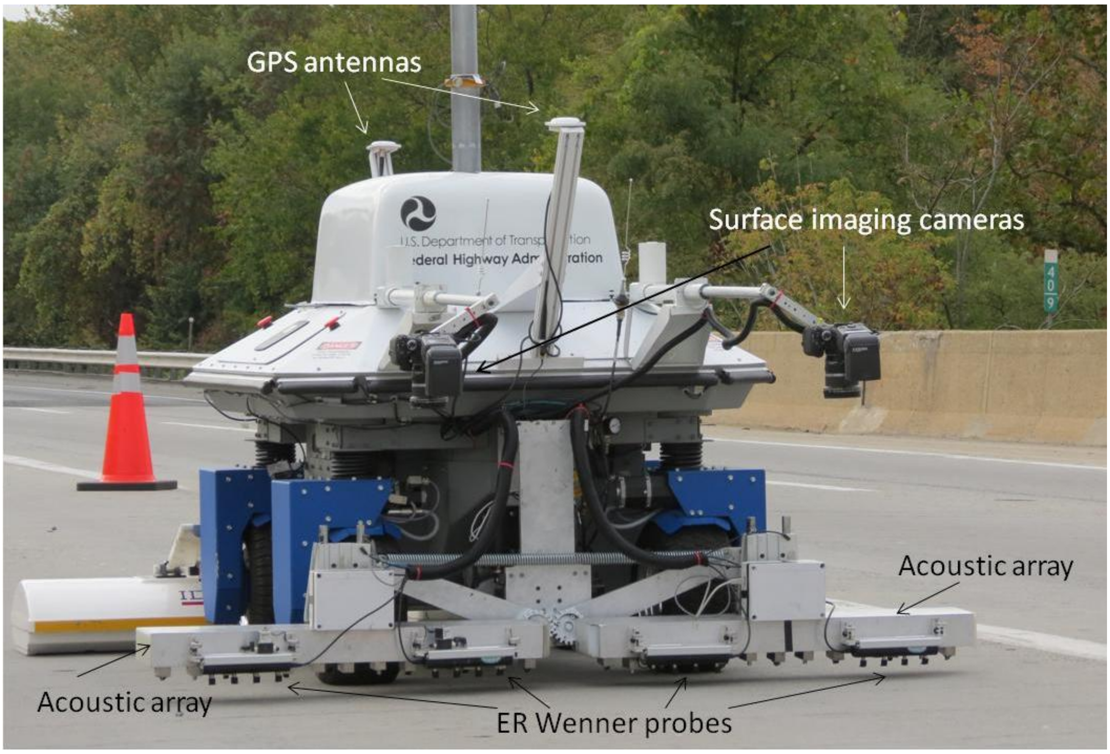

Figure 4. Front end of RABIT with NDE and navigation components.

The system is equipped with the sensors for the four previously described NDE technologies, and three digital cameras for high resolution bridge deck surface imaging and panoramic imaging of the test location surrounding. As shown in Figure 4, there are two acoustic arrays on the front end of the robot. Each of the arrays has four impact sources and seven receivers (accelerometers), enabling multiple IE and USW tests to be conducted. The sources and receivers are coupled to the deck surface pneumatically. The primary purpose of IE testing is to determine the extent and severity of delamination, while the USW testing is used to describe the concrete quality by measuring the concrete modulus. Also, attached to the acoustic array boxes are four ER Wenner types probes. Each of the probes has small diameter water supply lines that spray water on the probe's electrodes to establish the electrical contact between the electrodes and concrete surface. The ER measurements are conducted to assess the corrosive environment, which is primarily affected by the presence of moisture, salts, chlorides, etc. Finally, there are two high resolution cameras on the front end, each of them taking an image of approximately 0.7 m by 1.0 m area of the deck surface. All the images are stitched into a single high resolution image of the bridge deck.

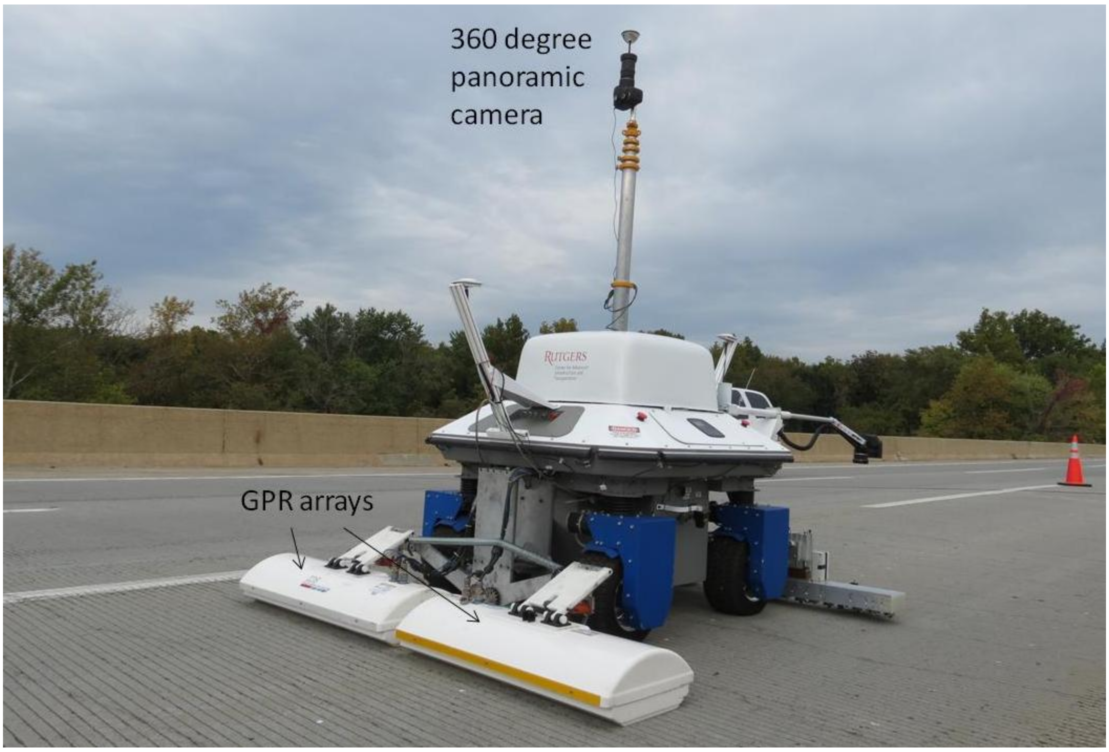

Figure 5. Rear side of RABIT with GPR arrays and panoramic camera.

The GPR arrays marked on the rear side of RABIT in Figure 5 have primary purpose to do rebar mapping, to measure the concrete cover, and to contribute to the assessment of the corrosive environment, concrete degradation and likelihood of delamination. Each of the two IDS Hi-Bright arrays has sixteen antennas, or two sets of eight antennas of dual polarization. Finally, there is the third digital camera mounted on a mast in the middle of the robotic platform. The mast can lift pneumatically the camera to a 4.5 m height to take 360 degree panoramic images of the bridge deck.

All the collected data are wirelessly transmitted from the robot to the "command van" as they are collected. All the data being collected can be monitored in the van. The data are analyzed as received, and some of the results are presented in near real time. For example, the impact echo records are analyzed to create a delamination map, the surface wave data are analyze to create a concrete quality map, a corrosion rate map is created from correlations to the resistivity data, etc. The robot operator can control and monitor data collection and analysis on four main monitors in the van. As an illustration, a screen describing the collection of GPR data for a single antenna, a time history and spectrum for one of the impact echo devices, deck surface imaging, and electrical resistivity from two ER probes are shown in Figure 6. In addition, the operator can monitor the robot movement and position on the deck based on the transmitted GPS coordinate, as illustrated in the figure.

Figure 6. Screen of one of the monitors in the "command van."

Conclusions

The robotic system RABIT, with its integrated multiple NDE technologies and vision, fully autonomous and rapid data collection, and associated data analysis and interpretation, opens new ways in the condition assessment of concrete bridge decks. The complementary use of four NDE technologies: electrical resistivity, impact echo, ground-penetrating radar, and ultrasonic surface wave testing, enables detection and characterization of corrosion, delamination, and concrete degradation with higher spatial resolution and confidence level. The associated platform for enhanced data integration and visualization facilitates more complete review of the collected data and more intuitive presentation of the main deterioration and defect types. While the system will find its first use in the data collection for the FHWA's LTBP Program, it has high potential for implementation by transportation agencies and bridge owners in their daily operations.

Acknowledgments

This publication was supported by a subcontract from Rutgers University, Center for Advanced Infrastructure & Transportation (CAIT), under DTFH61-08-C-00005 from the U.S. Department of Transportation – Federal Highway Administration (USDOT-FHWA). A large number of individuals from Rutgers' School of Engineering working within the Center for Advanced Infrastructure and Transportation (CAIT) have contributed to various aspects of the robotic system development, construction and implementation. The authors gratefully acknowledge contributions of: Professors Basily Basily, Jingang Yi and Kristin Dana, Research Associates Drs. Hung La and Seong-Hoon Kee, Research Engineers Hooman Parvardeh and Ronny Lim, and graduate students Parneet Kaur and Prateek Prasanna.

References

Gucunski, N. Romero, F., Imani, A. and Fetrat, F.A., "Nondestructive Evaluation-Based Assessment of Deterioration Progression in Concrete Bridge Decks," Proceedings of the 92nd Annual Transportation Board Meeting, Washington, D.C., January 13-17, 2013, on CD.

Gucunski, N., Maher, A., Ghasemi, H., and Ibrahim, F., "Segmentation and Condition Rating of Concrete Bridge Decks using NDE for More Objective Inspection and Rehabilitation Planning," the 6th International Conference on Bridge Maintenance, Safety and Management - IABMAS 2012, Stresa, Lake Maggiore, Italy, July 8-12, 2012, on CD.

Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of those of the U.S. Department of Transportation – Federal Highway Administration.