Abridgment

Network Bridge Deck Surveys Using High-Speed Radar: Case Studies of 44 Decks

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The DECAR radar system was evaluated for highway-speed bridge deck condition assessment by the New Hampshire Department of Transportation on three survey networks comprising 44 decks. DECAR (DEck Condition Assessment using Radar) incorporates van-mounted radar equipment, computer-based digital data acquisition equipment operating in the van, a set of procedures for organizing and conducting surveys, and software for collecting and processing the data. It was shown in each of the three surveys that groups of bridge decks could be successively surveyed at highway speeds up to 55 mph during a continuous round trip over the survey route. At this speed, production rates of 10 to 20 decks per day can be easily expected. Of the 44 decks surveyed, 19 were evaluated during replacement or repair to determine deck condition, and an additional 8 were new decks. The radar deterioration predictions using DECAR were compared with these known conditions, with a correlation (*R*-squared) of 0.81, and a standard error of ±4.4 percent of the total deck area. When the radar data were used to classify the decks into one of four categories, the radar results were accurate 93 percent of the time. The DECAR results were shown to be repeatable when repeat surveys were conducted at different times by different personnel. It was concluded that the DECAR system could be effectively and economically used to set up a bridge deck condition data base for bridge management and to monitor deck performance over time.

A major problem with bridge deck deterioration is the difficulty in assessing its severity and extent. The mechanisms of deterioration occur below the surface, and their manifestations are not readily seen in visual inspections. This is particularly true for overlaid decks, where both delamination and freeze/thaw damage can occur without visual manifestations. Many decks built during the Interstate construction period fall into this category, with degrees of deterioration from 0 to 50 percent. Agencies are forced to program, rank, and budget the repair and replacement of many structures whose conditions are virtually unknown.

Recent research has led to the development and verification of ground penetrating radar (GPR) for bridge deck condition assessment (*1*). The work described here focuses on a network survey application of GPR to support the implementation of a bridge management system (BMS). In a network level survey a radar van travels continuously at normal highway speed logging data for every bridge deck that it crosses. For a given round trip the van makes one pass on each lane. Multiple round trips are required to obtain complete transverse coverage of the deck. This survey method yields production rates of 20 to 30 decks in a day, a rate that would allow for complete coverage of a typical state bridge inventory in 50 to 300 working days. Additionally, the automated nature of the radar processing allows efficient analysis of the large quantity of data generated in these surveys. At this high production rate, a BMS data base of the condition of all decks in the network can be established during a 2- to 3-year period and updated periodically. These updates would yield deterioration rates and would be helpful in implementing a preventive maintenance program.

The objective of the reported work was to implement, test, and evaluate a pilot high-speed system for network-level bridge deck evaluations. A description of the DECAR (DEck Condition Assessment using Radar) system, developed and evaluated by INFRASENSE and delivered to the New Hampshire Department of Transportation (NHDOT), is presented here. Also described are the field surveys that were carried out with the DECAR system, including descriptions of the decks and the survey methods, the results of the analysis of the radar data collected during these surveys, and the comparison of these results to other available information (*2*).

DESCRIPTION OF RADAR DECK SURVEY SYSTEM

The DECAR system for highway-speed bridge deck surveys consists of the following elements (*2*):

- Radar equipment, fifth wheel, and van (Figure 1). The equipment used in this project was developed for FHWA by various vendors and loaned to NHDOT for this project (*3*).
- An on-board computer, with an analog/digital (A/D) conversion and data storage system.
- User interface and data analysis software.

The user interface software organizes a four step network survey methodology as follows:

- Layout of the survey route: Data on the decks to be covered are found in the bridge inventory and entered into the bridge description table of the program.

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- Detailed design of the survey: The surveyor estimates the number of passes required for each bridge from the width data and for the sequence of decks from maps. A network survey of a typical 2-lane Interstate deck would consist of 6 passes, one in each wheelpath of each lane, and two on the 10-ft shoulder.
- Conduct of the field survey: As each pass of each deck is about to be surveyed, the surveyor moves the cursor to the appropriate cell of the survey matrix and presses a key to initiate data collection. After the deck is crossed, data collection is terminated by pressing a key, and the data are automatically filed under a name that identifies the name of the bridge and the transverse location of the pass. Normally the radar vehicle will stay in the same wheelpath for a particular round trip. A complete survey is carried out by successive round trips of the survey vehicle, during which all passes of each deck are successively covered. The method was tested during this program and was found to work effectively at speeds up to 55 mph.
- Analysis of the radar data: The DECAR software is designed for quantity analysis of the network radar data. This analysis distinguishes the bridge deck data from the adjacent pavement sections; sets up a batch file that includes the names of the raw data files for each deck, the beginning footage of each deck pass, and the known bridge length; and runs the batch file for each deck, analyzing the data for each pass of the deck and computing the total deck deterioration.

FIELD SURVEYS AND RESULTS

Description of Decks and Deterioration Analysis

Three networks representing 44 Interstate bridge decks were surveyed during the course of this project. The surveys were designed to include decks scheduled for rehabilitation in the near future. A summary of the types and ages of decks included in these surveys is presented in Table 1.

FIGURE 1 Radar equipment.

TABLE 1 Types and Ages of Decks in Surveys

No. of decks	Type	Age (years)
27	IB-C, DPG	25–32
8	IB-C	<5
5	IB-C, CRF	18–19
4	CRF	25–32

NOTE: IB-C = concrete deck on I-beam girders, CRF = concrete rigid frame, and DPG = concrete deck on plate girders.

Data Analysis

The data collected during these surveys were analyzed with the DECAR data analysis system. The product of this analysis is a percentage deterioration for each deck surveyed. For decks whose conditions were known (because they were new) or subsequently determined during rehabilitation, the predicted percentages were compared with the known ones.

The prediction method used in this study was identical to that developed during previous research (*1,4,5*). The percent deterioration was determined by first computing the dielectric constant of the concrete from the amplitude of the asphalt/concrete reflection. For each pass, the percent of the pass that exceeded the mean plus a threshold was computed; this percent was averaged for all passes. This computation is shown graphically in Figure 2. The percent computed was then fit to the known deterioration conditions to develop a formula for computing the deck deterioration from the radar-based percentage. The formula for deterioration is based on the 20 percent threshold:

$$\text{Percent deterioration} = K1 + K2*(R20) \quad (1)$$

where $R20$ is the percentage of the dielectric constants exceeding the mean plus 20 percent, computed as described previously. The constants $K1$ and $K2$ were reevaluated during this project to take into account differences in the data acquisition equipment and level of detail in the radar survey from what was done previously.

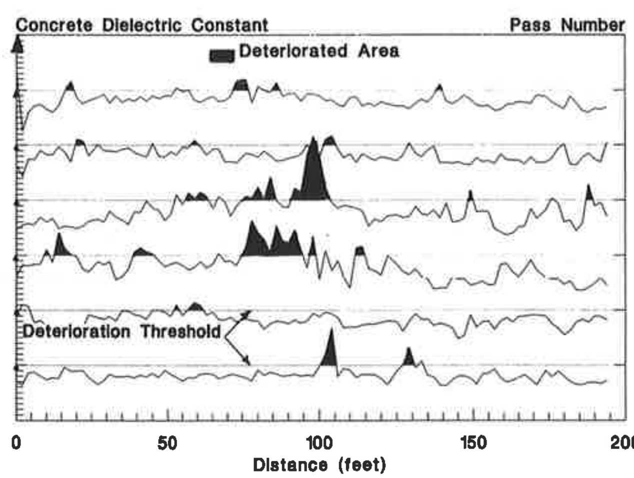

FIGURE 2 Concrete dielectric constant versus distance along deck.

For new decks the actual deterioration was assumed to be zero. For older decks the actual deck deterioration was determined during deck reconstruction after removal of the asphalt by visual observation and chain drag of the exposed concrete.

Table 2 presents a detailed analysis of the match between the radar predictions and known levels of deterioration. The analysis considers two factors: the accuracy in categorizing the condition of the deck for ranking purposes and the closeness of the match between the predicted versus known percent deterioration. The radar predictions are based on a regression fit between *R*20 values and the measured surface conditions for 26 of the 27 decks. One was eliminated from the regression because of the poor match between the radar value and the measured condition.

The radar predictions were used to place the decks into four categories, as shown in Table 2 and Figure 3. These radar-based categorizations were then compared with the categorization based on the observed deck surface conditions. Based on this comparison, the radar-based deck categorization is accurate 93 percent of the time and only two of the 27 decks are incorrectly categorized.

The closeness of match between the radar predictions and the surface-measured conditions are described by the *R*-squared and standard error. For the data in Table 2, the *R*-squared is 0.81, indicating a reasonably good fit between the radar predictions and the directly measured conditions. The standard error, which is the standard deviation between the predicted and actual values, is 4.42 percent of the deck area. An examination of the table shows that radar predictions for 21 of the 27 decks are within 5 percent of direct observations, and 25 of the 27 are within 7 percent. Only 2 decks show significant deviations: 116/109 at 11 percent and 207/041 at 25 percent. The 25 percent discrepancy for 207/041 was a result of the presence of large areas of deteriorated concrete, which were not covered by the survey passes.

TABLE 2 Summary of Actual Versus Predicted Conditions

BRIDGE ID#	DETERIORATION RADAR	DETERIORATION KNOWN	CATEGORY * Radar	CATEGORY * Measured	
NEW HAMPTON - ASHLAND					
148/081	15	18	2/3	3	
186/118	15	8	2/3	2	
089/050	30	25	3	3	
089/057	19	24	3	3	
086/119	23	25	3	3	
147/082	11	10	2	2	
148/081	4	0	1	1	
186/118	0	0	1	1	
089/050	3	0	1	1	
089/057	3	0	1	1	
FRANCONIA - LITTLETON					
132/086	0	0	1	1	
132/095	2	0	1	1	
069/122	4	1	1	1	
148/060	7	2	2	1	
219/040	16	10	2/3	2	
211/040	13	15	2	2/3	
208/042	13	7	2	2	
207/041	5	30	1/2	3	**
211/039	0	5	1	1/2	
100/050	18	25	3	3	
147/060	5	10	1/2	2	
053/122	1	3	1	1	
068/121	0	2	1	1	
077/115	29	25	3	3	
116/109	19	30	3	3/4	
131/095	1	0	1	1	
132/086	1	0	1	1	

* CATEGORIES
1= 0-5
2= 6-15
3= 16-30
4= >30

** Result not included in prediction model

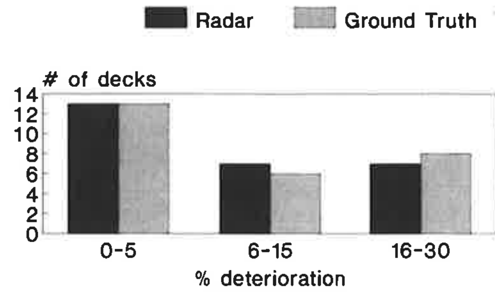

FIGURE 3 Radar versus ground truth, bridge deck categories.

Influence of Survey Speed

Survey speed influences the longitudinal spacing of the radar data. A study was conducted to investigate the influence of survey speed on the radar predictions for deck deterioration. For eight bridge decks, the deck deterioration was then calculated in two ways: (a) using data at 2-ft spacing and (b) using data at 1-ft spacing. The average difference between these two analyses was 0.64 percent, the maximum difference 1.8 percent. These differences are minimal, and, consequently, survey speed does not appear to significantly affect the results of the radar survey.

Repeatability Study

Factors affecting repeatability include (a) small differences in locating the beginning and end of the deck in the data from each pass, (b) deviations in the position of the antenna from survey to survey, (c) differences in deck conditions and environmental conditions, and (d) variations in the characteristics of the radar signal from survey to survey. To investigate repeatability, three repeat surveys were conducted: the first by INFRASENSE staff on May 2, one day after rain; the second by NHDOT personnel under INFRASENSE supervision on June 7, 2 days after rain; and the third by NHDOT personnel alone on August 14, 4 days after rain.

Figure 4 shows the comparisons of the results of the three surveys for each of the 8 bridges of the network. The figure shows that the radar analysis is highly repeatable. The average difference between the three sets of analyses is 1.5 percent, the maximum difference 3.1 percent.

CONCLUSION

The project has demonstrated that radar can be used to accurately survey bridge decks on a network basis. The data collection and analysis procedures have been automated and

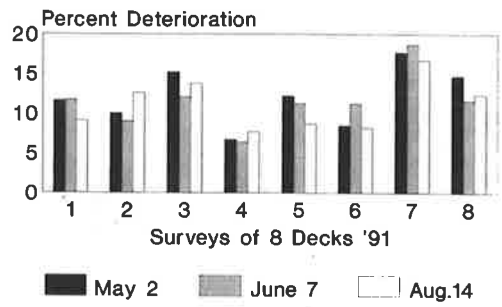

FIGURE 4 Repeatability study.

organized so that they can be carried out by state transportation department personnel with minimum training. The survey results are independent of survey speed and are objective and repeatable. The information from these surveys can be entered into a bridge deck condition data base, which can be used as an integral part of a BMS. Repeat surveys on the same decks can be carried out to monitor the progressive development of problem conditions.

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