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Reliability of Visual Inspection for Highway Bridges, Volume I: Final Report and, Volume II: Appendices

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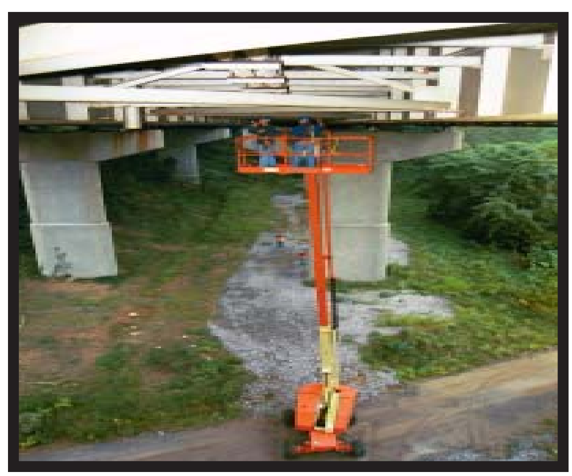
This technical summary announces the findings of an investigation by the Federal Highway Administration's Nondestructive Evaluation Validation Center (NDEVC) concerning the reliability of Visual Inspection for highway bridges. Details and results are fully documented in a two-volume final report entitled *Reliability of Visual Inspection for Highway Bridges* (Publication Nos. FHWA-RD-01-020 and FHWA-RD-01-021). To obtain a copy of the report, ordering information is included on the last page of this summary.

The visual inspection method is the predominant nondestructive evaluation technique used for bridge inspection. However, since implementation of the National Bridge Inspection Standards in 1971, a complete study of the reliability of visual inspection, as it relates to highway bridge inspection, has not been undertaken. Given these facts, and assuming that visual inspection may have limitations that affect its reliability, the NDEVC initiated a comprehensive study to examine the reliability of the visual inspection method for highway bridges as it is currently practiced in the United States.

The study had four specific objectives. Visual inspection is a primary component of both routine and in-depth inspections and, therefore, the first two objectives were to provide overall measures of the accuracy and reliability of routine and in-depth inspections. The third objective was to study the influence of several key factors to provide a qualitative measure of their influence on the reliability of routine and in-depth inspections. The fourth objective was to study the differences between state inspection procedures and reports.

Three primary activities were performed during the course of this study: (1) a literature review, (2) a survey of bridge inspection agencies, and (3) a series of performance trials utilizing State department of transportation bridge inspectors. The performance trials were conducted using 49 State bridge inspectors. These State bridge inspectors completed six routine Inspections, two in-depth Inspections, and two inspections following their respective State procedures (i.e., State-dependent procedures). Extensive information was collected about these inspectors and the environments in which they worked. This information was then used to study possible relationships of various factors with the inspection results.

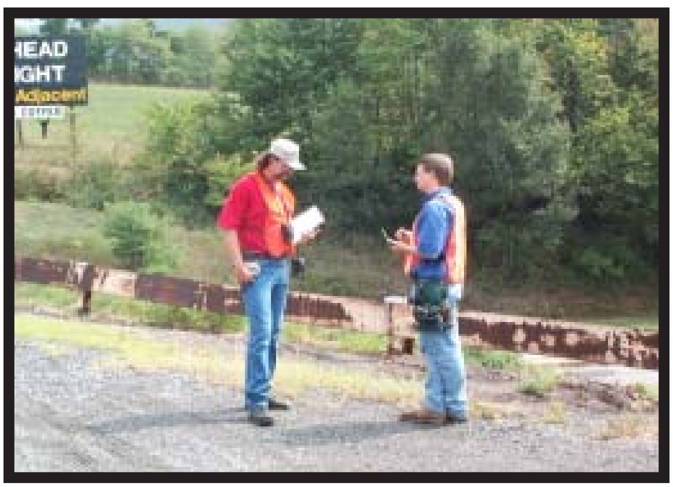
Seven of the NDEVC test bridges were used for the 10 performance trials. The NDEVC test bridges are located in Northern Virginia and in South-Central Pennsylvania. The Virginia bridges are in-service



In-Depth Inspection performed with the aid of a lift vehicle. Also note the second observer and inspector performing the Routine Inspector.

bridges under the jurisdiction of the Virginia Department of Transportation. The bridges in Pennsylvania are located on (or over) a decommissioned section of the Pennsylvania Turnpike, known as the Safety Testing and Research (STAR) facility. The STAR facility is an 18-km section of limited-access highway that has been preserved by the Pennsylvania Turnpike Commission as a location for conducting highway-related research. The STAR facility bridges have had minimal maintenance since being taken out of service in 1968 after approximately 35 years in service.

All inspectors were provided with identical sets of common, non-invasive inspection tools. These tools were introduced to the inspectors before they began any of the inspection tasks and were available for use during all inspections. In addition to the basic inspection tools, the i inspectors were provided special access equipment (e.g., a man-lift) as needed.



NDEVC observer interviews an inspector just before an inspection task.

Two primary types of data were collected. The dependent data are the results of the inspections, while the independent data are the characteristics of the inspector (i.e., human factors) and the inspection environment (i.e., environmental factors). Two primary media were used for the data collection. While completing their inspections, inspectors were asked to prepare handwritten field inspection notes on typical National Bridge Inspection Standards forms provided by the NDEVC. Field observations made by NDEVC staff observers were recorded utilizing Palm IIIx handheld computers. Electronic forms were prepared for the computers using commercially available software to expedite the process and ensure consistency in the data collection. The independent data in this study are the human and environmental factors. The independent data were collected through self reports, direct measurements, and firsthand observations. The methodology for the collection of this data is essential to establishing accurate cause-effect relationships with the dependent data. In this regard, consistent and unbiased tools were developed to assist in making these measurements. Furthermore, an attempt was made to allow most data to be collected in a quantitative or pseudo-quantitative form to allow numerical correlation studies to be performed.

Two principal types of dependent data were collected. The primary data collected for evaluating the routine inspection results were the standard condition ratings of the primary bridge components: deck, superstructure, and substructure. Secondary bridge component ratings, inspection field notes, and photographic documentation supplemented the primary bridge component ratings and were also evaluated. Condition ratings consider both the severity of bridge deterioration and the extent to which it is distributed throughout the components. For this study, the standard condition rating guidelines, as given in the *Bridge Inspector's Training Manual*, were used. The primary data collected for evaluating in-depth Inspections were inspector field notes generated during the inspections. Specifically, inspector notation of known deficiencies was the principal information used to evaluate the in-depth Inspection results.

Conclusions

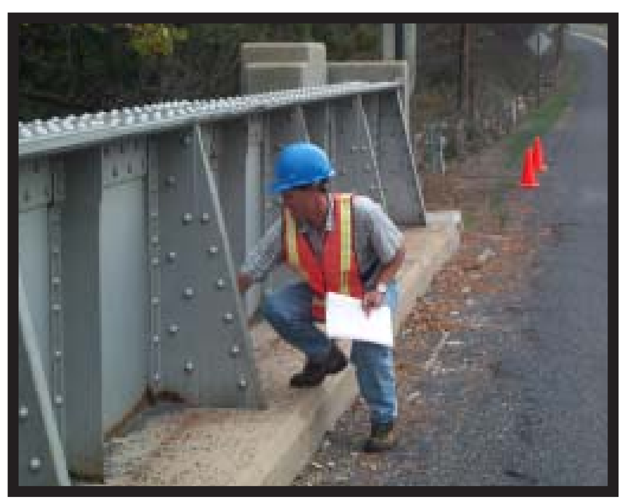
From the survey of bridge inspection organizations, it was determined that professional engineers are typically not present on site for bridge inspections. Specifically, 60 percent of State respondents indicated that a professional engineer was on site for less than 40 percent of the inspections. In addition, vision testing of inspectors is almost nonexistent, with only two State respondents indicating that their inspectors had their vision tested. As was anticipated, visual inspection was the most frequently cited nondestructive evaluation technique used for concrete, steel, and timber bridges. From the survey, it was also found that many bridge inspection organizations have a need for additional research in the area of concrete deck and prestressed concrete inspection.

Regardless of the type of inspection being completed, it was found that, when asked, many inspectors did not indicate the presence of important structural aspects of the bridge that they were inspecting. These would include such items as support conditions, bridge skew, fracture-critical members, and fatigue-sensitive details. In addition, there is significant variability in how long inspectors anticipate they need to complete an inspection and how long the inspection actually takes.

From the routine inspection tasks, it was observed that routine inspections are completed with significant variability. This variability is most prominent in the assignment of condition ratings, but is also present in inspection documentation. As an example, on average, four or five different condition ratings were assigned to each element. Based on the application of statistical models, it is predicted that only 68 percent of the condition ratings will vary within one rating point of the average. Similarly, it is predicted that 95 percent of the condition ratings from bridge inspections will be distributed over five contiguous condition ratings, centered about the average. Also, it was observed that condition ratings are generally not assigned through a systematic approach. Based on the distribution of the condition ratings and observations made during the study, the National Bridge Inspection Standards condition rating definitions may not be refined enough to allow for reliable routine inspection results. Nonlinear, multivariate regression analyses indicate that a number of factors appear to correlate with routine inspection results. In this study, they include factors related to Reported Fear of Traffic, Near Visual Acuity, Color Vision, Formal Bridge Inspection Training, Light Intensity, Reported Structure Maintenance Level, Reported Structure Accessibility Level, Reported Structure Complexity Level, Inspector Rushed Level, and Wind Speed.

From the in-depth Inspection tasks, it was observed that In depth inspections are unlikely to correctly identify many of the specific types of defects for which this type of inspection is frequently prescribed. As an example, only 3.9 percent of weld inspections correctly identified the presence of crack indications. Furthermore, it is concluded that a significant proportion of in-depth Inspections will not reveal deficiencies beyond those that could be noted during a routine inspection. As with routine inspections, a number of factors appear to correlate with in-depth inspection results. In this study, they include factors related to inspector comfort with access equipment and heights, time to complete inspection, structure complexity and accessibility, inspector viewing of welds, flashlight usage, and number of annual bridge inspections. In addition, the overall thoroughness with which inspectors complete inspections tended to have a large effect on the likelihood of defect detection. Not surprisingly, there also appears to be some correlation between the types of defects individual inspectors will note. Specifically, inspectors who find small, detailed defects are more likely to consistently note small, detailed defects regardless of the bridge. Also, inspectors who find gross dimensional defects are more likely to do so on other bridges as well.

Based on the State-dependent inspection tasks, it appears that most States follow similar inspection procedures and provide the same general information in their inspection reports. With some notable exceptions, when element-level inspections were completed, they were generally consistent with the *Commonly Recognized Element Guide* for the major bridge elements. Inconsistencies were observed in the use of units, division of quantities, and the definitions of the condition States. From the State-dependent routine inspection, it appears that few inspection teams perform an in-depth level inspection of bridge decks as part of their routine inspection. When inspection teams were asked to perform an in-depth level inspection of a bridge deck, it was found that significant inaccuracies existed. As an example, only 6 of 22 teams were within 5 percentage points of the delamination percentage determined by the NDEVC for the deck.



Part of a routine Inspection at a STAR bridge.

Part of an In-Depth Inspection task at a STAR bridge.

Recommendations

Based on these conclusions, several recommendations have been developed related to improving the state-of-the-practice, as well as additional research needed in the application of visual inspection to highway bridges.

With respect to routine inspections, the accuracy and reliability may be greatly increased by revising the condition rating system.

Additional work is needed to clearly define the source(s) of the inaccuracies. Similarly, the accuracy and reliability of in-depth inspections could be increased through increased training of inspectors in the types of defects that should be identified and the methods that would frequently allow this identification to be possible.

Further examination and definition of the types and sizes of specific defects that are likely to be identified during an in-depth inspection are warranted. Specifically, this would include a study of the types of defects occurring in concrete superstructures, as well as different sizes of defects occurring in steel superstructures.

The accuracy and reliability of both routine and in-depth Inspections could be further increased by considering the identified factors during the selection and training of inspectors, as well as during the design of bridges.

Additional research is needed into each of these factors to establish useful guidelines. Additional research is also needed to determine whether ensuring minimum vision standards through vision testing programs (with corrective lenses, if necessary) would benefit bridge inspection.

Since the primary focus of the routine inspection tasks in this study was on the assignment of condition ratings, more research should be performed to determine the accuracy with which the commonly recognized elements are used in the field.

Further study of deck inspections is also required. This research should investigate team and individual detection abilities, as well as difficulties inherent in the reporting process. This research could also compare mechanical sounding deck inspection techniques to other nondestructive evaluation techniques.

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