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

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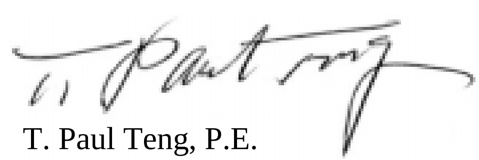
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

Since the implementation of the National Bridge Inspection Program in 1971, State Departments of Transportation have invested significant resources to evaluate the condition of their bridges. These inspections are primarily conducted within the context of the National Bridge Inspection Standards that require reporting of bridge condition in a standardized format. This standardized format uses a uniform set of condition ratings to describe the condition of a bridge. Key elements of the inspection include the condition ratings for the deck, superstructure, and substructure of the bridge. The assignment of condition ratings to elements of the bridge is used to measure bridge performance at the national level, to forecast future funding needs, to determine the distribution of funds between States, and to evaluate if a particular bridge renovation project qualifies for Federal assistance. Obviously, the accuracy of the condition ratings is important to ensure that FHWA programs for funding bridge construction and renovation are equitable and meet the goal of reducing the number of deficient bridges.

The accuracy and reliability of the inspection process that results in condition ratings for Highway Bridges has not been researched previously. This report documents the findings of the first comprehensive study of the inspection process since the adoption of the National Bridge Inspection Standards. The study provides overall measures of the reliability and accuracy of bridge inspection, identifies factors that may influence the inspection results, and determines what procedural differences exist between various State inspection programs. This report will be of interest to bridge engineers, designers, and inspectors who are involved with the inspection of our Nation's highway bridges.



T. Paul Teng, P.E.
Director, Office of Infrastructure
Research and Development

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16. Abstract

Visual Inspection is the predominant nondestructive evaluation technique used in bridge inspections. However, since implementation of the National Bridge Inspection Standards in 1971, a comprehensive study of the reliability of Visual Inspection as it relates to highway bridge inspections has not been conducted. The goals of the study include: providing overall measures of the accuracy and reliability of Routine and In-Depth Visual Inspections, studying the influence of several key factors that affect Routine and In-Depth Inspections, and studying the differences between State inspection procedures and reports.

Ten inspection tasks were performed at seven test bridges using State bridge inspectors. The sample of participating inspectors included 49 inspectors from 25 State agencies. Inspectors were provided with common information, instruction, and tools. Inspector characteristics were measured through self-report questionnaires, interviews, and direct measurements.

Routine Inspections were completed with significant variability, and the Condition Ratings assigned varied over a range of up to five different ratings. It is predicted that only 68 percent of the Condition Ratings will vary within one rating point of the average, and 95 percent will vary within two points. Factors that appeared to correlate with Routine Inspection results include Fear of Traffic; Visual Acuity and Color Vision; Light Intensity; Inspector Rushed Level; and perceptions of Maintenance, Complexity, and Accessibility.

In-Depth Inspections using Visual Inspection alone are not likely to detect or identify the specific types of defects for which the inspection is prescribed, and may not reveal deficiencies beyond those that could be noted during a Routine Inspection. The overall thoroughness with which inspectors completed one of the In-Depth tasks tended to have an impact on the likelihood of an inspector detecting weld crack indications. Other factors that may be related to In-Depth Inspection accuracy include: time to complete inspection, comfort with access equipment and heights, structure complexity and accessibility, viewing of welds, flashlight use, and number of annual inspections performed.

The State procedural and reporting tasks indicated that most States follow similar procedural and reporting criteria. Several inconsistencies were noted with the use of the element-level inspection systems, but it is not known if these variations are the result of State practices or inspector use. Deck delamination surveys were found to have significant variability, with only a few teams performing a delamination survey as part of the Routine Inspection.

This volume is the first in a series of two. The other volume in the series is: FHWA-RD-01-021, Volume II: Appendices

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1. INTRODUCTION

1.1. BACKGROUND

The Visual Inspection (VI) method is the predominant nondestructive evaluation (NDE) technique used for bridge inspections and serves as the baseline with which many other NDE techniques may be compared. Since implementation of the National Bridge Inspection Standards (NBIS), which define the frequency with which each bridge must be inspected and prescribes minimum qualifications for inspectors, a complete study of the reliability of VI as it relates to bridge inspections has not been undertaken.[1]

Given these facts and the understanding that VI may have limitations that affect its reliability, the Federal Highway Administration (FHWA) initiated a comprehensive investigation to examine the reliability of the VI method as it is currently practiced in the United States. The study includes a literature review, survey of bridge inspection agencies, and a series of field inspection performance trials. The study was conducted at the Nondestructive Evaluation Validation Center (NDEVC), a national center for the development and evaluation of NDE technologies.[2]

In April 1998, an Industry Expert Panel (IEP), consisting of experts from the aviation, power, and infrastructure industries, met at the Turner-Fairbank Highway Research Center to discuss the need for a VI reliability study and to develop preliminary information related to the reliability of VI. The results of this meeting indicated that a better understanding of the VI of highway structures is needed. Following the development of a preliminary experimental work plan for this investigation, a second IEP meeting was held in May 1999 to review the proposed work plan. As with the first IEP meeting, much information was developed and later incorporated into the final work plan. This report summarizes the work plan and the results obtained from the study.

1.2. OBJECTIVES

The goal of this study is to examine the reliability of VI of highway bridges. As such, reliability was studied within the context of its normal application. The *American Association of State*

Highway and Transportation Officials (AASHTO) Manual for Condition Evaluation of Bridges, 1994 describes five types of bridge inspections.[3] They are:

- Initial Inspection

  An Initial Inspection is the first inspection completed on any new bridge. There are two goals of the Initial Inspection: (1) to obtain all required Structure Inventory and Appraisal data, and (2) to determine the baseline structural conditions and to identify current or potential problem areas.

- Routine Inspection

  A Routine Inspection is a regularly scheduled inspection to determine the physical and functional condition of a bridge and to identify any changes since previous inspections. Furthermore, Routine Inspections serve to ensure that a bridge continues to satisfy all applicable serviceability requirements. Routine Inspections must satisfy all requirements of the NBIS with respect to frequency and inspector qualifications. These inspections are generally conducted from deck level, ground or water levels, or from permanent-access structures.

- In-Depth Inspection

  An In-Depth Inspection is a close-up, hands-on inspection of one or more members to identify deficiencies not normally detected during Routine Inspections. These types of inspections are generally completed at longer intervals than Routine Inspections and may include the use of more advanced NDE techniques.

- Damage Inspection

  A Damage Inspection is completed to assess structural damage resulting from environmental or human actions. The scope of each Damage Inspection is unique, with the general goal of assessing the need for further action.

- Special Inspection

  A Special Inspection is completed to monitor a known defect or condition. Special Inspections require the person completing the inspection be familiar with the severity and consequences of the deficiency. Special Inspections are generally not sufficient to satisfy the requirements of the NBIS.

This study focuses on the two most commonly completed inspections: Routine and In-Depth Inspections. In order to ensure that this study is applicable, the inspection results were studied in the forms in which they are normally manifested. Specifically, for the Routine Inspections, the *Bridge Inspector's Training Manual 90* definitions for the Condition Rating of the deck, superstructure, and substructure were used.[4] The Condition Rating system requires that inspectors assign a rating from zero to nine that reflects the structural capacity of a bridge and describes any structural deficiencies and the degree to which they are distributed. In one instance, inspectors were asked to use their own inspection forms to complete a Routine Inspection. In this case, inspection results may have also been generated in the form of an element-level inspection. Where appropriate, these results were evaluated with respect to the guidelines described in the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements*.[5] This guide defines the CoRe elements and describes their use. For the In-Depth Inspections, the inspection results were evaluated based solely on inspector field notes. These field notes were a reflection of the specific deficiencies that were reported.

There were four specific objectives developed for this study. These objectives are given below with potential benefits for each.

1. Provide an overall measure of the accuracy and reliability of Routine Inspection, of which VI is a primary component.

   Potential Benefits

   - Improved confidence levels related to Routine Inspection results.
   - Quantitative measurement of inspector performance.

2. Provide an overall measure of the accuracy and reliability of In-Depth Inspection, of which VI is a primary component.

   Potential Benefits

   - Improved confidence in In-Depth Inspection findings.

- Quantitative measurement of inspector performance.

3. Study the influence of several key factors to provide a qualitative measure of their influence on the reliability of Routine and In-Depth Inspections.

   Potential Benefits

   - Improved knowledge of bridge inspector performance and the influence of inspector characteristics.
   - Greater understanding of the influence of the inspection environment on the accuracy of bridge inspection.

4. Study inspection procedural and reporting differences between States.

   Potential Benefits

   - Greater understanding of different fundamental approaches to bridge inspection.
   - Increased knowledge about inspection procedures.

1.3. SUMMARY OF APPROACH

To accomplish the study objectives, the study consisted of a literature review, a survey of bridge inspection agencies, and a series of performance trials using State department of transportation (DOT) bridge inspectors.

The literature review was completed to build a solid foundation for this study. This review provided background information related to VI of highway structures, the use of VI in other industries, the influence of inspection factors on reliability, and information on the training and selection of bridge inspectors.

The survey of inspection agencies was completed to establish the current state of the bridge inspection practice. The results of this survey help to ensure that the study would address current bridge inspection problems and needs.

The largest aspect of the study was a series of performance bridge inspection trials. Forty-nine State DOT bridge inspectors completed six Routine Inspections, two In-Depth Inspections, and two inspections following their respective State procedures. Extensive information was collected about the inspectors and the environments in which they worked. This information was then used to determine the existence of any relationships with inspection results.

This report is divided into seven chapters. The literature review is presented in Chapter 2. The results from the survey of bridge inspection agencies are summarized in Chapter 3. A description of the experimental program, including the inspection specimens and data collection procedures, is presented in Chapter 4. Results from the performance trials are summarized in Chapter 5. A discussion of the findings is given in Chapter 6. The conclusions and recommendations are presented in Chapter 7. Supplemental information is given in the appendices in Volume II.

2. LITERATURE REVIEW

A literature review was conducted to collect available information on VI. Many sources were searched for information, including resources at the FHWA, National Technical Information Service (NTIS), Nondestructive Testing Information Analysis Center (NTIAC), Federal Aviation Administration (FAA), Electric Power Research Institute (EPRI), Transportation Research Board, and the National Cooperative Highway Research Program (NCHRP). In addition, searches were completed at major universities and on the Internet.

The literature reviewed in this study is not intended to be all-inclusive, but focuses on issues that are important to establishing a successful VI investigation. In the following sections, a number of investigations related to VI are summarized. These are presented under four broad categories: VI of highway structures, VI in other industries, factors affecting VI, and issues related to the selection and training of visual inspectors.

2.1. VISUAL INSPECTION OF HIGHWAY STRUCTURES

There has been little research done on the reliability of VI of highway bridges. This section summarizes information related to previous studies and the significance of VI, and discusses proposed methods for improving VI of highway bridges.

Three previous surveys on the application of NDE to highway structures were identified during the literature search. The previous surveys included a study by Caltrans (California Department of Transportation); a study by Rens, et al. for the American Association of Railroads; and a follow-up study by Rens and Transue. These surveys had broad scopes and provided only limited information related to VI.

In 1994, Caltrans conducted a survey targeted at the State DOTs. Thirty-seven States responded to this survey. The survey asked nine questions about nondestructive testing (NDT), focusing on what types of tests are used, which corresponding procedures are used, and who performs the tests.[6]

Question 1 of the Caltrans survey asked whether NDT methods were currently used in State DOT bridge inspection programs. If only VI was used, a note to that effect was requested. Responses are summarized in table 1 by the technique cited. The Caltrans summary indicated that 19 of the DOTs responded affirmatively regarding Visual Testing. The remaining 18 responses either were non-specific about which type of NDE was used or indicated specific NDT techniques other than Visual Testing. These 18 responses were equally divided between these 2 categories. It should be emphasized that while this question asked about NDT use in general, it was assumed that study participants all used VI. However, responses are compiled in terms of Visual Testing, which is a slightly different concept. The American Society for Nondestructive Testing (ASNT) reference, ASNT-TC-1A, defines Visual Testing as the use of boroscopes, microscopes, and other optical devices to aid VI.[7] The more common definition of VI includes all unaided inspection/evaluation techniques that use the five senses with only very basic tools (for example, flashlights, sounding hammers, tape measures, plumb bobs, etc.). VI may include Visual Testing, but many forms of VI are not included within Visual Testing. Confusion between VI and Visual Testing is probably the reason that Visual Testing was listed less frequently than other NDE techniques.

A separate question asked who typically performed the NDT work—engineers or technicians—and whether the work was ever contracted out: 16 DOTs indicated technicians, 2 DOTs indicated engineers, and 17 DOTs indicated both engineers and technicians performed the NDT. In addition, 20 DOTs indicated that their NDT work was at least partially completed through outside contracts, although it is not clear if these contracts used engineers or technicians.

Two questions touched on the qualifications of the inspectors with regard to the three certification levels defined by ASNT. According to ASNT-TC-1A, the Level III certified individual is involved in policy-level decisions about the use of his specialty area(s) of NDT.[7] Although neither question specifically asked about the use of ASNT Level III personnel, information regarding this certification level can be gleaned from the responses. The results indicate that seven different States used ASNT Level III certified personnel.

Table 1. Caltrans 1994 NDT Survey: Question 1 — NDT methods currently used.[6]

Type	Number of Responses (37 total respondents)
Ultrasonic Testing (UT)	26
Penetrant Testing (PT)	25
Visual Testing (VT)	19
Magnetic Particle Testing (MP)	17
Radiographic Testing (RT)	5
Acoustic Emission (AE)	2
Eddy Current Testing (ET)	1

Other questions revealed that 9 of the DOTs were doing research on NDT for steel or concrete bridges, while 28 indicated that they were not doing any NDT-related research. Also, 18 of the DOTs felt adequately directed/informed by the FHWA in the use of NDT for bridges. Six respondents felt adequately informed only part of the time, and 13 did not feel adequately informed.

In 1993, Rens, et al. completed an international survey, sponsored by the Association of American Railroads, on general NDE use.[8] While there was no specific evaluation of VI in this study, the study did generate relevant information regarding the general use of NDE. The survey was sent to a total of 58 State DOTs and industry organizations. The return rate was approximately 90 percent. Table 2 summarizes the findings relative to the general use of NDE in the United States from the study by Rens, et al. Note that the techniques have been re-ordered by decreasing order of number of responses.

Table 2. Rens, et al. (1993) responses to U.S. Questionnaire.[8]

Type	Number of Responses (52 total respondents)
Ultrasonic Testing (UT)	36
Magnetic Testing (MT)	21
Dye Penetrant (PT)	13
Rebar Locator (RL)	6
Schmidt Hammer (SH)	6
Radiographic Testing (XR)	6
Eddy Current Testing (ET)	6
Contract out NDE techniques (C)	6
Voltmeter (VM)	4
Do not use NDE techniques (N)	5
Other (O)	7

In 1996, Rens and Transue performed a follow-up survey to the 1993 Rens, et al. survey.[8-9] The same respondents were targeted, with a response rate of 86 percent. Again, this survey had no specific evaluation of VI, only general NDE use. In this survey, questions were developed to determine what information the user seeks from the use of NDE, and what bridge components are deemed difficult to evaluate. Seventy percent of the respondents indicated that bridge decks were the most difficult bridge component to evaluate. For concrete structures, approximately 74 percent of the respondents used NDE techniques to determine reinforcement details, while for steel structures, approximately 84 percent of the respondents used NDE to search for crack location and extent.

Some of the inherent problems with VI are discussed by Purvis in a report on the inspection of fracture-critical bridge members.[10] Although much of this information may appear to be obvious, a statement of these facts reinforces their importance. Purvis gives the following account:

> "In most situations the only method available to detect flaws in a bridge member is visual inspection. It is important to identify the flaws early in the typical crack-development scenario. If the defect is identified as soon as it can be seen by the inspector, the service life of the member often has been reduced by more than 80 percent.
>
> The flaw is often very small. The inspector has to be close, to know where to look, and to recognize the crack when it first becomes visible."

Purvis' description of VI, and the important role it plays, clearly exemplifies the need for accurate and consistent inspections. He further identifies inspector training as one of the keys to successful VI programs.

As part of a much larger study on the optimization of inspection and repair programs for highway bridges, Estes describes a program implemented by the Colorado Department of Transportation (CDOT) to improve inspector training and consistency.[11] Estes notes that consistency of VI between bridge inspectors does not come naturally and is, in essence, an outgrowth of training, quality control, and shared experiences. The CDOT program described by Estes consists of seven basic parts that, when used in combination, improve the reliability of each inspector's visual evaluation of a structure. The components of the CDOT program are:

- A Quality Assurance (QA) inspector conducts unannounced evaluations of each inspector's work. The QA inspector performs the inspection without knowledge of previous inspection results in order to eliminate any bias. Differences between the two inspections are evaluated and a check on consistency is easily made.
- Inspectors do not inspect the same structures each year. This ensures that inspections are not completed from within the same "rut" each time.
- Most inspectors have 15 or more years of experience.
- A minimum of 5 years of training is required to become a certified bridge inspector.
- Quarterly meetings between all inspectors are held to "discuss issues, identify discrepancies, and answer questions."
- A training program in which new inspectors work side-by-side with more experienced inspectors is required of all prospective inspectors.
- Definitions have been clarified by CDOT to make them less ambiguous to the field inspector.

Estes indicates that the inception of this seven-part program has helped CDOT inspections, and visual evaluations in particular, be performed with a higher level of consistency.

Elevating the quality of inspections is an important part of performing high-quality inspections. One way to counteract the difficulties associated with VI and to maintain a high level of inspection quality is by using a system of checks as described by Purvis and by Purvis and Koretzky.[12-13] The two parts of the monitoring system are briefly described below:

Quality control (QC) is the first part of the monitoring system. QC is maintained within a single organization and consists of team members checking one another's work. Inspectors "…review each other's sketches or descriptions, and they check for consistency of descriptions and measurements." Quality assurance (QA) is the second part and is performed by an independent, external third party. QA team members assess the quality of inspections previously completed and monitor activities to recommend changes to an established inspection program. The goal of QA is to ensure that inspections are performed in a manner consistent with established guidelines. Furthermore, QA serves to review a QC program and to offer suggested courses of action.

By maintaining an active and appropriate QA/QC program, bridge inspection managers can ensure that inspections are being completed within established limits. While a successful QA/QC program does not ensure safety, it can improve consistency and increase the reliability of inspections.

2.2. VISUAL INSPECTION IN OTHER INDUSTRIES

VI is an important inspection technique in many industries. The following paragraphs present a review of selected VI reliability investigations from various industries, including aviation, electronics, and telecommunications. In addition, information from general VI reliability investigations is also presented.

In response to the Aviation Safety Research Act of 1988, the FAA founded the Aging Aircraft Nondestructive Inspection Validation Center (AANC). An article by Smith and Walter describes the work of the AANC and indicates that the AANC was created to:[14]

> "…develop technologies to help the aviation industry to (1) better predict the effects of design, maintenance, testing, wear and fatigue in the life of an aircraft; (2) develop methods for improving aircraft maintenance technology and practices including nondestructive inspection; and (3) expand general long range research activities applicable to aviation systems."

Initial work at the AANC focused on the validation of inspection technologies as applied to aircraft. Since its inception, the AANC's activities have broadened to include activities in other areas of aircraft structures, including structural integrity analysis, repair assessment, and composite structure assessment. The AANC has also played a role in fostering cooperation between the FAA, airlines, and other air transportation organizations. The AANC has filled a critical void regarding the effectiveness of NDE of aging aircraft fleets.

Recognizing the significance of the VI method, one of the initial tasks of the AANC was to study the reliability of VI.[15] Spencer was charged with this investigation, which is summarized in the following paragraphs.

When one initially considers VI, the visual aspect dominates. The AANC took a broader approach to what "visual" inspection entails. The explicit definition given by Spencer is:

> "Visual Inspection is the process of examination and evaluation of systems and components by use of human sensory systems aided only by such mechanical enhancements to sensory input as magnifiers, dental picks, stethoscopes, and the like. The inspection process may be done using such behaviors as looking, listening, feeling, smelling, shaking, and twisting. It includes a cognitive component wherein observations are correlated with knowledge of structure and with descriptions and diagrams from service literature."

Similar to much of the literature summarized in this literature review, Spencer reports that most research related to VI has been aimed more toward visual search. Spencer reports that these studies have attempted to extrapolate the findings of numerous laboratory experiments to quality assessment systems in various manufacturing industries.

In Spencer's VI investigation, 12 inspectors from 4 airlines were asked to complete 10 different inspection tasks. Data on the inspectors' performances were collected via a number of different media types. First, all inspector activities were videotaped from strategic viewpoints. Second, experimenters took detailed notes regarding both the inspection environment and the inspector's activities. In addition, background data were gathered for each inspector for quantification of inspector attributes. The following paragraphs briefly summarize Spencer's principal findings.

There was a significant difference between inspector traits and personalities. Personal data collected for each inspector included:

- Training
- Visual acuity
- Age
- Previous aircraft experience
- Education level
- Visual Inspection experience
- Visual Inspection experience by aircraft type
- Visual Inspection training

In addition, data were collected for each inspector concerning their general physical, emotional, and mental condition before, during, and after testing. The investigation found that each of these factors appears to have some notable effect on VI reliability. However, no single or small group of factors could be identified as being the "key" to VI reliability.

Spencer also found that the quality of performance on one task was not necessarily a predictor of quality on other tasks. This apparently is related to the fact that the search component, as opposed to the decision component of the inspection process, was the larger contributing factor.

The four factors identified by Spencer as having the greatest correlation with VI performance are:

- Use of job cards
- Thoroughness
- Peripheral visual acuity
- General aviation experience

Although these four factors were specifically identified, Spencer also indicates that eliminating all other factors was not possible.

Another study of VI operations was performed by Endoh, et al., the focus of which was to analyze the capability of Japanese airline inspectors.[16] During the study, a number of Japanese inspectors were monitored and their performance was analyzed over a 3-year period. Although many of Endoh, et al.'s conclusions are applicable only to the VI of aircraft structures, there are some far-reaching implications. Principally, it was noted that a greater majority of defects were located when the inspectors had prior knowledge. Although "prior knowledge" is not defined, it is assumed that it is either previous inspection experience or the use of previous inspection reports. Other secondary factors affecting VI accuracy include distance to target, surface conditions, and crack origin.

A study aimed at understanding and improving VI in general, with specific application to small integrated circuit inspection, was conducted by Schoonard, et al.[17] During the development of this investigation, Schoonard, et al. surmised that VI is controlled by three undeniable facts. First, inspectors try to look at many things at the same time. Second, inspectors are expected to work very fast. Third, inspectors are not very accurate. From these postulates, four experiments were developed to test the capabilities of industrial inspectors. Based on this research, Schoonard, et al. offered many suggestions for the improvement of VI of small integrated circuits, as well as the following general conclusion:

> "It is concluded that even if the optimal level is selected for each variable the accuracy of inspection will not go up dramatically. It appears that if substantial improvement in human inspection accuracy can occur it will depend upon the study of three basic aspects of the inspection system: training, inspection procedures, and apparatus (optics, lighting, etc.)."

An investigation by Jamieson was initiated to study problems occurring during telecommunication inspections.[18] Inspection performance was measured during two different inspection operations: electro-magnetic switch inspection and rack wiring inspection. The test subjects consisted of 24 men, between 19 and 52 years old, and 54 men, between 23 and 60 years old, respectively. Jamieson concluded that older test subjects generally performed better and the VI of telephone racks was more reliable when the inspection was done separately from production operations. In addition, when judgments were made purely from visual stimuli, there were significantly more errors than when bi-sensory cues were required. Furthermore, the one management factor seen to most affect inspection reliability was the lack of a clear definition of tolerance limits for discerning defects. When limits were not clearly defined, inspectors had to rely on their own judgment, which tended to cause greater variations in inspection quality.

Like many other researchers, Spencer and Schurman found, from a reliability study on the inspection of commercial aircraft, that individual inspector differences are a major factor in determining inspection quality.[19] Furthermore, the inspection environment was also seen to influence inspection accuracy. However, no single quality or set of qualities could be identified as being a principal source of error. Rather, the sum total of all factors produced identifiable differences.

As part of a larger investigation to study the capabilities of the mainstream NDE techniques, Rummel and Matzkahnin evaluated the capability of VI.[20] The investigation consisted of visual inspections performed on 4.8-mm-diameter bolt holes in compressor disks with service-induced fatigue cracks of various sizes. The specimens were made of precipitation-hardened stainless steel with the original rough-polished surface. The results of this portion of the study indicated that VI had a 90 percent probability of detection of 7.09-mm cracks.

2.3. FACTORS AFFECTING VISUAL INSPECTION

In this section, information on the influence of various factors on VI reliability is discussed. Although factors affecting VI vary widely, they can be loosely grouped under a few headings. Megaw does this after a thorough review of research on the factors believed to affect VI.[21] Following a summary of Megaw's findings, specific work related to the factors affecting VI is presented.

Megaw outlines a four-category breakdown of the factors that may influence VI accuracy. These classifications are primarily based on the research that has been conducted on visual search/inspection. Megaw points out that the classification of factors into one category or another is somewhat arbitrary as there is much interaction between factors in different categories.

The four categories that Megaw proposes are: subject factors, physical and environmental factors, task factors, and organizational factors. Megaw gives the following listing of factors falling in each category.

Subject Factors

- Visual acuity
  - Static
  - Dynamic
  - Peripheral
- Color vision
- Eye movement
- Scanning strategies
- Age
- Experience
- Personality
- Sex
- Intelligence

Physical and Environmental Factors

- Lighting
  - General
  - Surround luminance
  - Lighting for color
- Aids
  - Magnification
  - Overlays
  - Viewing screen
  - Closed-circuit TV
  - Partitioning of display
  - Automatic scanner
- Background noise
- Music-while-you-work
- Workplace design

Task Factors

- Inspection time
  - Stationary
  - Conveyor paced
- Paced vs. unpaced
- Direction of movement
- Viewing area
- Shape of viewing area
- Density of items
- Spatial distribution of items
- Fault probability
- Fault mix
- Fault conspicuity
- Product complexity

Organizational Factors

- Number of inspectors
- Briefing/instructions
- Feedback
- Feedforward
- Training
- Selection
- Standards
- Time-on-task
  - Rest pauses
- Shift
- Sleep deprivation
- Social factors
  - General
  - Isolation of inspectors
  - Working in pairs
  - Effects on sampling schemes
- Motivation
- Incentives
- Product price information
- Job rotation

In order to more closely parallel the factors investigated in this study, factors thought to affect VI will be grouped in three categories: physical, environmental, and managerial. Research in each of the categories will be summarized in the following sections.

2.3.1. Physical Factors

Physical factors are those factors that depend on the inspector. There have been a number of studies focusing on these factors. Factors in this category include visual field, peripheral visual acuity, vigilance, rest, intelligence, introversion-extroversion, and attitude. The following paragraphs summarize research in this area.

A study conducted by Johnston attempted to determine the relationship between search performance of static displays and the size of the visual field.[22] To establish this, 5 different measurements were made on 36 male test subjects: visual acuity by the American Optical Sight Screener, visual field size by measuring peripheral vision acuity, two search tasks where inspectors were asked to identify specific visual targets in a group, and the Air Force Speed of Identification Test. This investigation was developed from previous research that indicated that when given adequate inspection equipment, the largest improvements in performance could be gained through training in speed of recognition. As a result, determining which factors affect search performance has inspector selection and training implications. As anticipated, it was found that people with relatively large visual fields can find targets with greater speed than people with relatively small visual fields. Furthermore, it was found that age was not a good predictor of search performance. The correlation between right-eye visual acuity and search performance was also found to be minimal. It should be pointed out, however, that the subjects used in this study were all selected because of their above average visual acuity and generalization to those with below average visual acuity may not be valid.

Erickson conducted an investigation designed to determine the relationship between peripheral visual acuity and search time.[23] Sixteen male subjects between the ages of 23 and 41 performed searches with three different object densities and two classes of objects. Erickson found that the subjects' peripheral acuity and search time scores had significant correlation when the peripheral visual acuity was measured at 0.063 and 0.084 rad from the visual axis with 16 or 32 objects. However, when the peripheral acuity was measured at 0.10 rad with 48 objects, the relationship was not found to be significant.

An investigation by Ohtani concluded that VI is composed of three different types of saccadic eye movements.[24] The first, involuntary eye movements, occur when an inspector is tracking a visible line and the eye deviates from the known path. Second, inspectors will engage in voluntary eye movement where the eye tracks from point to point without straying off course. The final type of saccadic eye movement is fixation. During fixation, the inspector focuses on a single point for an extended period of time without deviation. The possible interaction of these three types of eye movements illustrates the complexity of all visual tasks.

Many jobs, including some inspection operations, are performed for extended periods of time without a substantial change in stimulus. As Fox states, "[The] drop in [vigilance] is commonly referred to as 'boredom'."[25] Although the primary reason for registering signals from the environment is to ascertain what is happening, stimuli are not used solely for that purpose. Part of the signal is used to stimulate a part of the brain known as the reticular activating system. This part of the brain determines the degree to which the inspector needs to be alert. Thus, in a tedious inspection environment with little stimulation, an inspector can be bored to the point of needing to sleep. To illustrate this, Fox briefly describes a study in which a group of highly motivated radar scanners showed as much as a 70 percent drop in efficiency when their shift lasted for more than 30 minutes. To combat "boredom", Fox recommends that additional artificial stimuli be generated (e.g., background music) to stimulate the reticular activating system when other significant stimuli are not present.

Poulton summarizes much of the research on the factors affecting vigilance.[26] In brief, the findings of his investigation indicate that external arousal, or arousing stress, actually increases performance in vigilance tasks. This is very clearly explained in an example given by Poulton:

> "When sonar was first introduced into the Navy during World War II, the sonar man was given special treatment in recognition of the importance of his job. He was placed with his sonar set in a comfortably warm cabin well away from distraction. The lighting in the cabin was reduced, to enable him to see his sonar display well.
>
> The sonarman knew, as did everyone else on the ship, that their lives depended upon him detecting an enemy submarine before it launched a torpedo at the ship. Yet in spite of this, the sonarman was found asleep over his sonar set when the officer of the watch happened to look into the cabin.
>
> The fall in vigilance induced by having to watch and listen carefully all the time was facilitated by the isolation, the comfortable warmth, and the low level of lighting. If the sonarman stuck conscientiously to his job, it was difficult to avoid falling asleep."

Vigilance is also affected by many other factors beyond those mentioned in this brief excerpt. However, it seems clear that the operator's environment must supplement mundane vigilance tasks with external stimuli. The stimulus can be in many forms.

Similar to Fox's findings, Poulton notes that physical environments that require the operator to consciously adjust to the situation add sufficient stimuli to increase vigilance. Evidence to this fact has been found by subjecting experiment participants to a 5-Hz vertical vibration while monitoring vigilance. In the same respect, physical exercise has been found to increase vigilance.

At the initiation of an investigation by Colquhoun, there had been very little experimental work done to determine the effect of rest breaks during inspections.[27] Colquhoun's aim was to obtain factual evidence concerning this by monitoring inspectors while they performed industrial inspections with and without short rest breaks. The findings were conclusive that the overall efficiency for the experimental task was high for all subjects, but those inspectors who had a 5-min rest after the first half hour of inspection showed a markedly increased efficiency in the second half hour over those without the rest break.

Many studies have found that sleep deprivation impairs performance of signal detection tasks. Deaton, et al. determined the cause of this performance degradation by using signal detection theory.[28] The principal advantage of this theory is that it provides a means for determining the causes of impairment. To investigate the source of impairment, Deaton, et al. asked 12 subjects to perform a vigilance task 3 separate times: during a practice session, after normal sleep, and after 33 h of sleep deprivation. This setup allowed two important issues to be investigated. First, the effect of sleep deprivation was easily determined, and second, the deterioration of performance from the beginning to the end of a session could also be investigated. It was concluded that the major effect of sleep deprivation was a clear reduction in the intrinsic capability of the test subjects and not increased caution in decision making. By using signal detection theory, Deaton, et al. contended that they could prove this while previous researchers had only been able to speculate. In addition, it was found that a decrease in sensitivity over the duration of the experiment was present in both the normal sleep and sleep deprived groups. Although these test results are based on a purely auditory task, the authors indicate that similar reductions in sensitivity due to sleep deprivation could be expected in other types of vigilance. Similarly, reductions in performance over time can be expected during the course of other lengthy vigilance tasks.

Previous research has demonstrated that there is a positive relationship between target detection and both field independence and intelligence. A study by Lintern tested the generality of those relationships.[29] It should be pointed out that field independence is defined by Lintern as "the ability to separate a figure from an embedding context." Tests were completed by 120 U.S. Army male personnel under age 35. Testing consisted of test subjects being asked to detect stationary camouflaged mannequins in a medium-density jungle. Although many previous studies had concluded that there was a positive relationship between field independence, intelligence, and target detection, the study by Lintern failed to confirm this. One hypothesis for this difference is that the Lintern investigation imposed a time constraint on the test subjects that other investigations had not. Another explanation offered by Lintern is that other investigations may have used subjects who were relatively high in field independence. If this was the case, test results may skew further generalizations.

In a review of physical factor research for ultrasonic, in-service inspection, Pond, et al. acknowledge the applicability of one of the most widely studied personality dimensions—introversion-extroversion.[30] They also identify some other personality dimensions that should be included in future studies. These include:

- Field dependence/independence
- Locus of control
- Personality type
- Achievement motivation

Furthermore, they cite that a completely separate set of individual variables exist related to operator skills and abilities that have a notable affect on VI reliability. In addition, the accuracy with which an inspector can assess the level of their own skills and abilities, regardless of the actual level, has also been shown to be a factor. The authors also indicated that there are four cognitive factors found to result in a 400 percent difference in inspection quality. The four factors are:

- Development and testing of explicit hypotheses
- Avoidance of premature conclusions
- Application of if-then logic

- Not disregarding evidence

A study completed by a multi-discipline research team (Mitten, et al.) tried to identify the principal factors affecting VI as related to manufacturing inspection.[31] Of particular importance, this study found that the most prominent factor affecting VI quality was the attitude of the inspector. For the inspection task used in this investigation, it was found that the inspection rate could be increased by 300 to 400 percent with a considerable improvement in the quality of the job being done by simply providing a better working environment. In this investigation, management was positive that the factor most affecting inspector attitude was the wage rate. To their surprise, workers were most unhappy with a much simpler aspect of the work – the chairs.

2.3.2. Environmental Factors

The environmental factors affecting VI are manifested from the object being inspected. There have been a number of studies that have focused on environmental factors. Some of these include: task complexity, fault (or flaw) size and number, lighting, and visual noise. The following paragraphs summarize research in these areas.

Gallwey and Drury conducted an investigation focused on one particular type of visual inspection task complexity — the number of potential defects.[32] The authors point out that the number of potential defects is one of the primary differences between laboratory investigations and actual inspections. As such, early investigations showed that inspections with only a single defect type gave enhanced defect detection and indicated that the inspection reliability decreases with each additional fault type. However, it is pointed out that the reliability of inspections with large numbers of fault types can potentially be increased by allowing longer inspection times. Gallwey and Drury also noted two other complexity factors that affect inspection reliability. The first of these is the number of separate points that must be inspected, and the second is the complexity of the standards by which defects must be measured. Although these issues were recognized, they were not intended to be the focus of their investigation. For this study, Gallwey and Drury used 66 subjects to investigate task complexity: 18 industrial inspectors and 48 students. All subjects had 20/20 vision (corrected if necessary) and it was concluded that there was no statistical difference between the industrial inspectors and the students in so far as this test was concerned (i.e., differences in performance of actual industrial inspection tasks were not inferred). From their testing, the investigators found that the number of possible fault types did have an influence on both speed and accuracy of measurements. Furthermore, it was found that the decrease in accuracy after increasing the number of fault types from four to six was not as large as the decrease in accuracy between two and four faults, indicating that although there may be some continued decrease in accuracy with increased fault-type numbers, the accuracy may become asymptotic. It was also concluded that the size of the fault had a significant impact on the search component of VI. For example, as the size of the fault increased from "tiny" (3 mm) to "huge" (7 mm), the probability of a search error decreased by more than 50 percent. However, the change in inspection speed was not seen to be as dramatic for the various fault sizes.

A literature review by Faulkner and Murphy found that a large body of research on lighting for visual tasks focuses only on the quantity of light.[33] The results of these studies are quite varied. The authors cite studies indicating that inspection quality continues to increase with light levels up to 10,800 lux, while others have found that inspection quality plateaus at light levels around 540 lux. Faulker and Murphy also note that very little research has been completed concerning the quality of light. This was the focus of their investigation. Although direct recommendations for improving the VI of highway structures are not offered, the authors do describe 17 different types of lighting systems that inspectors could employ under various conditions. These types of light include: crossed polarization, polarized light, shadow-graphing, spotlighting, etc.

A study by Mackworth was initiated to determine how a visual detection task was affected by visual "noise."[34] Twenty test subjects were asked to fixate on a point on a screen. Alphabetic letters were then flashed on the screen and the test subject was asked to determine if the three letters, located in predetermined locations, were the same. The testing program considered two variables. First, the physical proximity of the subject and second, visual "noise" created by adding extra alphabetic characters on the screen. Mackworth found that although there was some decline in performance with an increased visual arc, it could be considered negligible.

However, the addition of visual “noise” significantly decreased performance regardless of the size of the visual arc.

In an investigation by Sheehan and Drury, a method for combining classification information using Signal Detection Theory was examined.[35] Signal Detection Theory, described previously, is concerned with the types of information with which an inspector would be confronted. The inspector must, in basic terms, distinguish between two groups of objects: “good” and “faulty.” These two groups can be differentiated from each other by various visual signals indicating the presence or lack of defects. However, the author theorizes that one problem associated with VI is that the defect signals are not the only signals present. There are three principal types of extraneous visual signals that are present. The first is in the form of accumulated dust and debris. Secondly, surface irregularities that would not be considered defects must be constantly registered and processed. Finally, random nerve impulses from the nervous system introduce a set of pseudo-stimuli that must also be processed. These three types of stimuli add to the complexity of any inspection and are stimuli that must constantly be filtered out of the decision-making process. Note that visual noise is imposed equally on both the “good” and “faulty” products. Therefore, the effectiveness of the inspector is dependent on the relative magnitude of the defect signals compared to the extraneous visual signals. This dependency on relative magnitudes of signals likens the inspector to a statistical decision maker who must process all incoming information and make informed, judgment-based decisions. One principal problem with this discrimination process is that the inspector is expected to formulate and draw a line in the magnitude of all stimuli to discriminate between “noise” and faulty products. Since each inspector does this internally, a degree of inconsistency is inherent in VI. To test their theory, Sheehan and Drury developed a controlled inspection investigation with various numbers and types of defects to determine the effectiveness of inspection operations. The experimenters also varied some of the environmental conditions to study the effect of the environment on inspection effectiveness.

Of particular interest from the Sheehan and Drury investigation is that no difference in inspection effectiveness could be attributed to learning (i.e., familiarity with the investigation), illumination, or visual acuity. In addition, the investigators found that the inclusion of either one or two defects had no effect on inspection effectiveness. On the other hand, it was determined that prior knowledge of defect types and inspector age was statistically significant. From these results, Sheehan and Drury recommend that inspectors be regularly "calibrated" to ensure their correct assessment of defect stimuli. In addition, greater attention should be paid to the criterion for discriminating defect stimuli. Finally, they conclude that information regarding all known potential defect types should be provided to all inspectors so that they are informed as to the types of defects to be expected.

2.3.3. Management Factors

Managerial factors affecting VI reliability are those factors dependent on the inspection process. These would include: work duration, inspection time allotted, and social pressures. Literature on this group of factors is summarized in the following paragraphs.

The goal of an investigation by Noro was to develop and evaluate a method for simultaneously recording an inspector and the object being inspected.[36] This method was then to be used in an actual industrial inspection application. The data could then be used to suggest ways to improve VI accuracy. The monitoring technique basically consists of videotaping an inspection operation simultaneously from two different angles. The two viewing angles allow both the visual and tactile search mechanisms to be studied. By simultaneously recording both the eye and hand movements, Noro was able to ascertain how the two senses work together. Although the system developed by Noro may have little application in bridge inspection, the suggested improvements to inspection operations may apply to inspections of all types. Noro's primary conclusion is that most inspection errors can be attributed to too little inspection time. On average, when errors in inspection were observed (either missed flaws or false reports), the inspector spent less time than when "good" inspections were completed.

As Thomas and Seaborne point out, most, if not all, investigations on the factors affecting inspection accuracy are completed in the sterile environment of the laboratory and, therefore, the direct and indirect "social" pressure placed on inspectors is systematically removed.[37] In this regard, the inspector is free to set their own expectation levels for performance and results. In reality, however, there are many forces affecting the performance of the inspector regardless of his actual capabilities. Thomas and Seaborne cite as an example the situation where a production department informs an inspector of what they anticipate the rejection rate will be. Knowledge of this information may guide an inspector to achieve the anticipated rejection rate regardless of the quality of the products he is inspecting.

A study by Lion, et al. was initiated to determine the effect of a number of factors on a simulated industrial VI task.[38] Among the variables identified as possibly affecting VI proficiency are:

- The visual display of the materials to be inspected
- Speed
- Rest
- Working singly or in pairs
- Noise
- Environmental conditions

By maintaining a constant inspection environment, keeping the test segments relatively short, and maintaining a constant rate of inspection, the number of variables was reduced to two: arrangement of materials and completion of work alone or in the company of others. From their study, Lion, et al. determined that working with others improves performance of VI tasks.

2.4. SELECTION AND TRAINING OF VISUAL INSPECTORS

It seems widely thought that one factor affecting VI proficiency is the inspector. The proficiency of the inspector can be reduced to two topics: the initial inspector selection and subsequent training. Issues related to the selection and training of visual inspectors are presented in the following paragraphs.

Gallwey developed a test program to determine what types of evaluation tests best predict future inspector performance.[39] He indicates that previous researchers have attempted the same type of investigation with limited success. Because of the lack of positive correlations, those researchers have concluded that the selection of inspectors is nothing more than a “crap shoot.” Gallwey likens this to the training “cart” being in front of the selection “horse.”

In Gallwey's experimental program, 10 selection tests were used to evaluate the 66 test subjects (48 university students, 18 industrial inspectors). The 10 tests are:

- Visual acuity
- Harris Inspection Test
- Eysenck personality inventory
- Questionnaire on mental imagery
- Card sorting
- Intelligence (IQ)
- Embedded Figures Test
- Single-fault type inspection
- Lobe size
- Short-term memory

After being given the selection tests, the subjects were then asked to complete an inspection task. Using multivariate analysis, Gallwey was able to formulate the following conclusions:

- There was no statistical difference between the university students and the industrial inspectors.
- The single-fault type test was a good predictor of multiple-fault type tasks.
- VI performance is significantly affected by lobe size.
- For geometrical tasks, the Embedded Figures Test was a good predictor of inspector performance.
- Inspectors with good mental imagery skills tended to perform more poorly.
- In the absence of other good predictors, the concentration subset of the Wechsler Adult Intelligence Scale (WAIS) test is a good predictor of performance.
- The Eysenck test of extroversion and the Gordon test of Mental Imagery Control are also acceptable predictors.

To illustrate the real difficulties in selecting proficient visual inspectors, a study by Tiffin and Rogers is presented.[40] The test bed for this investigation was a tin plate plant where 150 female inspectors assessed the condition of 150 pre-selected sheet specimens. The 150 sheets had been previously categorized into those containing no or minor surface blemishes, three classes of different appearance defects, and sheets with a weight defect. Each subject inspected all 150 plates while being timed. After compilation of the inspection results, each subject was given a battery of psychological and physical tests for the purpose of determining inspection accuracy correlations. From the correlation investigation, four factors were found to best correlate with inspection accuracy. First, the subjects must have passed a series of visual tests and a vertical balance test. Second, the inspectors should be at least 1.57 m tall. Third, the inspector should weigh at least 55 kg, and, finally, have a minimum amount of hand precision.

The wide use of VI as the first-line inspection prompted Riley, et al. to survey and evaluate sources of VI training that exist in the United States.[41] While the intent of the survey was to identify possible sources of training for aircraft industry personnel, searches were not limited to that field. While VI is the most commonly used type of NDE, common practice has been that VI is learned concurrently with other NDE techniques or simply from on-the-job experience. Institutions that identified VI as a specific objective in this survey were then evaluated further. From this study, it was found that although many institutions list VI as a course objective, the coverage is not sufficient to be considered formal training. In addition, those that did have an in-depth course on VI were so specialized in their respective fields that outside applicability was minimal.

Finally, a study completed by Chaney and Teel was initiated to study the effect of training and visual aids on inspector performance.[42] This study consisted of 27 experienced inspectors divided into 4 statistically equal groups. Each group was then tested twice. The first test was completed with only minimal information given to the inspectors. The second test was completed under different auspices. One group was not altered (i.e., the control group), the second was given a 4-hour training session, the third was given visual aids, and the fourth was given both the training and visual aids. Four clear findings were outlined: "(a) use of training alone resulted in a 32 percent increase in defects detected, (b) use of visual aids alone resulted in a 42 percent increase, (c) use of both resulted in a 71 percent increase, and (d) the performance of the control group did not change."

Although not intended to be all-inclusive, the literature summarized above provided a strong foundation for the remainder of the investigation. The literature review focused on issues specifically related to VI in highway structures, VI in other industries, the influence of factors on reliability, and issues related to the selection and training of inspectors.

3. SURVEY OF STATES

The survey of current policies and practices of VI had three main objectives. The first objective was to compile a state-of-the-practice report for bridge inspection, particularly as it pertains to VI. The second objective was to gather information on bridge inspection management and assess how inspection management may influence the reliability of inspections. The final objective was to gather data about the current use of NDE technologies and to attempt to identify current and future research needs. The target participants for this survey included State DOTs, county DOTs from Iowa, and select bridge inspection contractors. In general, the same questionnaire was used for each of the three participant groups. Where slight modifications to the questions were required, these are discussed in the Survey Results section of this report.

The survey conducted by the NDEVC is described first, including a brief description of the questionnaires, target groups, and participation. Survey results are then presented in a question-by-question format with a short discussion of the results. Finally, a summation is presented highlighting significant findings from the survey.

3.1. SURVEY PARTICIPATION

Fifty-two surveys were sent to the FHWA State Division Bridge Engineers to be completed in coordination with the State bridge inspection manager. Forty-two responses were received from State DOTs, for a response rate of 81 percent. To gain a more complete understanding of bridge inspection at all levels, and due to the researchers' familiarity with the Iowa county system, the 99 Iowa counties were targeted for a county-level questionnaire. Seventy-two county responses were received, for a response rate of 73 percent. For simplicity, all references to counties, county responses, or county DOTs (or other similar references) will refer to Iowa counties, Iowa county respondents, or Iowa county DOTs (or similar references). Finally, 15 bridge inspection contractors were targeted for the contractor survey, with 6 responses received (40 percent response rate). The combined response rate for the three target groups was 72 percent.

3.2. SURVEY DESCRIPTION

The primary questionnaire developed for this study was targeted toward the State DOTs. This State questionnaire was subsequently modified and used for both county and contractor surveys. As the county DOTs are also agencies responsible for bridge inspection and maintenance, only minor modifications were necessary for two of the questions. More significant modifications were required for the contractor questionnaire, with most of these modifications related to the relationship between the consultant and the bridge owner. For reference, the State, county, and contractor questionnaires are presented in Appendix A in Volume II.

Each questionnaire contained three sections. Section 1 dealt with the composition of the bridge inspection team, Section 2 dealt with the possible impact of administrative requirements on VI, and Section 3 dealt with current and future use of NDE techniques. A total of 24 questions were asked in the State and county questionnaires, with 7 questions in Section 1, 11 questions in Section 2, and 6 questions in Section 3. The contractor questionnaire used the same basic format; however, three questions that had no relevance to contractors were removed.

Sample topics for Section 1 included contractor use (and in what situations), the size and experience of the inspection team, and involvement of registered Professional Engineers as inspectors. Sample topics for Section 2 included inspection unit size, inspector training requirements, suggested policy changes, vision testing requirements, and the number of bridges inspected annually. Sample topics for Section 3 included inspector certifications, overall NDE techniques used (also those used most frequently), NDE techniques no longer used, and areas for possible future research.

3.3. SURVEY RESULTS

Results from the questionnaires are presented in a question-by-question format. The questions are repeated as they were given in the State questionnaire. Notes indicating changes for the county and contractor questionnaires are also shown. The motivation behind each question and the response percentages for each question begin each discussion, followed by a summary of the responses. Where appropriate, comments are also included that highlight specific responses.

3.3.1. Section 1 – Composition of Bridge Inspection Team for Visual Inspection

This section outlines the seven questions and responses that address the composition of the bridge inspection team for VI. The goal of this series of questions was to assess factors related to the individual inspectors performing bridge inspections.

Q1.1. ***State DOT:*** **Are your bridge inspections completed by Department of Transportation (DOT) staff or by outside contractors?** ***(circle one)***
Only DOT staff **Only Contractors** **Both DOT staff and Contractors**

County DOT: **Are your bridge inspections completed by county personnel, State personnel, or by contractors?** ***(circle one)***
County Personnel **State Personnel** **Contractors** **Blend of three**

Contractors: **Not asked.**

The purpose of this question was to determine the distribution of the different types of inspectors used by bridge owners to perform their bridge inspections. A 100 percent response rate was obtained from both States and counties. Results are presented in figure 1. The State survey indicates that in more than 90 percent of the cases, both State personnel and contractors perform inspections (38 responses). Three State DOTs responded that inspections were performed completely in-house, and one State DOT indicated that contractors were used exclusively. Eight State respondents provided additional information beyond what was solicited. Seven of these eight indicated that State personnel were used for the State inspections, but contractors were used for inspections below the State level. Another State indicated that the different divisions within the State had the authority to determine contractor use, with some divisions using contractors and other divisions using State inspectors.

County DOT responses to this question yielded a different usage distribution. Twenty-four percent of respondents indicated that only county personnel were used to perform inspections, while 51 percent indicated that contractors were used. The remaining 25 percent indicated that a mix of county, State, and contractor personnel were used. Of those indicating a mix of county, State, and contractor personnel, 14 of 18 further clarified their response to indicate that a specific combination of county and contractor personnel was used.

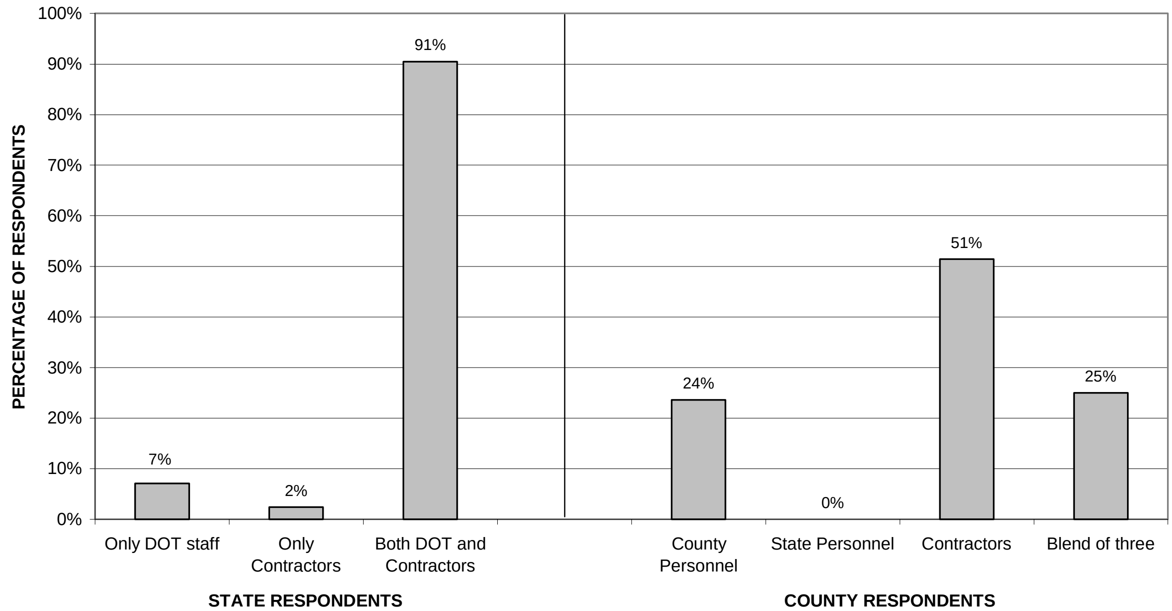


Figure 1. Inspector sourcing.

Q1.2. *State DOT:* If the answer to Question Q1.1 is "Both DOT staff and Contractors," in what situations are contractors utilized? *(mark all that apply)*

County DOT:* If non-county personnel are used for bridge inspections in Question Q1.1, in what situations are they involved? *(mark all that apply)

Contractors:* What types of bridge inspection services does your company perform? *(mark all that apply)

Answer choices:

_____ Routine Inspections
_____ Fracture-Critical Inspections
_____ Advanced NDE techniques
_____ Complex structures
_____ Structures with complex traffic control situations
_____ Underwater Inspections
_____ Other *(please describe below)*

The purpose of this question was to determine what situations lead to the use of a contractor to perform an inspection. All of the State DOT respondents that indicated "Both DOT staff and Contractors," also referred to as "partial contractor usage," answered this question, as did all county DOT respondents who indicated "Blend of three," also referred to as "use of outside assistance" or "partial contractor usage." Unfortunately, the wording for the county question was not precise. It was the intent of the question to exclude respondents who used single-source inspections, either all inspections by county staff or all inspections by contractor. To maintain the intent of the question, only responses indicating partial contractor usage in Question Q1.1 were considered. Contractors were also asked in what situations their services are used, and all six responded to this question.

Figure 2 presents a summary of the inspection types used by State DOTs, county DOTs, and contractors. Eighty-five percent of the State responses indicated that contractors were used for Underwater Inspections. In addition, 59 percent, 54 percent, and 67 percent of States responded that contractors were used for Routine Inspections, Fracture-Critical Inspections, and complex structures, respectively. Seventy-eight percent of counties and all of the contractors indicated that contractors were used for Routine Inspections. Fracture Critical Inspections and complex structures were also listed by 67 percent of counties and 83 percent of contractors. Some of the differences between State, county, and contractor respondents include the use of contractors in complex traffic control situations. Eighty-three percent of contractors, while only 39 percent of States and 6 percent of counties, indicated that contractors were used to inspect in complex traffic control situations. Another difference observed between State and county responses was that Underwater Inspections were listed as being performed with contractor assistance by about half as many counties (44 percent) as States (85 percent). This may have resulted from the relatively small number of county roads in Iowa that use substructures requiring Underwater Inspections. Some of the "Other" write-in responses listed by multiple respondents included: *contractors used below State level* (seven State respondents), *moveable bridges* (two State respondents), *ultrasonic testing of hanger pins* (two State respondents), *when behind schedule* (two State respondents), and *scour analysis* (two county respondents).

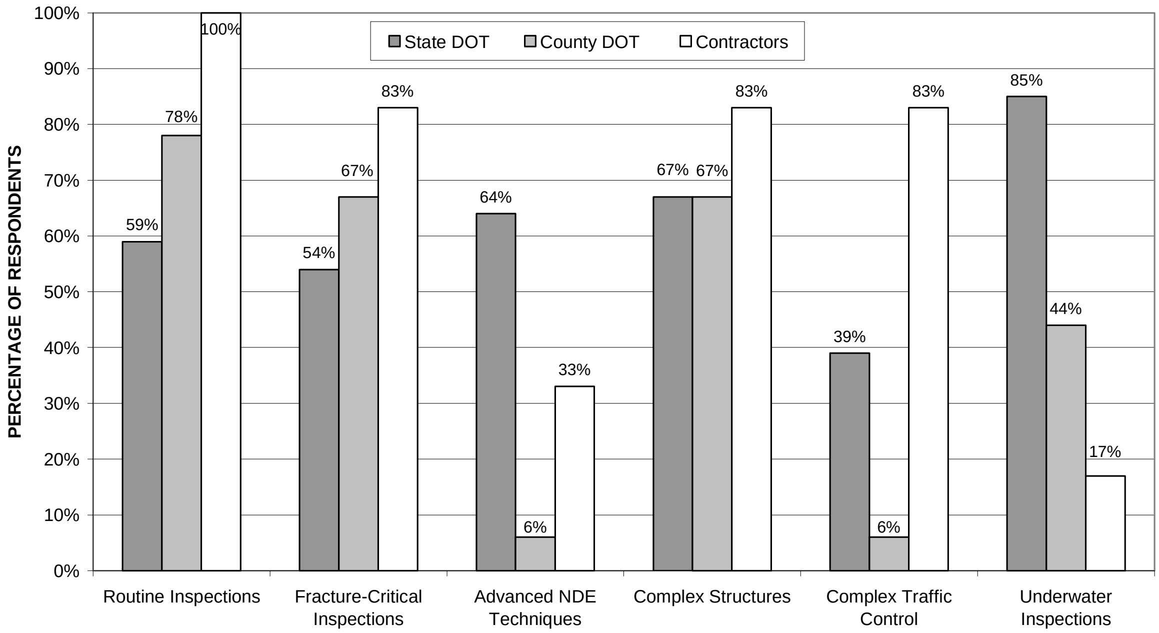


Figure 2. Inspection situations where partial contractor services are used.

Q1.3. *State DOT, County DOT, and Contractors:* For the following hypothetical bridge, how many people would make up a field inspection team (excluding traffic control personnel), and how much time (in man-hours) would be budgeted?

Twenty-year-old, two-span bridge carrying two-lane road (medium ADT) over a small creek, maximum height above the creek is 20 ft.
***Superstructure*: Steel, four-girder superstructure (rolled shapes); welded flange cover plates; concrete deck.**
***Substructure*: Concrete abutments, a single three-column concrete pier (with pier cap) out of the normal watercourse.**

People: __________
Man-hours: __________

The purpose of this question was to compare manpower levels and time budgets for a sample bridge inspection. All State respondents and 90 percent of county respondents answered this question. The average response for the manpower level ranged from 1.8 to 2.2 people. The average State and county time budgets were 4.8 and 4.2 man-hours, respectively. The average contractor time budget was 22.3 man-hours, however this estimate probably includes report preparation time that was probably not included in the State and county estimates. A summary of responses is provided in table 3. Note that this table also includes the reported ranges and standard deviations of responses, illustrating the organizational differences between individual DOTs.

Table 3. Staff budget and man-hours for bridge described in Question Q1.3.

	People			Man-Hours		
	Average	Standard Deviation	Range	Average	Standard Deviation	Range
State DOT	2.0	0.57	1-4	4.8	3.7	0.5-16
County DOT	1.8	0.69	1-4	4.2	6.1	0.5-32
Contractors	2.2	0.41	2-3	22.3	19.4	4.0-48

Q1.4. ***State DOT, County DOT, and Contractors:*** **What are the minimum, maximum, and typical number of personnel that would make up a bridge inspection team (excluding traffic control personnel)?**

Minimum: __________
Maximum: __________
Typical: __________

The purpose of this question was to determine information about the size of the inspection team. All State and contractor respondents and 93 percent of county respondents answered this question. The State responses ranged between 1 and 13 inspectors. County responses ranged from one to five inspectors and contractors ranged from two to six inspectors. Five State respondents and 22 county respondents indicated that their bridge inspection teams would consist of only one person. The average "Typical" response from the State DOTs was 2.0 people. The average "Typical" response for counties was 1.7 people, and for contractors it was 2.5 people. A summary of the responses is presented in table 4.

Q1.5. ***State DOT, County DOT, and Contractors:*** **Estimate the percentage of bridge inspections completed with a registered Professional Engineer (PE) on-site?** ***(circle one)***

0-20% 21-40% 41-60% 61-80% 81-100%

The purpose of this question was to determine the frequency of presence of a registered PE on site during bridge inspections. All State and contractor respondents and 96 percent of county

Table 4. Minimum, maximum, and typical number of personnel on a bridge inspection team.

	Minimum	Average Minimum	Average Typical	Average Maximum	Maximum
State DOT	1	1.6	2.0	3.9	13
County DOT	1	1.4	1.7	2.7	5
Contractors	2	2.2	2.5	5.5	6

respondents answered this question. As shown in figure 3, responses were clustered near the extremes of 0 to 20 percent and 81 to 100 percent. About 50 percent of the States and counties indicated a PE was on site for between 0 to 20 percent of inspections. Alternatively, about 25 percent of States and 30 percent of counties indicated that PEs were used on site between 61 and 100 percent of inspections. A much higher percentage of contractors (83 percent) indicated the use of PEs on site between 81 and 100 percent of the time.

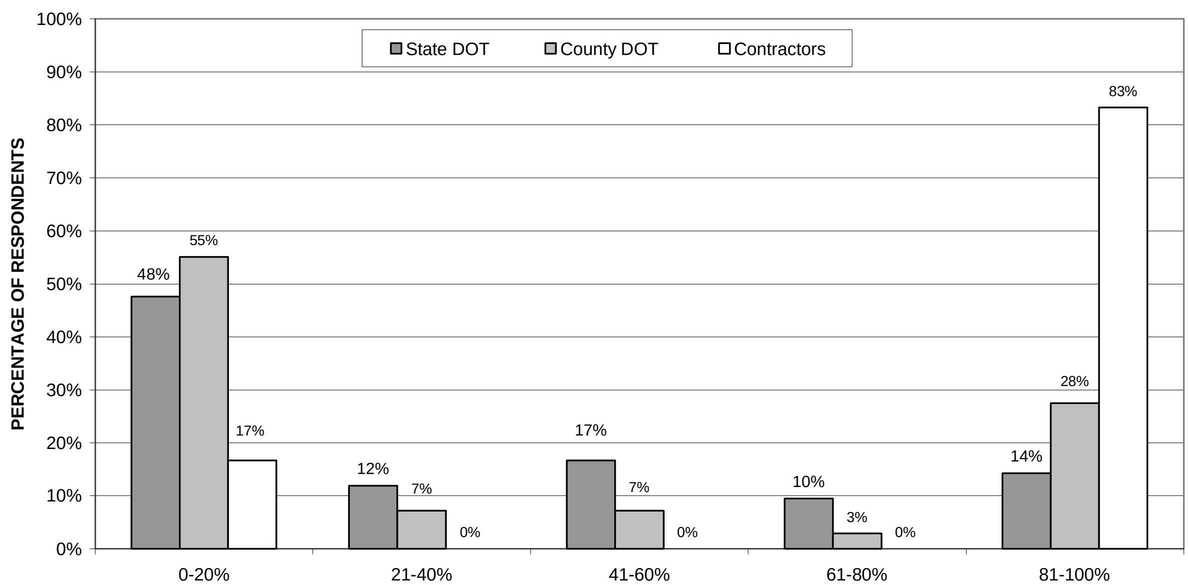


Figure 3. Inspections completed with PE on site.

Q1.6. *State DOT, County DOT, and Contractors:* When a PE is included as part of the on-site inspection team, what conditions would dictate his/her presence?

The purpose of this question was to determine under what conditions PEs were used on site during bridge inspections. Forty-one State respondents, 60 county respondents, and all 6 contractors answered this question. Due to the variability of the 107 write-in responses, some response fitting was used to present the responses in a series of 10 categories. The grouped responses are summarized in table 5. For State and contractor respondents, the most frequently cited condition for having a PE on site was that this was a normal part of the bridge inspection team (17 responses). In categorizing these data, many responses included comments indicating that PEs were part of inspection teams by coincidence, thus implying that some inspection teams in those 17 States may not have PE members. The most frequently indicated response for county respondents, and the second most frequently indicated response for State respondents, was that the PE is present to follow-up from a previous Routine Inspection that indicated the need for an assessment of specific damage or deterioration.

Table 5. Situations causing on-site PE presence.

		State DOT	County DOT	Contractors
A.	PE is normal member of inspection team	17	11	5
B.	Follow-up from previous Routine Inspection (assess damage/deterioration)	14	26	—
C.	Random presence/no special reason given	7	7	—
D.	Fracture-Critical Inspection	4	10	—
E.	Complex structures	4	5	1
F.	Underwater Inspection/Scour Inspection	4	5	—
G.	Critical-condition structure (poor condition, road closure considered)	3	13	—
H.	Complex NDE	3	—	—
I.	Workload permitting/inspections behind schedule	2	2	1
J.	Inspection complexity	—	1	1

Q1.7. ***State DOT, County DOT, and Contractors:*** **Please indicate the average number of years of experience in bridge inspection at each of the following positions.** ***(circle the appropriate responses)***

<u>Team Leader:</u>

0-5 years & PE	**5-10 years**	**More than 10 years**

<u>Other Team Members:</u>

0-5 years	**5-10 years**	**More than 10 years**

The purpose of this question was to determine the typical experience level of bridge inspectors. All State and contractor respondents and 92 percent of county respondents answered this question. Figure 4 shows the distribution for both team leaders and other team members. As expected, team leaders generally have more experience than other team members. Approximately 10 percent of State and county respondents indicated that their team leaders had an average of 0 to 5 years of experience and a PE license. Three States indicated that, on average, the other team members had more experience than team leaders. Contractor responses were generally similar to State and county responses, except that all contractor responses indicated that the other team members had less than 5 years of experience.

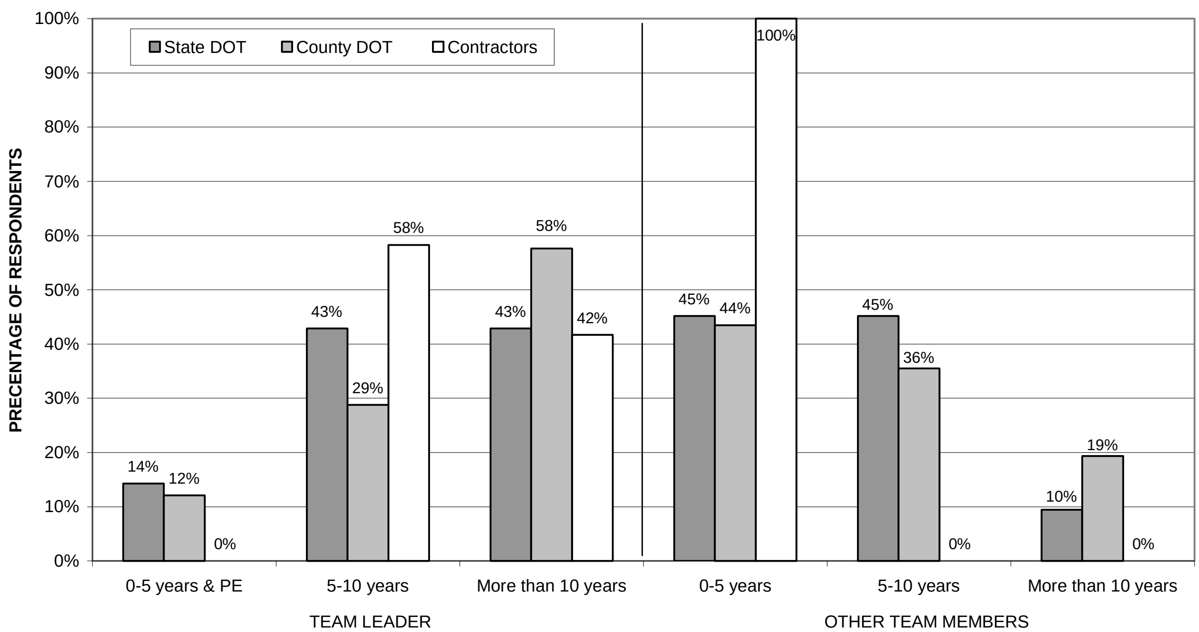


Figure 4. Years of experience for bridge inspectors.

3.3.2. Section 2 – Impact of Administrative Requirements on Visual Inspection

The following section outlines the 11 questions and responses from Section 2, which assesses the impact of administrative requirements on VI. The purpose of this series of questions was to assess how management decisions affect bridge inspections.

Q2.1. ***State DOT and County DOT:*** **If additional resources were made available for bridge inspection, please indicate how you might allocate those additional resources (for example, increased time per inspection, increased use of NDE methods, increased use of bridge inventory management software, etc.).**

Contractors: **Not asked**

The purpose of this question was to qualitatively identify the most critical need not being met by current bridge inspection programs. All State respondents and 58 county respondents answered this question. Table 6 summarizes findings from this question. As shown in the table, increased use of NDE and increased personnel were the most frequently cited need areas for additional resources by State respondents, with 15 responses each. The question may have been slightly leading by presenting three sample responses. One of the sample responses for example, increased use of NDE methods, did, in fact, tie for the most frequent response. The other State response listed most frequently, increased personnel, was not presented as a sample response, indicating its relative importance. Similarly, increased equipment (also not a sample response) was the second most frequently cited need by State respondents, and of these 14 responses, 9 specifically mentioned “snooper” inspection vehicles.

Q2.2. ***State DOT, County DOT, and Contractors:*** **Approximately how many bridge inspectors are in your bridge inspection unit?**
1-5 6-10 11-15 16-20 21-25 26-30 31-40 41-50 More than 50

The purpose of this question was to determine the size of inspection units. All State and contractor respondents, and 67 county respondents answered this question. As shown in figure 5, the size of inspection units varies considerably between the three organizational types. County respondents were generally clustered at the smaller end of the scale (mostly 1-10), while contractors were only slightly larger (1-20). Surprisingly, two county respondents indicated

Table 6. Allocation for additional resources.

	State DOT	County DOT
Increase use of NDE	15	20
Increase personnel	15	6
Increase equipment	14	4
Improvements to Bridge Management System	12	23
Increase time per inspection	10	17
Increase training	5	1
Maintenance improvements	2	—
Remote bridge monitoring	2	2
Improve QA/QC	2	—
Perform inspections in-house	2	—
Inspect “bridges” shorter than 20 ft (6.1 m)	—	1
Increase scope of scour surveys	—	1
Improve repair recommendations	—	1

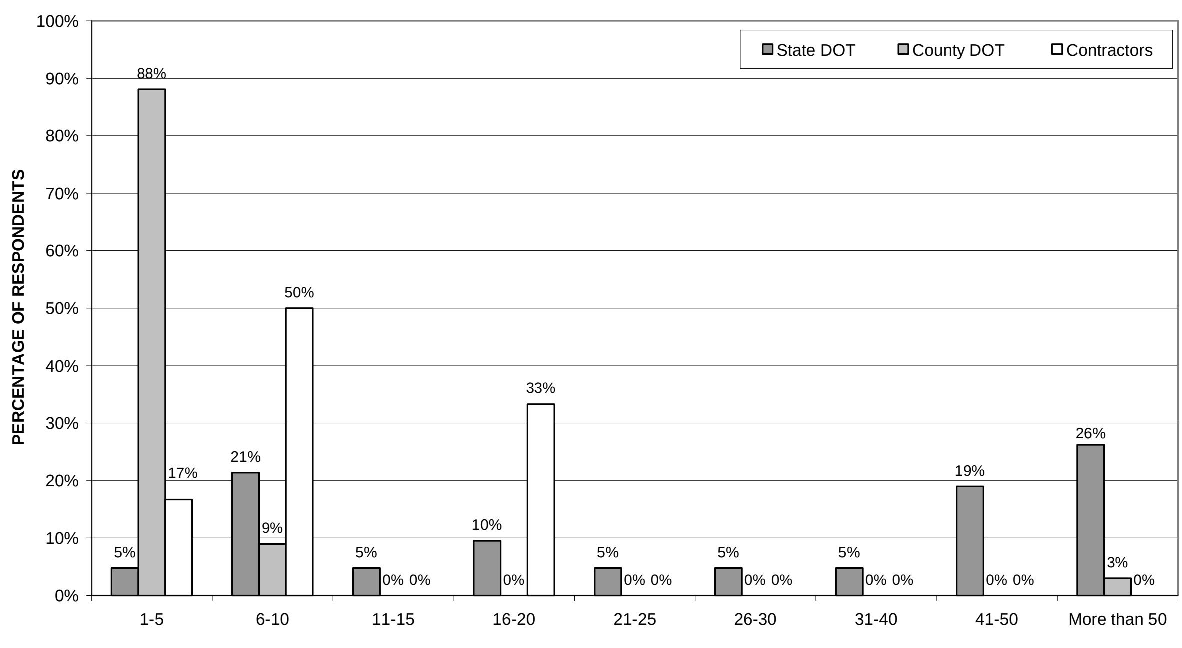


Figure 5. Number of bridge inspectors in inspection unit.

that their inspection units had more than 50 inspectors. State respondents indicated that the sizes of their inspection units were more uniformly distributed, with nearly as many small units as large units. These distributions make intuitive sense. The Iowa counties have land areas that are generally similar in size and terrain. Consequently, Iowa counties have inspection units of approximately similar sizes. On the other hand, the land areas of the States vary considerably, as does the local terrain, requiring different sizes of inspection units.

Q2.3. ***State DOT, County DOT, and Contractors:*** **What type of training do you require of bridge inspectors?** ***(mark all that apply)***

Team Leaders:

_____ Associate's Degree CE Technology
_____ Bachelor's Degree CE
_____ Bridge Inspector's Training Course
_____ Fracture-Critical Inspection Course
_____ Stream Stability Course
_____ Other Training Courses ***(please specify)***

Other Team Members:

_____ Associate's Degree CE Technology
_____ Bachelor's Degree CE
_____ Bridge Inspector's Training Course
_____ Fracture-Critical Inspection Course
_____ Stream Stability Course
_____ Other Training Courses ***(please specify)***

The purpose of this question was to quantify the required types of training for bridge inspectors. Figures 6 and 7 illustrate the distribution of training requirements for the three participant groups. All 42 State respondents, 65 of the county respondents, and all 6 contractors answered this question. As shown in the figures, the most frequently required form of training was the Bridge Inspector's Training Course, required by more than 90 percent of State and county respondents. In addition, there were more training requirements imposed on team leaders than on other team members. Further discussion of training and certification is made in Question Q3.2.

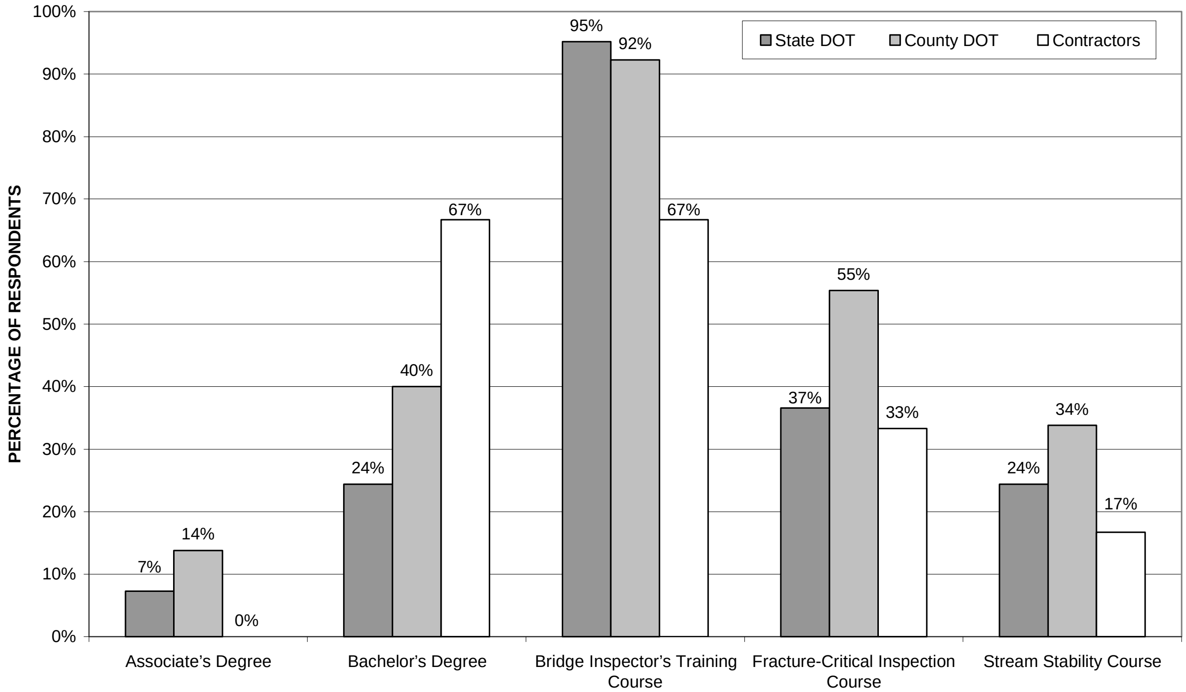


Figure 6. Required training – Team leaders.

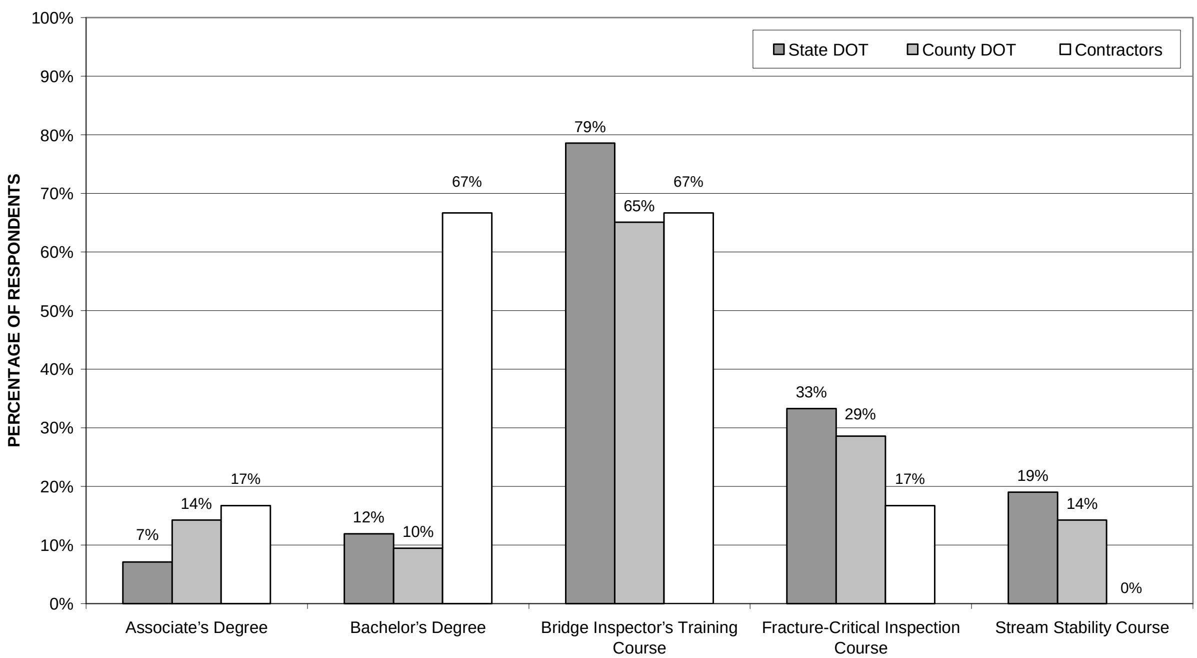


Figure 7. Required training – Other team members.

Q2.4. ***State DOT, County DOT, and Contractors:*** **Could you suggest any changes in administrative or inspection procedure or policy that may improve inspection performance? Explain.**

End-users can often provide valuable insight into how to improve the job they are performing. Therefore, the purpose of this question was to solicit improvements to administrative or inspection procedures or policies. Thirty-three State respondents, 28 county respondents, and 3 contractors answered this question. The write-in format of this question resulted in a wide variety of responses. Only two topics received more than two responses from any of the target groups. Six of the State respondents suggested the expansion of the bridge management system to include the direct electronic incorporation of field data. Five county respondents suggested that additional resources from the Federal government in the form of funding for contract inspectors, personnel, training, and software would improve their inspection process. Table 7 summarizes the compiled list of suggestions from State and county respondents, with the associated tally of responses.

Q2.5. ***State DOT, County DOT, and Contractors:*** **Do you test the vision of inspectors (with corrective lenses if necessary)?**

Yes No

Research related to the reliability of VI in other fields, including the Nuclear Power Industry and the Aviation Industry, indicated that some industries have certification programs for their inspectors. One component of these certification procedures often includes a vision test. This question attempted to determine whether any highway agencies are using similar methods to certify the vision of their inspectors. All State and contractor respondents, along with 66 county respondents, answered this question. None of the contractors indicated that they test the vision of their employees. Of the 66 county responses, 2 counties indicated that they test the vision of their inspectors. No information was provided as to what kind of vision test was used. Forty States indicated that they do not test the vision of their inspectors, while two States indicated that they did test the vision of their inspectors. These two States volunteered that the vision test requirement was part of a motor vehicle license test. From other questions, it was also learned that two other States had certification programs for their inspectors, but specific details on these programs were not provided beyond the negative response to the vision testing question.

Table 7. Suggested changes in administrative or inspection procedures or policies.

	State DOT	County DOT
Bridge Management System (BMS) Issues		
Electronic data from inspections w/direct input into BMS	6	—
Require element-level inspection data	1	—
Post bridge repair list on Internet	1	—
Devote more time to inspection and inventory management	—	2
Training/Continuing Education Related		
Continuing education requirements for team leaders	2	—
Monitor and audit content of NHI course	1	—
Require Bridge Inspector's Training Course for other team members	1	—
Single-day refresher course — more frequently	—	1
Standardize continuing education requirements	—	1
Inspection Operation/Procedure Improvements		
Better access for inspection in urban areas	2	—
Additional field time by bridge maintenance engineers	1	—
Improved procedures for inspection of prestressed concrete	1	—
Fully documented procedures in a Bridge Inspection Policy Manual	1	—
Regulations for scour (not guidelines)	1	—
4- to 5-year cycle on Fracture Critical members and Special Inspection of major bridges	1	—
Statewide Quality Control	1	—
Summertime inspections	1	—
Mandatory inspections for timber bridges more than 30 years old	—	1
Structure Inventory and Appraisal (SI&A) form changes too quickly, keep same form for a minimum of 3 to 4 years	—	1
More equipment to check scour conditions	—	1
Miscellaneous		
Pay consultants on a unit basis, not hourly basis	1	—
More Federal money (contract inspections, more personnel, training, and software)	—	5

Q2.6. ***State DOT, County DOT, and Contractors:*** **For a given bridge, are copies of previous inspection reports made available to the inspectors prior to arriving at the bridge site?** ***(circle one)***

Yes No

Q2.7. ***State DOT, County DOT, and Contractors:*** **Are inspectors permitted to use copies of previous inspection reports at the bridge site?** ***(circle one)***

Yes No

The purpose of these two related questions was to gauge the use of previously completed inspection reports. Forty-one of the 42 State respondents, 67 of the 72 county respondents, and all 6 contractors answered these two questions. All respondents indicated that copies of previous inspection reports were made available both before arrival at the bridge site and at the bridge site. One State indicated that it allows previous inspection reports to be used in the field, but does not recommend this practice.

Q2.8. ***State DOT, County DOT, and Contractors:*** **Who determines the order of field inspection tasks?** ***(mark the most appropriate response)***

_____ "Management" provides a checklist to the on-site team to organize the inspection process.

_____ Individual inspectors on-site set the inspection process.

The purpose of this question was to determine the amount of latitude individual inspectors have in relation to the on-site inspection process. All State and contractor respondents answered this question, and 65 of the 72 county respondents answered the question. Ninety-one percent of State respondents indicated that individual inspectors set the inspection process, while only 9 percent indicated that a checklist of tasks was provided by "management." Similarly, 65 percent of the county respondents indicated that the individual sets the process, while 35 percent indicated that a checklist was provided. Eighty-three percent of the contractors indicated that individuals set the inspection process.

Q2.9. ***State DOT, County DOT, and Contractors:*** **Approximately how many bridges are inspected by your organization *each year*?**

The NBIS generally requires inspections be completed at least every 2 years.[1] This interval is sometimes reduced due to suspect structural conditions. Therefore, it was desirable to determine how many bridges are inspected each year. Forty-one State DOTs, 68 county DOTs, and all 6 contractors answered this question. Table 8 presents a summary of average, minimum, maximum, and total responses. The indicated total number of bridges inspected by the States each year — 250,000 — appears reasonable. This number is approximately half of the accepted total number of bridges, which is in excess of 500,000. Since 79 percent of the 52 FHWA

Table 8. Bridges inspected each year.

	Average	Minimum	Maximum	Total
State DOT	6,300	120	30,000	250,000
County DOT	240	0*	3,500	17,000
Contractors	820	30	2,500	3,800

*Bridges inspected in alternate years.

Divisions responded, it would be expected that this total would exceed 200,000 bridges per year (79 percent of the total number of bridges, multiplied by the number of inspections at each bridge per year). One possible reason for the 50,000 extra bridges per year is due to increased inspection frequency. Alternatively, the county total is slightly suspect, since it is anticipated that there are only about 20,000 secondary road bridges in Iowa.[43] With the number of responses, and a typical inspection frequency of once every other year, it would be expected that the total response would have been just over 7,000. No States gave any indication that all inspections were performed every other year. Five of the county respondents did indicate that they had all their bridges inspected every other year.

Q2.10. *State DOT, County DOT, and Contractors:* What measures do you have in place to assure quality inspections?

The purpose of this question was to compare quality assurance/quality control (QA/QC) measures used. Forty of the State respondents, 56 of the county respondents, and all 6 contractors answered this question. Again, some response fitting was necessary to compile these responses, and the 20 broad categories presented in table 9 summarize all the responses. Note that many responses included multiple items, and each listed item was categorized as a separate response. This multiple listing results in a tally larger than the number of respondents. The two most frequent quality measures used by the States were an office review of the inspection reports (19 QC responses) and an independent field re-inspection program (15 QA responses). Two of the more novel QA/QC program responses included a rotation program, so that inspectors are alternated for subsequent inspections at each bridge, and a rating comparison/validation program where all inspectors within the State rate the same group of bridges to ensure consistency.

Table 9. Quality measures.

	State DOT	County DOT	Contractors
Quality Control Measures			
Office review of inspection reports	19	9	3
Rotation of inspectors	5	3	1
QA/QC program (no specific details)	4	—	1
Hand-search database for irregularities	2	—	—
Require use of inspection manuals and checklists	1	7	2
Training courses	1	7	—
Photographs and written documentation required to change condition rating	1	—	—
Hire consultant to perform inspections	—	10	—
Hire quality employees	—	5	—
Bridge Engineer also performs inspections	—	2	—
Qualified/Certified inspectors	—	1	2
Continuing education	—	1	—
Hire inspectors without fear of heights	—	—	1
Good communication between client/consultant	—	—	1
Quality Assurance Measures			
Field re-inspection program to spot-check team's reports	15	11	2
Occasional PE "ride-alongs" and field review of inspection teams	11	—	—
Annual review by FHWA for NBIS compliance	6	—	—
Internal NBIS compliance reviews	5	—	—
Regular staff meetings	5	—	—
QA/QC program (no specific details)	4	—	1
All inspectors inspect common bridge and discuss results	1	—	—

Q2.11. ***State DOT and County DOT:*** **Please describe any recent accomplishments of your bridge inspection program. (For example, an innovative inspector training program, successful implementation of new NDE technologies, identification of potentially life-threatening conditions, etc.).**

Contractors: **Not asked.**

The purpose of this question was to share recent accomplishments of the participants' bridge inspection programs. Thirty-three State and 20 county respondents answered this question. Due to the significant variability of responses, complete responses are compiled in Appendix B in Volume II. Entries in Appendix B are nearly complete, but name references have been changed to preserve anonymity, and responses such as "N/A" or "None" have been omitted. Table 10 summarizes responses grouped into 14 categories. Most of the responses dealt with information management or bridge management systems (11 responses from each of the State and county respondents). Descriptions of emergency conditions that had been identified and addressed were the second most frequently noted accomplishment.

Table 10. Accomplishments of bridge inspection programs.

	State DOT	County DOT
Bridge Management System-type accomplishments (Implementation of Pontis-type system, spreadsheet and database applications, electronic field data incorporation, Internet applications of repair lists)	11	11
Emergency conditions found and addressed	7	4
Scour surveys	4	2
Training courses/Inspector certification program	4	1
Hanger pin replacement program/NDT of hanger pins	4	—
NDT used for clearance, scour, and depth	3	—
Pile capacity testing/NDT for pile length	2	—
Proof testing of load-rated bridges	2	—
Climbing techniques implemented	2	—
Bridge Inspection Handbook/Guidelines	2	—
QA/QC program	2	—
New equipment	2	—
Analysis to confirm fracture-critical members	1	—
Back on 2-year cycle	1	—

3.3.3. Section 3 – Current and Future Use of NDE Techniques

This section outlines the six questions and responses dealing with the current and future use of NDE techniques. This section was included to gather general data on NDE use and the need for future research.

Q3.1. ***State DOT, County DOT, and Contractors:*** **Do you have any American Society for Nondestructive Testing (ASNT) Level III Inspectors on staff?** ***(circle one)***

Yes No

If so, what method(s) are they certified for? ***(check all those that apply)***

_____ Acoustic Emission (AE)
_____ Electromagnetic Testing (ET)
_____ Leak Testing (LT)
_____ Liquid Penetrant Testing (PT)
_____ Magnetic Particle Testing (MT)
_____ Neutron Radiographic Testing (NRT)
_____ Radiographic Testing (RT)
_____ Thermal/Infrared Testing (TIR)
_____ Ultrasonic Testing (UT)
_____ Vibration Analysis Testing (VA)
_____ Visual Testing (VT)

If applicable, are these ASNT Level III Inspectors routinely used in field situations? ***(circle one)***

Yes No

According to ASNT-TC-1A, a Level III certified individual is involved in policy-level decisions about the use of his specialty area(s) of NDT.[7] The purpose of this question was to determine the use of this certification program for the bridge inspection area. In addition, it was desirable to know how a Level III certified inspector was used during bridge inspections. All State and contractor respondents, and 66 of the county respondents, answered this question. For the county or contractor respondents, no ASNT Level III inspectors were on staff. Fourteen of the 42 State respondents indicated that they had ASNT Level III inspectors on staff. Table 11 presents a breakdown of disciplines in which the Level III inspectors were certified. Three disciplines had response percentages greater than 70 percent: Liquid Penetrant Testing (79 percent), Ultrasonic Testing (79 percent), and Magnetic Particle Testing (71 percent). All 14 of the affirmative responses indicated that the Level III inspectors were used in field situations.

Recall that the 1994 Caltrans survey contained some information relevant to ASNT Level III personnel. Specifically, recall that 7 of the 37 Caltrans respondents indicated that Level III personnel were used. This number can be compared with the usage determined from this survey, where 14 of the 42 respondents indicated that ASNT Level III personnel were used. In percentage terms, this is an increase from 19 percent to 33 percent of respondents, indicating that the use of the ASNT Level III certification program has increased.

Table 11. ASNT Level III by types.

	State DOT Responses
Liquid Penetrant Testing (PT)	11
Ultrasonic Testing (UT)	11
Magnetic Particle Testing (MT)	10
Visual Testing (VT)	7
Radiographic Testing (RT)	5
Electromagnetic Testing (ET)	1
Acoustic Emission (AE)	0
Leak Testing (LT)	0
Neutron Radiographic Testing (NRT)	0
Thermal/Infrared Testing (TIR)	0
Vibration Analysis Testing (VA)	0

Q3.2. ***State DOT, County DOT, and Contractors:*** **Mark any certifications which the typical bridge inspection team member may hold?** ***(Mark all that apply. Note that NICET refers to the National Institute for Certification in Engineering Technologies (NICET) Bridge Safety Inspection.)***

Team Leader		**Other Team Members**	
____	**PE License**	____	**PE License**
____	**ASNT Level I**	____	**ASNT Level I**
____	**ASNT Level II**	____	**ASNT Level II**
____	**ASNT Level III**	____	**ASNT Level III**
____	**NICET Level I**	____	**NICET Level I**
____	**NICET Level II**	____	**NICET Level II**
____	**NICET Level III**	____	**NICET Level III**
____	**NICET Level IV**	____	**NICET Level IV**
____	**Other ______________**	____	**Other ______________**

The purpose of this question was to gauge typical certification programs used by inspection units. Thirty-nine State, 47 county, and all contractor respondents answered this question. As shown in figures 8 and 9, the PE License was the most commonly indicated certification held by either team leaders or other team members. More than 70 percent of State respondents, 67 percent of county respondents, and all contractor respondents indicated that the team leader might hold a PE License. The PE License was also commonly indicated for the other team members, with a minimum positive response of 22 percent (State). The results of this question also indicate that the NICET certification program has a low level of use. The highest positive

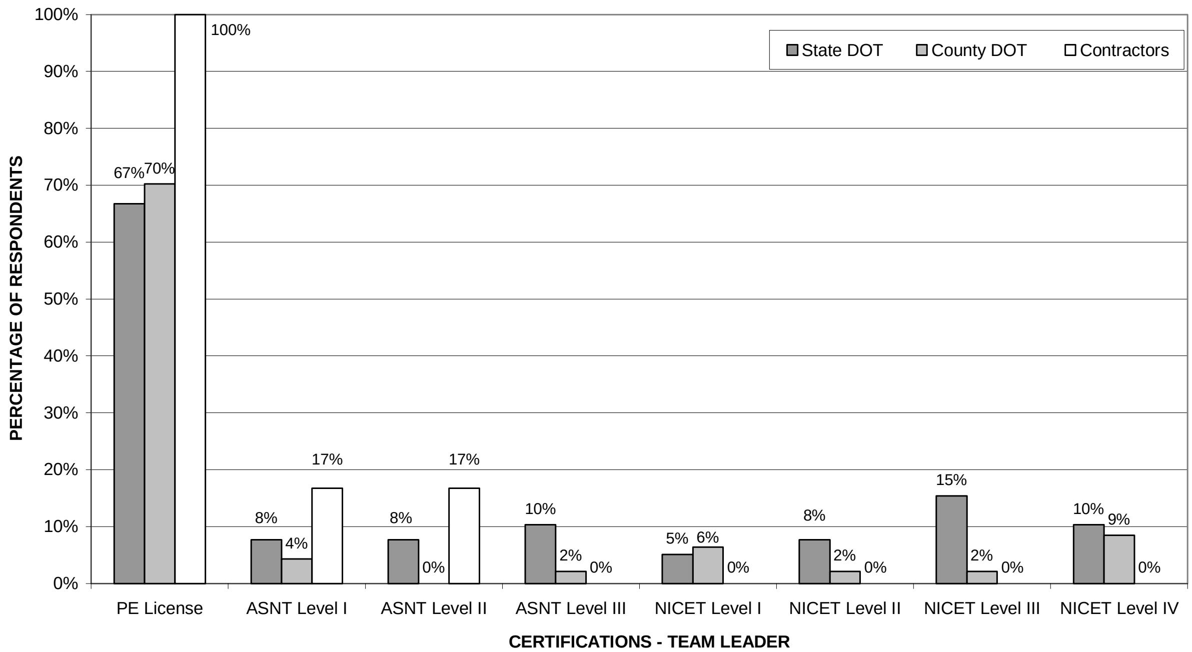


Figure 8. Team leader certifications.

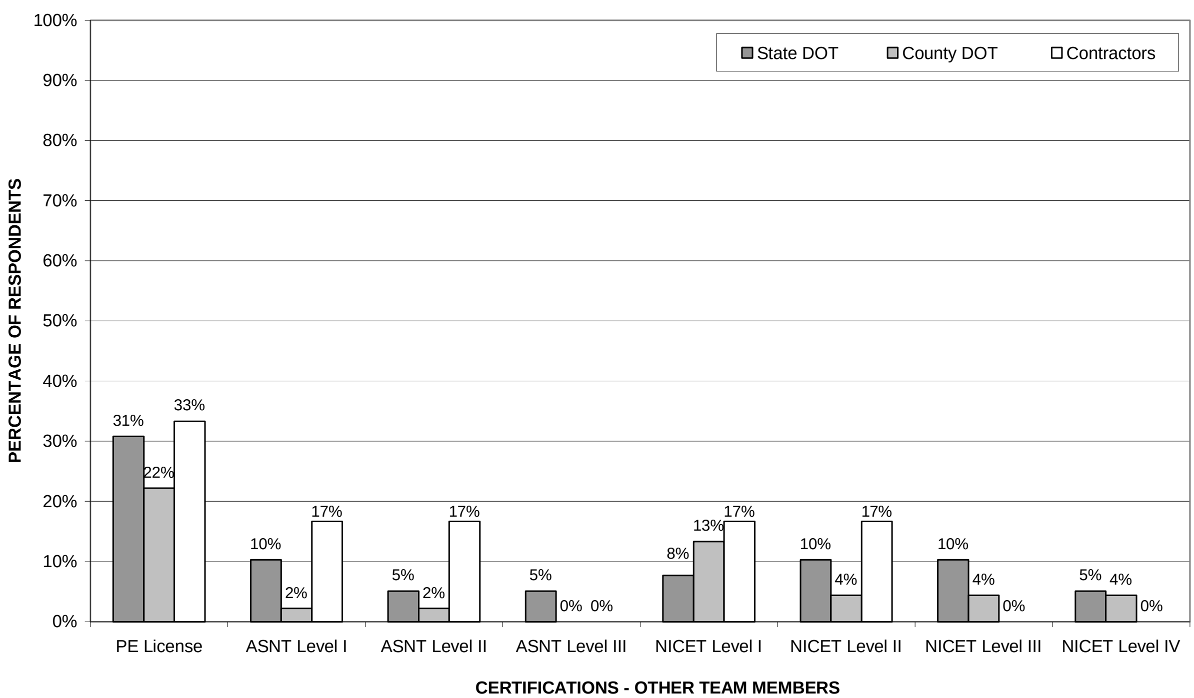


Figure 9. Other team member certifications.

response for any NICET certification from State respondents was 15 percent (NICET Level III, team leader). For county respondents, the highest NICET certification level was 13 percent (NICET Level I, other team members).

The data clearly show the relative prevalence with which the Bridge Inspector's Training Course is used to satisfy NBIS requirements for inspection teams. The three NBIS methods for qualification as team leader are any of: (1) a PE license, (2) 5 years of experience and completion of the Bridge Inspector's Training Course, or (3) NICET certification as a Level III or IV Bridge Safety Inspector.[1] From Question Q2.3, more than 90 percent of both States and counties indicated that the Bridge Inspector's Training Course was required for team leaders. Similarly, about two-thirds of contractors indicated that they require their team leaders to complete the Bridge Inspector's Training Course. The requirement for the Bridge Inspector's Training Course for other team members was almost as high, with a minimum response of 65 percent. In comparison, when asked in Question Q3.2 about typical certifications that team leaders may have, only 15 percent of the States indicated NICET Level III, with an additional 10 percent indicating NICET Level IV certification.

Q3.3. *State DOT, County DOT, and Contractors:* What NDE techniques are currently utilized on bridges under your jurisdiction? *(mark all that apply)*

Steel:

Acoustic Emission	**Eddy Current**
Other Electromagnetic Testing	**Liquid Penetrant**
Magnetic Particle	**Radiography**
Thermal/Infrared	**Ultrasonic**
Vibration Analysis	**Visual Inspection**
Other	

Concrete:

Acoustic Emission	**Cover Meters/Pachometers**
Electrical Potential Measurements	**Mechanical Sounding (Chain Drag)**
Radar	**Radiography**
Rebound Hammer	**Thermal/Infrared**
Ultrasonics (Pulse Velocity)	**Ultrasonics (Impact-Echo)**
Vibration Analysis	**Visual Inspection**
Other	

Timber:

Acoustic Emission
Moisture Meter
Stress Wave Analysis
Other
Mechanical Sounding
Radiography
Visual Inspection

Other Materials:

Material/Technique

1)
2)
3)

The purpose of this question was to determine which NDE techniques are currently being used for bridge inspections. All of the State respondents, 49 of the county respondents, and all contractors answered this question. Results are presented in two formats. First, all of the data will be presented in three material-specific tables. These material-specific tables are presented as tables 12 through 14. A fourth table, table 15, shows the techniques that are used for more than one material, to allow for easy comparison. No respondents from any group provided responses for the Other Materials category question.

Table 12. Steel NDE techniques used.

Steel NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	40	46	6
Liquid Penetrant	34	2	4
Ultrasonics	34	0	4
Magnetic Particle	27	0	4
Radiography	7	0	1
Acoustic Emission	5	1	2
Vibration Analysis	4	2	1
Eddy Current	4	0	0
Other Electromagnetic Techniques for Steel	1	0	0
Mechanical Sounding*	—	1	—
Thermal/Infrared	0	0	0
Other: Sonic Force*	1	—	—
Other: D-Meter*	—	—	1

* Write-in response.

Table 13. Concrete NDE techniques used.

Concrete NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	38	46	6
Mechanical Sounding	32	31	4
Cover Meter	21	0	2
Rebound Hammer	19	9	2
Electrical Potential Measurements	11	0	2
Radar	9	0	1
Ultrasonics (impact-echo)	8	0	1
Thermal/Infrared	5	1	1
Acoustic Emission	1	1	0
Vibration Analysis	0	1	0
Radiography	0	0	0
Ultrasonics (pulse velocity)	0	0	0

Table 14. Timber NDE techniques used.

Timber NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	36	46	5
Mechanical Sounding	35	19	3
Moisture Meter	5	1	1
Stress Wave Analysis	2	0	0
Acoustic Emission	0	0	0
Radiography	0	0	0
Other: Boring/Coring*	4	2	—
Other: Inspection Pick*	2	1	10
Other: Timber Decay Detecting Drill*	2	—	—

* Write-in response.

VI was indicated as a technique used by the largest number of respondents for each of the three materials. There were some relatively new applications (to bridge inspections) of existing NDE technology cited by respondents. Examples include acoustic emission for steel (five State and one county) and concrete materials (one State and one county), radar for concrete materials (nine States), and thermal/infrared for concrete materials (five States and one county). The use of these advanced techniques on both the State and county levels indicates a willingness by at least some of the DOT agencies to try new technologies to improve bridge inspections.

Table 15. Comparison of NDE techniques used on multiple materials.

NDE Technique	State DOT	County DOT	Contractors
Acoustic Emission			
steel	5	1	2
concrete	1	1	0
timber	0	0	0
Mechanical Sounding			
steel*	—	1	—
concrete	32	31	4
timber	35	19	3
Radiography			
steel	7	0	1
concrete	0	0	0
timber	0	0	0
Thermal/Infrared			
steel	0	0	0
concrete	5	1	1
Ultrasonics			
steel	34	0	4
concrete (pulse velocity)	0	0	0
concrete (impact-echo)	8	0	1
Vibration Analysis			
steel	4	2	1
concrete	0	1	0
Visual Inspection			
steel	40	46	6
concrete	38	46	6
timber	36	46	5

* Write-in response.

Q3.4. *State DOT, County DOT, and Contractors:* Of these NDE techniques, which method do you use most often for each material?

Steel:
Concrete:
Timber:
Other Materials:

The purpose of this question was to refine Question Q3.3 to determine which specific NDE technique was used most frequently. Forty State respondents, 39 county respondents, and 5 contractors answered this question. Tables 16 through 18 summarize the respondents' most commonly used NDE techniques on steel, concrete, and timber, respectively. Some respondents listed more than one technique per material. As a result, individual tallies may exceed the

Table 16. Steel NDE techniques used most by State, county, and contractor respondents.

Steel NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	27	39	4
Liquid Penetrant	12	0	1
Ultrasonics	9	0	0
Magnetic Particle	3	0	2
Eddy Current	1	0	0
Mechanical Sounding	0	1	0

Table 17. Concrete NDE techniques used most by State, county, and contractor respondents.

Concrete NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	28	39	4
Mechanical Sounding	17	6	4
Rebound Hammer	1	3	0
Cover Meter	1	0	0
Electrical Potential Measurements	1	0	0
Ultrasonics (impact-echo)	1	0	0
Coring	1	0	0

Table 18. Timber NDE techniques used most by State, county, and contractor respondents.

Timber NDE Technique	State DOT	County DOT	Contractors
Visual Inspection	28	38	3
Mechanical Sounding	19	3	2
Boring/Coring	1	2	0
Moisture Meter	1	0	0

number of respondents. For each of the three materials, VI was the most frequently listed technique. VI was listed on all county responses for steel and concrete materials, and on all but one county response for timber. VI was not as frequently listed by States, being cited on only 70 percent of State responses. Nearly all of the county respondents listed VI as the most frequently used technique. More than one-quarter of the State respondents indicated a most frequently used technique other than VI for each of the three materials. These respondents may have confused VI with visual-aided testing (boroscopes, microscopes, etc.).

Q3.5. ***State DOT, County DOT, and Contractors:*** **Have you stopped using any NDE techniques due to unreliable performance or for any other reason? If so, which techniques and why?**

Past experiences with NDE might affect future use, so the purpose of this question was to determine whether the use of any NDE techniques had been discontinued. Thirty-four State respondents, 19 county respondents, and 4 contractors answered this question. No suspensions of NDE use were reported by any of the county or contractor respondents. Similarly, 20 of the 34 State respondents indicated no suspension of use of any NDE techniques. The other 14 State respondents indicated that the use of some NDE techniques had been stopped. Of these respondents, three listed ultrasonics of pin/hanger connections, three listed various forms of pile testing, two listed radar, and another two listed acoustic emission. Single-response answers included magnetic particle testing, vibration analysis, cover meters, electrical potential measurements, and an impact-echo system.

Q3.6. ***State DOT, County DOT, and Contractors:*** **What general area of NDE applications would you like to see more research into?** ***(mark one)***

___ Concrete decks
___ Concrete superstructure
___ Steel superstructure
___ Prestressed concrete superstructure
___ Timber decks/timber substructure

The purpose of this question was to quantify the need for future research. Forty State respondents, 45 county respondents, and 4 contractors answered this question. Results are presented in figure 10. In general, research into concrete decks was one of the most frequent responses for State and county respondents. Prestressed concrete superstructures also had high response rates, especially from States and contractors. Contractors appeared to have no demand for timber substructure research or general concrete superstructure research.

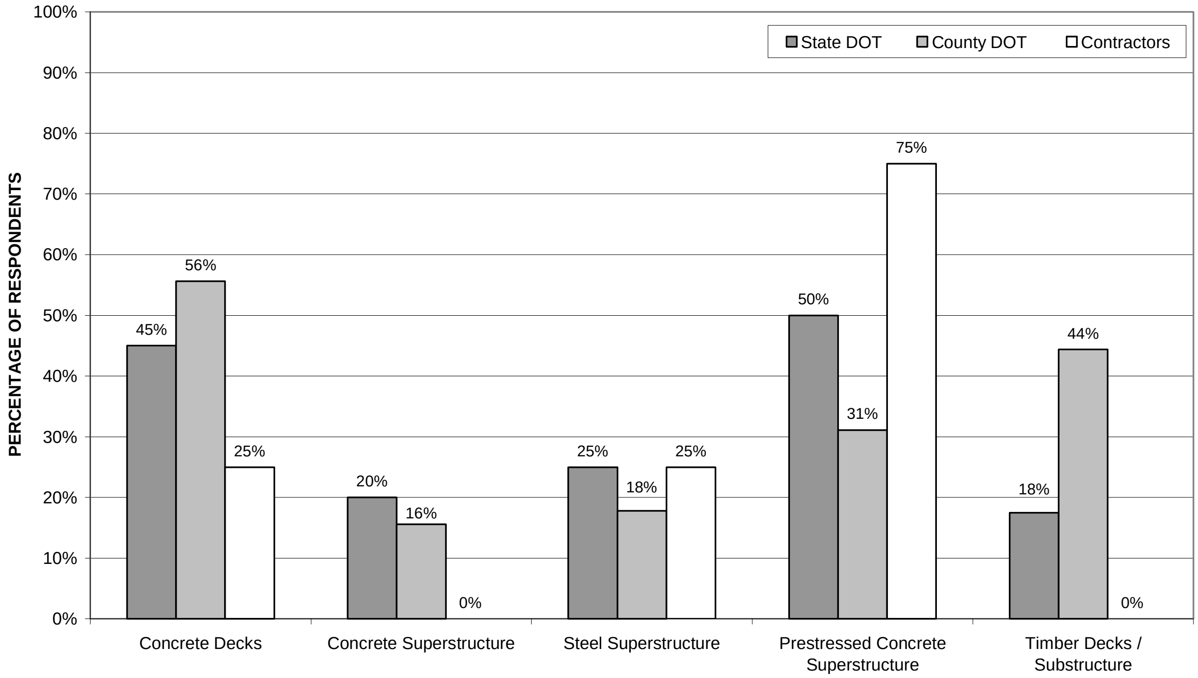


Figure 10. Need for future research.

4. EXPERIMENTAL PROGRAM

4.1. STUDY OVERVIEW

The experimental program described in this chapter consisted of having a representative sample of practicing bridge inspectors complete a battery of pre-defined inspection tasks at the NDEVC test bridges under realistic summer inspection conditions. Quantifiable information regarding the inspection environment was collected to establish the influence of the inspection environment on VI reliability. In addition, extensive information was collected about the inspector's physical and psychological characteristics, allowing the influence of these inspector characteristics on VI reliability to be assessed. Many of the NDEVC resources were used to gain a more thorough understanding of VI reliability. This included using seven of the NDEVC test bridges to conduct the field inspections and the NDEVC laboratory for controlled laboratory measurements. The test bridges used in this study were fully characterized such that specific conclusions about VI reliability could be drawn.

The experimental work plan that served as the foundation to achieve the objectives of this study is presented in the following sections. The characteristics of the inspection specimens used in this study, as well as a summary of the inspection tasks, are presented. In addition, an in-depth discussion of how the various experimental variables were assessed is presented.

Before arriving at the NDEVC, participating inspectors were sent a package of information. Appendix C in Volume II illustrates relevant portions of this package. This package gave information related to the general goal of the study, what inspectors should bring with them, what would be provided by the NDEVC, and requested that inspectors do some advance preparation. The advance preparation was one of the most important items addressed in this information package. It consisted of instructions related to a specific task they would be asked to complete. This task, known as Task I, is described in greater detail subsequently.

4.2. STUDY PARTICIPANTS

To ensure that the results of this study could be extrapolated to the general population of bridge inspectors, the sample for this study consisted entirely of practicing bridge inspectors. Each

State DOT was solicited for participation in this study and was asked to volunteer two inspectors with different experience levels (i.e., one “more” experienced inspector and one “less” experienced inspector). In all, 25 States participated in the field evaluation, including 49 participating inspectors. Note that time constraints limited the number of participating States, resulting in more States volunteering than could be included. To ensure the anonymity of inspector performance, individual States and inspectors will not be identified. A geographically diverse collection of States participated in the study (e.g., Eastern, Western, and Central States; large and small States; States with many bridges and States with few bridges; Northern and Southern States; etc.). Additional information about the inspectors is presented in subsequent sections.

To ensure that the participating inspectors would not feel like they were being “graded” or “tested”, each inspector was assigned an Inspector ID that could not be linked to the inspector nor to the State. In addition, each pair of inspectors was assigned a Team ID that was used for any inspections they completed as a team. Following their participation, all Inspector IDs and Team IDs were changed. As a result, any reference made to a specific ID in this report is different than that used during the field evaluation.

4.3. INSPECTION SPECIMENS

Seven of the NDEVC test bridges were used to perform 10 discrete inspection tasks. The NDEVC test bridges are located in Northern Virginia and in South-Central Pennsylvania. The Northern Virginia bridges are in-service bridges under the jurisdiction of the Virginia DOT (VDOT). 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. Note that one of the Pennsylvania bridges is an in-service bridge traversing the STAR facility and is under the jurisdiction of the Pennsylvania DOT (PennDOT). The following sections describe the basic geometry and general condition of these structures.

4.3.1. Bridge B521

Bridge B521, shown in figure 11, is an in-service, single-span, through-girder bridge carrying State Route 4007 over the STAR facility. Route 4007 is a low-volume, two-lane road. The bridge spans 57.30 m and is 6.10 m wide between curbs. Bridge B521 has a minimum 5.06-m clearance over the STAR facility and is oriented with 0.79-rad skew. The bridge deck is a nominal 230-mm-thick cast-in-place reinforced concrete slab with a 65-mm concrete wearing surface and an additional 25-mm-thick asphalt overlay. The deck is supported by 11 W30 x 108 floor beams on approximately 2.74-m centers. The floor beams are connected to the main girders by riveted, stiffened knee-brace details. The main girders are built-up riveted sections with variable flanges. Bridge B521 is a fracture-critical structure.

The asphalt overlay is typically cracked, loose, and debonded, with potholes that are especially prominent over the girders. The deck has been patched in the past, with many of the patches now cracked and delaminated. Approximately 30 to 40 percent of the deck soffit exhibits alligator cracking with minor efflorescence staining. Other areas have honeycomb surfaces with some exposed reinforcing steel. During the course of the study, the PennDOT placed a deck chip/seal coat on Bridge B521.

The exterior surface of the two longitudinal girders has minimal signs of corrosion or loose paint. The interior surfaces have some corrosion staining with pitting and efflorescence staining. The most prominent location for pitting and staining is at the floor beam-to-girder connection. Pitting is generally less than 1.5 mm deep. Moderate surface rust can also be noted at the deck-to-web interface due to water retention in those locations. Most of the floor beams are in fair condition, with some exhibiting corrosion on the horizontal surfaces due to water leakage.

The north abutment shows general water staining, with numerous 25-mm spalls at form tie locations. The remaining portions of the substructure exhibit similar conditions and are, in general, in fair condition. Appendix D in Volume II further summarizes the overall condition of Bridge B521. Note that the Condition Ratings given in Appendix D will be referred to as the Reference Condition Ratings in subsequent sections.

a. Elevation view of Bridge B521.

b. Bridge B521 superstructure and abutment.

Figure 11. Bridge B521.

4.3.2. Bridge B101A

Bridge B101A, shown in figure 12, is a single-span, concrete T-beam bridge carrying the STAR facility over a gravel access road, known as the Oregon Trail, in the Buchanan State Forest. The bridge is 22.35 m wide (21.34 m curb to curb), with a clear span of 6.81 m, without skew. Design drawings indicate a 215-mm-thick cast-in-place reinforced concrete slab with a 65-mm bonded concrete wearing surface. The bonded concrete wearing surface was subsequently removed and replaced with a 150-mm asphalt wearing surface. An expansion joint runs longitudinally along the bridge with an alignment shear key. Sixteen cast-in-place reinforced concrete beams form the stem of the T-beams and provide the primary strength. Cast-in-place parapet walls bound the roadway along the northern and southern edges. The parapets are seated upon 200-mm curbs poured integrally with the deck. The bridge is founded on 910-mm-thick cast-in-place reinforced concrete footings supporting cast-in-place reinforced concrete abutments.

There are various types of deterioration of the bridge deck, including shrinkage cracking, alligator cracking, alligator cracking with debonding of the surface course, and disintegration of the surface course. In general, the deck is in extremely poor condition. The parapet walls are severely deteriorated with extensive freeze/thaw damage. The damage has basically occurred in the top 125 mm of the parapets and has resulted in exposed reinforcement. The parapets are approximately 40 to 50 percent delaminated.

The underside of the deck is generally in good condition. There is extensive damage within 610 mm of the longitudinal expansion joint where deterioration has extended as much as 100 mm into the slab thickness. Slab delaminations are usually indicated by heavy mineral deposits. Inadequate concrete cover can also be observed in the superstructure, and deterioration of the stems of the T-beams was more severe than that occurring in the deck soffit. The deterioration consisted of severe delaminations and longitudinal cracking, as evidenced by heavy mineral deposits.

The substructure has experienced deterioration from water infiltration and soil movement. A significant horizontal crack is located just above mid-height along the length of one abutment.

a. Elevation of Bridge B101A.

b. Exterior face of north parapet of Bridge 101A.

Figure 12. Bridge B101A.

The abutment wall also has a slight bow, further illustrating the distress. Appendix D in Volume II provides a more detailed summary of the general condition of Bridge B101A.

4.3.3. Bridge B111A

Bridge B111A, shown in figure 13, is a decommissioned, single-span, concrete T-beam bridge over State Route 1011. The deck is superelevated and is 21.34 m wide from curb to curb. Bridge B111A spans a clear distance of 6.65 m, just wide enough to accommodate Route 1011 below. This bridge has a 0.26-rad skew. The bridge deck is 215-mm-thick cast-in-place reinforced concrete with a 165-mm-thick asphalt wearing surface. A longitudinal expansion joint runs the length of the bridge with an alignment shear key. The remaining geometry of Bridge B111A is similar to Bridge B101A and is not repeated here.

Bridge B111A exhibits the same general types of deterioration seen in Bridge B101A. However, in general, Bridge B111A is deteriorated to a lesser degree. Appendix D in Volume II further summarizes the general condition of Bridge B111A.

4.3.4. Bridge B543

The westernmost bridge on the STAR facility, Bridge B543, is a single-span, cast-in-place reinforced concrete rigid frame that spans over a decommissioned access ramp. Bridge B543, shown in figure 14, is approximately 33.22 m wide and spans approximately 12.80 m at a 0.44-rad skew. The Pennsylvania Turnpike Commission uses the area directly below Bridge B543 for temporary storage of equipment and materials. The frame of the bridge consists of an arched reinforced concrete deck slab with a thickness varying from 495 mm to 990 mm. A 165-mm-thick asphalt overlay has been placed over the entire width of Bridge B543. An expansion joint and alignment shear key divide Bridge B543 down its length. The bridge abutments are constructed integrally with the deck, while the wingwalls are isolated from the abutments by a 25-mm cork-filled joint.

The deterioration of Bridge B543 is quite varied. The most significant deterioration is present in the bridge deck overlay and especially in the parapets. It could generally be described as being consistent with the other previously described STAR bridges. The superstructure and

a. Elevation view of Bridge B111A.

b. Bridge B111A superstructure.

Figure 13. Bridge B111A.

Figure 14. Bridge B543.

substructure are in fair to good condition, with the exception of freeze/thaw damage observed near the slab edges. Appendix D in Volume II further summarizes the general condition of Bridge B543.

4.3.5.   Bridge B544

Bridge B544, shown in figure 15, is a decommissioned, single-span, steel plate girder bridge carrying the STAR route over U.S. Route 30. Near Bridge B544, U.S. Route 30 is a medium-to-high volume highway in a business district/rural setting. The bridge spans 28.65 m and is 21.34 m wide from curb to curb. Bridge B544 is skewed at approximately 0.91 rad and has a 230-mm-thick cast-in-place reinforced concrete slab with a 150-mm asphalt overlay riding surface. There are three expansion joints in Bridge B544 — one longitudinal joint and one at each abutment. The bridge superstructure is complex for the overall size of the structure, with each half of the deck supported by three longitudinal plate girders and a series of alternating transverse floor beams and sway frames. In addition, a W18 x 47 rolled shape runs the length of the bridge along the expansion joint. The plate girders consist of a 1.91-m-deep by 11-mm-thick web plate and

a. Elevation view of Bridge B544.

b. Bridge B544 superstructure.

Figure 15. Bridge B544.

200-mm by 200-mm angles with multiple, variable-length cover plates. The transverse members (i.e., floor beams and sway frames) are spaced at approximately 2.90 m on center.

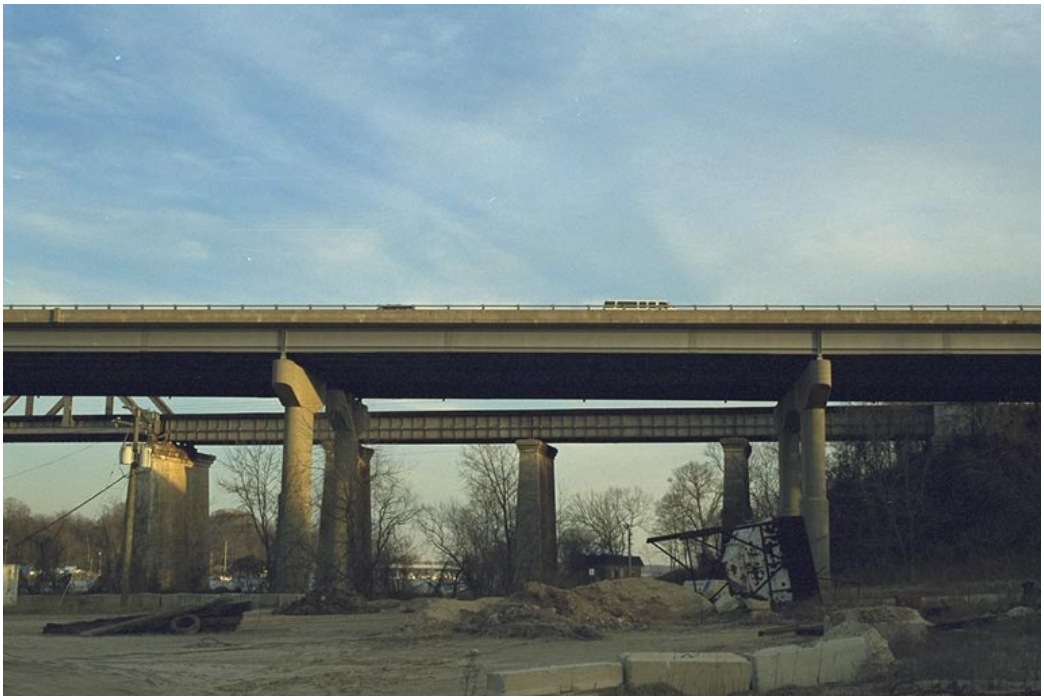
The deck condition is quite varied. Generally, the deck surface is in very poor condition. The bridge parapet/railing has severe deterioration, with extensive damage to the concrete and exposed curb reinforcement. The deck soffit, and more specifically, the cantilever soffit below the parapets, shows signs of severe freeze/thaw damage, with spalling and exposed reinforcement. The interior portion of the deck soffit is approximately 40 percent delaminated.

The exterior surfaces of the two exterior girders are generally in fair condition, while the interior surfaces of the two exterior girders and the four interior girders have general corrosion along the top of the bottom flange. With the exception of the horizontal surfaces, the steel-plate girders are in fair condition. Deterioration in the transverse members is primarily restricted to the bottom flange surface and the web plate-to-girder connection. The bridge bearings show general surface corrosion at the base. The anchor bolt holes for the three expansion supports nearest the northeast corner of the bridge were originally improperly located as evidenced by abandoned holes in the vicinity of the existing supports.

Deterioration of the abutments and wingwalls is generally limited to surface staining. Appendix D further summarizes the condition of Bridge B544.

4.3.6. Route 1 Bridge

The U.S. Route 1 Bridge over the Occoquan River was constructed in 1975. The 335.28-m structure is divided into two independent, four-span structures as shown in figure 16. The southern four-span unit served as a test bridge for this study. The roadway is 10.97 m wide, accommodating two lanes of traffic and two shoulders. Each span measures approximately 37.0 m with a vertical clearance varying from 1 m to 18 m. This bridge has no skew. The superstructure consists of 1.83-m-deep welded plate girders with variable-thickness flange plates. Girder construction includes welded transverse and longitudinal stiffeners, bolted angle diaphragms, bolted and welded flange transitions, and an in-plane lateral bracing system comprised of WT members attached to lateral gusset plates that are welded to the girder webs



a. Overall view of bridge (foreground).

b. View of superstructure.

Figure 16. Test portion of U.S. Route 1 Bridge over the Occoquan River.

near the bottom flange. The superstructure framing is composite, with a 235-mm-thick cast-in-place, conventionally reinforced concrete deck that is overlaid with a 6-mm-thick epoxy resin embedded with fine aggregate.

The Route 1 Bridge includes construction details and defect conditions that are typical of major steel highway bridges. Overall, the bridge is in good condition, with only minor deterioration. However, there are crack indications located at the weld toe of some Category E details. The specific deficiencies will be described in greater detail in a subsequent chapter. Appendix D, in Volume II, further summarizes the condition of the Route 1 Bridge.

4.3.7. Van Buren Road Bridge

The Van Buren Road Bridge over the Quantico Creek, shown in figure 17, was constructed around 1960 and consists of three spans, each simply supported, with a span length of 18.29 m. The overall bridge is 55.65 m long and 7.67 m wide. The curb-to-curb deck width is 6.1 m and the bridge has a 0.26-rad skew. The deck is 175-mm-thick, cast-in-place reinforced concrete supported by four wide flange stringers that are composite with the deck. The steel stringers are reinforced with tapered-end, welded cover plates. The superstructure is supported by reinforced concrete piers and abutments founded on spread footings or steel H-piles.

The average daily traffic on the Van Buren Road Bridge is minimal. The deck has significant delaminations throughout the length of the deck. In addition, some of the bearings appear to be locked in the expanded configuration with evidence of continued bearing plate sliding. Several crack indications can also be noted along weld toes. Aside from these deficiencies, the structure is in good condition. Appendix D of Volume II further summarizes the condition of the Van Buren Road Bridge.

4.4. INSPECTION TASKS

This section describes the inspection tasks completed for this study. Each inspector was asked to complete 10 inspection tasks on the 7 NDEVC test bridges.

Figure 17. Van Buren Road Bridge.

To ensure that the interaction between the NDEVC staff who administered the tasks and the inspector would not bias how, what, and when the inspector completed the inspection tasks, protocols defining their interaction were used. These protocols were developed to help ensure that each NDEVC staff member (hereafter known as an “observer”) provided the same information in the same manner to each inspector. The protocols for the 10 tasks are given in Appendix E in Volume II. In general, the protocols provided the inspectors with general information concerning the execution of each inspection task.   Specifically, information presented to the inspectors from the protocols included the following:

- Basic information about the structure to be inspected.
- Type of inspection to be completed.
- Areas to be inspected.
- Safety issues.
- Role of the observer.
- Instructions on use of inspection forms.
- Time limits.

- Restrictions on the use of invasive inspection procedures.

In addition to the above, inspectors were also instructed that gross dimension checks, inspection of non-structural members, and underwater stream profiles were not required. To ensure uniformity in the presentation of the protocols, they present the same type of information at the same point in the same manner. In Appendix E in Volume II, special or different information contained in each protocol has been shown in bold.

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 tools listed below, on two occasions, the inspectors were provided with special access equipment. The tools provided include the following:

- Masonry hammer
- 7.62-m tape measure
- 30.48-m tape measure
- Engineering scale
- 3 D-cell flashlight
- 2 AA-cell flashlight
- Lantern flashlight
- 2.44-m stepladder
- 9.75-m extension ladder
- 610-mm level
- Chain
- Binoculars
- Magnifying glass
- Protractor
- Plumb bob
- String
- Hand clamps

In general, the inspection tasks were completed in one of two sequences. The two sequences arose from the fact that the two inspectors typically were split to perform each task independently. Generally, the sequence of tasks completed was either A, B, C, D, E, F, G, H, I, J or E, F, A, B, C, D, H, G, I, J.

4.4.1. Task A

Task A consisted of the Routine Inspection of the deck, superstructure, and substructure of Bridge B521. Inspectors were allotted 40 min to complete the inspection and were asked to evaluate the deck condition from the shoulder due to traffic considerations.

4.4.2. Task B

Task B consisted of the Routine Inspection of the deck, superstructure, and substructure of Bridge B101A. Inspectors were given 50 min to complete the task and were allowed full access to the bridge.

4.4.3. Task C

Task C consisted of the Routine Inspection of the deck, superstructure, and substructure of Bridge B111A. The time allotted was limited to 30 min and, due to traffic volume and a narrow roadway width below bridge B111A, inspectors were not allowed to use ladders during their inspections.

4.4.4. Task D

Task D consisted of the Routine Inspection of the deck, superstructure, and substructure of Bridge B543. Inspectors were given 40 min to complete the task. Unlike the other inspection tasks, inspectors were also asked to use a digital camera to obtain supplementary visual documentation of their findings.

4.4.5. Task E

Task E consisted of the Routine Inspection of the deck, superstructure, and substructure of Bridge B544. Inspectors were given 60 min to complete the task. Due to heavy truck traffic below Bridge B544, inspectors were not allowed access to the superstructure immediately above

Route 30. However, inspectors were allowed access to the bridge bearings and other superstructure areas outside of the traffic path.

4.4.6. Task F

Task F consisted of the In-Depth Inspection of approximately one-fifth of the below deck superstructure of Bridge B544. Inspectors were given 3 h to complete the task. The inspection area corresponded with the superstructure areas out of the normal traffic pattern. To provide access to the superstructure, inspectors could use a 12.2-m boom lift in addition to the previously mentioned ladders. During this task, the NDEVC staff operated the boom lift under the direction of the inspectors.

4.4.7. Task G

Task F consisted of the Routine Inspection of the deck, superstructure, and substructure of the southern four-span unit of the southbound U.S. Route 1 Bridge between the four piers and the southern abutment, inclusive. Inspectors were given 2 h to complete this task. Despite the difficulty in gaining access to this structure, inspectors were asked to complete this inspection without special access equipment. In addition, to ensure the safety of the inspectors, access to the top surface of the deck was prohibited. The deck evaluation was limited to that which was visible from behind the end guardrail.

4.4.8. Task H

Task H consisted of the In-Depth Inspection of one bay of one span of the Route 1 Bridge superstructure. Inspectors were given 2 h to complete this task. During this task, inspectors were allowed to use an 18.3-m boom lift positioned below the bridge. The boom lift was operated by the NDEVC staff under the direction of the inspectors.

4.4.9. Task I

Task I consisted of the Routine Inspection of deck, superstructure, and substructure of the Van Buren Road Bridge. Inspectors were given 2 h to complete this task. Unlike the other tasks performed for this study, inspectors worked together and were asked to prepare and use their own State inspection forms to document their findings. As mentioned above, inspectors were previously mailed copies of the bridge plans to develop their own State forms. In addition, inspectors were asked to complete the inspection as if the bridge were within their own home State. Due to time constraints, inspectors were asked to not inspect non-structural elements nor enter the waterway.

4.4.10. Task J

In Task J, inspectors were asked to complete an in-depth level inspection (delamination survey) of the southern two deck spans. Similar to Task I, Task J was also a team task. The goal of the inspection task was to identify and map the deck deterioration. A total of 2 h were allotted for this task. For Task J, instead of using a standard protocol, the protocol was dictated by the inspections performed in Task I. For example, if a team performed a complete delamination survey as part of Task I, Task J was omitted.

4.5. DATA COLLECTION

Two primary types of data were collected. The dependent data are the result 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). The following describes what data was collected and how during this study.

Two primary media were used for the data collection. While completing their inspections, inspectors were asked to prepare handwritten “field” inspection notes on typical NBIS forms that were provided by the NDEVC. To facilitate the collection of data by the NDEVC observers, Palm IIIx handheld computers were used. The Palm IIIx is a handheld computer with 4 Mb of storage space. Used in combination with commercially available software, prepared forms can be developed to expedite the collection of data. After data collection, the Palm IIIx can be connected to a desktop personal computer and the data can be transferred into a common spreadsheet program. Figure 18 shows the Palm IIIx computer during field use.

4.5.1. Independent Data

The independent data in this study are the human and environmental factors. The independent data are collected through self-reports, direct measurements, and firsthand observations. The

a. Palm IIIx computer.

b. NDEVC observer using Palm IIIx during field inspections.

Figure 18. Palm IIIx handheld computer.

methodology for collection of these 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 in order to allow numerical correlation studies to be performed. The following section describes the techniques used to collect the independent data in this investigation.

4.5.1.1. HUMAN FACTORS MEASUREMENTS

The goal of this portion of the study was to provide and maintain a systematic method for the quick, accurate, and consistent measurement of the numerous subjective human attributes. These measurements were completed using several tools. First, inspectors completed a written, self-report questionnaire related to their general physical/psychological characteristics. Second, direct physical measurements of inspectors' vision characteristics were made. Finally, assessments of the human factors were made immediately prior to, during, and immediately following the completion of each inspection task. Orally administered pre- and post-task questionnaires were given in an interview format. Firsthand observations were also collected by the observers to document the inspectors' activities.

4.5.1.1.1. Self-Report Questionnaires

In order to ensure that non-biased data could be collected regarding the many "non-measurable" human attributes that may influence VI reliability, all participating inspectors were asked to complete two voluntary questionnaires. For the most part, the self-report questionnaires (SRQs) yielded pseudo-quantitative evaluations of many physical/psychological qualities. As some of the information in these questionnaires may be perceived as personal in nature or intrusive, it was consistently reinforced that all questions were voluntary and that all answers were strictly confidential.

The SRQs were administered at the beginning of the first day of participation and at the end of the last day of participation. As can be seen from the questionnaires presented in Appendix F in Volume II, many of the questions are the same for both questionnaires, allowing for cross-checking of answers. A protocol was followed that outlined how the initial SRQ was to be administered and is given as Appendix G in Volume II. The exit SRQ was typically given immediately after the inspectors completed Task J and, therefore, no specific protocol was followed. Figure 19 shows an inspector completing the questionnaire on the first day of participation.

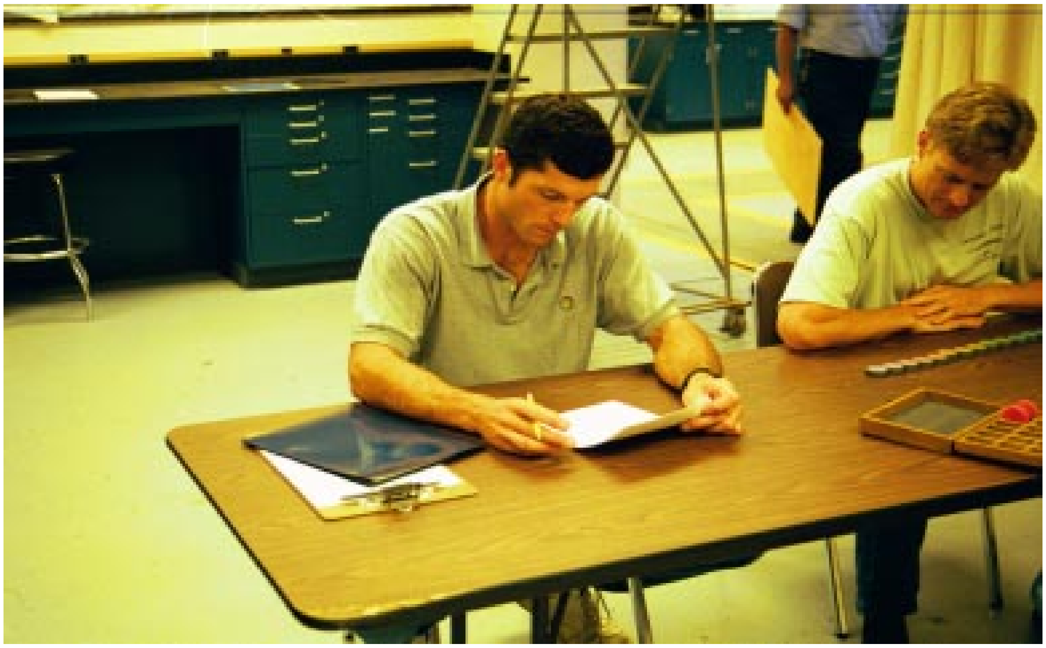


Figure 19. Inspector completing the Self-Report Questionnaire.

4.5.1.1.2. Vision Testing

To supplement the SRQ data, a series of vision tests were administered. Three tests were administered, including a near vision test, a distance vision test, and a color vision test, and these tests are described in the following sections.

DIRECT VISUAL ACUITY: As discussed in Chapter 3, inspectors are typically not tested for visual acuity. NDE techniques, however, rely on an inspector's use of their eyes and observations may be influenced by how well they can see. Direct visual acuity, both near and distance, was tested using the Logarithmic Visual Acuity Chart 2000. These tests are similar to standard vision tests commonly given in a doctor's office. Figure 20 shows inspectors taking the near and distance visual acuity tests. As before, protocols were followed when administering the direct visual acuity tests and these protocols are given in Appendix G in Volume II.

a. Inspector taking the near visual acuity test.

b. Inspector taking the distance visual acuity test.

Figure 20. Direct visual acuity testing.

COLOR VISION: Often, indications of a defect come only in the form of a subtle color change. It was speculated that a bridge inspector with a color vision deficiency may not perform as reliably as an inspector with normal color vision. “Color blindness” is the general term used to describe various abnormalities in color vision resulting from the interference, alteration, or malfunction of the trichromatic color vision system. In most instances, color blindness does not necessarily involve the absence of discrimination of all color stimuli. As such, a more appropriate descriptor might be “color vision deficiency”.

The PV-16 Quantitative Color Vision Test was used to determine the type of color vision deficiency, if any. The PV-16 Quantitative Color Vision Test consists of a set of 16 test caps of various hues. The goal of the test is to orient the caps in such a way that adjacent caps are closest in color. The PV-16 test uses large cap sizes, giving more accurate color vision information because it does not rely on an inspector’s direct visual acuity. In addition, the PV-16 test is easy to administer and all types of color vision deficiencies can be rapidly identified. Figure 21 illustrates an inspector completing the PV-16 Color Vision Test. A protocol was followed for the administration of the color vision test and is given in Appendix G in Volume II.

4.5.1.1.3. Pre-Experimental Evaluation

An orally administered pre-experimental evaluation was conducted prior to each task. This evaluation was administered in interview format and provided a baseline measure of the inspector’s physical and psychological condition at the initiation of each inspection task. In addition, information was collected to ascertain how the inspector was planning to approach the inspection. The pre-experimental evaluation forms for all tasks are represented in Appendix H in Volume II. In the actual study, this information was collected using the Palm IIIx handheld computer. Figure 22 shows an NDEVC observer administering a pre-experimental evaluation.

4.5.1.1.4. Post-Experimental Evaluation

Similar to the pre-experimental evaluation, a post-experimental evaluation was conducted at the conclusion of each inspection task. The goal of the post-experimental evaluation was to identify what influence completing the inspection had on the inspector, as well as quantifying the

Figure 21. Inspector taking the color vision test.

Figure 22. Observer administering a pre-task evaluation.

inspector's perception of the inspection tasks and the environment in which the inspection was completed. This data was collected with the Palm IIIx computer with orally administered questionnaires as represented in Appendix I in Volume II.

4.5.1.1.5. Firsthand Observations

The inspector's behavior during each inspection task was closely monitored and documented by an observer. Specifically, information about how the inspector performed the inspection, where the inspector's attention was focused, the inspector's overall attention to the task, and the tools used were recorded. Although the data were recorded with the Palm IIIx, the forms used to record this information, as well as information related to the environmental conditions, are presented in Appendix J, in Volume II.

4.5.1.2. ENVIRONMENTAL FACTORS MEASUREMENTS

In order to assess the influence of the inspection environment, a series of standard environmental measurements were made during the inspection tasks. These measurements provide an easy means for correlating environmental conditions with inspection results. The environmental conditions that were monitored include the following:

- Temperature
- Humidity
- Wind speed
- Light intensity
- Noise level

All measurements were made using standard equipment, with data recorded on the Palm IIIx via forms presented in Appendix J in Volume II. The measurements were made at consistent locations for each inspection specimen. To supplement these direct environmental measurements, qualitative assessments of the general weather conditions were also made and recorded on the forms in Appendix J. Figure 23 illustrates an observer measuring the environmental conditions.

Figure 23. Observer measuring the environmental conditions.

4.5.2. Dependent Data

Two principal types of dependent data were collected. This data is the foundation for forming conclusions about VI. The following sections describe specifically what data was collected and how it was collected.

The primary data collected for evaluating the Routine Inspection tasks were the Standard Condition Ratings of the primary bridge components: deck, superstructure, and substructure. These primary bridge component ratings were supplemented by secondary bridge component ratings and inspection field notes. These condition ratings consider both the severity of bridge deterioration and the extent to which it is distributed throughout the components. The Standard Condition Rating guidelines, as given in the *Bridge Inspectors Training Manual,* was used.[4] The rating system, including the qualitative definitions, is given in figure 24.

N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION – no problems noted.
7	GOOD CONDITION – some minor problems.
6	SATISFACTORY CONDITION – structural elements show minor deterioration.
5	FAIR CONDITION – all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	POOR CONDITION – advanced section loss, deterioration, spalling, or scour.
3	SERIOUS CONDITION – loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	CRITICAL CONDITION – advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"IMMINENT" FAILURE CONDITION – major deterioration or section loss present in critical structural components, or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put bridge back in light service.
0	FAILED CONDITION – out of service; beyond corrective action.

Figure 24. Standard Condition Rating system.

The primary data collected for evaluating In-Depth Inspection were the inspector's field notes generated during the inspections. Specifically, inspector identification of deficiencies was the principal information used to evaluate the In-Depth Inspection results.

In order to facilitate the collection of the dependent data, each inspector was provided with an inspection field book to record their inspection findings for Tasks A through J (excluding I). This book provided all required rating forms, as well as select bridge plans. In addition, inspectors were provided with a guide sheet that outlined the Standard Condition Rating system that they were to use. The inspection field book is presented in Appendix K in Volume II in the same format used by the inspectors.