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

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Research, Development, and Technology
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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.

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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.

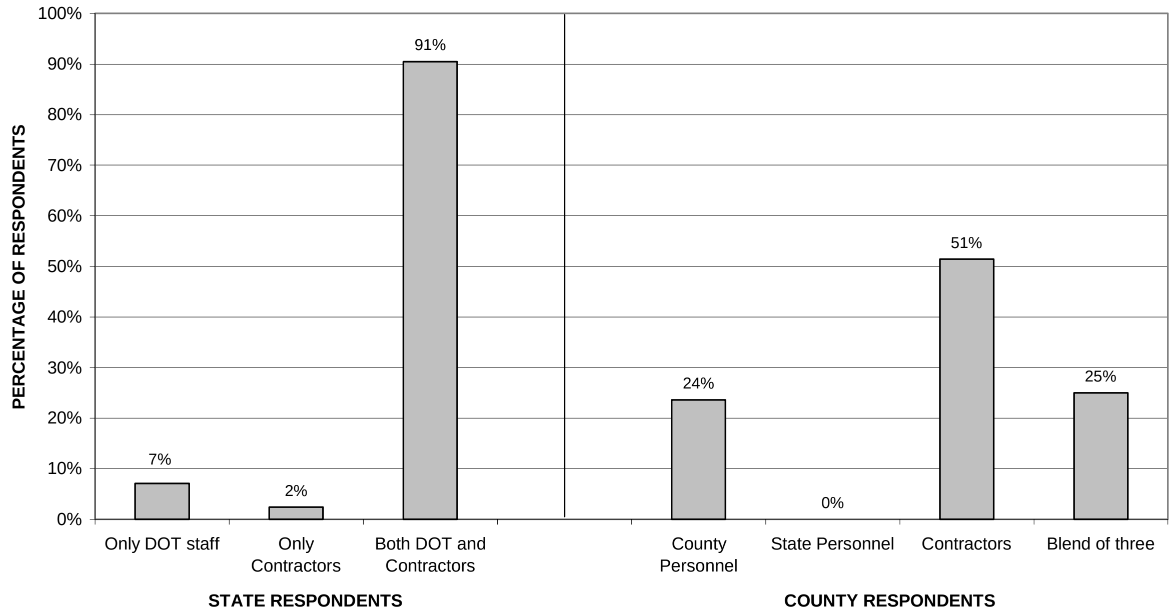


Figure 1. Inspector sourcing.

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).

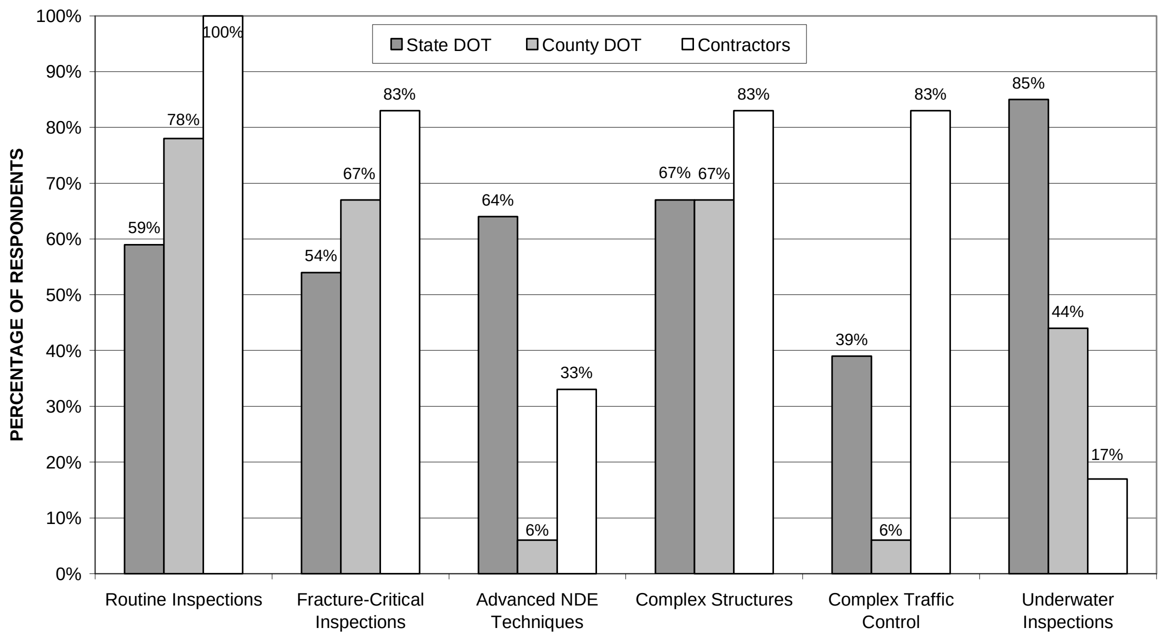


Figure 2. Inspection situations where partial contractor services are used.

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) <u>on-site</u>?** ***(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.

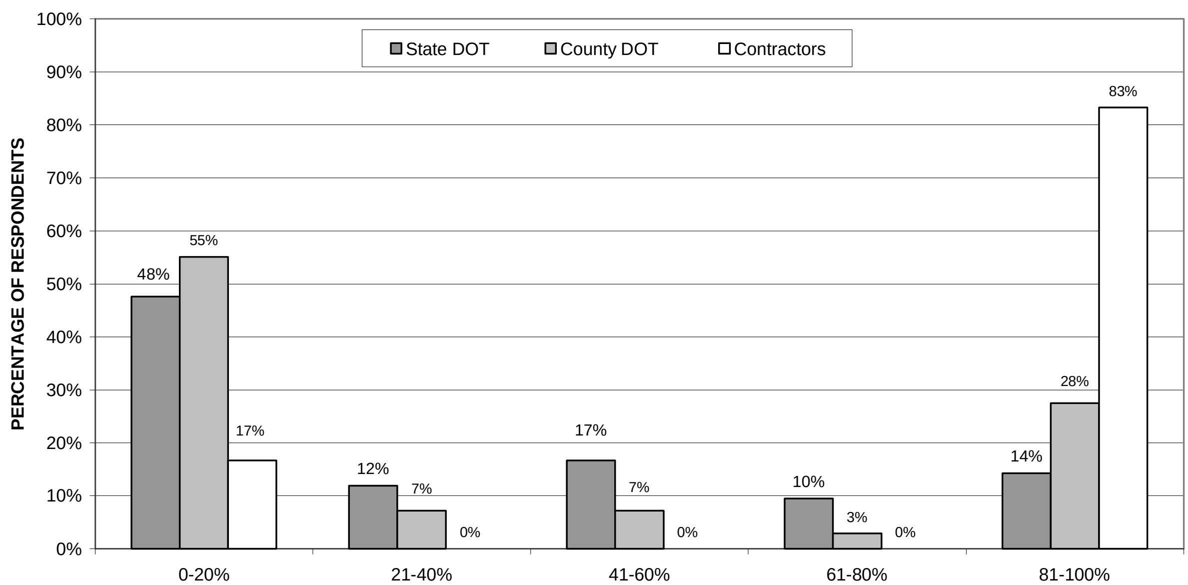


Figure 3. Inspections completed with PE on site.

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.

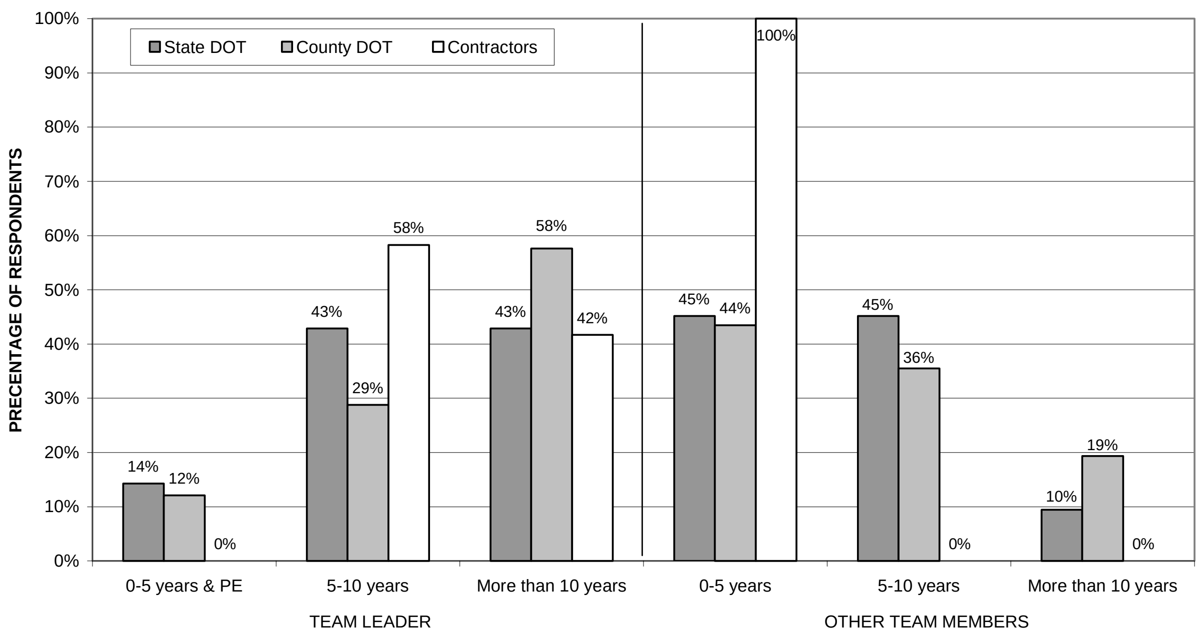


Figure 4. Years of experience for bridge inspectors.

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

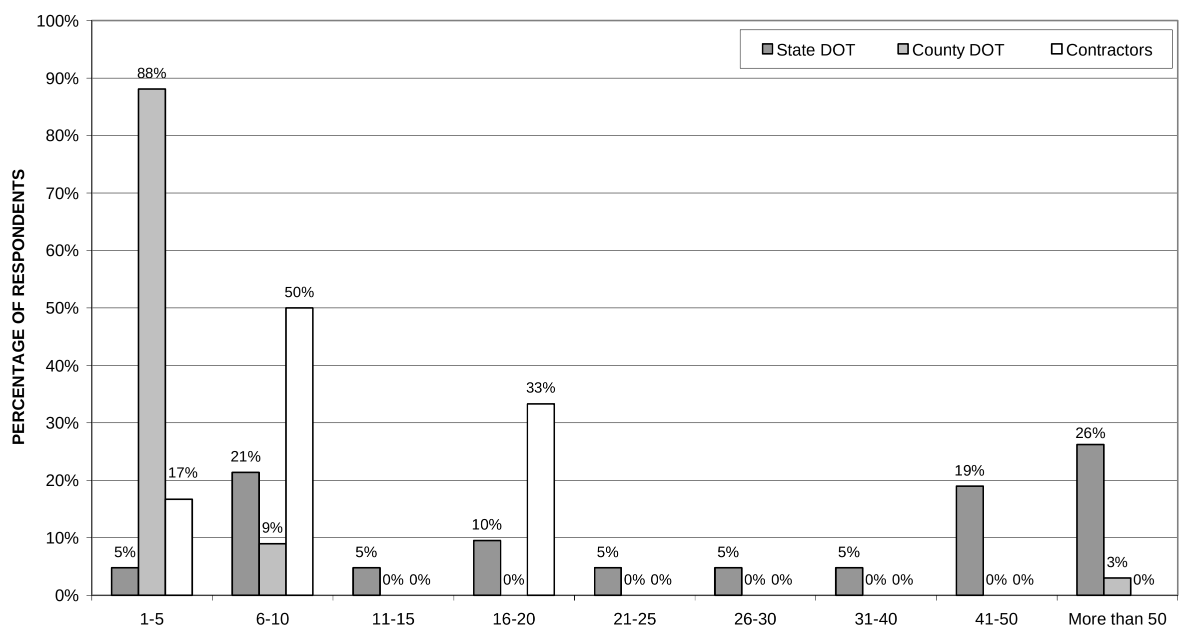


Figure 5. Number of bridge inspectors in inspection unit.

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.

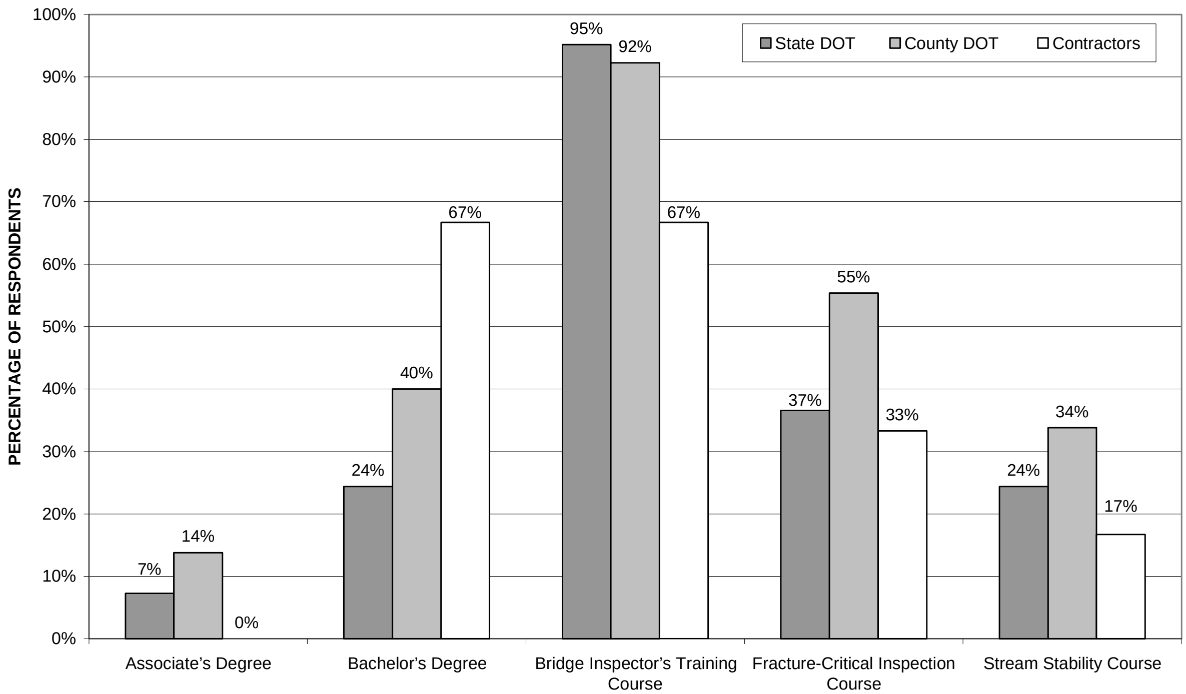


Figure 6. Required training – Team leaders.

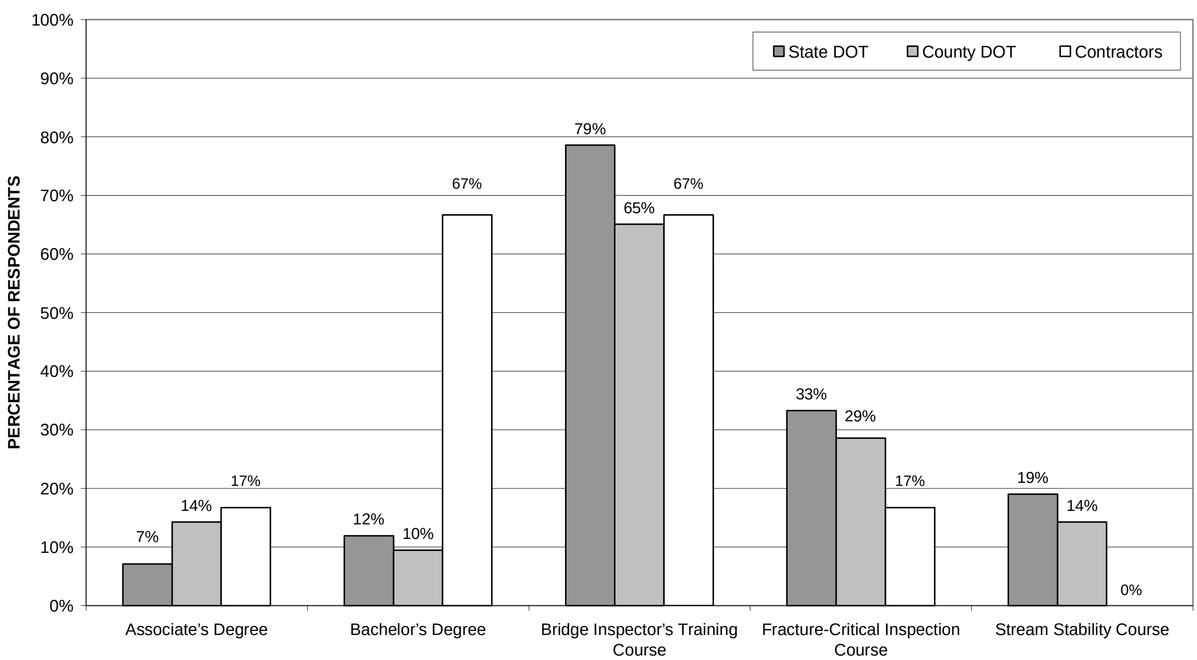


Figure 7. Required training – Other team members.

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

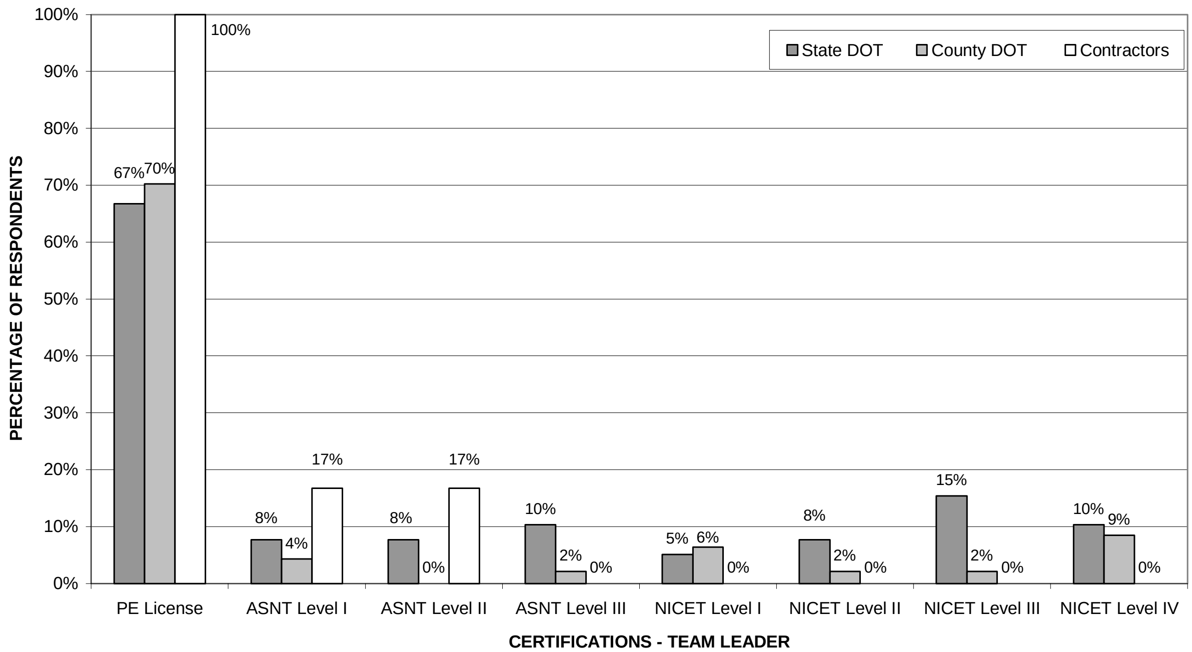


Figure 8. Team leader certifications.

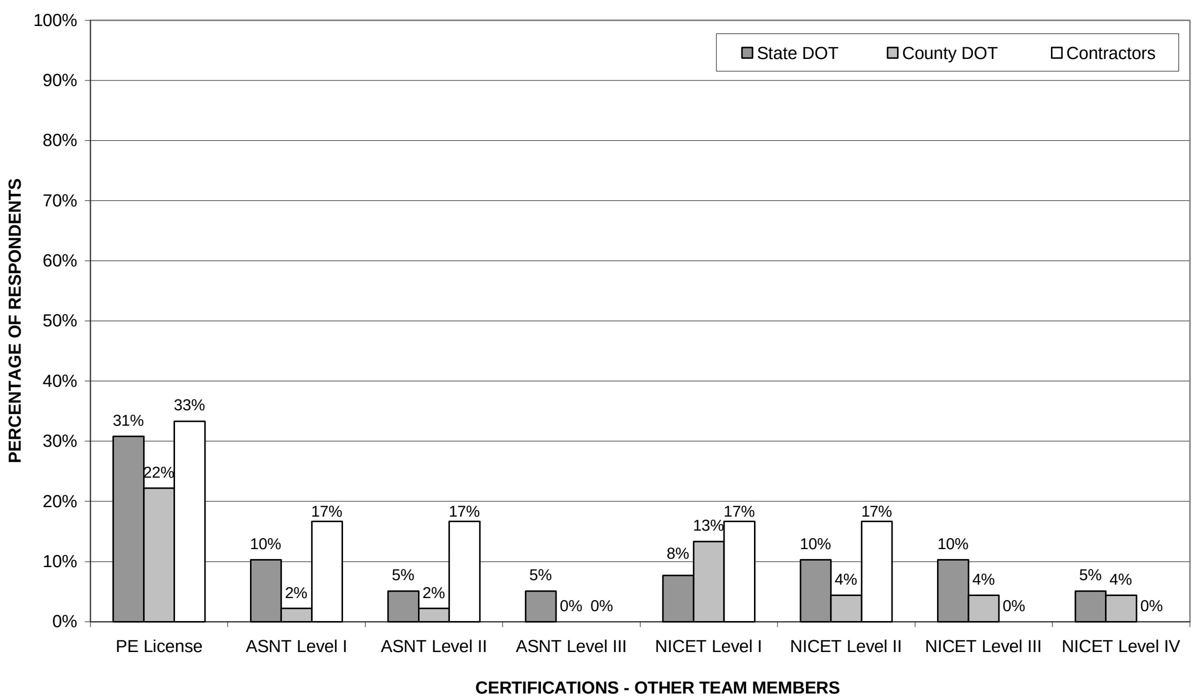


Figure 9. Other team member certifications.

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	

<u>Timber</u>:

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

<u>Other Materials</u>:
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.

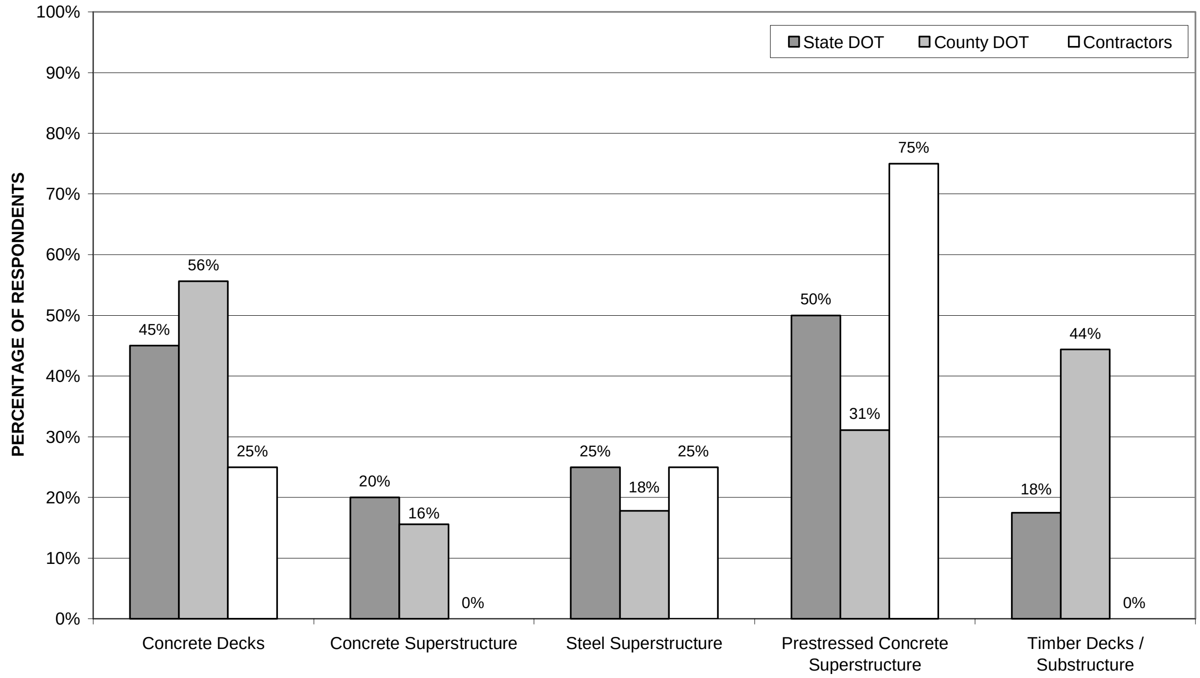


Figure 10. Need for future research.

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.

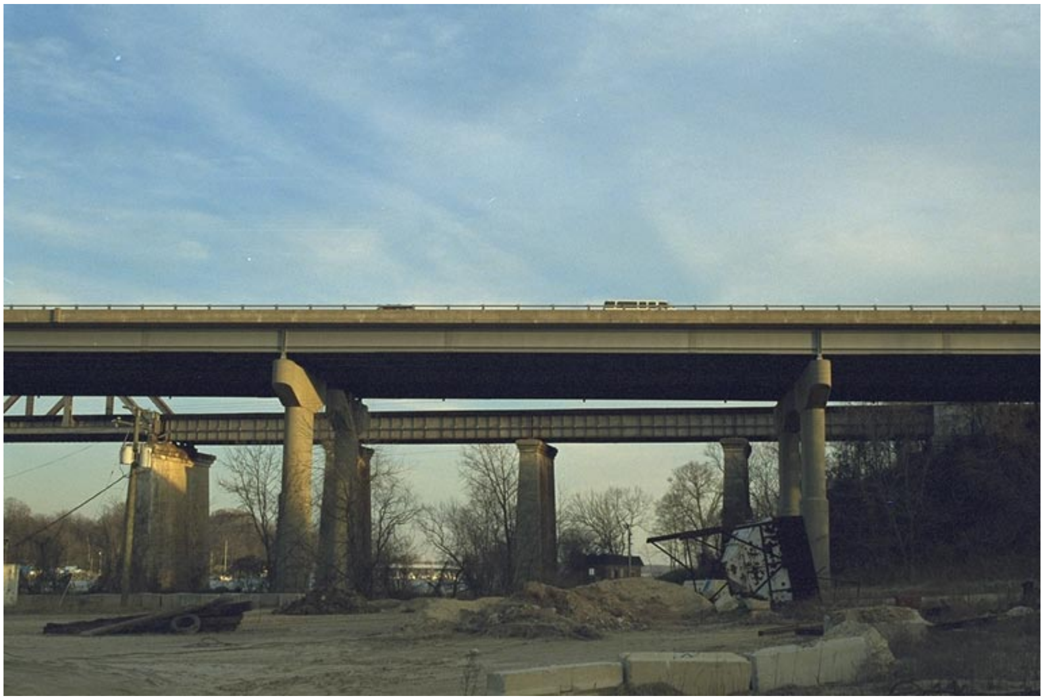
The deck condition is quite varied. Generally, the deck surface is in very poor condition. The bridge parapet/railing has severe deterioration, with extensive damage to the concrete and exposed curb reinforcement. The deck soffit, and more specifically, the cantilever soffit below the parapets, shows 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.

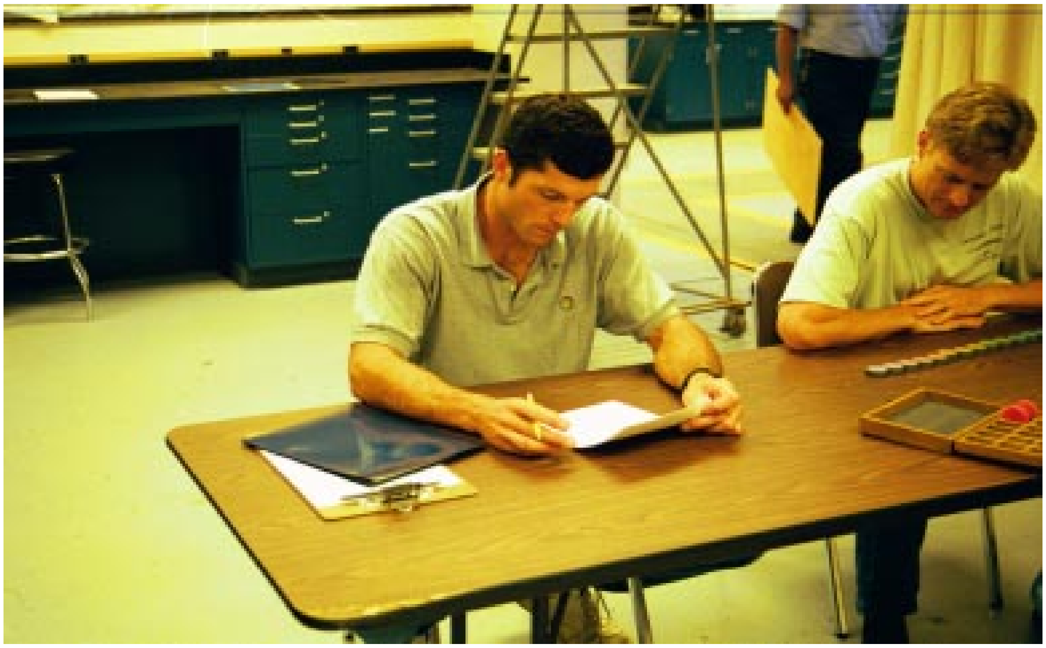


Figure 19. Inspector completing the Self-Report Questionnaire.

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.

5. SUMMARY OF OBSERVATIONS AND FINDINGS

The following sections summarize the results of the experimental portion of this investigation. Results will be presented in four primary sections. First, the inspector physical/psychological characteristics collected through the SRQs and vision tests will be summarized. Second, results from the Routine Inspection tasks (Tasks A, B, C, D, E, and G) will be presented. Third, results from the two In-Depth Inspections (Tasks F and H) will be presented. Finally, results from the State-dependent tasks (Tasks I and J) will be presented.

5.1. INSPECTOR CHARACTERISTICS

As was mentioned previously, inspectors were asked to complete two written SRQs and to take three vision tests. The results from these will be presented in the following three sections.

5.1.1. SRQ Results

The following presents the results from each question on the SRQs. Results will be presented in a question-by-question format similar to that used in Chapter 3. The questions will be repeated exactly as they were presented on the SRQs. The motivation behind each question will then briefly be discussed, followed by a summary of the data collected. Where appropriate, commentary may also be included to supplement the basic data presentation. Some of the questions were common to both SRQs. In general, inspectors gave consistent responses to these questions on both SRQs. In light of this, results from common questions will only be presented from responses on the first SRQ.

SRQ1. **Age:** ___________
Height: ___________
Weight: ___________

Question SRQ1 was asked to simply collect some physical data about each inspector. Table 19 summarizes inspector responses to question SRQ1.

Table 19. Age, height, and weight characteristics of inspectors.

	Average	Standard Deviation	Minimum	Maximum
Age, years	40.5	6.5	28	54
Height, m	1.82	0.076	1.68	2.01
Weight, kg	87.0	13.7	68.2	134.1

SRQ2. How would you describe your general physical condition?

Poor	Below Average	Average	Above Average	Superior
1	**2**	**3**	**4**	**5**

The goal of this question was to establish a pseudo-quantitative measure of each inspector's physical condition. The average for this question was a 3.4, with a standard deviation of 0.61. Figure 25 shows the distribution of the responses.

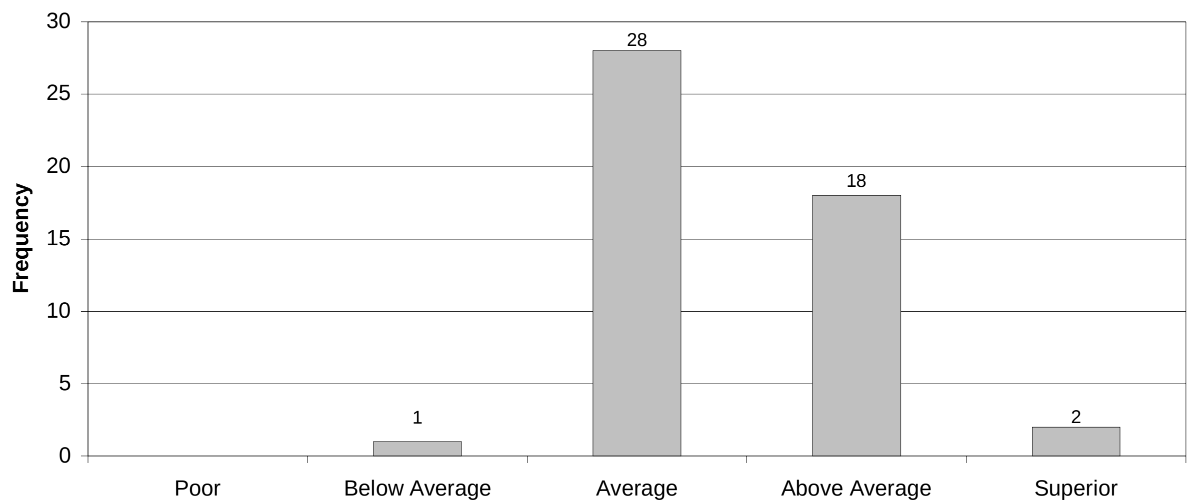


Figure 25. Distribution of inspector-reported general physical condition.

SRQ3. Do you currently have any orthopedic ailments (e.g., bad knees, bad back)?
Yes No

If so, list: ______________________________

It was envisioned that an inspector with orthopedic ailments may not be able to perform some of the physically demanding aspects of a bridge inspection. Eighteen inspectors indicated that they had some type of orthopedic ailment. These could generally be classified as bad knees (6), bad shoulders (4), or a bad back (13).

SRQ4. Are you currently experiencing any temporary physical ailments (e.g., flu, head cold, etc.)?
Yes No

If so, list:______________________________

The goal for this question was to ascertain if any inspectors were suffering temporary physical ailments during their participation in the study. Six inspectors indicated that they were experiencing, or just getting over, a temporary physical ailment. The most commonly listed physical ailments were allergies (3) and influenza (3).

SRQ5. How would you describe your general mental condition?

Poor	Below Average	Average	Above Average	Superior
1	**2**	**3**	**4**	**5**

Similar to question SRQ2, question SRQ5 was developed to get a measure of the inspector's overall mental condition. Although tools exist to measure general mental condition, time constraints did not allow such a thorough assessment. The average answer to this question was a 3.7, with a standard deviation of 0.58. Figure 26 illustrates the distribution of inspector responses.

SRQ6. Are you currently experiencing additional stress due to personal problems (e.g., death in family, etc.)?
Yes No

Similar to question SRQ4, question SRQ6 was developed to determine if "out of the ordinary" stress might influence VI. Five inspectors indicated that they were experiencing some type of additional stress. Due to the personal nature of this question, information about the source of the stress was not requested.

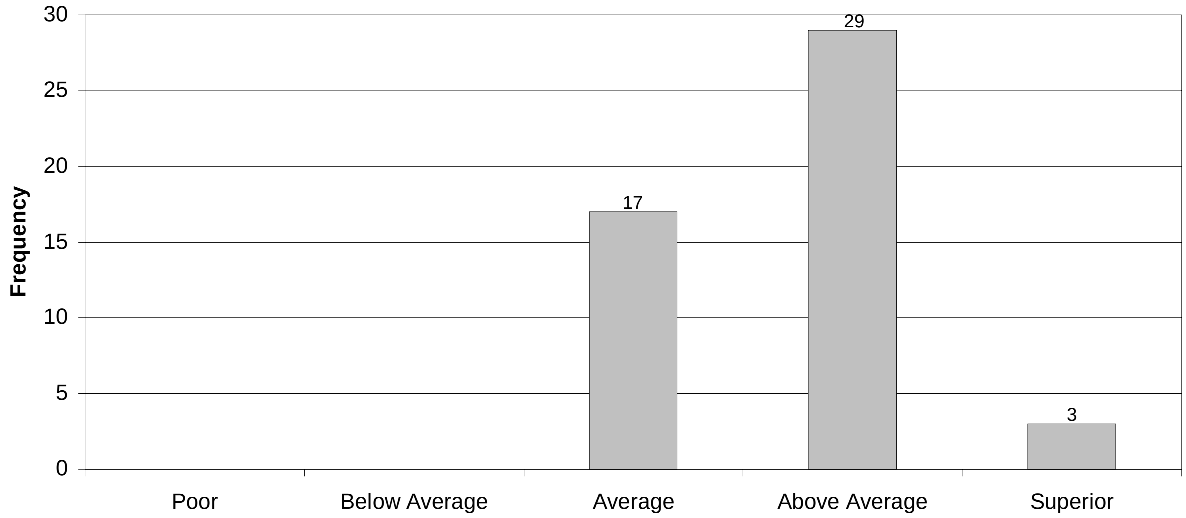


Figure 26. Distribution of inspector-reported general mental condition.

SRQ7. Overall today, how do you feel?

Poor	Below Average	Average	Above Average	Superior
1	**2**	**3**	**4**	**5**

To supplement the information gathered in questions SRQ1 through SRQ6, question SRQ7 gave inspectors the chance to quantify how they were generally feeling. The average response to question SRQ7 was a 3.5, with a standard deviation of 0.65. Figure 27 illustrates the distribution of the responses.

SRQ8. During an average bridge inspection, do you ever feel so tired or winded that you have to work slower or temporarily stop working?

Never	Very Rarely	Sometimes	Often	Almost Always
1	**2**	**3**	**4**	**5**

If so, under what conditions and how often: ______________________________

____

This question was asked to give a measure of the inspector's physical conditioning. The average response to question SRQ8 was 1.9 (standard deviation of 0.56). The most common conditions cited for working slower were on hot/humid days or when the inspector needed to navigate very rugged terrain. Figure 28 illustrates the quantitative distribution of the answers to question SRQ8.

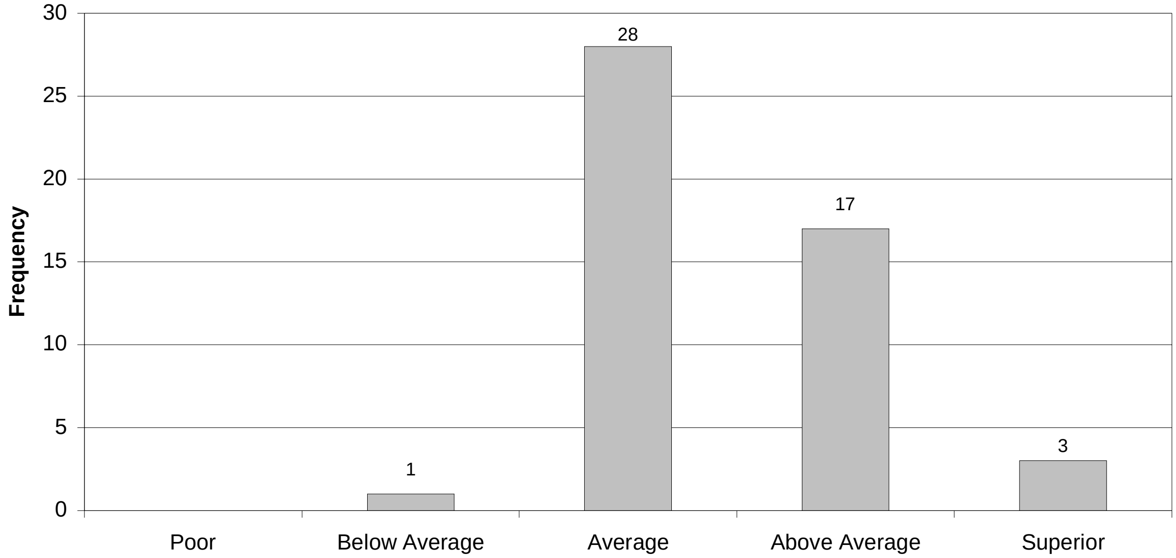


Figure 27. Distribution of inspector-reported overall condition.

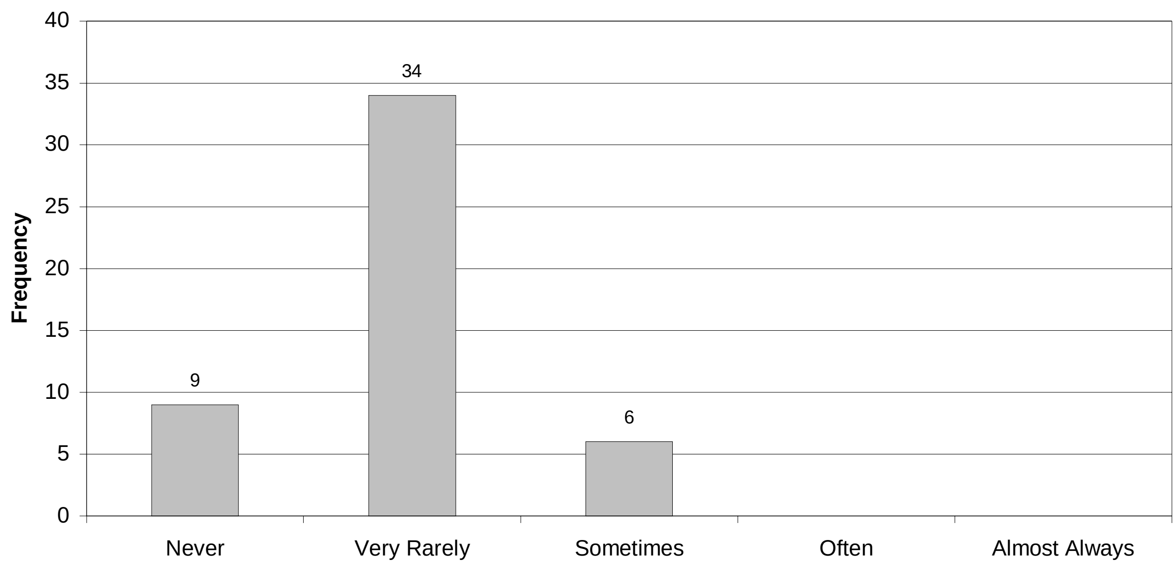


Figure 28. Distribution of how often inspectors get tired/winded during work.

SRQ9. Do you feel your work as a bridge inspector is important to public safety?

Not at all	Slightly Important	Important	Very Important	Essential
1	2	3	4	5

There were two motivating factors behind this question. First, this question could be used to gauge job satisfaction and, second, to determine if inspectors thought bridge inspection had a positive social impact. The average response to this question was a 4.6, with a standard deviation of 0.54. This indicates that, overall, inspectors feel their work is important to maintaining public safety. Figure 29 shows the frequency distribution for question SRQ9.

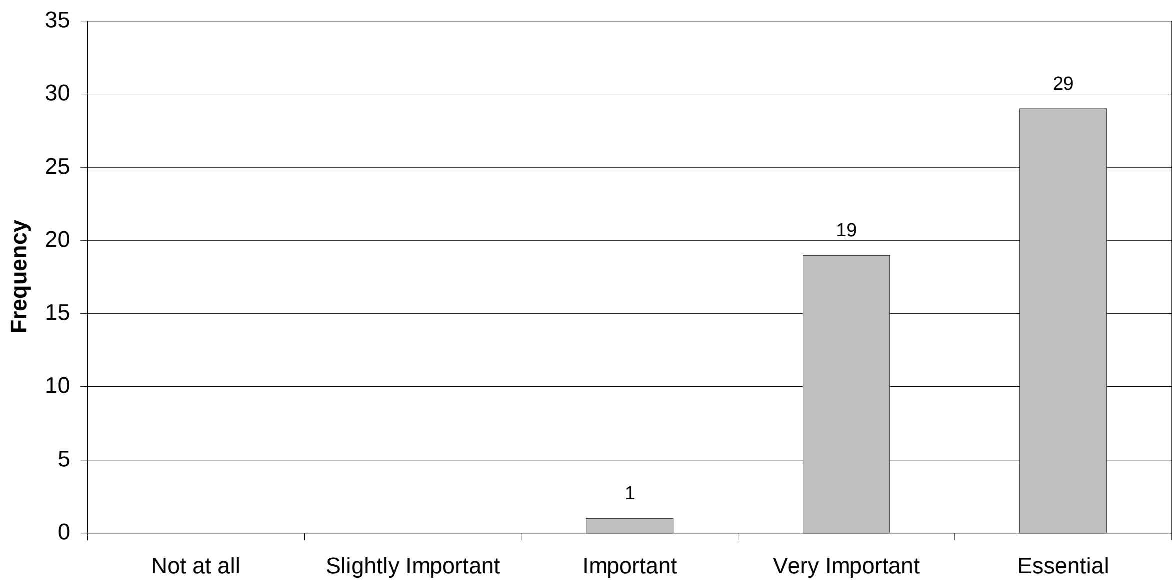


Figure 29. Distribution of perception of importance of work.

SRQ10. Do you ever assess the importance to public safety of the inspection that you are performing?
Yes No

Similar to question SRQ9, this question was asked to see if inspectors considered public safety while they were completing an inspection. Only 45 of 48 responding inspectors answered yes to this question. Although this indicates that many inspectors are completing their inspections with the goal of ensuring the safety of the public, it also indicates that some inspectors may have some other motivation. Unfortunately, the question format did not allow inspectors to elaborate on their answers and therefore additional information is not available.

SRQ11. In general, how would you describe your level of mental focus over an entire bridge inspection?

Poor	Slightly Unfocused	Average	Somewhat Focused	Very Focused
1	**2**	**3**	**4**	**5**

The goal of this question was to determine if performing a bridge inspection is interesting enough to hold an inspector's attention. The average inspector indicated that they were between "somewhat focused" and "very focused" (average of 4.4) while they were completing an inspection. Figure 30 illustrates the distribution of the responses.

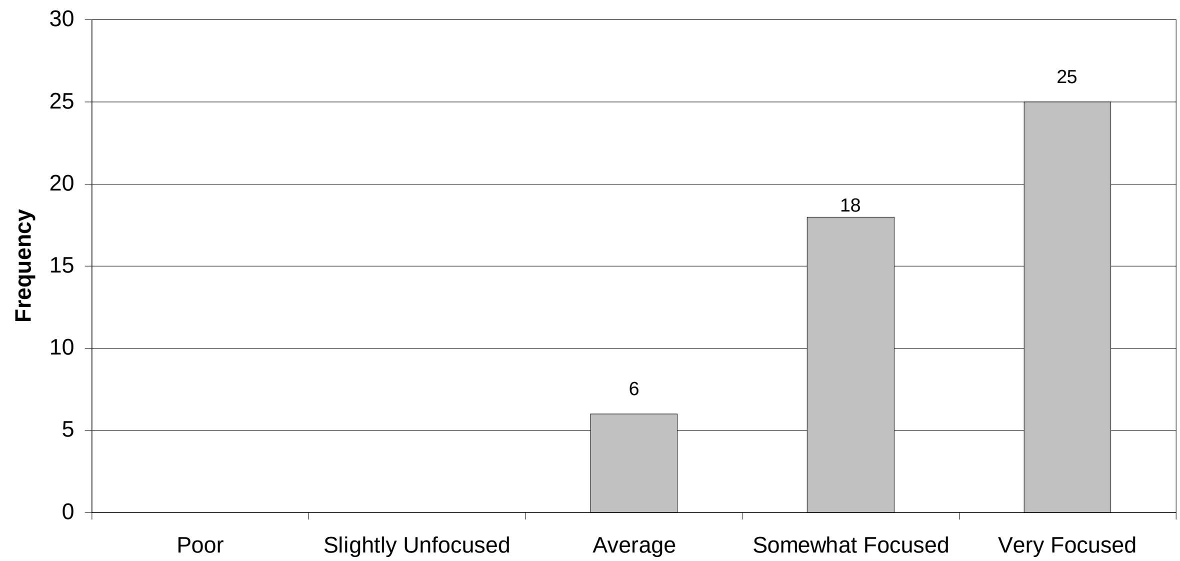


Figure 30. Level of focus during bridge inspections.

SRQ12. How interesting is your work as a bridge inspector?

Very Boring	Boring	Average	Somewhat Interesting	Very Interesting
1	**2**	**3**	**4**	**5**

Question SRQ12 was asked to supplement and to reinforce the answers to question SRQ11. The average was 4.5 (standard deviation of 0.58), indicating that most inspectors thought that their daily work was interesting. Figure 31 shows the distribution of the responses.

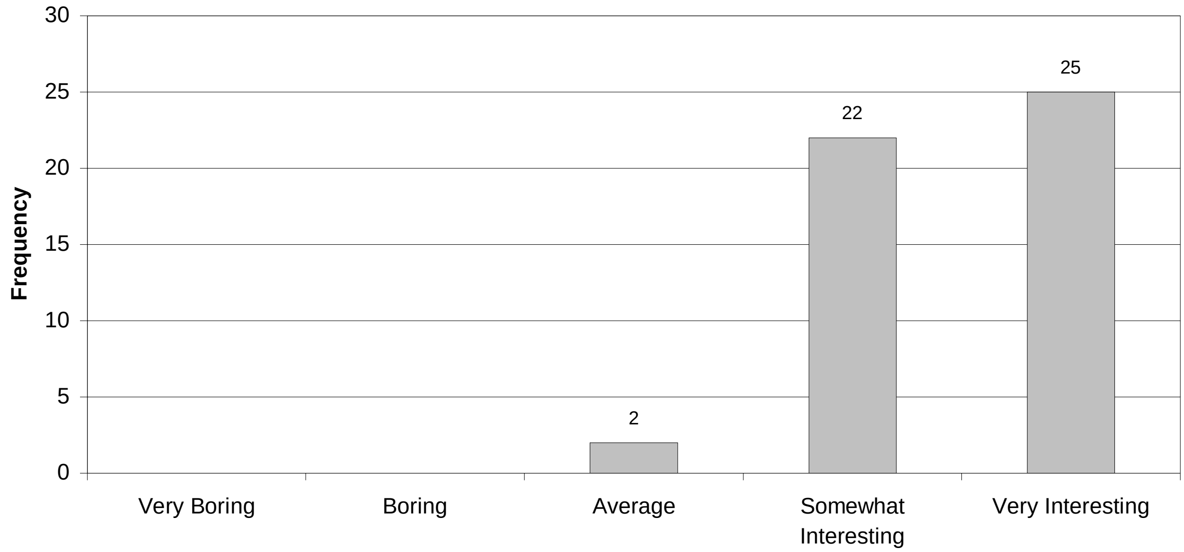


Figure 31. Distribution of inspector interest level in their work.

SRQ13. Imagine the following situation:

You are inspecting the superstructure of a steel girder/concrete deck bridge. The bridge is 60 ft high and the only means of access to the girders is from a snooper truck and the wind is gusting to 20 mph.

How fearful of the working height do you feel you would be?

Very Fearful	Somewhat Fearful	Mostly Fearless	No Fear
1	**2**	**3**	**4**

By proposing the hypothetical situation, it was envisioned that question SRQ13 would give insight into an inspector's fear of heights. The average response to question SRQ13 was approximately a 3 (Mostly Fearless), indicating that most inspectors are not bothered by modest working heights. As can be seen from figure 32, no inspector answered question SRQ13 with a 1. However, as will be discussed later, one inspector refused to use the 18.3-m boom lift necessary to complete Task H.

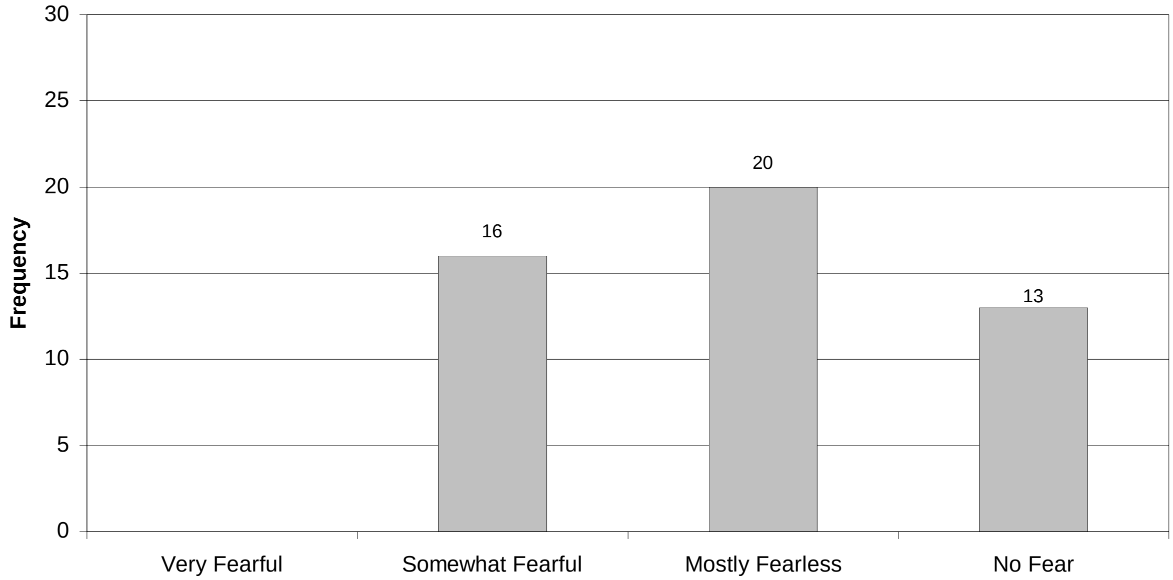


Figure 32. Distribution of reported fear of heights.

SRQ14. Imagine the following situation:

You are inspecting the interior of a 150-ft-long prestressed concrete box girder. The only light source is your flashlight. Traffic on the bridge continues uninterrupted and you can feel every passing vehicle.

How fearful of working in this enclosed space would you be?

Very Fearful	Somewhat Fearful	Mostly Fearless	No Fear
1	**2**	**3**	**4**

Similar to question SRQ13, this hypothetical scenario was presented with the goal of determining if inspectors might be afraid of working in enclosed spaces. With an average response of 3.1, it appears that most inspectors are generally not afraid of working in enclosed spaces. The distribution of the responses is shown in figure 33.

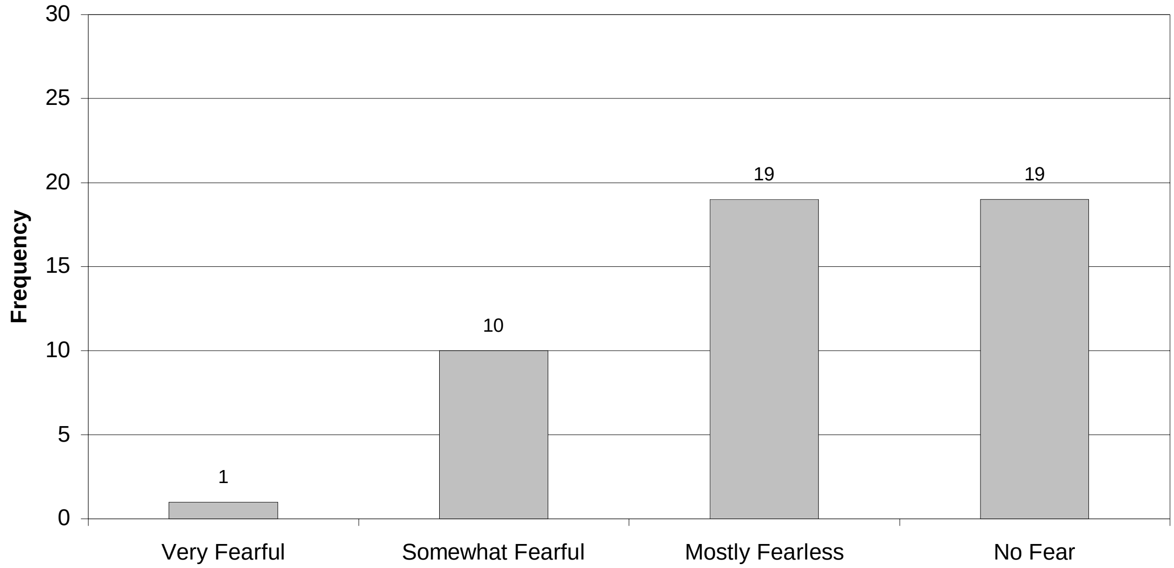


Figure 33. Inspector-reported fear of enclosed spaces.

SRQ15. Imagine the following situations:

You are completing an in-depth inspection of a major two-lane divided highway bridge. Only one lane can be closed at a time. Most of your time is spent kneeling at deck level to inspect the deck.

How fearful of the vehicular traffic do you feel you would be?

Very Fearful	Somewhat Fearful	Mostly Fearless	No Fear
1	**2**	**3**	**4**

The goal of this hypothetical situation was to ascertain if inspectors were afraid of being struck by vehicular traffic. Of the three scenarios presented in questions SRQ13 through SRQ15, inspectors indicated the greatest fear of traffic. The distribution of responses indicates that the traffic present during an inspection may have some influence on how inspections are completed. The distribution of the responses is shown in figure 34.

SRQ16. Have you ever been involved in an accident where you as a pedestrian were struck by a moving vehicle?
Yes No

To help interpret answers to question SRQ15, question SRQ16 sought to provide a reason for high fear levels. One inspector did report having been struck by a moving vehicle.

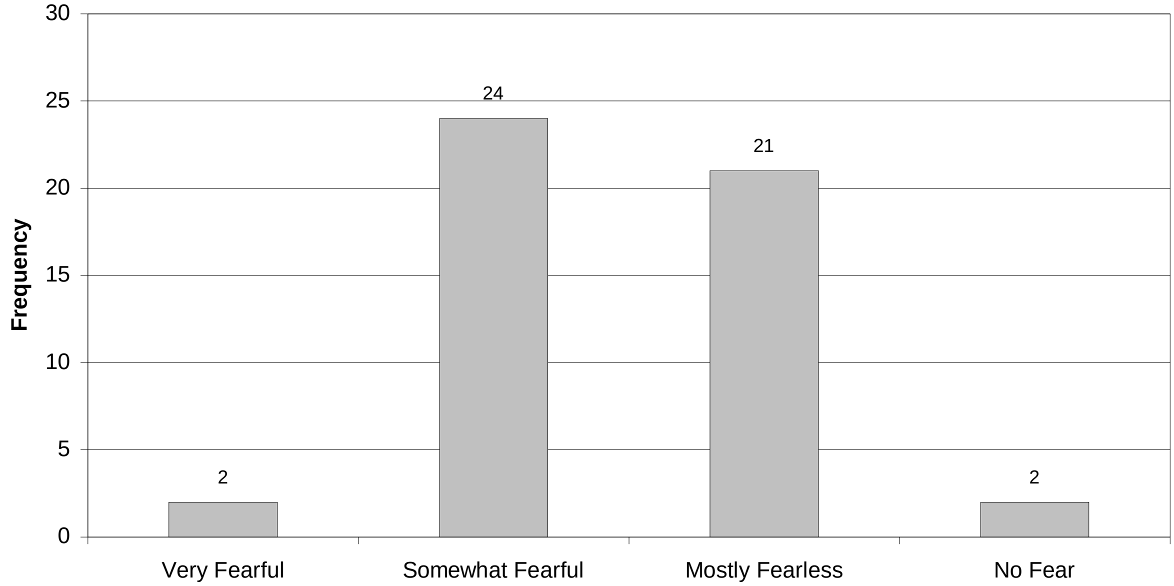


Figure 34. Inspector fear of vehicular traffic.

SRQ17. Have you ever been involved in an accident where you fell from typical bridge inspection working heights?
Yes No

This question was asked to help interpret the fear of heights levels determined from question SRQ13. Three inspectors indicated that they had fallen from a typical bridge inspection height. These particular inspectors indicated that they were either "somewhat fearful" or "mostly fearless" of heights in question SRQ13, indicating a low influence upon their current fear of heights.

SRQ18. What is the highest educational level that you have completed?

_____ Some High School			
_____ High School Degree or equivalent			
_____ Some Trade School			
_____ Trade School Degree			
_____ Some College			
_____ Associate's Degree	***Choose one***	***CE Technology***	***Other***
_____ Bachelor's Degree	***Choose one***	***Civil Engineering***	***Other***
_____ Some Graduate Work	***Choose one***	***Civil Engineering***	***Other***
_____ Master's Degree	***Choose one***	***Civil Engineering***	***Other***
_____ Terminal Degree (e.g., Ph.D.)	***Choose one***	***Civil Engineering***	***Other***
_____ Other: _________________			

There are many types of training thought to possibly have an influence on VI reliability. Question SRQ18 was developed to assess just one of these: general education level. Table 20 summarizes the response rate for each education level. This table shows that most inspectors have had some general education beyond high school and that many have completed a tertiary degree. However, less than half had obtained a bachelor's degree or higher.

Table 20. General Education Level.

Education Level	Number of Inspectors
Some High School	0
High School Degree or equivalent	10
Some Trade School	2
Trade School Degree	0
Some College	9
Associate's Degree	
CE Technology	3
Other	7
Bachelor's Degree	
Civil Engineering	12
Other	4
Some Graduate Work	
Civil Engineering	1
Other	0
Master's Degree	
Civil Engineering	1
Other	0
Terminal Degree	
Civil Engineering	0
Other	0
Other	0

SRQ19. What specific type of training have you had in bridge inspection? ***(you may check more than one)***

State Training
_____ In-house State-run bridge inspection training program.
_____ 'Apprentice' training on the job by experienced inspectors.
_____ Other: __________________

FHWA Training

_____ Bridge Inspector's Training Course Part I – Engineering Concepts for Bridge Inspectors (NHI #13054)
_____ Bridge Inspector's Training Course Part II – Safety Inspection of In-Service Bridges (NHI #13055)
_____ Inspection of Fracture-Critical Bridge Members Training Course
_____ Bridge Inspectors Training Course Refresher Training
_____ Nondestructive Testing Methods for Steel Bridges
_____ Culvert Design (NHI #13056)
_____ Other: _________________

Other: ____

____

In addition to general education, specific training in the area of bridge inspection may also influence VI reliability. Question SRQ19 was asked to determine the level of specific bridge inspection training courses that inspectors had completed. Thirty-seven inspectors indicated that they had completed some type of a State-run bridge inspection program and 32 inspectors indicated that they had received "apprentice"-type training from experienced inspectors. Ten inspectors indicated some type of "other" State training. Typical write-in answers included courses on scour, load rating, and the use of laptop computers. One inspector listed the Internet as a source of training.

Twenty-eight inspectors indicated that they had completed the Bridge Inspector's Training Course Part I, while 35 indicated that they had completed Part II. This percentage is consistent with the results of the State-of-the-Practice survey presented previously. Recall that more than 95 percent of the States require the Bridge Inspector's Training Course for team leaders and 79 percent of the States require it for other team members. It should, however, be pointed out that no distinction was made in the State-of-the-Practice survey between Parts I and II of the Bridge Inspector's Training Course. Thirty-five inspectors indicated that they had completed the course on the inspection of fracture-critical members. Only 21 inspectors had completed the refresher course, while 25 had completed the training course on the use of NDT for steel bridges. Eleven inspectors indicated that they had completed the FHWA training course on culvert design and six inspectors listed some type of "Other" FHWA training. The most common write-in answer, regardless of the source of the training, was training on scour. Some inspectors indicated training in underwater inspections, paint and coatings, and historic bridges.

SRQ20. How many years of experience do you have in bridge inspection? ______

SRQ21. How many years of experience do you have in highway structures? _____

SRQ22. Have you ever worked as an inspector in another industry (e.g., aircraft, nuclear power, etc.)?
Yes No

Questions SRQ20 through SRQ22 were asked to determine how much experience the inspectors had and where that experience was obtained. The average inspector had just over 10 years of experience in bridge inspection (standard deviation of 6.1 years) and approximately 11.5 years of experience in the general area of highway structures (standard deviation of 7.6 years). The minimum experience that any inspector indicated was under 1 year and the maximum was 26 years in bridge inspection and 32 years in highway structures. The distribution of the answers to question SRQ20 is shown in figure 35. Eleven of the participating inspectors also indicated that they had been an inspector in another industry.

Figure 35. Distribution of inspector experience in bridge inspection.

SRQ23. How many more years do you expect to be performing bridge inspection before you move to another job or retire? __________

It was envisioned that inspectors who were nearing the end of their bridge inspection careers might perform a less thorough inspection. This could result from being close to retirement, having so much experience that inspections become mundane, or from a lack of job satisfaction and plans to change positions. The average inspector indicated that they anticipated working as a bridge inspector for approximately 11 additional years. One inspector anticipated working as a bridge inspector for less than a year, while another anticipated 30 more years inspecting bridges.

SRQ24. Is your organization's bridge inspection philosophy more similar to a) or b)?

_____ a) Provide an adequate inspection with the goal being to comply with NBIS.

_____ b) Provide a thorough inspection with the goal being to find all defects.

In order to establish each State's general philosophy with regard to bridge inspection, question SRQ24 provided two distinct philosophies. Fifteen inspectors indicated that their organization's bridge inspection philosophy was more similar to (a), while 32 indicated (b). Of note, 10 States had one inspector indicate (a), while the other inspector from that State indicated (b), seemingly contradicting one another.

SRQ25. How do you mentally prepare to complete a typical bridge inspection? ***(you may check more than one)***

_____ Study previous inspection reports for the particular bridge.

_____ Study cases of similar bridges for help in determining probable places to look for defects.

_____ Mentally recall similar bridges you have inspected.

_____ No preparation.

Proper preparation for an inspection may lead to more efficient and accurate inspections. Question SRQ25 was asked to ascertain what types of preparation inspectors typically complete. Forty-four inspectors indicated that they would review previous inspection reports, 12 indicated that they study similar bridges, and 39 indicated that they think back to similar bridges they have inspected. Three inspectors indicated no preparation, which may be due to a lack of preparation time caused by a limited inspection season.

SRQ26. In general, do your supervisors: (check only one)

_____ a) Provide you with a detailed checklist of items to inspect while at the bridge site?

_____ b) Provide loose guidelines for the inspection but leave the exact process up to you?

_____ c) Allow you to inspect the bridge using solely your own techniques, skills, and knowledge of the bridge inspection process?

Determining how inspectors generally approach an inspection was the goal of question SRQ26. Responses were fairly well distributed among the three choices. Thirteen inspectors indicated (a), while 16 and 20 indicated (b) and (c), respectively. Clearly, various States have different levels of administrative control placed on the inspectors.

SRQ27. How would you describe your relationship with your direct superior?

Very Poor	Poor	Average	Good	Very Good
1	2	3	4	5

The relationship between inspectors and their supervisor could have implications on VI reliability. Quantifying the quality of this relationship was the goal of question SRQ27. In general, inspectors indicated a "good" to "very good" relationship with their superiors (average of 4.3, standard deviation of 0.66). Although not entirely indicative of job satisfaction, this is one aspect of their jobs with which inspectors appear to be satisfied. Figure 36 shows the distribution of inspector responses to question SRQ27.

SRQ28. Do you feel that management feels that the work you do is important?

Not at all	Slightly Important	Important	Very Important	Essential
1	2	3	4	5

The perception of being appreciated is a significant motivator for many employees. This was the information sought through question SRQ28. Inspectors generally perceive that management feels bridge inspection is very important, but not essential (average of 3.9, standard deviation of 0.93). This fact can be clearly seen in figure 37. It can also be seen from figure 37 that more than 10 percent of the inspectors perceive that management feels their work is only slightly important.

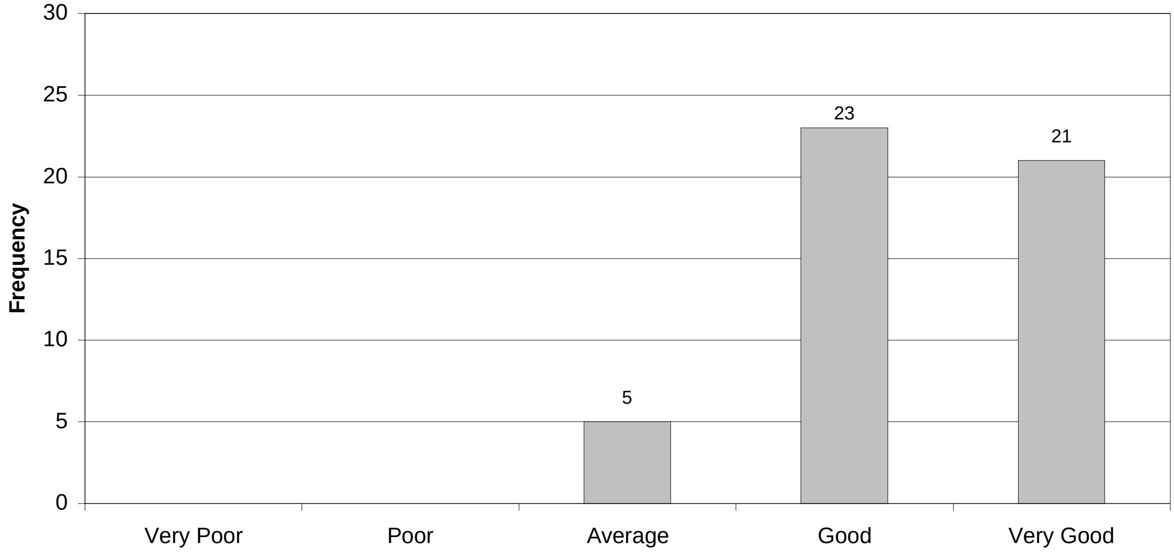


Figure 36. Quality of inspector relationship with direct superior.

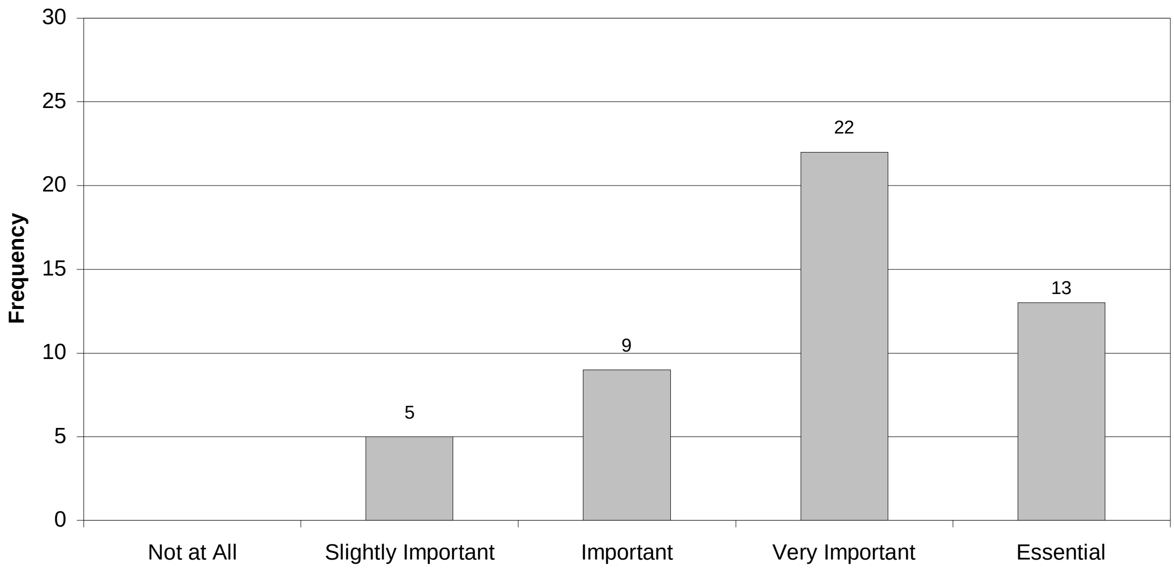


Figure 37. Inspector perception of the importance of inspection to management.

SRQ29. Within your duties for the State DOT, do you perform any work other than bridge inspection (i.e., construction inspection, etc.)? If so, what percentage of your time is spent at each activity?

Activity: Bridge Inspection % of time: __________
Activity: ___________________________________ % of time: __________
Activity: ___________________________________ % of time: __________
Activity: ___________________________________ % of time: __________

Bridge inspectors often have other duties in addition to bridge inspection. The goal of question SRQ29 was to determine how much time was actually devoted to bridge inspection and where other time might be allocated. On average, inspectors indicated that more than 80 percent of their time was spent on bridge inspection. The most common write-in activity was construction inspection. Also, one inspector indicated that approximately 20 percent of his time was spent on bridge inspection, while the remaining 80 percent was generally reserved for administrative duties and coordination with inspection contractors.

SRQ30. Given the following two definitions:

- **Routine Inspection—Routine Inspections are regularly scheduled inspections completed to determine the physical and functional condition of a bridge and to identify changes from the last inspection. Further, Routine Inspections serve to ensure that a bridge continues to satisfy all applicable serviceability requirements. Routine Inspections are also commonly known as NBI inspections.**
- **In-Depth Inspection—In-Depth Inspections are close-up, hands-on inspections of one or more bridge members in order to identify deficiencies not normally detectable during Routine Inspections.**

What percentage of your inspection duties could be classified as Routine Inspections?

____

What percentage of your inspection duties could be classified as In-Depth Inspections?

____

Assessing the split of time spent on Routine and In-Depth Inspections was the goal of question SRQ30. Inspectors indicated that approximately 65 percent of their inspections were Routine Inspections and 35 percent were In-Depth Inspections. However, the responses yielded a standard deviation of approximately 30 percent, indicating a fairly wide distribution of responses. In fact, inspectors indicated a range of Routine Inspection percentages from as little as 20 percent to as much as 99 percent. It should be pointed out that individual States may use different definitions than the ones presented above. These differences may have resulted in some inconsistent responses.

SRQ31. 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: __________

This question was repeated from the State-of-the-Practice survey with the goal of determining how inspectors' answers differed from State answers. Inspectors indicated that from one to seven people would be required (average of 2.3) and that the inspection would require between 0.5 man-hours and 28 man-hours (average of 5.3). The range of responses is indicative of the different inspection approaches used in different States. In comparison, responses from the State-of-the-Practice survey indicated a range of personnel from one to four (average of 2.0) with a time budget range from 0.5 to 16 man-hours (average of 4.8).

SRQ32. Estimate the percentage of bridge inspections completed with a registered Professional Engineer (PE) on-site. ***(circle one)***
0-20 20-40 40-60 60-80 80-100

Similar to question SRQ31, question SRQ32 was repeated from the State-of-the-Practice survey with a similar goal. Twenty-nine inspectors indicated 0 to 20 percent and 12 inspectors indicated 80 to 100 percent. This indicates that most States either use PEs nearly all of the time or very rarely use them. The remaining eight responses were fairly well distributed along the 20 to 80 range. These on-site percentages are similar to those obtained from the State-of-the-Practice survey. Recall that nearly 50 percent of the States indicated that a PE was on site for less than 20 percent of the inspections, while 25 percent indicated that a PE was on site for more than 60 percent of the inspections. Figure 38 shows the distribution of the responses.

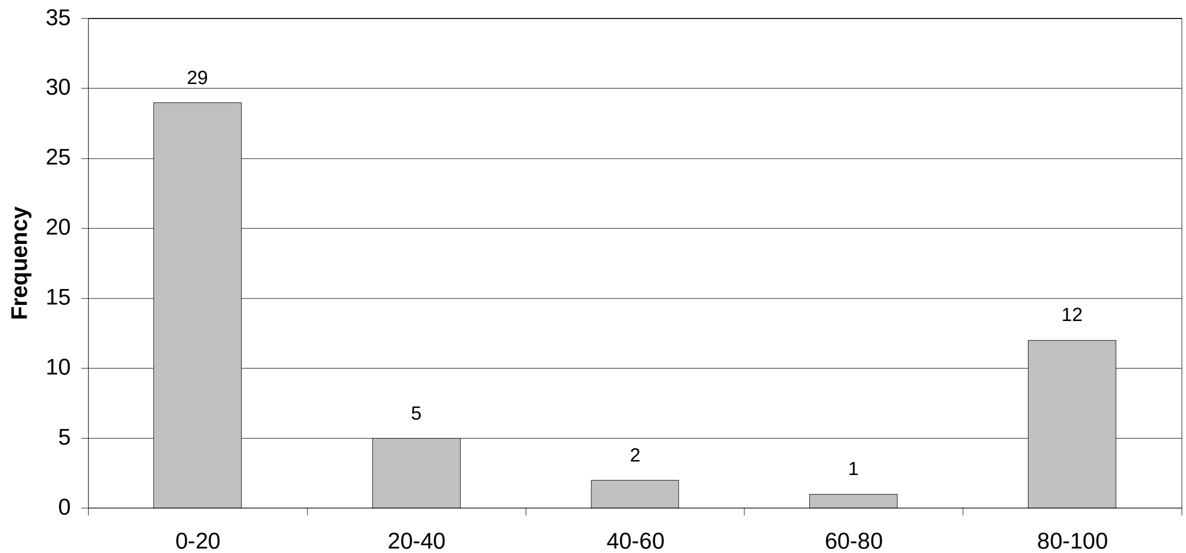


Figure 38. On-site percentage of PE indicated by inspectors.

After the conclusion of the field portion of the study, inspectors deemed likely to be registered PEs were asked a follow-up question. This question was asked to determine how many participants were registered. Of the 49 inspectors that participated, 7 were registered PEs.

SRQ33. Do you currently take any of the following substances?

Bilberry
Viagra
B vitamin complex

Yes No

Studies in other industries have shown that these substances may temporarily affect color vision. The goal with this question was to provide data for correlation with color vision deficiencies. Only three inspectors indicated that they were currently taking any of these substances. Of these three inspectors, color vision testing indicated a possible color vision deficiency for one of these inspectors.

SRQ34. In comparison to other bridge inspectors, how would you classify yourself based on your past performance?

Poor	Below average	Average	Above average	Excellent
1	**2**	**3**	**4**	**5**

Interestingly, the average answer to question SRQ34 was 3.6 (standard deviation of 0.76). The most common response was that the inspectors who participated in the study thought that they were an above average inspector. Figure 39 shows the distribution of inspector responses. The figure clearly shows that none of the inspectors thought they were below average or poor. It seems unlikely that an inspector would rate himself as "poor" or "below average" and, therefore, the answers to this question are probably artificially skewed to the right.

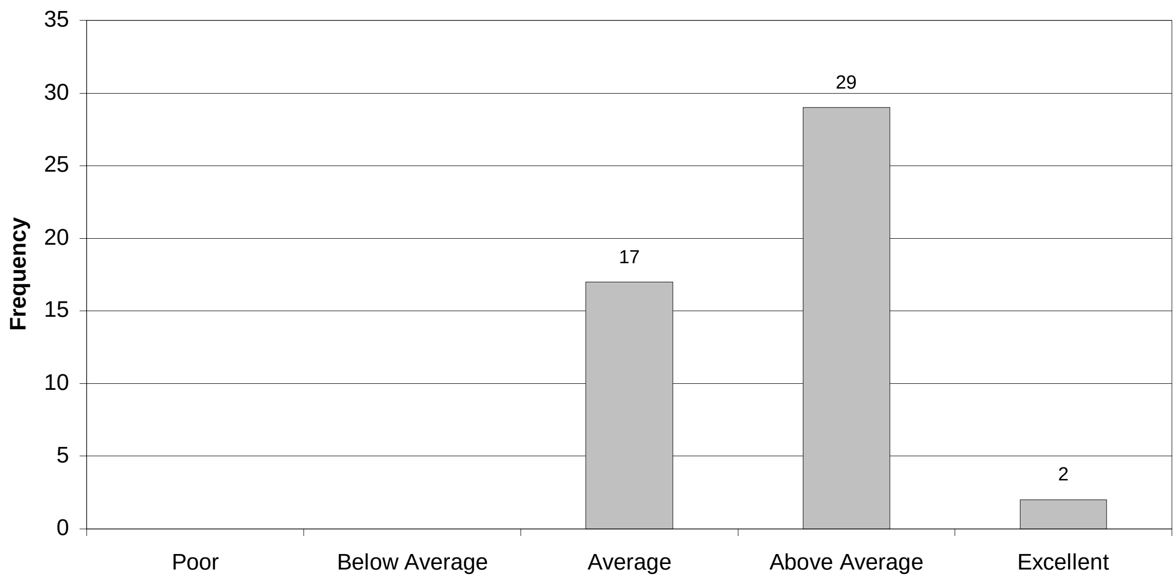


Figure 39. Inspector self-appraisal in comparison with other bridge inspectors.

SRQ35. If it was under your control, how do you think that bridge inspections could be improved?

____

____

____

Many times, the people most affected by administrative decisions are not directly involved in making those decisions. This question gave the inspectors a medium to provide suggestions for improving bridge inspection. Although a wide variety of write-in answers were given, they could generally be grouped into six broad categories. Two of the general categories focus on the number of bridge inspections each inspector must complete: more time per inspection and more inspectors/staff. In addition, some inspectors indicated that they would like more training and that an increase in uniformity in the rating system would increase inspection accuracy. The final two categories are directly related to the equipment the inspectors use: electronic data collection/modern field laptop computers and better access equipment.

SRQ36. Have you ever seen a bridge failure in person?
Yes No

If yes, please describe:

____
____
____

Firsthand experience with a bridge failure may have some impact on the care exercised during an inspection. Approximately half of the bridge inspectors had seen a bridge failure in person. The types of bridges that were described ranged from small pedestrian bridges to higher volume roadways. In the interest of maintaining anonymity, specific failures will not be discussed.

SRQ37. What time zone do you normally work in? _______________

The goal of this question was to assess whether jet lag influenced inspection performance. Twenty-seven of the inspectors normally work in the Eastern time zone, 12 in the Central time zone, four in the Mountain time zone, and six in the Pacific time zone. Note that this is a relatively even distribution when one considers the number of States in each time zone.

SRQ38. Approximately how many bridges do you inspect each year? _______________

The goal of this question was to quantify yearly bridge inspection experience. The average participating inspector indicated that they completed a total of 380 bridge inspections each year. The minimum that an inspector indicated was 50, while the maximum was 1,000. It should be pointed out that this question yielded a standard deviation of 245, indicating a wide distribution in the number of inspections completed.

SRQ39. Briefly describe how you became a bridge inspector.

____

____

____

Inspectors who became bridge inspectors by chance or by simply being moved into the position may not have the motivation to do as good of a job as those who sought out bridge inspection careers. Therefore, question SRQ39 asked inspectors to describe how they came to be an inspector. The most common answers to question SRQ39 were that they were either transferred from other areas in the DOT (14) or simply applied for the position in response to a job announcement (22). Two inspectors indicated that they were in the bridge inspection unit as part of a position “rotation” plan.

SRQ40. Within your organization, how important do you feel bridge inspection is?

Not Important	Slightly Important	Average	Somewhat Important	Very Important
1	2	3	4	5

Similar to some previous questions, question SRQ40 was developed to assess the importance of the work. Overall, inspectors felt that bridge inspection was between “somewhat important” and “very important” (average of 4.5) within their organization. This question differs from question SRQ28 where the inspectors indicated their perception of management’s view of the importance of bridge inspection. Figure 40 summarizes the distribution of the responses.

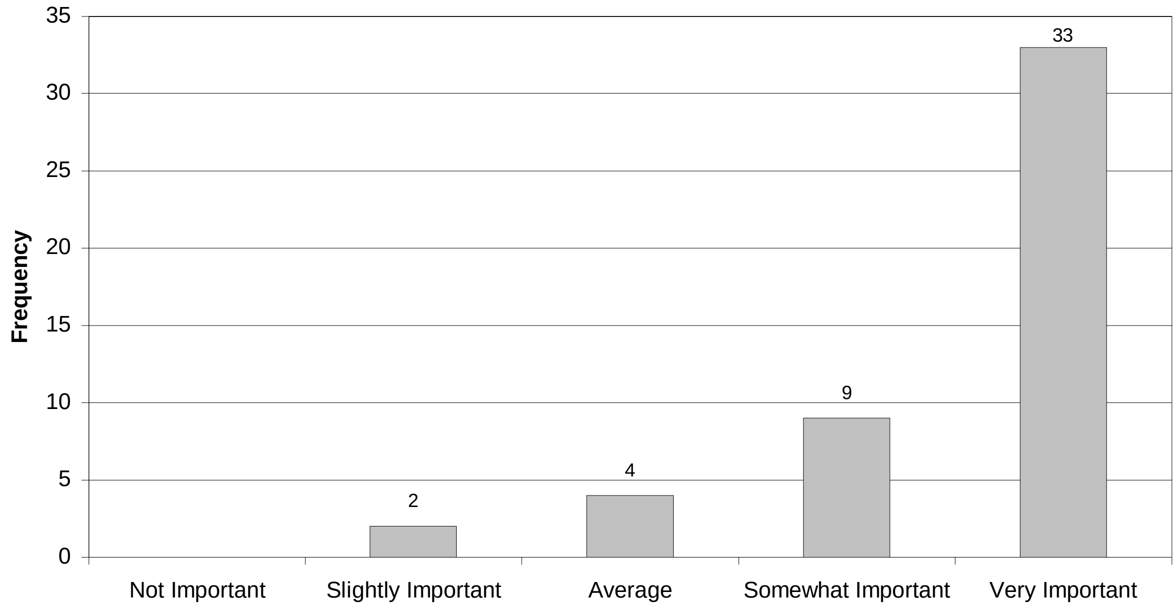


Figure 40. Inspector perception of bridge inspection within their organization.

5.1.2. Exit SRQ Results

As was mentioned previously, two SRQs were administered. The results from the initial SRQ were presented above. Questions ESRQ1 through ESRQ21 (out of 24) on the exit SRQ were identical to some of the questions on the initial SRQ. In general, inspectors gave the same answers to both questionnaires (e.g., question SRQ8: initial SRQ average was 1.94, exit SRQ average was 1.98). However, there were three questions on the exit SRQ not given on the initial SRQ that related to the inspectors' general perception of their participation in the study. The following summarizes the results of these three questions.

ESRQ22. Did you enjoy participating in these inspection tasks?
Yes   No

This question was asked to determine if the inspector enjoyed participating in the study. Of the 46 responding inspectors, only 3 indicated that they did not enjoy completing the tasks.

ESRQ23. Do you feel that the observers did a good job?
Yes   No

In order to ascertain if the inspectors thought that the observers did a good job, question ESRQ23 was asked. Only 1 of the 46 responding inspectors indicated that the observers did not do a good job. This indicates that, in general, the observers were cordial and tried to make a conscious effort to make the experience a pleasant one.

ESRQ24. On a scale from 1 to 10, what rating would you give the observers (1 = poor, 10 = excellent)?

____

Similar to question ESRQ23, question ESRQ24 was asked to gauge the inspectors' impression of the observers. The average response was an 8.2 (standard deviation of 1.2). The distribution of the responses is shown in figure 41.

5.1.3. Vision Test Results

The following summarizes the results of the three vision tests described previously. These vision tests were administered to assess three types of vision thought to influence VI.

5.1.3.1. NEAR AND DISTANCE VISUAL ACUITY

In general, inspectors had what could be considered "normal" near and distance visual acuity. Recall that inspectors were allowed to use any corrective lenses ordinarily used. However, there

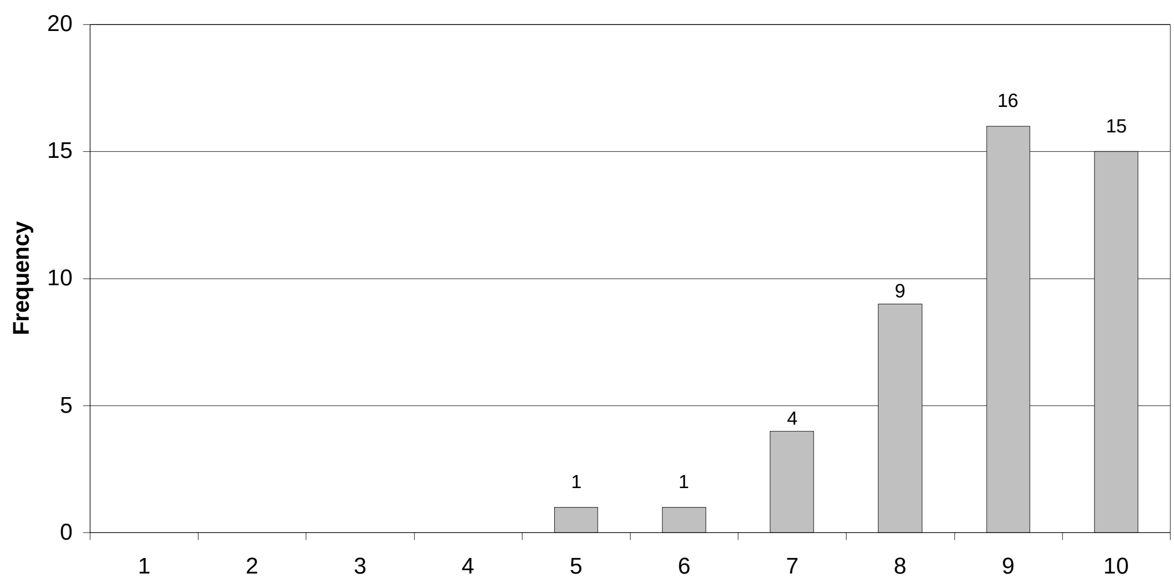


Figure 41. Distribution of inspector rating of observers.

was enough variation in the vision test results to be able to say that inspector vision is not necessarily 20/20. In two cases, an inspector had very poor visual acuity (i.e., 20/160 or worse) in one eye. However, those two inspectors had better than 20/20 vision (both near and distance) in the other eye. The distribution of near and distance visual acuity is shown in figures 42 and 43, respectively.

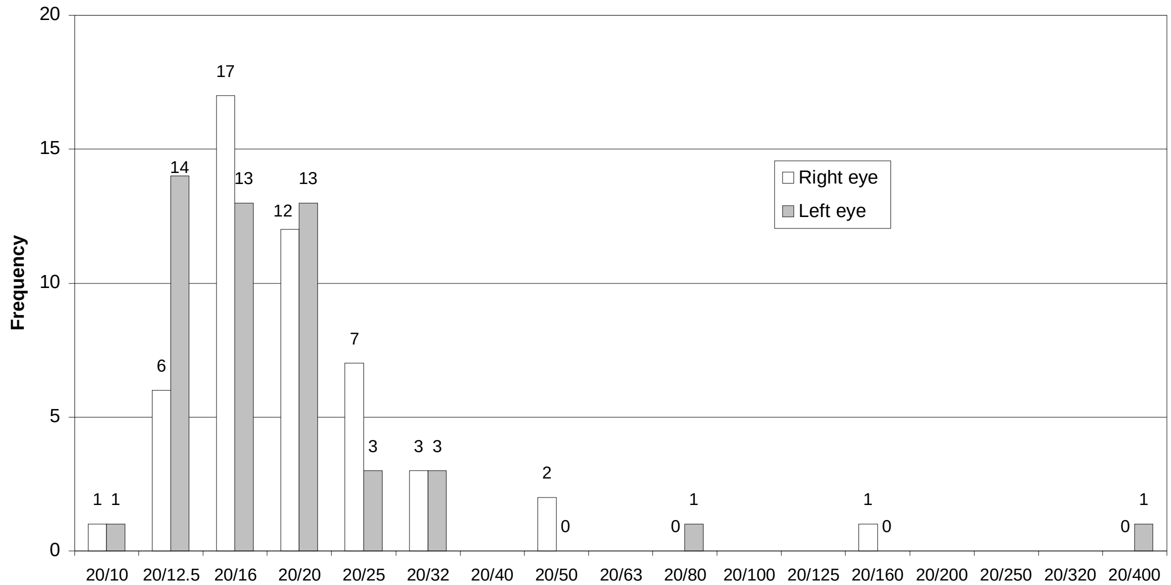


Figure 42. Distribution of near visual acuity.

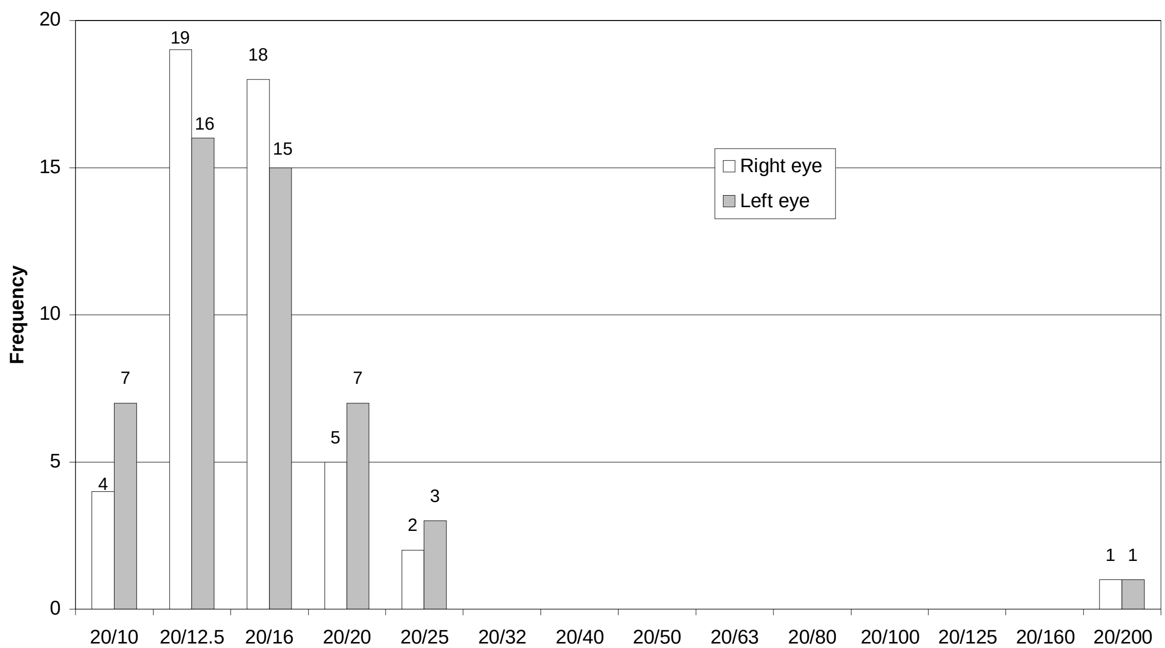


Figure 43. Distribution of distance visual acuity.

5.1.3.2. COLOR VISION

Approximately 10 percent of the general population exhibits some form of color vision deficiency. Consistent with this, the results of the color vision tests administered for this study indicated that 5 of 49 inspectors showed signs of a color vision deficiency. Of these five inspectors, two showed signs of Protan (i.e., red) color vision deficiency, one showed signs of Deutan (i.e., green) color vision deficiency, one showed signs of Tritan (i.e., blue) color vision deficiency, and one showed signs of all three types of color vision deficiencies.

5.1.4. Summary

Based on the responses to the SRQ questions and the results of the vision testing, it appears that the participating sample of bridge inspectors are, in general, representative of the population of bridge inspectors. However, it should be noted that although States were asked to send a “more” experienced inspector and a “less” experienced inspector, it is possible that some States may have sent two “more” experienced inspectors, skewing the sample.

5.2. ROUTINE INSPECTION RESULTS

The following sections present results from Tasks A, B, C, D, E, and G. These tasks are Routine Inspection tasks that typically resulted in three pieces of data. First, the three primary elements of each bridge were assigned Condition Ratings. Second, secondary bridge elements were also assessed and given Condition Ratings. Finally, to supplement the Condition Ratings, inspectors typically generated hand-written notes. During Task D, inspectors were also asked to provide visual documentation of their findings to supplement the Condition Ratings and notes. Results from the data collected during the Routine Inspection tasks are presented in the following sections. There are five primary subsections: a description of Routine Inspection and the inspection process; statistical analysis of the primary element Condition Ratings, including an assessment of the relationship of human and environmental factors; analysis of the photographs generated during Task D; analysis of inspection notes; and general statistical analysis of secondary element Condition Ratings.

5.2.1. Description of Routine Inspection

Before presenting the results of the Routine Inspection tasks, the following discussion presents the previously given definition of Routine Inspection used in this study. The *Manual for Condition Evaluation of Bridges, 1994* defines "Routine Inspection" as follows:[3]

> "Routine Inspections are regularly scheduled inspections consisting of observations and/or measurements needed to determine the physical and functional condition of the bridge, to identify any changes from "Initial" or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements.
>
> The Routine Inspection must fully satisfy the requirements of the National Bridge Inspection Standards with respect to maximum inspection frequency, the updating of Structure Inventory and Appraisal data and the qualifications of the inspection personnel. These inspections are generally conducted from the deck, ground and/or water levels, and from permanent work platforms and walkways, if present. Inspection of underwater portions of the substructure is limited to observations during low-flow periods and/or probing for signs of undermining. Special equipment, rigging, or staging, is necessary for Routine Inspection in circumstances where its use provides for the only practical means of access to areas of the structure being monitored.
>
> The areas of the structure to be closely monitored are those determined by previous inspections and/or load rating calculations to be critical to load-carrying capacity. In-Depth Inspection of the areas being monitored should be performed in accordance with Article 3.2.4. If additional close-up, hands-on inspection of other areas is found necessary during the inspection, then an In-Depth Inspection of those areas should also be performed in accordance with Article 3.2.4.
>
> The results of a Routine Inspection should be fully documented with appropriate photographs and a written report that includes any recommendations for maintenance or repair and for scheduling of follow-up In-Depth Inspections if necessary. The load

> capacity should be re-evaluated to the extent that changed structural conditions would affect any previously recorded ratings."

In general, the Routine Inspection tasks completed as part of this study were administered and completed according to this definition. One notable deviation from this standard definition was the identification of changes from initial or previously recorded conditions. For these tasks, inspectors were not provided with previously recorded inspection information, thus ensuring that each inspector was recording their estimation of the bridge conditions and not simply relying on the accuracy of previously completed inspections. Another deviation from the standard definition occurred in the level of access allowed during some tasks. Specifically, there were safety constraints that prevented the inspectors from gaining full access to some bridges (e.g., use of ladders was prohibited completely for one task (Task C) and limited on another (Task E), and access to the deck was restricted on a third (Task G)).

5.2.2. Routine Inspection Process

The following summarizes how inspectors approached and completed the Routine Inspection tasks. In addition, the conditions under which they were completed and the inspectors' perceptions of the inspections are also presented. Data for this discussion comes from three previously described sources – the pre-task questionnaires, the firsthand observations, and the post-task questionnaires.

5.2.2.1. TASK A

Task A is the Routine Inspection of Bridge B521, an in-service, single span, through-girder bridge. Inspectors were allowed 40 min to complete the inspection with an average time of 38 min (standard deviation of 6 min) and a minimum and maximum completion time of 23 min and 50 min, respectively. Figure 44 shows the frequency distribution of completion times.

Figure 45 and table 21 summarize the pre-task question results in which inspectors provided quantitative responses. From this table, it can be seen that, on average, it had been slightly more than half a year since each inspector had last inspected a bridge of a similar type. Note that three

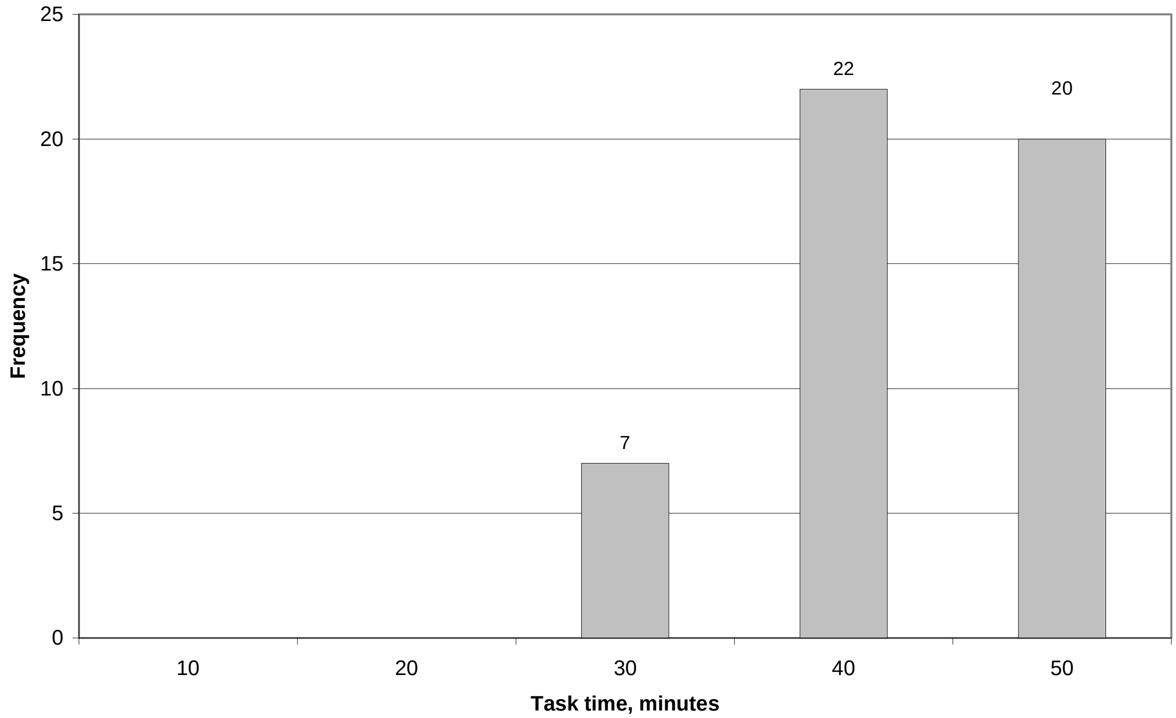


Figure 44. Task A – Actual inspection time.

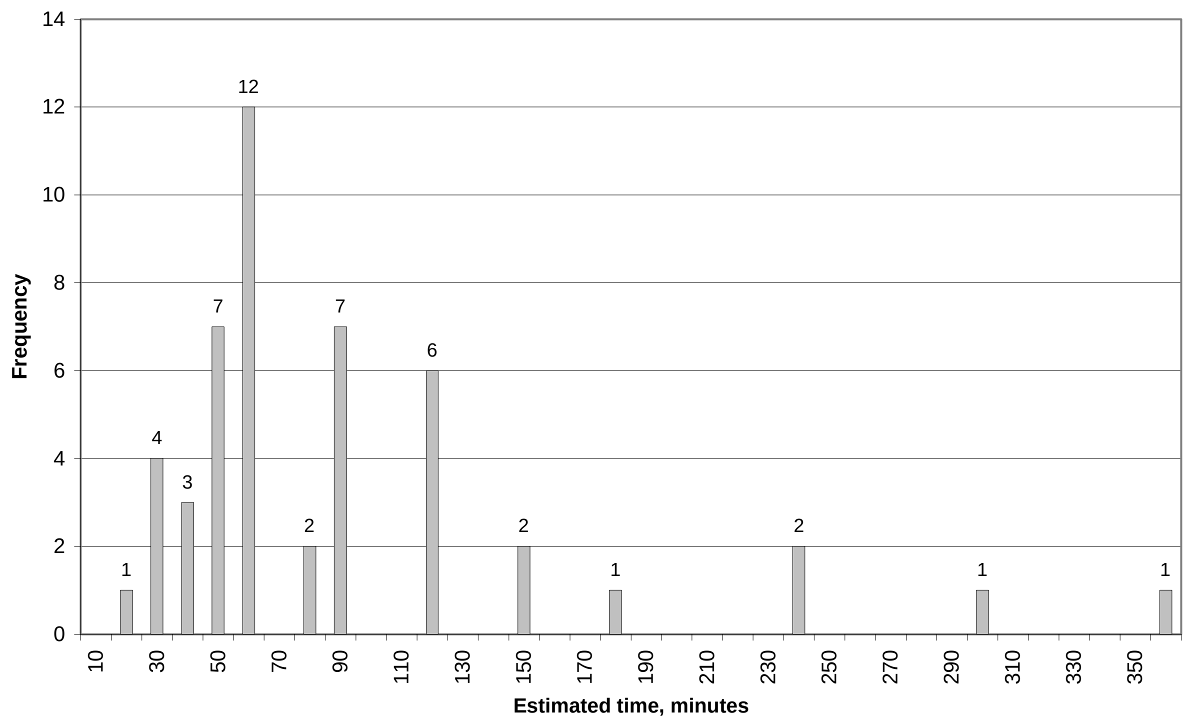


Figure 45. Task A – Predicted inspection time.

Table 21. Task A – Quantitative pre-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)?	N/A*	N/A	26.8	64.2	416	1
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	90.1	70.0	360	20
How rested are you?	1 = very tired	9 = very rested	7.2	1.3	9	3

* N/A = Not applicable.

of the participating inspectors had never inspected a bridge similar to Bridge B521, and the time since a similar inspection only considers inspectors who had inspected a similar bridge. Also, the average predicted time, as shown in the table, was 125 percent more than was being allowed. Finally, table 21 shows that, overall, inspectors indicated a relatively high rested level before beginning this task. It should be pointed out that Task A was typically the first task performed in the morning or after lunch.

During Task A, inspectors were provided with two ladders (a 2.4-m stepladder and a 9.75-m extension ladder) and given full access to the superstructure from below. In order to assess what types of access equipment would normally be used for this type of an inspection, inspectors were asked to describe the type of equipment they would typically use. Table 22 summarizes their responses. Although none occurs here, the "Other" category of respondents would typically be specialized pieces of equipment that could not feasibly be grouped in another category. Note that some inspectors indicated that they would use multiple types of access equipment and therefore the sum of percentages is greater than 100 percent.

Table 22. Task A – Normal access equipment use.

Accessibility Equipment/Vehicle Type	Percentage of Respondents
Snooper	10%
Lift	24%
Ladder	51%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	2%
None	20%
Other	0%

Prior to initiation of the inspection, the inspectors were asked to describe the type of construction used on the bridge. The goal of this question was to assess if inspectors recognized important aspects of the structure that could influence how it should be inspected. The results from this question are summarized in table 23. The 39 percent of the inspectors indicating an "Other" characteristic typically were providing a description of the type of bearing. Only 6 percent of the inspectors indicated that the structure was simply supported and only 4 percent noted that the bridge was skewed.

Table 23. Task A – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Floor beams	65%
Riveted	65%
Cast-in-place concrete slab	61%
Steel through girder	59%
Plate girder	53%
Fracture-critical	45%
Simply supported	6%
Skewed	4%
Asphalt overlay	4%
Other	39%

To further assess inspector familiarity with similar inspections, inspectors were asked to identify problems that they might expect to find on a bridge of a similar type, general condition, and age. The responses are summarized in table 24. The 47 percent "Other" responses could generally be grouped into five categories: bearing problems, pack rust, joint deterioration, chloride contamination, and abnormal member distortions.

Table 24. Task A – Problems expected.

Problem Type	Percentage of Respondents
Steel corrosion or section loss	86%
Concrete deterioration	75%
Fatigue-cracking	29%
Leakage	29%
Underside deck cracking	22%
Missing rivets or rivet heads	20%
Paint deterioration	18%
Settlement cracking of abutments	16%
Cracked or loose asphalt	14%
Leaching	12%
Impact damage	10%
Inadequate concrete cover	4%
Other	47%

While the inspector was completing the inspection, the observer had three primary duties to complete. First, to monitor and record the environmental conditions. Second, to record which portions of the bridge were inspected. Finally, to note what inspection tools were used. Tables 25 through 28 summarize this information. Table 25 presents the direct environmental measurements made during the inspections, including temperature, humidity, heat index (calculated from the temperature and humidity), wind speed, and light intensity at two locations. To supplement the environmental data presented in table 25, a qualitative descriptor of the environmental conditions was also noted and is summarized in table 26.

Table 25. Task A – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (°C)	22.7	5.5	31.7	12.2
Humidity (%)	61.5	17.9	89	28
Heat Index (°C)	23	5.6	32	12
Wind Speed (km/h)	5.1	6.6	22.5	0.0
Light Intensity Under Center of Superstructure (lux)	15,290	22,290	96,190	226
Light Intensity at Deck Level (lux)	43,240	38,850	122,450	1,420

Table 26. Task A – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	29%
20 – 40% Cloudy	22%
40 – 60% Cloudy	0%
60 – 80% Cloudy	2%
80 – 100% Cloudy	12%
Hazy	6%
Fog	4%
Drizzle	18%
Steady Rain	6%
Thunderstorm	0%

In order to document an inspector's activities during the inspection, a list of some important inspection items was developed. When an inspector inspected a certain portion of the structure, regardless of how thoroughly it may have been completed, the observer noted that the item had been inspected. The data for Task A are presented in table 27. From this table, the percentage of inspectors completing each specific inspection item can be observed. It is clear from the data that the majority of the inspectors initiated most of the recorded "inspect" items. However, although all inspectors inspected both abutments, less than 70 percent were observed looking at the wingwalls and very few did any sounding of the substructure.

The observers also noted which inspection tools were used. This information is presented in table 28. Note how few inspectors used the ladder, a flashlight, or any sounding tools.

As with all tasks, the Task A post-task questions were typically related to the inspector's impression of the inspection, as well as the inspector's mental and physical condition. In all, 11 quantitative questions were asked for this task, with the results presented in table 29. The data in this table show that, in general, the inspectors felt that Task A was fairly similar to their normal inspections. Not surprisingly, they also reported that the task was fairly accurate at measuring their inspection skills. It can also be seen that, as compared to the results in table 21, the inspectors were slightly less rested at the completion of the task than at the initiation. Furthermore, inspectors felt that they understood the instructions that they were given, and most thought that, overall, the bridge was fairly accessible. Inspectors reported that being observed

Table 27. Task A – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
General	Check Overall Alignment (west side)	26%
	Check Overall Alignment (east side)	28%
Superstructure	Inspect East Girder	98%
	Inspect West Girder	100%
	Inspect North Bearings	92%
	Inspect South Bearings	96%
	Inspect Floorbeams	100%
	Inspect East Girder Above Deck Level	96%
	Inspect West Girder Above Deck Level	98%
	Inspect East Transverse Stiffeners	90%
	Inspect West Transverse Stiffeners	92%
Substructure	Inspect North Abutment	100%
	Sound North Abutment	18%
	Inspect South Abutment	100%
	Sound South Abutment	18%
	Inspect Northwest Wingwall	67%
	Sound Northwest Wingwall	2%
	Inspect Northeast Wingwall	63%
	Sound Northeast Wingwall	2%
	Inspect Southwest Wingwall	65%
	Sound Southwest Wingwall	6%
	Inspect Southeast Wingwall	60%
	Sound Southeast Wingwall	4%
Deck	Inspect East Curb	94%
	Sound East Curb	18%
	Inspect West Curb	98%
	Sound West Curb	20%
	Inspect East Curb to Web Interface	88%
	Inspect West Curb to Web Interface	86%
	Inspect North Transverse Expansion Joint	71%
	Inspect South Transverse Expansion Joint	55%
	Inspect Underside of Deck	98%

Table 28. Task A – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	24%
2.4-m Stepladder	0%
9.75-m Extension Ladder	55%
Any Flashlight	16%
Two AA-Cell Flashlight	0%
Three D-Cell Flashlight	4%
Lantern Flashlight	12%
Any Sounding Tool	45%
Masonry Hammer	45%
Chain	2%
Level as a Level	0%
Level as a Straightedge	0%
Binoculars	22%
Magnifying Glass	2%
Engineering Scale	6%
Protractor	4%
Plumb Bob	0%
String	0%
Hand Clamp	0%

had minimal influence on their performance. They reported their effort level was, on average, about the same as normal and that they were slightly less thorough than normal. In most cases, when inspectors indicated that they were less thorough than normal, this was often attributed to not having sufficient time to gain access to particular bridge components, such as every vertical stiffener in the superstructure. It should be pointed out that the average reported rushed level for Task A equaled that of Task E, both reporting average rushed levels of 3.6 — the highest encountered in this study. This indicates that inspectors may have thought that they needed additional time to complete the inspection.

5.2.2.2. TASK B

Task B is the Routine Inspection of Bridge B101A, a single-span, concrete T-beam bridge. Inspectors were given 50 min to complete the inspection, with the average inspector using 35 min (standard deviation of 11 min) and a minimum and maximum completion time of 14 min and 55 min, respectively. Figure 46 shows the distribution of inspection times.

Table 29. Task A – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How similar were these inspection tasks to the tasks performed in your normal Routine Inspections?	1 = not similar	9 = very similar	7.1	2.0	9	1
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.1	1.5	9	2
How rested are you?	1 = very tired	9 = very rested	7.1	1.3	9	3
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.4	0.7	9	7
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	7.7	1.1	9	6
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	5.9	1.3	8	3
How complex was this bridge?	1 = very simple	9 = very complex	4.1	1.2	6	2
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	2.7	2.0	7	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	3.6	2.6	9	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.0	0.6	7	3
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	4.3	1.3	6	1

Table 30 summarizes the quantitative pre-task question responses for Task B. On average, it had been about 5 months since inspectors had inspected a similar bridge. One inspector indicated that he had never inspected a bridge similar to Bridge B101A. There was significant variability in the predicted time (see figure 47) required to complete the inspection (15 min to 480

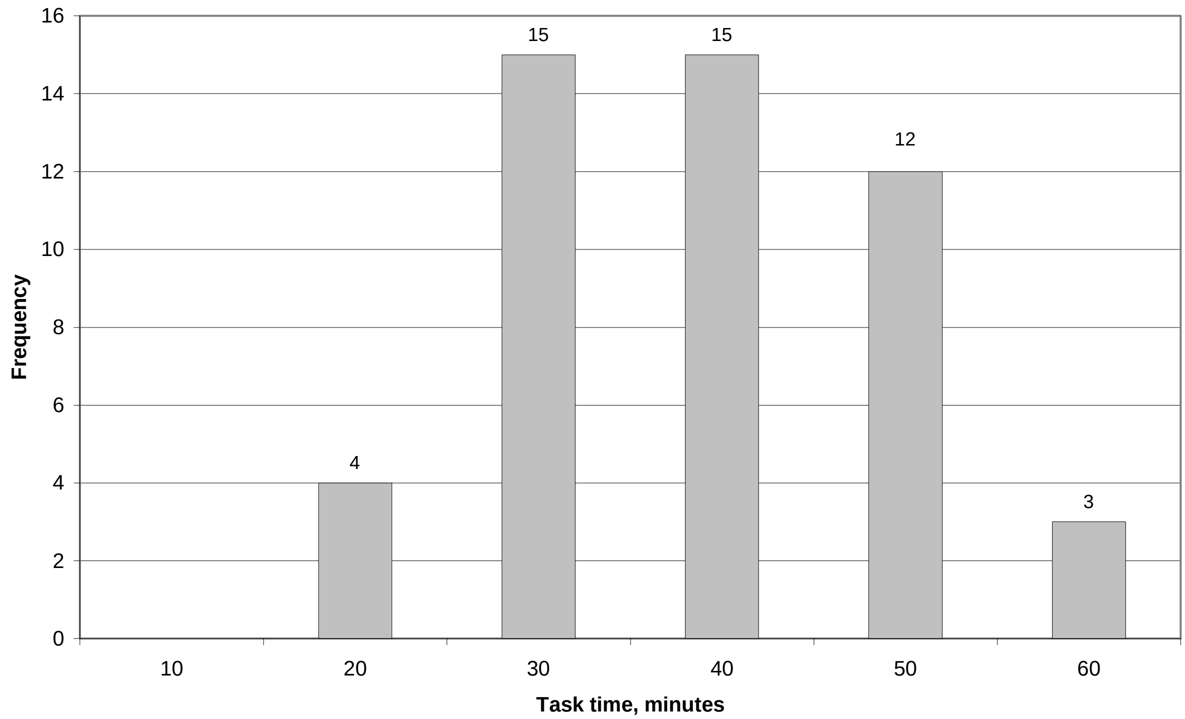


Figure 46. Task B – Actual inspection time.

min) and the average predicted time was about 70 percent more than was being allowed. At the initiation of Task B, the average inspector indicated that they were as rested as they were at the beginning of Task A (average rested level of 7.2).

As during Task A, inspectors were provided with ladders and were allowed full access to the superstructure from below. Table 31 illustrates the types of access equipment that inspectors indicated they would typically have used to complete Task B.

Although Bridge B101A is a relatively simple structure, there are some key attributes of the bridge that may influence how it should be inspected. Table 32 presents the inspector responses regarding the type of construction used on Bridge B101A. Although nearly all inspectors indicated that the bridge was constructed using concrete T-beams, only two inspectors (4 percent) indicated that the structure was simply supported. For this question, the “Other” responses were typically related to the deck/wearing surface and that there was only one span.

Table 30. Task B – Quantitative pre-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)?	N/A*	N/A	21.0	43.5	208	1
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	83.8	93.4	480	15
How rested are you?	1 = very tired	9 = very rested	7.2	1.3	9	3

* N/A = Not applicable

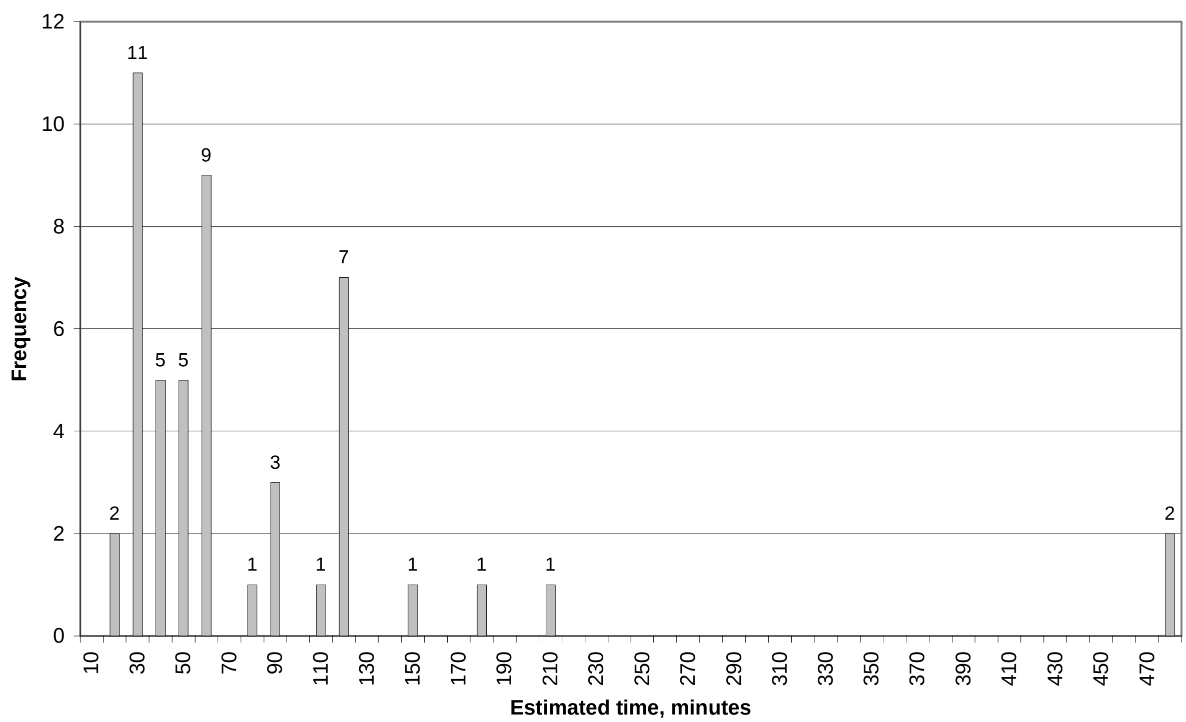


Figure 47. Task B – Predicted inspection time.

Table 31. Task B – Normal access equipment use.

Accessibility Equipment/Vehicle Type	Percentage of Respondents
Snooper	0%
Lift	14%
Ladder	57%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	0%
None	20%
Other	0%

Table 32. Task B – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Concrete T-Beam	94%
Cast-in-Place Reinforced Concrete Deck	77%
Simply Supported	4%
Other	13%

Inspector responses regarding anticipated problems are summarized in table 33. Note that 100 percent of the inspectors expected to find concrete deterioration; however, there was less consensus on how that deterioration would be manifested (concrete spalling was the most frequently cited response). For this question, two typical responses in the "Other" category were chloride contamination and general misalignment.

Table 33. Task B – Problems expected.

Problem Type	Percentage of Respondents
Concrete Deterioration	100%
Concrete Spalling	65%
Concrete Delamination	38%
Underside Cracking of Deck	38%
Leaching	33%
Leakage	27%
Settlement Cracking of Abutments	21%
Inadequate Concrete Cover	10%
Expansion Joint Deterioration	8%
Freeze/Thaw Damage	6%
Impact Damage	4%
Other	8%

As during Task A, the observer monitored the environmental conditions, what inspection items were initiated, and what tools were used. Tables 34 through 37 summarize these observations. From table 34, there generally was very little light under the superstructure and the average temperature was just slightly cooler under the bridge during Task B than during Task A. Table 35 indicates that the inspections were typically performed when the sky was fairly clear; however, 18 percent of the inspectors did complete the inspection in rain or drizzle. From table 36, it can be seen that, with the exception of inspecting the joints, there was a greater than 50 percent item initiation rate on all “inspect” items, while there was less than a 50 percent inspection item initiation rate on all “sound” items. This information, along with the data from table 37, indicates that only about half of the inspectors used the sounding equipment to assess the extent of the concrete deterioration. Even though there was minimal light below the superstructure, only 10 percent of the inspectors used a flashlight. As had been previously mentioned, Bridge B101A has a significant bow in the east abutment wall. Ten percent of the inspectors used the 610-mm level as a straightedge to estimate the amount of bowing. The one inspector (2 percent) who used the string, used it to extend the length of the plumb bob string.

Table 38 summarizes the 11 questions administered at the completion of Task B. From these data, it can be seen that, in general, the inspectors thought that Task B was similar to their normal inspections and required about the same effort level. Note that upon completion of this task, the rested level had dropped from an average of 7.2 at the beginning of the task down to an average of 7.0.

5.2.2.3. TASK C

Similar to Task B, Task C consisted of the Routine Inspection of Bridge B111A, a decommissioned, single-span, concrete T-beam bridge. Inspectors were allowed 30 min to complete the inspection, with the inspectors using an average of 24 min (standard deviation of 6 min), with a minimum and maximum completion time of 11 and 34 min, respectively. Figure 48 shows the distribution of inspection times.

Table 34. Task B – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (°C)	22.2	5.37	31.7	10.0
Humidity (%)	61.4	17.7	87	29
Heat Index (°C)	22	5.4	32	10
Wind Speed (km/h)	2.6	2.8	12.9	0.0
Light Intensity Under Center of Superstructure (lux)	73	57	228	5
Light Intensity at Deck Level (lux)	42,070	31,650	108,350	1,940

Table 35. Task B – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	47%
20 – 40% Cloudy	12%
40 – 60% Cloudy	4%
60 – 80% Cloudy	6%
80 – 100% Cloudy	12%
Hazy	0%
Fog	0%
Drizzle	12%
Steady Rain	6%
Thunderstorm	0%

Table 36. Task B – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
Superstructure	Inspect T-Beams	100%
	Sound T-Beams	24%
	Inspect Longitudinal Expansion Joint	90%
Substructure	Inspect West Abutment	100%
	Sound West Abutment	43%
	Inspect West Abutment Joint	90%
	Sound Near West Abutment Joint	33%
	Inspect East Abutment	100%
	Sound East Abutment	35%
	Inspect East Abutment Joint	88%
	Sound Near East Abutment Joint	24%
	Inspect Northeast Wingwall	59%
	Sound Northeast Wingwall	10%
	Inspect Northwest Wingwall	61%
	Sound Northwest Wingwall	16%
	Inspect Southeast Wingwall	61%
	Sound Southeast Wingwall	12%
	Inspect Southwest Wingwall	65%
	Sound Southwest Wingwall	12%
	Inspect Northeast Wingwall/Abutment Joint	86%
	Sound Northeast Wingwall/Abutment Joint	22%
	Inspect Northwest Wingwall/Abutment Joint	96%
	Sound Northwest Wingwall/Abutment Joint	31%
	Inspect Southeast Wingwall/Abutment Joint	86%
	Sound Southeast Wingwall/Abutment Joint	24%
	Inspect Southwest Wingwall/Abutment Joint	92%
	Sound Southwest Wingwall/Abutment Joint	31%
Deck	Inspect North Parapet	96%
	Sound North Parapet	19%
	Inspect South Parapet	92%
	Sound South Parapet	16%
	Inspect Underside of Deck	96%
	Sound Underside of Deck	20%
	Inspect Wearing Surface	94%
	Inspect West Transverse Expansion Joint	45%
	Inspect East Transverse Expansion Joint	39%

Table 37. Task B – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	41%
2.4-m Stepladder	0%
9.75-m Extension Ladder	24%
Any Flashlight	10%
Two AA-Cell Flashlight	0%
Three D-Cell Flashlight	8%
Lantern Flashlight	2%
Any Sounding Tool	53%
Masonry Hammer	51%
Chain	4%
Level as a Level	4%
Level as a Straightedge	10%
Binoculars	0%
Magnifying Glass	0%
Engineering Scale	2%
Protractor	0%
Plumb Bob	6%
String	2%
Hand Clamp	0%

Because of the similarity of Bridge B111A to the bridge inspected during Task B (Bridge B101A), many of the pre- and post-task questions were not repeated for Task C. The only question asked before the inspectors began Task C was related to their rested level. The inspectors reported an average rested level of 7.0 (standard deviation of 1.2), with a minimum and maximum of 3 and 9, respectively. Note that the average rested level at the completion of Task B was also 7.0 (standard deviation of 1.3).

Table 39 summarizes the measured environmental conditions and table 40 gives the qualitative weather condition during Task C. As before, the majority of the inspections were completed on mostly sunny days, with conditions similar to those recorded during Task B.

Table 38. Task B – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How similar were these inspection tasks to the tasks performed in your normal Routine Inspections?	1 = not similar	9 = very similar	7.9	1.2	9	5
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.6	1.0	9	5
How rested are you?	1 = very tired	9 = very rested	7.0	1.3	9	3
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.5	0.7	9	6
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	7.9	1.2	9	3
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	2.7	1.7	7	1
How complex was this bridge?	1 = very simple	9 = very complex	3.0	1.5	7	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	1.8	1.2	5	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	2.2	1.8	7	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.2	1.1	9	3
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	4.9	1.2	7	2

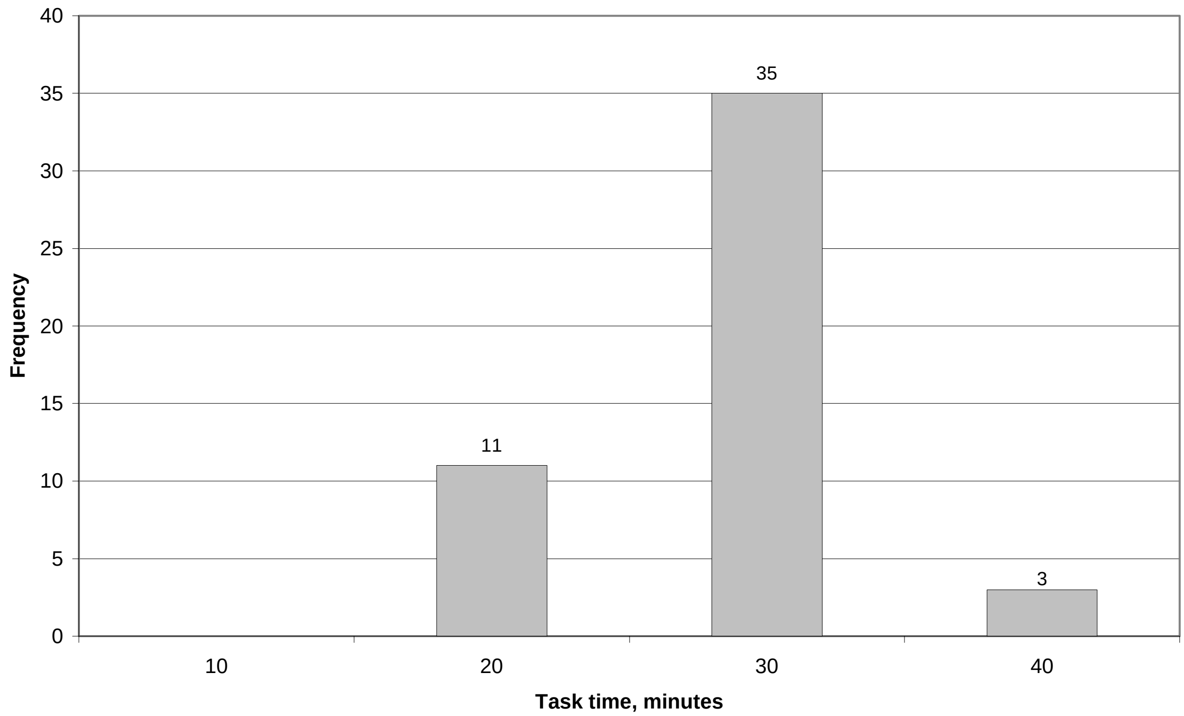


Figure 48. Task C – Actual inspection time.

Table 39. Task C – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (°C)	23.4	5.4	32.2	11.7
Humidity (%)	55.5	17.7	88	22
Heat Index (°C)	23	5.3	32	12
Wind Speed (km/h)	3.4	3.4	11.3	0.0
Light Intensity Under Center of Superstructure (lux)	226	108	549	28
Light Intensity at Deck Level (lux)	49,180	35,870	115,890	4,090

Table 40. Task C – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	45%
20 – 40% Cloudy	14%
40 – 60% Cloudy	4%
60 – 80% Cloudy	0%
80 – 100% Cloudy	18%
Hazy	4%
Fog	0%
Drizzle	10%
Steady Rain	4%
Thunderstorm	0%

Table 41 summarizes the inspection item data for Task C. It should be reiterated that inspectors were not allowed to use a ladder to access the superstructure due to the traffic volume, speeds, and sight distances near the bridge. As with previous tasks, the majority of the inspectors completed most of the "inspect" items, while few completed the "sounding" items. Furthermore, inspectors generally completed fewer "sounding" inspection items during Task C than they did during Task B. This can probably be attributed to two factors. First, the overall condition of the Task B bridge is generally worse than that of the Task C bridge. Second, familiarity with the Task B bridge probably led to a greater confidence in their ability to visually determine the condition of the Task C bridge, thereby requiring less sounding. Overall, the use of the inspection tools was very limited during Task C, as summarized in table 42. It can also be seen that 31 percent of the inspectors used the masonry hammer and that no other tool was used by more than 10 percent of the inspectors.

Upon completion of Task C, inspectors were again asked a series of questions. Certain questions asked following Task B were omitted from the Task C series of questions. Table 43 summarizes the responses. Similar to previous tasks, the completion of the task resulted in the average inspector "Rested Level After Task" dropping from 7.0 to 6.9. As one would expect, inspectors generally indicated that the Task C bridge had been maintained better than the Task B bridge (4.1 versus 2.7).

Table 41. Task C – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
Superstructure	Inspect T-Beams	100%
	Sound T-Beams	0%
	Inspect Longitudinal Expansion Joint	90%
Substructure	Inspect West Abutment	100%
	Sound West Abutment	20%
	Inspect West Abutment Joint	94%
	Sound Near West Abutment Joint	20%
	Inspect East Abutment	100%
	Sound East Abutment	39%
	Inspect East Abutment Joint	86%
	Sound Near East Abutment Joint	39%
	Inspect Northeast Wingwall	49%
	Sound Northeast Wingwall	10%
	Inspect Northwest Wingwall	53%
	Sound Northwest Wingwall	8%
	Inspect Southeast Wingwall	47%
	Sound Southeast Wingwall	8%
	Inspect Southwest Wingwall	49%
	Sound Southwest Wingwall	6%
	Inspect Northeast Wingwall to Abutment Joint	82%
	Sound Northeast Wingwall to Abutment Joint	14%
	Inspect Northwest Wingwall to Abutment Joint	78%
	Sound Northwest Wingwall to Abutment Joint	16%
	Inspect Southeast Wingwall to Abutment Joint	80%
	Sound Southeast Wingwall to Abutment Joint	18%
	Inspect Southwest Wingwall to Abutment Joint	78%
	Sound Southwest Wingwall to Abutment Joint	12%
Deck	Inspect North Parapet	90%
	Sound North Parapet	13%
	Inspect South Parapet	94%
	Sound South Parapet	12%
	Inspect Underside of Deck	100%
	Sound Underside of Deck	0%
	Inspect Wearing Surface	98%
	Inspect West Transverse Expansion Joint	27%
	Inspect East Transverse Expansion Joint	35%

Table 42. Task C – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	8%
2.4-m Stepladder	0%
9.75-m Extension Ladder	0%
Any Flashlight	8%
Two AA-Cell Flashlight	0%
Three D-Cell Flashlight	6%
Lantern Flashlight	2%
Any Sounding Tool	33%
Masonry Hammer	31%
Chain	4%
Level as a Level	0%
Level as a Straightedge	0%
Binoculars	0%
Magnifying Glass	0%
Engineering Scale	0%
Protractor	0%
Plumb Bob	0%
String	0%
Hand Clamp	0%

5.2.2.4. TASK D

In this task, inspectors were asked to complete a Routine Inspection of Bridge B543. In addition to providing the standard Condition Ratings and field notes, inspectors were asked to use a digital camera to provide visual documentation of their findings. Results related to these photographs will be discussed in a subsequent section. Inspectors were allotted 40 min to complete Task D, with an average time used of 30 min (standard deviation of 7 min). The minimum and maximum completion times were 18 and 43 min, respectively. The distribution of inspection times is shown in figure 49.

As has been described previously, table 44 summarizes the quantitative pre-task questions for Task D. On average, it had been more than 6 months since the inspectors had last inspected a similar bridge. The average estimated inspection time was 68 min (70 percent more time than allotted). One inspector indicated that the inspection would only require 12 min to complete, while another inspector anticipated needing 5 h. The distribution of predicted inspection times is shown in figure 50.

Table 43. Task C – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How rested are you?	1 = very tired	9 = very rested	6.9	1.3	9	3
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.5	0.6	9	6
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	7.4	1.4	9	1
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	4.1	1.8	8	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	1.7	1.1	6	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	2.6	2.3	9	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	4.9	1.1	8	1
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	4.9	1.3	8	1

Although inspectors were provided with the two ladders described previously, the geometry of Bridge B543 is such that they could not safely be used to access the underside of the superstructure. Table 45 summarizes the types of access equipment that inspectors indicated they would typically use on an inspection similar to Task D. Note that the most common response was that no access equipment would normally be used.

As before, inspectors were asked to describe the type of construction used on the bridge. Table 46 summarizes the responses. One important result from this table is that none of the inspectors noted that the bridge was skewed, despite the fact that skew on this type of bridge has implications on the overall structural behavior. It should also be noted that most of the "Other"

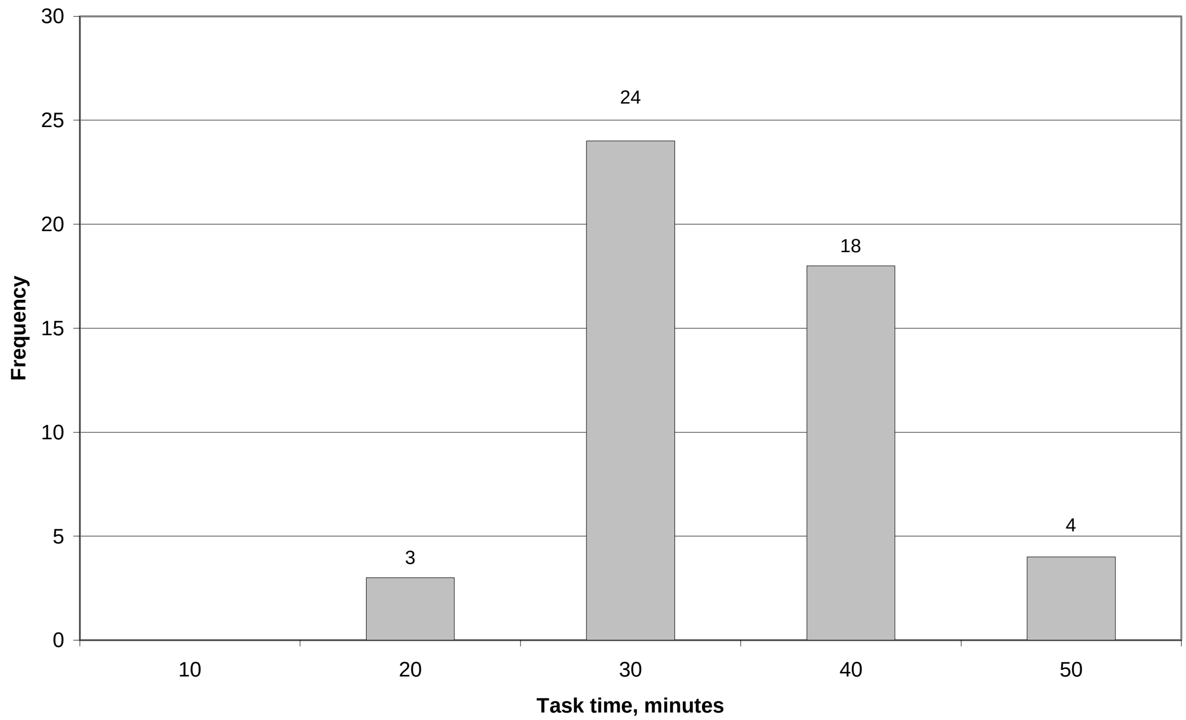


Figure 49. Task D – Actual inspection time.

responses were responses related to the general structure type, such as arch, concrete arch, arch slab, slab bridge, concrete box, etc., that did not precisely fit with the "concrete rigid frame" description. Other responses in this category described the substructure or the asphalt overlay.

As shown in table 47, when the inspectors were asked what types of deterioration they might expect to find on Bridge B543, only 8 percent indicated that they expected to find freeze/thaw damage. Note that the physical conditions at the bridge included concrete parapets that are severely deteriorated and this deterioration is very obvious as one approaches the bridge. As shown in table 47, the specific types of deterioration that they were expecting to find were quite varied, with "concrete spalling" being the most commonly cited. The two "Other" responses were related to the bridge joints and initial construction defects.

Table 44. Task D – Quantitative pre-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)?	N/A*	N/A	28.8	39.7	225	1
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	67.5	43.3	300	12
How rested are you?	1 = very tired	9 = very rested	7.0	1.2	9	4

* N/A = Not applicable.

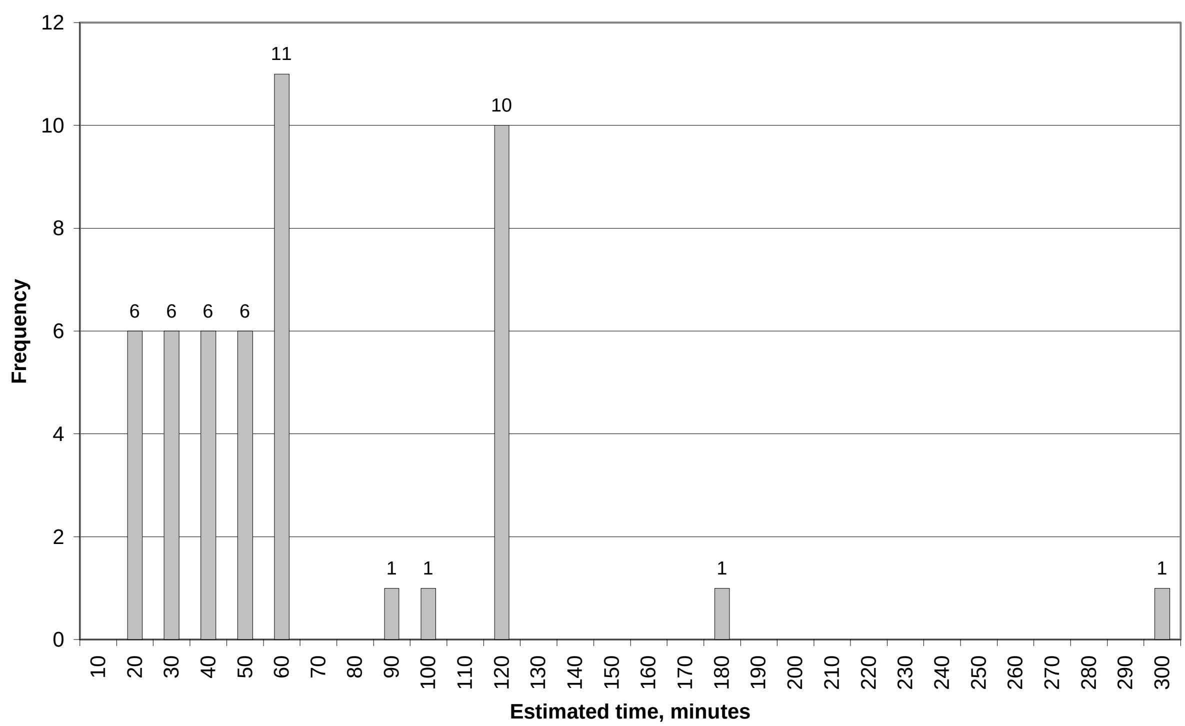


Figure 50. Task D – Predicted inspection time.

Table 45. Task D – Normal access equipment use.

Accessibility equipment/vehicle type	Percentage of Respondents
Snooper	0%
Lift	20%
Ladder	35%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	2%
None	41%
Other	0%

Table 46. Task D – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Concrete rigid frame	63%
Skewed	0%
Other	39%

Table 47. Task D – Problems expected.

Problem Type	Percentage of Respondents
Concrete Deterioration	96%
Concrete Spalling	45%
Underside Cracking of Deck	39%
Settlement Cracking of Abutments	33%
Concrete Delamination	29%
Leaching	24%
Leakage	20%
Expansion Joint Deterioration	14%
Inadequate Concrete Cover	10%
Freeze/Thaw Damage	8%
Impact Damage	6%
Other	4%

Data collected by the observers during this task are presented in tables 48 through 51. From the data on the weather conditions (tables 48 and 49), it can be seen that Task D was completed under various conditions. Bridge B543 is located in a fairly unique location. The top of the deck is very exposed and the landscape offers little protection from sun, wind, or rain. However, the area under the bridge is very well protected and offers inspectors shelter from the weather, while at the same time lowering the light intensity. Table 50 summarizes the inspection item data. Interestingly, 88 percent of the inspectors inspected the south elevation, but only 67 percent inspected the north elevation. This is possibly attributable to the relatively steep terrain on the north side. This fact indicates that structure accessibility can have an influence on how an inspection is completed. Almost no sounding was performed on this bridge. From table 51, it can be seen that 4 percent of the inspectors used a ladder during the inspection. These inspectors used the ladder to inspect and/or sound the abutment wall and the abutment-to-deck interface. In addition, note that only 18 percent of the inspectors used a flashlight even though the embankment on the north end limited the light intensity under the bridge.

Table 48. Task D – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (°C)	23.9	4.8	31.1	13.3
Humidity (%)	55.5	15.4	81	27
Heat Index (°C)	24	5.0	38	13
Wind Speed (km/h)	1.3	2.1	8.0	0.0
Light Intensity Under Center of Superstructure (lux)	415	1,702	12,020	9
Light Intensity at Deck Level (lux)	53,350	32,130	99,420	1,510

Table 49. Task D – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	41%
20 – 40% Cloudy	12%
40 – 60% Cloudy	4%
60 – 80% Cloudy	6%
80 – 100% Cloudy	18%
Hazy	0%
Fog	0%
Drizzle	8%
Steady Rain	10%
Thunderstorm	0%

Table 50. Task D – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
Superstructure	Inspect Arch for Cracking	96%
	Inspect Longitudinal Expansion Joint	96%
	Inspect North Elevation	67%
	Inspect South Elevation	88%
Substructure	Inspect West Abutment	100%
	Sound West Abutment	20%
	Inspect East Abutment	100%
	Sound East Abutment	20%
	Inspect Northeast Wingwall	16%
	Sound Northeast Wingwall	4%
	Inspect Northwest Wingwall	39%
	Sound Northwest Wingwall	4%
	Inspect Southeast Wingwall	59%
	Sound Southeast Wingwall	6%
	Inspect Southwest Wingwall	63%
	Sound Southwest Wingwall	6%
Deck	Inspect North Parapet	100%
	Sound North Parapet	10%
	Inspect South Parapet	100%
	Sound South Parapet	12%
	Inspect Wearing Surface	96%
	Inspect West Transverse Expansion Joint	33%
	Inspect East Transverse Expansion Joint	33%

A series of post-task questions were asked of inspectors after completing Task D. The response data are given in table 52. The majority of these data are similar to that provided for other tasks and similar conclusions can be drawn. However, when asked about bridge accessibility, the average response was more than 7 on a scale of 1 to 9. This indicates that the inspectors felt that the bridge was fairly accessible. This is despite the fact that effectively and safely using a ladder was very difficult and the northern embankment obviously influenced accessibility.

Table 51. Task D – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	22%
2.4-m Stepladder	0%
9.75-m Extension Ladder	4%
Any Flashlight	18%
Two AA-Cell Flashlight	2%
Three D-Cell Flashlight	12%
Lantern Flashlight	4%
Any Sounding Tool	35%
Chain	4%
Masonry Hammer	33%
Level as a Level	0%
Level as a Straightedge	4%
Binoculars	0%
Magnifying Glass	0%
Engineering Scale	2%
Protractor	0%
Plumb Bob	0%
String	0%
Hand Clamp	0%

5.2.2.5. TASK E

Task E is the Routine Inspection of Bridge B544, which is a decommissioned, single-span, riveted steel bridge. Inspectors were allotted 60 min to complete the inspection, with the inspectors using an average of 52 min (standard deviation of 9 min). The quickest inspector completed the inspection in 31 min, while others used the full 60 min. The distribution of actual inspection times is shown in figure 51.

Table 53 summarizes three questions asked during the pre-task evaluation. The data show that, in general, inspectors had fairly recently inspected a similar bridge. The average predicted time to complete the task was 104 min. This average estimated time is nearly twice that being allotted and, as before, there was significant dispersion in the estimates. In fact, the longest estimated time was 21 times longer than the shortest estimate. The distribution of predicted inspection times is shown in figure 52.

Table 52. Task D – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How similar were these inspection tasks to the tasks performed in your normal Routine Inspections?	1 = not similar	9 = very similar	7.7	1.5	9	2
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.4	1.3	9	5
How rested are you?	1 = very tired	9 = very rested	6.8	1.4	9	2
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.4	0.6	9	7
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	7.4	1.8	9	1
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	3.6	1.8	8	1
How complex was this bridge?	1 = very simple	9 = very complex	2.8	1.6	7	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	1.9	1.2	6	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	2.9	2.3	7	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.1	0.7	7	4
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	5.0	0.8	7	3

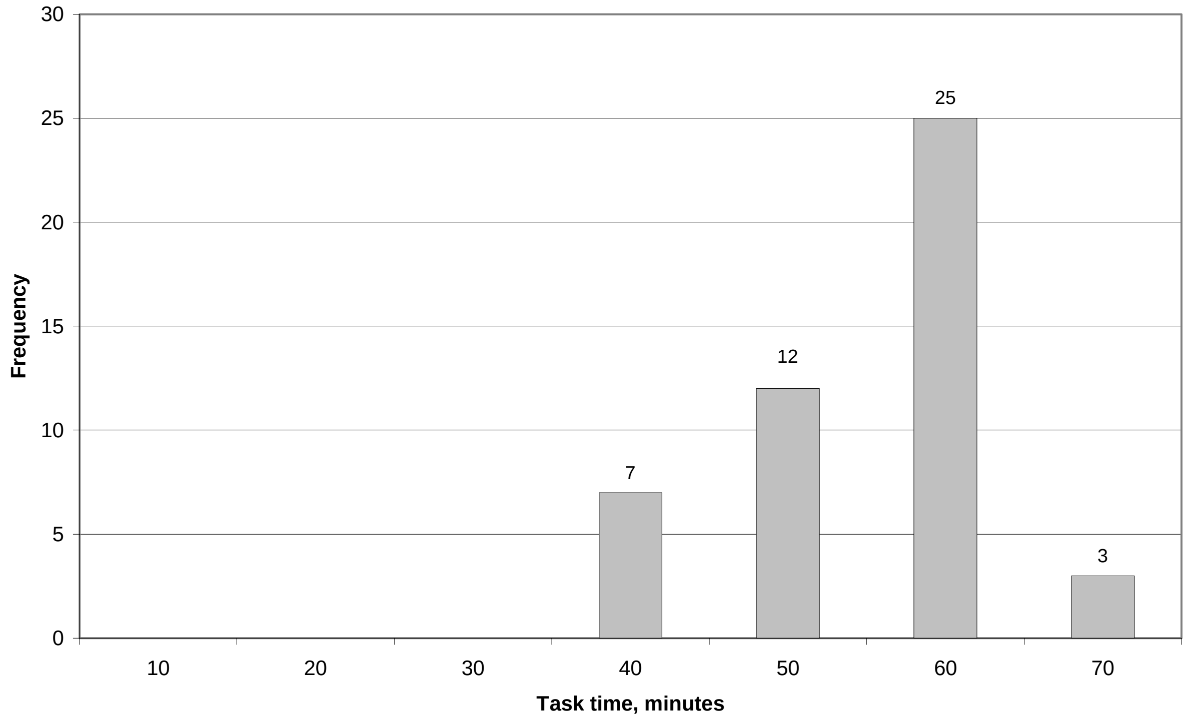


Figure 51. Task E – Actual inspection time.

Table 53. Task E – Quantitative pre-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)?	N/A*	N/A	16.5	20.5	104	0.5
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	103.6	77.2	360	17
How rested are you?	1 = very tired	9 = very rested	7.1	1.1	9	5

* N/A = Not applicable.

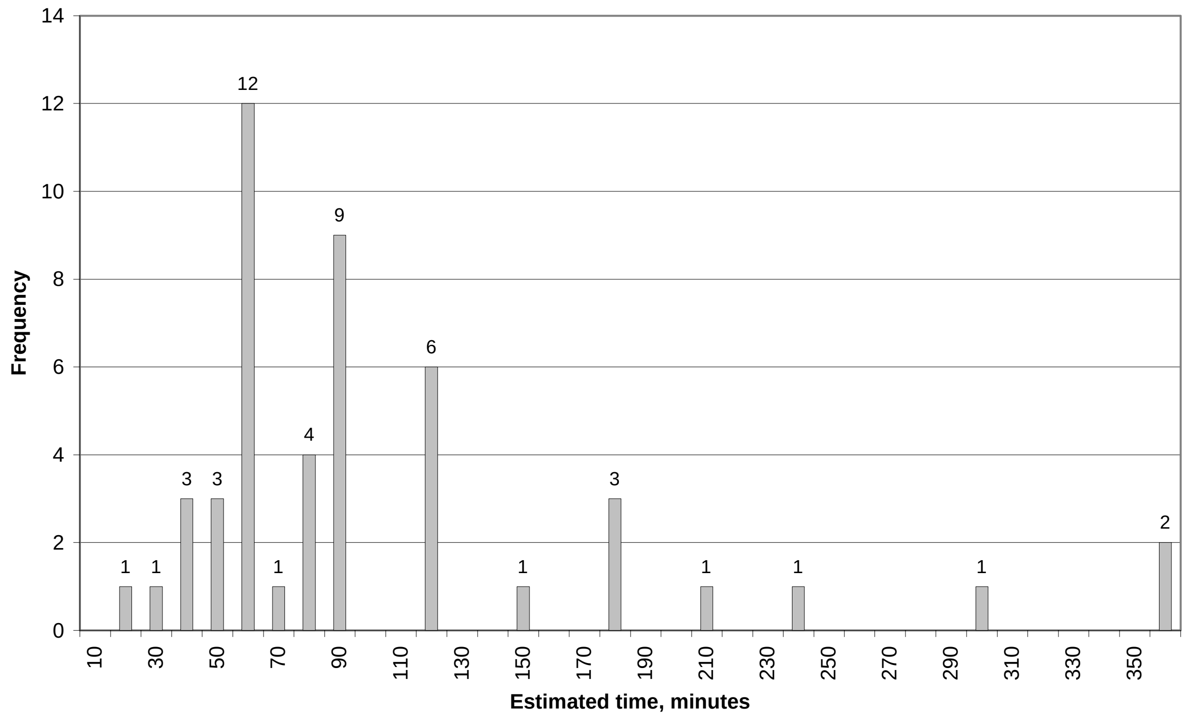


Figure 52. Task E – Predicted inspection time.

Although inspectors were provided with ladders, their use was restricted to areas that would not interfere with U.S. Route 30. Therefore, access to the superstructure was limited to areas near the bearings. Table 54 summarizes the types of access equipment that the inspectors indicated that they would typically have used. The most common responses included the use of a ladder and the use of no special access equipment. The inspectors generally indicated that because of the heavy traffic and the limited site distances due to the roadway alignment, they would only use special access equipment on this bridge to perform an In-Depth Inspection.

When the inspectors were asked to describe the type of construction used on Bridge B543, nearly all inspectors indicated that it was a riveted, steel plate girder bridge, as shown by table 55. However, only 8 percent of the inspectors noted that the bridge was skewed. The relatively large skew on this bridge influences the behavior of the bridge and could have implications on how it should be inspected. In addition, only 31 percent of the inspectors noted the unusual configuration of floor beams and sway frames. This important feature of Bridge B544 is indicative of the unusual behavior of the concrete deck (e.g., two-way slab vs. one-way slab).

Table 54. Task E – Normal access equipment use.

Accessibility Equipment/Vehicle Type	Percentage of Respondents
Snooper	10%
Lift	22%
Ladder	55%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	2%
None	29%
Other	0%

Table 55. Task E – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Steel Plate Girder	86%
Riveted	78%
CIP Concrete Slab	65%
Floor beams/Sway Frames	31%
Simply Supported	31%
Skewed	8%
Asphalt Overlay	6%
Other	20%

The most common "Other" response was related to the type of substructure. Also, one inspector indicated that the bridge did not have any welds when, in fact, there were a few welds. Finally, one inspector indicated that the superstructure was welded and another referred to the superstructure as a through-girder.

As can be seen in table 56, the most common problems that inspectors expected to find were corrosion of the steel and general concrete deterioration. "Other" types of identified deterioration included deterioration of the deck, joints, and bearings.

Tables 57 through 60 summarize the data collected by the observer during the inspection task. As can be seen from these tables, the average temperature at this bridge was slightly lower than at the other STAR bridges. This is probably due to the bridge being located in a slight depression and in a shaded area. In addition, note that a greater percentage of inspectors used the

Table 56. Task E – Problems expected.

Problem Type	Percentage of Respondents
Steel Corrosion	80%
Concrete Deterioration	76%
Cracked Asphalt	37%
Paint Deterioration	29%
Leakage	27%
Leaching	22%
Fatigue Cracks in Tack Welds	22%
Underside Deck Cracking	18%
Inadequate Concrete Cover	16%
Missing Rivets	16%
Settlement Cracking in Abutment	8%
Impact Damage	4%
Other	16%

sounding tools during this task than at the other STAR bridges. However, the use was intermittent, as evidenced by the relatively low completion rate on individual sounding items.

Table 57. Task E – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (ºC)	26.7	5.4	29.4	8.3
Humidity (%)	70.0	16.7	96	33
Heat Index (ºC)	22	5.6	30	8
Wind Speed (km/h)	2.6	4.2	16.1	0.0
Light Intensity Below Superstructure (lux)	1,290	2,160	14,030	2
Light Intensity at Deck Level (lux)	29,800	35,440	107,710	178

Table 61 presents the quantitative post-task question responses. As shown in this table, even though the inspectors had previously indicated that they would need more time than allotted, when asked if they felt rushed, the average response was a 3.6 on a scale of 1 to 9. In addition, note that, on average, the inspectors indicated that their effort level was slightly higher than normal on this task.

Table 58. Task E – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	37%
20 – 40% Cloudy	4%
40 – 60% Cloudy	6%
60 – 80% Cloudy	2%
80 – 100% Cloudy	27%
Hazy	2%
Fog	0%
Drizzle	10%
Steady Rain	12%
Thunderstorm	0%

Table 59. Task E – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
General	Check Overall Alignment (West Side)	47%
	Check Overall Alignment (East Side)	45%
Superstructure	Inspect With Binoculars	18%
	Inspect Bearings While Elevated	63%
	Measure Bearing Rotation	47%
Substructure	Inspect West Abutment	98%
	Sound West Abutment	28%
	Inspect East Abutment	98%
	Sound East Abutment	34%
	Inspect Northwest Wingwall	84%
	Sound Northwest Wingwall	12%
	Inspect Northeast Wingwall	80%
	Sound Northeast Wingwall	12%
	Inspect Southwest Wingwall	86%
	Sound Southwest Wingwall	16%
	Inspect Southeast Wingwall	86%
	Sound Southeast Wingwall	14%
Deck	Inspect Deck Surface	92%
	Inspect West Transverse Expansion Joint	82%
	Inspect East Transverse Expansion Joint	82%
	Inspect Longitudinal Joint	29%
	Inspect North Parapet	94%
	Sound North Parapet	16%
	Inspect South Parapet	92%
	Sound South Parapet	20%

Table 60. Task E – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	29%
2.4-m Stepladder	0%
9.75-m Extension Ladder	49%
Any Flashlight	24%
Two AA-Cell Flashlight	2%
Three D-Cell Flashlight	10%
Lantern Flashlight	12%
Any Sounding Tool	61%
Masonry Hammer	59%
Chain	2%
Level as a Level	0%
Level as a Straightedge	0%
Binoculars	16%
Magnifying Glass	2%
Engineering Scale	6%
Protractor	4%
Plumb Bob	0%
String	0%
Hand Clamp	0%

5.2.2.6. TASK G

As described previously, Task G is the Routine Inspection of the southern half of the U.S. Route 1 Bridge over the Occoquan River. Inspectors were given 2 h to complete the inspection. The task was completed in an average of 62 min (standard deviation of 20 min), with a minimum and maximum completion time of 14 min and 108 min, respectively. The distribution of inspection times is shown in figure 53.

Table 62 summarizes the quantitative questions from the pre-task questionnaire. Most notable from this table is the fact that, in general, the inspectors had fairly recently completed an inspection of a similar bridge. In addition, unlike the other Routine Inspection tasks, the average estimated inspection time was less than what was being allotted. A distribution of the estimated inspection times is shown in figure 54.

Table 61. Task E – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How similar were these inspection tasks to the tasks performed in your normal Routine Inspections?	1 = not similar	9 = very similar	7.7	1.3	9	3
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.2	1.7	9	1
How rested are you?	1 = very tired	9 = very rested	7.1	1.1	9	5
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.4	0.8	9	6
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	6.4	1.9	9	1
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	3.7	1.8	7	1
How complex was this bridge?	1 = very simple	9 = very complex	4.9	1.8	8	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	2.3	1.6	6	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	3.6	2.6	9	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.3	1.2	9	3
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	4.8	1.0	7	1

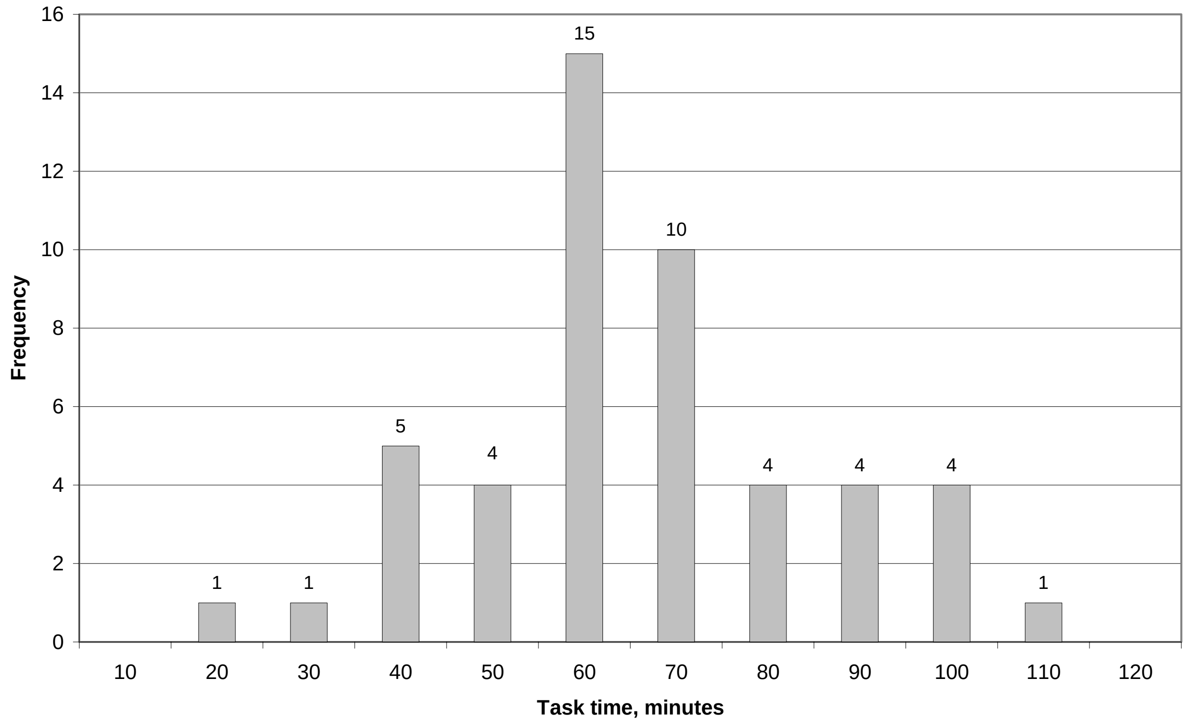


Figure 53. Task G – Actual inspection time.

Table 62. Task G – Quantitative pre-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)?	N/A*	N/A	14.5	21.3	104	1
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	110.0	101.3	480	25
How rested are you?	1 = very tired	9 = very rested	7.3	1.5	9	3

* N/A = Not applicable.

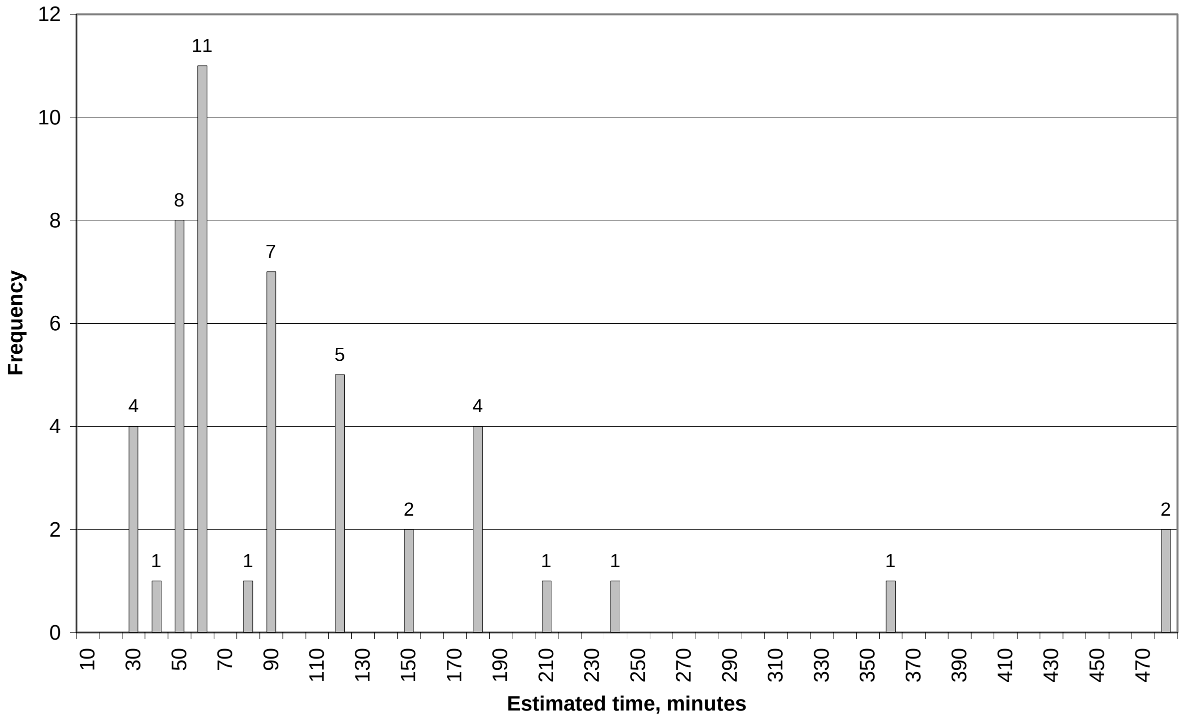


Figure 54. Task G – Predicted inspection time.

In order to assess what types of equipment the inspectors would have normally used, they were asked to describe the equipment they typically would have used. Table 63 summarizes the responses.

Table 63. Task G – Normal access equipment use.

Accessibility Equipment/Vehicle Type	Percentage of Respondents
Snooper	53%
Lift	4%
Ladder	10%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	4%
Movable Platform	2%
None	27%
Other	0%

Within the pre-task questionnaire, the inspectors were asked to describe the type of construction used on this bridge. The results from this question are presented in table 64. These results are the same as will be presented for this question within Task H, as this question was asked only at the start of whichever of Tasks G and H was performed first. Only 51 percent of the inspectors indicated that the bridge is continuous. This can have an impact on the inspection and could lead to less accurate inspection results as a result of not identifying the critical inspection areas. The "Other" category typically contains references to the substructure and splice plates. One inspector indicated that the bridge was simply supported.

Table 64. Task G – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Steel Girder	80%
Reinforced Concrete Deck	71%
Concrete Piers	55%
Continuous	51%
Welded Plate Girder	51%
Multi-Girder	41%
Single-Angle Cross-Bracing	12%
Rocker Bearing	6%
Composite Construction	4%
Other	18%

To further assess how they were formulating their approach to the inspection, inspectors were asked to identify problems that they might expect to find on a bridge of a similar type, condition, and age. These responses are summarized in table 65. These results show that inspectors expect relatively few types of problems to exist. Of this list of possible defects, only steel corrosion and fatigue cracks were mentioned by more than half of the inspectors and no defects were mentioned by more that 60 percent of the inspectors.

As before, tables 66 through 69 summarize data collected by the observer as the inspectors completed Task G. Temperature conditions were generally warmer than during the other Routine Inspection tasks, and due to the proximity to a major metropolitan area, there was a greater percentage of "hazy" days. Also note that approximately 80 percent of the inspectors used binoculars to inspect the superstructure, but less than 25 percent did any sounding of the substructure.

Table 65. Task G – Problems expected.

Problem Type	Percentage of Respondents
Fatigue Cracks	59%
Steel Corrosion	53%
Concrete Deterioration	49%
Underside Deck Cracking	29%
Deck Delaminations	27%
Locked Bearings	22%
Missing or Loose Bolts	20%
Expansion-Joint Deterioration	18%
Leakage	16%
Paint Deterioration	14%
Impact Damage	6%
Leaching	6%
Other	20%

Table 66. Task G – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (°C)	23.0	4.3	31.1	11.1
Humidity (%)	70.0	11.5	91	46
Heat Index (°C)	28	5.4	38	11
Wind Speed (km/h)	3.8	4.8	19.3	0.0
Light Intensity Under Center of Superstructure (lux)	13,090	15,270	65,430	441
Light Intensity on Top of South Abutment (lux)	29	30	183	1

Table 67. Task G – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	43%
20 – 40% Cloudy	8%
40 – 60% Cloudy	0%
60 – 80% Cloudy	0%
80 – 100% Cloudy	29%
Hazy	10%
Fog	2%
Drizzle	4%
Steady Rain	2%
Thunderstorm	0%

Table 68. Task G – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
Superstructure	Inspect Span 5 With Binoculars	78%
	Inspect Span 6 With Binoculars	78%
	Inspect Span 7 With Binoculars	78%
	Inspect Span 8 With Binoculars	76%
	Inspect Pier 4 Bearing	76%
	Inspect Pier 5 Bearing	78%
	Inspect Pier 6 Bearing	76%
	Inspect Pier 7 Bearing	71%
Substructure	Inspect Pier 4	88%
	Sound Pier 4	4%
	Inspect Pier 5	94%
	Sound Pier 5	10%
	Inspect Pier 6	96%
	Sound Pier 6	16%
	Inspect Pier 7	100%
	Sound Pier 7	10%
	Sound Abutment Seat	24%
	Sound Abutment Backwall	22%
Deck	Inspect South Expansion Joint From Above	88%
	Inspect South Expansion Joint From Below	71%
	Check West Alignment	55%

As done after all other inspection tasks, inspectors were asked a series of questions upon completing Task G. Inspector responses are summarized in table 70. Although most inspectors initially indicated that they would have used more access equipment than was provided, upon completion of the task, most indicated that the task was quite similar to what they would normally do. However, on average, inspectors indicated that Task G was the least accurate of all the tasks at measuring their inspection skills. In addition, note that the inspectors indicated that they gave more effort than normal. This is probably attributable to the lack of special access equipment.

5.2.3. Statistical Analysis of Primary Bridge Elements

In the following sections, the statistical analyses performed on the Routine Inspection primary element Condition Ratings will be presented. The discussion has two primary sections. First,

Table 69. Task G – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	22%
Engineering Scale	0%
2.4-m Stepladder	0%
9.75-m Extension Ladder	0%
Any Flashlight	41%
Two AA-Cell Flashlight	16%
Three D-Cell Flashlight	10%
Lantern Flashlight	14%
Any Sounding Tool	41%
Masonry Hammer	41%
Chain	0%
Level as a Level	0%
Level as a Straightedge	0%
Binoculars	80%
Magnifying Glass	0%
Protractor	10%
Plumb Bob	2%
String	0%
Hand Clamp	0%

the Condition Ratings alone are analyzed. Second, the correlation of the human and environmental factors measurements with the Condition Ratings are presented.

5.2.3.1. GENERAL ANALYSIS

The general analysis presented in this section uses common statistical methods to identify trends in the primary element Condition Ratings. In addition, the trends from the sample Condition Ratings are also extrapolated to the population.

5.2.3.1.1. Basic Statistical Task Information

The following presents the basic statistical analysis of the Condition Ratings assigned to the primary elements during the Routine Inspection tasks. Tables 71 through 76 provide the following information: the reference rating for each element as was described previously, the average Condition Rating from the sample, the standard deviation from the sample, the Coefficient of Variation (COV) (standard deviation divided by the average) from the sample, the

Table 70. Task G – Quantitative post-task question responses.

	Range of Possible Answers		Inspector Response			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How similar were these inspection tasks to the tasks performed in your normal Routine Inspections?	1 = not similar	9 = very similar	6.8	2.5	9	1
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	6.7	2.0	9	1
How rested are you?	1 = very tired	9 = very rested	7.1	1.3	9	4
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.5	0.8	9	5
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	4.1	2.3	9	1
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	7.0	1.1	9	4
How complex was this bridge?	1 = very simple	9 = very complex	5.9	1.5	9	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	1.7	1.2	6	1
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	1.7	1.2	6	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.2	1.0	7	1
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	4.9	1.5	8	1

minimum and maximum Condition Ratings, the mode (i.e., the most common Condition Rating), and the number of inspectors assigning Condition Ratings for each element for Tasks A, B, C, D, E, and G, respectively. Note that not all inspectors gave Condition Ratings for all elements, resulting in the number of inspectors assigning Condition Ratings for the element being less than the total number of participating inspectors. Figures 55 through 60 illustrate the frequency with which the inspectors gave individual Condition Ratings to each element for each task.

Table 71. Task A – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	5	5	6
Average	5.8	5.9	6.1
Standard Deviation	0.81	0.78	0.79
COV	0.14	0.13	0.13
Minimum	3	4	3
Maximum	7	8	7
Mode	6	6	6
N	49	49	49

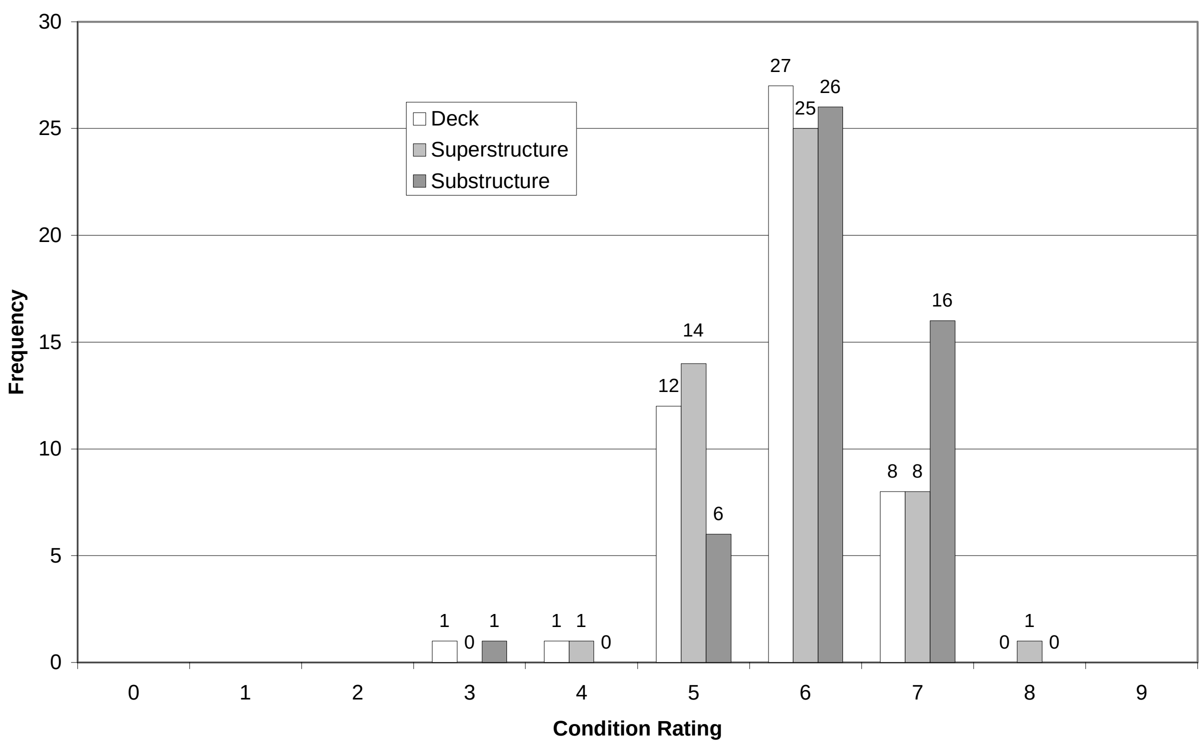


Figure 55. Task A – Condition Rating frequency distribution.

Table 72. Task B – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	4	4	4
Average	4.9	4.2	4.3
Standard Deviation	0.94	0.77	0.76
COV	0.19	0.18	0.18
Minimum	2	2	3
Maximum	7	6	6
Mode	5	4	4
N	48	49	49

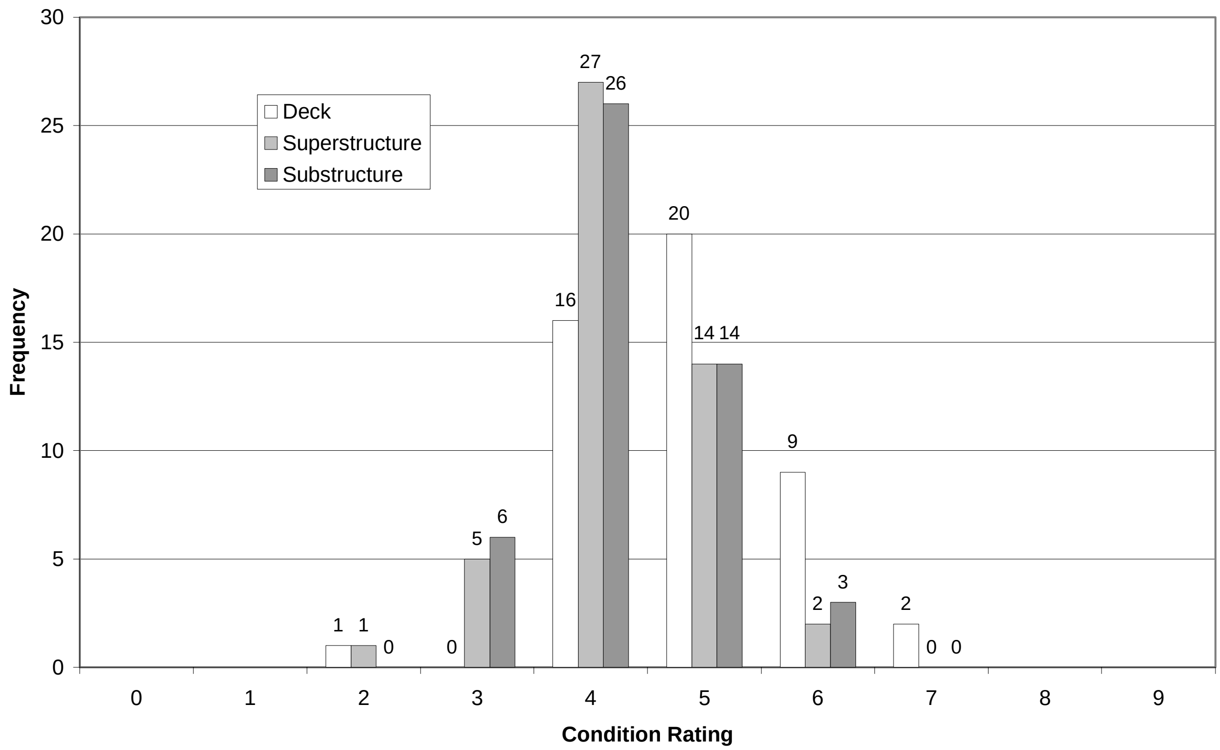


Figure 56. Task B – Condition Rating frequency distribution.

Table 73. Task C – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	4	4	5
Average	5.2	4.6	5.5
Standard Deviation	0.92	0.86	0.77
COV	0.18	0.19	0.14
Minimum	3	2	4
Maximum	7	7	7
Mode	6	5	5 and 6
N	49	49	48

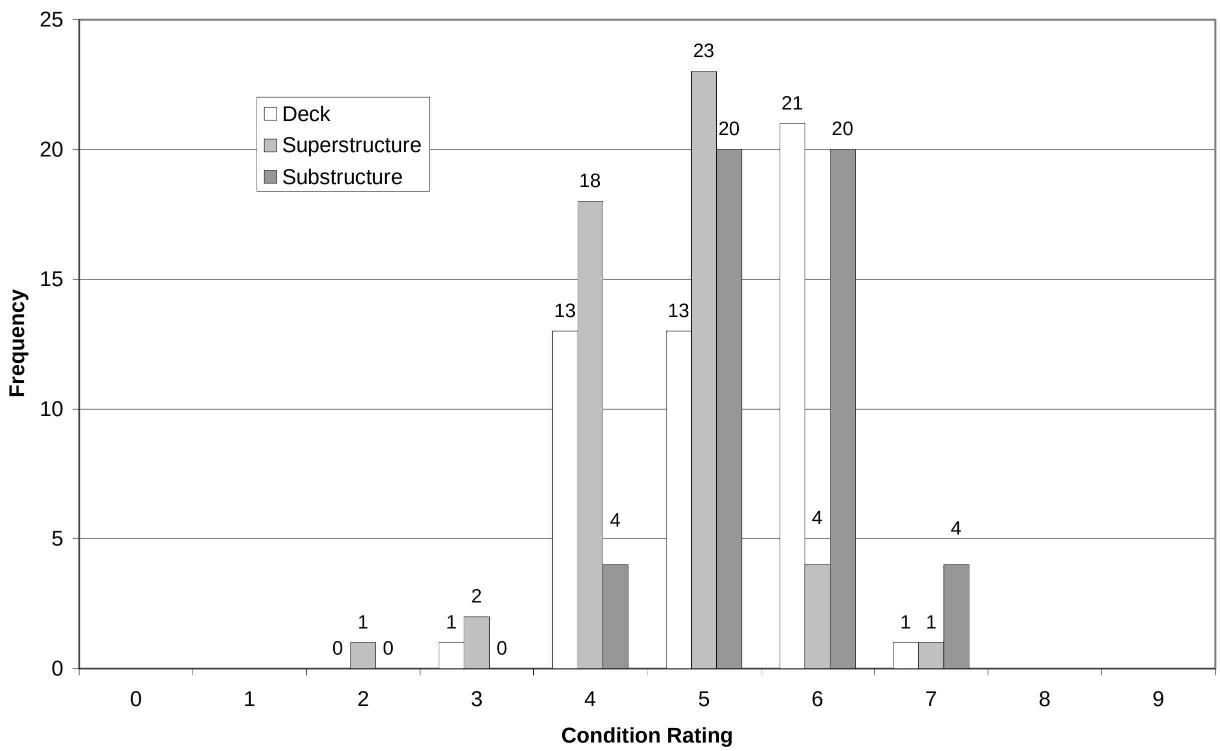


Figure 57. Task C – Condition Rating frequency distribution.

Table 74. Task D – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	5	5	6
Average	4.8	5.3	6.1
Standard Deviation	0.94	0.88	0.89
COV	0.19	0.17	0.15
Minimum	2	4	4
Maximum	6	7	8
Mode	5	5	6
N	48	44	47

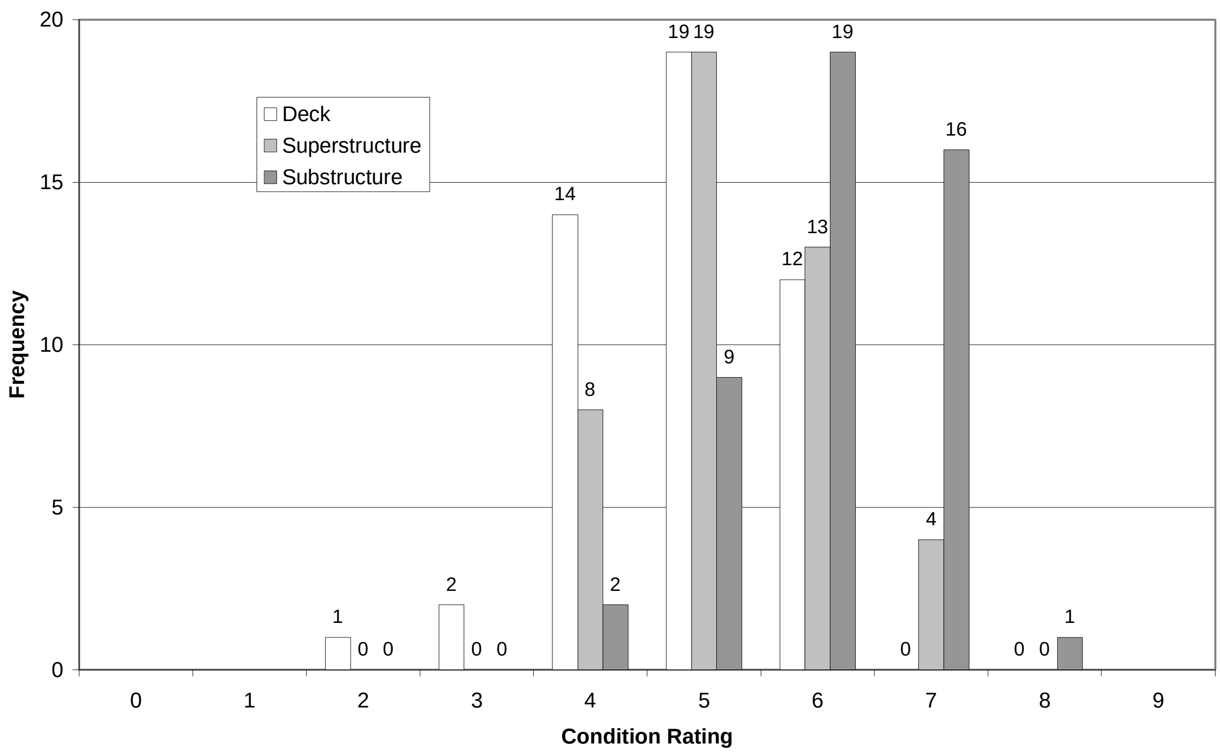


Figure 58. Task D – Condition Rating frequency distribution.

Table 75. Task E – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	4	6	6
Average	4.5	5.8	5.3
Standard Deviation	0.74	0.72	0.83
COV	0.16	0.13	0.16
Minimum	3	4	3
Maximum	6	7	7
Mode	5	6	5
N	48	48	47

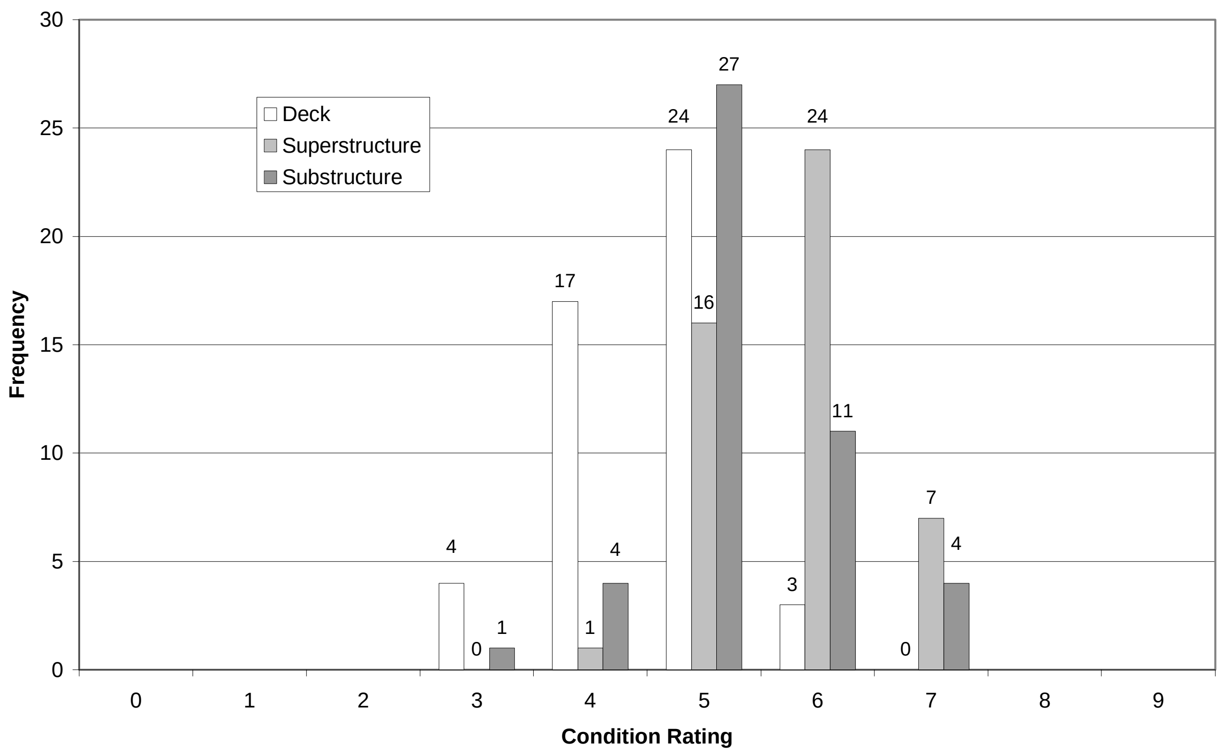


Figure 59. Task E – Condition Rating frequency distribution.

Table 76. Task G – Basic statistical information.

	Primary Element		
	Deck	Superstructure	Substructure
Reference	7	7	8
Average	7.1	6.7	7.2
Standard Deviation	0.53	0.66	0.57
COV	0.08	0.10	0.08
Minimum	6	5	6
Maximum	8	8	8
Mode	7	7	7
N	49	49	49

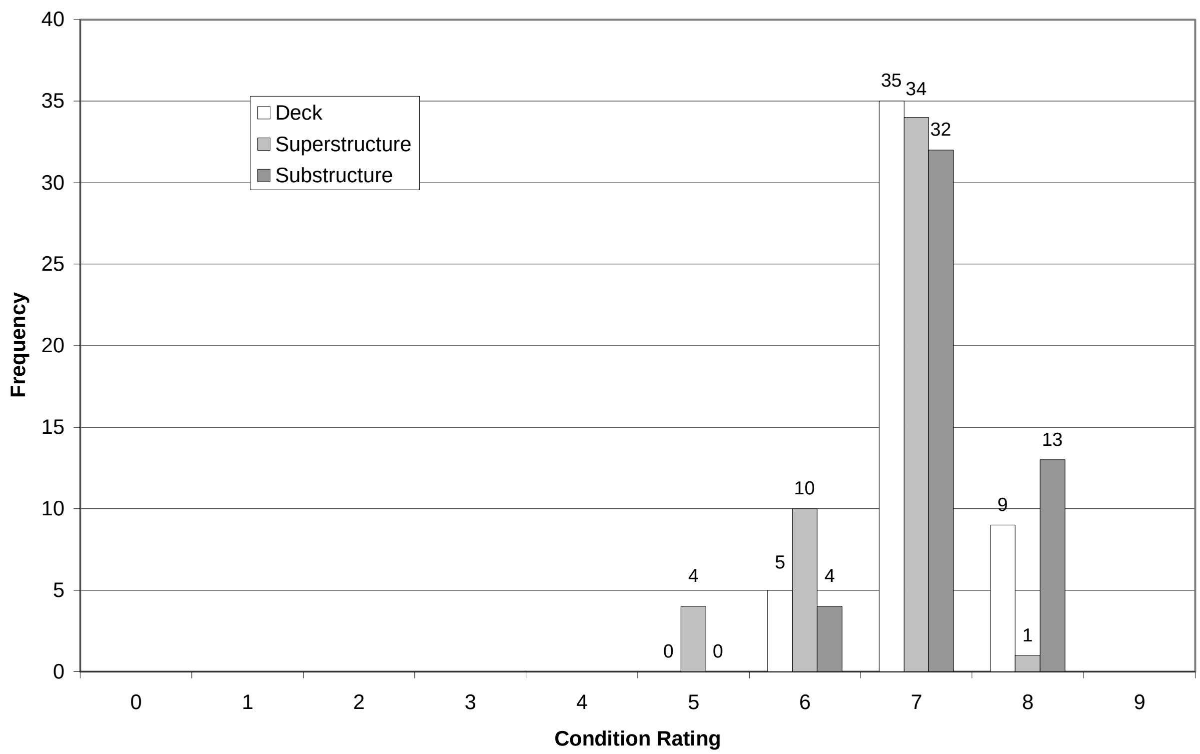


Figure 60. Task G – Condition Rating frequency distribution.

These data are the foundation for the analyses and discussion in the following sections. However, prior to the formal presentation that follows, some general trends in the data are mentioned here. First, the standard deviation for each primary element, in every task, is at least 0.53, illustrating the level of dispersion of the inspection results about the mean. In all, the average Condition Ratings for 13 of the primary elements are greater than the reference ratings, and for 5 of the elements, the Condition Ratings are less than the reference ratings. On average, there are between four and five different Condition Rating values assigned to each primary element, with a minimum of three and a maximum of six.

In order to determine if the average inspector Condition Ratings were statistically different from the reference ratings, the t-test was applied. For these analyses, the t-test was used as a statistical tool to test the null hypothesis that the sample average is equal to some value on the basis of a random sample. Table 77 summarizes the results of the t-test at a 5 percent significance level. "Fail" indicates that the data failed the t-test, meaning that the average Condition Rating was found to be different from the reference Condition Rating at the 5 percent significance level. "Pass" indicates that the data passed the t-test, thus the average Condition Rating and the reference Condition Rating cannot be considered different at a 5 percent significance level. From this table, it is apparent that, in most cases, the average inspector Condition Rating is different from the reference Condition Rating, with at least a 95 percent probability. The inspector Condition Ratings and the reference Condition Ratings are the data used in the discussion in the following sections.

Table 77. The t-test results at 5 percent significance level for the average Condition Ratings.

	Task					
Element	A	B	C	D	E	G
Deck	Fail	Fail	Fail	Pass	Fail	Pass
Superstructure	Fail	Fail	Fail	Fail	Fail	Fail
Substructure	Pass	Fail	Fail	Pass	Fail	Fail

Although the strict numerical difference between the reference and the average Condition Ratings discussed above may appear to be small, in many cases, the amount of difference that is statistically significant cannot be estimated without considering the size and distribution of the sample. Statistical significance in this context refers to how much of a deviation the reference and average Condition Ratings can have and still be attributed to random variations in the sample. Figure 61 shows the relationship of the sample size and distribution with the minimum amount of deviation from the actual condition that is statistically significant. The figure does so for two different standard deviations. These standard deviations are the bounds of the standard deviations observed in this study. This information is based on the t-test at a 5 percent significance level by backcalculating the maximum difference between the average and the reference for statistical insignificance. In terms of statistical significance, the figure shows that as the number of inspectors increases, the allowable deviation of the average Condition Rating from the actual Condition Rating decreases. As an example, if five inspectors were to assign Condition Ratings for a specific structure with a standard deviation of 0.53, the maximum amount that the average Condition Rating could deviate from the actual condition and still be considered statistically correct is 0.66. Similarly, although not shown in figure 61, if two inspectors assigned Condition Ratings for a structure, a difference larger than 4.8 rating points would be necessary for the average to be incorrect. This analysis illustrates why, although the numerical differences between the average and reference Condition Ratings in this study may appear small, knowledge of the sample size and dispersion is also necessary to determine whether the average Condition Ratings are statistically different from the reference ratings. The sample of inspectors in this analysis varied between 44 and 49, depending on the task. This results in an allowable deviation from the actual Condition Rating of between 0.14 and 0.27 rating points, depending on the task and the element type.

In order to draw conclusions from the above discussion concerning the accuracy of inspector Condition Ratings, one must assume a correct Condition Rating. In order to avoid making such an assumption, a second analysis was performed to ascertain Condition Rating accuracy without requiring that a correct Condition Rating be assumed. This analysis is again based on the t-test for statistical significance. In this analysis, the maximum allowable deviation from the correct Condition Rating was calculated from the t-statistic based on the sample size, sample distribution, and the appropriate maximum t-value. From this, one can determine the maximum deviation from the actual Condition Rating, Δ, that could be considered statistically insignificant

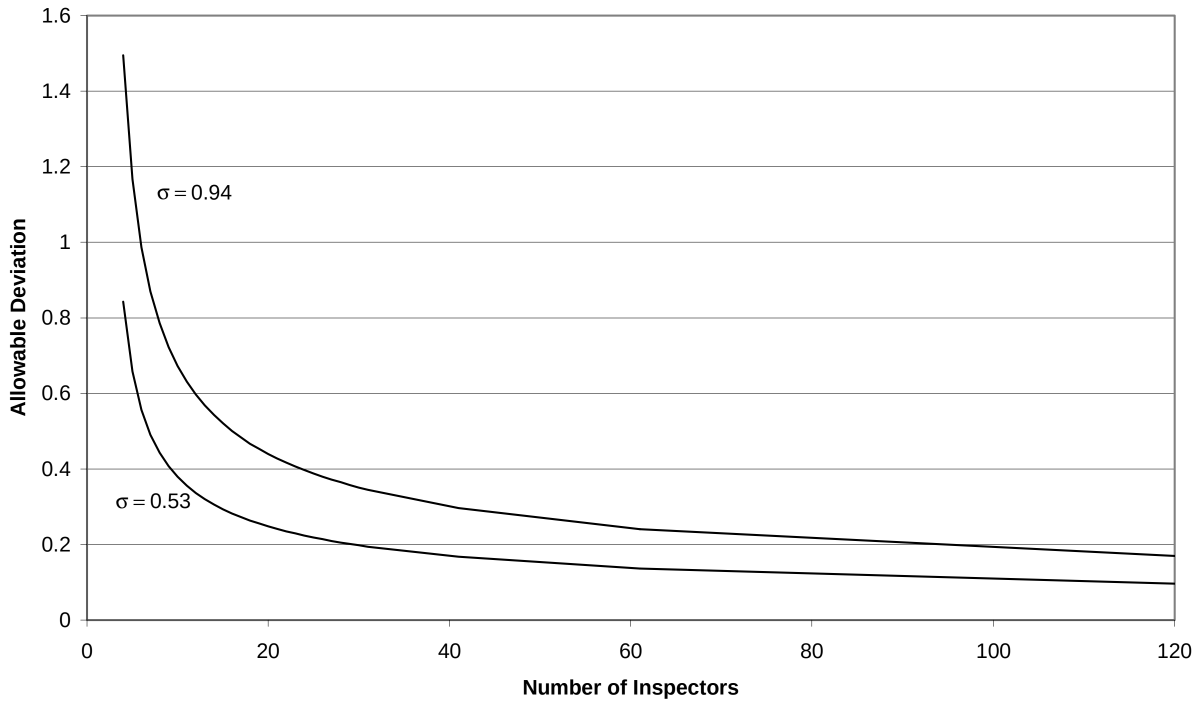


Figure 61. Influence of sample size and distribution on allowable deviation.

(or similarly, the minimum deviation from the actual that could be considered statistically significant). Then, using that deviation, the average Condition Rating for each element for each task was checked to see if it fell within that amount of the 10 Condition Ratings (i.e., 0, 1, 2,…,9). If the average did not fall within Δ for any discrete Condition Rating (i.e., $0 \pm\Delta$, $1 \pm\Delta$, $2 \pm\Delta,\ldots,9\pm\Delta$), one can conclude that the average Condition Rating *is* statistically incorrect. If the Condition Rating did fall within Δ of a discrete Condition Rating, one could say that the average Condition Rating *may* be correct. Note that one can only say that the average *may* be correct, because for this to be true, one must assume that the correct Condition Rating is the one within Δ of the average Condition Rating. From this analysis, the following results were found.

- At least 56 percent of the average Condition Ratings are incorrect with a 95 percent probability.
- At least 22 percent of the average Condition Ratings are incorrect with a 99 percent probability.

- If the NDEVC reference ratings are correct, then 78 percent of the average Condition Ratings are incorrect with a 95 percent probability.
- If the NDEVC reference ratings are correct, then 56 percent of the average Condition Ratings are incorrect with a 99 percent probability.

The previous analysis looked at the overall accuracy of Condition Rating assignment for the sample. One could also analyze the accuracy on an individual inspector basis. In this analysis, one must assume that a bridge element only has one correct Condition Rating (e.g., a bridge cannot be an “8” (no problems noted) and a “7” (some minor problems) at the same time). With this assumption in mind, one can determine the maximum percentage of individual Condition Ratings that could possibly have been correct. This is done by calculating the maximum percentage of inspectors that gave a single Condition Rating for each component in each task. In a similar manner, one can also determine the maximum number of inspectors within one Condition Rating of the correct Condition Rating. Using this approach, the following results were obtained:

- At most, 52 percent of the individual Condition Ratings were assigned correctly.
- At least 48 percent of the individual Condition Ratings were assigned incorrectly.
- At most, 95 percent of the individual Condition Ratings were within one rating point of the correct Condition Rating.

For comparative purposes, the following results were determined assuming that the reference Condition Ratings are correct:

- If the reference Condition Ratings are correct, 42 percent of the individual Condition Ratings were assigned correctly.
- If the reference Condition Ratings are correct, 58 percent of the individual Condition Ratings were assigned incorrectly.
- If the reference Condition Ratings are correct, 89 percent of the individual Condition Ratings were within one point of the correct Condition Rating.

Given the large number of bridges in the National Bridge Inventory, it is possible that situations could arise in which two contiguous Condition Ratings could both describe the condition of a bridge element nearly equally well. In this case, it is likely that two Condition Ratings may each be assigned with a relatively high frequency. This could arise in at least two scenarios: (1) if the Condition Rating definitions are not refined enough to assign a single Condition Rating (e.g., the distinction between the definition of "6" (structural elements show minor deterioration) and "5" (all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour") may not be great enough to always enable a clear differentiation) and (2) an element could have discrete regions with different levels of deterioration. In this situation, a rational assessment would give each area of the element a rating with a corresponding weighting factor based on the location of each area. These weighted conditions would then be combined to determine the Condition Rating. For example, if an element could be considered to be approximately 55 percent a "6" and 45 percent a "5", a rational assessment would give the element a "6". However, if one were to make the percentage assessments in a slightly different manner and arrive at 45 percent a "6" and 55 percent a "5", a rational assessment would give the element a "5". Although the two assessments are very close to one another, they each resulted in different Condition Ratings being assigned.

In situations like these, either of the two Condition Ratings could arguably be correct. Although it is not accurate to say that both Condition Ratings are correct, for this discussion, this situation will be referred to as the case where it is assumed that two Condition Ratings are correct. Based on this assumption, the following results were obtained. At most, 81 percent of the Condition Ratings could be considered correct if one assumes that two correct Condition Ratings could exist. Conversely, at least 19 percent of the Condition Ratings must be considered incorrect based on this scenario.

The previous discussion focused on assessing the accuracy of the primary element Condition Ratings independent of other influences. Figures 62 through 64 show the relationship of the maximum percentage of correct Condition Ratings with the reference, mode, and average Condition Ratings, respectively. These figures illustrate the correct Condition Ratings rate for the two situations described previously. Type 1 indicates the case when a single correct

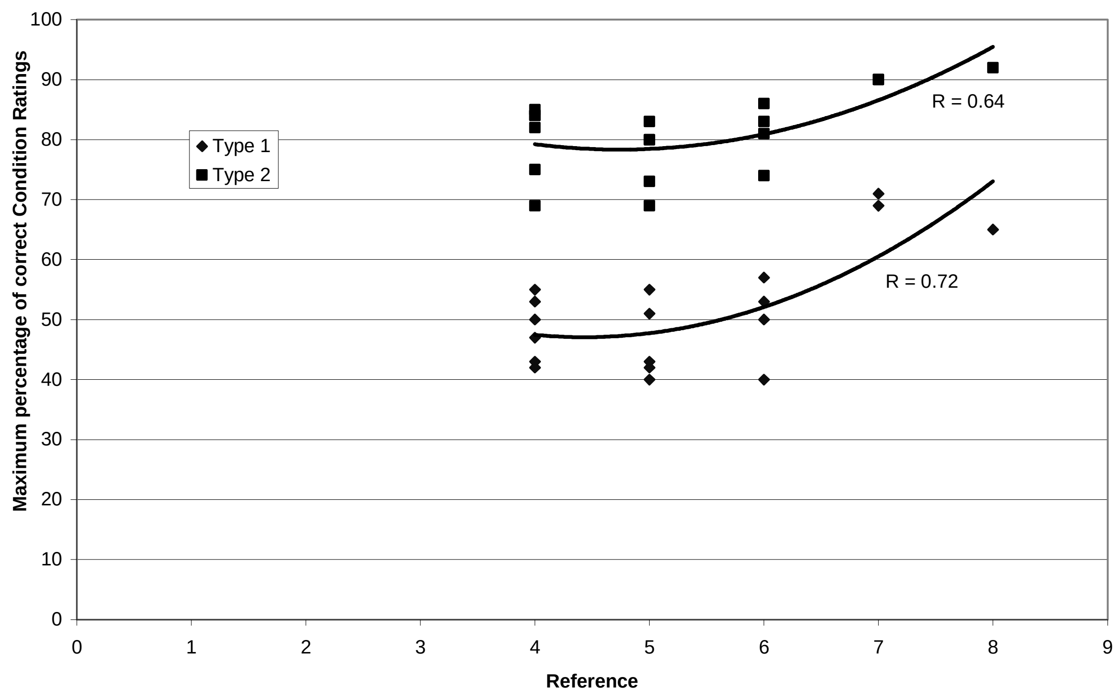


Figure 62. Relationship between Condition Rating accuracy and reference Condition Rating.

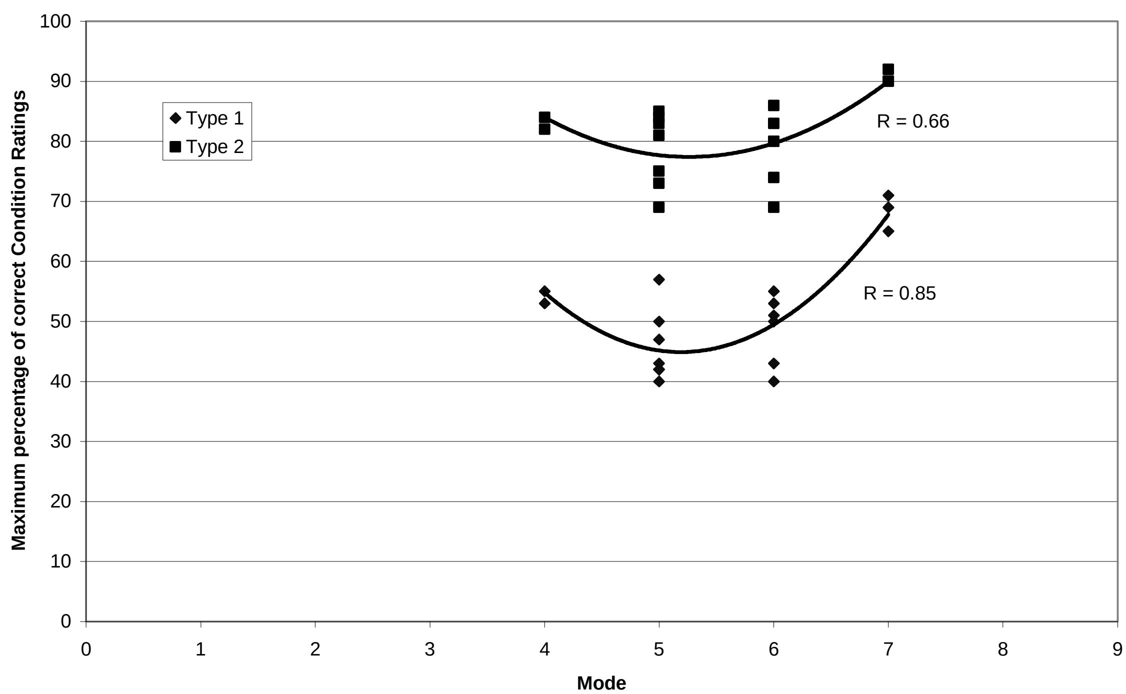


Figure 63. Relationship between Condition Rating accuracy and mode Condition Rating.

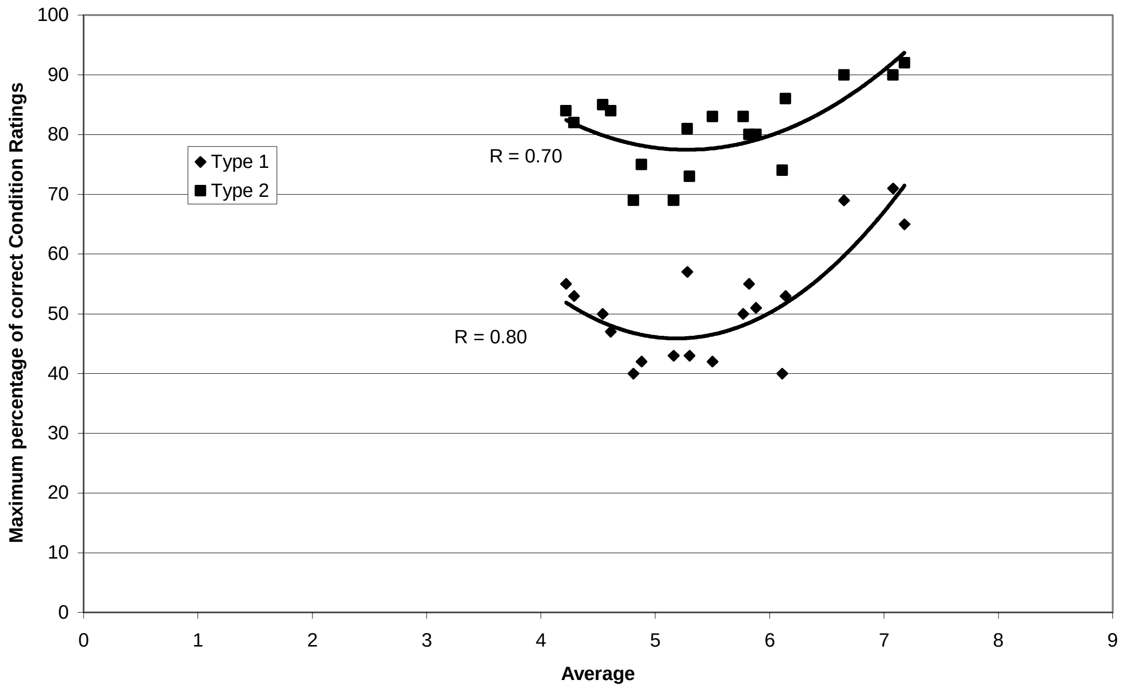


Figure 64. Relationship between Condition Rating accuracy and average Condition Rating.

Condition Rating is assumed and Type 2 indicates the case where two correct Condition Ratings are assumed. From these figures, it can be observed that regardless of the Condition Rating used for comparison, the poorer condition bridge elements within the study bridge component sample were assigned fewer correct Condition Ratings. This is probably attributable to inspector difficulties in defining the level of deterioration in terms of the verbiage used in the Condition Rating system.

5.2.3.1.2. Distribution of Experimental Population

The variations over the sample of inspection results are the cornerstone for drawing many conclusions. Although direct extrapolation of the sample distribution to the population of State bridge inspectors may not be statistically valid, the experimental distribution is nevertheless insightful.

Table 78 summarizes the distribution of the sample about three statistically or physically meaningful benchmarks. The first benchmark is the reference condition rating. This rating is an important benchmark because it represents the Condition Rating established by the NDEVC that

Table 78. Distribution of sample Condition Ratings.

Task	Element	Reference	Average	Mode	Percentage of Sample Within ± 1 of Reference	± 2 of Reference	± 1 of Average	± 2 of Average	± 1 of Mode	± 2 of Mode
A	Deck	5	5.8	6	82	100	80	98	96	98
	Superstructure	5	5.9	6	82	98	80	98	96	100
	Substructure	6	6.1	6	98	98	86	98	98	98
B	Deck	4	4.9	5	75	96	75	94	94	98
	Superstructure	4	4.2	4	94	100	84	98	94	100
	Substructure	4	4.3	4	94	100	82	100	94	100
C	Deck	4	5.2	6	55	98	69	98	71	98
	Superstructure	4	4.6	5	88	98	84	96	92	98
	Substructure	5	5.5	5,6	92	100	83	100	92	100
D	Deck	5	4.8	5	94	98	69	98	94	98
	Superstructure	5	5.3	5	91	100	73	100	91	100
	Substructure	6	6.1	6	94	100	74	96	94	100
E	Deck	4	4.5	5	94	100	85	100	92	100
	Superstructure	6	5.8	6	98	100	83	100	98	100
	Substructure	6	5.3	5	89	98	81	98	89	100
G	Deck	7	7.1	7	100	100	90	100	100	100
	Superstructure	7	6.7	7	92	100	90	100	92	100
	Substructure	8	7.2	7	92	100	92	100	100	100

is believed to be the “actual” Condition Rating. The second benchmark, the average Condition Rating, gives a description of the central tendency of the sample Condition Ratings. Finally, the mode is the peak value of a frequency diagram. It provides a rough measure of central tendency and is the inspector consensus on the Condition Ratings.

The data presented in table 78 are the percentage of the sample that are within one or two rating points from the reference, average, and mode Condition Ratings. When comparing these data to the reference values, it becomes apparent that approximately 90 percent of the Condition Ratings are within one point of the reference. In addition, approximately 99 percent of the Condition Ratings are within two rating points and all of the Condition Ratings are within three rating points of the reference.

The distribution of the Condition Ratings about the average shows greater variability than the distribution about the reference. However, this decrease in consistency may not accurately describe the distribution. The apparent drop stems from the type of data that was collected (i.e., only integer Condition Ratings). As an example, if the Task G deck Condition Ratings are compared to the reference value, 100 percent are within one rating point, whereas when compared to the average, only 90 percent are within one rating point. This results from the fact that when compared to the reference value, Condition Ratings 6, 7, and 8 were used to compute the percentage. However, when compared to the average value, only Condition Ratings in the range from 6.1 to 8.1 (i.e., 7 and 8) were used.

In order to avoid this phenomenon, one could use the mode as the central tendency measure. The results of these analyses are summarized in table 78. The distribution about the mode data shows a similar, but slightly smaller, distribution when compared to the distribution about the reference values.

Regardless of the value used for the analysis, most inspection results had a relatively narrow distribution. The one exception to this occurred in the evaluation of the Task C deck. This can probably be attributed to the fact that approximately 20 percent of the Task C deck had a relatively new wearing surface. This may have resulted in inconsistencies in the inspector assessments.

Table 79 shows the distribution of the deviation from reference (DFR) data for all tasks. The DFR is calculated as the inspector rating minus the reference rating. By completing this simple arithmetic manipulation, Condition Ratings from multiple tasks can rationally be combined. The data set used to develop table 79 is the DFR from each inspector and shows the percentage of Condition Ratings that are within a zero DFR, the average DFR, and the mode DFR. It should be pointed out that tables 78 and 79 give similar information. The difference is that the data in table 78 gives the percentage of inspector Condition Ratings about three benchmark Condition Ratings, whereas table 79 gives the percentage of inspector DFRs about three benchmark DFRs.

Table 79. Distribution of sample DFRs.

Element	Average DFR	Mode DFR	Percentage of Sample Within ± 1 of Zero DFR	± 2 of Zero DFR	± 1 of Average DFR	± 2 of Average DFR	± 1 of Mode DFR	± 2 of Mode DFR
All Decks	0.55	0	83	99	75	97	83	99
All Superstructures	0.24	0	91	99	76	97	91	99
All Substructures	-0.08	0	93	99	69	97	93	99
All Elements	0.24	0	89	99	72	97	89	99

These data indicate that, overall, the average of the inspector Condition Ratings for the decks is 0.55 points higher than the reference, 0.24 points higher than the reference for the superstructures, and 0.08 points lower than the reference for the substructures. This resulted in an overall average DFR, regardless of the element type, that was 0.24 points higher than the reference rating.

5.2.3.1.3. Analytical Modeling and Theoretical Distribution of the General Population

Although much can be learned about the sample from the previous data, direct extrapolation of the data to the population is not statistically justifiable. One means of extrapolating a sample to a population is by using theoretical probability distributions based on data from the sample. From this type of analysis, it is possible to make statements regarding predicted results for the population. Theoretical probability distributions account for the natural variability in the sample and estimate how this variability would propagate into the population.

Because it occurs in many practical problems and has been widely studied, the normal, or Gaussian, distribution is one of the most commonly used theoretical distributions. This distribution is often referred to as one of the fundamentals of statistical analysis because of its widespread, natural occurrence. The general form of the normal distribution is given by Equation 1:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (1)$$

where:

μ = Sample mean

σ = Sample standard deviation

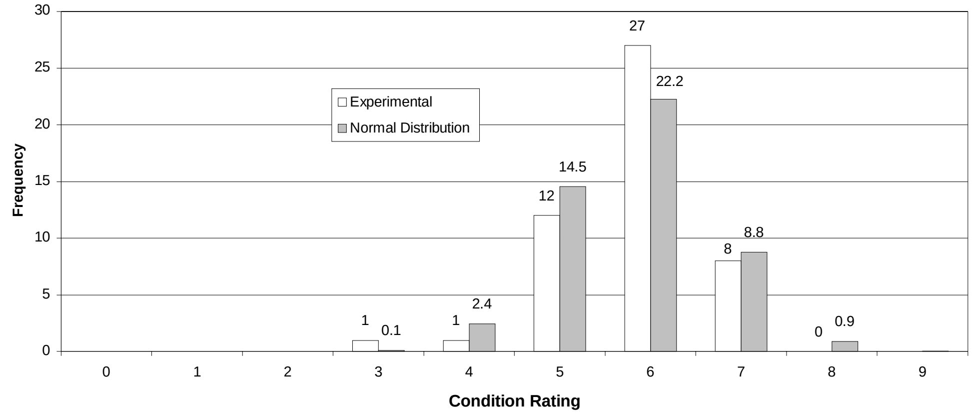
x = Value being distributed

$f(x)$ = Relative frequency

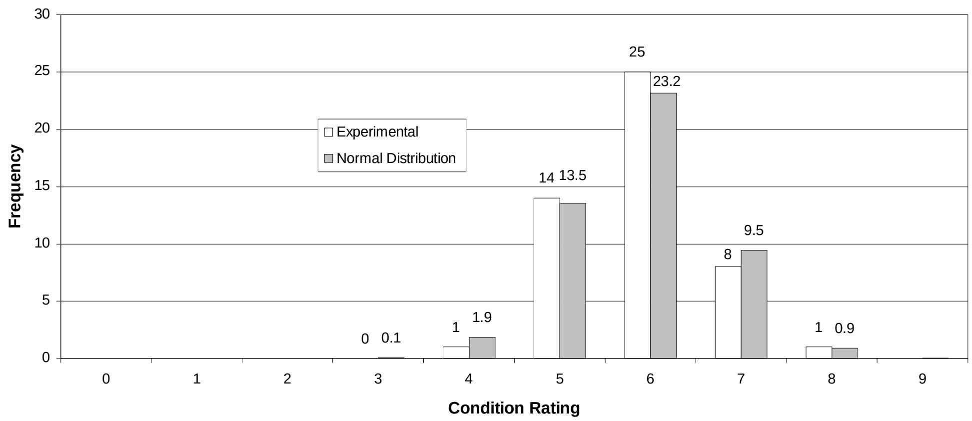
The normal distribution was used to analyze the Condition Rating results for each of the primary element Condition Ratings. The appropriateness of the distribution was then verified by applying the χ^2 test for goodness-of-fit. The χ^2 test revealed that all but one element of one task (the substructure for Task A) had a Condition Rating distribution that could be considered to be normally distributed. Figures 65 through 70 illustrate the relationship between the sample Condition Rating and the analytical (i.e., normal) Condition Rating distribution.

Based on the previous analyses, the sample Condition Ratings can be considered normally distributed. Thus, extrapolation from the sample to the population is considered valid. Accordingly, table 80 shows the range of Condition Ratings for each task where various percentages of the population are predicted to fall. The difference between these data and the experimental data presented earlier cannot be overemphasized. These data are not directly indicative of how the sample performed, but rather are an extrapolation to the population based on how the sample performed. It should be pointed out that the data in the 68 percent column simply represent a range of two times the sample standard deviations, the 95 percent data are a range of four times the sample standard deviation, and the 99 percent data represent a range of six times the sample standard deviation.

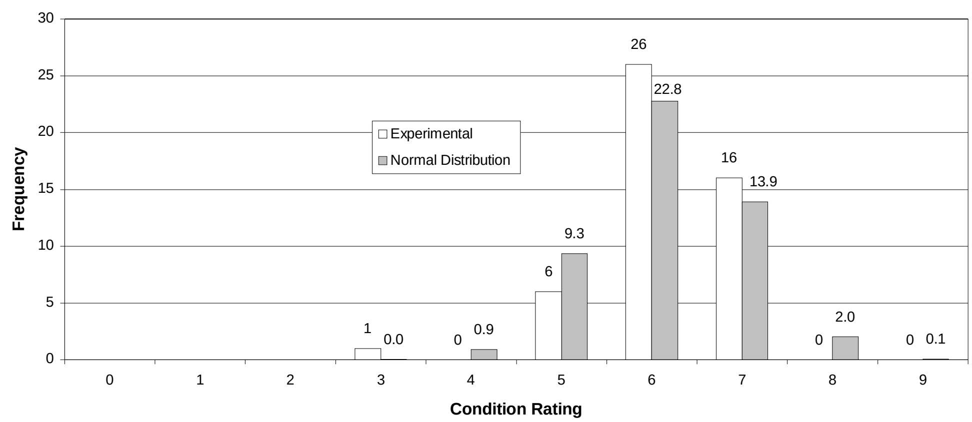
The data presented in table 80 are task- and element-specific and may not be very useful for general use. In this regard, data from all tasks were combined such that wider generalizations could be made. This was completed by combining the DFR data for all tasks. The properties of the combined data were then used to develop theoretical normal distribution frequencies that were again tested for goodness-of-fit. As before, these tests revealed that the distribution of the combined DFR data was normal (see figures 71 through 74). The products of these analyses are summarized in table 81. Typically, the theoretical value of 95 percent of the population is used



a. Deck

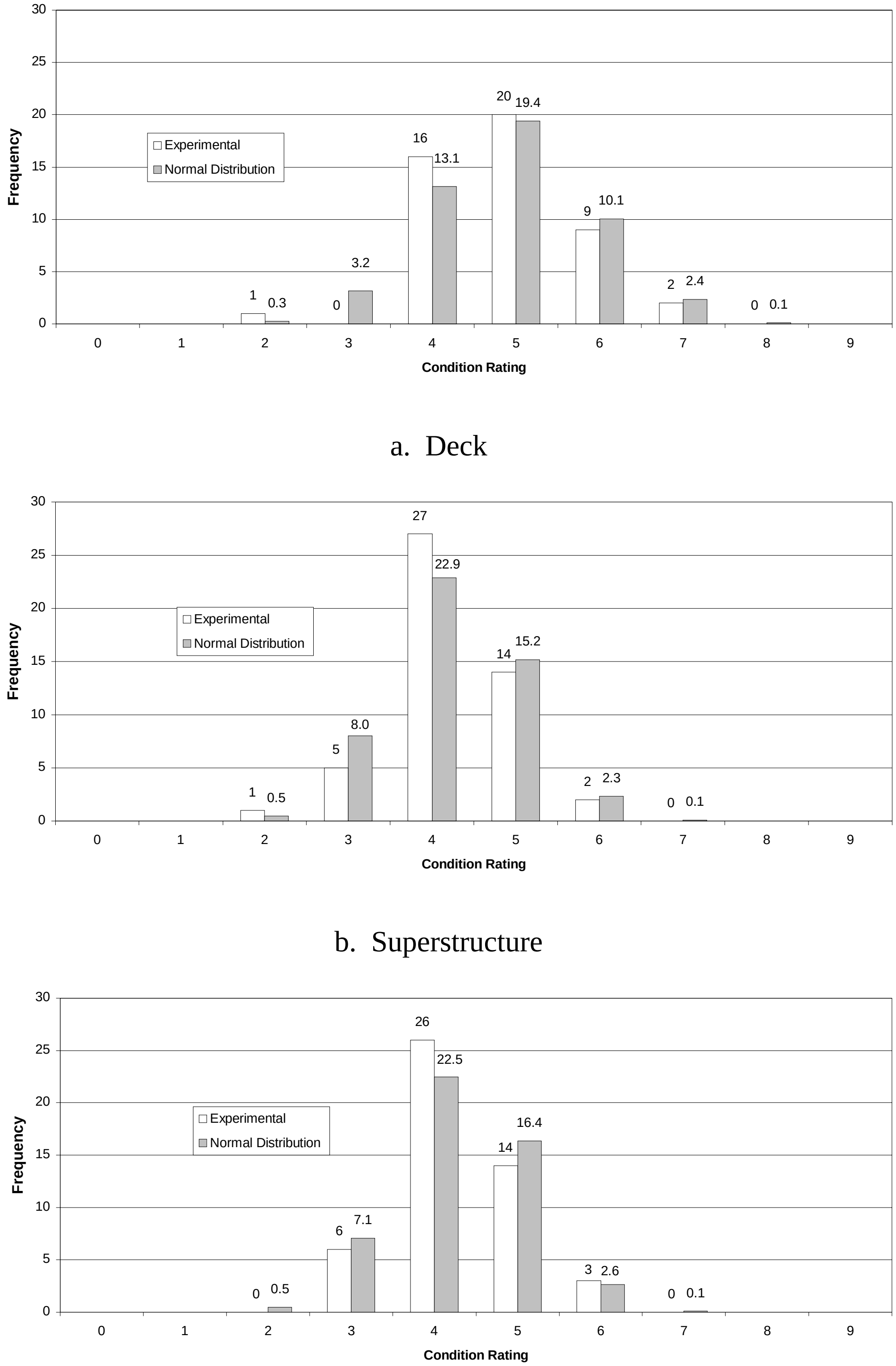


b. Superstructure



c. Substructure

Figure 65. Task A experimental and theoretical Condition Rating distributions.

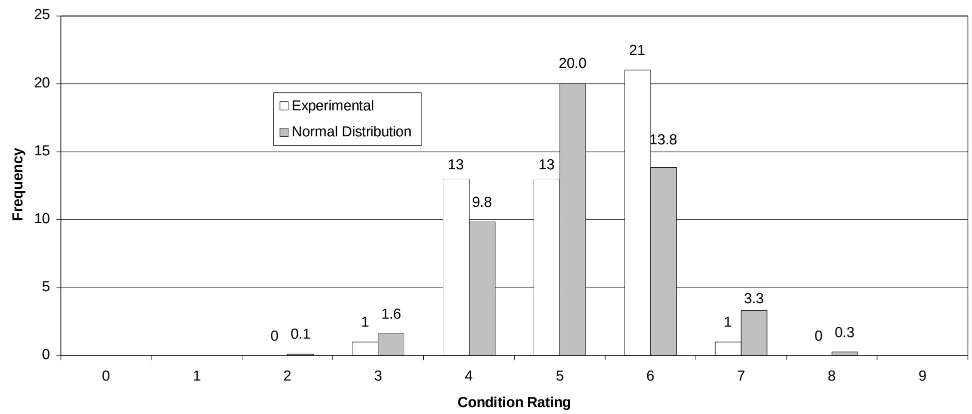


a. Deck

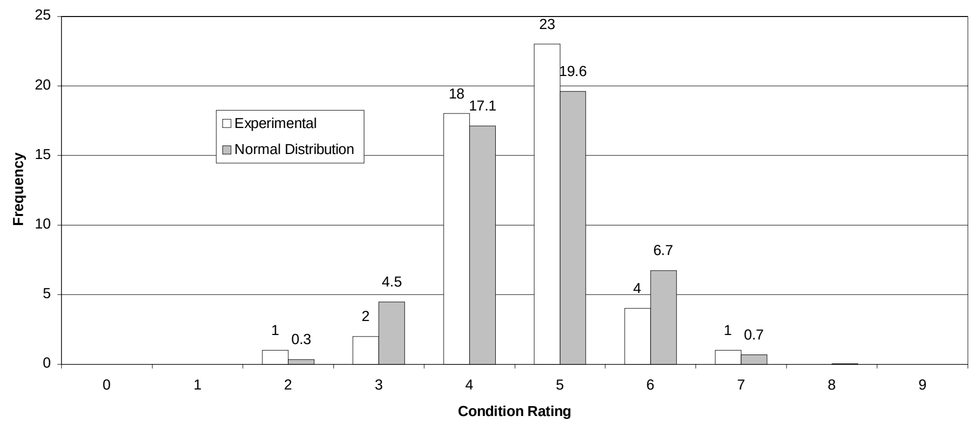
b. Superstructure

c. Substructure

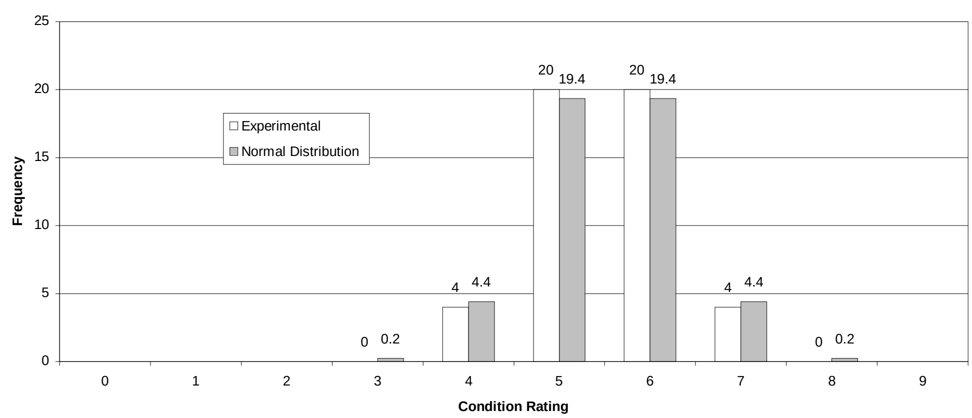
Figure 66. Task B experimental and theoretical Condition Rating distributions.



a. Deck

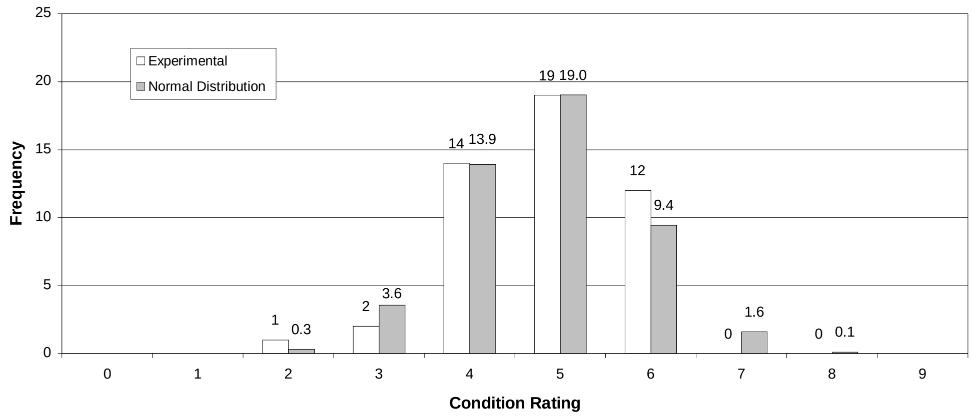


b. Superstructure

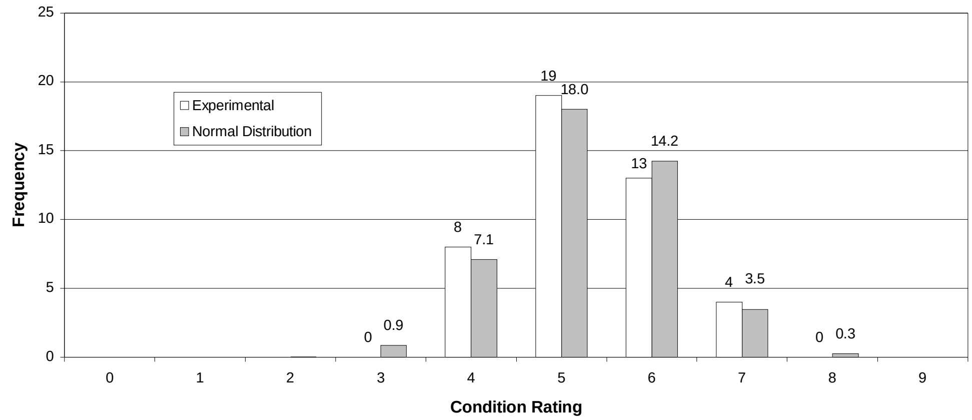


c. Substructure

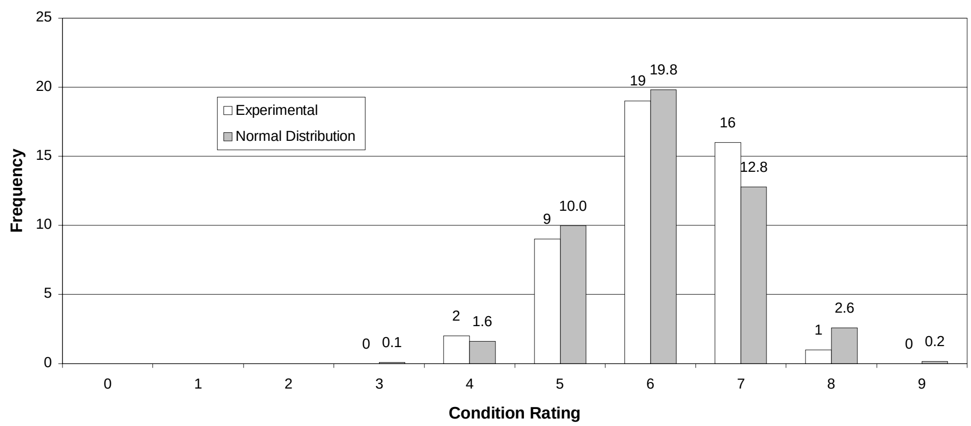
Figure 67. Task C experimental and theoretical Condition Rating distributions.



a. Deck

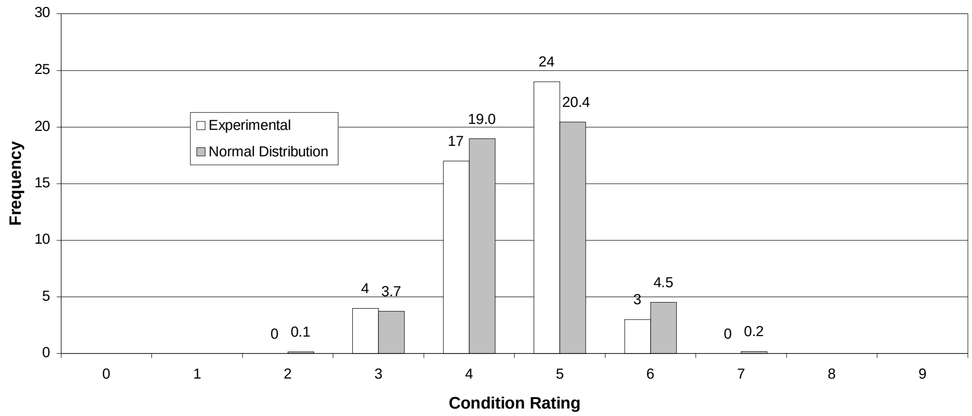


b. Superstructure

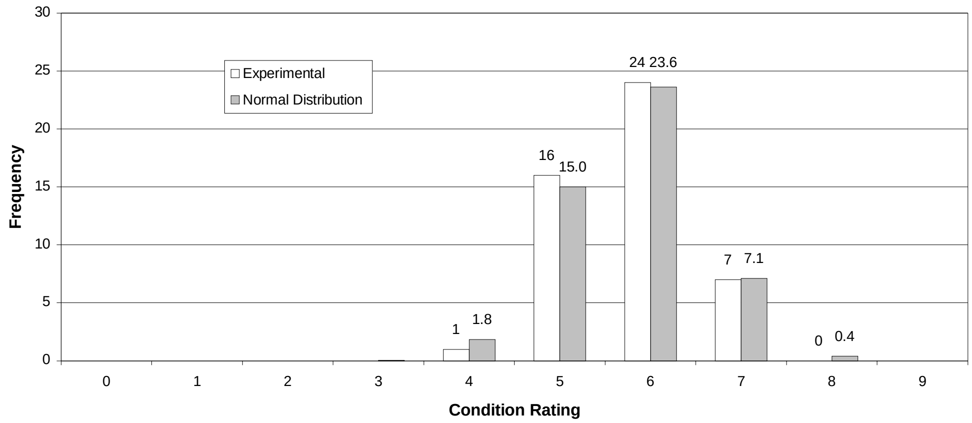


c. Substructure

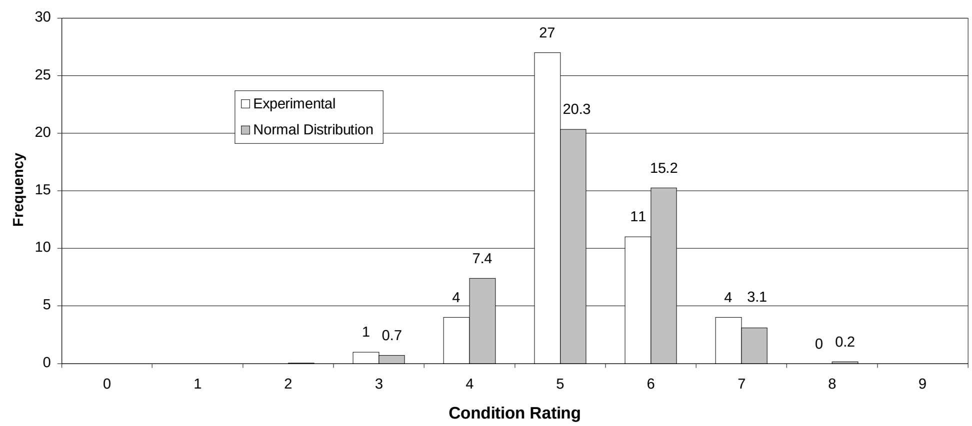
Figure 68. Task D experimental and theoretical Condition Rating distributions.



a. Deck

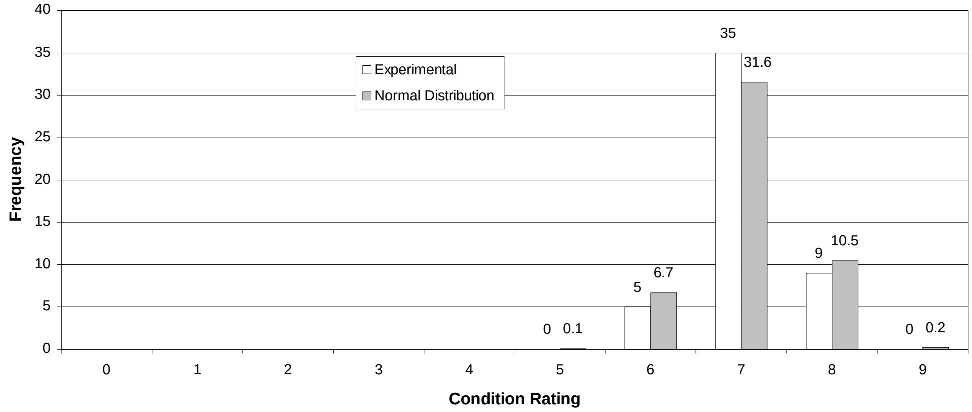


b. Superstructure

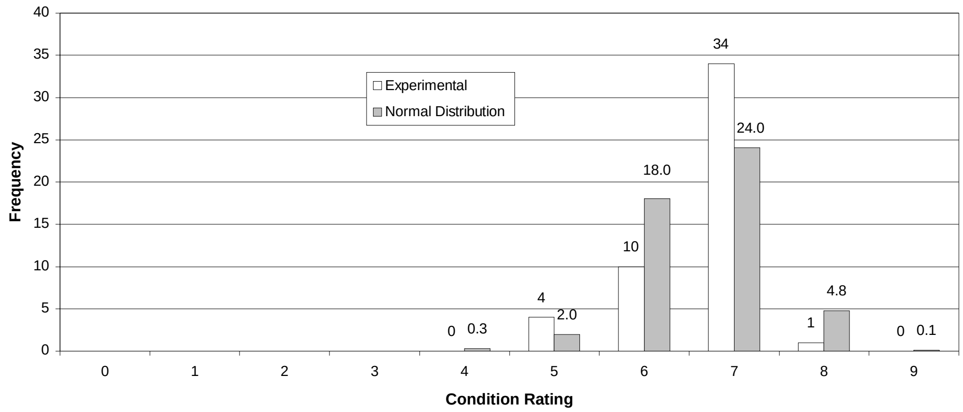


c. Substructure

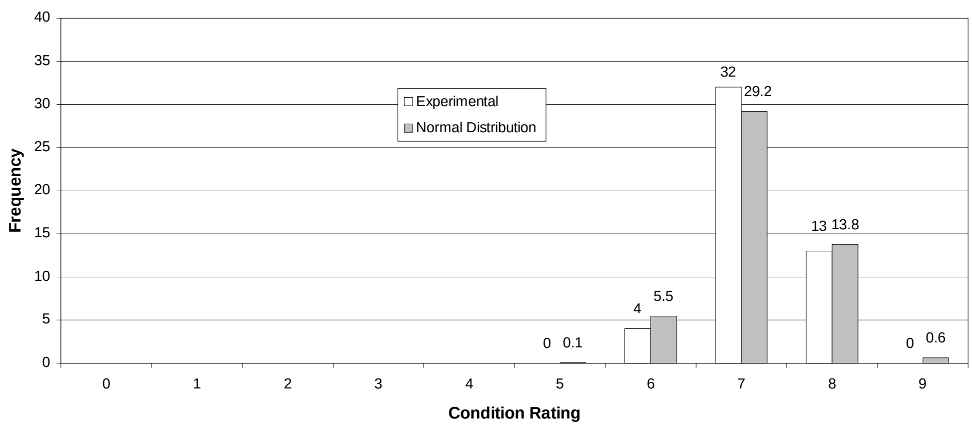
Figure 69. Task E experimental and theoretical Condition Rating distributions.



a. Deck.



b. Superstructure



c. Substructure

Figure 70. Task G experimental and theoretical Condition Rating distributions.

Table 80. Theoretical distribution of Condition Ratings.

Task	Element	Reference	Average	Predicted Condition Rating Ranges for Percentages of the Population		
				68%	95%	99%
A	Deck	5	5.8	5.0 to 6.6	4.2 to 7.4	3.4 to 8.3
	Superstructure	5	5.9	5.1 to 6.7	4.3 to 7.4	3.5 to 8.2
	Substructure*	6	6.1	5.4 to 6.9	4.6 to 7.7	3.8 to 8.5
B	Deck	4	4.9	3.9 to 5.8	3.0 to 6.8	2.1 to 7.7
	Superstructure	4	4.2	3.5 to 5.0	2.7 to 5.8	1.9 to 6.5
	Substructure	4	4.3	3.5 to 5.1	2.8 to 5.8	2.0 to 6.6
C	Deck	4	5.2	4.2 to 6.1	3.3 to 7.0	2.4 to 7.9
	Superstructure	4	4.6	3.8 to 5.5	2.9 to 6.3	2.0 to 7.2
	Substructure	5	5.5	4.7 to 6.3	4.0 to 7.0	3.2 to 7.8
D	Deck	5	4.8	3.9 to 5.8	2.9 to 6.7	2.0 to 7.6
	Superstructure	5	5.3	4.4 to 6.2	3.5 to 7.1	2.7 to 7.9
	Substructure	6	6.1	5.2 to 7.0	4.3 to 7.9	3.4 to 8.8
E	Deck	4	4.5	3.8 to 5.3	3.1 to 6.0	2.3 to 6.8
	Superstructure	6	5.8	5.1 to 6.5	4.3 to 7.2	3.6 to 7.9
	Substructure	6	5.3	4.5 to 6.1	3.6 to 6.9	2.8 to 7.8
G	Deck	7	7.1	6.6 to 7.6	6.0 to 8.1	5.5 to 8.7
	Superstructure	7	6.7	6.0 to 7.3	5.3 to 8.0	4.7 to 8.6
	Substructure	8	7.2	6.6 to 7.8	6.0 to 8.3	5.5 to 8.9

* Did not satisfy χ^2 test for goodness-of-fit.

Table 81. Theoretical distribution of DFR ranges.

Element	Average DFR	Predicted DFR Ranges for Percentages of the Population		
		68%	95%	99%
All Decks	0.55	-0.4 to 1.5	-1.3 to 2.4	-2.3 to 3.4
All Superstructures	0.24	-0.7 to 2.0	-1.5 to 2.0	-2.4 to 2.9
All Substructures	-0.08	-1.0 to 0.84	-1.9 to 1.8	-2.8 to 2.7
All Elements	0.24	-0.7 to 1.2	-1.7 to 2.1	-2.6 to 3.1

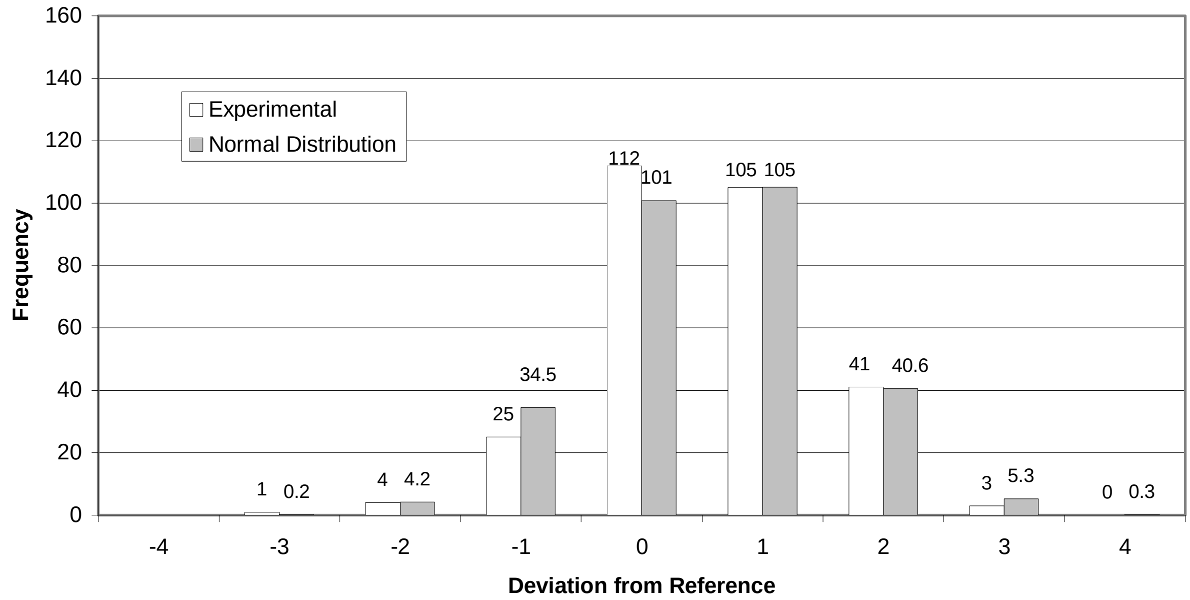


Figure 71. Experimental and theoretical DFR distributions – Deck.

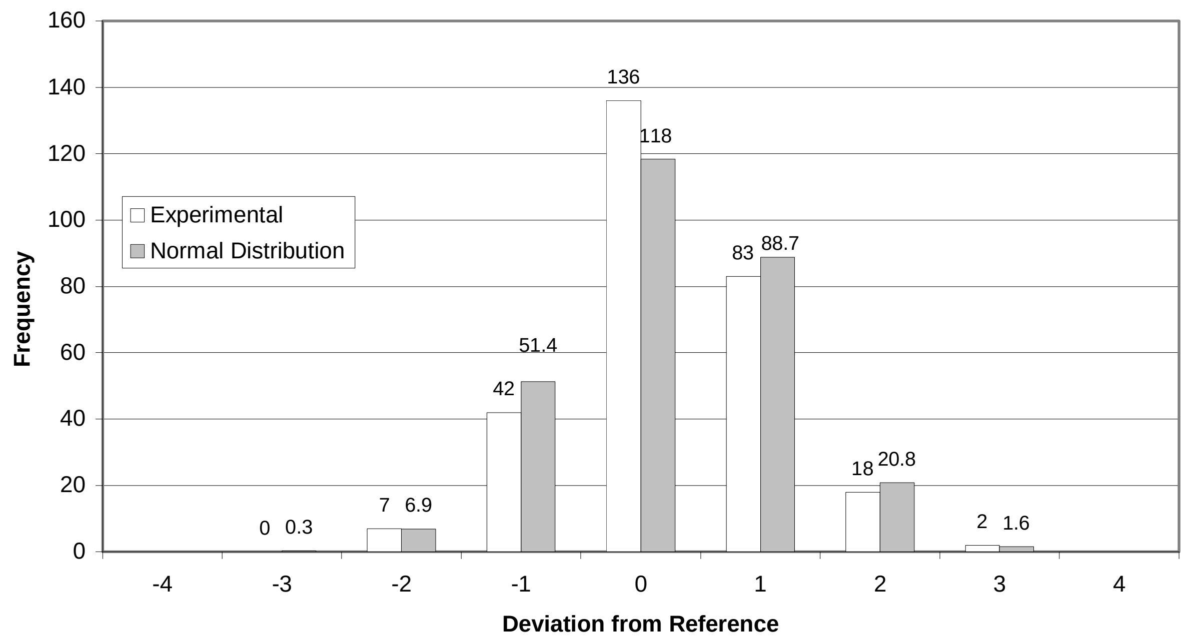


Figure 72. Experimental and theoretical DFR distributions – Superstructure.

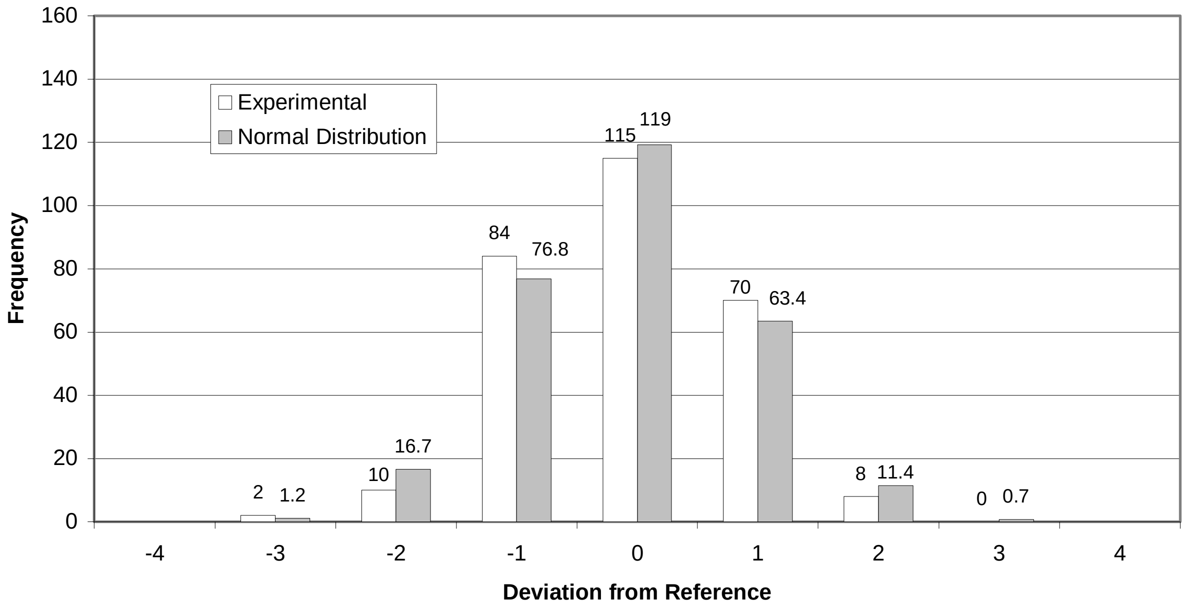


Figure 73. Experimental and theoretical DFR distributions – Substructure.

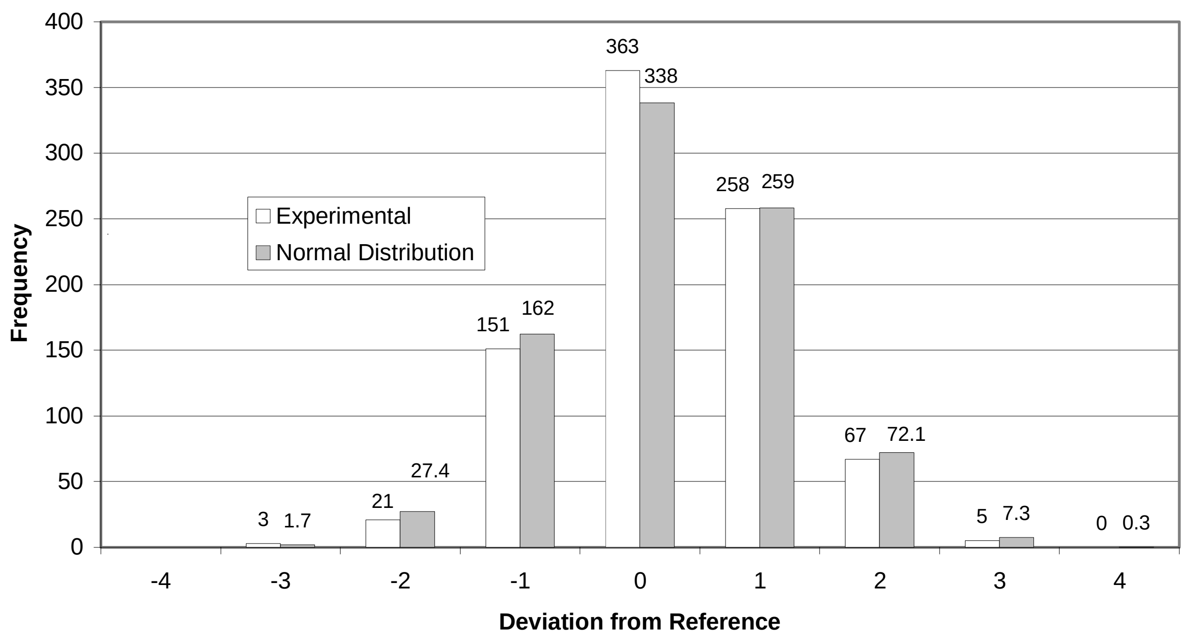


Figure 74. Experimental and theoretical DFR distributions – All element types.

to gauge predicted ranges of data because a 95 percent probability is typically viewed as an acceptable risk level. With this in mind, one can conclude that, in general, 95 percent of the Condition Ratings for a specific bridge will vary within approximately plus or minus two rating points from the average inspector Condition Rating for that bridge. In addition, note that approximately 68 percent of the Condition Ratings will be within approximately plus or minus one rating point of that average.

5.2.3.1.4. Influence of Primary Element Condition and Type on Condition Ratings

Variations in inspection results could be related to the overall condition and/or type of the element being inspected. In order to assess the relationship with element condition, the bridge elements were divided into two broad categories – “better” and “poorer.” These categories are based on the reference Condition Rating assigned to each element. Components were assigned a “better” General Condition if they had a reference rating of 9 through 6 and a “poorer” General Condition if they had a reference rating of 5 through 0. Table 82 summarizes these classifications.

Table 83 presents a summary of the DFR data grouped by element type and General Condition. This table shows that the deck, regardless of the General Condition, was, on average, rated higher than the reference. Note, however, there was only one “better” condition deck and it was rated with the least DFR, as well as the least dispersion. Alternately, the “better” condition superstructures and substructures were rated lower than the reference, but to a lesser extent than the “poorer” condition superstructures and substructures were rated higher.

Table 83 also shows that the “poorer” condition elements were typically rated with the greatest dispersion, as illustrated by the standard deviation of the DFR data. The data also illustrate that, of the different element types, the superstructures were evaluated, overall, with the least dispersion. The maximum positive and maximum negative DFR data are also presented in table 83 for comparative purposes. These data illustrate the data spread and support the general trends given elsewhere.

Table 82. Classification of primary element General Condition.

Task	Element	Reference Condition Rating	General Condition
A	Deck	5	poorer
	Superstructure	5	poorer
	Substructure	6	better
B	Deck	4	poorer
	Superstructure	4	poorer
	Substructure	4	poorer
C	Deck	4	poorer
	Superstructure	4	poorer
	Substructure	5	poorer
D	Deck	5	poorer
	Superstructure	5	poorer
	Substructure	6	better
E	Deck	4	poorer
	Superstructure	6	better
	Substructure	6	better
G	Deck	7	better
	Superstructure	7	better
	Substructure	8	better

Table 83. DFR by component type and General Condition.

Element	General Condition	N	Average	Standard Deviation	Maximum Positive Deviation	Maximum Negative Deviation
Deck	poorer	5	0.64	0.98	3	-3
	better	1	0.08	0.53	1	-1
	all	6	0.55	0.94	3	-3
Superstructure	poorer	4	0.51	0.86	3	-2
	better	2	-0.29	0.69	2	-2
	all	6	0.24	0.80	3	-2
Substructure	poorer	2	0.39	0.77	2	-1
	better	4	-0.32	0.89	2	-3
	all	6	-0.08	0.92	2	-3
All	poorer	11	0.55	0.90	3	-3
	better	7	-0.25	0.80	2	-3
Overall		18	0.24	0.95	3	-3

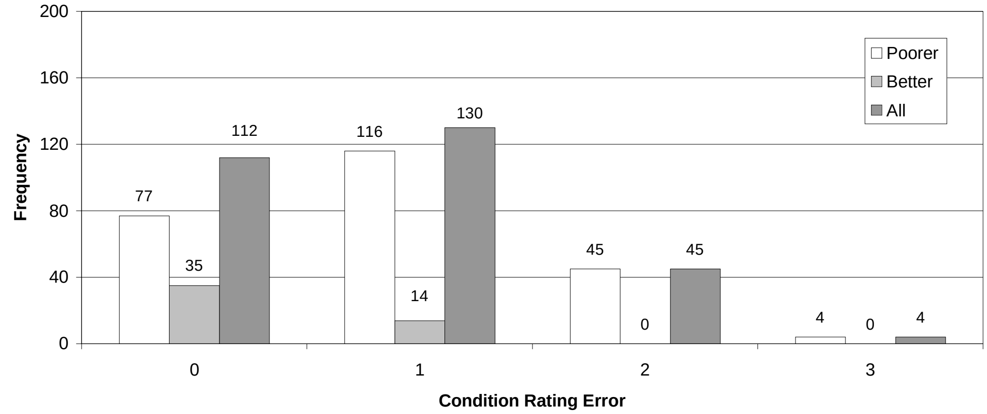
5.2.3.1.5. Influence of Primary Element Type and Conditions on Condition Rating Error

Some observations can be made from the Condition Rating errors. In this discussion, "Condition Rating error" is defined as the absolute value of the DFR data. This information is useful for bridge owners because it establishes how often and to what extent Condition Ratings vary from the reference rating, regardless of whether the deviation is negative or positive. Table 84 summarizes these data. From this table, it can be seen that "poorer" condition elements consistently exhibited the greatest error, as well as the largest dispersion of those errors. The "poorer" condition decks had both the largest average error and the largest dispersion of all element types, while the "better" condition deck had both the smallest average error and the smallest dispersion of all components. This indicates that inspectors may have the greatest difficulty in assessing the severity of the deficiencies in relatively more deficient bridge decks.

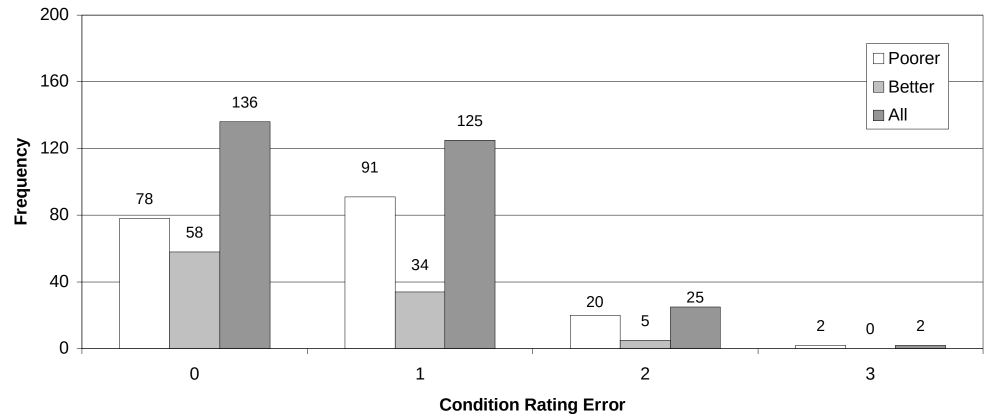
Table 84. Condition Rating error by component type and General Condition.

Element	General Condition	N	Average Error	Standard Deviation	Maximum	Mode
Deck	poorer	5	0.90	0.75	3	1
	better	1	0.29	0.46	1	0
	all	6	0.80	0.75	3	1
Superstructure	poorer	4	0.72	0.69	3	1
	better	2	0.45	0.60	2	0
	all	6	0.63	0.67	3	0
Substructure	poorer	2	0.60	0.62	2	0
	better	4	0.72	0.62	3	1
	all	6	0.68	0.62	3	1
All	poorer	11	0.78	0.72	3	1
	better	7	0.58	0.61	3	0
Overall		18	0.70	0.68	3	1

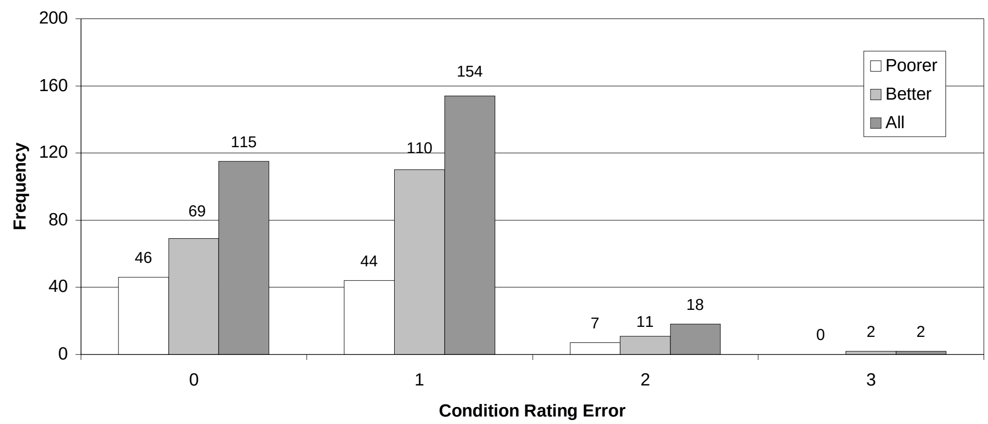
From table 84, it can also be seen that, overall, inspectors were most likely to give a Condition Rating with an error of 1 (i.e., either +1 or -1 from the reference). This is also shown in figures 75 and 76 that give the frequency distribution of the Condition Rating error data. These figures clearly indicate that the most common level of inspector error was providing a rating that was less than or equal to one point removed from the reference value. This further illustrates the accuracy of the sample.



a. Deck



b. Superstructure



c. Substructure

Figure 75. Condition Rating error distribution by element type and General Condition.

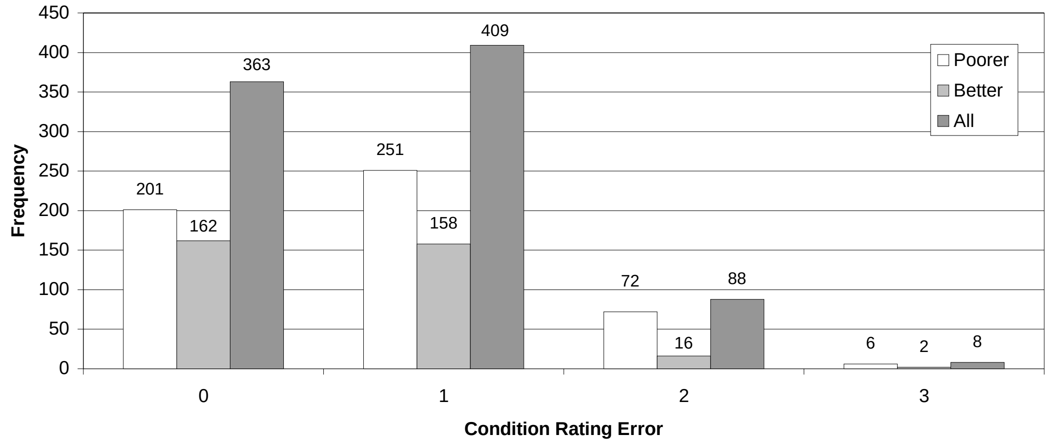


Figure 76. Condition Rating error distribution for all elements by element General Condition.

5.2.3.1.6. Consistency of Inspection Ratings by Element Type and Element Condition

A useful piece of information for bridge owners is the level of inspector consistency between different elements of a bridge (i.e., does an inspector who tends to rate decks low also do so for superstructures and substructures?). Table 85 summarizes this relationship. The procedure for developing the data in table 85 was to first calculate each inspector's average DFR by element type. This resulted in three average DFRs for each inspector (i.e., one for the decks, one for the superstructures, and one for the substructures). For each element type combination (e.g., deck and superstructure, superstructure and substructure, etc.), the number of inspectors in each case was then tallied. As an example, if an inspector's average Deck DFR was 0.5 and the average superstructure DFR was 0.3, the inspector would be tallied under the "Always Positive" case for the "Deck and Superstructure" element combination. The table also indicates, for some cases, the frequency with which both or all average DFRs were within one rating point.

From table 85, it can be seen that inspectors were, in general, consistent for DFR for different element types. Specifically, 83 percent of the deck/superstructure element combination, 84 percent of the superstructure/substructure element combination, and 67 percent of the substructure/deck element combination had average DFRs that were either always positive or always negative. Also in this table is the subcategory data related to the general accuracy. This indicates that most inspectors were, for a given case, within one rating point for both elements.

Table 85. Inspection consistency by element type.

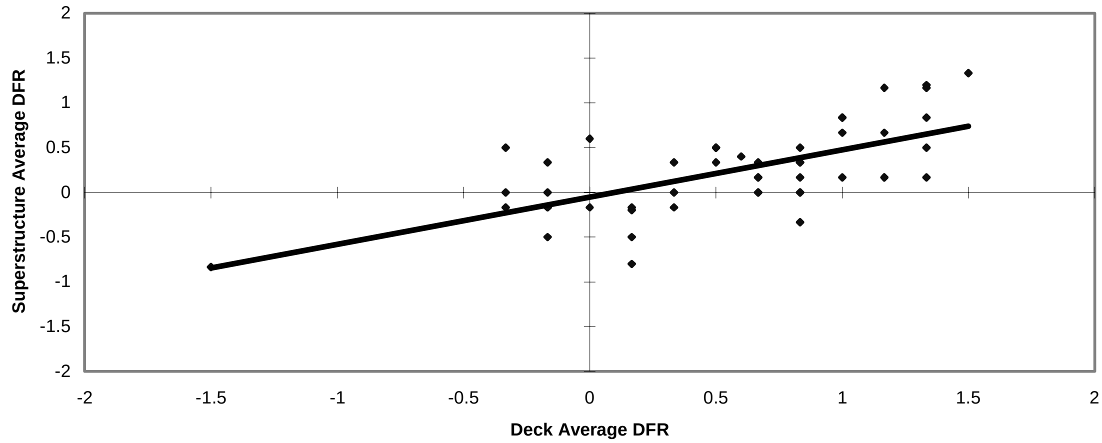
Case	Deck and Superstructure	Superstructure and Substructure	Substructure and Deck	Deck, Superstructure, and Substructure
Always Positive	33 (67%)	23 (47%)	23 (47%)	22 (45%)
within +1	*24 (49%)*	*19 (39%)*	*13 (27%)*	*12 (24%)*
Always Negative	8 (16%)	18 (37%)	10 (20%)	8 (16%)
within -1	*7 (14%)*	*17 (35%)*	*9 (18%)*	*7 (14%)*
One Positive/ One Negative	8 (16%)	8 (16%)	16 (33%)	N/A
within ±1	*8 (16%)*	*8 (16%)*	*16 (33%)*	*N/A*
One Positive/ Two Negative	N/A	N/A	N/A	6 (12%)
One Negative/ Two Positive	N/A	N/A	N/A	13 (27%)

N/A = Not applicable.

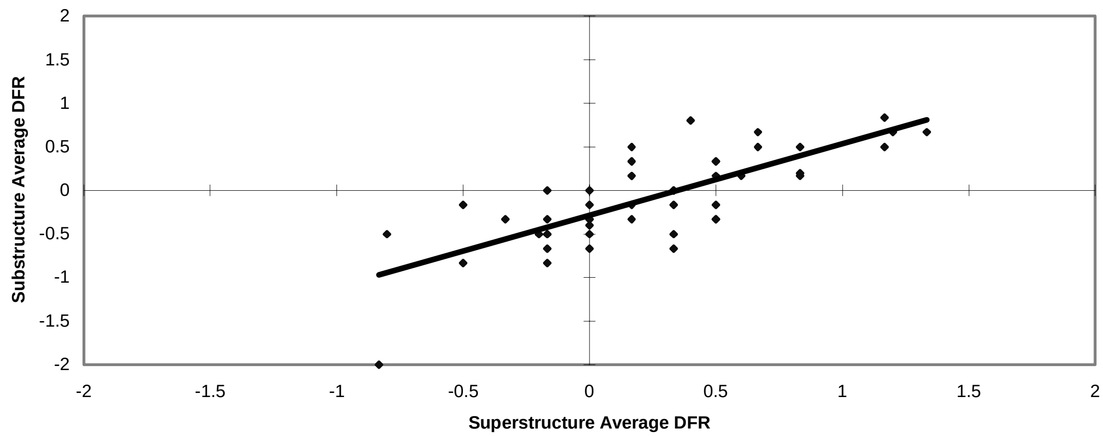
The case where the most inspectors did not fall in the “within one rating point” range was the always positive case.

The relationship between the average element DFR data is also readily apparent from figure 77, which graphically compares the average deviation data for each component against the other components. In addition, a first-order best-fit line has been added to illustrate the general trend for each case. From figure 77 and the data in table 85, it becomes apparent that the relationship between the deviation data is positive in all cases.

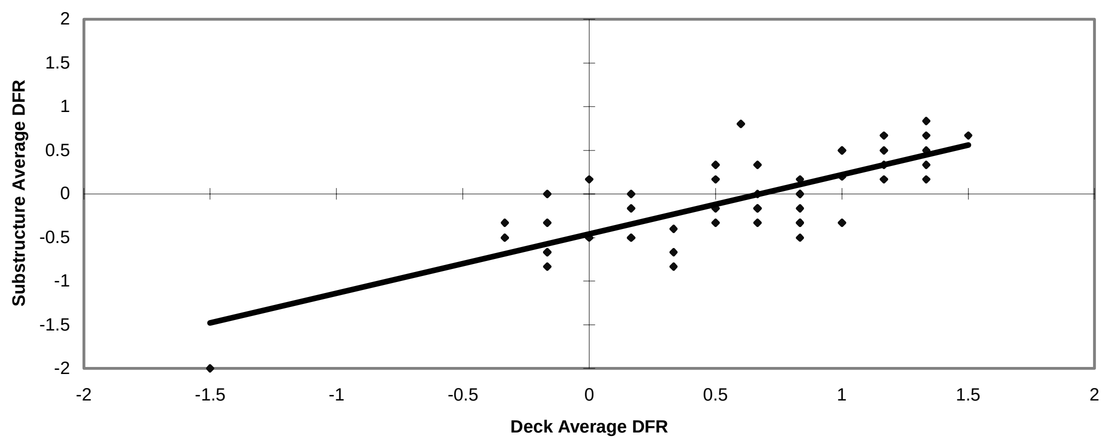
Similar to the previous discussion, table 86 and figure 78 illustrate the relationship between inspections on “poorer” and “better” condition elements. Although the relationship is not as clear from the tabular values, when one combines figure 78 with table 86, it becomes apparent that there is a positive correlation between the average DFR for “better” and “poorer” condition elements. However, the relationship has a negative vertical shift and a smaller slope than those exhibited in figure 77.



a. Deck and Superstructure



b. Superstructure and Substructure



c. Substructure and Deck

Figure 77. Consistency of DFR by element type.

Table 86. Inspection consistency by element General Condition.

Case		"better" and "poorer"
Always Positive		17 (35%)
	within +1	*11 (22%)*
Always Negative		7 (14%)
	within -1	*6 (12%)*
One Positive/One Negative		25 (51%)
	within ±1	*25 (51%)*

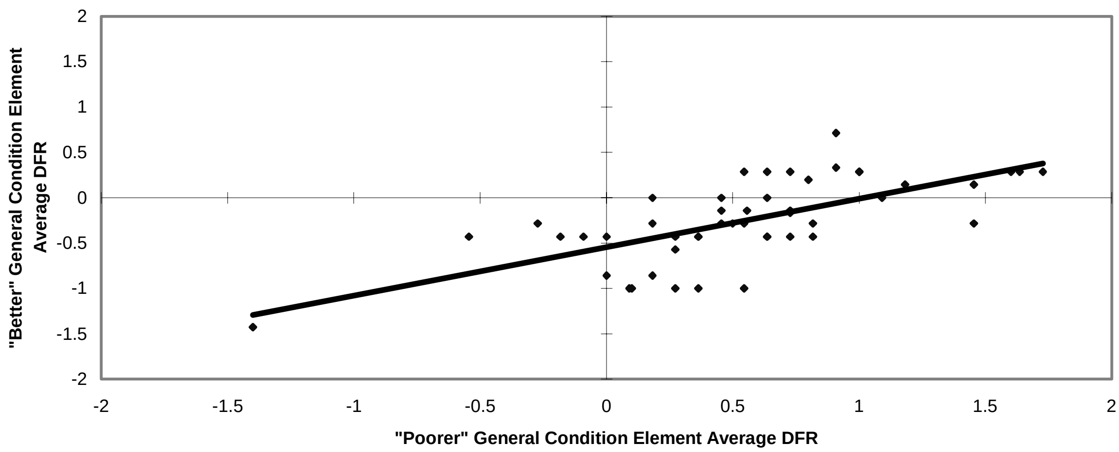


Figure 78. Consistency of DFR by element General Condition.

5.2.3.1.7. Inspector Dispersion and Inspector DFR Range

Table 87 summarizes inspector dispersion of the DFR data. Inspector dispersion is the spread in the DFR data from an individual inspector. These data describe the variability in DFRs for each inspector. Note that an inspector who always had the same DFR would have a dispersion of 0, regardless of the accuracy of the Condition Ratings. Therefore, Inspector dispersion is not a measure of inspector accuracy, but rather an indicator of consistency.

The data in table 87 indicate that the greatest dispersion in inspection results was from assessments of the substructures and from the "poorer" General Condition elements. The minimum and maximum dispersion data indicate the range of inspector dispersions. These

Table 87. Inspector dispersion of DFR.

		Average Inspector Dispersion	Minimum Inspector Dispersion	Maximum Inspector Dispersion
Element Type	Deck	0.75	0.00	1.47
	Superstructure	0.77	0.00	1.33
	Substructure	0.80	0.41	1.47
General Condition	poorer	0.73	0.40	1.38
	better	0.69	0.00	1.27
Overall		0.84	0.50	1.15

ranged from a dispersion of 0.0 (i.e., always having the same DFR value) to a dispersion of approximately 1.5.

In order to extrapolate the experimental data to the population, a normal distribution was applied to these data and was tested for goodness-of-fit. Results from the application of the normal distribution are illustrated in figure 79. The goodness-of-fit test revealed that the normal distribution is an appropriate approximation for the overall dispersion data. From this, it can be concluded that 95 percent of the inspectors will have a DFR dispersion of 0.55 to 1.12.

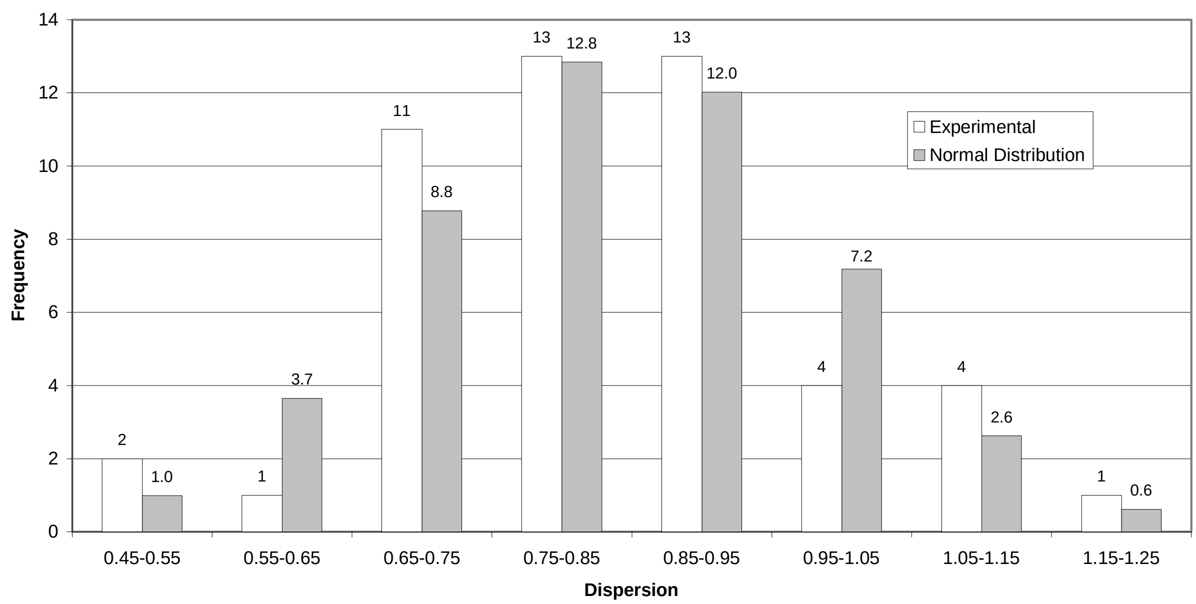


Figure 79. Experimental and normal distributions of inspector dispersion.

Table 88 summarizes the range of DFRs for the sample of inspectors. This table shows the average DFR range, the dispersion of these ranges, and the minimum and maximum DFR ranges for each category. The data indicate that the substructures and the “poorer” condition elements had the largest average range of DFR data, which reiterates many of the previously given findings. In addition, it can be observed that, on average, inspectors had a DFR range of 2.94. This indicates that the average inspector gave Condition Ratings that ranged in DFR by approximately three points (e.g., -3 to 0, -1 to +2, 0 to +3, etc.), with a lowest DFR range of 1 and a highest range of 4. From the table, it can be seen that the average range for each element (i.e., deck, superstructure, or substructure) is less than the overall by approximately one point. This indicates that there is greater consistency for a single element type than for all element types combined.

Table 88. Range of DFRs.

	Average Range	Range Standard Deviation	Minimum Range	Maximum Range
Element Type				
Deck	1.88	0.83	0	4
Superstructure	1.88	0.81	0	3
Substructure	1.96	0.79	1	4
General Condition				
poorer	2.16	0.72	0	4
better	1.73	0.70	0	3
Overall	2.94	0.69	1	4

5.2.3.1.8. Variability in Condition Ratings by State

Although the sample of inspectors were instructed to use the same Condition Rating system, it was thought that differences in interpretation of the Condition Rating definitions may exist between States. The following will present results related to differences in Condition Rating assignment by individual States. Note that for much of this discussion, reference will be made to various States. This should not imply that the two inspectors from each State worked together, but rather were from the same State. Furthermore, it must be pointed out that the sample size from any State is only two and it may not be statistically correct to extrapolate these results to each State's entire population of bridge inspectors

Table 89 summarizes how consistent inspectors from the same State were with respect to their Condition Rating assignment. The data in Table 89 are the difference between the Condition Ratings assigned by the inspectors from each individual State for each task. From these data, it can be seen that in approximately 90 percent of the cases, the two inspectors from the same State were within one rating point of each other.

Table 90 gives the probability that the average Condition Ratings assigned by the inspectors from each State for each task are not statistically different from the remainder of the sample. Tables 91 and 92 give the average probability for each State by element type and element condition. From the data in these tables, it can be seen that the average Condition Ratings from most States are not statistically different from the sample. The one exception to this is State 6. The difference is most prominent in assigning Condition Ratings to poorer condition elements, but can also be seen in the other groupings of elements.

Tables 93 through 95 summarize the influence of the use of various State QA/QC procedures on Condition Rating assignment. To accomplish these analyses, the inspectors were grouped by the type of QA/QC programs that their respective States had identified in the survey of States presented previously. As can be seen from these data, the only QA/QC procedure that may have influenced Condition Rating assignment in this study is the rotation of inspectors to different bridges.

5.2.3.2. REGRESSION ANALYSIS OF MEASURED FACTORS WITH SAMPLE ROUTINE INSPECTION RESULTS

The following presents regression analysis results using the previously presented data (i.e., Condition Ratings and measured factors). The goal of this analysis was to determine if, and to what extent, the human and environmental factors correlated with the Routine Inspection results. This discussion will focus exclusively on examining the relationship between the human and

Table 89. Difference in assigned Condition Rating by State.

State	Task A			Task B			Task C		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
1	0	0	1	0	0	0	0	1	1
2	0	0	1	1	0	0	0	1	1
3	1	3	1	1	1	1	0	2	1
4	1	1	0	0	0	2	1	0	1
5	1	1	2	0	0	0	2	1	0
6	3	0	2	2	1	0	1	1	N/A
7	1	0	1	1	1	0	1	0	0
8	1	2	1	0	0	0	1	2	1
9	1	1	0	2	1	1	0	0	1
10	0	0	1	0	1	0	1	1	1
11	1	1	1	1	0	1	0	0	1
12	0	0	0	N/A*	2	1	1	1	0
13	1	0	2	1	2	1	0	2	1
14	1	1	0	1	0	1	1	1	1
15	0	1	1	1	1	0	1	1	1
16	1	0	0	1	1	1	1	1	1
17	0	1	1	1	0	0	1	1	1
18	0	1	0	0	1	1	1	0	1
19	1	0	0	1	1	2	2	1	2
20	2	2	0	2	1	2	2	2	2
21	0	0	0	1	0	1	1	0	0
22	0	0	1	2	0	2	2	1	1
23	0	0	1	0	0	1	0	1	0
24	0	0	0	0	0	0	1	0	2

Table 89. Difference in assigned Condition Rating by State (continued).

State	Task D			Task E			Task G		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
1	1	1	0	0	0	N/A	0	1	0
2	0	0	0	0	0	1	1	0	1
3	1	2	1	1	1	1	0	0	0
4	0	0	1	1	1	0	1	1	0
5	0	0	0	0	1	1	1	1	1
6	1	1	2	1	2	1	0	1	1
7	2	2	0	2	2	0	1	0	0
8	1	N/A	1	0	1	1	1	0	0
9	1	2	1	0	2	2	0	1	0
10	0	0	0	1	0	0	1	0	0
11	N/A	2	0	0	0	0	0	0	1
12	2	N/A	1	0	0	0	0	0	0
13	1	2	0	0	1	0	0	0	1
14	1	1	1	1	1	1	0	0	0
15	0	N/A	2	0	1	1	2	2	0
16	1	1	1	1	0	0	0	0	0
17	0	1	N/A	0	1	0	1	1	0
18	1	1	0	0	1	1	0	1	0
19	1	0	N/A	2	2	0	1	1	0
20	2	2	2	2	1	2	0	0	0
21	0	0	1	0	0	1	0	0	0
22	0	0	0	N/A	N/A	N/A	0	0	1
23	1	2	1	1	0	0	0	2	0
24	1	1	0	0	0	1	1	1	1

*N/A = Not available.

Table 90. Probability of difference in Condition Rating by State.

State	Task A			Task B			Task C		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
1	15%	11%	24%	85%	68%	18%	80%	85%	100%
2	75%	1%	52%	34%	68%	59%	19%	85%	100%
3	23%	49%	52%	34%	61%	69%	19%	52%	100%
4	58%	N/A*	80%	18%	61%	59%	30%	52%	100%
5	58%	25%	80%	18%	61%	59%	80%	85%	35%
6	2%	11%	0.002%	0.003%	0.07%	1%	1%	0.02%	N/A
7	58%	82%	24%	58%	18%	59%	60%	31%	35%
8	23%	82%	52%	85%	15%	18%	60%	2%	6%
9	23%	25%	12%	8%	61%	69%	19%	52%	6%
10	75%	82%	52%	85%	2%	59%	30%	14%	6%
11	23%	25%	52%	34%	15%	2%	19%	52%	6%
12	75%	82%	80%	N/A	68%	69%	60%	85%	35%
13	23%	11%	80%	34%	15%	69%	19%	52%	100%
14	58%	49%	80%	57%	68%	69%	30%	85%	100%
15	75%	49%	52%	57%	18%	59%	60%	85%	100%
16	23%	82%	80%	57%	61%	14%	30%	85%	100%
17	75%	25%	52%	34%	68%	59%	60%	85%	100%
18	75%	49%	80%	18%	61%	69%	30%	52%	100%
19	58%	82%	80%	57%	61%	59%	80%	85%	35%
20	15%	4%	12%	8%	61%	18%	80%	52%	35%
21	15%	25%	80%	34%	68%	14%	80%	52%	35%
22	3%	82%	52%	85%	68%	18%	80%	85%	100%
23	15%	49%	24%	18%	68%	69%	7%	85%	35%
24	75%	82%	12%	8%	68%	59%	3%	31%	35%

Table 90. Probability of difference in Condition Rating by State (continued).

State	Task D			Task E			Task G		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
1	29%	74%	87%	30%	12%	N/A	0.3%	1%	0.2%
2	78%	63%	15%	38%	65%	70%	26%	46%	42%
3	64%	25%	53%	6%	59%	70%	83%	46%	64%
4	21%	63%	33%	4%	N/A	63%	12%	1%	64%
5	21%	3%	7%	30%	1%	18%	12%	74%	8%
6	0.02%	19%	7%	4%	65%	0.1%	83%	74%	42%
7	78%	63%	87%	38%	65%	63%	26%	46%	4%
8	29%	N/A	53%	38%	59%	70%	26%	46%	64%
9	64%	63%	2%	38%	65%	21%	83%	74%	4%
10	7%	25%	15%	94%	65%	21%	26%	16%	64%
11	N/A	25%	15%	38%	1%	0.2%	83%	46%	8%
12	21%	N/A	53%	30%	65%	63%	83%	46%	64%
13	29%	25%	87%	38%	59%	63%	83%	46%	42%
14	64%	19%	33%	94%	59%	70%	83%	46%	4%
15	21%	N/A	87%	30%	59%	70%	83%	16%	64%
16	29%	74%	33%	94%	65%	63%	83%	46%	64%
17	78%	74%	N/A	38%	59%	63%	26%	74%	64%
18	64%	19%	87%	38%	59%	70%	83%	74%	64%
19	64%	63%	N/A	30%	65%	63%	26%	6%	4%
20	79%	63%	87%	38%	15%	63%	83%	46%	64%
21	79%	63%	33%	38%	65%	71%	83%	46%	64%
22	7%	25%	15%	N/A	N/A	N/A	83%	46%	42%
23	64%	25%	1%	4%	65%	63%	83%	16%	64%
24	29%	74%	1%	38%	65%	70%	26%	74%	42%

*N/A = Not available.

Table 91. Average probability of difference in Condition Rating by State and element type.

Team	Deck	Superstructure	Substructure	All Elements
1	40%	42%	46%	42%
2	45%	56%	56%	53%
3	38%	49%	68%	52%
4	24%	44%	67%	45%
5	27%	42%	35%	38%
6	15%	28%	10%	18%
7	53%	51%	45%	50%
8	44%	41%	44%	43%
9	39%	57%	19%	38%
10	53%	34%	36%	41%
11	39%	27%	14%	26%
12	54%	69%	61%	61%
13	38%	35%	74%	49%
14	64%	54%	59%	59%
15	54%	45%	72%	58%
16	53%	69%	59%	60%
17	52%	64%	68%	61%
18	51%	52%	78%	61%
19	53%	60%	48%	54%
20	50%	40%	47%	46%
21	55%	53%	50%	52%
22	52%	61%	45%	63%
23	32%	51%	43%	42%
24	30%	66%	37%	44%

environmental factors and the primary element Condition Ratings (i.e., deck, superstructure, and substructure).

For the following discussion, the human and environmental factors have been regrouped to facilitate completing the analysis. The factors will be divided into two categories – inspector and inspection factors. The inspector factors are those factors that were measured from the SRQ and vision testing. The inspection factors are those factors that were measured during a specific inspection through the pre-task evaluations, firsthand observations, or the post-task evaluations (e.g., Temperature, Inspector Rested Level, etc.).

This categorization resulted in 26 discrete inspector factors used in these analyses. The following list summarizes the inspector factors and the source of the inspector factor

Table 92. Average probability of difference in Condition Rating by State and element condition.

Team	Poorer	Better	All Elements
1	54%	21%	42%
2	57%	46%	53%
3	46%	51%	52%
4	47%	42%	45%
5	43%	29%	38%
6	4%	39%	18%
7	53%	45%	50%
8	36%	53%	43%
9	39%	37%	38%
10	44%	37%	41%
11	24%	29%	26%
12	58%	65%	61%
13	37%	66%	49%
14	63%	54%	59%
15	55%	62%	58%
16	59%	62%	60%
17	63%	56%	61%
18	52%	74%	61%
19	61%	41%	54%
20	41%	53%	46%
21	46%	63%	52%
22	55%	48%	63%
23	40%	45%	42%
24	46%	41%	44%

measurement:

- Age (SRQ1)
- Height (SRQ1)
- Weight (SRQ1)
- General Physical Condition (SRQ2)
- General Mental Condition (SRQ5)
- Perception of Bridge Inspection Importance to Public Safety (SRQ9)
- Public Safety Assessment During Bridge Inspection (SRQ10)
- General Mental Focus (SRQ11)
- Reported Fear of Heights (SRQ13)
- Reported Fear of Enclosed Spaces (SRQ14)

Table 93. Probability of difference of Condition Rating assignment by QA/QC program.

QA/QC Type	Task A			Task B			Task C		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
Any	96%	41%	67%	85%	94%	73%	68%	57%	76%
Report Review	52%	32%	95%	83%	20%	25%	70%	45%	84%
Field Review	79%	95%	24%	11%	95%	4%	25%	31%	71%
Independent Reinspection	2%	21%	28%	93%	57%	70%	81%	81%	65%
FHWA Review	72%	32%	25%	22%	91%	39%	9%	65%	36%
Training/ Meetings	43%	21%	13%	7%	57%	19%	7%	20%	48%
Rotation of Inspectors	3%	32%	0.2%	1%	5%	3%	4%	1%	5%

Table 93. Probability of difference of Condition Rating assignment by QA/QC program (continued).

QA/QC Type	Task D			Task E			Task G		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
Any	64%	92%	42%	86%	23%	43%	61%	22%	8%
Report Review	40%	84%	89%	99%	65%	88%	57%	81%	36%
Field Review	92%	46%	16%	58%	14%	2%	26%	66%	37%
Independent Reinspection	74%	99%	22%	25%	89%	83%	59%	78%	61%
FHWA Review	96%	70%	21%	45%	89%	92%	44%	18%	5%
Training/ Meetings	24%	67%	41%	36%	97%	27%	23%	78%	92%
Rotation of Inspectors	0.3%	20%	7%	2%	51%	1%	52%	28%	11%

Table 94. Average probability of difference in Condition Rating by QA/QC type and element type.

QA/QC Type	Deck	Superstructure	Substructure	All Elements
Any	77%	55%	52%	61%
Report Review	67%	55%	70%	64%
Field Review	49%	58%	26%	44%
Independent Reinspection	56%	71%	55%	60%
FHWA Review	48%	61%	36%	48%
Training/Meeting	23%	57%	40%	40%
Rotation of Inspectors	10%	23%	5%	13%

Table 95. Average probability of difference in Condition Rating by QA/QC type and element condition.

QA/QC Type	Poorer	Better	All Elements
Any	76%	38%	61%
Report Review	58%	73%	64%
Field Review	55%	26%	44%
Independent Reinspection	61%	60%	60%
FHWA Review	53%	42%	48%
Training/Meeting	32%	53%	40%
Rotation of Inspectors	7%	22%	13%

- Reported Fear of Traffic (SRQ15)
- Experience in Bridge Inspection (SRQ20)
- Experience in Highway Structures (SRQ21)
- Estimated Additional Years as a Bridge Inspector (SRQ23)
- Quality of Relationship With Supervisor (SRQ27)
- Perceived Importance of Work by Management (SRQ28)
- Percentage of Time on Bridge Inspection (SRQ29)
- Percentage of Routine Inspections (SRQ30)
- Comparison to Other Inspectors (SRQ34)
- Number of Annual Bridge Inspections (SRQ38)
- General Education Level (SRQ18)
- Formal Bridge Inspection Training (SRQ19)
- Jet Lag (SRQ37)
- Color Vision (two different measures from PV-16 color vision test)

- Near Visual Acuity (right and left eye from near vision test)
- Distance Visual Acuity (right and left eye from distance vision test)

Twenty-one discrete inspection factors were also identified. The following list summarizes these factors and the source of their measurement:

- Time Since Similar Inspection (pre-task questionnaire)
- Estimated Time for Task (pre-task questionnaire)
- Rested Level Before Task (pre-task questionnaire)
- Wind Speed (direct environmental measurement)
- Light Intensity Below Superstructure (direct environmental measurement)
- Light Intensity on Deck (direct environmental measurement)
- Heat Index (direct environmental measurement)
- Observed Inspector Focus Level (firsthand observation)
- Observed Inspector Rushed Level (firsthand observation)
- Actual Time to Complete Task (firsthand observation)
- Reported Task Similarity to Normal (post-task questionnaire)
- Accuracy of Task at Measuring Inspection Skills (post-task questionnaire)
- Rested Level After Task (post-task questionnaire)
- Reported Level of Instruction Understanding (post-task questionnaire)
- Reported Structure Accessibility Level (post-task questionnaire)
- Reported Structure Maintenance Level (post-task questionnaire)
- Reported Structure Complexity Level (post-task questionnaire)
- Reported Observer Influence (post-task questionnaire)
- Reported Rushed Level (post-task questionnaire)
- Reported Effort Level (post-task questionnaire)
- Reported Thoroughness Level (post-task questionnaire)

Most of the inspector and inspection factors used in the analyses presented in this section were assessed in such a way that quantitative data could be collected. However, some of the data were collected in a purely qualitative form. The qualitative data were subsequently transformed into a pseudo-quantitative form for use in the regression analyses. Specifically, the inspector factor "General Education Level" was transformed into a quantitative form using the following scale:

1 = Some high school
2 = High school degree or equivalent
3 = Some trade school
4 = Trade school degree
5 = Some college
6 = Associate's degree
7 = Bachelor's degree
8 = Some graduate work
9 = Master's degree
10 = Terminal degree

Similarly, the "Formal Bridge Inspection Training" factor was calculated as the total number of FHWA training courses that an inspector had reported completing.

Color vision attributes were quantified in two different manners to simulate different uses of color vision. First, the total number of minor confusions (i.e., errors between contiguous test caps) from the PV-16 color vision test was used as a measure of inspector ability to distinguish similar colors. It was speculated that this could be of importance in assessing structural deterioration that manifests itself only as a slight change in color (e.g., some types of concrete deterioration). Second, the number of major confusions from the PV-16 color vision test was used as a measure of inspector ability to distinguish specific colors (e.g., red). It was thought that this type of color vision may be a trait necessary for fatigue crack detection. Direct visual acuity (both near and distance) was quantified as the "bottom" number from the vision test results (e.g., 20/12.5 equals a visual acuity of 12.5).

Two major categories of results will be presented. First, the discussion focuses on factor correlation with respect to specific tasks and element types. Second, the correlation of the factors with the DFR is presented. Recall that the DFR is calculated as the inspector's Condition Rating minus the corresponding reference rating.

Before presenting the results of the regression analyses, the limitations associated with this type of analysis must be discussed. There are four primary general limitations on any regression analysis and each will be discussed in the following paragraphs.

The first limitation has to do with extrapolation of the factors to levels not measured in this study. In essence, this limitation requires that all factors input into the developed equations be within the range of those measured in the study. For example, equations with terms based on the "General Mental Condition" factor are only valid over a range from 3 to 5.

The second limitation relates to the generalization of the regression results from the sample to the population of bridge inspectors. The danger in making generalizations to the population is that the two groups (i.e., the sample and the population) might not posses identical characteristics. As such, generalizations may not be statistically valid.

Making assertions of causation is the third point of limitation. Cause-and-effect relationships between the independent and dependent factors cannot be established solely on the basis of a regression analysis. To be able to make statements about causation, it is not only required to show accurate prediction in the response to the independent variables, but also that the independent variables control the response. In other words, causation demands that changes in the dependent variables can be induced by changes in the identified independent variables and that the identified independent variables are the only variables that influence the magnitude of the response. Establishing causation is beyond the scope of this study.

The final limitation lies in the method of measuring the variables. Statements indicating that a factor or a set of factors have a high correlation coefficient with the dependent data may only be valid for the specific techniques used in this study to measure them. In other words, any resulting equations that contain the factor "Reported Fear of Traffic" are only valid when measuring the "Reported Fear of Traffic" with question SRQ15.

Although these limitations must be recognized, they do not imply that the regression analysis results are without value. Accepting these limitations, the value lies in the fact that the regression analysis results can be used to accurately predict the sample results under the experimental conditions. If one can also accept that the sample and the population possess similar characteristics, then the regression results can be used to predict hypothetical inspection results. The level of required similarity depends solely on the level of risk one is willing to accept.

5.2.3.2.1. Condition Ratings

The following summarizes the regression analysis of the Condition Ratings for Tasks A through E, and Task G. The regression analysis results for predicting inspector Condition Ratings will be presented in three sections. The first presents the developed regression equation solely in terms of the inspector factors. Second, the regression analysis results solely in terms of the inspection factors alone are presented. Finally, the inspector and inspection factors are analyzed simultaneously to predict the Condition Ratings. By first considering the inspector and inspection factors individually and then examining them together, one can develop a greater understanding of the correlation of each, in addition to their interdependence.

INSPECTOR FACTORS: The procedure for establishing the regression equation for predicting the Condition Ratings in terms of the inspector factors was completed as follows. The first step was to establish whether the Condition Ratings varied linearly with any single factor. Although there were some factors that did have high (i.e., greater than 0.5) linear correlation coefficients with an individual element on a single task, none showed a consistently high degree of correlation with multiple tasks or elements. The second step was to establish whether the Condition Ratings varied with a second-order variation in the individual factors. As before, no consistent correlation existed. At this point, other types of simple functions were investigated (e.g., logarithmic, exponential, etc.) for correlation. Again, no significant relationship existed.

Since no single factor could be found to correlate with the Condition Ratings, a multivariate equation was needed. Again, starting with only linear variations in the factors, different combinations were investigated. As before, no significant relationship could be established using linear combinations alone. The final step was to use a second-order, multivariate equation.

In order to ensure that the equations were useful, it was desirable to keep the number of variables to a minimum. In addition, since the inspector factors were constant for all tasks, it was desirable to find a single set of inspector factors that could be used for all tasks. Initially, only a few factors were combined together, with the selection of factors based on the individual level of correlation with the Condition Ratings. In other words, those factors with the highest individual second order correlation coefficients were the first to be analyzed together. It quickly became apparent that seven factors would be needed to consistently obtain significant correlation coefficients. However, it should be pointed out that this does not mean that individual Condition Ratings could not be satisfactorily predicted using fewer factors, rather, for the combination of six tasks together, a non-linear equation in terms of seven variables is required.

After the initial selection of the seven factors, various other combinations of factors were evaluated to ensure that the initial selection had a significant degree of correlation. In no case could a correlation coefficient higher than that identified previously be found.

Using the above outlined procedure, Equation 2 was developed to predict the Condition Ratings in terms of seven non-linear inspector factors.

$$\text{Condition Rating} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \quad (2)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Fear of Traffic

F_2 = General Mental Condition

F_3 = Number of Annual Bridge Inspections

F_4 = General Education Level

F_5 = Right Eye Near Visual Acuity

F_6 = Color Vision (minor confusions)

F_7 = Formal Bridge Inspection Training

Values for the coefficients y_0 and a through n for the deck Condition Rating equation are given in table 96. Similarly, the coefficients for the superstructure and substructure equations are given in tables 97 and 98, respectively. The correlation coefficients obtained for each of these equations are given in table 99, illustrating the accuracy of these equations at predicting the sample Condition Ratings. The fact that the identified inspector factors resulted in high correlation coefficients can easily be rationalized because the possible existence of a relationship between the Condition Ratings and the factor is highly intuitive. Clearly, how distracted the inspector is by the traffic (i.e., Reported Fear of Traffic) could influence the condition assessments. In addition, the inspector's General Mental Condition, General Education Level, and Formal Bridge Inspection Training all relate to the inspector's mental condition and

Table 96. Equation coefficients for predicting deck Condition Ratings – Inspector factors.

	Task					
Coefficient	A	B	C	D	E	G
y_0	2.59	-6.64	0.97	-8.83	7.12	9.67
a	1.54	0.610	-0.103	2.43	-1.62	0.417
b	-0.214	-.0154	0.104	-0.410	0.412	-0.0911
c	1.60	5.98	1.71	5.45	-0.868	-1.51
d	-0.269	-0.910	-0.275	-0.766	0.0826	0.216
e	-2.94e-4	4.37e-3	0.0052	6.28e-4	3.06e-3	3.94e-4
f	-6.26e-7	-4.33e-6	-5.51e-6	-1.76e-7	-4.32e-6	-9.19e-7
g	-0.478	0.0843	0.155	0.189	0.594	0.0520
h	0.0580	0.055	-0.0061	-0.0122	-0.0729	-5.96e-4
i	-.0445	-0.0270	-0.0102	-0.0122	-0.0280	-.0380
j	2.82e-4	1.98e-4	8.79e-5	1.15e-4	1.55e-4	2.06e-4
k	-0.161	-0.170	-0.224	0.0615	-0.2145	-0.160
l	0.0352	0.0160	0.0381	3.28e-3	0.0251	0.0168
m	0.123	-0.167	-0.378	0.114	-0.0138	-0.0315
n	-.0100	0.0245	0.0099	-0.156	0.0190	0.0146

Table 97. Equation coefficients for predicting superstructure Condition Ratings – Inspector factors.

Coefficient	Task					
	A	B	C	D	E	G
y_0	8.32	0.583	3.42	-7.13	5.31	11.57
a	0.461	2.24	0.885	-3.80	0.0420	-0.601
b	-0.0258	-0.390	-0.0690	0.776	0.0616	0.114
c	-1.49	0.994	0.414	7.86	-0.790	-2.48
d	0.207	-0.160	-0.116	-1.047	0.0908	0.320
e	-9.66e-4	-2.15e-3	-6.66e-4	0.0053	-6.12e-4	2.85e-3
f	3.66e-7	1.38e-6	5.35e-7	-3.35e-6	-6.96e-7	-3.10e-6
g	-0.245	-0.346	-0.226	-0.0938	1.38	0.0309
h	0.0234	0.0345	0.032	0.0192	-0.156	-1.28e-3
i	-0.0216	-1.68e-3	-4.44e-3	-0.0322	-0.0341	-0.0163
j	1.46e-4	2.37e-5	2.70e-5	2.83e-4	2.36e-4	1.06e-4
k	0.0495	-0.185	-0.255	0.269	-0.0126	-0.0128
l	-0.0155	0.0464	0.0487	-0.0256	-0.0121	0.0069
m	0.306	0.146	0.0073	0.187	0.0561	0.0516
n	-0.0435	-1.47e-3	0.0192	-0.0035	8.80e-4	4.25e-5

Table 98. Equation coefficients for predicting substructure Condition Ratings – Inspector factors.

Coefficient	Task					
	A	B	C	D	E	G
y_0	-4.01	8.24	-5.26	-13.70	4.17	7.56
a	2.41	-0.0358	3.992	0.648	2.15	-0.739
b	-0.40	0.0054	-0.716	-0.125	-0.296	0.160
c	4.13	-0.782	3.70	12.09	-1.014	0.351
d	-0.560	0.0753	-0.511	-1.71	0.134	-0.0757
e	1.38e-3	-9.34e-5	-9.89e-4	-0.00540	7.62e-4	9.37e-4
f	-2.24e-6	2.74e-7	3.62e-7	4.41e-6	-2.98e-6	-1.23e-6
g	-0.47	-0.989	-0.442	0.0755	0.907	0.353
h	0.0567	0.0991	0.0447	0.0132	-0.110	-0.0344
i	-0.0148	-0.0205	-0.0404	-0.0564	-0.110	-0.0259
j	9.11e-5	1.65e-4	2.55e-4	3.84e-4	6.45e-4	1.03e-4
k	-0.0976	-0.177	-0.160	-0.202	-0.382	-0.0346
l	0.180	0.0350	0.0301	0.0434	0.0368	3.68e-3
m	0.180	0.321	0.474	-0.486	0.211	-0.138
n	0.0300	-0.0547	-0.0518	0.0620	-0.0076	0.0199

Table 99. Correlation coefficients for influence of inspector factors on Condition Ratings.

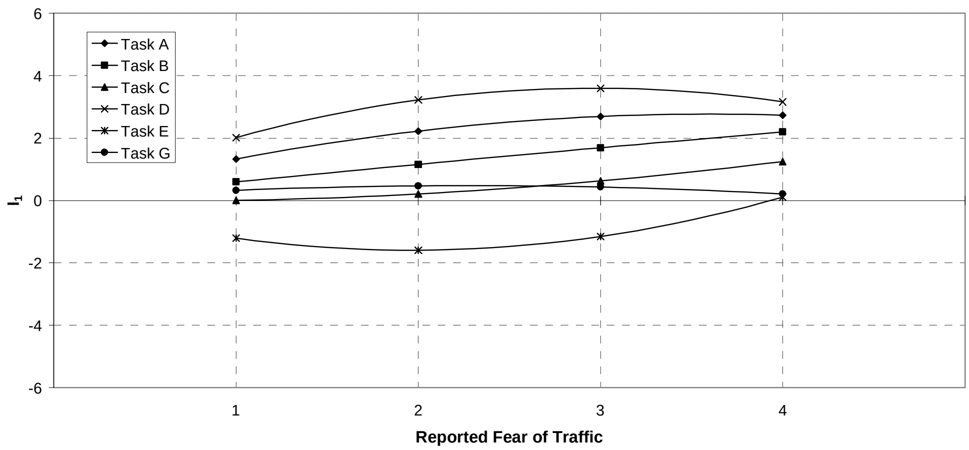
	Task					
Element	A	B	C	D	E	G
Deck	0.75	0.72	0.62	0.62	0.72	0.52
Superstructure	0.49	0.73	0.69	0.50	0.69	0.41
Substructure	0.69	0.67	0.70	0.65	0.84	0.57

capacity, which could influence inspection results. Furthermore, the number of Annual Bridge Inspections can easily be rationalized because it is an indicator of an inspector's overall familiarity with the bridge inspection process. In addition, since the execution of a bridge inspection relies so heavily on an inspector's vision characteristics, it is not surprising that the vision test results did show some correlation.

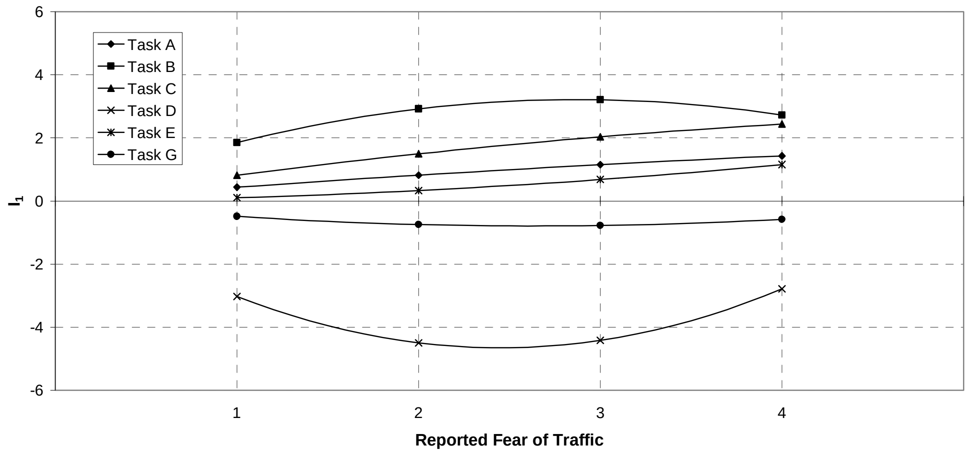
In this section, I_1 through I_7 from Equation 2 are shown graphically in figures 80 through 86, respectively, to illustrate the influence of each of the factors. In subsequent sections, figures presenting factor influence are presented in Appendix L in Volume II. The important information to note in figures 80 through 86 and in similar figures are the general shape and trends. Also note that the magnitude of the curves is of lesser importance, with the range over which a particular curve lies being of greater importance. The reason for these facts result from the form of the general equation.

In general, figures 80 through 86 show relatively consistent trends across the element types and tasks. However, some variability in the relationships can be observed and, generally, should be expected. It is interesting to note that Tasks D, E, and G are typically the tasks where the greatest variations occurred. This can probably be attributed to the relatively complex superstructures (Tasks E and G) or to the relatively uncommon structure type in Task D.

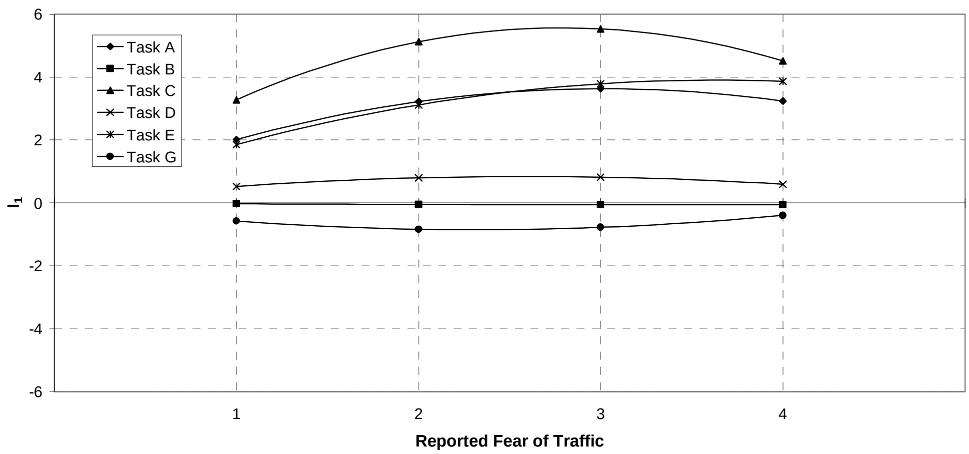
Specifically, the equations that are shown graphically in these figures do not have a constant term. Rather, the constant term y_0 given in the general equation combines the constants for all of the factors into one. In other words, if one could include a constant term in each equation, each line would have been shifted by that amount.



a. Deck

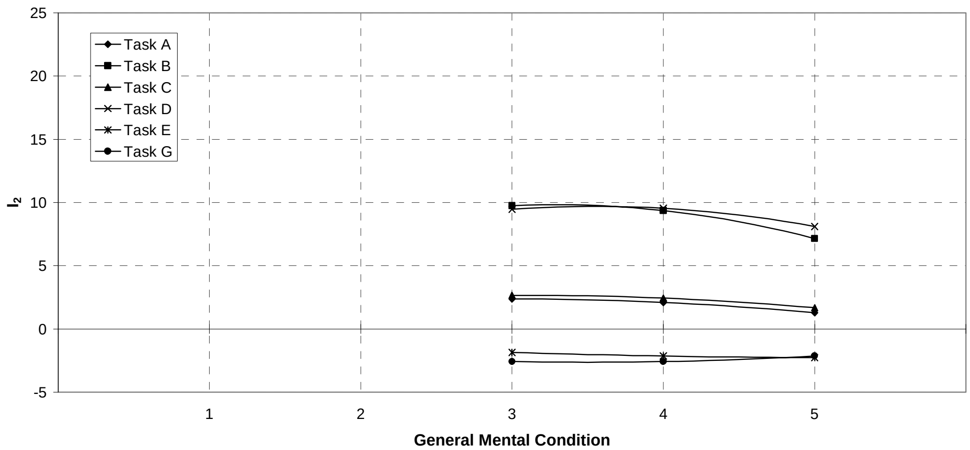


b. Superstructure

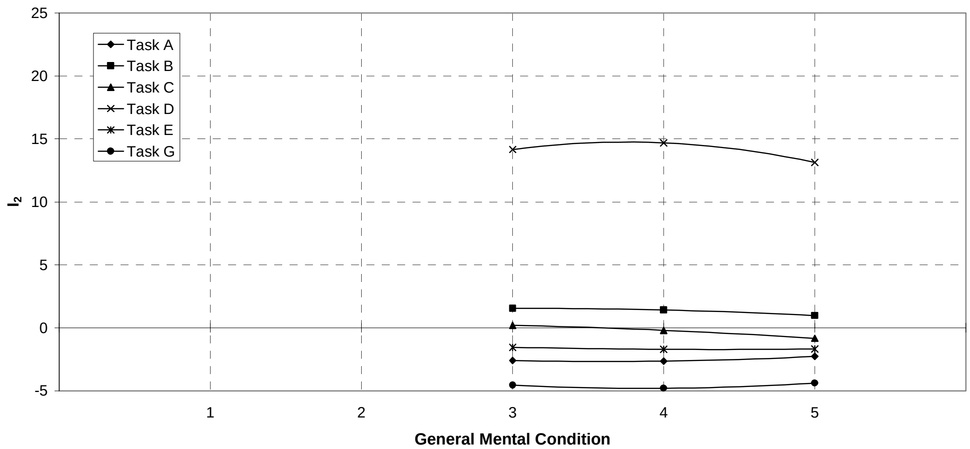


c. Substructure

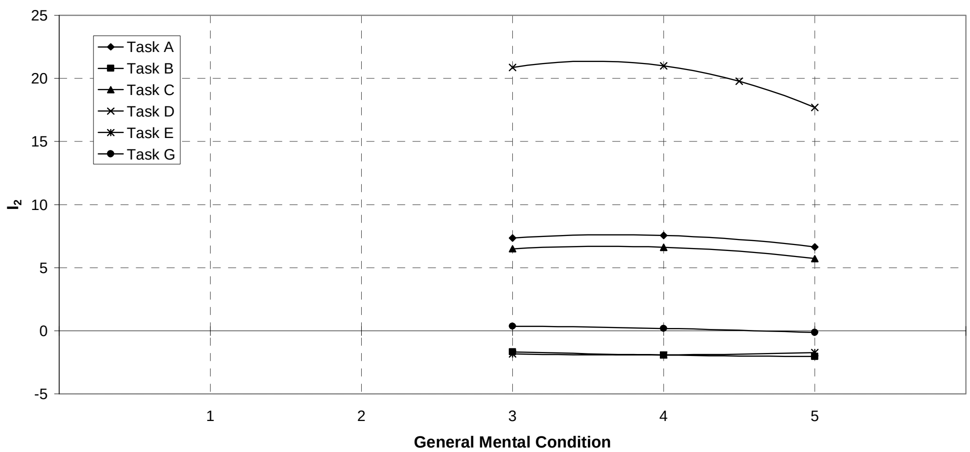
Figure 80. Influence of inspector factor Reported Fear of Traffic (1=Very Fearful, 4=No Fear) on Condition Ratings.



a. Deck

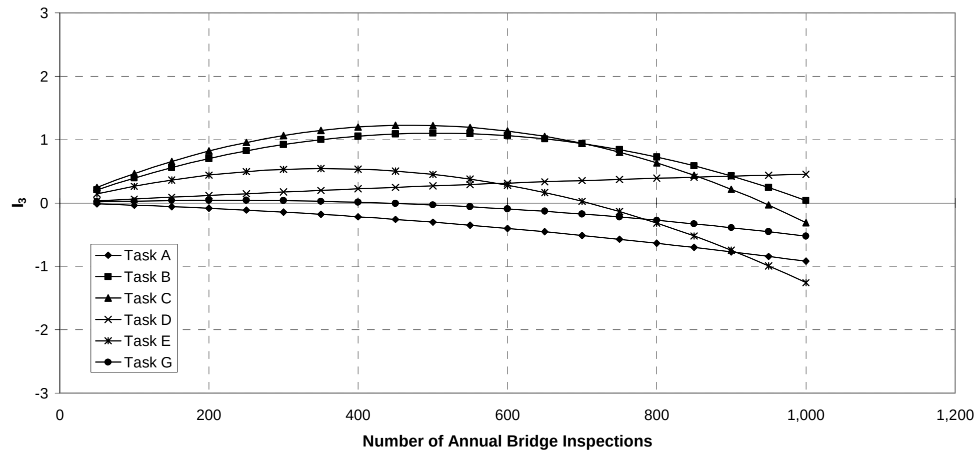


b. Superstructure

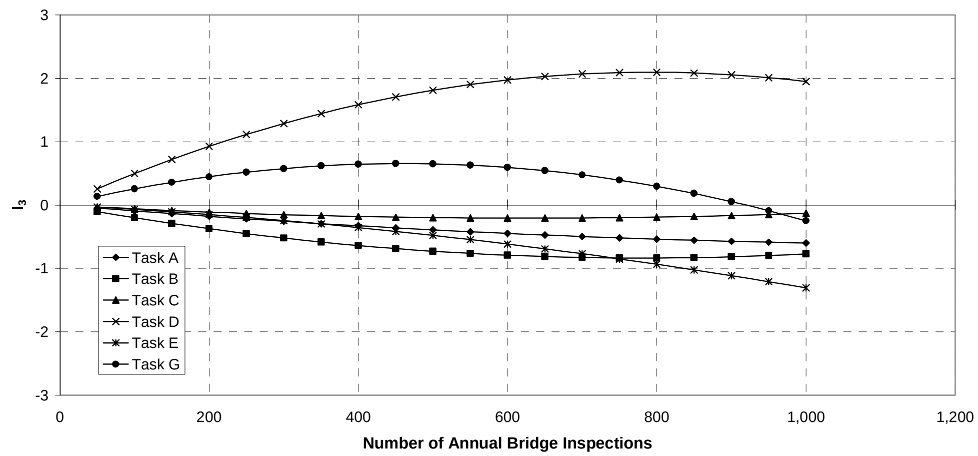


c. Substructure

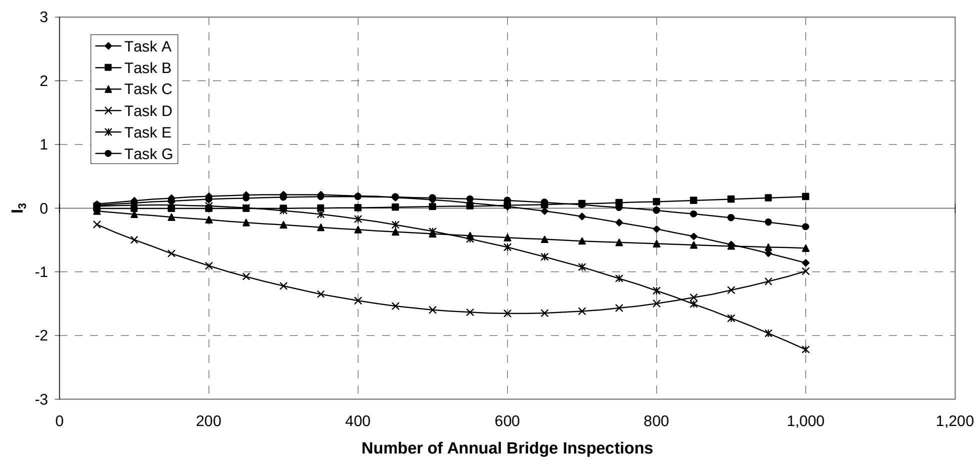
Figure 81. Influence of inspector factor General Mental Condition (1=Poor, 5=Superior) on Condition Ratings.



a. Deck

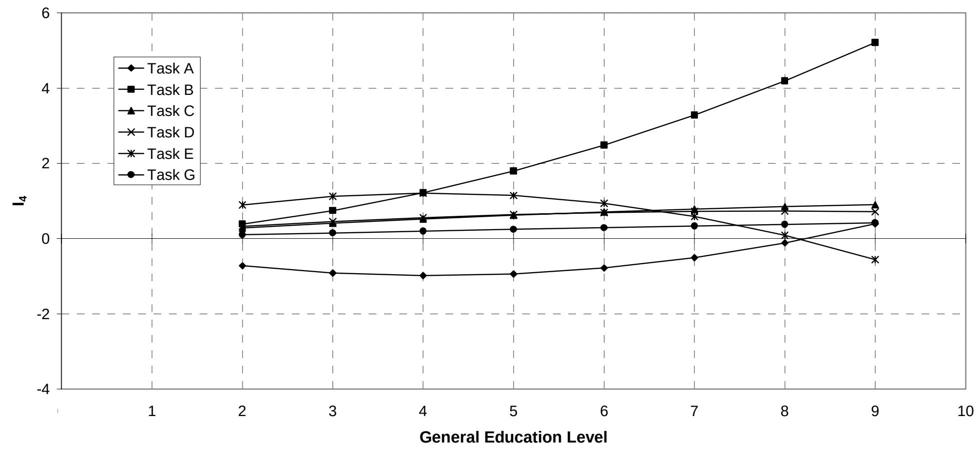


b. Superstructure

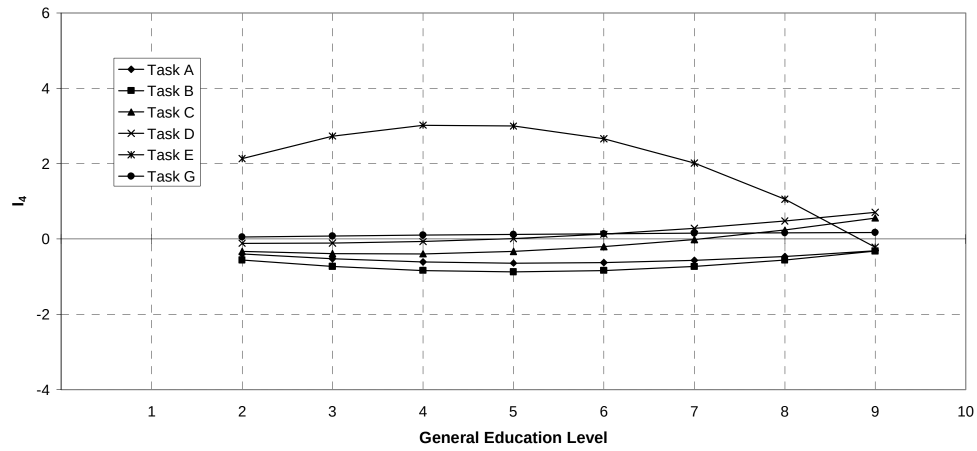


c. Substructure

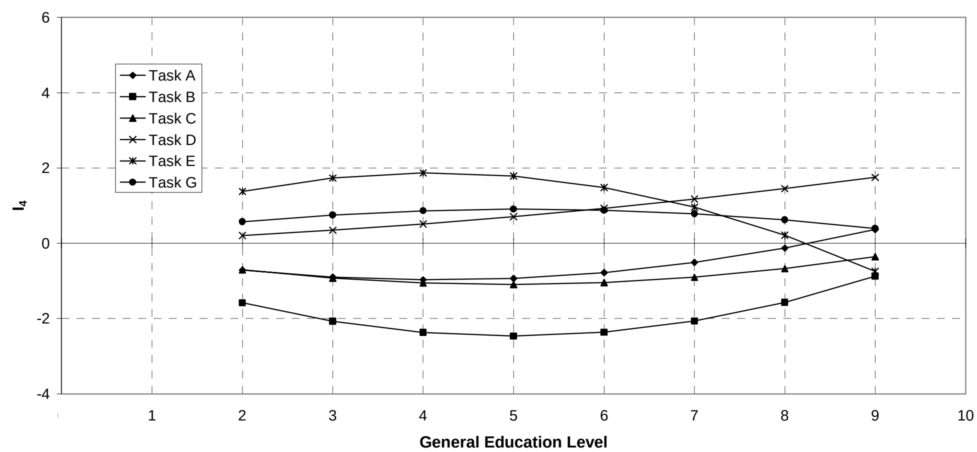
Figure 82. Influence of inspector factor Number of Annual Bridge Inspections on Condition Ratings.



a. Deck

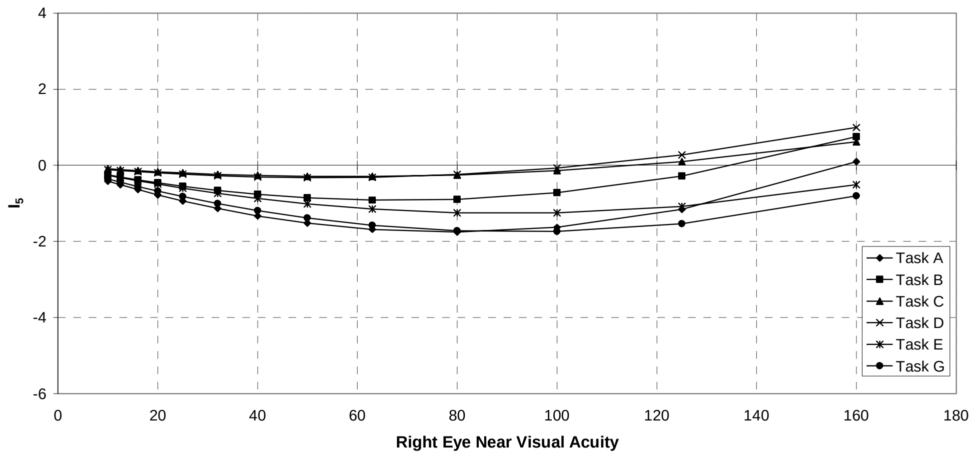


b. Superstructure

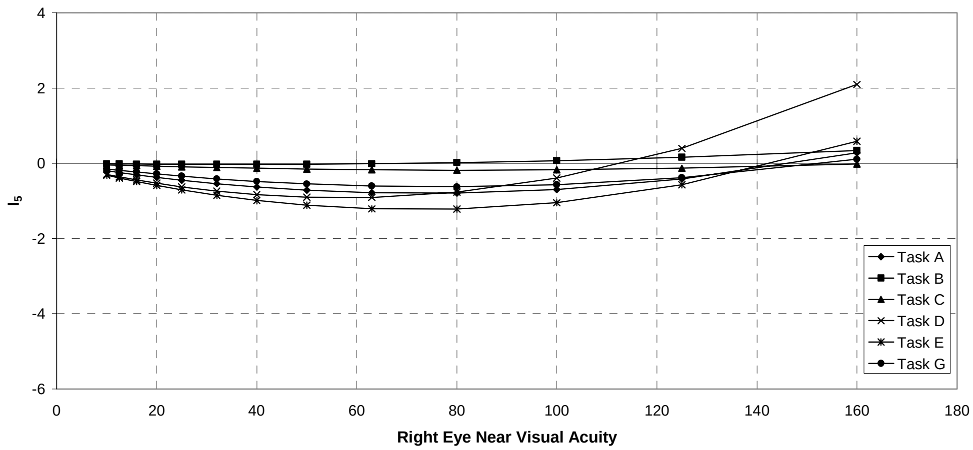


c. Substructure

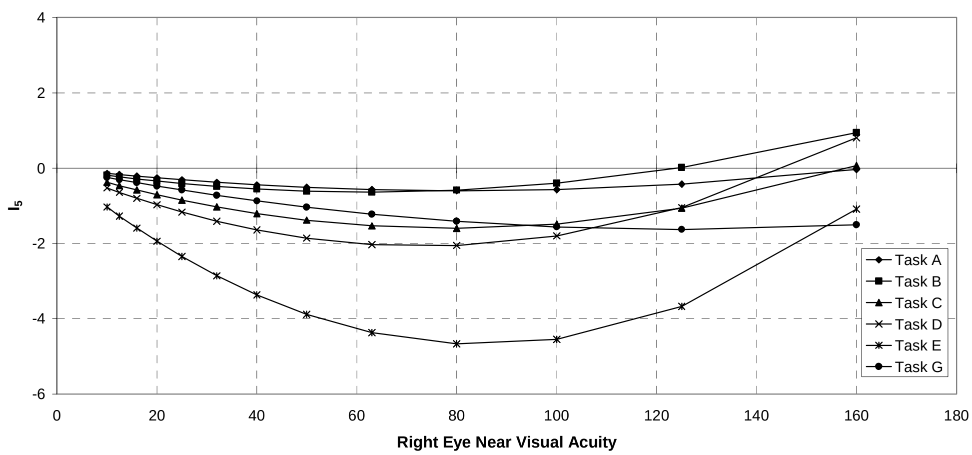
Figure 83. Influence of inspector factor General Education Level (1=Some High School, 10=Terminal Degree) on Condition Ratings.



a. Deck

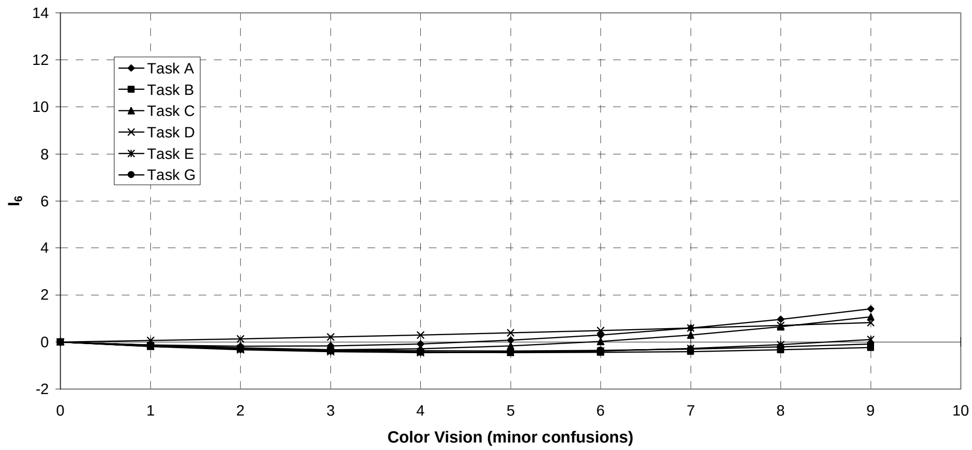


b. Superstructure

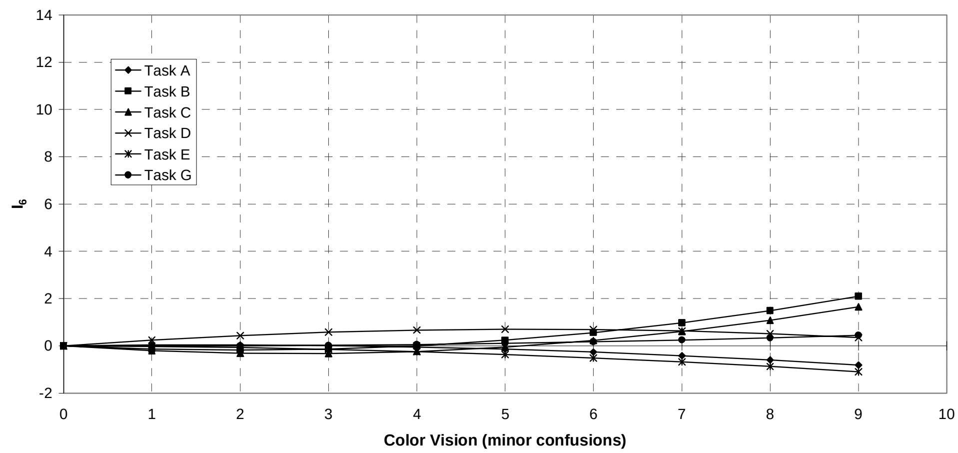


c. Substructure

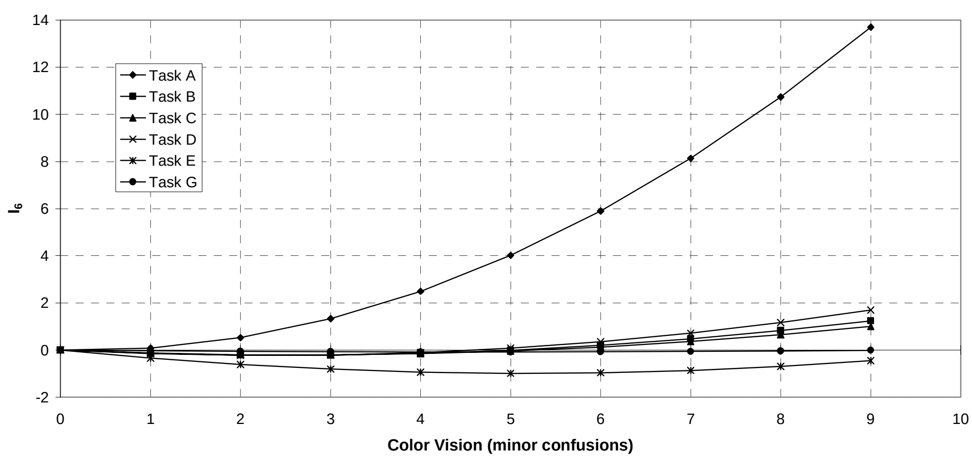
Figure 84. Influence of inspector factor Right Eye Near Visual Acuity on Condition Ratings.



a. Deck

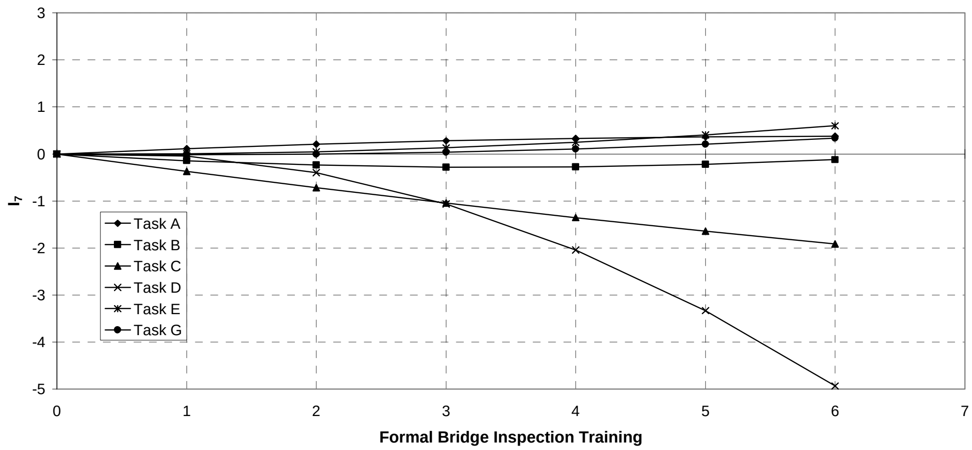


b. Superstructure

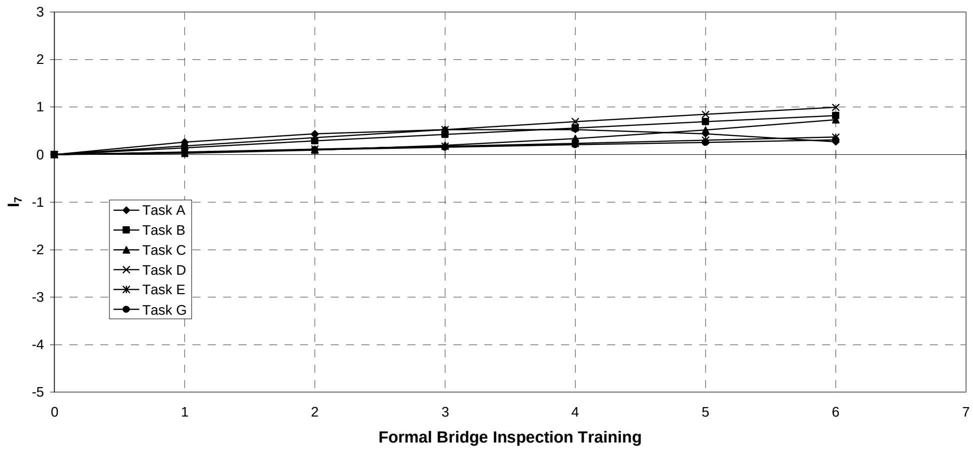


c. Substructure

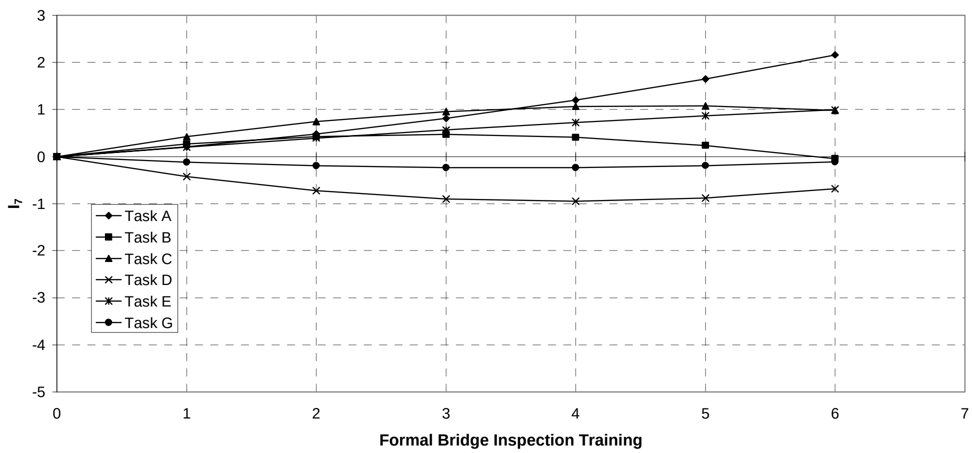
Figure 85. Influence of inspector factor Color Vision (number of minor confusions) on Condition Ratings.



a. Deck



b. Superstructure



c. Substructure

Figure 86. Influence of inspector factor Formal Bridge Inspection Training (Number of FHWA Training Courses) on Condition Ratings.

Please note that the question “What influence does this factor have on VI accuracy?” cannot be answered outright. The influence of the factors cannot be discussed in terms of a single factor. One must always remember that the interaction of the factors with one another cannot be ignored. The following hypothetical example will help to illustrate this fact:

> Assume that a sample of inspectors all had the same factors for I_1 through I_6, but they had different I_7 characteristics and one wanted to study the influence of I_7 on the inspection results. For simplicity, assume that I_7 varies linearly from 0 to 3 with a positive slope and that the condition rating for a specific element is 5. For the first scenario, assume that $y_0 + I_1 \ldots I_6 = 2$. What can be said for the first scenario is that inspectors with higher I_7 factors could be predicted to give more accurate inspection results (i.e., closer to 5). However, for the second scenario, assume that $y_0 + I_1 \ldots I_6 = 5$. It can be said for the second scenario that inspectors with lower I_7 factors could be predicted to give more accurate inspection results.

This simple example illustrates that the influence of a specific factor (e.g., I_7 in the above example) on accuracy can only be investigated if a particular known set of other factors (e.g., I_1 through I_6 in the above example) is available. However, general statements can be made if a generic set of factors is assumed to have some constant value for a sample of inspectors. In other words, if the specific value of $y_0 + I_1 \ldots I_6$ is known in the example, one could say that “with all other factors being equal, inspectors with higher I_7 factors would tend to give higher Condition Ratings.” Again, note that this statement is not related to the accuracy of the Condition Rating, only the relationship of a specific factor. Finally, the issues illustrated by the example, and the issues discussed in the previous paragraphs, pertain to the correlation results in this and in subsequent sections.

INSPECTION FACTORS: As mentioned previously, the inspection factor data were collected from the pre- and post-task evaluations and through firsthand observations. Unlike the previous analyses where the inspector factors were constant for all tasks, the inspection factors could have different values for each task. In light of this, the inspection factor analyses were completed in a slightly different manner. The notable difference is that each task was analyzed independently and could have resulted in a different set of seven best-correlating inspection factors for each task. Other than this difference, the general steps for completing the analyses were the same as those previously described.

Equation 3 shows the general equation resulting from the inspection factor regression analyses. Table 100 summarizes the individual F_1 through F_7 factors for each task. Note that the factors listed for each task in table 100 are listed in rank order from the factor with the highest individual correlation coefficient to the lowest. Tables 101 through 106 give the coefficients for each element from each task and table 107 gives the resulting correlation coefficients for each equation.

$$\text{Condition Rating} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \qquad (3)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

With the exception of Wind Speed, the identified inspection factors are, again, fairly intuitive. The factors basically quantify the inspector's perception of the structure, how the inspection was completed, and the light intensity during the inspection. Another factor, Rested Level Before Task, is related to the inspector's general condition. Again, these factors are intuitive because they deal with what, how, and under what conditions the inspection was performed. Wind Speed, on the other hand, is not as intuitive. One could speculate that the Wind Speed could influence how well inspections could be performed from a ladder. However, the ladders were used very infrequently (by 24, 0, 4, and 0 percent) on the four tasks (B, C, D, and G, respectively) where Wind Speed was found to correlate.

Table 100. Inspection factors for predicting Condition Ratings.

	Task A	Task B	Task C	Task D	Task E	Task G
F_1	Reported Thoroughness Level	Reported Structure Accessibility Level	Reported Structure Maintenance Level	Wind Speed	Reported Structure Maintenance Level	Reported Structure Maintenance Level
F_2	Light Intensity Below Superstructure	Reported Structure Maintenance Level	Light Intensity Below Superstructure	Reported Structure Maintenance Level	Estimated Time for Task	Wind Speed
F_3	Reported Structure Maintenance Level	Reported Thoroughness Level	Reported Observer Influence	Reported Structure Accessibility Level	Rested Level Before Task	Reported Observer Influence
F_4	Observed Inspector Rushed Level	Wind Speed	Reported Effort Level	Reported Structure Complexity Level	Accuracy of Task at Measuring Inspection Skills	Reported Task Similarity to Normal
F_5	Reported Rushed Level	Reported Task Similarity to Normal	Reported Thoroughness Level	Time Since Similar Inspection	Reported Structure Complexity Level	Actual Time to Complete Task
F_6	Reported Task Similarity to Normal	Reported Observer Influence	Observed Inspector Focus Level	Estimated Time for Task	Actual Time to Complete Task	Reported Structure Complexity Level
F_7	Observed Inspector Focus Level	Light Intensity Deck	Wind Speed	Rested Level Before Task	Observed Inspector Rushed Level	Time Since Similar Inspection

Table 101. Task A – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	4.58	5.48	-0.0148
a	0.531	-0.0705	0.203
b	-0.0527	0.0117	-0.00980
c	-4.55e-6	-2.70e-5	-3.38e-5
d	1.59e-10	2.34e-10	4.36e-10
e	-0.104	-0.0668	0.532
f	0.0160	0.0290	-0.0490
g	-0.4075	-0.0113	0.0188
h	0.0367	-1.94e-4	-1.65e-4
i	0.250	0.0348	0.213
j	-0.0273	-4.33e-3	-0.0265
k	-0.619	-0.516	-0.489
l	0.0452	0.0482	0.0455
m	0.716	0.400	1.37
n	-0.0485	-0.0322	-0.0972

Table 102. Task B – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	-9.21	4.36	0.595
a	2.30	0.687	-0.412
b	-0.149	-0.0322	0.0331
c	0.332	0.202	0.8164
d	-0.0239	-0.0152	-0.0994
e	-0.533	-0.183	0.9486
f	0.0385	0.0310	-0.0731
g	0.0383	0.245	0.187
h	-2.97e-3	-2.60e-2	-1.55e-2
i	0.9565	-1.189	0.483
j	-0.0464	0.0757	-0.0471
k	1.55	0.3938	0.240
l	-0.277	-0.0545	-0.0840
m	5.97e-6	-3.49e-6	-1.11e-5
n	-2.11e-11	6.92e-11	5.98e-11

Table 103. Task C – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	16.34	28.98	25.1
a	0.890	0.384	0.204
b	-0.0706	-0.0328	-0.0111
c	0.0105	3.83e-3	-2.14e-3
d	-1.92e-5	-8.02e-6	-2.55e-6
e	1.03	0.441	0.584
f	-0.183	-0.0476	-0.0363
g	-0.825	-0.774	-0.765
h	0.0709	0.0835	0.0656
i	-0.327	-0.523	-0.434
j	2.11e-3	3.10e-3	2.66e-3
k	-0.238	-0.817	-0.620
l	0.0173	0.0620	0.0774
m	2.20e-2	-0.0628	0.0764
n	-4.98e-4	7.69e-3	-7.61e-3

Table 104. Task D – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	-0.496	8.16	-4.46
a	8.89e-3	1.15	0.304
b	-4.36e-3	-0.0190	-0.0542
c	0.576	0.1167	0.110
d	-0.0638	-0.0125	-0.0324
e	1.42	0.6196	-0.0557
f	-0.104	-0.0601	-0.0064
g	-0.0095	-0.139	1.26
h	0.0110	0.0232	-0.220
i	0.0079	0.0269	0.0074
j	-4.22e-5	-1.22e-4	-5.75e-5
k	0.0090	-0.0076	2.21e-3
l	-4.54e-5	-1.04e-5	1.23e-5
m	-0.341	-1.67	2.83
n	0.0323	0.139	-0.203

Table 105. Task E – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	4.35	-8.43	-7.82
a	0.139	0.185	0.252
b	0.0118	-0.0053	-0.0187
c	0.0105	0.0126	0.0061
d	-2.03e-5	-2.02e-5	-9.06e-7
e	0.0436	4.30	3.93
f	-0.0181	-0.326	-0.290
g	-0.142	-0.285	-0.394
h	0.0136	0.0199	0.0237
i	0.0492	-0.510	0.148
j	4.11e-3	0.0559	-0.0078
k	-0.0731	-0.0239	-0.0618
l	7.97e-4	4.50e-4	5.69e-4
m	0.558	0.520	1.13
n	-0.0742	0.0621	-0.161

Table 106. Task G – Equation coefficients for predicting Condition Ratings – Inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	4.86	1.59	5.16
a	0.926	1.66	0.595
b	-0.0608	-0.103	-0.0358
c	-0.0889	0.0752	-0.092
d	4.79e-3	3.05e-3	5.29e-3
e	-0.256	0.0251	-0.104
f	0.0568	-0.0277	0.0269
g	-0.0146	0.0216	0.152
h	2.51e-4	-0.0091	-0.0137
i	-0.0437	-2.01e-3	-0.0317
j	3.76e-4	-2.15e-5	2.13e-4
k	-0.0832	-0.290	0.0553
l	0.0212	0.0271	4.65e-3
m	2.25e-3	0.0062	0.0073
n	1.50e-5	-3.24e-5	-3.76e-5

Table 107. Correlation coefficients for influence of inspection factors on Condition Ratings.

	Task					
Element	A	B	C	D	E	G
Deck	0.69	0.63	0.77	0.68	0.58	0.61
Superstructure	0.59	0.58	0.53	0.74	0.67	0.77
Substructure	0.70	0.73	0.63	0.54	0.67	0.54

Figures L1 through L18 in Appendix L in Volume II show the general trends of the I_i equations given in Equation 3. Note that not all tasks will appear in all figures since the inspection factors varied for each task. Some interesting trends can be observed in these figures. First, when a certain factor was found to only correlate with a specific task, the relationship of that factor to the deck, superstructure, and substructure Condition Ratings generally was consistent between the elements. However, when a factor was found to correlate with two tasks, the influence of that factor was not, in general, consistent for the two tasks. Finally, when a factor was found to correlate with more than two tasks, there was greater consistency in the influence of that factor across the tasks. Also note that the ambient light intensity had the greatest influence on the deck Condition Rating and less of an influence on the Condition Rating of the superstructure and substructure. In addition, note that feeling moderately rushed tended to have the greatest influence on the assignment of the Condition Rating regardless of the element type. With respect to Reported Structure Accessibility, it appears that this factor influences the deck and superstructure Condition Ratings the most. Similar to Reported Rushed Level, the influence of Reported Effort Level was greatest at moderate levels.

COMBINED INSPECTOR/INSPECTION FACTORS: In this section, equations for predicting the Condition Ratings in terms of the combined inspector/inspection factors will be presented. A similar procedure to that for determining the inspection factors was used in the inspector and inspection factors analyses.

Equation 4 shows the general equation resulting from the regression analyses. Table 108 summarizes the individual F_1 through F_7 factors for each task. As before, note that the factors for each task in table 108 are in rank order from the factor with the highest individual correlation coefficient to the lowest. Tables 109 through 114 give the equation coefficients for each element from each task and table 115 gives the resulting correlation coefficients for each equation.

Table 108. Combined inspector/inspection factors for predicting Condition Ratings.

	Task A	Task B	Task C	Task D	Task E	Task G
F_1	Reported Fear of Traffic	Reported Structure Accessibility Level	Reported Structure Maintenance Level	Reported Fear of Traffic	Reported Structure Maintenance Level	Reported Structure Maintenance Level
F_2	Reported Thoroughness Level	Reported Fear of Traffic	Reported Fear of Traffic	Wind Speed	Estimated Time for Task	Reported Fear of Traffic
F_3	Light Intensity Below Superstructure	Reported Structure Maintenance Level	Light Intensity Below Superstructure	Reported Structure Maintenance Level	Rested Level Before Task	Wind Speed
F_4	Reported Structure Maintenance Level	Reported Thoroughness Level	General Mental Condition	General Mental Condition	Reported Fear of Traffic	Reported Observer Influence
F_5	Observed Inspector Rushed Level	Wind Speed	Number of Annual Bridge Inspections	Reported Structure Accessibility Level	Accuracy of Task at Measuring Inspection Skills	General Mental Condition
F_6	Reported Rushed Level	Reported Task Similarity to Normal	General Education Level	Reported Structure Complexity Level	Reported Structure Complexity Level	Number of Annual Bridge Inspections
F_7	General Mental Condition	Reported Observer Influence	Right Eye Near Visual Acuity	Number of Annual Bridge Inspections	Actual Time to Complete Task	General Education Level

Table 109. Task A – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	1.30	7.66	-2.09
a	1.76	0.439	2.79
b	-0.238	-0.0052	0.448
c	-0.0425	-0.0767	-0.197
d	-2.10e-3	0.0087	0.0076
e	-8.75e-6	-2.60e-5	-2.45e-5
f	1.35e-10	1.89e-10	2.75e-10
g	0.0884	0.0057	0.437
h	-0.0090	0.0173	-0.0444
i	-0.629	-0.0672	-0.186
j	0.0547	0.0012	0.0205
k	0.229	-0.0173	0.0915
l	-0.0282	8.04e-5	-0.0202
m	1.69	-1.56	1.98
n	-0.230	0.221	-0.245

Table 110. Task B – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	-10.4	3.37	-1.41
a	1.38	0.178	-0.492
b	-0.0944	-9.84e-4	0.0414
c	1.69	0.611	0.105
d	-0.217	-0.0413	0.0198
e	0.628	0.357	0.829
f	-0.0624	-0.0339	-0.0990
g	-0.227	-0.0563	0.612
h	0.0118	0.0215	-0.0445
i	5.66e-3	0.237	0.167
j	-1.35e-3	-0.0267	-0.0160
k	1.45	-0.811	1.14
l	-0.0827	0.0480	-0.0918
m	1.11	0.362	0.298
n	-0.196	-0.0421	-0.0895

Table 111. Task C – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	-1.78	3.74	-6.77
a	0.279	0.553	0.876
b	-0.0073	-0.0539	-0.0942
c	-0.134	1.16	4.99
d	0.0953	-0.112	-0.8936
e	6.91e-3	1.32e-3	3.75e-3
f	-1.49e-5	-3.66e-6	-9.16e-6
g	2.28	-0.392	3.34
h	-0.3358	-0.0074	-0.450
i	2.53e-3	-0.0039	-4.13e-3
j	-2.69e-6	4.10e-6	3.93e-6
k	0.165	-0.0192	-0.423
l	-0.0094	-0.00237	0.0363
m	0.0136	-0.0094	-0.0313
n	-2.83e-5	5.74e-5	2.01e-4

Table 112. Task D – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	-10.5	-3.17	-8.68
a	3.62	-1.75	-0.909
b	-0.645	0.437	0.130
c	0.117	0.864	0.168
d	-6.22e-3	-0.178	-4.21e-3
e	0.907	0.132	0.131
f	-0.0844	-0.0313	-0.0185
g	6.03	4.49	9.37
h	-0.835	-0.455	-1.31
i	-0.229	-0.419	0.168
j	0.0128	0.0248	-0.0236
k	-0.582	0.0144	0.695
l	0.0877	-0.364	-0.112
m	-1.35e-3	0.0050	-0.0064
n	7.19e-7	-3.46e-6	5.25e-6

Table 113. Task E – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	6.98	7.55	11.5
a	0.343	0.314	0.702
b	-0.0130	-0.0212	-0.0714
c	0.0064	0.0128	5.89e-4
d	-1.09e-5	-2.43e-5	1.27e-5
e	0.132	4.34	3.58
f	0.0208	-0.326	-0.261
g	-2.96	-1.51	0.410
h	0.649	0.308	0.0568
i	-0.0377	-0.347	-0.328
j	-0.0025	0.0201	0.0119
k	0.0091	-0.541	0.112
l	0.0088	0.0586	-0.0080
m	-0.0308	0.0480	0.153
n	3.39e-4	-2.52e-4	-1.78e-3

Table 114. Task G – Equation coefficients for predicting Condition Ratings – Combined inspector/inspection factors.

Coefficient	Element		
	Deck	Superstructure	Substructure
y_0	2.68	0.426	7.07
a	0.776	1.76	0.139
b	-0.0527	-0.108	-1.16e-3
c	0.122	0.0717	-1.33
d	0.0294	-0.0337	0.273
e	0.0607	-0.0640	0.0375
f	2.09e-3	3.22e-3	1.89e-3
g	-0.507	-0.0135	-0.167
h	0.0877	-0.0173	0.0332
i	0.917	-0.274	0.201
j	-0.104	0.0483	-0.0577
k	6.86e-5	8.57e-4	7.35e-4
l	-2.77e-7	-9.74e-7	7.42e-7
m	0.0443	-0.0937	0.388
n	2.58e-4	0.0078	-0.0381

Table 115. Correlation coefficients for the influence of combined inspector/inspection factors on Condition Ratings.

Element	Task A	B	C	D	E	G
Deck	0.74	0.68	0.77	0.77	0.67	0.51
Superstructure	0.61	0.85	0.66	0.65	0.67	0.72
Substructure	0.75	0.69	0.71	0.60	0.66	0.52

$$\text{Condition Rating} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \quad (4)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

If one compares table 108 with table 100 and the inspector factor analysis identified previously, it is clear that the same factors reoccur for the combined inspector/inspection factors analyses. Therefore, the previous discussion about the specific factors holds true here as well.

Note from table 108 that all tasks have both inspector and inspection factors in their respective equations. In fact, the minimum number of inspector factors is one (Task E) and the minimum number of inspection factors is two (Task C). On average, there were 2-2/3 inspector factors and 4-1/3 inspection factors for each task. The general trend resulting from combining the inspector and inspection factors was to generally increase the correlation coefficients for each task. Note, however, that the correlation coefficient may not have increased for each element, only that the overall effect was to increase the correlation. These results indicate that to best predict Condition Rating results, one must consider both the inspector and inspection factors.

Figures L19 through L37 in Appendix L, in Volume II show the general trends of the I_i equations given previously. Note that not all tasks will appear in all figures since each task may have a different set of combined inspector/inspection factors. The resulting general trend from combining the inspector and inspection factors to predict the Condition Ratings was to increase the consistency of the equation trends for different tasks and to decrease the consistency of the equation trends for different element types. Specifically, note the influence of Reported Fear of Traffic on the substructure Condition Rating, indicating that inspectors may have the greatest fear of being hit by traffic below the bridge being inspected. Also note the consistency of the influence of General Mental Condition, indicating that the influence of this factor is independent of the structure being inspected.

5.2.3.2.2. Deviation From Reference (DFR)

The regression analysis for predicting the DFR will be presented in two primary sections, each containing three subsections. The first primary section will present the regression analysis for each bridge element and the second will present the results without regard to the element type. The three subsections within each primary section present specific results in terms of the inspector factors, the inspection factors, and the combined inspector/inspection factors.

PRIMARY BRIDGE ELEMENTS: In this section, the relationship between the measured factors and the deck, superstructure, and substructure DFR data will be discussed. The results are presented in the same format as used previously. First, the influence of the inspector factors alone are presented; second, the influence of the inspection factors alone are presented; and finally, the combined inspector/inspection factors are discussed together.

Inspector Factors: The general procedure for establishing the relationships is exactly the same as was used in the previous discussion. The only difference is that the equations predict the DFR instead of the Condition Ratings. The inspector factors can be combined into the nonlinear, multivariate equation given in equation 5:

$$\text{DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \qquad (5)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Fear of Traffic

F_2 = Color Vision (major confusions)

F_3 = Left Eye Near Visual Acuity

F_4 = Formal Bridge Inspection Training

F_5 = Quality of Relationship With Supervisor

F_6 = Left Eye Distance Visual Acuity

F_7 = Reported Fear of Enclosed Spaces

Note that most of the factors in Equation 5 are the same as had been used previously. However, note that the vision assessments have changed from the right eye to the left and from the number of minor confusions to the number of major confusions. This shift indicates that inspector vision in both eyes and both color vision assessments may be important to Routine Inspection results because attributes for both eyes have been used in the regression analysis.

Values for the equation coefficients for the deck, superstructure, and substructure are given in table 116. The correlation coefficients for these equations are 0.46, 0.34, and 0.41, respectively. Figures L38 through L44 in Appendix L in Volume II illustrate the relationship of each of the factors with the DFR for the deck, superstructure, and substructure. Also note that these graphs represent the equations for I_1 through I_7 given above. With the exception of the color vision factor, there is a high degree of consistency in the relationship of each factor with regard to the element type. One possible explanation of this lack of consistency in the color vision factor could be that different material types are used for the superstructures, whereas the decks and substructures were all concrete.

Table 116. Coefficients for DFR equations – Inspector factors.

Coefficient	Bridge Element Deck	Superstructure	Substructure
y_0	-4.80	-7.19	-10.2
a	1.90	0.934	1.91
b	-0.326	-0.134	-0.343
c	-0.0346	0.0066	-0.0368
d	1.64e-4	-1.39e-4	6.42e-4
e	-0.0142	-0.0081	-3.08e-3
f	3.25e-5	3.85e-6	-7.70e-5
g	0.272	0.252	0.311
h	-0.0310	-0.0276	-0.0395
i	2.12	2.86	3.92
j	-0.283	-0.348	-0.473
k	-0.0364	-0.0159	-0.0400
l	1.76e-4	1.25e-4	5.08e-4
m	-0.709	0.0261	-0.385
n	0.153	0.0085	0.106

Inspection Factors: The procedure for establishing the relationship of the inspection factors to the DFR was exactly the same as that used to determine Equation 5. As before, the inspection factors can be combined into the nonlinear, multivariate equation given as Equation 6:

$$\text{DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \qquad (6)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Structure Accessibility Level

F_2 = Reported Structure Maintenance Level

F_3 = Reported Structure Complexity Level

F_4 = Light Intensity on Deck

F_5 = Light Intensity Below Superstructure

F_6 = Reported Rushed Level

F_7 = Wind Speed

Similar inspection factors to those identified previously were again identified here. With the exception of Wind Speed, the probable relationship of these factors with the DFR is again intuitive. These factors quantify what was inspected, under what conditions the inspection was completed, and how hastily the inspection was completed.

Values for the equation coefficients are given in table 117. The correlation coefficients obtained for these equations are 0.40, 0.49, and 0.44, respectively. Figures L45 through L51 in Appendix L in Volume II illustrate the relationship of each of the factors with the DFR for the deck, superstructure, and substructure. With the exception of Reported Maintenance Level, Reported

Table 117. Coefficients for DFR equations – Inspection factors.

	Bridge Element		
Coefficient	Deck	Superstructure	Substructure
y_0	-1.38	-1.62	-0.557
a	0.303	0.0526	-0.0257
b	-0.0204	0.0067	0.0083
c	0.224	0.155	0.379
d	-0.0144	-3.09e-3	-0.0414
e	0.205	0.0212	-0.262
f	-0.0226	-0.0073	0.0196
g	-1.53e-5	5.06e-6	-4.79e-7
h	1.36e-10	-3.71e-11	-9.41e-12
i	-1.18e-5	-3.18e-6	-4.45e-6
j	2.36e-10	3.46e-11	1.33e-10
k	0.0870	0.284	0.181
l	-0.0142	-0.0244	-0.0265
m	0.0512	0.0505	0.0721
n	-2.28e-3	-2.34e-3	-3.28e-3

Structure Complexity Level, and the Light Intensity on the Deck, the relationships are relatively consistent for various elements. The relationship for the Reported Maintenance Level showed a different relationship for the substructure, as one would expect, due to there being generally less deterioration in the substructure. With regard to complexity, the difference in the relationships can probably be attributed to the fact that inspector complexity assessments were probably heavily influenced by the superstructure and less so by the substructure and deck. In addition, the influence of the light intensity on the deck had a significantly different influence on the deck inspection, as one would expect.

Combined Inspector/Inspection Factors: The inspector and inspection factors can also be combined using the previously described process into the nonlinear, multivariate equation given below as Equation 7:

$$\text{DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \quad (7)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Structure Accessibility Level

F_2 = Reported Fear of Traffic

F_3 = Reported Structure Maintenance Level

F_4 = Reported Structure Complexity Level

F_5 = Light Intensity on Deck

F_6 = Color Vision (major confusions)

F_7 = Light Intensity Below Superstructure

Values for the equation coefficients are given in table 118. The correlation coefficients obtained for these equations are 0.54, 0.49, and 0.48, respectively. Figures L52 through L58 in Appendix L in Volume II illustrate the predicted influence of each of the factors on the DFR for each element. When the inspector and inspection factors are evaluated together, the trends discussed previously are generally repeated.

Table 118. Coefficients for DFR equations – Combined inspector/inspection factors.

	Bridge Element		
Coefficient	Deck	Superstructure	Substructure
y_0	-3.68	-1.52	-1.78
a	0.226	-0.0512	-0.127
b	-0.0164	0.0116	0.0148
c	1.83	0.417	1.20
d	-0.273	-0.0120	-0.160
e	0.262	0.117	0.366
f	-0.0177	2.81e-3	-0.0375
g	0.198	0.0559	-0.279
h	-0.0216	-0.0113	0.0202
i	-1.52e-5	3.24e-6	-7.59e-7
j	1.42e-10	-2.32e-11	1.57e-12
k	-0.0276	-0.0109	-0.0371
l	1.71e-4	6.26e-4	8.61e-4
m	-1.72e-5	4.36e-6	-1.25e-5
n	2.77e-10	-5.45e-11	2.23e-10

GENERAL INSPECTION: In the previous analyses, the results were specific either to a task completed during this investigation or to a specific element type. In this section, the DFR data are analyzed without regard to the specific task or the element type. This information leads to the establishment of a set of factors found to correlate with the sample bridge inspection results in general. The results presented here can be considered, when compared with respect to the results from the previous sections, to be the most useful for general applications. This stems from the fact that these results are independent of the task that was completed, the type of element being evaluated, and the relative condition of the element. In other words, these results describe the general relationship of those factors found to have the greatest correlation with overall Routine Inspection. In light of this, minimal discussion beyond presenting the results is given. Note that all findings obtained in this section resulted from the same procedure described previously.

Inspector Factors: The inspector factors can be combined into a nonlinear, multivariate equation similar to the ones presented previously. This equation is given below as Equation 8:

$$\text{General DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \quad (8)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Fear of Traffic

F_2 = Color Vision (major confusions)

F_3 = Left Eye Near Visual Acuity

F_4 = Formal Bridge Inspection Training

F_5 = Left Eye Distance Visual Acuity

F_6 = General Mental Focus

F_7 = Reported Fear of Enclosed Spaces

Values for the equation coefficients are given in table 119. The correlation coefficient obtained for this equation is 0.35. Figures L59 through L65 in Appendix L in Volume II illustrate the influence of each of the factors on the general DFR.

Inspection Factors: The inspection factors can be combined into a nonlinear, multivariate equation similar to the ones presented previously. This equation is given below as Equation 9:

$$\text{General DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \quad (9)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

Table 119. Coefficients for general DFR equation – Inspector factors.

Coefficient	General DFR
y_0	4.14
a	0.923
b	-0.131
c	-0.110
d	0.0194
e	-0.0210
f	2.13e-4
g	0.168
h	-0.0143
i	-0.0170
j	2.24e-5
k	-2.08
l	0.245
m	-0.750
n	0.149

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Structure Accessibility Level

F_2 = Reported Structure Maintenance Level

F_3 = Light Intensity on Deck

F_4 = Light Intensity Below Superstructure

F_5 = Reported Structure Complexity Level

F_6 = Wind Speed

F_7 = Reported Rushed Level

Values for the coefficients “a” through “n” are given in table 120. The correlation coefficient obtained for this equation is 0.35. Figures L66 through L72 in Appendix L in Volume II illustrate the influence of each of the factors on the general DFR.

Table 120. Coefficients for general DFR equation – Inspection factors.

Coefficient	General DFR
y_0	-1.15
a	0.102
b	-1.37e-3
c	0.253
d	-0.0197
e	-43.75e-6
f	3.14e-11
g	-6.51e-6
h	1.36e-10
i	-0.0139
j	-3.16e-3
k	0.0577
l	-2.59e-3
m	0.185
n	-0.0218

Combined Inspector/Inspection Factors: The inspector and inspection factors can be combined into a nonlinear, multivariate equation similar to the ones presented previously. This equation is given below as Equation 10:

$$\text{General DFR} = y_0 + I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 \tag{10}$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

$I_5 = i(F_5) + j(F_5)^2$

$I_6 = k(F_6) + l(F_6)^2$

$I_7 = m(F_7) + n(F_7)^2$

with: F_1 = Reported Structure Accessibility Level

F_2 = Reported Fear of Traffic

F_3 = Reported Structure Maintenance Level

F_4 = Light Intensity on Deck

F_5 = Color Vision (major confusions)

F_6 = Light Intensity Below Superstructure

F_7 = Left Eye Near Visual Acuity

Values for the general equation coefficients are given in table 121. The correlation coefficient obtained for this equation is 0.45. Figures L75 through L79 in Appendix L in Volume II illustrate the influence of each of the factors on the general DFR.

Table 121. Coefficients for general DFR equation – Combined inspector/inspection factors.

Coefficient	General DFR
y_0	-1.99
a	-0.0356
b	0.0065
c	1.21
d	-0.162
e	0.222
f	-0.0131
g	-1.48e-7
h	1.86e-12
i	-0.112
j	0.0141
k	-1.54e-5
l	1.93e-10
m	-0.0127
n	1.04e-4

5.2.4. Task D Inspector Photographic Documentation

During Task D, inspectors were asked to use a digital camera to document their findings in addition to their field notes and Condition Ratings. There were two reasons for asking inspectors for this type of documentation: (1) to investigate what type of visual documentation is typically collected and (2) to study whether obtaining photographic documentation correlates with the Condition Rating results.

5.2.4.1. TYPES OF INSPECTOR PHOTOGRAPHS

The inspector photographs could generally be grouped into 18 different types of photographs. Of these 18 photographs, 13 have been identified by the NDEVC as the minimum photographs required to fully document the bridge. The other five photograph types are either outside of the scope of the inspection (e.g., the approach rail) or supplement deterioration shown in other photographs. Figures 87 through 104 show examples of the typical photograph types.

On average, each inspector took just over 7 photographs (standard deviation of 3.8), with a maximum of 19 and a minimum of 1. Table 122 summarizes the frequency with which each of these 18 photographs was taken. Note, however, that many inspectors may have taken more than one photograph of the same item, a fact that is not represented by the data in Table 122. It is clear from Table 122 that the photographs of the deck joint deterioration, the deterioration of the parapet, the south elevation view, and the general approach view were the most common photographs. All other photographs were taken by fewer than half of the inspectors. Also, while more than 30 of the inspectors took a photograph of the south elevation, only 5 inspectors took a similar photograph of the north elevation. This is probably attributed to the difficult access to the northern elevation discussed previously. The wide variability in the type and number of photographs taken may illustrate differences in inspection agency documentation policies. Note that figures 89 through 91 show the same type of deterioration in multiple locations and one could argue that all three are not necessary.

5.2.4.2. CORRELATION OF INSPECTOR PHOTOGRAPHS WITH CONDITION RATINGS

It was speculated that an inspector who provided more photographic documentation may have identified more deficiencies, which may lead to a lower Condition Rating. Two techniques were used to assess this relationship. First, the total number of the previously mentioned photographs, minus any repeats, that each inspector took was compared with their Condition Ratings for the deck, superstructure, and substructure. In the same manner, the number of the 13 photographs identified by the NDEVC discussed previously that were taken was also analyzed with respect to the Condition Ratings. For the second technique, the relationship between specific photographs was investigated by comparing the average Condition Rating for inspectors taking each

Figure 87. Inspector Photograph 1 – Longitudinal cracking in southern face of superstructure.

Figure 88. Inspector Photograph 2 – Typical underside deck cracking.

Figure 89. Inspector Photograph 3 – West backwall longitudinal joint deterioration.

Figure 90. Inspector Photograph 4 – Underside deck longitudinal joint deterioration.

Figure 91. Inspector Photograph 5 – East backwall longitudinal joint deterioration.

Figure 92. Inspector Photograph 6 – Failed overhead sign connection.

Figure 93. Inspector Photograph 7 – Hole in east approach.

Figure 94. Inspector Photograph 8 – Typical parapet concrete deterioration and exposed reinforcement.

Figure 95. Inspector Photograph 9 – Localized spalling in northeast wingwall.

Figure 96. Inspector Photograph 10 – Typical wearing surface deterioration.

Figure 97. Inspector Photograph 11 – North elevation view.

Figure 98. Inspector Photograph 12 – General approach view.

Figure 99. Inspector Photograph 13 – South elevation view.

Figure 100. Inspector Photograph 14 – General backwall condition.

Figure 101. Inspector Photograph 15 – General wingwall condition.

Figure 102. Inspector Photograph 16 – General approach rail condition.

Figure 103. Inspector Photograph 17 – General photograph of bridge underside.

Figure 104. Inspector Photograph 18 – Localized soil erosion.

Table 122. Frequency of specific photographic documentation.

Photograph	Inspectors
1	17 (35%)
2	18 (37%)
3	12 (24%)
4	45 (92%)
5	13 (27%)
6	2 (4%)
7	15 (31%)
8	40 (82%)
9	2 (4%)
10	20 (41%)
11	5 (10%)
12	31 (63%)
13	31 (63%)
14	3 (6%)
15	6 (12%)
16	10 (20%)
17	3 (6%)
18	1 (2%)

photograph with the overall average Condition Rating. The goal of this type of analysis was to determine whether the average Condition Ratings for the two groups were statistically different.

Regardless of the type of analysis used, no correlation between the visual documentation and the Condition Ratings could be established. Specifically, with regard to the number of photographs taken, there were no overall differences in Condition Ratings for inspectors who took different quantities of photographs. Furthermore, the comparison of the primary element Condition Ratings for inspectors who took each of the pictures versus the entire sample of inspectors showed that there were minor differences. However, the t-test used previously indicated that, in all cases, there was no statistical difference between the inspectors who took pictures and those who did not.

This analysis does not imply that visual documentation is not useful or valuable. Certainly, tools such as cameras allow an inspector to document inspection results more thoroughly and accurately. This analysis simply indicates that the number and type of photographs taken during Task D did not correlate with the Task D Condition Ratings.

5.2.5. Field Inspection Notes

This section summarizes notes collected by inspectors during the six Routine Inspection tasks. Typically, inspection notes are used to supplement or to reinforce assigned Condition Ratings. Although the inspectors participating in this study may have taken a large number of inspection notes during the inspection tasks, this analysis will focus only on a small set of notes deemed to be of principal importance. These notes generally describe poorly rated elements.

This discussion is presented in four sections. First, the specific notes that were analyzed are presented. Second, general information about the inspector note-taking performance is discussed. Third, the relationship between the inspector factors and note-taking performance is then presented. Finally, the correlation of note-taking with the primary element Condition Ratings is discussed.

5.2.5.1. EXPECTED NOTES

Although there are many possible field inspection notes that could be generated, a limited number of important notes were selected for these analyses. These notes were typically provided by the inspectors to describe low Condition Ratings. The specific notes analyzed for each task are summarized in table 123 and pictures of the deterioration they describe are shown in figures 105 through 124. Note that the text in table 123 is a typical description of the deterioration that the inspectors were expected to note. The inspectors were not, for analysis purposes, required to have the exact verbiage shown in the table to receive credit for taking a respective note.

However, general notes (i.e., corrosion) were not permitted if specific notes (i.e., corrosion of end floor beam) were expected. The Note Numbers shown in table 123 will be used in subsequent discussions to refer to these notes.

Table 123. Inspection field notes analyzed.

Task	Note Number	Note
A	A1	Underside deck cracking and/or efflorescence
	A2	Heavy corrosion of end floor beam
	A3	Minor to moderate corrosion of stringer web at deck interface
	A4	Full-height vertical crack in north abutment
	A5	Impact damage to superstructure stiffeners
B	B1	Severe deterioration of wearing surface
	B2	Severe parapet deterioration
	B3	T-beam deterioration
	B4	Full-length horizontal crack in west abutment
C	C1	Severe deterioration of wearing surface
	C2	T-beam deterioration
	C3	Three-quarter length transverse crack in east abutment
D	D1	Severe deterioration of wearing surface
	D2	Severe parapet deterioration
	D3	Longitudinal joint deterioration
E	E1	Severe deterioration of wearing surface
	E2	Underside deck cracking and/or efflorescence
	E3	Minor to moderate superstructure corrosion
	E4	Impact damage to south fascia girder
G	G1	Moderate to severe corrosion of abutment bearings

5.2.5.2. INSPECTOR NOTES

This section will summarize the inspector performance at taking the specific notes outlined in table 123. The data for each task will be presented in a task-by-task format.

5.2.5.2.1. Task A

Of the five field notes investigated for Task A, the inspectors took an average of 3.0 notes (standard deviation of 1.1), with a minimum of zero and a maximum of five. Table 124 summarizes the frequency with which individual Task A notes were taken and table 125 gives the frequency distribution with which different numbers of Task A notes were taken.

Figure 105. Deterioration described by Note A1 – Underside deck cracking and/or efflorescence.

Figure 106. Deterioration described by Note A2 – Heavy corrosion of end floor beam.

Figure 107. Deterioration described by Note A3 – Minor to moderate corrosion of stringer web at deck interface.

Figure 108. Deterioration described by Note A4 – Full-height vertical crack in north abutment.

Figure 109. Deterioration described by Note A5 – Impact damage to superstructure stiffeners.

Figure 110. Deterioration described by Note B1 – Severe deterioration of wearing surface.

Figure 111. Deterioration described by Note B2 – Severe parapet deterioration.

Figure 112. Deterioration described by Note B3 – T-beam deterioration.

Figure 113. Deterioration described by Note B4 – Full-length horizontal crack.

Figure 114. Deterioration described by Note C1 – Severe deterioration of wearing surface.

Figure 115. Deterioration described by Note C2 – T-beam deterioration.

Figure 116. Deterioration described by Note C3 – Three-quarter length transverse crack in east abutment.

Figure 117. Deterioration described by Note D1 – Severe deterioration of wearing surface.

Figure 118. Deterioration described by Note D2 – Severe parapet deterioration.

Figure 119. Deterioration described by Note D3 – Longitudinal joint deterioration.

Figure 120. Deterioration described by Note E1 – Severe deterioration of wearing surface.

Figure 121. Deterioration described by Note E2 – Underside deck cracking and/or efflorescence.

Figure 122. Deterioration described by Note E3 – Minor to moderate superstructure corrosion.

Figure 123. Deterioration described by Note E4 – Impact damage to south fascia girder.

Figure 124. Deterioration described by Note G1 – Moderate to severe corrosion of abutment bearings.

Table 124. Task A – Note-taking frequency.

Note	Percentage of Inspectors
A1	67%
A2	82%
A3	65%
A4	61%
A5	24%

Table 125. Task A – Distribution of number of notes taken.

Number of Notes	Frequency
0	1
1	3
2	10
3	18
4	15
5	2

From tables 124 and 125, it can be seen that, with the exception of Note A5 (impact damage to superstructure stiffener), more than half of the inspectors took each note. One possible reason that Note A5 may have been overlooked is that the damage was in the upper half of the girders and the inspector's attention may have been focused more on evaluating the deck than the superstructure. The most common number of notes taken was three. One inspector did not take any of the notes and only two inspectors took all five of the notes.

5.2.5.2.2. Task B

Of the four field notes investigated for Task B, the inspectors took an average of 3.1 notes (standard deviation of 1.0), with a minimum of one and a maximum of four. Table 126 summarizes the frequency with which individual Task B notes were taken and table 127 gives the frequency distribution with which different numbers of Task B notes were taken.

Table 126. Task B – Note-taking frequency.

Note	Percentage of Inspectors
B1	65%
B2	73%
B3	88%
B4	84%

Table 127. Task B – Distribution of number of notes taken.

Number of Notes	Frequency
0	0
1	3
2	12
3	11
4	23

From tables 126 and 127, it can be seen that more than half of the inspectors took each note, with more than 80 percent taking Notes B3 and B4. Although these are relatively high percentages, the severity of the deterioration that would have precipitated each note is such that one would expect nearly all inspectors to have taken each note. As one would expect given the percentage of inspectors taking each note, the most frequent number of notes taken was four. Ninety-four percent of the inspectors took at least two of the notes.

5.2.5.2.3. Task C

Of the three field notes investigated for Task C, inspectors took an average of 2.1 notes (standard deviation of 1.0), with a minimum of zero and a maximum of three. Table 128 summarizes the frequency with which individual Task C notes were taken and table 129 gives the frequency distribution with which different numbers of Task C notes were taken.

Table 128. Task C – Note-taking frequency.

Note	Percentage of Inspectors
C1	69%
C2	76%
C3	67%

Table 129. Task C – Distribution of number of notes taken.

Number of Notes	Frequency
0	3
1	11
2	12
3	23

More than 60 percent of the inspectors took each note. Just as in Task B, given the severity of the deterioration described by each note, one could reasonably argue that nearly all of the inspectors should have taken Notes C1 through C3. Similar to Task B, nearly half of the inspectors took all three notes. However, three inspectors failed to take any of the investigated notes. This lack of any note-taking could be attributed to the fact that the Task B and Task C bridges are very similar.

5.2.5.2.4. Task D

Of the three field notes investigated for Task D, the inspectors took an average of 2.3 notes (standard deviation of 0.8), with a minimum of zero and a maximum of three. Table 130 summarizes the frequency with which individual Task D notes were taken and table 131 gives the frequency distribution with which different numbers of Task D notes were taken.

Table 130. Task D – Note-taking frequency.

Note	Percentage of Inspectors
D1	76%
D2	76%
D3	78%

Table 131. Task D – Distribution of number of notes taken.

Number of Notes	Frequency
0	2
1	6
2	17
3	24

As can be seen from these tables, approximately 75 percent of the inspectors took each note. More than 80 percent of the inspectors took at least two of the notes. Again, although these are relatively high frequencies, the level of deterioration in the elements described by Notes D1 through D3 is so severe that one could expect all inspectors to have noted them.

5.2.5.2.5. Task E

Of the four field notes investigated for Task E, the inspectors took an average of 2.7 notes (standard deviation of 0.8), with a minimum of one and a maximum of four. Table 132 summarizes the frequency with which individual Task E notes were taken and table 133 gives the frequency distribution with which different numbers of Task E notes were taken.

With the exception of noting the impact damage to the south fascia girder (Note E4), more than half of the inspectors took each note. Although the impact damage is quite localized, the ramifications of being hit by an over-height vehicle can be significant and, therefore, a note may be expected.

Table 132. Task E – Note-taking frequency.

Note	Percentage of Inspectors
E1	78%
E2	88%
E3	69%
E4	33%

Table 133. Task E – Distribution of number of notes taken.

Number of Notes	Frequency
0	0
1	3
2	17
3	22
4	7

5.2.5.2.6. Task G

For the one field note investigated for Task G, 34 inspectors took the note and 15 did not. This is approximately 70 percent of the inspectors. It is plausible that, because the bridge is in very good condition overall, localized deficiencies such as the one described by Note G1 could be overlooked.

5.2.5.3. INFLUENCE OF INSPECTOR FACTORS ON NOTE-TAKING

In this section, the relationship between the inspector factors described previously and note-taking will be discussed. This type of analysis is important because some State DOTs may rely heavily on their inspector field notes and less on Condition Ratings for making condition assessments.

Most of the analyses presented in this section are based on the t-test for statistical difference between two samples. Specifically, the goal in applying the t-test here was to determine if inspectors who took a particular note had statistically different inspector factors from those who did not take the note. Table 134 shows the probabilities that the inspectors who took individual notes are not statistically different from those who did not take the individual notes. In other words, low probabilities in table 134 indicate a higher likelihood that the inspector factor may have some correlation with taking the note. The inspector factors summarized in table 134 are the SRQ questions for which inspectors could give a quantitative or scaled response (e.g., on a scale of 1 to 5).

Although some low probabilities are shown in table 134, no clear trends are observed. To supplement the data given in table 134, groups of similar notes were combined to determine whether relationships between similar notes and the inspector factors existed. The similar note groups are summarized in table 135, with the probability data given in table 136. The data in table 136 were developed by averaging the individual probabilities in table 134. As such, these data only give a relative measure of correlation. As before, no clear trends are observed. Five factors had probabilities of less than or equal to 10 percent for at least one of the note categories: Perception of Bridge Inspection Importance to Public Safety, Reported Fear of Heights, Reported Fear of Traffic, Experience in Bridge Inspection, and Comparison to Other Inspectors. An additional six factors had probabilities less than or equal to 20 percent for at least one of the categories: Height, Quality of Relationship With Supervisor, Percentage of Time on Bridge Inspection, Number of Annual Bridge Inspections, General Education Level, and Formal Bridge Inspection Training.

Table 134. Influence of inspector factors on note-taking.

Task	Note	Age	Height	Weight	General Physical Condition	General Mental Condition	Perception of Bridge Importance to Public Safety	General Mental Focus	Interest in Bridge Inspection Work
A	A1	64%	24%	2%	36%	46%	52%	61%	43%
	A2	75%	36%	32%	93%	12%	21%	19%	89%
	A3	64%	87%	19%	41%	56%	4%	55%	62%
	A4	73%	22%	60%	95%	83%	54%	88%	65%
	A5	89%	68%	23%	94%	42%	60%	53%	72%
B	B1	7%	78%	45%	0%	34%	13%	50%	31%
	B2	58%	21%	48%	46%	87%	15%	66%	62%
	B3	21%	47%	46%	76%	34%	25%	4%	89%
	B4	68%	17%	35%	79%	64%	30%	9%	25%
C	C1	52%	91%	83%	20%	36%	75%	22%	3%
	C2	31%	58%	54%	94%	37%	26%	76%	84%
	C3	92%	11%	46%	36%	82%	63%	4%	80%
D	D1	54%	86%	59%	32%	75%	60%	44%	13%
	D2	58%	42%	100%	94%	81%	49%	76%	76%
	D3	89%	86%	57%	7%	21%	34%	54%	21%
E	E1	0%	99%	43%	34%	9%	66%	27%	92%
	E2	94%	48%	65%	27%	34%	5%	68%	55%
	E3	91%	41%	41%	8%	88%	17%	61%	12%
	E4	74%	13%	94%	67%	81%	52%	44%	7%
G	G1	90%	68%	61%	78%	4%	37%	22%	3%

Table 134. Influence of inspector factors on note-taking (continued).

Task	Note	Reported Fear of Heights	Reported Fear of Enclosed Spaces	Reported Fear of Traffic	Experience in Bridge Inspection	Experience in Highway Structures	Estimated Additional Years as a Bridge Inspector	Quality of Relationship With Supervisor	Perceived Importance of Work by Management
A	A1	69%	40%	48%	62%	91%	89%	42%	99%
	A2	10%	75%	21%	68%	26%	34%	25%	67%
	A3	99%	38%	66%	95%	96%	49%	84%	35%
	A4	95%	92%	8%	24%	75%	46%	46%	92%
	A5	46%	61%	2%	2%	35%	6%	14%	87%
B	B1	69%	9%	17%	13%	11%	75%	27%	98%
	B2	93%	96%	15%	60%	75%	21%	18%	84%
	B3	4%	65%	59%	26%	70%	44%	53%	1%
	B4	21%	69%	10%	70%	67%	23%	5%	68%
C	C1	41%	49%	0%	67%	42%	42%	96%	48%
	C2	16%	91%	75%	32%	34%	44%	14%	87%
	C3	69%	53%	10%	24%	20%	66%	1%	51%
D	D1	34%	91%	2%	87%	70%	31%	30%	11%
	D2	34%	13%	18%	67%	56%	40%	97%	11%
	D3	31%	29%	93%	76%	72%	17%	47%	81%
E	E1	56%	86%	93%	12%	24%	17%	47%	18%
	E2	73%	94%	59%	25%	6%	6%	53%	29%
	E3	67%	96%	98%	71%	87%	34%	33%	11%
	E4	44%	8%	8%	8%	31%	85%	8%	53%
G	G1	67%	96%	1%	57%	59%	56%	17%	48%

Table 134. Influence of inspector factors on note-taking (continued).

Task	Note	Percentage Time on Bridge Inspection	Percentage Routine Inspections	Percentage of Inspections With On-Site PE	Comparison to Other Inspectors	Number of Annual Bridge Inspections	General Education Level	Formal Bridge Inspection Training	Jet Lag
A	A1	28%	60%	92%	70%	73%	38%	78%	38%
	A2	81%	72%	84%	23%	85%	29%	90%	45%
	A3	67%	71%	51%	71%	68%	22%	58%	81%
	A4	87%	75%	96%	74%	36%	26%	94%	71%
	A5	48%	74%	48%	48%	21%	59%	37%	55%
B	B1	9%	76%	63%	71%	59%	19%	5%	61%
	B2	8%	30%	57%	23%	53%	34%	61%	24%
	B3	59%	11%	40%	9%	74%	41%	34%	15%
	B4	10%	62%	16%	8%	60%	15%	9%	6%
C	C1	45%	17%	95%	6%	92%	50%	18%	44%
	C2	42%	52%	95%	5%	52%	91%	6%	77%
	C3	96%	93%	81%	100%	56%	18%	78%	78%
D	D1	26%	70%	61%	46%	51%	44%	64%	20%
	D2	23%	39%	5%	34%	31%	27%	49%	20%
	D3	6%	84%	63%	94%	11%	18%	30%	46%
E	E1	83%	9%	92%	34%	80%	92%	71%	23%
	E2	83%	73%	40%	9%	87%	41%	23%	85%
	E3	85%	71%	64%	86%	70%	95%	6%	50%
	E4	37%	67%	67%	67%	13%	75%	43%	79%
G	G1	65%	59%	81%	6%	40%	50%	25%	6%

Table 135. General note categories.

Category	Notes	General Description
GC1	B1, C1, D1, E1	Wearing surface condition
GC2	A1, E2	Underside deck cracking/efflorescence
GC3	B2, D2	Parapet condition
GC4	A3, E3	Corrosion of steel superstructure
GC5	B3, C2	Deterioration of concrete superstructure
GC6	A5, E4	Superstructure impact damage
Deck	A1, B1, B2, C1, D1, D2, E1, E2	All Deck-related notes
Super	A2, A3, A5, B3, C2, D3, E3, E4, G1	All Superstructure-related notes
Sub	A4, B4, C3	All Substructure-related notes
All	A1-A5, B1-B4, C1-C3, D1-D3, E1-E4, G1	All notes

Based on the broad All Notes category, the following factors showed the strongest, although not necessarily statistically significant, relationship with note-taking:

- Fear of Traffic
- Perception of Bridge Inspection Importance to Public Safety
- Quality of Relationship With Supervisor
- Estimated Additional Years as a Bridge Inspector
- Comparison to Other Inspectors
- General Education Level
- Formal Bridge Inspection Training

In addition to the quantitative and scaled SRQ questions presented previously, SRQ questions in which inspectors either answered yes or no, or indicated one of two possible categories, were also analyzed. Unfortunately, the t-test cannot be used to determine statistical significance for these types of questions. In light of this, the following were determined from the analyses of all such SRQ questions and may or may not be statistically significant:

Table 136. Influence of inspector factors on general note-taking.

Note Category	Age	Height	Weight	General Physical Condition	General Mental Condition	Perception of Bridge Importance to Public Safety	General Mental Focus	Interest in Bridge Inspection Work
GC1	28%	89%	57%	22%	38%	53%	36%	35%
GC2	79%	36%	34%	31%	40%	29%	64%	49%
GC3	58%	32%	74%	70%	84%	32%	71%	69%
GC4	78%	64%	30%	24%	72%	10%	58%	37%
GC5	26%	53%	50%	85%	35%	26%	40%	86%
GC6	81%	40%	59%	81%	62%	56%	49%	39%
Deck	48%	61%	56%	36%	50%	42%	52%	47%
Super	69%	56%	48%	62%	42%	31%	43%	49%
Sub	78%	17%	47%	70%	76%	49%	33%	57%
All	62%	52%	51%	53%	50%	38%	45%	49%

Table 136. Influence of inspector factors on general note-taking (continued).

Note Category	Reported Fear of Heights	Reported Fear of Enclosed Spaces	Reported Fear of Traffic	Experience in Bridge Inspection	Experience in Highway Structures	Estimated Additional Years as a Bridge Inspector	Quality of Relationship With Supervisor	Perceived Importance of Work by Management
GC1	50%	59%	28%	45%	37%	41%	50%	43%
GC2	71%	67%	54%	43%	48%	47%	47%	64%
GC3	63%	54%	17%	64%	66%	57%	57%	47%
GC4	83%	67%	82%	83%	92%	58%	58%	23%
GC5	10%	78%	67%	29%	52%	34%	34%	44%
GC6	45%	34%	5%	5%	33%	11%	11%	70%
Deck	59%	60%	32%	49%	47%	51%	51%	50%
Super	43%	62%	47%	48%	57%	33%	33%	52%
Sub	62%	71%	9%	39%	54%	17%	17%	70%
All	52%	62%	35%	47%	52%	38%	38%	54%

Table 136. Influence of inspector factors on general note-taking (continued).

Note Category	Percentage Time on Bridge Inspection	Percentage Routine Inspections	Percent of Inspections With On-Site PE	Comparison to Other Inspectors	Number of Annual Bridge Inspections	General Education Level	Formal Bridge Inspection Training	Jet Lag
GC1	41%	43%	77%	39%	70%	51%	40%	37%
GC2	56%	67%	66%	40%	80%	39%	50%	61%
GC3	16%	35%	31%	28%	42%	30%	55%	22%
GC4	75%	71%	57%	79%	69%	59%	32%	66%
GC5	51%	31%	68%	7%	63%	66%	20%	46%
GC6	43%	70%	58%	58%	17%	67%	40%	67%
Deck	38%	47%	63%	37%	66%	43%	46%	39%
Super	54%	62%	66%	45%	48%	53%	37%	50%
Sub	64%	76%	64%	61%	51%	20%	61%	52%
All	49%	58%	64%	44%	56%	44%	44%	46%

- In general, a larger percentage of the inspectors who did not take notes indicated that they were experiencing additional stress due to personal problems (11.5 percent versus 10.3 percent).
- In general, a larger percentage of the inspectors who did not take notes indicated that they assess the importance of bridge inspection to public safety (96.3 percent versus 93.5 percent).
- In general, a larger percentage of note-taking inspectors indicated that they had worked as an inspector in another industry (27.7 percent versus 21.6 percent).
- In general, a larger percentage of note-taking inspectors indicated that they were taking either bilberry, Viagra, or B vitamin complex (7.8 percent versus 3.9 percent).
- Twenty-nine percent of the note-taking inspectors and 39 percent of the inspectors who did not take notes indicated that their State's inspection philosophy was to comply with the NBIS requirements.
- Seventy-one percent of the note-taking inspectors and 61 percent of the inspectors who did not take notes indicated that their State's inspection philosophy was to identify all defects.

In addition to the inspector factors that were analyzed, one inspection factor was also analyzed. Since the amount of time each inspector was allowed to spend on each task was limited, it was hypothesized that the amount of inspection time used may correlate with note-taking. The results of this analysis indicated that the amount of time spent on each task did not correlate with inspector note-taking.

5.2.5.4. INFLUENCE OF NOTE-TAKING ON PRIMARY ELEMENT CONDITION RATINGS

In this section, the influence of taking specific field inspection notes on the primary element Condition Ratings is presented. The goal of this analysis is to determine whether taking, or not taking, a specific note may influence Condition Ratings. The t-test was used to determine whether inspectors who took notes gave statistically different Condition Ratings than those that did not take notes.

Tables 137 through 142 summarize the probability that the note-taking inspectors and the inspectors who did not take notes did not give statistically different Condition Ratings. As in the previous discussion, no clear trends exist in the data. Furthermore, when one looks at the relationship between notes on a specific element and the Condition Rating for that element (shown in bold in the tables), in all cases except Note D1 and the Deck, no significant relationship existed. From this, one can conclude that taking the notes studied herein had no influence on the assigning of Condition Ratings. However, this does not imply that inspection notes are not valuable.

To supplement the task-by-task analysis, the DFR data were used to combine the Condition Ratings from all tasks. For this analysis, the inspectors were grouped into High and Low General Note-Taking Groups based on the total number of notes taken during all of the tasks ("High" is more than 16 notes and "Low" is fewer than 14 notes out of a possible 20). The average DFR for the two groups was then compared using the t-test for statistical difference with the results given in table 143. From these data, it appears that general note-taking may have

Table 137. Task A – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
A1	**13%**	12%	21%
A2	88%	**68%**	98%
A3	96%	**43%**	83%
A4	1%	54%	**32%**
A5	75%	**52%**	77%

Table 138. Task B – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
B1	**22%**	28%	96%
B2	**86%**	65%	17%
B3	91%	**72%**	69%
B4	22%	37%	**89%**

Table 139. Task C – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
C1	**25%**	26%	72%
C2	71%	**31%**	67%
C3	0.004%	33%	**84%**

Table 140. Task D – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
D1	**1%**	0.3%	5%
D2	**15%**	0.1%	22%
D3	48%	**67%**	**75%**

Table 141. Task E – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
E1	**35%**	48%	99%
E2	**66%**	23%	83%
E3	38%	**81%**	24%
E4	50%	**49%**	88%

Table 142. Task G – Influence of note-taking on Condition Ratings.

	Element		
Note	Deck	Superstructure	Substructure
G1	66%	**31%**	22%

Table 143. Relationship between general note-taking groups and DFR.

Element	General Note-Taking Group				Significance Level
	Low		High		
	Average	Standard Deviation	Average	Standard Deviation	
Deck	0.44	0.79	0.82	0.44	17%
Superstructure	0.23	0.59	0.44	0.47	33%
Substructure	-0.15	0.70	0.09	0.51	12%
All Elements	0.14	0.64	0.41	0.42	24%

some relationship with the DFR data. From these data, it is clear that the High General Note-Taking Group had larger average DFRs with less dispersion, indicating that inspectors who noted more deficiencies gave higher Condition Ratings.

5.2.6. Statistical Analysis of Secondary Bridge Elements

In this section, general statistical information will be presented for Condition Ratings assigned to the secondary bridge elements during the Routine Inspection tasks. In a typical NBIS inspection, Condition Ratings are not assigned to the secondary elements. Rather, these elements are rated differently based on individual State requirements. One inspection model assigns either a G, F, P, or N (good, fair, poor, or not applicable, respectively). The previously described 0 to 9 system used by the inspectors participating in this study may be an abnormal format. In light of this, very little advanced analysis was completed on these data, and the results are presented to illustrate three trends within the data: (1) the distribution of the Condition Ratings that were assigned; (2) the differences in the State definitions of the secondary elements; and (3) the secondary elements that generally control the primary element Condition Ratings. As in previous discussions, the results are presented in a task-by-task format.

5.2.6.1. TASK A

Tables 144 through 146 summarize the assigned Condition Ratings for Task A. Note from table 144 that 46 or fewer inspectors gave Condition Ratings for each of the secondary elements, whereas 49 inspectors gave an overall Condition Rating for the deck (average of 5.8, standard deviation of 0.81). From table 144, it appears that condition assessments from the wearing surface, deck underside, and curbs are the controlling secondary elements for the overall deck

Table 144. Task A – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	5.8	5.2	6.0	N/A*	5.7	5.0	5.0	6.3	5.6	5.3	6.0	N/A	N/A
Standard Deviation	1.23	0.95	0.73	N/A	1.03	1.41	0.82	0.49	0.51	1.02	1.00	N/A	N/A
COV	0.21	0.18	0.12	N/A	0.18	0.28	0.16	0.08	0.09	0.19	0.17	N/A	N/A
Minimum	4	4	4	N/A	3	4	4	6	5	3	5	N/A	N/A
Maximum	8	7	7	N/A	8	6	6	7	6	8	7	N/A	N/A
Mode	6	5	6	N/A	6	N/A	5	6	6	5	7	N/A	N/A
N	23	23	46	N/A	46	2	4	7	12	34	5	N/A	N/A

	Frequency												
Condition Rating	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A
1	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A
2	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A
3	0	0	0	N/A	1	0	0	0	0	2	0	N/A	N/A
4	5	6	1	N/A	4	1	1	0	0	4	0	N/A	N/A
5	3	8	9	N/A	15	0	2	0	5	14	2	N/A	N/A
6	7	7	25	N/A	16	1	1	5	7	12	1	N/A	N/A
7	7	2	11	N/A	9	0	0	2	0	1	2	N/A	N/A
8	1	0	0	N/A	1	0	0	0	0	1	0	N/A	N/A
9	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A

Note: Average overall deck Condition Rating = 5.8.
* N/A = Not applicable.

Table 145. Task A – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	5.8	5.8	5.3	N/A*	6.2	N/A	3.0	5.5	6.1	6.4	6.7
Standard Deviation	0.96	0.77	0.89	N/A	0.78	N/A	N/A	1.15	1.22	0.90	0.76
COV	0.17	0.13	0.17	N/A	0.13	N/A	N/A	0.21	0.20	0.14	0.11
Minimum	5	4	4	N/A	5	N/A	3	3	1	4	6
Maximum	7	7	7	N/A	8	N/A	3	8	8	8	8
Mode	5	6	5	N/A	6	N/A	3	6	6	7	7
N	4	39	8	N/A	47	N/A	1	46	44	30	7

Condition Rating	Frequency										
	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	0	0	0	N/A	0	N/A	0	0	0	0	0
1	0	0	0	N/A	0	N/A	0	0	1	0	0
2	0	0	0	N/A	0	N/A	0	0	0	0	0
3	0	0	0	N/A	0	N/A	1	2	0	0	0
4	0	1	1	N/A	0	N/A	0	7	2	1	0
5	2	13	5	N/A	8	N/A	0	14	6	3	0
6	1	18	1	N/A	23	N/A	0	14	19	10	3
7	1	7	1	N/A	14	N/A	0	8	13	14	3
8	0	0	0	N/A	2	N/A	0	1	3	2	1
9	0	0	0	N/A	0	N/A	0	0	0	0	0

Note: Average overall superstructure Condition Rating = 5.9.
* N/A = Not applicable.

Table 146. Task A – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	6.0	8.0	6.0	6.1	6.5	6.2	6.9	N/A*	N/A	N/A	7.0	6.5
Standard Deviation	0.73	N/A	N/A	0.77	0.93	0.73	0.81	N/A	N/A	N/A	N/A	0.71
COV	0.12	N/A	N/A	0.13	0.14	0.12	0.12	N/A	N/A	N/A	N/A	0.11
Minimum	5	8	6	5	4	4	5	N/A	N/A	N/A	7	6
Maximum	7	8	6	7	8	7	8	N/A	N/A	N/A	7	7
Mode	6	8	6	6	7	6	7	N/A	N/A	N/A	7	6,7
N	33	1	1	16	44	45	48	N/A	N/A	N/A	1	2

	Frequency											
Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	0	0	0	0	0	0	N/A	N/A	N/A	0	0
1	0	0	0	0	0	0	0	N/A	N/A	N/A	0	0
2	0	0	0	0	0	0	0	N/A	N/A	N/A	0	0
3	0	0	0	0	0	0	0	N/A	N/A	N/A	0	0
4	0	0	0	0	1	1	0	N/A	N/A	N/A	0	0
5	8	0	0	4	5	5	2	N/A	N/A	N/A	0	0
6	16	0	1	7	15	23	11	N/A	N/A	N/A	0	1
7	9	0	0	5	18	16	23	N/A	N/A	N/A	1	1
8	0	1	0	0	5	0	12	N/A	N/A	N/A	0	0
9	0	0	0	0	0	0	0	N/A	N/A	N/A	0	0

Note: Average overall substructure Condition Rating = 6.1.
* N/A = Not applicable.

Condition Rating. Note that 23 inspectors assigned Condition Ratings for the deck topside, even though less than 5 percent of the deck surface was visible. From table 145, it is apparent that the condition of the floor beams and girders/stringers controls the overall superstructure Condition Rating (average of 5.9, standard deviation of 0.78). However, there appears to be some confusion in the definitions of the bridge element types (e.g., girders vs. stringers, floor beams vs. floor system bracing, etc.). The data in table 146 indicate that inspectors may be basing their overall substructure Condition Ratings (average of 6.1, standard deviation of 0.79) on assessments of the abutments and the bearing seat. Finally, note that one inspector gave a Condition Rating for column/stem even though this bridge had no intermediate piers.

5.2.6.2. TASK B

Tables 147 through 149 summarize the assigned Condition Ratings for Task B. Similar to Task A, the wearing surface and deck underside were the most commonly rated secondary elements. Interestingly, one inspector rated stay-in-place (SIP) forms and two rated sidewalks, despite the fact that they did not exist on Bridge B101A. As before, there appears to be some confusion in the classification of the superstructure elements. Most inspectors classified the superstructure as multibeam followed by girder and stringer. Two inspectors rated floor beams when none existed. From the data in table 149, the overall assessment of the substructure (average of 4.3, standard deviation of 0.76) is controlled by the abutment conditions. As in Task A, one inspector rated substructure elements that did not exist (e.g., piers and bents).

5.2.6.3. TASK C

Tables 150 through 152 summarize the assigned Condition Ratings for Task C. Since the Task B and Task C bridges are very similar, it is not surprising that the trends discussed above are repeated for the Task C secondary elements.

5.2.6.4. TASK D

Tables 153 through 155 summarize the assigned Condition Ratings for Task D. From the data in

Table 147. Task B – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	4.0	4.6	5.2	3.0	4.0	4.5	5.5	3.7	3.4	3.4	4.7	N/A*	N/A
Standard Deviation	0.81	1.04	0.87	N/A	0.80	0.88	0.71	0.90	0.74	1.14	2.08	N/A	N/A
COV	0.20	0.23	0.17	N/A	0.20	0.19	0.13	0.24	0.22	0.34	0.45	N/A	N/A
Minimum	2	3	2	3	3	3	5	2	2	2	3	N/A	N/A
Maximum	6	7	7	3	6	6	6	6	5	5	7	N/A	N/A
Mode	4	4	5	3	4	4	5,6	4	3	3	3,4,7	N/A	N/A
N	44	18	46	1	21	13	2	21	35	5	3	N/A	N/A

	Frequency												
Condition Rating	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A
1	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A
2	1	0	1	0	0	0	0	1	3	1	0	N/A	N/A
3	8	2	0	1	6	1	0	8	17	2	1	N/A	N/A
4	25	8	5	0	11	6	0	9	13	1	1	N/A	N/A
5	8	5	28	0	3	4	1	2	2	1	0	N/A	N/A
6	2	2	9	0	1	2	1	1	0	0	0	N/A	N/A
7	0	1	3	0	0	0	0	0	0	0	1	N/A	N/A
8	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A
9	0	0	0	0	0	0	0	0	0	0	0	N/A	N/A

Note: Average overall deck Condition Rating = 4.9.
* N/A = Not applicable.

Table 148. Task B – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	4.2	3.0	4.0	4.3	4.2	N/A*	N/A	N/A	N/A	N/A	N/A
Standard Deviation	0.44	1.41	N/A	0.85	0.68	N/A	N/A	N/A	N/A	N/A	N/A
COV	0.10	0.47	N/A	0.20	0.16	N/A	N/A	N/A	N/A	N/A	N/A
Minimum	4	2	4	3	3	N/A	N/A	N/A	N/A	N/A	N/A
Maximum	5	4	4	6	5	N/A	N/A	N/A	N/A	N/A	N/A
Mode	4	2,4	4	4	4	N/A	N/A	N/A	N/A	N/A	N/A
N	9	2	1	20	15	N/A	N/A	N/A	N/A	N/A	N/A

Condition Rating	Frequency										
	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
1	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
2	0	1	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
3	0	0	0	4	2	N/A	N/A	N/A	N/A	N/A	N/A
4	7	1	1	8	8	N/A	N/A	N/A	N/A	N/A	N/A
5	2	0	0	7	5	N/A	N/A	N/A	N/A	N/A	N/A
6	0	0	0	1	0	N/A	N/A	N/A	N/A	N/A	N/A
7	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
8	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
9	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A

Note: Average overall superstructure Condition Rating = 4.2.
* N/A = Not applicable.

Table 149. Task B – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	4.1	6.0	5.9	4.4	4.7	4.5	5.2	5.0	N/A*	8.0	5.0	N/A
Standard Deviation	0.68	0.00	0.64	0.86	0.99	0.87	1.01	N/A	N/A	N/A	N/A	N/A
COV	0.16	0.00	0.11	0.20	0.21	0.19	0.19	N/A	N/A	N/A	N/A	N/A
Minimum	3	6	5	3	4	3	3	5	N/A	8	5	N/A
Maximum	6	6	7	6	7	6	8	5	N/A	8	5	N/A
Mode	4	6	6	5	4	4	5	5	N/A	8	5	N/A
N	36	2	18	17	17	25	47	1	N/A	1	1	N/A

	Frequency											
Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	0	0	0	0	0	0	0	N/A	0	0	N/A
1	0	0	0	0	0	0	0	0	N/A	0	0	N/A
2	0	0	0	0	0	0	0	0	N/A	0	0	N/A
3	5	0	0	3	0	3	1	0	N/A	0	0	N/A
4	22	0	0	6	10	10	11	0	N/A	0	0	N/A
5	8	0	4	7	3	9	19	1	N/A	0	1	N/A
6	1	2	11	1	3	3	12	0	N/A	0	0	N/A
7	0	0	3	0	1	0	3	0	N/A	0	0	N/A
8	0	0	0	0	0	0	1	0	N/A	1	0	N/A
9	0	0	0	0	0	0	0	0	N/A	0	0	N/A

Note: Average overall substructure Condition Rating = 4.3.
* N/A = Not applicable.

Table 150. Task C – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	3.7	4.5	5.3	5.0	5.2	4.6	N/A*	5.8	6.2	4.1	6.0	N/A	N/A
Standard Deviation	0.91	0.89	0.98	N/A	0.90	1.01	N/A	1.30	0.82	1.27	1.73	N/A	N/A
COV	0.24	0.20	0.19	N/A	0.17	0.22	N/A	0.65	0.13	0.31	0.29	N/A	N/A
Minimum	2	3	3	5	3	3	N/A	2	5	3	4	N/A	N/A
Maximum	6	6	7	5	7	6	N/A	8	8	6	7	N/A	N/A
Mode	4	4	6	5	5	4	N/A	5	6	3	7	N/A	N/A
N	46	16	40	1	25	9	N/A	19	35	9	3	N/A	N/A

	Frequency												
Condition Rating	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	0	0	0	N/A	0	0	0	0	N/A	N/A
1	0	0	0	0	0	0	N/A	0	0	0	0	N/A	N/A
2	3	0	0	0	0	0	N/A	1	0	0	0	N/A	N/A
3	15	1	1	0	1	1	N/A	0	0	4	0	N/A	N/A
4	21	9	9	0	4	4	N/A	0	0	2	1	N/A	N/A
5	5	3	12	1	11	2	N/A	6	8	1	0	N/A	N/A
6	2	3	15	0	8	2	N/A	6	14	2	0	N/A	N/A
7	0	0	3	0	1	0	N/A	5	12	0	2	N/A	N/A
8	0	0	0	0	0	0	N/A	1	1	0	0	N/A	N/A
9	0	0	0	0	0	0	N/A	0	0	0	0	N/A	N/A

Note: Average overall deck Condition Rating = 5.2.
* N/A = Not applicable.

Table 151. Task C – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	4.8	3.0	6.0	4.7	4.7	N/A*	N/A	N/A	N/A	N/A	N/A
Standard Deviation	0.41	1.41	N/A	0.91	0.69	N/A	N/A	N/A	N/A	N/A	N/A
COV	0.10	0.47	N/A	0.20	0.15	N/A	N/A	N/A	N/A	N/A	N/A
Minimum	4	2	6	3	4	N/A	N/A	N/A	N/A	N/A	N/A
Maximum	5	4	6	6	6	N/A	N/A	N/A	N/A	N/A	N/A
Mode	5	2,4	6	5	4,5	N/A	N/A	N/A	N/A	N/A	N/A
N	6	2	1	21	18	N/A	N/A	N/A	N/A	N/A	N/A

Condition Rating	Frequency										
	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
1	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
2	0	1	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
3	0	0	0	2	0	N/A	N/A	N/A	N/A	N/A	N/A
4	1	1	0	7	8	N/A	N/A	N/A	N/A	N/A	N/A
5	5	0	0	8	8	N/A	N/A	N/A	N/A	N/A	N/A
6	0	0	1	4	2	N/A	N/A	N/A	N/A	N/A	N/A
7	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
8	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A
9	0	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A

Note: Average overall superstructure Condition Rating = 4.6.
* N/A = Not applicable.

Table 152. Task C – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	5.4	N/A*	5.3	5.3	6.1	5.6	6.0	N/A	N/A	6.0	N/A	N/A
Standard Deviation	0.80	N/A	0.82	0.91	0.94	0.71	0.81	N/A	N/A	1.41	N/A	N/A
COV	0.15	N/A	0.15	0.17	0.15	0.13	0.13	N/A	N/A	0.24	N/A	N/A
Minimum	4	N/A	3	4	4	4	4	N/A	N/A	5	N/A	N/A
Maximum	7	N/A	6	7	7	7	8	N/A	N/A	7	N/A	N/A
Mode	5	N/A	6	5	6	5	6	N/A	N/A	5,7	N/A	N/A
N	37	N/A	19	14	11	25	45	N/A	N/A	2	N/A	N/A

Frequency

Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
1	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
2	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
3	0	N/A	1	0	0	0	0	N/A	N/A	0	N/A	N/A
4	4	N/A	1	3	1	1	1	N/A	N/A	0	N/A	N/A
5	17	N/A	8	5	1	11	10	N/A	N/A	1	N/A	N/A
6	13	N/A	9	5	5	11	22	N/A	N/A	0	N/A	N/A
7	3	N/A	0	1	4	2	11	N/A	N/A	1	N/A	N/A
8	0	N/A	0	0	0	0	1	N/A	N/A	0	N/A	N/A
9	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A

Note: Average overall substructure Condition Rating = 5.5.
* N/A = Not applicable.

Table 153. Task D – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	3.8	4.6	5.1	N/A*	4.9	4.3	N/A	3.9	3.5	4.0	3.8	N/A	N/A
Standard Deviation	0.86	1.09	0.82	N/A	1.01	0.71	N/A	0.94	0.78	1.66	0.96	N/A	N/A
COV	0.23	0.24	0.16	N/A	0.21	0.16	N/A	0.16	0.22	0.41	0.26	N/A	N/A
Minimum	2	3	3	N/A	3	4	N/A	3	2	1	3	N/A	N/A
Maximum	6	6	6	N/A	7	6	N/A	6	5	7	5	N/A	N/A
Mode	4	4	5	N/A	4	4	N/A	4	4	4	3	N/A	N/A
N	44	16	39	N/A	29	9	N/A	22	30	9	4	N/A	N/A

	Frequency												
Condition Rating	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	N/A	0	0	N/A	0	0	0	0	N/A	N/A
1	0	0	0	N/A	0	0	N/A	0	0	1	0	N/A	N/A
2	2	0	0	N/A	0	0	N/A	0	3	0	0	N/A	N/A
3	14	3	1	N/A	1	0	N/A	9	11	2	2	N/A	N/A
4	22	5	8	N/A	11	7	N/A	9	14	3	1	N/A	N/A
5	4	4	16	N/A	9	1	N/A	2	2	2	1	N/A	N/A
6	2	4	14	N/A	6	1	N/A	2	0	0	0	N/A	N/A
7	0	0	0	N/A	2	0	N/A	0	0	1	0	N/A	N/A
8	0	0	0	N/A	0	0	N/A	0	0	0	0	N/A	N/A
9	0	0	0	N/A	0	0	N/A	0	0	0	0	N/A	N/A

Note: Average overall deck Condition Rating = 4.8.
* N/A = Not applicable.

Table 154. Task D – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	N/A*	N/A	N/A	N/A	N/A	5.4	N/A	N/A	N/A	N/A	N/A
Standard Deviation	N/A	N/A	N/A	N/A	N/A	1.00	N/A	N/A	N/A	N/A	N/A
COV	N/A	N/A	N/A	N/A	N/A	0.19	N/A	N/A	N/A	N/A	N/A
Minimum	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A
Maximum	N/A	N/A	N/A	N/A	N/A	7	N/A	N/A	N/A	N/A	N/A
Mode	N/A	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A
N	N/A	N/A	N/A	N/A	N/A	17	N/A	N/A	N/A	N/A	N/A

	Frequency										
Condition Rating	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A
1	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A
2	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A
3	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A
4	N/A	N/A	N/A	N/A	N/A	4	N/A	N/A	N/A	N/A	N/A
5	N/A	N/A	N/A	N/A	N/A	5	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A
7	N/A	N/A	N/A	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A
9	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A

Note: Average overall superstructure Condition Rating = 5.3.
* N/A = Not applicable.

Table 155. Task D – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	6.1	N/A*	6.1	6.1	6.0	6.4	5.9	N/A	N/A	8.0	N/A	N/A
Standard Deviation	0.84	N/A	0.80	0.49	1.00	0.88	1.04	N/A	N/A	N/A	N/A	N/A
COV	0.14	N/A	0.13	0.08	0.17	0.14	0.18	N/A	N/A	N/A	N/A	N/A
Minimum	4	N/A	5	5	5	5	4	N/A	N/A	8	N/A	N/A
Maximum	8	N/A	7	7	7	8	8	N/A	N/A	8	N/A	N/A
Mode	6	N/A	6	6	5,6,7	6	6	N/A	N/A	8	N/A	N/A
N	32	N/A	15	13	3	9	35	N/A	N/A	1	N/A	N/A

	Frequency											
Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
1	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
2	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
3	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A
4	1	N/A	0	0	0	0	3	N/A	N/A	0	N/A	N/A
5	6	N/A	4	1	1	1	9	N/A	N/A	0	N/A	N/A
6	16	N/A	6	10	1	4	13	N/A	N/A	0	N/A	N/A
7	8	N/A	5	2	1	3	8	N/A	N/A	0	N/A	N/A
8	1	N/A	0	0	0	1	2	N/A	N/A	1	N/A	N/A
9	0	N/A	0	0	0	0	0	N/A	N/A	0	N/A	N/A

Note: Average overall substructure Condition Rating = 6.1.
* N/A = Not applicable.

table 153, it appears as though the inspectors primarily used assessments of the wearing surface, deck topside, and deck underside to establish the overall deck Condition Rating (average of 4.8, standard deviation of 0.94). The only secondary superstructure element to be given a rating was “arches”. As with the other tasks, the abutments were the primary secondary elements controlling the overall substructure Condition Rating (average of 6.1, standard deviation of 0.89). Finally, one inspector rated pier footings even though no piers existed.

5.2.6.5. TASK E

Tables 156 through 158 summarize the assigned Condition Ratings for Task E. The trends for Task E are similar to those already discussed. One inspector rated arches even though none existed (although some of the floor beams are curved). As in the previous tasks, one inspector rated piers and bents even though none existed.

5.2.6.6. TASK G

Tables 159 through 161 summarize the assigned Condition Ratings for Task G. It appears that most inspectors may have assigned their overall deck Condition Rating (average of 7.1, standard deviation of 0.53) based on the deck underside condition. The 49 inspectors rated the expansion joint on the Route 1 Bridge with considerable spread in the Condition Ratings (from 3 to 8). It should be pointed out that the expansion joint was recently replaced and one could therefore conclude that it could have been rated a 9. There was again some confusion in the secondary element definitions for Task G. Thirty-eight inspectors used the girders secondary element with another 8 and 3 using multibeams and stringers, respectively. Inspectors using the girders secondary element gave the highest ratings. Unlike the previous tasks, no clear trends exist in the substructure secondary element Condition Ratings.

Table 156. Task E – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	3.6	4.3	4.6	N/A*	3.9	4.3	5.0	4.6	4.8	4.2	4.5	N/A	N/A
Standard Deviation	0.86	0.86	0.76	N/A	0.69	0.73	1.41	0.88	0.87	1.28	1.73	N/A	N/A
COV	0.24	0.20	0.16	N/A	0.18	0.17	0.28	0.19	0.18	0.30	0.38	N/A	N/A
Minimum	1	3	3	N/A	3	3	4	3	3	1	3	N/A	N/A
Maximum	6	6	6	N/A	5	6	6	6	6	7	7	N/A	N/A
Mode	4	4	5	N/A	4	4	4,6	4	5	5	4	N/A	N/A
N	46	20	47	N/A	29	14	2	28	34	33	4	N/A	N/A

Condition Rating	Frequency												
	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A
1	1	0	0	N/A	0	0	0	0	0	1	0	N/A	N/A
2	3	0	0	N/A	0	0	0	0	0	1	0	N/A	N/A
3	15	3	3	N/A	9	1	0	2	2	7	1	N/A	N/A
4	24	10	16	N/A	15	9	1	13	10	9	2	N/A	N/A
5	2	5	23	N/A	5	3	0	8	14	12	0	N/A	N/A
6	1	2	5	N/A	0	1	1	5	8	1	0	N/A	N/A
7	0	0	0	N/A	0	0	0	0	0	2	1	N/A	N/A
8	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A
9	0	0	0	N/A	0	0	0	0	0	0	0	N/A	N/A

Note: Average overall deck Condition Rating = 4.5.
* N/A = Not applicable.

Table 157. Task E – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	5.8	6.0	6.1	5.7	5.9	6.0	N/A*	5.1	5.4	5.9	6.6
Standard Deviation	0.97	0.69	0.68	0.82	0.69	N/A	N/A	1.05	0.86	0.97	0.88
COV	0.17	0.11	0.11	0.14	0.12	N/A	N/A	0.21	0.16	0.16	0.13
Minimum	4	5	5	5	5	6	N/A	3	2	4	5
Maximum	7	7	7	7	7	6	N/A	8	7	7	8
Mode	5	6	6	5	6	6	N/A	5	5	6	7
N	14	28	18	6	35	1	N/A	43	45	35	9

	Frequency										
Condition Rating	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	0	0	0	0	0	0	N/A	0	0	0	0
1	0	0	0	0	0	0	N/A	0	0	0	0
2	0	0	0	0	0	0	N/A	0	1	0	0
3	0	0	0	0	0	0	N/A	4	0	0	0
4	1	0	0	0	0	0	N/A	4	2	3	0
5	5	6	3	3	11	0	N/A	22	22	8	1
6	4	15	10	2	18	1	N/A	10	17	12	3
7	4	7	5	1	6	0	N/A	2	3	12	4
8	0	0	0	0	0	0	N/A	1	0	0	1
9	0	0	0	0	0	0	N/A	0	0	0	0

Note: Average overall superstructure Condition Rating = 5.8.
* N/A = Not applicable.

Table 158. Task E – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	5.2	5.0	5.7	5.4	4.8	5.6	5.6	5.0	N/A*	N/A	6.0	5.4
Standard Deviation	0.72	0.00	0.58	1.09	0.96	0.97	0.98	N/A	N/A	N/A	N/A	0.89
COV	0.14	0.00	0.10	0.20	0.20	0.17	0.17	N/A	N/A	N/A	N/A	0.17
Minimum	4	5	5	3	3	4	4	5	N/A	N/A	6	5
Maximum	7	5	6	7	7	8	7	5	N/A	N/A	6	7
Mode	5	5	6	5	5	6	6	5	N/A	N/A	6	5
N	37	2	3	16	46	39	46	1	N/A	N/A	1	5

	Frequency											
Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	0	0	0	0	0	0	0	N/A	N/A	0	0
1	0	0	0	0	0	0	0	0	N/A	N/A	0	0
2	0	0	0	0	0	0	0	0	N/A	N/A	0	0
3	0	0	0	1	3	0	0	0	N/A	N/A	0	0
4	4	0	0	1	15	5	7	0	N/A	N/A	0	0
5	22	2	1	7	20	13	13	1	N/A	N/A	0	4
6	9	0	2	4	5	15	17	0	N/A	N/A	1	0
7	2	0	0	3	3	5	9	0	N/A	N/A	0	1
8	0	0	0	0	0	1	0	0	N/A	N/A	0	0
9	0	0	0	0	0	0	0	0	N/A	N/A	0	0

Note: Average overall substructure Condition Rating = 5.3.
* N/A = Not applicable.

Table 159. Task G – Deck secondary element Condition Rating statistical information.

	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
Average	7.5	7.4	7.1	N/A*	7.4	7.0	N/A	7.4	7.4	6.9	7.0	7.0	7.3
Standard Deviation	0.59	0.55	0.55	N/A	0.53	N/A	N/A	0.57	0.57	1.09	0.91	N/A	0.88
COV	0.08	0.07	0.08	N/A	0.07	N/A	N/A	0.08	0.08	0.16	0.13	N/A	0.12
Minimum	6	6	6	N/A	7	7	N/A	6	6	3	5	7	5
Maximum	9	8	8	N/A	8	7	N/A	8	8	8	8	7	8
Mode	7	7	7	N/A	7	5	N/A	7	7	7	7	7	8
N	45	35	46	N/A	9	1	N/A	25	46	49	42	1	29

	Frequency												
Condition Rating	Wearing Surface	Deck-topside	Deck-underside	SIP Forms	Curbs	Medians	Sidewalks	Parapets	Railing	Expansion Joints	Drainage System	Lighting	Utilities
0	0	0	0	N/A	0	0	N/A	0	0	0	0	0	0
1	0	0	0	N/A	0	0	N/A	0	0	0	0	0	0
2	0	0	0	N/A	0	0	N/A	0	0	0	0	0	0
3	0	0	0	N/A	0	0	N/A	0	0	1	0	0	0
4	0	0	0	N/A	0	0	N/A	0	0	1	0	0	0
5	0	0	0	N/A	0	7	N/A	0	0	3	4	0	2
6	1	1	5	N/A	0	0	N/A	1	2	7	4	0	2
7	22	20	32	N/A	5	1	N/A	14	25	24	20	1	11
8	21	14	9	N/A	4	0	N/A	10	19	13	14	0	14
9	1	0	0	N/A	0	0	N/A	0	0	0	0	0	0

Note: Average overall deck Condition Rating = 7.1.
* N/A = Not applicable.

Table 160. Task G – Superstructure secondary element Condition Rating statistical information.

	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
Average	6.3	7.3	7.0	6.5	6.8	7.0	N/A*	6.1	5.8	7.0	6.9
Standard Deviation	1.15	0.58	0.47	0.53	0.66	N/A	N/A	0.82	1.00	0.74	0.99
COV	0.18	0.08	0.07	0.08	0.10	N/A	N/A	0.13	0.17	0.11	0.14
Minimum	5	7	6	6	5	7	N/A	4	4	5	4
Maximum	7	8	8	7	8	7	N/A	7	8	8	8
Mode	7	7	7	6	7	7	N/A	6	6	7	7
N	3	3	19	8	38	1	N/A	45	47	41	39

	Frequency										
Condition Rating	Stringers	Floor Beams	Floor System Bracing	Multibeams	Girders	Arches	Cables	Paint	Bearing Devices	Connections	Welds
0	0	0	0	0	0	0	N/A	0	0	0	0
1	0	0	0	0	0	0	N/A	0	0	0	0
2	0	0	0	0	0	0	N/A	0	0	0	0
3	0	0	0	0	0	0	N/A	0	0	0	0
4	0	0	0	0	0	0	N/A	1	4	0	2
5	1	0	0	0	2	0	N/A	10	14	1	0
6	0	0	2	4	7	0	N/A	18	20	8	9
7	2	2	15	4	26	1	N/A	16	6	22	17
8	0	1	2	0	3	0	N/A	0	3	10	11
9	0	0	0	0	0	0	N/A	0	0	0	0

Note: Average overall superstructure Condition Rating = 6.7.
* N/A = Not applicable.

Table 161. Task G – Substructure secondary element Condition Rating statistical information.

	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
Average	7.2	7.0	7.0	7.4	7.2	7.1	7.2	7.4	7.0	7.5	7.5	7.2
Standard Deviation	0.74	N/A*	1.00	0.67	0.66	0.62	0.75	0.62	0.00	0.71	0.59	0.64
COV	0.10	N/A	0.14	0.09	0.09	0.09	0.10	0.08	0.00	0.09	0.08	0.09
Minimum	5	7	6	6	6	6	5	6	7	7	6	6
Maximum	8	7	8	8	8	8	8	8	7	8	8	8
Mode	7	7	6,7,8	7	7	7	7	7	7	7,8	8	7
N	32	1	3	11	40	38	33	30	3	2	42	45

	Frequency											
Condition Rating	Abutments	Piles	Footing	Stem	Bearing Seat	Backwall	Wingwalls	Piers and Bents	Piles	Footing	Columns/Stem	Cap
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	1	0	0	0	0	0
6	3	0	1	1	5	5	3	2	0	0	2	5
7	17	1	1	5	21	23	16	14	3	1	18	25
8	11	0	1	5	14	10	13	14	0	1	22	15
9	0	0	0	0	0	0	0	0	0	0	0	0

Note: Average overall substructure Condition Rating = 7.2.
* N/A = Not applicable.

5.3. IN-DEPTH INSPECTION RESULTS

The following sections describe the results obtained from Tasks F and H. These tasks were In-Depth Inspections of portions of the below-deck superstructures of STAR Bridge B544 and the U.S. Route 1 Bridge over the Occoquan River, respectively. Detailed descriptions of these bridges and tasks were presented in Chapter 4. Data from these tasks were collected in the form of inspector field notes, inspector responses to questions, and firsthand observations of the inspector performing the inspections. The results for Task F are presented first. The discussion first focuses on the inspection process and the description of the known defects. The known defects are then compared to the inspector-reported defects. To conclude Task F, the factors found to correlate with the inspection results are presented. In a similar manner, the results obtained from Task H are then presented.

5.3.1. Description of In-Depth Inspection

The *Manual for Condition Evaluation of Bridges, 1994* defines "In-Depth Inspection" as follows:[3]

> "An In-Depth Inspection is a close-up, hands-on inspection of one or more members above or below the water level to identify any deficiency(ies) not readily detectable using Routine Inspection procedures. Traffic control and special equipment, such as under-bridge inspection equipment, staging and workboats, should be provided to obtain access, if needed. Personnel with special skills such as divers and riggers may be required. When appropriate or necessary to fully ascertain the existence of or the extent of any deficiency(ies), nondestructive field tests and/or other material tests may need to be performed.
>
> The inspection may include a load rating to assess the residual capacity of the member or members, depending on the extent of the deterioration or damage. Non-destructive load tests may be conducted to assist in determining a safe bridge load-carrying capacity.
>
> On small bridges, the In-Depth Inspection, if warranted, should include all critical elements of the structure. For large and complex structures, these inspections may be

> scheduled separately for defined segments of the bridge or for designated groups of elements, connections or details that can be efficiently addressed by the same or similar inspection techniques. If the latter option is chosen, each defined bridge segment and/or each designated group of elements, connections or details should be clearly identified as a matter of record and each should be assigned a frequency for re-inspection. To an even greater extent than is necessary for Initial and Routine Inspections, the activities, procedures and findings of In-Depth Inspections should be completely and carefully documented."

In general, the two In-Depth Inspection tasks were administered and completed according to this definition. In both cases, the tasks were clearly defined inspections of portions of a bridge superstructure that included the use of special access equipment.

5.3.2. Task F

Task F is the In-Depth Inspection of approximately one-fifth of the below-deck superstructure of Bridge B544, a decommissioned bridge at the STAR facility. The bridge and Task F are fully described in Chapter 4.

5.3.2.1. INSPECTION PROCESS

This section provides a general description of how the inspectors completed this task. The data for this discussion come from the pre-task questionnaire, firsthand observation of the inspectors performing the tasks, and the post-task questionnaire.

Forty-two inspectors completed this task. Seven inspectors did not complete this task due to either adverse weather conditions, lift malfunction, or refusal due to minor physical impairment. Inspectors were allowed 3 h to complete the In-Depth Inspection of the superstructure of approximately one-fifth of this bridge. The average time to complete this task was 75 min and the median time was 70 min. The standard deviation was 30 min, with a maximum time to completion of 156 min and a minimum of 29 min. The distribution of actual inspection times is shown in figure 125.

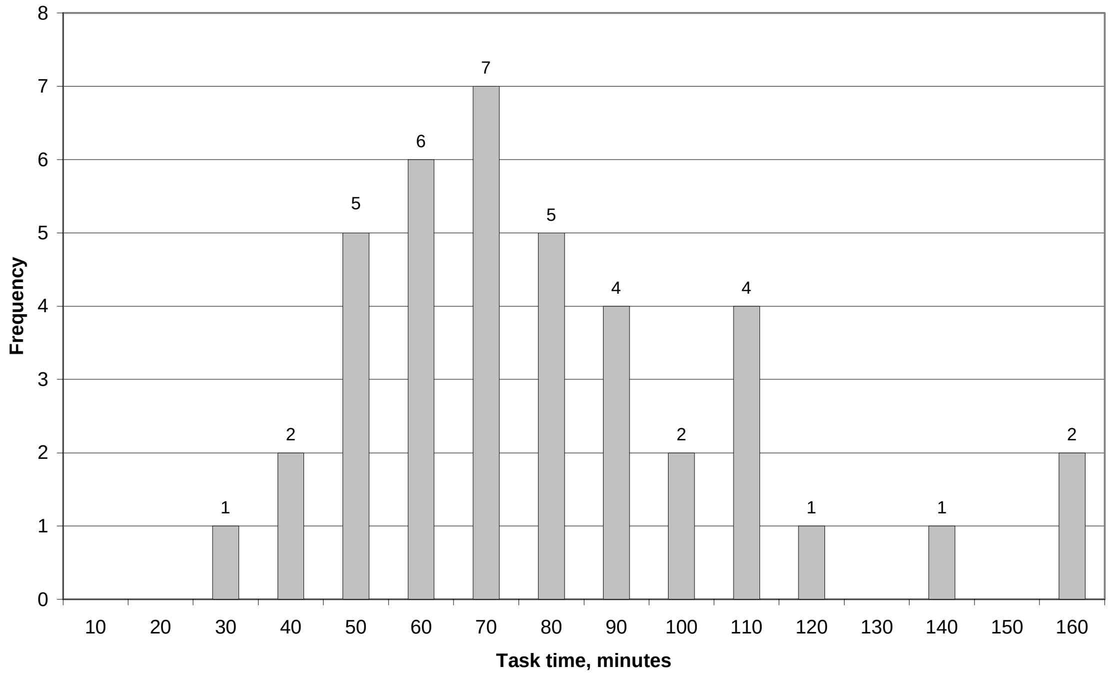


Figure 125. Task F – Actual inspection time.

Table 162 summarizes some of the questions asked in the pre-task questionnaire. These results show that, on average, it has been more than 8 months since an inspector performed an inspection similar to Task F. There was one inspector who had not performed an inspection similar to this one in more than 8 years and two inspectors who had never inspected a structure similar to this one. Figure 126 illustrates the distribution of predicted task times.

For this inspection, inspectors were provided with the full set of inspection tools, as well as a 12.2-m boom lift that could provide hands-on access to the structure. In order to assess what types of access equipment would normally be used for this type of an inspection, inspectors were asked to describe the equipment they would normally have used. Table 163 provides the results of this question. The inspectors' responses to this question indicate that 90 percent of the inspectors would have used a snooper or a lift to access the structure. Ten percent of the inspectors indicated that they would have either used only a ladder or no access equipment at all. This final group of inspectors would have had great difficulty accessing large portions of the bridge while performing a hands-on inspection.

Table 162. Task F – Quantitative pre-task questionnaire responses.

Question	Range of possible answers: Low	Range of possible answers: High	Inspector Response: Average	Inspector Response: Median	Inspector Response: Standard Deviation	Inspector Response: Maximum	Inspector Response: Minimum
How long has it been since you completed an In-Depth Inspection of a bridge of this type (in weeks)?	N/A*	N/A	38	21	82	440	1
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	77.1	60.0	41.7	200	30
How rested are you?	1 = very tired	9 = very rested	6.9	7	1.2	9	4

* N/A = Not applicable.

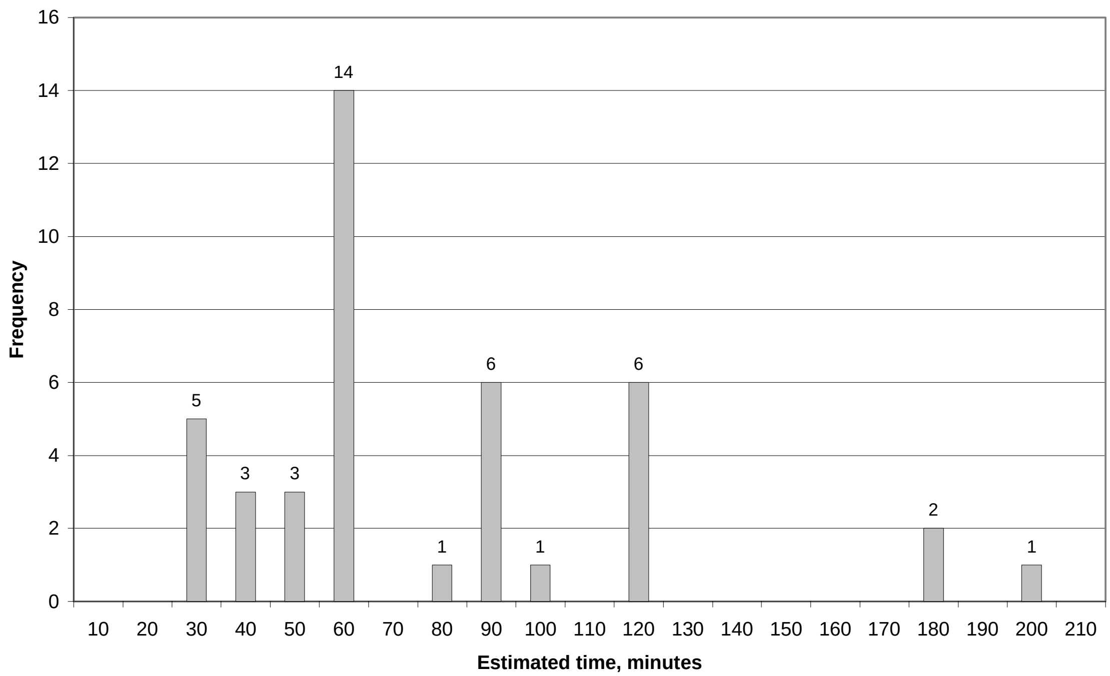


Figure 126. Task F – Predicted inspection time.

Table 163. Task F – Normal access equipment use.

Equipment	Percentage of Respondents
Snooper	55%
Lift	50%
Ladder	21%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	2%
None	2%
Other	0%
Snooper and/or Lift	90%

Within the pre-task questionnaire, the inspectors were asked to describe the type of construction used on this bridge. The results from this question are presented in table 164. Note that these results are very similar to the results that were presented for this question for Task E. The minor differences are due to seven inspectors who completed Task E, but did not perform Task F, thus leading to a different inspector sample between the two tasks. It is important to note that only 10 percent of the inspectors indicated that the bridge is skewed. In a bridge of this type, skew can lead to out-of-plane distortions and particular types of defects that are only likely to occur if the bridge is skewed. This knowledge may have significant implications on the focus of the inspection, and could lead to less accurate inspection results.

Table 164. Task F – Description of type of construction used.

Bridge Characteristic	Percentage of Respondents
Steel Plate Girder	88%
Riveted	79%
Cast-in-Place (CIP) Concrete Slab	62%
Simply Supported	36%
Floor Beams/Sway Frames	33%
Skewed	10%
Asphalt Overlay	7%
Other	19%

To further assess how inspectors were formulating their approach to the inspection, inspectors were asked to identify problems that they might expect to find on a bridge of a similar type, condition, and age. These responses are summarized in table 165. These results show that inspectors expect relatively few types of problems to exist. Of this list of possible deficiencies, steel corrosion and concrete deterioration were mentioned by approximately three-quarters of the inspectors, while no other defects were cited by more that 40 percent.

Table 165. Task F – Problems expected.

Problem Type	Percentage of Respondents
Steel Corrosion	79%
Concrete Deterioration	69%
Cracked Asphalt	36%
Paint Deterioration	31%
Tack Weld Cracks	24%
Leakage	24%
Leaching	21%
Underside Deck Cracking	21%
Missing Rivets	19%
Inadequate Concrete Cover	17%
Impact Damage	5%
Settlement Cracking of Abutments	5%
Other	14%

As previously mentioned, while the inspector was completing the inspection, the observer recorded environmental conditions, recorded how the inspection was completed, noted what inspection tools were used, and operated the lift. Tables 166 and 167 provide a summary of the environmental conditions that were encountered during this task. As the tables reiterate, this task was performed under normal summer weather conditions. Note that these environmental measurements were gathered at an elevated position just under the southwest quadrant of the bridge.

Table 168 summarizes the portions of the inspection task performed by the inspectors. Specifically, this table lists many of the general components that exist in the bridge and shows the number of inspectors who performed at least a partial inspection of that component. This table is divided into two parts, the first section reporting the items that were inspected in the southwest quadrant of the bridge (referred to as a "lift inspection") and the second section reporting what items were inspected in the northeast quadrant (referred to as a "ladder inspection"). Based on this table, it is clear that some inspectors left this inspection task partially incomplete. For example, although approximately 80 percent of the inspectors inspected the bearings, only about 50 percent of the inspectors inspected behind the end diaphragms.

Table 166. Task F – Direct environmental measurements.

Environmental Measurement	Average	Median	Standard Deviation	Maximum	Minimum
Temperature (°C)	21.7	22.8	5.5	30.0	10.6
Humidity (%)	63.3	64	14.7	96	38
Heat Index (°C)	22	23	5.8	32	11
Wind Speed (km/h)	1.4	0	2.5	11.3	0
Light Intensity (lux)	216	62	330	1390	2

Table 167. Task F – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	40%
20 – 40% Cloudy	7%
40 – 60% Cloudy	5%
60 – 80% Cloudy	10%
80 – 100% Cloudy	17%
Hazy	2%
Fog	0%
Drizzle	10%
Steady Rain	7%
Thunderstorm	0%

Inspector tool use is presented in table 169. This table shows that only 48 percent of the inspectors used a flashlight, even though the light level under the bridge was relatively low as reported in table 166. Also, fewer than half of the inspectors performed any sounding during this task as evidenced by the low usage rate of the sounding tools.

The observers made a number of observations regarding inspector behavior during this task. These results are presented in table 170. Note that, on average, very few of the inspectors seemed rushed while completing the task and most inspectors seemed relatively comfortable with the lift.

After completion of the task, the inspectors were again asked a series of questions. These questions were typically related to the inspector's impression of the inspection they just completed and to their general physical and mental condition. In all, 15 questions were asked, with the results presented in table 171.

Table 168. Task F – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
Lift Inspection	Outer Bearing	88%
	Middle Bearing	86%
	Inner Bearing	86%
	Fascia Girder	83%
	Middle Girder	88%
	Inner Girder	86%
	End Diaphragm Connections	60%
	Intermediate Diaphragm – Web Connections	79%
	Sway Frame – Web Connections	79%
	Bottom Flange Rivets	50%
	Behind End Diaphragm	48%
Ladder Inspection	Outer Bearing	83%
	Middle Bearing	76%
	Inner Bearing	79%
	Fascia Girder	71%
	Middle Girder	67%
	Inner Girder	67%
	End Diaphragm Connections	62%
	Intermediate Diaphragm – Web Connections	21%
	Sway Frame – Web Connections	31%
	Bottom Flange Rivets	31%
	Behind End Diaphragm	55%

Table 169. Task F – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	36%
2.4-m Stepladder	0%
9.75-m Extension Ladder	79%
Any Flashlight	48%
Two AA-Cell Flashlight	12%
Three D-Cell Flashlight	21%
Lantern Flashlight	19%
Any Sounding Tool	38%
Masonry Hammer	38%
Chain	0%
Level as a Level	5%
Level as a Straightedge	5%
Binoculars	0%
Magnifying Glass	5%
Engineering Scale	7%
Protractor	7%
Plumb Bob	2%
String	0%
Hand Clamp	0%

Table 170. Task F – Summary of quantitative observations.

Question	Range of possible answers		Observer Assessment				
	Low	High	Average	Median	Standard Deviation	Maximum	Minimum
Was the inspector focused on the task?	1 = very unfocused	9 = very focused	6.6	7	1.7	9	3
Did the inspector seem rushed?	1 = not rushed	9 = very rushed	2.6	2	1.7	7	1
How comfortable was the inspector with the working height?	1 = very uncomfortable	9 = very comfortable	7.9	9	1.5	9	3
How comfortable was the inspector with the lift?	1 = very uncomfortable	9 = very comfortable	7.7	9	1.9	9	1
What was the quality of lift operation?	1 = very poor	5 = very good	3.5	3	0.8	5	2

Table 171. Task F – Qualitative post-task questionnaire responses.

Question	Range of possible answers		Inspector Response				
	Low	High	Average	Median	Standard Deviation	Maximum	Minimum
How similar was this task to the tasks performed in your normal In-Depth Inspections?	1 = not similar	9 = very similar	7.3	7.5	1.7	9	3
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.3	7	1.6	9	4
How rested are you?	1 = very tired	9 = very rested	6.4	6.5	1.5	9	2
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.4	9	.8	9	6
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	8.1	8	1.0	9	5
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	4.4	4	1.8	7	1
How complex was this bridge?	1 = very simple	9 = very complex	4.9	5	1.8	8	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	2.7	2	2.1	7	1
Do you feel that the working height influenced your performance?	1 = no influence	9 = great influence	1.5	1	1.0	6	1
How adequate do you feel the light level was?	1 = very inadequate	9 = very adequate	7.3	8	1.3	9	4
On average, how close do you think you got to the welds you were inspecting (in meters)?*	N/A**	N/A	0.52	0.61	0.33	1.52	0.25
Do you feel you were able to get the proper viewing angle for the components you were inspecting?	1 = never	9 = always	7.8	8	0.9	9	6
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	2.5	1	2.1	7	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.2	5	1.1	9	3
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	5.2	5	0.8	7	3

* Inspector responses were originally given in English units and have since been converted into metric.
** N/A = Not applicable.

5.3.2.2. COMPARISON OF KNOWN AND INSPECTOR-REPORTED DEFICIENCIES

Many reportable defect indications exist within the portion of STAR Bridge B544 that was inspected in Task F. Inspectors performing this task were asked to note any defects that they found during their inspection. These defect indications (hereafter referred to as defects) can be categorized into two main types: global and local. The following section will discuss the known defects as compared to the defects that were reported by the inspectors.

5.3.2.2.1. Global Defects

The "Global Defect" category encompasses deficiencies in the bridge that pertain to general sections of the bridge, not to specific locations. This type of defect includes paint system failure, moderate to severe corrosion of girders and secondary members, rivet section loss, and efflorescence. These four defects are present throughout Bridge B544.

The paint system failure is prevalent throughout the test specimen. This type of defect includes locations where the paint has failed, probably due to poor bonding between the paint and the steel surface at locations of severe corrosion. Figure 127 is indicative of the extent of this deficiency. All 42 inspectors who performed this task indicated that there was some level of paint system failure.

Figure 127. Paint system failure and moderate to severe corrosion.

The moderate to severe corrosion of girders and secondary members also occurs at numerous locations throughout the test specimen. This deficiency includes corrosion ranging from minor corrosion over a large area to severe corrosion that has caused measurable section loss. Figure 127 also illustrates a portion of this global defect. Ninety-eight percent of the inspectors who performed this task noted corrosion problems.

Extensive corrosion of rivets and rivet heads can lead to fastener section loss and eventually a decrease in member capacity. This deficiency is present at various locations throughout the bridge. Figure 128 illustrates an example of this deficiency. Forty-five percent of the inspectors who performed this task noted the severe rivet head corrosion.

Figure 128. Severe corrosion of rivet heads.

Finally, efflorescence, due primarily to deck-related deterioration, has crystallized on the superstructure in many locations. Sixty-nine percent of the inspectors noted this effloresence, represented in figure 129.

Figure 129. Typical efflorescence.

5.3.2.2.2. Local Defects

Local defects are deficiencies that occur at discrete locations within the structure. These types of problems include a crack indication at a tack weld, localized member distortion due to impact, a missing rivet head, and bearings displaying abnormal rotations. Note that the tack weld crack indication and the missing rivet head were defects implanted by the NDEVC.

Tack welds exist at a number of locations in this bridge. This type of weld results in a fatigue-sensitive detail. A crack indication was implanted at the root of one of these welds. The schematic drawing shown in figure 130 indicates the location of this defect, while figure 131 shows this defect. The crack indication was identified by 3 of the 42 inspectors (7 percent) who performed this task.

A rivet head was removed to simulate another common deficiency. The location of this defect is indicated in figure 130 and the defect can be seen in figure 132. Two of the inspectors (5 percent) identified the missing rivet head.

There are two locations on the bridge that have impact damage. The first, a localized flange distortion, is located on a sway frame just inside the northern girder near the west abutment.

This defect probably occurred during erection of the superstructure. Figure 130 denotes the location of this defect. Two inspectors (5 percent) noted this impact damage. Impact damage is also present on the bottom flange of the southern girder, as indicated in figure 130. Scrapes are present on the bottom flange, indicating that an overheight vehicle may have damaged the girder. Six of the inspectors (14 percent) noted the impact damage on this girder. In total, seven different inspectors (17 percent) noted impact damage to this bridge.

The rocker bearings on the eastern abutment of the southern half of this bridge display an abnormal setting given the thermal conditions surrounding the bridge. First, the three bearings exhibit overly expanded positions. Also, the southern bearing has rotated more than the other two, indicating a possible planar rotation of the bridge. Figure 133 shows one of the rocker bearings when the air temperature is approximately 24 °C. Twenty-one of the inspectors (50 percent) noted this bearing abnormality.

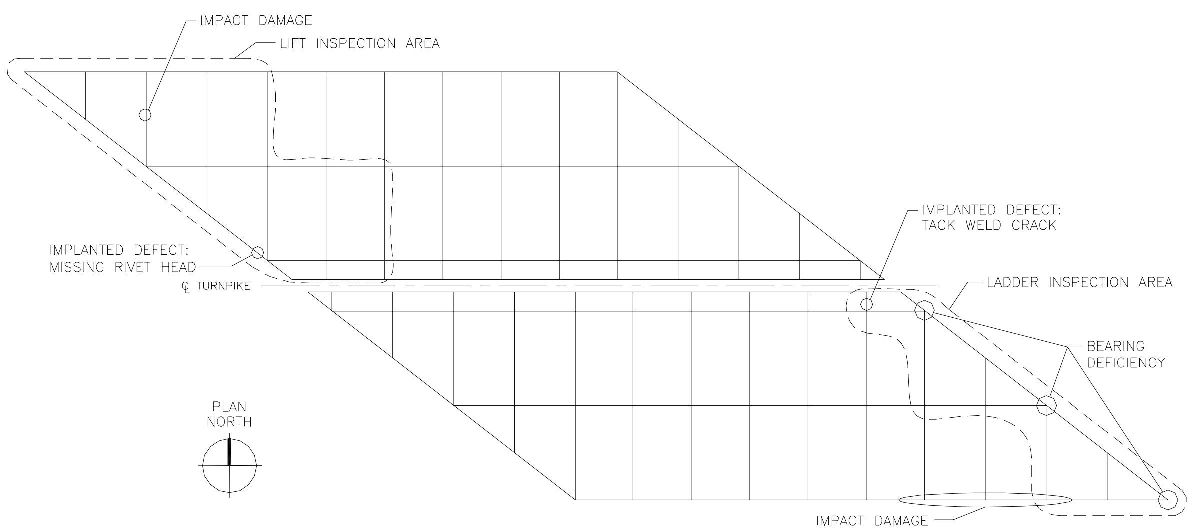
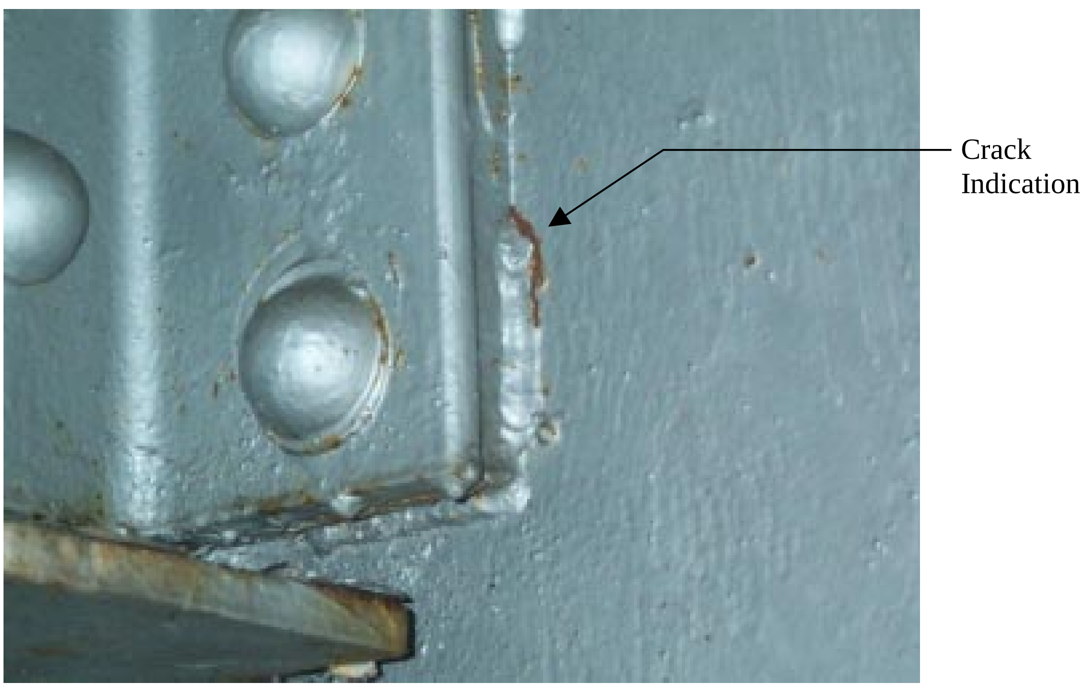


Figure 130. Schematic of the locations of local defects.

a. General location of implanted defect.



b. Close-up of defect.

Figure 131. Crack indication at the root of a tack weld.

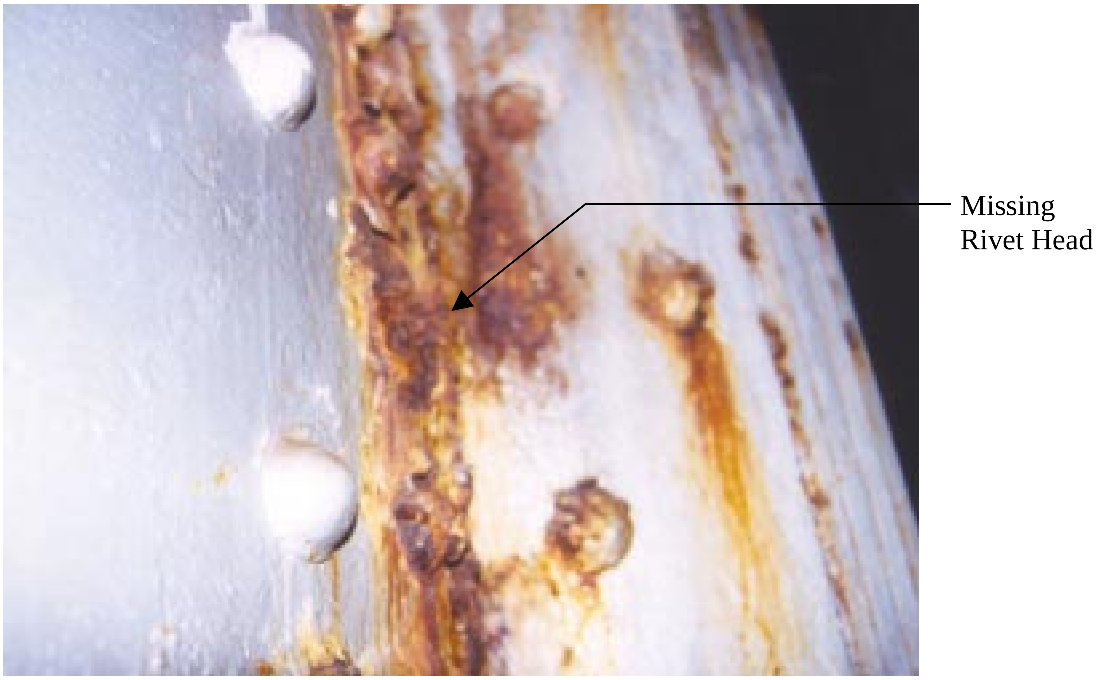


Figure 132. Missing rivet head defect.

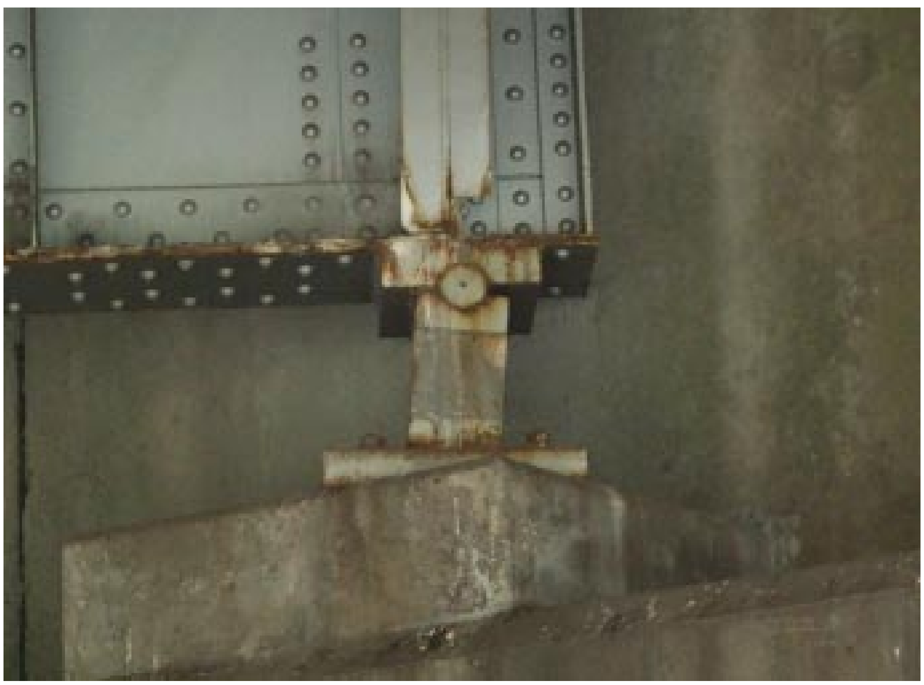


Figure 133. Rocker bearing rotation.

5.3.2.3. FACTORS INFLUENCING INSPECTION

A number of factors may affect an inspector's ability to correctly locate a deficiency during an inspection. The following discusses some of these factors with regard to the inspectors and defects studied in Task F. Note that only a portion of the overall set of factors that could affect the inspection results are discussed. In general, these are the factors found to correlate well with the inspection findings. A few additional factors that do not correlate strongly are also discussed. These factors are either commonly perceived to be important to bridge inspection or are factors that provided strong correlation with Task H and are therefore presented here for comparison. In total, approximately 20 of the factors are discussed. The remaining factors not discussed here were found to provide little correlation with the inspection results.

For the purpose of this discussion, the inspectors who correctly identified the previously mentioned defects are grouped into four subsets: inspectors who identified the rivet corrosion defect, the bearing rotation defect, either implanted defect, or either impact damage defect. Note that individual inspectors may be included in more than one of these subsets. A fifth subset, the subset of inspectors who indicated there were no deficiencies in the bridge other than coating or general corrosion defects, is also discussed. The paint and efflorescence defects are not discussed here as they were noted by most inspectors. Finally, the subset of all inspectors that completed the task is also presented. Also note, Task E, a Routine Inspection of the same bridge, was always completed prior to Task F. The inspector notes for both Tasks E and F were used to determine which defects the inspector reported.

The following results are presented in terms of a comparison between the mean values of the various factors for the subsets of the inspectors. The t-test was used to determine whether the particular inspector subset could be considered to be significantly different from the remainder of the inspectors who did not fit the criteria for inclusion in the subset. To reiterate, the t-test was not used to compare the inspector subsets to the overall inspector sample, but to the set of inspectors who did not fit the criteria for the subset. This is due to the t-test providing information regarding whether a set of data can or cannot be considered to be the same as another set of data. Using the t-test to compare the subset to the overall sample would weaken the results because, clearly, the subset does originate from the overall set. The t-test results for the 5 and 10 percent significance levels are presented in the tables that accompany most of the factor discussions.

5.3.2.3.1. Time

The amount of time an inspector is allotted in order to perform an inspection will probably affect the results of the inspection. A rushed inspector may provide a more focused inspection, but may also miss some deficiencies due to lack of time. In addition, if the time limit is sufficiently long, inspectors may spend more time than normal searching for defects. Finally, if an inspector begins to find defects, he may spend more time looking for these particular types of defects, extending the time spent on the inspection.

Table 172 presents the "Actual Time to Complete Task" information for the subsets of inspectors studied. The one notable tendency is for inspectors who correctly identified defects to spend longer than average on the inspection, with times ranging from 75 to 84 min for the subsets of inspectors who found defects. Note, however, that these results should only be viewed as general trends since most of the subsets do not pass the t-test.

Table 172. Task F – Actual Time to Complete Task (in minutes).

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	75	29	N/A*	N/A
Rivet Corrosion Defect	84	35	Yes	Yes
Implanted Defect	81	19	No	No
Bearing Defect	75	29	No	No
Impact Damage	79	33	No	No
No Deficiencies	68	22	No	No

* N/A = Not applicable.

Tables 173 and 174 present the results with regard to Observed Inspector Rushed Level and Reported Rushed Level. In general, these tables show that inspectors who noted defects tended to both act and report feeling slightly more hurried than the overall average of the sample. In addition, inspectors who did not note any of the deficiencies discussed here both reported being and were observed to act less hurried than average. Again, note that these are solely general trends because much of the data did not pass the t-test at either the 5 or 10 percent significance levels.

Table 173. Task F – Observed Inspector Rushed Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	2.6	1.7	N/A*	N/A
Rivet Corrosion Defect	3.1	1.8	No	Yes
Implanted Defect	3.0	1.4	No	No
Bearing Defect	2.5	1.9	No	No
Impact Damage	3.6	1.9	Yes	Yes
No Deficiencies	1.7	0.7	No	Yes

* N/A = Not applicable.

Table 174. Task F – Reported Rushed Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	2.5	2.1	N/A*	N/A
Rivet Corrosion Defect	3.2	2.6	Yes	Yes
Implanted Defect	4.0	2.9	No	Yes
Bearing Defect	2.6	2.2	No	No
Impact Damage	3.0	2.2	No	No
No Deficiencies	1.9	1.6	Yes	Yes

* N/A = Not applicable.

5.3.2.3.2. Comfort Level During Inspection

Portions of Task F were completed at low to moderate heights. For this reason, a number of factors related to the inspector's comfort level during the inspection were studied. These included Fear of Heights, Observed Comfort With Heights, and Observed Comfort With Lift. The inspectors tended to be very comfortable with the heights and the lift. With regard to the inspector's comfort level during the inspection, no correlations are evident between any of the data collected and the various subsets of inspectors. This is probably due to the maximum height of this inspection being only 9 m, with the majority of the inspection performed at even lower heights.

5.3.2.3.3. Mental Focus

Inspector mental focus may affect inspection results. This factor was quantified twice, once in the SRQ as "General Mental Focus" and once by the observer during the task as "Observed Inspector Focus Level". None of the inspector subsets studied for either of these factors pass the t-test at the 10 percent significance level, thus the data will only be discussed in general terms. With regard to General Mental Focus, the inspector subsets who identified the rivet corrosion defect, the implanted defects, or the impact defects tend to have reported a slightly above average mental focus on the SRQ. Inspectors who noted the bearing defect reported a value consistent with the average and inspectors who did not note any deficiencies aside from the coating and corrosion defects reported a mental focus level slightly below average. The Reported Inspector Focus Level values do not necessarily follow the same trend, with some subsets of inspectors who noted deficiencies being above and some being below the overall average. The subset of inspectors who did not note any deficiencies received an Observed Inspector Focus Level average score of slightly above the overall average.

5.3.2.3.4. Inspector-Reported Thoroughness and Effort Level

Inspectors did not necessarily perform the inspection in Task F in the same way that they would normally perform a similar inspection during their normal duties as a bridge inspector. For this reason, the inspectors were asked to rate their thoroughness and effort level compared to their normal effort level. The majority of inspectors reported that they performed this task to the same degree of thoroughness as they would perform a similar task during their normal duties as a bridge inspector. The overall average inspector-reported thoroughness level was 5.2 on a scale of 1 to 9. All five subsets of inspectors had reported thoroughness level averages between 5.0 and 5.6. The majority of the inspectors also indicated that their effort level was the same as their normal effort level. Again, the overall average effort level was 5.2 on a 1 to 9 scale. Except for the inspectors who located an implanted defect (average of 6.3), the other four subsets of inspectors provided an average effort level of between 4.4 and 5.6.

5.3.2.3.5. Reported Bridge Description and Expected Bridge Defects

Prior to Task E, inspectors were asked to both provide a description of the construction of the bridge and to state any defects that they would expect to encounter on a similar bridge. The overall findings from this question were presented previously in this chapter. No specific correlations between inspector subsets and inspector descriptions resulted from these questions. With regard to expected defects, two deficiency types were of interest. First, overall, only 5 percent of the inspectors expected any sort of impact damage and none of the inspectors who noted impact damage stated, prior to the task, that they expected it. Second, while only 24 percent of the inspectors mentioned the possibility of weld crack indications, 50 percent of the inspectors who noted at least one of the implanted deficiencies had mentioned this possible problem. However, in neither case do the results pass the t-test with 10 percent significance.

5.3.2.3.6. Reported Structure Complexity, Accessibility, and Maintenance Levels

The complexity of the bridge, as reported by the inspector, may have an effect on the way the inspector performs the inspection and also on the results of the inspection. The inspector subset ratings of the complexity of the bridge are presented in table 175. Overall, the average bridge complexity rating was 4.7 on a scale of 1 to 9. Inspector subsets for most defects provided an average rating of near, or slightly above, the overall average; however, the inspectors who noted the implanted defects provided an average response of 7.0. Inspectors who noted no defects aside from the general coating and corrosion problems provided an average complexity response of 4.2. Although this value did not pass the t-test, the general trend still indicates that inspectors who felt that the bridge was less complex correlated with the location of fewer defects. The converse also seems to be true.

The Reported Structure Accessibility Level is a factor quite similar to Reported Structure Complexity Level. It is likely that the ease of access to the areas of the bridge to be inspected may affect the methods an inspector uses to perform the inspection. Overall, the average reported bridge accessibility response was 8.1 (i.e., very accessible). All inspector subsets provided average ratings between 8.0 and 8.3, thus no direct correlations are evident.

Table 175. Task F – Reported Structure Complexity Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	4.7	1.9	N/A*	N/A
Rivet Corrosion Defect	5.1	2.0	No	No
Implanted Defect	7.0	0.8	Yes	Yes
Bearing Defect	4.7	1.8	No	No
Impact Damage	4.7	1.3	No	No
No Deficiencies	4.2	1.6	No	No

* N/A = Not applicable.

The Reported Structure Maintenance Level may distort the inspector's perception of the bridge, changing the way he performs his inspection. The average inspector subset responses are presented in table 176. Inspector subsets who noted rivet corrosion and impact damage rated the maintenance level a 3.9 and inspectors who noted no deficiencies rated it a 4.0. Inspectors who identified the bearing defect and the implanted defect rated the maintenance level a 4.9 and a 5.5, respectively. Thus, inspectors who felt that the bridge was better maintained tended to correlate well with the identification of a larger number of specific defects.

Table 176. Task F – Reported Structure Maintenance Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	4.4	1.8	N/A*	N/A
Rivet Corrosion Defect	3.9	2.0	No	Yes
Implanted Defect	5.5	1.9	No	Yes
Bearing Defect	4.9	1.8	Yes	Yes
Impact Damage	3.9	1.5	No	No
No Deficiencies	4.0	1.6	No	No

* N/A = Not applicable.

5.3.2.3.7. Tool Use

The tools that an inspector uses to perform an inspection are indicative of the type of deficiencies that the inspector is looking for and, possibly, the types of defects that the inspector will find. Of the tools provided to the inspector, the flashlight and the extension ladder stand out as two tools that may aid in the identification of defects. The results for flashlight use are presented in table 177. Overall, 48 percent of the inspectors used a flashlight during this task, while the usage rate was 75 percent for the inspectors who identified either of the implanted defects and 71 percent for the inspectors who identified an impact damage defect. Only 22 percent of the inspectors who indicated that there were no deficiencies other than corrosion and coating failure used a flashlight. With regard to the ladder, some of the defects present in the bridge are extremely difficult to identify without the use of a ladder. Overall, 79 percent of the inspectors used this tool, while 100 percent of those identifying an implanted defect used it. Although this does not necessarily indicate that the use of tools aids in the identification of defects, this does show that some particular methods used by inspectors may have an effect on the results of the inspection.

Table 177. Task F – Tool Use: Flashlight.

Inspector Subset	Average
Overall Sample	48%
Rivet Corrosion Defect	47%
Implanted Defect	75%
Bearing Defect	48%
Impact Damage	71%
No Deficiencies	22%

5.3.2.3.8. Inspector Age and Experience in Bridge Inspection

The overall average inspector age was 40. All of the inspector subsets had average ages between 39 and 41, except for the set of inspectors who noted no deficiencies beyond the general corrosion and coating defects. These inspectors had an average age of 43. The results with regard to inspection experience are presented in table 178. Inspectors who noted impact damage, bearing rotation, or implanted defects averaged between 7.4 and 8.8 years of experience in bridge inspection. The inspectors who did not note any specific defects averaged 11.9 years of experience. These results indicate that the more experienced inspectors may report fewer defects.

Table 178. Task F – Experience in Bridge Inspection (in years).

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	9.2	6.2	N/A*	N/A
Rivet Corrosion Defect	10.5	5.2	No	No
Implanted Defect	7.4	3.1	No	No
Bearing Defect	8.8	5.1	No	No
Impact Damage	8.4	4.7	No	No
No Deficiencies	11.9	9.0	No	No

* N/A = Not applicable.

5.3.2.3.9. General Education Level and Formal Bridge Inspection Training

The education level and formal training of inspectors are both factors that may affect the work an inspector performs. For this task, the General Education Level of the inspector does not seem to correlate with any set of inspection results. However, the results from the overall formal bridge inspection training courses completed do correlate with some subsets of inspectors. These results are presented in table 179. They indicate that inspectors who have completed more formal training courses tend to correlate well with the correct location of more defects. Correspondingly, inspectors who noted no defects outside of the coating and corrosion defects tended to have completed fewer formal training courses. Thus, inspector training may influence the types of defects that are located.

Table 179. Task F – Formal bridge inspection training courses completed.

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	3.3	1.7	N/A*	N/A
Rivet Corrosion Defect	4.0	1.5	Yes	Yes
Implanted Defect	3.5	2.4	No	No
Bearing Defect	3.7	1.6	No	Yes
Impact Damage	3.0	1.9	No	No
No Deficiencies	2.3	1.3	Yes	Yes

* N/A = Not applicable.

5.3.2.3.10. Professional Engineer License

Following the study, inspectors were contacted to determine whether they held a Professional Engineer (PE) license. Table 180 provides the corresponding results in terms of the subsets of inspectors defined for this task. These results show no clear correlation between this factor and the inspection results. However, the small size of the sample, along with the small size of most of the inspector subsets, makes interpreting these results difficult.

Table 180. Task F – Inspectors holding a PE license.

Inspector Subset	Average
Overall Sample	17%
Rivet Corrosion Defect	11%
Implanted Defect	0%
Bearing Defect	10%
Impact Damage	14%
No Deficiencies	33%

5.3.2.3.11. Management Inspection Philosophy and Control Over Inspection Process

The SRQ contained a question regarding whether the management philosophy of the inspector's State focused more on locating all defects in the bridge or on complying with the NBIS regulations (SRQ24). Overall, 30 percent of the inspectors reported that their State focused on complying with the NBIS regulations, while the remainder focused on finding all of the defects. Similar percentages held for most of the other subsets of inspectors. The exceptions are the inspectors who found an implanted deficiency or noted impact damage — 86 and 100 percent, respectively, reported that their State focused on finding defects.

The SRQ also asked inspectors to report the level of control that management typically exercised over their inspections. Overall, 29 percent of the inspectors stated that they were provided with a detailed checklist for their inspections, 29 percent were provided with loose guidelines, and 43 percent were allowed to inspect according to their own inspection knowledge and techniques. Except for the subset of inspectors who identified implanted defects, these percentages approximately stayed the same across the various subsets of inspectors. However, 75 percent of the inspectors who noted implanted defects reported that their supervisors provide a detailed checklist.

These results indicate that States that focus on finding defects may, in fact, locate more of the defects that occur in their bridge population. In addition, it is possible that management's role in how the inspection is performed may affect the inspection results.

5.3.2.3.12. Vision

The near and far visual acuity of each inspector was quantified, with the overall data presented previously. With regard to this task, the inspector visual acuity did tend to correlate with one subset of inspectors. Specifically, the inspectors who noted implanted defects tended to have exceptional visual acuity, with the worst eye of one inspector having a visual acuity of 20/25. The inspectors who are grouped into the other subsets tended to have visual acuities that fell within the overall visual acuity of the sample. The correlation between visual acuity and the inspectors who found implanted defects may indicate that these types of defects are more likely to be located by inspectors who possess better eyesight. Note, however, that these results were not tested with the t-test due to difficulties in implementing the t-test with this data set.

5.3.2.3.13. Inspector-Rated Importance of Bridge Inspection

In the SRQ, inspectors were asked to rate both the importance of bridge inspections to public safety and their general feelings on the importance of bridge inspections. Overall, the responses to these two questions showed that most inspectors feel that bridge inspections are very important, with average ratings of 4.6 (standard deviation of 0.5) and 4.5 (standard deviation of 0.9), respectively, on scales of 1 to 5. However, one specific subset of inspectors, those inspectors who located an implanted defect, provided an average rating of 5.0 (standard deviation of 0.0) to both questions. The strong feelings that these inspectors have toward the importance of their work may tend to encourage them to conduct a more thorough inspection than average.

5.2.3.2.14. Environmental Factors

The environmental factors did not have any discernible impact on the findings of this inspection. Granted, factors such as these could adversely affect an inspection; however, the results obtained in this study provided no specific data to support this supposition.

5.3.3. Task H

Task H is an In-Depth Inspection of a portion of the superstructure of the Route 1 Bridge. The bridge and Task H are both fully described in Chapter 4. The results from this task are presented in a manner similar to that used for Task F. First, information regarding the inspection process is provided. Following this, the known and reported defects are described, along with the accuracy results regarding the detection of these defects. Finally, the factors that tend to correlate with the inspection results are presented.

5.3.3.1. INSPECTION PROCESS

This section provides a general description of how the inspectors completed this task. The data for this discussion come from the pre-task questionnaire, firsthand observation of the inspectors performing the tasks, and the post-task questionnaire.

Forty-four inspectors completed this task. The reasons five inspectors did not complete this task included refusal due to fear of heights, lift unavailability, and unavailability of required safety equipment. In addition, 2 of the 44 inspectors only partially completed the task. This was due to a lift malfunction. The fact that these inspectors only partially completed the task has been accounted for in their results.

Inspectors were allowed 2 h to complete the In-Depth Inspection of one bay of one span of the superstructure of this bridge. The average time to complete this task was 64 min, with the median time being 60 min. The standard deviation was 28 min, with a maximum time to completion of 115 min and a minimum time of 6 min. Also note that some minor additional variability is included in these times due to the lift equipment and its operation by two different observers. Figure 134 illustrates the distribution of the inspection times.

Table 181 summarizes some of the questions asked in the pre-task questionnaire. These results show that, on average, it had been more than 7 months since an inspector performed an inspection similar to Task H; however, there were two inspectors who had not performed an inspection similar to this in more than 5 years. Also, the inspection at heights question demonstrates that, on average, the inspectors perform 28 inspections per year at heights of greater than 12.2 m (40 ft). Some inspectors perform very few of these types of inspections, including two inspectors who, on average, do not perform any inspections above this height. Figure 135 illustrates the distribution of predicted inspection times.

For this inspection, inspectors were provided with the full set of inspection tools, as well as an 18.3-m boom lift that could provide hands-on access to the structure. In order to assess what types of access equipment would normally be used for this type of an inspection, inspectors were asked what type of equipment they would normally use to access the structure. Ninety-six percent of the inspectors stated that they would use a snooper to access the structure. Other responses included a lift (2 percent), permanent inspection platform (4 percent), and movable platform (2 percent). Finally, one inspector said that he would not normally use any access equipment to access this bridge. During his subsequent inspection, he declined the use of the lift and performed the task using binoculars.

In the pre-task questionnaire, the inspectors were asked to describe the type of construction used on this bridge. The results from this question are presented in table 182. Note that these results are the same as were presented for this question in Task G due to the question being bridge-specific. The table shows that only 52 percent of the inspectors indicated that the bridge is continuous. Although this should not be construed to mean that only half of the inspectors were able to make this distinction, it is true that only about half thought to mention it during the pre-task questionnaire. This knowledge can have great bearing on the focus of portions of the inspection. Clearly, if an inspector was unable to recognize this fact, less accurate inspection results could be produced.

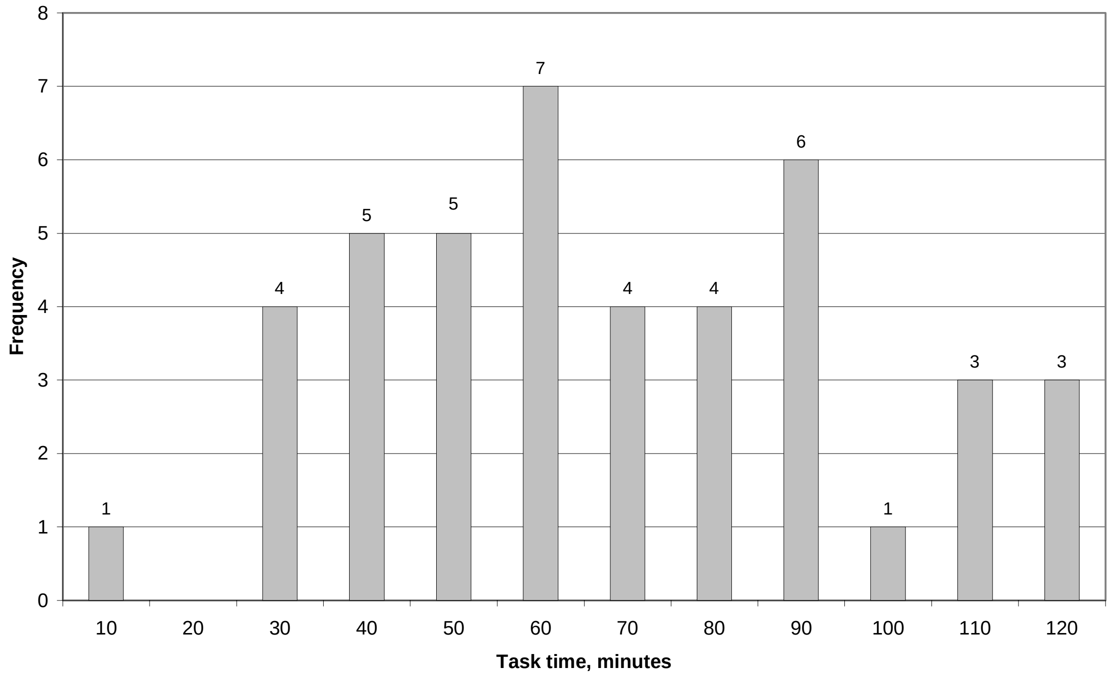


Figure 134. Task H – Actual inspection time.

Table 181. Task H – Qualitative pre-task questionnaire responses.

Question	Range of possible answers		Inspector Response				
	Low	High	Average	Median	Standard Deviation	Maximum	Minimum
How long has it been since you completed an In-Depth Inspection of a bridge of this type (in weeks)?	N/A*	N/A	34.3	16.0	58.5	300	1
How often per year do you perform inspections at heights above 40 feet?	N/A	N/A	28.3	20	31.6	150	0
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	67.8	60.0	37.6	180	5
How rested are you?	1 = very tired	9 = very rested	7.0	7	1.4	9	3

* N/A = Not applicable.

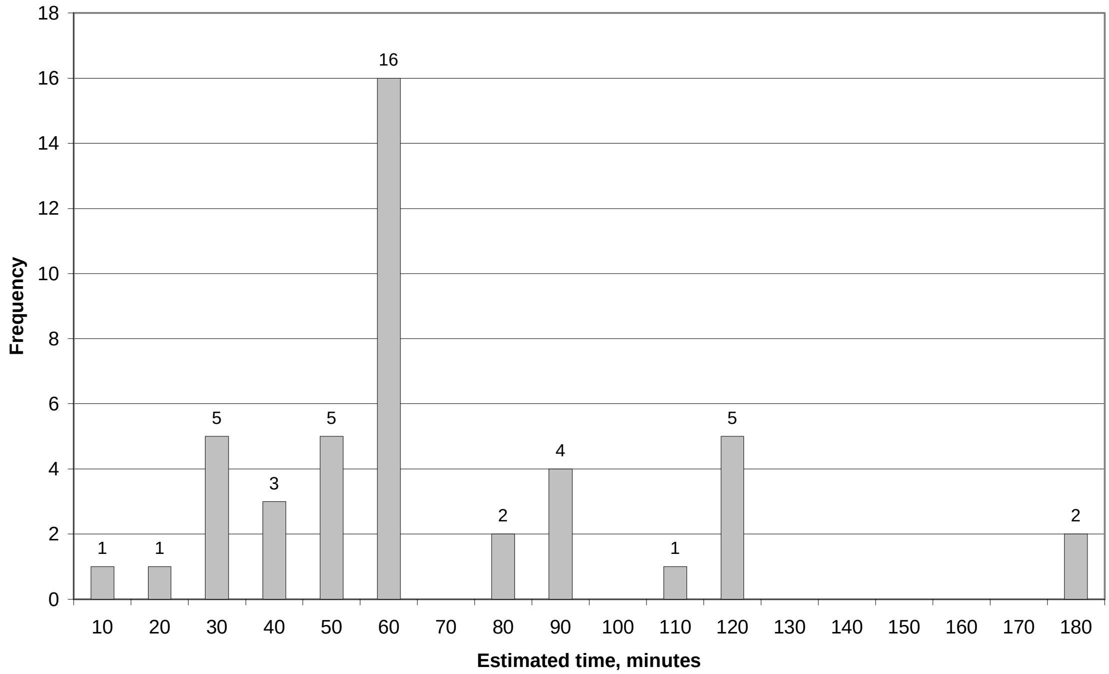


Figure 135. Task H – Predicted inspection time.

Table 182. Task H – Description of type of construction used.

Bridge Characteristic	Percent of Respondents
Steel Girder	82%
Welded Plate Girder	52%
Multi-Girder	41%
Reinforced Concrete Deck	73%
Continuous	52%
Rocker Bearing	7%
Concrete Piers	57%
Single-Angle Cross-Bracing	14%
Composite Construction	5%
Other	18%

To further assess how inspectors were formulating their approach to the inspection, they were asked to identify problems that they might expect to find on a bridge of a similar type, condition, and age. These responses are summarized in table 183. These results indicate that inspectors expect to find relatively few problems. Of this list of possible deficiencies, only steel corrosion and fatigue cracks were mentioned by more than half of the inspectors and no defects were mentioned by more that 60 percent of the inspectors.

As previously mentioned, while the inspector was completing the inspection, the observer recorded environmental conditions, recorded how the inspection was completed, noted what inspection tools were used, and operated the lift. Tables 184 and 185 provide a summary of the environmental conditions that were encountered during this task. These measurements were taken at an elevated position immediately under the superstructure. As the tables reiterate, this task was performed under normal summer morning weather conditions. Also, note the variation that was encountered in both wind and light levels.

Table 183. Task H – Problems expected.

Problem Type	Percentage of Respondents
Fatigue Cracks	57%
Steel Corrosion	55%
Concrete Deterioration	52%
Underside Deck Cracking	27%
Deck Delaminations	27%
Locked Bearings	23%
Missing or Loose Bolts	23%
Leaching	18%
Paint Deterioration	16%
Leakage	7%
Impact Damage	7%
Other	46%

Table 184. Task H – Direct environmental measurements.

Environmental Measurement	Average	Median	Standard Deviation	Maximum	Minimum
Temperature (°C)	22.6	22.8	4.9	30.6	10.6
Humidity (%)	68.2	68.0	10.8	89.0	46.0
Heat Index (°C)	23	24	5.8	37	11
Wind Speed (km/h)	5.2	2.4	6.8	25.7	0.0
Light Intensity (lux)	374	366	281	1160	34

Table 186 summarizes the portions of the inspection task performed by the inspectors. This table is divided into two parts, the first section reporting the items that were visually inspected and the second part reporting what items were inspected through sounding. It is important to note that for this task, the level of inspection for certain components was also recorded. Based on this table, it is clear that some inspectors left this inspection task partially incomplete. Only 56

Table 185. Task H – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	49%
20 – 40% Cloudy	2%
40 – 60% Cloudy	4%
60 – 80% Cloudy	7%
80 – 100% Cloudy	24%
Hazy	2%
Fog	4%
Drizzle	2%
Steady Rain	4%
Thunderstorm	0%

Table 186. Task H – Bridge inspection completion results.

	Inspection Item	Percentage of Inspectors
Visual	North Flange Transitions	36%
	South Flange Transitions	33%
	Girder #3 Splice, North	82%
	Girder #4 Splice, North	87%
	Girder #3 Splice, South	82%
	Girder #4 Splice, South	82%
	Girder #4 Stiffener Retrofits	53%
	No Utility Bracket Welds	42%
	1-25% Utility Bracket Welds	0%
	26-75% Utility Bracket Welds	20%
	76-100% Utility Bracket Welds	38%
	No Drain Tack Welds	22%
	Non-Thorough Inspection of Drain Tack Welds	31%
	Thorough Inspection of 3 Drain Tack Welds	47%
	No Lateral Gusset Connection Welds	4%
	1-25% Lateral Gusset Connection Welds	22%
	26-75% Lateral Gusset Connection Welds	18%
	76-100% Lateral Gusset Connection Welds	56%
	Stiffener to Web Connection at Top Flange	69%
	Stiffener to Web Connection at Bottom Flange	53%
Sounding	No Bolts per Splice	84%
	1-3 Bolts per Splice	2%
	4-9 Bolts per Splice	7%
	10+ Bolts per Splice	7%
	No Lateral Connection Bolts	73%
	Bolts on 1-50% of Lateral Connections	22%
	Bolts on 51-100% of Lateral Connections	4%

percent of the inspectors inspected more than 75 percent of the lateral gusset plate connection inspection areas and only 47 percent of the inspectors thoroughly inspected all three drain tack weld inspection areas.

Inspector tool use is presented in table 187. This table shows that only 58 percent of the inspectors used a flashlight. Also, as could be inferred from table 186, very few inspectors performed any sounding during this task as evidenced by the low usage of sounding tools.

The observers reported on a number of observations regarding inspector behavior during this task. These results are presented in table 188. Note that, on average, very few of the inspectors seemed rushed while completing the task and most inspectors seemed relatively comfortable with the lift.

After completion of the task, the inspectors were again asked a series of questions. These questions were typically related to the inspector’s impression of the inspection they just completed and to their general physical and mental condition. In all, 15 questions were asked

Table 187. Task H – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	18%
2.4-m Stepladder	0%
9.75-m Extension Ladder	0%
Any Flashlight	58%
Two AA-Cell Flashlight	20%
Three D-Cell Flashlight	24%
Lantern Flashlight	18%
Any Sounding Tool	29%
Masonry Hammer	29%
Chain	0%
Level as a Level	0%
Level as a Straightedge	0%
Binoculars	4%
Magnifying Glass	16%
Engineering Scale	2%
Protractor	0%
Plumb Bob	0%
String	0%
Hand Clamp	0%

and the results are presented in table 189. The results show that, in general, the inspectors felt that they were slightly more thorough and provided slightly more effort than they would on a normal inspection. Also, on average, inspectors felt that they were about 630 mm away from any welds that they were inspecting. This result contrasts with the observer value from table 188 that shows the inspectors were about 1.2 m away from any welds that they were inspecting.

Table 188. Task H – Summary of quantitative observations.

Question	Range of Possible Answers		Observer Assessment				
	Low	High	Average	Median	Standard Deviation	Maximum	Minimum
Was the inspector focused on the task?	1 = very unfocused	9 = very focused	5.9	6	1.6	9	2
Did the inspector seem rushed?	1 = not rushed	9 = very rushed	2.2	2	1.6	8	1
How close did the inspector get to the welds he was inspecting (in meters)?*	N/A**	N/A	1.17	0.61	2.27	15.2	0.15
Was the inspector's viewing angle varied while inspecting the welds?	1 = never	9 = always	5.4	6	2.3	9	1
How comfortable was the inspector with the working height?	1 = very uncomfortable	9 = very comfortable	7.1	8	1.6	9	3
How comfortable was the inspector with the lift?	1 = very uncomfortable	9 = very comfortable	6.2	7	2.2	9	1
What was the quality of lift operation?	1 = very poor	5 = very good	3.4	3	0.7	5	2

* Observer responses were originally given in English units and have since been converted into metric units.
** N/A = Not applicable.

5.3.3.2. COMPARISON OF KNOWN AND INSPECTOR-REPORTED DEFICIENCIES

Many reportable deficiencies exist within the inspected portion of the superstructure of the Route 1 Bridge. Inspectors performing this task were asked to note any defects they found during their inspection. The defects can be categorized into three main types: general defects, welded connection defects, and bolted connection defects. Thirty-six of the 44 inspectors performing this task noted at least one of these deficiencies. The following section will discuss the known deficiencies, as compared to the inspector-reported deficiencies.

Table 189. Task H – Quantitative post-task questionnaire responses.

Question	Range of Possible Answers: Low	Range of Possible Answers: High	Inspector Response: Average	Inspector Response: Median	Inspector Response: Standard Deviation	Inspector Response: Maximum	Inspector Response: Minimum
How similar was this task to the tasks performed in your normal In-Depth Inspections?	1 = not similar	9 = very similar	7.5	8	1.4	9	5
Did this task do an accurate job of measuring your inspection skills?	1 = not accurate	9 = very accurate	7.9	8	1.0	9	5
How rested are you?	1 = very tired	9 = very rested	7.0	7	1.4	9	3
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.5	9	0.6	9	7
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	7.8	8	1.4	9	4
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	7.3	7	0.8	9	5
How complex was this bridge?	1 = very simple	9 = very complex	6.0	6	1.5	9	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	2.5	2	2.0	9	1
Do you feel that the working height influenced your performance?	1 = no influence	9 = great influence	1.8	1	1.3	6	1
How adequate do you feel the light level was?	1 = very inadequate	9 = very adequate	7.2	7	1.4	9	4
On average, how close do you think you got the welds you were inspecting (in meters)?*	N/A**	N/A	0.63	0.61	0.38	1.83	0.08
Do you feel you were able to get the proper viewing angle for the components you were inspecting?	1 = never	9 = always	7.3	7	1.0	9	5
Did you feel rushed while completing this task?	1 = not rushed	9 = very rushed	2.0	1	1.5	6	1
What was your effort level on this task in comparison with your normal effort level?	1 = much lower	9 = much greater	5.2	5	0.7	7	4
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	5.5	5	1.0	8	4

* Inspector responses were originally given in English units and have since been converted into metric units.
** N/A = Not applicable.

5.3.3.2.1. General Defects

The General Defect category encompasses structural deficiencies in the bridge that do not pertain to welded or bolted connections. This type of deficiency includes paint system failure, corrosion, member distortions, and fabrication errors. All four of these types of deficiencies are present within the test specimen portion of this bridge.

Paint system failure and corrosion are present in various locations throughout the test specimen. Figures 136 and 137 show typical examples of this deficiency. Of the inspectors who completed this task, 66 percent specifically indicated some sort of paint system failure. Corrosion is a bridge defect that is generally directly linked to the paint system failure. Minor localized corrosion, also known as speckled rust, has occurred in various locations throughout the specimen. Fifty-five percent of the inspectors noted that corrosion was present in the test specimen. Hereafter, paint system failure and corrosion will be combined into a general coating deficiency. Sixty-six percent of the inspectors noted the coating deficiency.

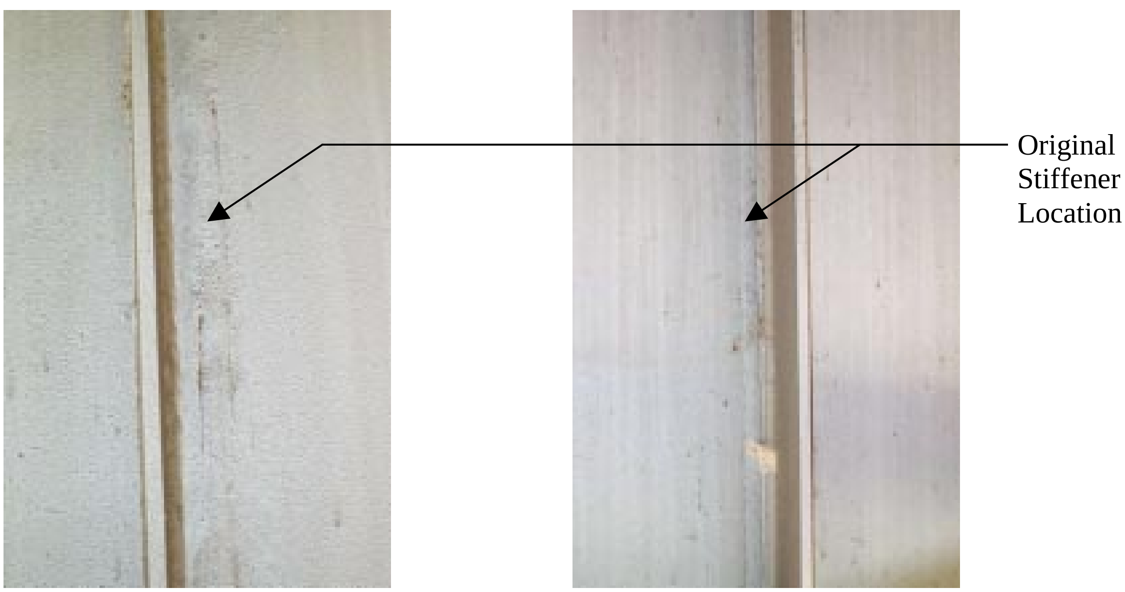
Figure 136. Paint failure on girder web.

Figure 137. Localized corrosion on flange and web near the drain-to-girder web connection.

Member distortions can be indicative of, or may lead to, overall problems with the structure. As shown in figure 138, the bottom flange of the interior girder in the test specimen is not entirely straight, having a “wavy” nature between midspan and pier 5. Eleven percent of the inspectors noted this defect.

Fabrication errors, due to the nonhomogeneity they introduce into the structure, have the possibility of later developing into more serious defects. Frequently, these errors are difficult to detect; however, in some instances, depending on the repair that was employed, they may be detected by normal visual means. In this test specimen, there are two locations where vertical stiffeners were installed at incorrect locations, removed, and replaced at nearby locations. Figure 139 shows the two locations of fabrication errors. Only one inspector noted the fabrication error in the interior girder and no inspectors noted the defect in the exterior girder.

Figure 138. Flange distortion.



a. Interior Girder.

b. Exterior Girder.

Figure 139. Misplaced vertical stiffeners on interior and exterior girders.

5.3.3.2.2. Welded Connection Defects

Welded connection defects consist of cracks or crack indications that occur in or close to a weld. Within the test specimen for Task H, the welded connections were divided into four groups of locations that were most likely to produce crack indications, either due to poor workmanship or low fatigue resistance. These locations include the stiffener-to-girder connections, the lateral bracing-to-girder connections, the drain-to-girder connections, and the utility bracket-to-girder connections. In total, seven weld crack indications are present within the portion of the bridge inspected in Task H. Figure 140 shows a line drawing of the test specimen for Task H, including the locations of the seven indications.

Following the field trials, the seven weld crack indications were thoroughly investigated through the use of visual, dye penetrant, and magnetic particle inspection techniques. None of the indications responded to any of the techniques used, with the exception of Visual Inspection. This indicates that it is unlikely that any of these defect indications are actual weld cracks.

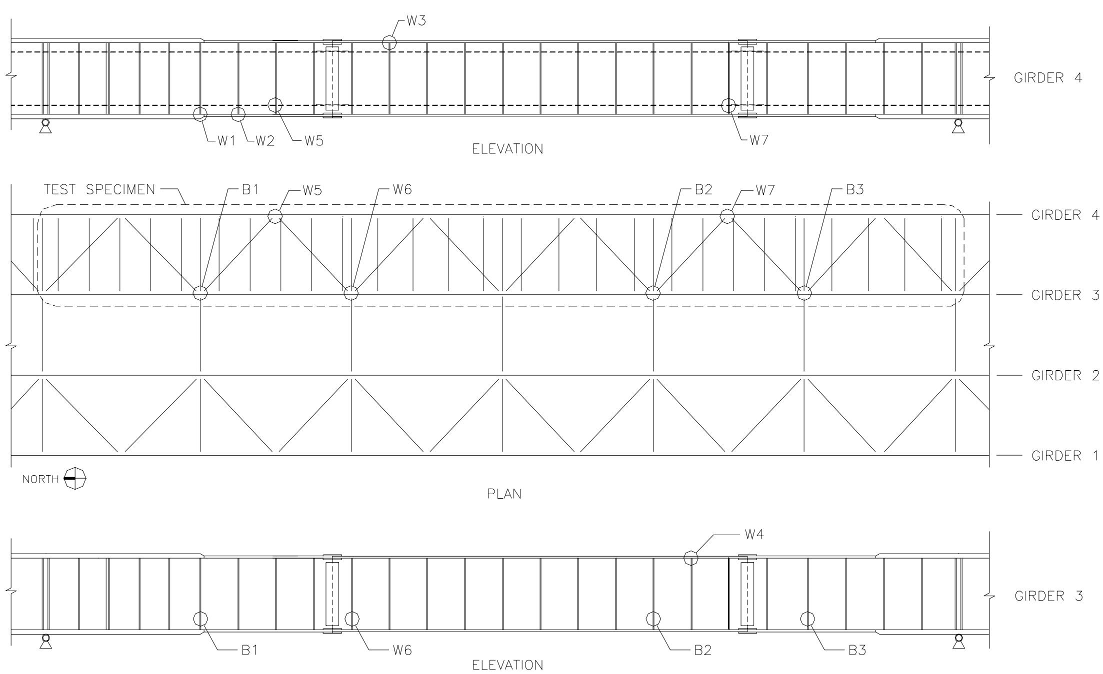


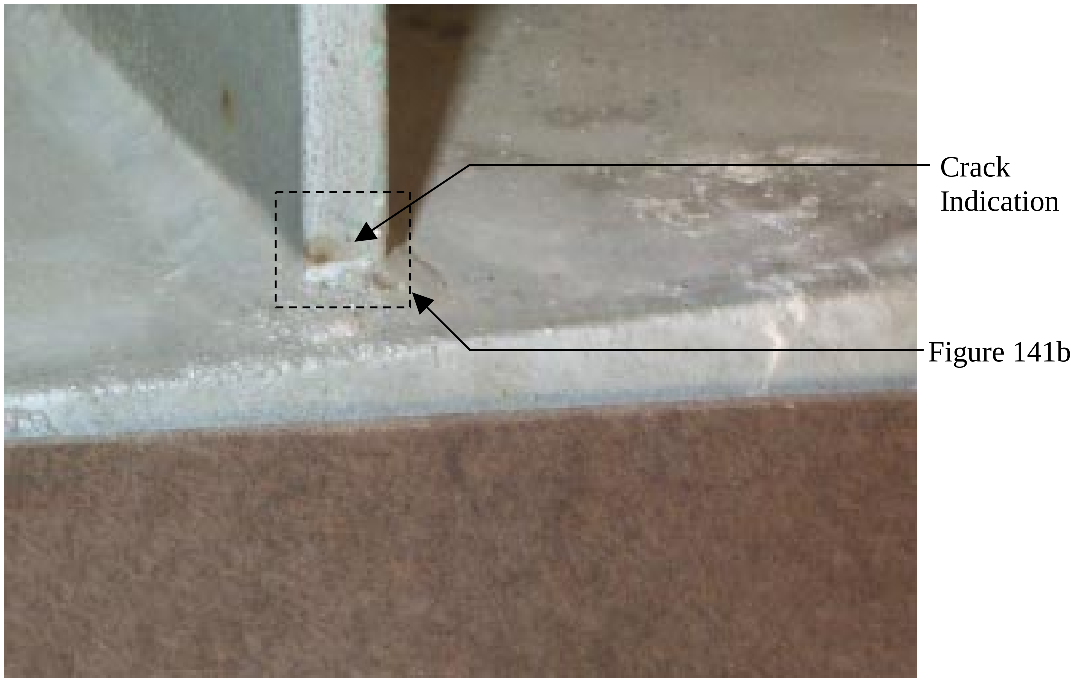
Figure 140. Schematic of the locations of welded and bolted connection defects.

The first critical welded connection location is at the stiffener-to-girder connection. The welds near both the top and bottom flanges at every vertical stiffener were defined to be inspection areas. This includes welds between the stiffener and the web, as well as the welds between the stiffener and the flange, if present. The test bed for Task H contained 104 total inspection areas for this type of connection. Weld crack indications were present in 4 of the 104 inspection areas. Weld crack indication W1 is shown in figure 141. This deficiency is a 5-mm-long indication in the paint at the base of a vertical stiffener. One inspector correctly identified this defect. Another indication, weld crack indication W2, is shown in figure 142. This deficiency is a 12-mm-long indication in the paint in the bottom flange-to-web weld directly under a vertical stiffener. Two inspectors correctly identified this defect.

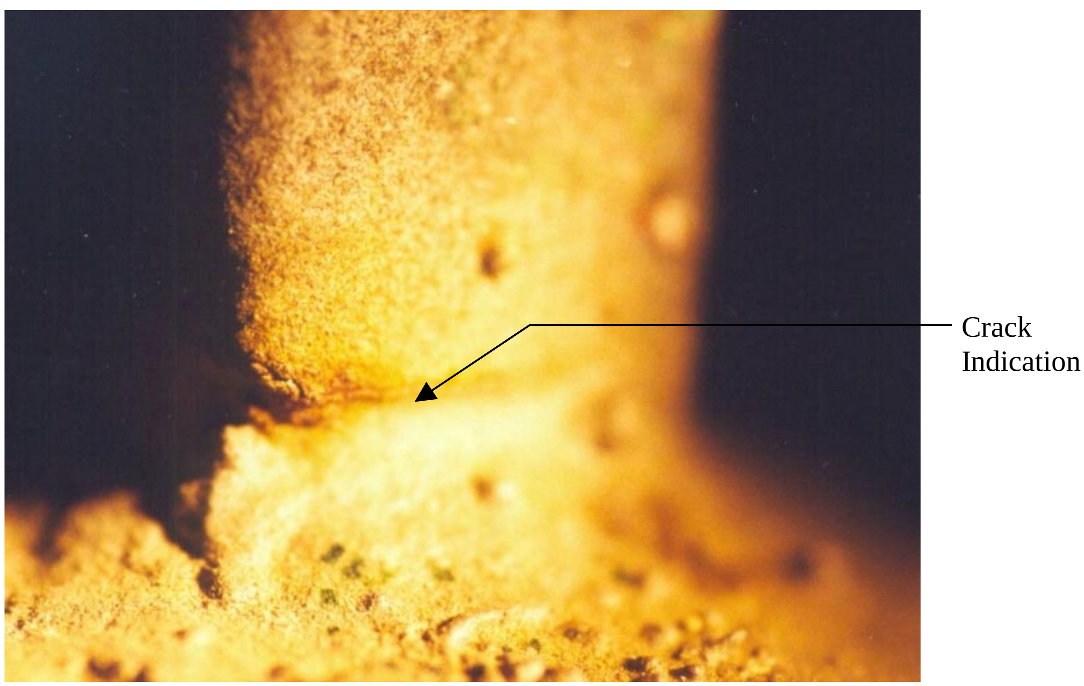
Crack indications exist in two locations at the vertical stiffener-to-top flange connection. The first defect, W3, can be seen in figure 143. This defect is a 30-mm-long indication surrounded by corrosion staining. Three inspectors correctly identified this indication. Weld crack indication W4 is shown in figure 144. It is a 25-mm-long indication also surrounded by corrosion staining. One inspector correctly identified this indication.

A number of false calls were also made with regard to the vertical stiffener-to-girder web connection. In total, 27 false calls were reported. However, a single inspector reported 11 of these false calls, with the remaining 16 being made by 6 other inspectors. To be clear, the inspector who made the majority of the false calls was primarily indicating welds on which he would have requested further testing, not welds that he was sure contained defects.

The welds connecting the lateral bracing gusset plate to the girder web and vertical stiffeners are also likely locations for cracks to occur. Thirteen inspection areas of this type exist within the test bed for Task H. Each inspection area contained two gusset plates, one welded to each side of a vertical stiffener. Figure 145 shows half of one inspection area for this type of connection. Crack indications were contained in 3 of the 13 inspection areas.



a. Stiffener-to-flange connection.



b. Crack indication enlarged for clarity.

Figure 141. Weld crack indication W1 at the base of a vertical stiffener.

a. Web-to-flange connection.

b. Crack indication enlarged for clarity.

Figure 142. Weld crack indication W2 near the base of a vertical stiffener.

Figure 143. Weld crack indication W3 at vertical stiffener-to-top flange connection.

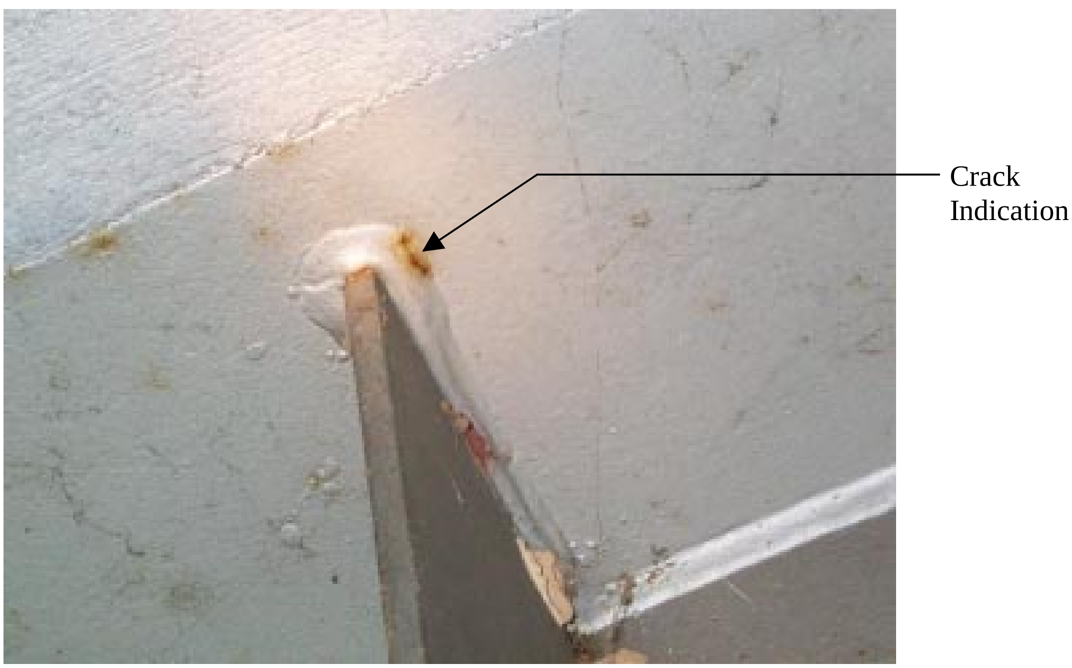


Figure 144. Weld crack indication W4 at vertical stiffener-to-top flange connection.

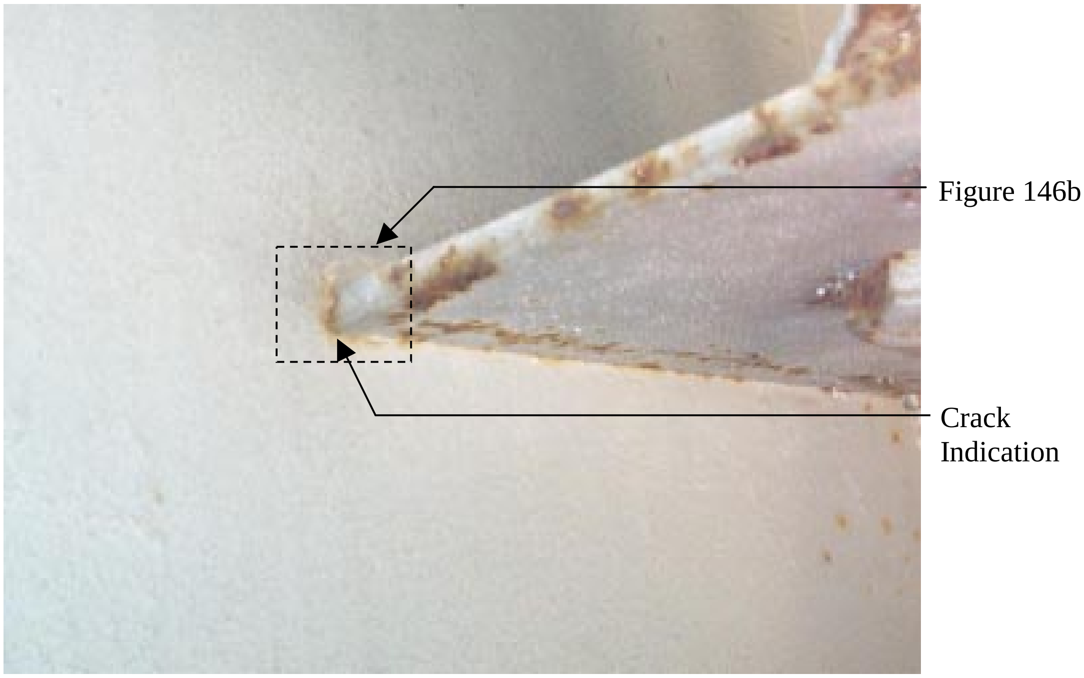
Figure 145. One-half of the lateral gusset plate-to-girder web and vertical stiffener inspection area.

The first defect of this type, weld crack indication W5, is shown in figure 146. This defect is a 16-mm-long crack indication at the termination of the gusset plate-to-web weld. Two inspectors correctly identified this defect. The second defect of this type is weld crack indication W6. It can be seen in figure 147. This defect is a 19-mm-long indication at the termination of the gusset plate-to-web weld. One inspector correctly identified this defect. The final defect of this type is weld crack indication W7, shown in figure 148. It is a 10-mm-long indication, also located at the termination of the gusset plate-to-web weld. Two inspectors correctly identified this defect. The lateral gusset plate-to-girder web connection detail also produced some false calls. In total, four different inspectors made a total of four false calls regarding this connection detail.

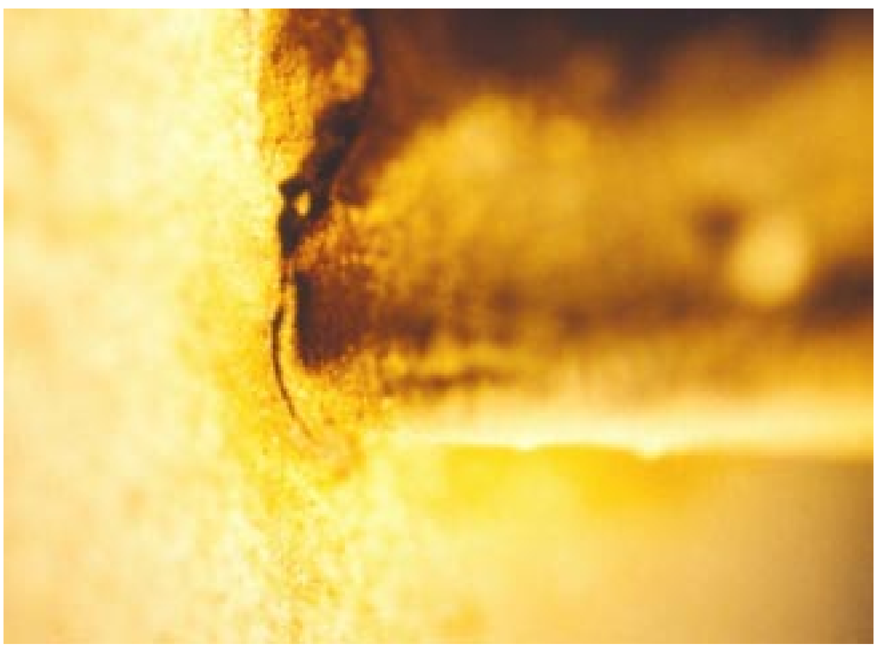
This test bed contained two other areas that are considered to be likely locations for the development of weld cracks. Tack welds were used to connect drain pipes to the exterior girder web. This type of connection occurs three times within the Task H portion of the bridge. Figure 137 shows a photograph of this type of detail. Although the welds are generally of poor quality, no crack indications were present within these connections. Five inspectors made a total of five false calls. Note, however, that these welds are of very poor quality, poor enough that some people may consider them defective even without a crack indication.

The final suspect welded connection pertains to the utilities that run the length of the bridge. After installation of the main girders of the bridge, brackets were field-welded to the girder web to create a support system for the utilities. This type of connection occurs 54 times within the test specimen; thus, there are 54 inspection areas. Figure 149 shows a photograph of this type of detail. Although the welds are generally of poor quality, no defects were present within these connections. Five inspectors made a total of seven false calls.

In summary, there were 174 possible weld inspection areas in the test specimen. A total of 7,538 weld inspection areas should have been inspected by the sample of inspectors. Of these areas, seven contained crack indications. In total, 304 inspections should have been performed on these defects. A total of 12 weld crack indications were correctly identified. Thus, the overall accuracy rate for correctly identifying crack indications is 3.9 percent. In the remaining 167 weld inspection areas that contained no crack indications, 43 false calls were made during the 7,234 inspections of these areas. Therefore, the overall false call rate for identifying good welds as containing indications is 0.6 percent. Combining correct and false calls, 55 crack indication calls were made, indicating that calls were correct only 22 percent of the time. Finally, note that only 41 percent of the inspectors indicated the presence of any type of weld crack indication within the test bed.

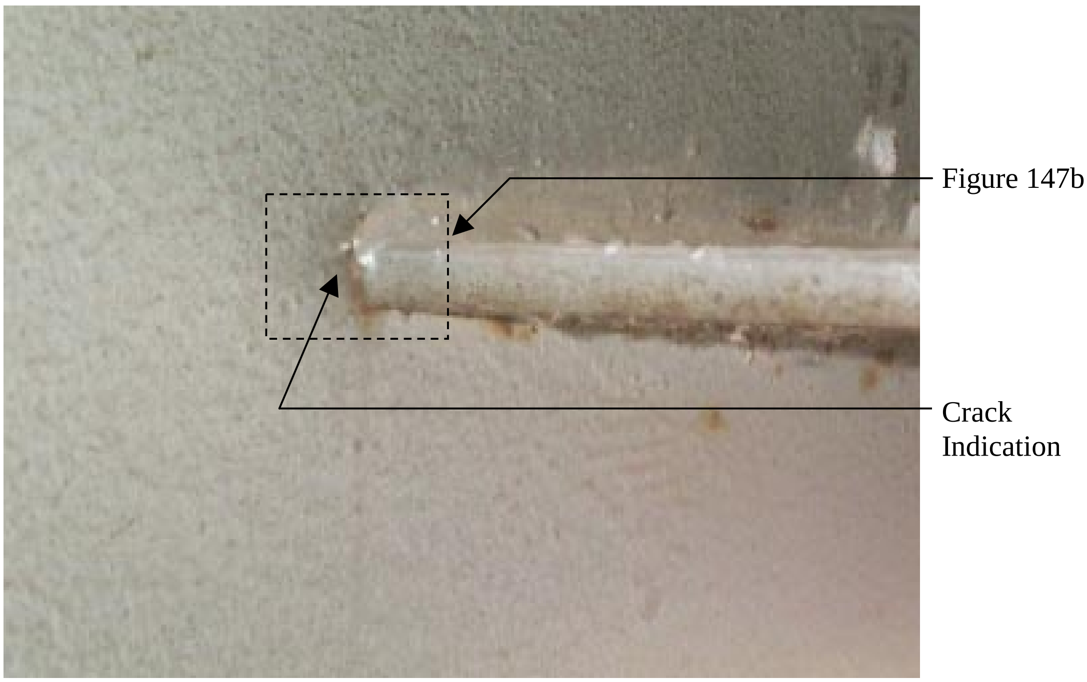


a. Gusset plate-to-web connection.

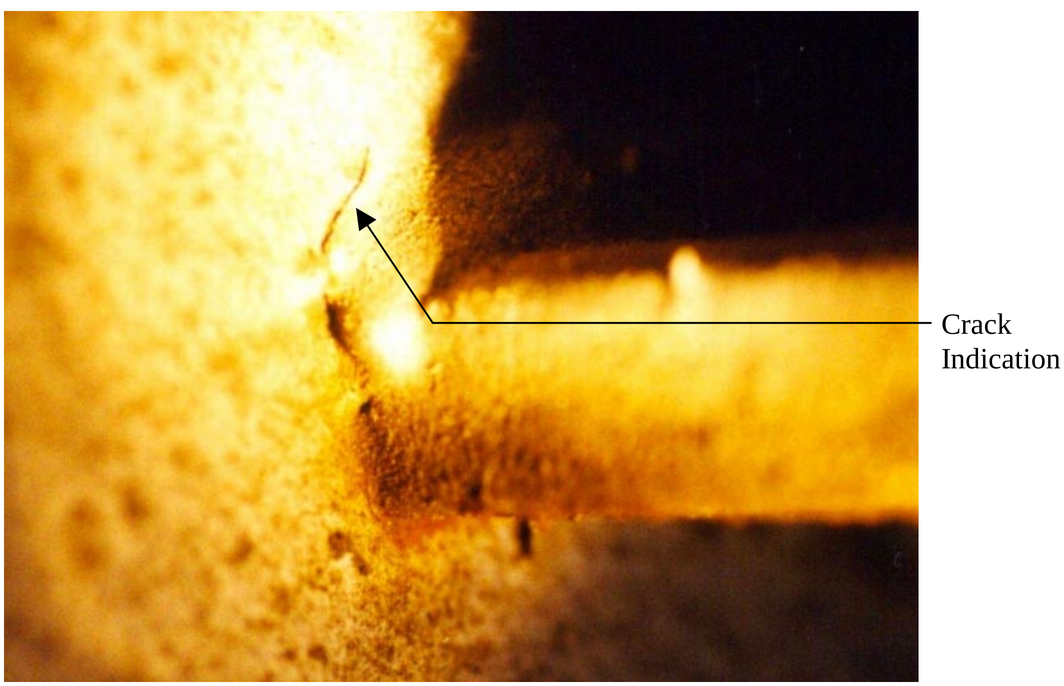


b. Crack indication enlarged for clarity.

Figure 146. Weld crack indication W5 at the lateral bracing gusset plate-to-web connection.

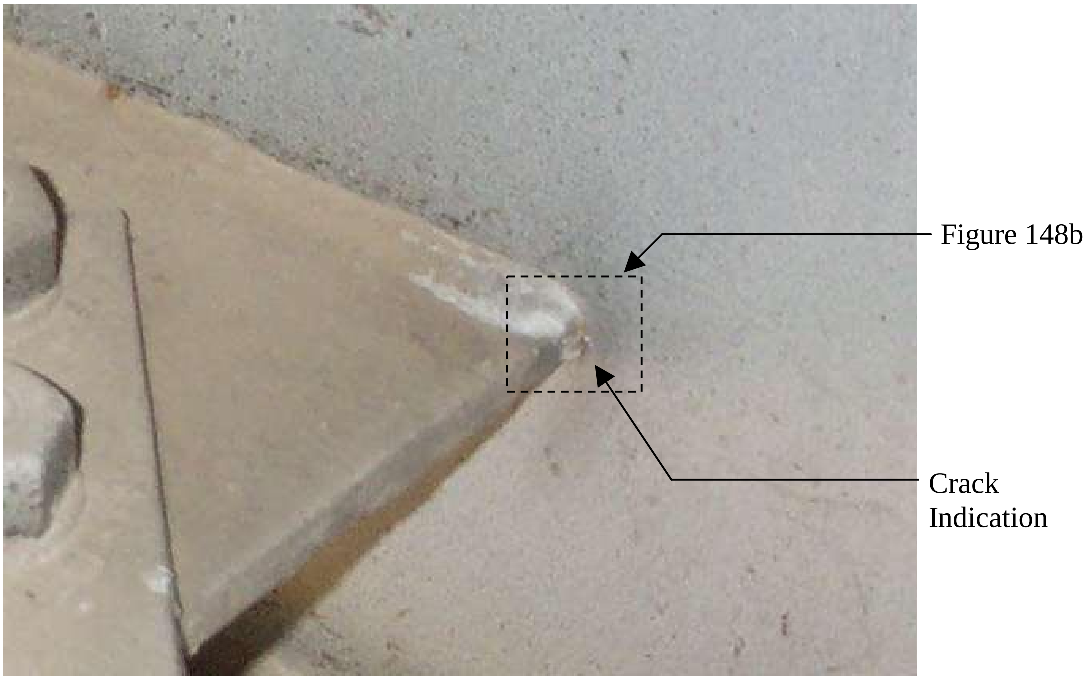


a. Gusset plate-to-web connection.

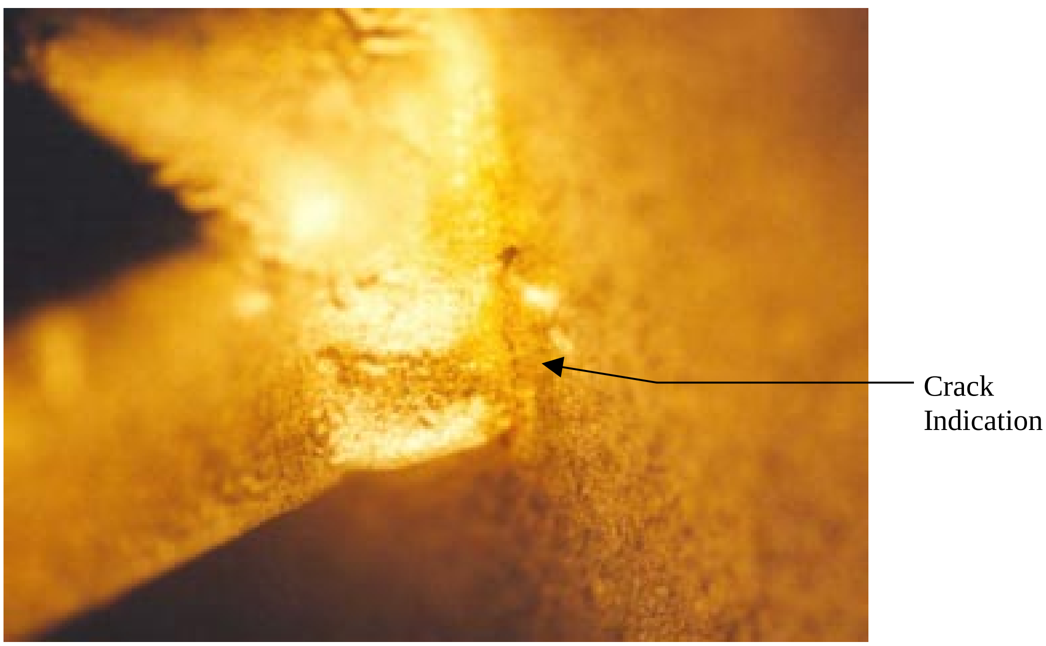


b. Crack indication enlarged for clarity.

Figure 147. Weld crack indication W6 at the lateral bracing gusset plate-to-web connection.



a. Gusset plate-to-web connection.



b. Crack indication enlarged for clarity.

Figure 148. Weld crack indication W7 at the lateral bracing gusset plate-to-web connection.

Figure 149. Typical utility bracket-to-web welded connection.

5.3.3.2.3. Bolted Connection Defects

This bridge contains bolted connections at cross-frame-to-vertical stiffener connections and at girder splices. As with the welded connections, these bolted connections were divided into inspection areas. The girder splices were divided with an inspection area defined for each top flange splice, web splice, and bottom flange splice. The cross-frame-to-vertical stiffener connections were divided such that the bolted connections at any vertical stiffener were considered to be one inspection area. In total, this created 37 potential defect-containing locations within the test specimen.

Three bolted connection defects were present in the test specimen. These defects all occurred at cross-frame-to-vertical stiffener connections and all exhibited themselves as bolts whose nuts were at least 4 mm removed from the plate that they were to be bearing against. The locations of the defects, identified at defects B1, B2, and B3, are illustrated in figure 140. Figure 150 shows one of the three bolted connection defects.

Figure 150. Representative bolted connection defect.

The accuracy of the detection of bolted connection defects was as follows: Defect B1 was correctly identified by 14 inspectors (32 percent), while B2 and B3 were correctly identified by 8 (19 percent) and 9 (21 percent) inspectors, respectively. In total, 31 correct bolted connection defect calls were made throughout the 128 inspections of these inspection areas. Thus, the overall accuracy rate for correctly identifying defective bolted connections is 24 percent. A total of 6 bolt locations (8 total calls) were falsely identified as being defective, while inspections were performed on a total of 1,468 bolted connections classified as non-defective. Therefore, the false call rate for incorrectly identifying non-defective bolts as defective is 0.5 percent. Combined, a total of 39 defective bolted connection calls were made, indicating that calls were correct 79 percent of the time. In addition, note that only 48 percent of the inspectors identified any bolted connections as defective.

5.3.3.3. FACTORS INFLUENCING INSPECTION

The following discusses factors that may have influenced the results of Task H. First, a discussion parallel to the factor presentation from Task F is provided. Following this, results based on the thoroughness with which the inspectors completed the weld inspection portion of the task are presented.

5.3.3.3.1. Individual Factors

A number of factors affect an inspector's ability to correctly locate a defect during a bridge inspection. The following discusses some of these factors with regard to the inspectors and deficiencies studied in Task H. The set of factors presented, although not the complete set of factors studied within this research, does represent the factors that provide the best correlations with the inspection data. A few additional factors that do not correlate strongly are also discussed. These factors are either commonly perceived to be important to bridge inspection or are factors that provided strong correlation in Task F and are presented here for comparison. In total, approximately 20 of the factors are discussed. The remaining factors not discussed here were found to provide little correlation with the inspection results.

For the purposes of this discussion, the inspectors who correctly identified the deficiencies mentioned previously are grouped into six subsets: inspectors who identified a weld crack indication, multiple weld crack indications, bolt defects, multiple bolt defects, coating defects, and the flange distortion defect. Note that individual inspectors may be included in more than one of these subsets. A seventh subset, the subset of inspectors who indicated that there were no deficiencies in the bridge, is also discussed. All inspectors are included in at least one of the seven subsets. The fabrication error defect is not discussed here since only one inspector noted it.

In general, the following results are presented in terms of a comparison between the mean value of a factor for each subset of inspectors and the mean value of the factor for the overall sample of inspectors who completed the task. As in Task F, the t-test was used to determine whether the particular inspector subset can be considered to be significantly different than the remainder of the inspectors who did not fit the criteria for inclusion in the subset. The t-test results for the 5 and 10 percent significance levels are presented in the tables that accompany most of the factor discussions. In addition, these tables also contain the average and standard deviation values for each subset of inspectors.

TIME: As discussed previously, the amount of time an inspector uses to perform an inspection is likely to affect the results of the inspection. Table 190 presents the average and the standard deviation of the Actual Time to Complete Task for the overall sample of inspectors, as well as the subsets of inspectors. In a manner similar to the information presented in table 190, table 191 presents the differences between the Estimated Time for Task and the Actual Time to Complete Task.

Table 190. Task H – Actual Time to Complete Task (in minutes).

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	66	28	N/A*	N/A
Weld Crack Indication	67	25	No	No
Multiple Crack Indications	88	17	No	Yes
Bolt Defect	78	22	Yes	Yes
Multiple Bolt Defects	85	13	Yes	Yes
Coating Defect	70	29	No	Yes
Distortion Defect	76	12	No	No
No Deficiencies	43	21	Yes	Yes

* N/A = Not applicable.

Table 191. Task H – Actual Time to Complete Task minus Estimated Time for Task.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	-3	44	N/A*	N/A
Weld Crack Indication	11	43	No	No
Multiple Crack Indications	38	13	Yes	Yes
Bolt Defect	11	43	No	Yes
Multiple Bolt Defects	33	20	Yes	Yes
Coating Defect	-2	42	No	No
Distortion Defect	19	10	No	No
No Deficiencies	-25	50	No	Yes

* N/A = Not applicable.

The average Actual Time to Complete Task for this task was 66 min. The average Estimated Time for Task was 69 min. With regard to weld crack indications, the subset of inspectors who noted this defect spent an average of 67 min on this task, while the three inspectors who noted multiple weld crack indications spent an average of 87 min on the task. The inspectors who found a weld crack indication tended to underestimate their time by 11 min, while the inspectors who found multiple weld crack indications tended to underestimate by 38 min. With regard to bolt defects, the amount of time spent on this inspection by inspectors who found defects varied from 22 to 113 min, with an average of 78 min. However, of the 33 correct bolt defect identifications, 29 were made by inspectors spending at least 72 min on the task. Also, the inspectors who noted multiple bolt defects tended to spend 85 min on the task. Inspectors who found bolt defects tended to underestimate their time by 11 min and inspectors who found multiple bolt defects tended to underestimate by 33 min.

Inspectors who did not note any deficiencies tended to spend 43 min on this task. On average, these inspectors performed the inspection in 25 min less time than they predicted. The results from the coating and distortion defect subsets of inspectors do not show significant deviation from the overall averages.

The results presented above show that there is good correlation between inspectors finding specific defects and spending more time completing the inspection. Clearly, the inspectors who did not note any deficiencies tended to perform the inspection faster than the average and faster than they predicted that they would. The inspectors who noted weld or bolt defects, especially the inspectors who noted multiple defects, tended to spend much longer on the inspection.

Also with regard to time, both the inspector and the observer were asked to rate the Rushed Level of the inspector during the task. These results are relatively minor and thus will not be presented in tabular form. As was reported previously, no inspectors said they were overly rushed; however, the observers reported that four inspectors seemed very rushed. None of these four inspectors correctly identified the weld or flange distortion defects; however, two of the four inspectors did note one of the bolt defects. Inspectors who reported no deficiencies were both observed to be, and reported being, less rushed than average. These results provide some evidence that a more hurried inspector may locate fewer deficiencies.

COMFORT LEVEL DURING INSPECTION: Task H was completed at a moderate height using access equipment that was relatively unfamiliar to most of the inspectors. The inspector’s comfort level with working at heights and with the operation of the lift may have an effect on the results of the inspection. In this regard, the inspectors were asked to rate their personal fear of heights in the SRQ and the observers were asked to rate the inspectors' comfort both with heights and with the lift vehicle. Tables 192 through 194 present an analysis using this information. Note that Reported Fear of Heights is rated on a 1 to 4 scale, while Observed Inspector Comfort With Heights and With Lift are rated on a 1 to 9 scale.

These tables show a few clear trends with regard to inspector comfort during the inspection and the inspection results that the inspector provides. First, all correct weld crack indication calls were made by inspectors who stated that they were "Mostly Fearless" or had "No Fear" with regard to Fear of Heights. Overall, only 68 percent of the inspectors fell into these categories. The average response to this question was 3.4 for inspectors who found a weld crack indication, while it was 2.9 overall. The observed inspector comfort with height averaged 8.0 for inspectors who found a weld defect indication, but averaged only 7.1 overall. The observed inspector comfort with the lift was 7.1 for these inspectors, while the overall average was 6.2.

The inspectors who identified the flange distortion were also relatively comfortable during the inspection. Even though these inspectors reported varying levels of fear of heights in the SRQ, the observer reported that comfort with lift and height were both 7.8, above the overall average. The inspectors who indicated that there were no deficiencies during this task were less

Table 192. Task H – Reported Fear of Heights.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	2.9	0.76	N/A*	N/A
Weld Crack Indication	3.4	0.53	Yes	Yes
Multiple Crack Indications	3.3	0.58	No	No
Bolt Defect	3.1	0.75	No	No
Multiple Bolt Defects	3.1	0.57	No	No
Coating Defect	3.1	0.75	No	Yes
Distortion Defect	3.0	1.00	No	No
No Deficiencies	2.1	0.35	Yes	Yes

* N/A = Not applicable.

Table 193. Task H – Observed Inspector Comfort With Height.

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	7.0	1.57	N/A*	N/A
Weld Crack Indication	8.0	0.82	Yes	Yes
Multiple Crack Indications	7.7	0.58	No	No
Bolt Defect	6.8	1.52	No	No
Multiple Bolt Defects	6.9	1.37	No	No
Coating Defect	7.2	1.61	No	No
Distortion Defect	7.8	0.45	No	No
No Deficiencies	6.4	1.99	No	No

* N/A = Not applicable.

Table 194. Task H – Observed Inspector Comfort With Lift.

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	6.2	2.77	N/A*	N/A
Weld Crack Indication	7.1	1.68	No	No
Multiple Crack Indications	7.0	2.00	No	No
Bolt Defect	6.4	2.32	No	No
Multiple Bolt Defects	6.4	2.46	No	No
Coating Defect	6.1	2.26	No	No
Distortion Defect	7.8	0.45	Yes	Yes
No Deficiencies	5.0	2.58	No	Yes

* N/A = Not applicable.

comfortable while performing the task. Their average for Fear of Heights was 2.1. For these inspectors, the Observer-Reported Comfort With Height average was 6.4 and the Comfort With Lift average was 5.0.

The results presented above show that the inspector comfort during the task can correlate with the inspection findings. Specifically, inspectors who identified the weld or the flange distortion defects tended to be much more comfortable while performing the inspection. The inspectors who did not note any deficiencies tended to be less comfortable and also reported having a stronger than average fear of heights.

MENTAL FOCUS: Inspector mental focus may also affect inspection results. This factor was measured through inspector responses on the SRQ, as well as through observations during the execution of this task. Results of the analyses with these data are presented in tables 195 and 196.

Table 195. Task H – General Mental Focus.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	4.4	0.72	N/A*	N/A
Weld Crack Indication	4.6	0.53	No	No
Multiple Crack Indications	4.7	0.58	No	No
Bolt Defect	4.3	0.85	No	No
Multiple Bolt Defects	4.4	0.84	No	No
Coating Defect	4.6	0.69	Yes	Yes
Distortion Defect	4.6	0.55	No	No
No Deficiencies	4.0	0.53	Yes	Yes

* N/A = Not Applicable.

Table 196. Task H – Observed Inspector Focus Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	5.9	1.53	N/A*	N/A
Weld Crack Indication	7.0	0.82	Yes	Yes
Multiple Crack Indications	7.3	0.58	No	Yes
Bolt Defect	5.9	1.50	No	No
Multiple Bolt Defects	6.5	1.43	No	Yes
Coating Defect	5.9	1.73	No	No
Distortion Defect	5.6	1.95	No	No
No Deficiencies	5.5	0.93	No	No

* N/A = Not Applicable.

These results indicate that the mental focus level of the inspector may correlate with the results obtained in an inspection of this type. Specifically, inspectors who identified no deficiencies during this task reported an SRQ mental focus of 4.0, well below the overall average. Although possibly not significant, inspectors who identified a weld crack indication, the flange distortion, or the coating defect reported a mental focus above the overall average of 4.4. In addition, the observer-reported mental focus on the task shows that inspectors who noted a weld crack indication tended to exhibit a significantly higher mental focus level than the overall average. The results from this factor also show that, for certain tasks, a higher level of mental focus could lead to better inspection results.

INSPECTOR-REPORTED THOROUGHNESS AND EFFORT LEVEL: Inspectors did not necessarily perform the inspection in Task H in the same way that they would typically perform a similar inspection during their regular duties as a bridge inspector. For this reason, the inspector was asked to rate his thoroughness and effort compared to normal. The majority of the inspectors (65 percent) reported that they performed this task with the same thoroughness as they would perform a similar task during their normal duties as a bridge inspector. Only 15 percent of the inspectors reported a thoroughness above 6, with the remainder falling between 4 and 6. Seventy-five percent of the inspectors rated their effort level identical to their normal effort level, with 90 percent responding with an answer between 4 and 6. The overall average inspector-reported thoroughness was 5.5 and the overall average effort level was 5.2.

The Reported Thoroughness Level for the various subsets of inspectors who correctly identified defects ranged from 5.0 to 5.5. The Reported Effort Level ranged from 4.6 to 5.3. The average Reported Effort Level for the inspectors who identified no deficiencies was a 5.0, while their average Reported Thoroughness Level was a 6.0, the highest among all the inspector subsets. Only one subset of inspectors — the inspectors who noted the distortion defect — were shown by the t-test to provide a different rating at the 5 percent significance level. Their rating, a 4.6, indicates that they may have provided slightly less effort than they would normally provide. Overall, these results indicate that inspectors performed the inspections in a manner similar to their normal routine.

EXPECTED BRIDGE DEFECTS: Prior to the initiation of this task, inspectors were asked to identify any defects that they felt might occur within the bridge. It seems that inspector expectations may have an effect on the defects that the inspector ultimately finds. Specifically, only 57 percent of the inspector sample indicated that fatigue-related defects were likely; however, 86 percent of the inspectors who found a weld crack indication had previously indicated that they were likely. The same holds true for the location of the bolt defects. Here, 35 percent of the inspectors who found a bolt defect had indicated that there might be this type of deficiency, while only 23 percent of the general inspector sample mentioned this problem. These results indicate that the type of defects an inspector expects to find may increase the likelihood that the inspector will find that type of defect.

REPORTED BRIDGE DESCRIPTION: Prior to the beginning of the task, inspectors were asked to describe the type of construction used on the bridge. Of particular interest here is the number of inspectors who specifically mentioned that the bridge is continuous. These results are presented in table 197. While 52 percent of the inspectors who completed the task noted this fact, 71 percent of the inspectors who identified a weld crack indication and 80 percent of the inspectors who noted the distortion deficiency provided this information. Although mentioning specific items regarding the bridge structure does not necessarily directly result in a better inspection, there does seem to be a tendency for inspectors who more accurately describe critical parts of the bridge to perform inspections that locate more defects.

Table 197. Task H – Reported Bridge Description: Continuous.

Inspector Subset	Average
Overall Sample	52%
Weld Crack Indication	71%
Multiple Crack Indications	67%
Bolt Defect	47%
Multiple Bolt Defects	50%
Coating Defect	48%
Distortion Defect	80%
No Deficiencies	50%

REPORTED STRUCTURE COMPLEXITY LEVEL: The complexity of the bridge, as reported by the inspector, may have an effect on the way the inspector performs the inspection and also on the results of the inspection. Table 198 provides the results of the various inspector subsets with regard to their rating of bridge complexity. Overall, the average bridge complexity rating was 6.0. More than 50 percent of the inspectors rated the bridge a 6 or below. All weld crack indications were identified by inspectors who rated the bridge complexity at 7 or higher, with an average of 7.1. The inspectors who identified the flange distortion provided an average rating of 4.8. These results seem to show that differing levels of perceived complexity may lead to an inspector looking for a different type of defect.

Table 198. Task H – Reported Structure Complexity Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	6.0	1.49	N/A*	N/A
Weld Crack Indication	7.1	0.38	Yes	Yes
Multiple Crack Indications	7.0	0.00	No	No
Bolt Defect	6.3	1.16	No	No
Multiple Bolt Defects	6.9	0.88	Yes	Yes
Coating Defect	5.8	1.61	No	No
Distortion Defect	4.8	1.92	Yes	Yes
No Deficiencies	6.0	1.00	No	No

* N/A = Not applicable.

REPORTED STRUCTURE ACCESSIBILITY LEVEL: Perceived bridge accessibility is a factor quite similar to perceived bridge complexity. It is likely that the ease of access to the areas of the bridge to be inspected may affect the methods an inspector uses to perform the inspection. The results of the various inspector subsets with regard to their rating of bridge accessibility are presented in table 199. Overall, the average perceived bridge accessibility rating was 7.8. For inspectors who located a weld crack indication, the average rating was 6.6, while for inspectors who identified the flange distortion, the average rating was 8.6. As with the complexity findings, these results also indicate that an inspector's perception of the bridge may affect the defects located. Here, inspectors who found large-scale defects were the same inspectors who felt that the bridge was very accessible. The inspectors who correctly identified a weld crack indication are the ones who felt the bridge was far less accessible.

VIEWING OF WELDS: A specific set of the factors studied in this research focused on the methods used by inspectors to perform In-Depth Inspections of welded connections. Specifically, after completion of this task, inspectors were asked whether they were able to achieve the proper viewing angle for the welds they were inspecting, whether the light level was sufficient, and at what distance they were usually inspecting the welds. In addition, observers were asked to provide an estimation of the distance between the inspector and the welds being inspected, as well as noting whether the inspector varied the inspection viewpoint while inspecting the welds. The light level question did not provide any useful information and will not be discussed here.

Table 199. Task H – Reported Structure Accessibility Level.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	7.8	1.40	N/A*	N/A
Weld Crack Indication	6.6	2.23	Yes	Yes
Multiple Crack Indications	5.7	2.08	Yes	Yes
Bolt Defect	7.9	1.11	No	No
Multiple Bolt Defects	7.7	1.34	No	No
Coating Defect	7.8	1.31	No	No
Distortion Defect	8.6	.55	No	Yes
No Deficiencies	7.7	1.70	No	No

* N/A = Not applicable.

With regard to Observed Variation in Viewing Angle, inspectors who identified a weld crack indication were significantly more likely to be reported as having frequently varied their viewing angle. The results of the inspector subsets with regard to this factor are presented in table 200. Overall, inspectors had an average rating of 5.5, while inspectors who found a weld crack indication had an average rating of 7.3. Although not significantly different from the overall average, inspectors who noted no deficiencies received an average rating of 4.8. Alternatively, the Reported Ability to Achieve Required Viewing Angle factor provided a narrow band of results, clustered around 7. This indicates that nearly all inspectors felt that they were able to get the viewing angle they were striving for during the inspection.

The weld inspection distance findings also correlated well with the inspectors who found a weld crack indication. The results of the inspector subsets with regard to this factor are presented in table 201. The inspectors who correctly identified a weld crack indication were reported to have conducted the inspection from an average distance of 330 mm, while all other subsets of inspectors averaged inspection distances of greater than 500 mm. This subset of inspector results does not pass the t-test, which is probably due to the highly skewed, and thus not Gaussian, distribution of the data. However, it is clear that proximity to the weld has a large impact on the detection of weld defect indications. Also note that the inspectors who noted no deficiencies were reported to be an average of 2.79 m from the welds that they were inspecting, a rather large distance from which to note any deficiencies.

Table 200. Task H – Observed Variation in Viewing Angle.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	5.5	2.22	N/A*	N/A
Weld Crack Indication	7.3	0.76	Yes	Yes
Multiple Crack Indications	7.7	0.58	Yes	Yes
Bolt Defect	5.7	2.31	No	No
Multiple Bolt Defects	6.9	1.60	Yes	Yes
Coating Defect	5.4	2.26	No	No
Distortion Defect	6.6	2.70	No	No
No Deficiencies	4.8	2.64	No	No

* N/A = Not applicable.

Inspectors were also asked to personally rate their distance from the welds that they were inspecting. Aside from the subset of inspectors who located a weld crack indication, nearly all inspectors estimated themselves to be much closer to the welds that they were inspecting than the observers reported them being. The overall average value was 0.63 m, with a standard deviation of 0.38 m. Clearly, most inspectors felt that they were performing an "arm's-length" inspection.

TOOL USE: The tools that an inspector uses to perform an inspection are indicative of the types of deficiencies that the inspector is looking for and, possibly, the types of deficiencies that the inspector will find. Of the tools provided to the inspector, the flashlight and the masonry hammer stand out as two tools that would aid in the identification of weld crack indications and bolt defects, respectively. Inspector subset usage results for these two tools are presented in table 202.

Table 201. Task H – Observed Distance to Weld Inspected (in meters).

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	1.17	2.30	N/A*	N/A
Weld Crack Indication	0.33	0.15	No	No
Multiple Crack Indications	0.33	0.23	No	No
Bolt Defect	0.69	0.46	No	No
Multiple Bolt Defects	0.56	0.38	No	No
Coating Defect	0.86	0.79	No	No
Distortion Defect	0.51	0.41	No	No
No Deficiencies	2.79	5.11	Yes	Yes

* N/A = Not applicable.

Table 202. Task H – Tool Use.

Inspector Subset	Flashlight	Masonry Hammer
Overall Sample	59%	30%
Weld Crack Indication	86%	43%
Multiple Crack Indications	67%	33%
Bolt Defect	53%	41%
Multiple Bolt Defects	60%	50%
Coating Defect	66%	28%
Distortion Defect	60%	60%
No Deficiencies	38%	13%

Overall, 59 percent of the inspectors used a flashlight during this task, while 86 percent of the inspectors who identified a weld crack indication used supplemental lighting. With regard to the bolt defects, overall, 30 percent of the inspectors used the masonry hammer, while 41 percent of those identifying a bolt defect used it. In addition, note that most of the inspectors who identified no deficiencies tended to use very few or no tools during this inspection. Although this does not necessarily indicate that the use of tools aids in the identification of defects, this does show that the methods used by some inspectors may have an effect on the results of the inspection.

NORMAL BRIDGE INSPECTION: The types of bridges an inspector normally inspects may play an important role in the quality of the inspection that was provided for this study. It is possible that an inspector who is not used to performing a certain type of inspection will perform a poorer inspection. The number of bridges an inspector inspects each year can provide some insight into the types of inspections that are usually performed. Also, the inspector responses to the SRQ question regarding percentage of time spent performing In-Depth Inspections and to the post-task question regarding the similarity of this task to his normal work can also be good indicators. Information concerning the number of bridges each subset of inspectors inspects per year is presented in table 203.

Table 203. Task H – Number of Annual Bridge Inspections.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	388	246	N/A*	N/A
Weld Crack Indication	254	100	No	Yes
Multiple Crack Indications	317	76	No	No
Bolt Defect	413	250	No	No
Multiple Bolt Defects	463	249	No	No
Coating Defect	353	276	No	Yes
Distortion Defect	465	129	No	No
No Deficiencies	500	158	No	Yes

* N/A = Not applicable.

In general, In-Depth Inspections are more thorough inspections that may be performed on relatively large bridges. Given this fact, an inspector who performs a large number of inspections per year would probably be performing fewer In-Depth Inspections. Overall, the inspectors who completed this task inspected an average of 388 bridges per year. However, the inspectors who correctly identified a weld crack indication averaged 254 bridge inspections per year, with none inspecting more than 400 bridges per year. The inspectors who reported no deficiencies averaged 500 bridge inspections per year.

The results with regard to the similarity of this task to an inspector's normal In-Depth Inspection, as well as to the percentage of an inspector's inspections that are In-Depth Inspections, are less clear. Inspectors who correctly identified a weld crack indication or the flange distortion reported that they tended to spend more than 40 percent of their time performing In-Depth Inspections, while the overall average and the remainder of the other deficiency identification subsets tended to average between 32 and 36 percent. Also, overall, inspectors rated the similarity of this task to their normal In-Depth Inspections as a 7.5, while inspectors who correctly identified a weld crack indication or bolt defects rated it as a 7.7, and inspectors who noted the distortion rated it as an 8.2. However, with regard to these inspector responses, none of the subsets of the inspectors passed the t-test at the 10 percent significance level; therefore, these results are only presented for the general trends that they may exhibit.

INSPECTOR AGE AND BRIDGE INSPECTION EXPERIENCE: Inspector age and bridge inspection experience provide some noteworthy results. The results of the number of years of experience that the inspectors have in bridge inspection are presented in table 204. The overall average inspector age was 40. The inspectors who noted a weld crack indication, bolt defect, or coating defect had average ages of 39, 38, and 39, respectively. The inspectors who reported the flange distortion defect were, on average, 36 years old, while the inspectors who reported no deficiencies had an average age of 43. As none of these subsets of inspectors passed the t-test with 5 percent significance, these results are presented for general trends only. With regard to inspection experience, the overall average was 9.8 years. Inspectors who noted a weld crack indication, or bolt, coating, or distortion defect all averaged within 1.2 years of experience of the overall average. However, the inspectors who reported no deficiencies averaged 14.3 years of experience. These results indicate that more experienced inspectors may tend to report fewer defects.

EDUCATION AND FORMAL TRAINING: The education level and formal training of inspectors are both factors that may affect the work that an inspector performs. Table 205 shows the education level of the inspectors who completed this task. The inspectors are shown grouped into six categories, including all inspectors, inspectors who identified the four subsets of deficiencies, and inspectors who did not identify any deficiencies. Two conclusions can be

Table 204. Task H – Experience in Bridge Inspection (in years).

Inspector Subset	Average	Standard Deviation	Pass t-Test? 5% Significance Level	Pass t-Test? 10% Significance Level
Overall Sample	9.8	6.1	N/A*	N/A
Weld Crack Indication	8.6	4.9	No	No
Multiple Crack Indications	8.5	3.5	No	No
Bolt Defect	8.6	5.7	No	No
Multiple Bolt Defects	7.9	4.4	No	No
Coating Defect	8.8	5.8	No	Yes
Distortion Defect	10.3	7.2	No	No
No Deficiencies	14.6	7.3	Yes	Yes

* N/A = Not applicable.

drawn from this table. First, inspectors who identified a weld crack indication tended to have completed more formal education, with 71 percent of them having obtained a Bachelor's degree. Second, inspectors who did not identify any deficiencies tended to have an Associate's degree. Overall, 63 percent of them had obtained this degree. Combined, these findings indicate that the level of education may have an impact on inspection performance.

The number and type of formal training classes did not seem to have any effect on the results of this task. The results from each subset of inspectors were relatively similar to the overall averages for the courses studied. The overall results were provided within the presentation of the SRQ results.

Table 205. Task H – General Education Level.

Inspector Subset	Some High School	High School or Equivalent	Some Trade School	Trade School Degree	Some College	Associate's Degree	Bachelor's Degree	Some Graduate School	Master's Degree	Terminal Degree
All Inspectors	0%	18%	5%	0%	18%	20%	34%	2%	2%	0%
Weld Crack Indication	0%	14%	0%	0%	14%	0%	71%	0%	0%	0%
Bolt Defect	0%	24%	6%	0%	6%	18%	47%	0%	0%	0%
Coating Defect	0%	14%	3%	0%	24%	10%	41%	3%	3%	0%
Distortion Defect	0%	20%	0%	0%	20%	20%	40%	0%	0%	0%
No Deficiencies	0%	13%	13%	0%	0%	63%	13%	0%	0%	0%

PROFESSIONAL ENGINEER LICENSE: Following the study, inspectors were contacted to determine if they held a Professional Engineer (PE) license. Table 206 provides the corresponding results in terms of the subsets of inspectors defined for this task. This information shows no clear correlation between this factor and the inspection results. However, the small size of the sample, along with the small size of most inspector subsets, makes interpreting these results difficult.

Table 206. Task H – Inspectors holding a PE license.

Inspector Subset	PE License
Overall Sample	14%
Weld Crack Indication	29%
Multiple Crack Indications	33%
Bolt Defect	12%
Multiple Bolt Defects	20%
Coating Defect	14%
Distortion Defect	20%
No Deficiencies	13%

MANAGEMENT INSPECTION PHILOSOPHY: There are two locations from which inferences regarding this factor can be made. First, the SRQ contained a question regarding whether the management philosophy of their State focused more on identifying all defects in the bridge or on complying with NBIS regulations. Overall, 33 percent of the inspectors reported that their State focuses on complying with the NBIS regulations, while the remainder focused on finding all defects. Similar percentages held for most subsets of inspectors, except for the inspectors who noted a weld defect indication or the flange distortion, 80 and 86 percent, respectively, reported that their State focused on finding defects.

The SRQ also asked inspectors to report the level of control that their managers typically exercised over their inspections. Overall, 27 percent of the inspectors stated that they were provided with a detailed checklist for the inspections, 34 percent were provided with loose guidelines, and 39 percent were allowed to inspect solely using their own inspection knowledge and techniques. In general, these percentages held across the various subsets of inspectors who noted certain deficiency types.

The results presented above indicate that States that focus on finding defects may, in fact, locate more of the defects that occur in their bridge population. However, there is no clear indication that management playing a greater or lesser role in how the inspection is performed will affect the inspection results.

VISION: The near and far visual acuity of each inspector was quantified, with the overall data presented previously. Recall that the use of corrective lenses was allowed during this testing. With regard to this task, inspector visual acuity did tend to correlate with some subsets of inspectors. Specifically, four of the five inspectors who noted the distortion of the flange had 20/16 or better near and far vision in both eyes. The remaining inspector had 20/32 or better near and far vision in each eye. All the inspectors who correctly identified a weld crack indication had at least 20/20 far vision in both eyes and 86 percent had 20/20 near vision. The subset of inspectors who found bolt defects, the coating defect, or no deficiencies at all tended to fall within the overall distribution of inspector visual acuity. The correlation between visual acuity and the inspectors who found the weld or distortion defects may indicate that these types of defects are more likely to be located by inspectors who possess better vision.

ATTITUDE TOWARD WORK: Whether bridge inspectors find their work interesting tends to have a slight effect on the results that the inspector produces. Overall, the SRQ results show that inspectors rated their level of interest in their work at 4.5 on a 1 to 5 scale, with 5 being very interesting. The results for the specific subsets of inspectors are presented in table 207. This table shows that inspectors who noted defects tended to provide ratings slightly above the overall average, with inspectors who found weld crack indication, bolt defects, and coating defects providing a rating of 4.6 and inspectors who found the distortion defect providing a rating of 5.0. The inspectors who did not note any deficiencies provided an average rating of 4.0. Although a one-point difference on this scale is relatively minor, the fact that many of these subsets pass the t-test indicates that this factor may correlate with inspectors who perform differing qualities of inspection.

ENVIRONMENTAL FACTORS: The environmental factors did not have any discernible impact on the findings of this inspection. This is probably due to insufficient variability in the weather conditions encountered. Granted, factors such as these could adversely affect an inspection; however, the results obtained in this study provided no concrete data to support this supposition.

Table 207. Task H – Interest in Bridge Inspection Work.

Inspector Subset	Average	Standard Deviation	Pass t-Test?	
			5% Significance Level	10% Significance Level
Overall Sample	4.5	0.59	N/A*	N/A
Weld Crack Indication	4.6	0.53	No	No
Multiple Crack Indications	4.7	0.58	No	No
Bolt Defect	4.6	0.61	Yes	Yes
Multiple Bolt Defects	4.6	0.70	No	No
Coating Defect	4.6	0.50	Yes	Yes
Distortion Defect	5.0	0.00	Yes	Yes
No Deficiencies	4.0	0.53	Yes	Yes

* N/A = Not applicable.

5.3.3.3.2. Inspection Profiling

OVERVIEW: While each inspector was performing the task, the observer noted how the task was performed and what items were inspected. This information can be used to provide a pseudo-quantitative measure of the thoroughness of each inspection. Although the data collected were not sufficient to aid in the discussion of the identification of bolt, coating, or distortion defects, it was sufficient to provide a relatively complete rating as to the thoroughness of the weld inspection.

The weld inspection portion of Task H was divided into four parts based on the locations within the test bed that were probable places for weld crack indications to occur. These locations included the stiffener-to-girder connections, the drain-to-web connections, the utility bracket-to-web connections, and the lateral bracing-to-web connections. Inspectors were assigned rating points contingent on the thoroughness of their inspection of these areas. The rating point scheme is as follows:

- Stiffener-to-girder connection:
  - 0 points if very few or none of the connections were inspected, or
  - 1 point if most significant top flange connections were inspected, and
  - 1 point if most significant bottom flange connections were inspected.
- Drain-to-web connection:
  - 0 points if none of the connections were inspected, or
  - 1 point if some connections were inspected or if inspections were cursory, or
  - 2 points if all connections were inspected thoroughly.
- Utility bracket-to-web connection:
  - 0 points if none of the connections were inspected, or
  - 1 point if some, but less than 25 percent, of the connections were inspected, or
  - 2 points if between 25 and 75 percent of the connections were inspected, or
  - 3 points if more than 75 percent of the inspections were inspected.
- Lateral bracing-to-web connection:
  - 0 points if none of the connections were inspected, or
  - 1 point if some, but less than 25 percent, of the connections were inspected, or
  - 2 points if between 25 and 75 percent of the connections were inspected, or
  - 3 points if more than 75 percent of the connections were inspected.

This rating system allows each inspector to achieve a rating from 0 to 10 based on the thoroughness of his weld inspection. Note, however, that this rating system focuses on whether the inspector seemed to inspect the general categories of welded connections. It makes no inference as to whether the inspector performed a specific, individual inspection of each weld within the components in a systematic and complete manner that would allow for correct identification of weld crack indications.

RESULTS: The inspector thoroughness ratings were used to classify the inspectors into groups. The groups are defined as those inspectors who received a score of 8 to 10, those who received a score of 5 to 7, and those who received a score of 0 to 4. The following discusses these groupings of inspectors and the factors that tend to correlate with these groupings. Note that other divisions of the inspector sample were also studied, such as inspectors who received scores from 0 to 3, 4 to 6, and 7 to 10. In all cases, slight changes to the groupings of the inspectors provided no substantial change in the results presented in this section.

Forty-five percent of the inspectors earned an inspection thoroughness rating of 8 or higher. These inspectors could be considered to have completed a comparatively thorough In-Depth Inspection of the superstructure. Six of the seven inspectors who correctly identified a weld crack indication were in this group, and 11 of the 12 correct weld crack indication calls came from this group. Also, in terms of correct crack indication calls, a t-test comparison between this group and the remainder of the inspectors not in this group shows that the groups are different at a 5 percent significance level. Even so, the overall accuracy rate for this group at correctly identifying crack indications was only 8.0 percent.

Eighteen percent of the inspectors earned a profile rating from 5 to 7; thus, they are considered to have completed a partial In-Depth Inspection. One of the seven inspectors who correctly identified a weld crack indication fell into this group, accounting for only 1 of the 12 correct weld crack indication calls. The overall accuracy rate for this group for correctly identifying crack indications was 1.9 percent.

Finally, 36 percent of the inspectors earned a rating from 0 to 4. These inspectors can be considered to have performed an incomplete In-Depth Inspection. None of the inspectors who correctly identified a weld crack indication fell into this group.

Table 208 shows the results corresponding to the profile groupings of inspectors with regard to a number of factors. Various trends are evident in this table. Specifically, the inspectors who earned the higher profile ratings tended to take longer to complete the inspection, were generally more mentally focused, and were more comfortable than average when performing the inspection. These inspectors were also more likely to use a flashlight, to expect fatigue-related deficiencies, and to be closer to the welds that they were inspecting. The converse is true for each of these factors for the inspectors who earned the lower inspection profile ratings.

These results demonstrate that the type of inspection an inspector performs will probably have an influence on the type of results obtained. Inspectors who performed a more thorough weld inspection were much more likely to correctly identify a weld crack indication. As stated above, 92 percent of the correct weld crack indication identifications came from this group. The factors that correlate better with the more highly rated group than the other groups are the same factors that intuitively would seem likely to affect this type of inspection. In general, inspectors who received high weld inspection thoroughness ratings were the inspectors who also tended to be focused, had a high tolerance for working at heights, had managers who encouraged them to locate all deficiencies, used the necessary tools, and inspected in the more critical locations.

Table 208. Task H – Inspector profiling results.

Factor	Profile Rating 8-10		Profile Rating 5-7		Profile Rating 0-4	
	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Actual Time to Complete Task (in minutes)	80	24	64	32	48	21
Reported Thoroughness Level	5.6	1.1	5.7	1.2	5.2	0.7
Reported Effort Level	5.3	0.7	5.2	0.9	5.0	0.7
Observed Inspector Focus Level	6.8	0.6	6.3	0.7	4.8	1.3
General Mental Focus	4.7	1.4	4.6	0.5	3.9	0.8
Experience in Bridge Inspection (in years)	8.6	4.6	10.4	5.1	11.0	8.1
Age (in years)	40	5.3	41	4.1	40	8.5
Fear of Heights	3.1	0.6	2.9	0.8	2.8	0.9
Observed Inspector Comfort With Heights	7.6	1.2	6.9	1.7	6.5	1.8
Management Inspection Philosophy: Locate All Defects	74%	N/A*	57%	N/A	62%	N/A
Expected Bridge Deficiencies: Fatigue-Related Deficiencies	70%	N/A	38%	N/A	44%	N/A
Tool Use: Flashlight	85%	N/A	50%	N/A	31%	N/A
Observed Distance to Weld Inspected (in meters)	0.58	0.64	1.01	0.98	1.98	3.6

* N/A = Not applicable.

5.4. STATE-DEPENDENT INSPECTION RESULTS

While performing Tasks A through H, inspectors were asked to follow pre-defined guidelines and to record their findings on NDEVC forms. These guidelines were based on the AASHTO definitions of the various inspection types, and the forms were hybrid forms primarily based on the National Bridge Inventory (NBI) items. Several different inspection formats exist, most notably element-level inspections (for example, the commercially available Pontis program) and NBIS inspections. Since both the procedures and the forms used in Tasks A through H may have been different from those that some inspectors normally use, two additional tasks were developed that allowed inspectors to operate under conditions closer to "normal." The objective of Tasks I and J was to provide insight into the inspection procedures and reporting techniques used by the individual States. These two tasks are referred to as the State-dependent tasks.

5.4.1. State-Dependent Task Descriptions

Inspectors were asked to work in teams while performing Tasks I and J. Teams were to inspect according to their normal procedures and to record information on normal State forms for Task I, and on forms provided by the NDEVC for Task J. Recall that Task I was a Routine Inspection of the southern two spans of the Van Buren Road Bridge, and that Task J was an In-Depth Inspection (delamination survey) of the southern two deck spans. The Van Buren Road Bridge is a three-span bridge with a concrete deck on a steel, multi-girder superstructure. Each span is approximately 18 m in length, and is simply supported. The introductory information on this bridge, given in Appendix C in Volume II, was forwarded to the participating DOTs prior to the arrival of the inspectors. Within this information packet were relevant drawings of the structure, information on traffic volume, and equipment to be brought.

The delamination survey of the deck (Task J) had a flexible format, since it was anticipated that some States might perform Task J within the scope of Task I. To prevent knowledge of a delamination survey task from influencing the activities within the Routine Inspection, information regarding Task J was not divulged until after the completion of the Routine Inspection. Once it was clear that the Routine Inspection was not going to include a delamination survey, Task J was administered. If a delamination survey of the deck was performed to a specified extent, Task J was not administered separately. Details regarding the criteria used to judge the performance of a deck inspection are presented in this chapter with the Task J information.

5.4.2. Inspection Process

As with all other tasks, the observers recorded information before, during, and after the actual performance of the task. The following two sections discuss the data recorded from these observations.

5.4.2.1. TASK I INFORMATION RECORDED BY OBSERVERS

Task I is the Routine Inspection of the Van Buren Road Bridge using individual State procedures. Each team of inspectors was given 2 h to complete the task. The average time taken to complete the inspection was 63 min (standard deviation of 25 min), with times ranging from 27 min to 121 min. The distribution of inspection times is shown in figure 151.

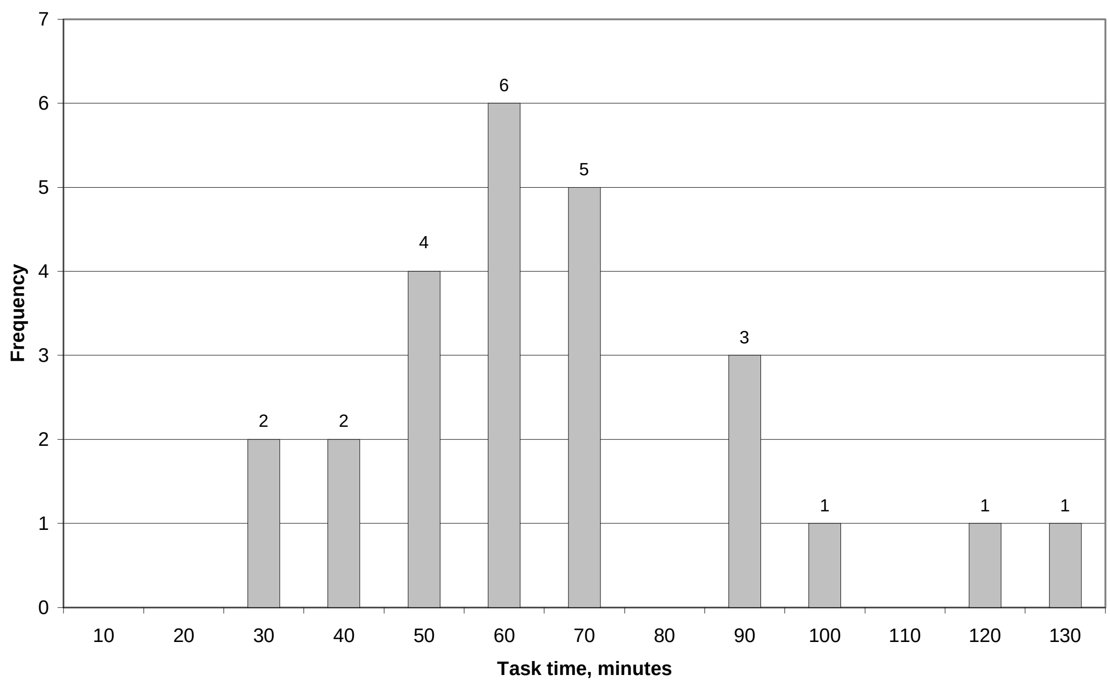


Figure 151. Task I – Actual inspection time.

As in other tasks, pre-task and post-task questionnaires were administered to provide insight into the general condition of the inspectors. Two of the questions asked for information about each inspector, so each individual inspector provided a response. Since the team could prepare for this task in advance, an additional question was asked about the amount of preparation time. Table 209 summarizes all of the responses to the quantitative pre-task questions. The factor Time Since Similar Inspection had a short average period of time of approximately 6 weeks. This is the shortest period of time for any of the tasks. Also, the teams' estimates of the amount of time it would take to inspect this bridge were significantly higher than the actual time spent. As shown in table 209, the estimates ranged from 30 min to 8 h. The average actual inspection time was less than two-thirds of the average estimated time. Of the three teams that had estimates higher than the allotted time, all finished before the expiration of the allotted time. Seven teams took more time than their estimates, but only one team had to be stopped at the end of the allotted time. The distribution of estimated inspection times is shown in figure 152.

Table 209. Task I – Quantitative pre-task questionnaire responses.

	Range of Possible Answers		Inspector Responses			
	Low	High	Average	Standard Deviation	Maximum	Minimum
How long has it been since you completed an inspection of a bridge of this type (in weeks)? (question for individuals)	N/A*	N/A	5.6	8.8	52	1
How long did you spend preparing to complete this inspection prior to arriving at the bridge site (in man-hours)?	N/A	N/A	2.2	3.1	16	0
Given the available equipment and the defined tasks, how long do you think you would normally spend on this inspection (in minutes)?	N/A	N/A	98.4	92.8	480	30
How rested are you? (question for individuals)	1 = very tired	9 = very rested	7.0	1.3	9	4

* N/A = Not applicable.

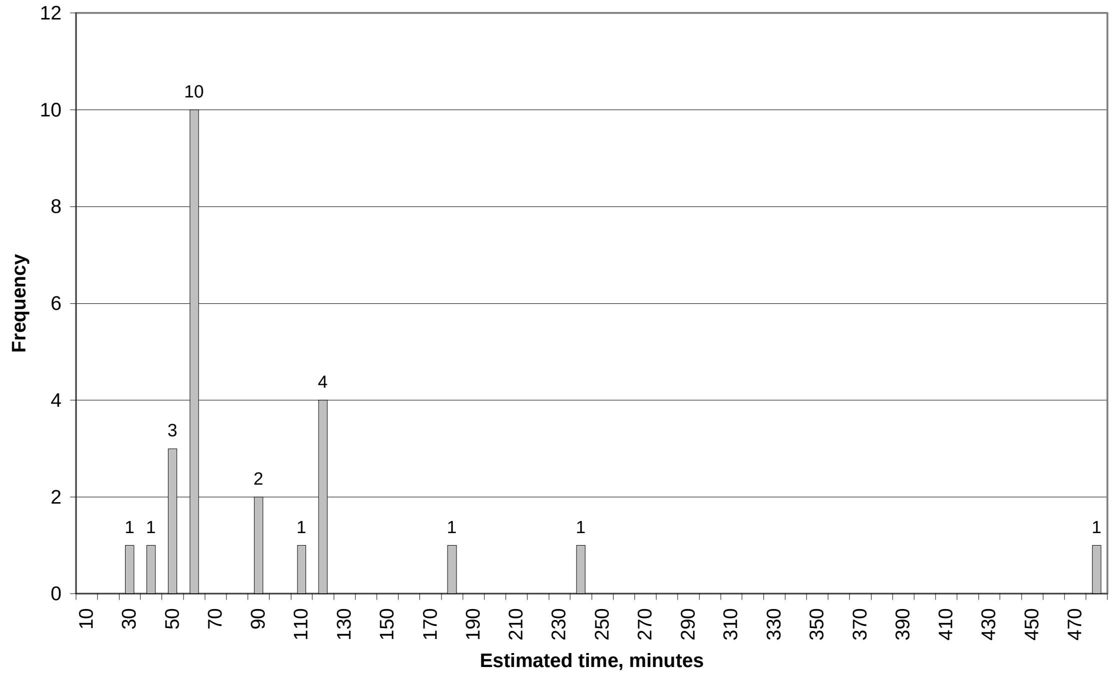


Figure 152. Task I – Predicted inspection time.

Unlike the other tasks, teams only had access to a 6.1-m extension ladder, not the 9.8-m ladders used elsewhere. Since the majority of the superstructure of the Van Buren Road Bridge could be reached from ground level, this ladder was considered adequate for the task. However, to ascertain if any of the participating States would have used different access equipment, one of the questions in the pre-task questionnaire concerned access equipment. Table 210 summarizes the responses to this question. None of the teams indicated that any form of access equipment beyond a ladder would be used to inspect this bridge. Note that 80 percent of the teams indicated that they would use a ladder, even though most of the bridge could be reached from ground level.

Unlike the other tasks, the pre-task question dealing with the description of the structure was not asked, since the plans for the bridge had previously been made available to the teams. However, the pre-task question that focused on what kinds of problems the teams might expect to find during their inspection was asked. The responses are summarized in table 211. Steel corrosion and concrete deterioration were expected by about three-quarters of the teams. All but one of the “Other” responses related to either scour or settlement cracking of the substructure.

As with all of the other tasks, the NDEVC observers recorded the environmental conditions. Tables 212 and 213 summarize the environmental data recorded. Also note the very low measured wind speed. The underside of the Van Buren Road Bridge is sheltered from wind by small trees and brush, creating very still conditions.

Table 210. Task I – Normal access equipment use.

Accessibility Equipment/Vehicle Type	Percentage of Respondents
Snooper	0%
Lift	0%
Ladder	80%
Scaffolding	0%
Climbing Equipment	0%
Permanent Inspection Platform	0%
Movable Platform	0%
None	16%
Other	4%

Table 211. Task I – Problems expected.

Problem Type	Percentage of Respondents
Concrete Deterioration	76%
Steel Corrosion or Section Loss	76%
Fatigue Cracking	40%
Bearing Problems	36%
Deck Delaminations	36%
Joint Deterioration	36%
Underside Deck Cracking	32%
Paint Deterioration	20%
Leakage	12%
Leaching	4%
Impact Damage	4%
Other: Missing/Loose Bolts	4%
Other	16%

Table 212. Task I – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (ºC)	26.8	4.7	35.0	13.9
Humidity (%)	53.9	13.3	83	31
Heat Index (ºC)	27.8	5.6	37.8	13.9
Wind Speed (km/h)	0.5	0.9	3.2	0.0
Light Intensity Within Superstructure (lux)	70	39	172	11
Light Intensity on Deck (lux)	63,100	27,500	104,500	8,040

Table 213. Task I – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	44%
20 – 40% Cloudy	12%
40 – 60% Cloudy	0%
60 – 80% Cloudy	4%
80 – 100% Cloudy	24%
Hazy	8%
Fog	0%
Drizzle	4%
Steady Rain	4%
Thunderstorm	0%

A list was developed detailing items on the bridge that could be inspected. This list, along with the percentage of the teams that inspected each item, is summarized in table 214. The usage percentages are best estimates of what the teams examined; however, some percentages are approximate since some of the individual items were difficult to differentiate in the field. An example of this is “Inspect … bearing location” and “Inspect … bearing rotation.” Without the use of a rotation-measuring device, it was difficult to determine if an inspection at a bearing location included a visual assessment of the rotation. Some of the notable items include the following:

- Approximately 90 percent of the inspection teams inspected the major substructure elements.

Table 214. Task I – Bridge component inspection results.

	Inspection Item	Percentage of Inspectors
General	Check Overall Alignment (West side)	24%
	Check Overall Alignment (East side)	28%
Superstructure	Inspect South Bearing Location	96%
	Inspect South Bearing Rotation	60%
	Inspect Middle Bearing Location	96%
	Inspect Middle Bearing Rotation	64%
	Inspect North Bearing Location	80%
	Inspect North Bearing Rotation	56%
South Span	Inspect Coverplate Terminations	76%
	Inspect for Missing/Loose Bolts	48%
	Inspect Diaphragm Weld Connections	64%
Middle Span	Inspect Coverplate Terminations	76%
	Inspect for Missing/Loose Bolts	52%
	Inspect Diaphragm Weld Connections	60%
Substructure	Inspect South Pier Cap	100%
	Sound South Pier Cap	52%
	Inspect North Pier Cap	96%
	Sound North Pier Cap	28%
	Inspect South Pier Columns	88%
	Sound South Pier Columns	28%
	Inspect North Pier Columns	92%
	Sound North Pier Columns	24%
	Some Substructure Sounding	60%
Deck	Any Deck "Sounding"	80%
	Sound Deck (masonry hammer)	44%
	Chain-Drag Deck (partial)	24%
	Chain-Drag Deck (complete)	36%
	Sound West Parapet	28%
	Sound East Parapet	20%
	Inspect South Expansion Joint	92%
	Inspect Middle Deck Joint	88%
	Inspect North Deck Joint	88%
South Span	Inspect Underside of Deck for Cracking	88%
North Span	Inspect Underside of Deck for Cracking	88%

- About half of the inspection teams did not perform any sounding on the substructure.
- Nearly all of the inspection teams examined the bearing locations.

- About three-quarters of the inspection teams examined the area around the termination of the flange cover plates.
- Almost 90 percent of the inspection teams examined the underside of the deck for cracking.
- Nearly all of the inspection teams examined the deck joints.
- Eighty percent of the inspection teams performed sounding on the top of the deck.

Tool use for Task I was similar to most of the other Routine Inspection tasks. Almost all of the tools used can be placed into four categories: ladder, tape measure, flashlights, and sounding equipment. The two other items used are binoculars (once), and a level used as a straightedge (once). Complete tool use is summarized in table 215.

Table 215. Task I – Use of inspection tools.

Tool	Percentage of Inspectors
Tape Measure	64%
2.4-m Stepladder	0%
6.1-m Extension Ladder	56%
Any Flashlight	44%
Two AA-cell Flashlight	12%
Three D-cell Flashlight	12%
Lantern Flashlight	24%
Any "Sounding" Tool	84%
Masonry Hammer	68%
Chain	48%
Level as a Level	0%
Level as a Straightedge	4%
Binoculars	4%
Magnifying Glass	0%
Engineering Scale	0%
Protractor	0%
Plumb Bob	0%
String	0%
Hand Clamp	0%

A post-task questionnaire was administered following Task I. Responses to these questions are summarized in table 216. Several of the questions solicited individual responses. To present

Table 216. Task I – Quantitative post-task questionnaire responses.

	Range of Possible Answers		Inspector/Team Responses			
	Low	High	Average	Standard Deviation	Maximum	Minimum
Did this task do an accurate job of measuring your inspection skills? (individual question)	1 = not accurate	9 = very accurate	7.9	1.0	9	5
How rested are you? (individual question)	1 = very tired	9 = very rested	6.8	1.3	9	4
How well did you understand the instructions you were given?	1 = very poorly	9 = very well	8.4	0.9	9	5
How accessible do you feel the various bridge components were?	1 = very inaccessible	9 = very accessible	8.2	0.7	9	7
How well do you feel that this bridge has been maintained?	1 = very poorly	9 = very well	6.6	1.3	9	4
How complex was this bridge?	1 = very simple	9 = very complex	3.9	1.2	6	1
Do you think my presence as an observer had any influence on your inspection?	1 = no influence	9 = great influence	1.9	1.3	6	1
Did you feel rushed while completing this task? (individual question)	1 = not rushed	9 = very rushed	2.1	1.8	7	1
What was your effort level on this task in comparison with your normal effort level? (individual question)	1 = much lower	9 = much greater	5.1	0.4	7	4
How thorough were you in completing this task in comparison to your normal inspection?	1 = less thorough	9 = more thorough	5.4	0.8	8	5

these data, answers have been compiled from both inspectors. Since this task asked teams to use their own State procedures, the question about similarity to normal Routine Inspections was not asked. The inspectors indicated that their rested level dropped during the performance of this task, as reflected in the Rested Level Before Task of 7.0 and 6.8 after. The question, “Did this task do an accurate job of measuring your inspection skills?” received a high average response. The average response to this question was 7.9, which, along with Task H, is the highest average response.

5.4.2.2. TASK J INFORMATION RECORDED BY OBSERVERS

Task J was administered in a much more liberal format than any other task. This allowed for observations about the levels of detail of delamination surveys during Routine Inspections. If the delamination survey portion of Task I was deemed thorough enough, Task J was not specifically administered. The two criteria for judging the thoroughness of the Task I inspection were: (1) the use of a systematic approach to cover nearly all of the deck top surface, and (2) the creation of a schematic sketch to indicate the size and extent of the defects discovered. Regardless of the thoroughness of the delamination survey performed as part of Task I, inspectors were allowed the opportunity to perform a further inspection for Task J.

Three inspection teams refused to perform this task. All three refusals came when it was raining at the bridge, with the teams frequently citing that the rain would interfere with the sounding operation.

A total of 2 h were allotted for the completion of this task. The average time spent was 36 min (standard deviation of 27 min), with a range from 8 min to 105 min. Note that the teams that performed Task J within Task I do not have time records; therefore, the average time does not include these teams. Furthermore, three teams performed the delamination survey in less than 20 min.

It was anticipated that some teams might perform Task J within Task I. Therefore, pre- and post-task questionnaires were not uniformly administered, and the results are not presented.

Typical environmental measurements were recorded. A light intensity measurement was always taken on the deck surface, while temperature, humidity, and wind measurement locations varied. When a team completed Task J as part of Task I, these measurements were taken from under the deck, as in Task I. If Task J was administered separately, these measurements were taken above the deck. The under-deck measurements are not included with the Task J environmental measurements summarized in table 217.

Again, a qualitative descriptor was included to further describe the environmental conditions under which each task was performed. As shown in table 218, the task was never performed in the rain.

Observers tracked the methods used to evaluate the condition of the deck. Hammer use and chain-drag use are summarized in table 219. An additional category was tracked for the inspection teams that performed Task J, noting whether they refined the shape of suspect areas once they were discovered. However, since this information was not tracked for those who performed Task J as part of Task I, it is omitted from this presentation.

Table 217. Task J – Direct environmental measurements.

Environmental Measurement	Average	Standard Deviation	Maximum	Minimum
Temperature (ºC)	30.5	3.9	37.2	22.8
Humidity (%)	48.3	10.8	74	33
Wind (km/h)	2.0	2.8	9.7	0.0
Heat Index (ºC)	33.0	6.2	45.9	22.8
Light Intensity on Deck (lux)	67,400	27,500	109,400	17,000

Table 218. Task J – Qualitative weather conditions.

Weather Condition	Percentage of Inspections
0 – 20% Cloudy	62%
20 – 40% Cloudy	10%
40 – 60% Cloudy	10%
60 – 80% Cloudy	5%
80 – 100% Cloudy	5%
Hazy	10%
Fog	0%
Drizzle	0%
Steady Rain	0%
Thunderstorm	0%

Table 219. Task J – Bridge component inspection results.

	Inspection Item	Percentage of Teams
Deck	Some Deck Sounding	100%
	Sound Deck (Chain-drag)	90%
	Sound Deck (Hammer)	33%

No inspection teams used any tools beyond the basic masonry hammer, tape measure, and chain to perform Task J. A usage breakdown of these three items is summarized in table 220.

Table 220. Task J – Use of inspection tools.

Tool	Percentage of Teams
Any "Sounding" Tool	100%
Chain	90%
Masonry Hammer	43%
Tape Measure	71%

Since some teams performed Task J within Task I, the post-task questionnaires were not administered. Therefore, there is no post-task data to report.

5.4.3. Task I

Task I results are summarized in four sections. First, the notable procedural differences observed between the inspection teams are presented. Second, reporting format differences are discussed. Next, a statistical evaluation of the Condition Ratings is discussed. Finally, observations of the element-level inspection results are presented.

5.4.3.1. PROCEDURAL VARIATIONS

One of the goals of the State-dependent tasks was to study procedural similarities and differences in the inspection techniques used by the States. Procedural similarities and differences for the task that have been noted are presented in the following section.

Teamwork between the participating inspectors was an aspect of Task I that varied between the individual teams. Before discussing aspects of how the inspectors worked together, it is first important to establish which teams arrived as working partners and which teams were assembled for this study. A nearly even division was present, with 11 pre-existing teams, and 13 assembled teams out of the 24 total teams. The 25th State only sent one individual, so therefore this inspector is not a member of either of the team groupings.

The inspection styles varied considerably. Some teams had a very experienced inspector primarily taking notes, while the less experienced partner performed most of the observations. The converse was also observed, where the senior inspector performed most of the observations and dictated notes to the partner. Alternately, a number of teams performed the inspection with a relatively equal distribution of note-taking and inspection. Some of these equal partnerships inspected independently, while others inspected jointly. To summarize the different styles, teams were categorized by two sets of descriptors. One descriptor characterized the division of labor between the two inspectors, the other characterized the relationship between the two inspectors. The division of labor was characterized by the following categories: worked together, inspector and note-taker, and independent inspectors (with or without consultation). The relationship category was characterized by the following categories: equals, leader/inspector, and leader/helper. Both descriptors also needed the "Unclassified" category to be able to completely capture all of the teams. A description matrix is presented in figure 153, summarizing the criteria used to categorize the different teams. Figure 154 summarizes the total number of teams in each combination, while figures 155 and 156 present the number of teams in each category for pre-existing teams and assembled teams, respectively. As shown in the figures, 9 of the 11 pre-existing teams performing Task I were judged to have worked with a degree of hierarchy (such as leader/helper or leader/inspector). Along similar lines, 11 of the 13 assembled teams worked as equals.

5.4.3.2. REPORTING VARIATIONS

Significant differences were observed in the reports resulting from this inspection task. While most of these differences are form and format-related, there are other more important differences as well.

		Relationship			
		Equals	Leader/Inspector	Leader/Helper	Unclassified
Division of Labor	Worked Together	Inspectors generally looked at inspection areas together and conferred. No clear leadership role assumed.	Inspectors generally looked at inspection areas together. Clear leadership role assumed by one person. Subordinate knowledgeable inspector with some independence.	Inspectors generally looked at inspection areas together. Clear leadership role assumed by one person. Subordinate working at the direction of the leader.	Inspectors generally worked together. No noted leadership division.
	Inspector and Note-Taker	One inspector and one note-taker. No clear leadership role assumed.	One inspector and one note-taker. Clear leadership role assumed by one person. Subordinate knowledgeable inspector with some independence.	One inspector and one note-taker. Leader either directs helper's inspection or dictates inspection notes.	One inspector and one note-taker. No noted leadership division.
	Independent Inspectors	Inspectors divided the inspection task and inspected separately. Inspectors may or may not have conferred. No clear leadership role assumed.	Inspectors divided the inspection task and inspected separately. Inspectors may or may not have conferred. Clear leadership role assumed by one person. Subordinate knowledgeable inspector with some independence.	Inspectors divided the inspection task and inspected separately. Inspectors may or may not have conferred. Leader makes inspection decisions with little input from helper.	Inspectors divided the inspection task and inspected separately. Inspectors may or may not have conferred. No noted leadership division.
	Unclassified	No noted teamwork aspects. No clear leadership role assumed.	No noted teamwork aspects. Clear leadership role assumed by one person. Subordinate knowledgeable inspector with some independence.	No noted teamwork aspects. Clear leadership role assumed by one person. Subordinate working at the direction of the leader.	No noted teamwork aspects. No noted leadership division.

Figure 153. Inspection team characterization criteria matrix.

	Equals	Leader/ Inspector	Leader/ Helper	Unclassified
Worked Together	5	0	1	1
Inspector and Note-Taker	1	3	0	0
Independent Inspectors	5	2	3	0
Unclassified	1	1	0	1

Figure 154. Overall inspection team characterization matrix of data.

	Equals	Leader/ Inspector	Leader/ Helper	Unclassified
Worked Together	0	0	1	1
Inspector and Note-Taker	0	3	0	0
Independent Inspectors	1	1	3	0
Unclassified	0	1	0	0

Figure 155. Pre-existing team characterization matrix of data.

	Equals	Leader/ Inspector	Leader/ Helper	Unclassified
Worked Together	5	0	0	0
Inspector and Note-Taker	1	0	0	0
Independent Inspectors	4	1	0	0
Unclassified	1	0	0	1

Figure 156. Assembled team characterization matrix of data.

5.4.3.2.1. Form Preparation

Preparation was one area where there were significant differences observed. There are three primary areas in which inspectors spent time preparing for this task: (1) Structure Inventory and Appraisal (SI&A) forms, (2) other forms for the condition report, and (3) physical/mental preparation (non-form related). Of these three areas, any time spent for physical/mental preparation is often personal, and therefore, there will be no tangible evidence of the time spent. No conclusions can be made regarding this component of the preparation time. No specific instructions were given regarding SI&A forms for Task I. Submission of SI&A forms was welcome; but was not expected since the majority of this information is fixed, with very little field data. Only nine States prepared SI&A forms for inclusion in their report.

For the main condition reports, teams have been subdivided into three groups based on the level of preparation that can be observed in their reports. Table 221 summarizes the Reported Preparation Time data for the "No Preparation Observed" group, the "Some Preparation Observed" group, and the "Indeterminate Preparation" group. As shown in table 221, 13 States had no apparent preparation for their forms. These 13 States may have done some other types of preparation or selected appropriate generic forms; however, this is not reflected in the group division. Six States had obviously made some preparations for their forms prior to arrival. The remaining six States had an indeterminate level of preparation. This level is indeterminate because they only submitted a final computer-generated report, with no intermediate notes (i.e., the level of preparation could not be ascertained from the final work product). The average Reported Preparation Time for those with evidence of preparation is 4.4 man-hours, while the average for the indeterminate group is 1.5 man-hours. Of the indeterminate preparation group, two teams indicated that less than 0.5 man-hours had been spent in Reported Preparation Time, which indicates that form preparation was not likely for those two teams. It is not discernable how the other four teams in the indeterminate group spent their time preparing for Task I.

Overall, the inspection teams indicated an average Reported Preparation Time of 2.2 man-hours (standard deviation of 3.1), with responses ranging from 0 to 16 man-hours. Only two teams indicated that no preparation work had been performed prior to arrival at the bridge site. One of these teams departed their home State early and did not receive the Advance Information Packet in time to make any preparations prior to arrival.

Table 221. Task I – Reported Preparation Time.

Preparation Group	Reported Preparation Time (in man-hours)				
	Number of Teams	Average	Standard Deviation	Minimum	Maximum
No Preparation Observed	13	1.5	1.0	0	3
Some Preparation Observed	6	4.4	5.8	1	16
Indeterminate Preparation	6	1.5	1.4	0.25	4
≤ 0.5 man-hours	2	0.4	0.2	0.25	0.5
> 0.5 man-hours	4	2.1	1.3	1	4
Overall	25	2.2	3.1	0	16

5.4.3.2.2. Inspection Report Presentation

Reports that were submitted generally fell into one of three categories. The first category includes teams that submitted an apparently final report that was filled out by hand in the field. This category includes hand-coded reports ready for data entry by others, but excludes field-generated, computer-processed reports. A second category includes those teams that submitted a complete inspection report; however, from sample reports provided, it is clear that the reports were not yet in their final form. The third category includes teams that submitted a final report similar to their sample reports. These reports were computer-generated, and these teams had either asked to take their data back to their office to generate the final report or had the use of a portable computer to generate the report in the field. These computer reports ranged from line-item data summaries to word-processed inspection reports. Some printouts were mere listings of information without formatting, while others used boxes, color, and other formatting techniques to make the information stand out.

Nine teams submitted field-written final reports; 4 teams submitted field-written intermediate reports; and 11 teams submitted computer-generated final reports. Sample pages of each style are shown in figures 157 through 163. Figures 157 through 159 are from a single field-written final report; figures 160 and 161 are from a single field-written intermediate report; and figures 162 and 163 are from a single computer-generated final report. In these sample report pages, specific information that could identify any individual performing the inspection or their corresponding State has been blacked out. These figures illustrate some of the ranges of information density per page and the readability of the reports. Note that these figures are all

[redacted]

DEPARTMENT OF TRANSPORTATION

Bridge Condition Coding Form

County:	
Route:	
Special Case:	
County Sequence:	
Log Mile:	

Bridge Number: (Includes Item 5A) Van Buren

Feature Intersected:

CODE ONLY THOSE NUMBERS WHICH HAVE CHANGED

ITEM #	DESCRIPTION	VALUE
90	INSPECTION DATE	06/09/99
10	MINIMUM V.C. OVER DECK (ROADWAY + SHOULDERS)	99 FT. 99 IN.
520	MINIMUM V.C. OVER DECK (EXCLUDES SHOULDERS)	99 FT. 99 IN.
54	MINIMUM VERTICAL UNDERCLEARANCE (EXCLUDES SHOULDERS) Circle One: H R (N)	00 FT. 00 IN.
36	TRAFFIC SAFETY FEATURES: Br. Rail 1, Trans. 0, Appr. Rail 0, Appr. Rail Ends 0	
41	STRC OPEN/CLOSED/POSTED A K P	A
58	DECK	5
59	SUPERSTRUCTURE	6
60	SUBSTRUCTURE	6
61	CHANL/CHANL PROTECTION	7
62	CULVERT AND RETAIN WALL	N
72	APPROACH RDWY ALIGNMENT (USE VALUES OF 3, 6, OR 8)	6

OVERALL CONDITION (Circle One)

GOOD (FAIR) POOR CRITICAL

SIGNATURE

[redacted]

DATE

COMMENTS

RATINGS FOR CODING ITEMS 58, 59, 60 AND 62

N NOT APPLICABLE

9 EXCELLENT CONDITION

8 VERY GOOD CONDITION - NO PROBLEMS NOTED.

7 GOOD CONDITION - SOME MINOR PROBLEMS.

6 SATISFACTORY CONDITION - MINOR DETERIORATION OF STRUCTURAL ELEMENTS.

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 SERIOURSLY 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 STRUCTURAL STABILITY. BRIDGE IS CLOSED TO TRAFFIC BUT CORRECTIVE ACTION MAY PUT BACK IN LIGHT SERVICE.

0 FAILED CONDITION - OUT OF SERVICE AND BEYOND CORRECTIVE ACTION.

Figure 157. Sample Condition Rating page from a field-written final report.

[redacted] BRIDGE LOCATION NO. Van Buren - - (CO. ROUTE LOG MILE) Page No. [redacted]

DATE: [redacted]

SUBSTRUCTURE

ABUTMENTS

		COMMENTS
CAPS	(G) F P C	Lt debris on bridge seat
BREASTWALL	G F P C	N/A
WINGS	(G) F P C	
BACKWALL	(G) F P C	slight scale, water stains
PLUMB	(G) F P C	
FOOTING	G F P C	Not visible
PILES	G F P C	" "
EMBANKMENT	(G) F P C	
BEARING SURFACE	(G) F P C	
SLOPE PAVING	(G) F P C	
RIP RAP	G F P C	N/A

PIERS N/A

CAPS	G F P C	
COLUMNS	G F P C	
PLUMB	G F P C	
FOOTINGS	G F P C	
PILES	G F P C	
BEARING SURFACE	G F P C	

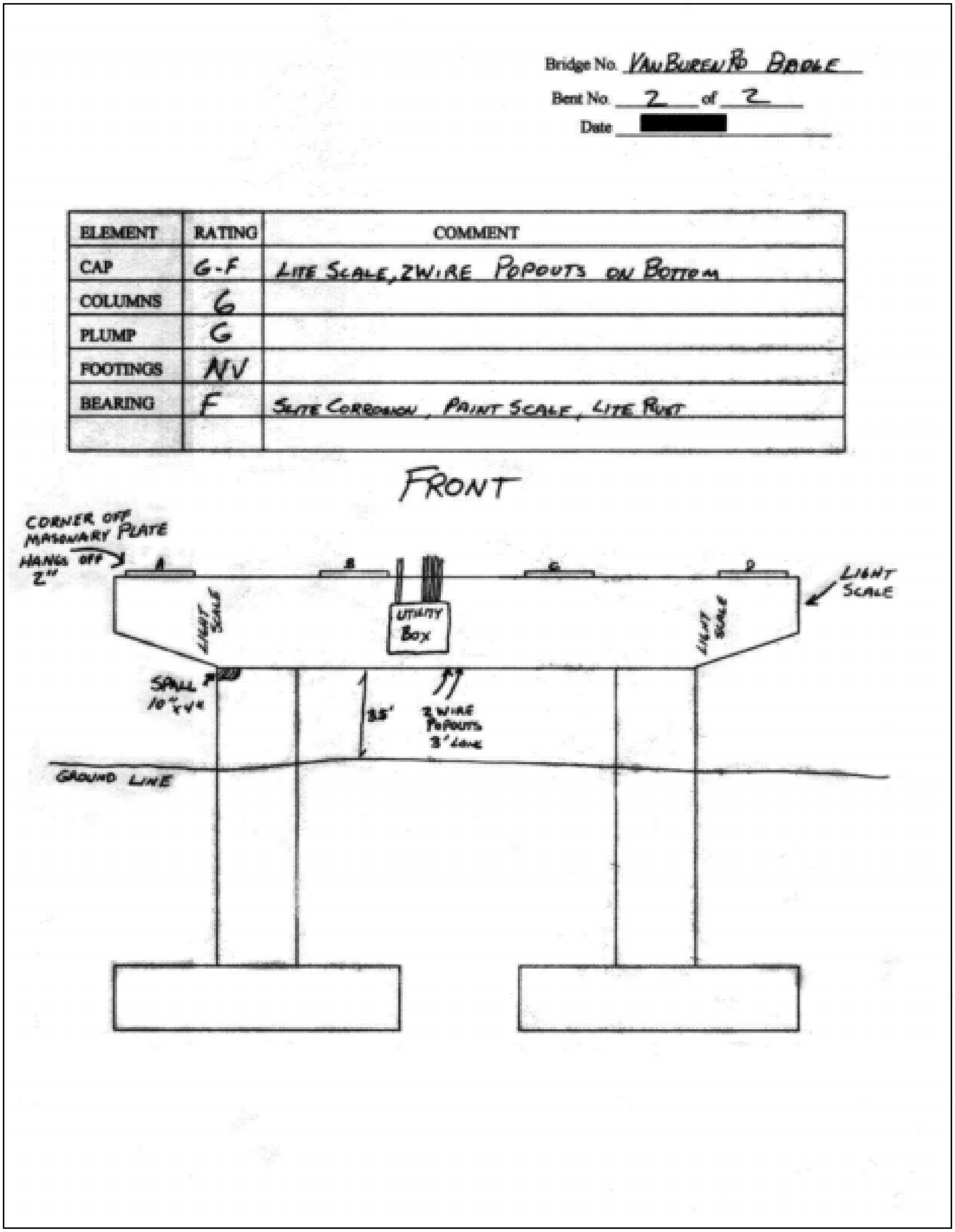
BENTS

CAPS	(G) F P C	wire popouts, rebar spall
COLUMNS	(G) F P C	"
PLUMB	(G) F P C	
FOOTINGS	G F P C	not visible
PILES	G F P C	" "
BEARING SURFACE	(G) F P C	

PILES NEED REPLACEMENT NO [ ] YES [ ]

PILES TO BE REPLACED: PILE BENT PILE BENT PILE BENT PILE BENT PILE BENT

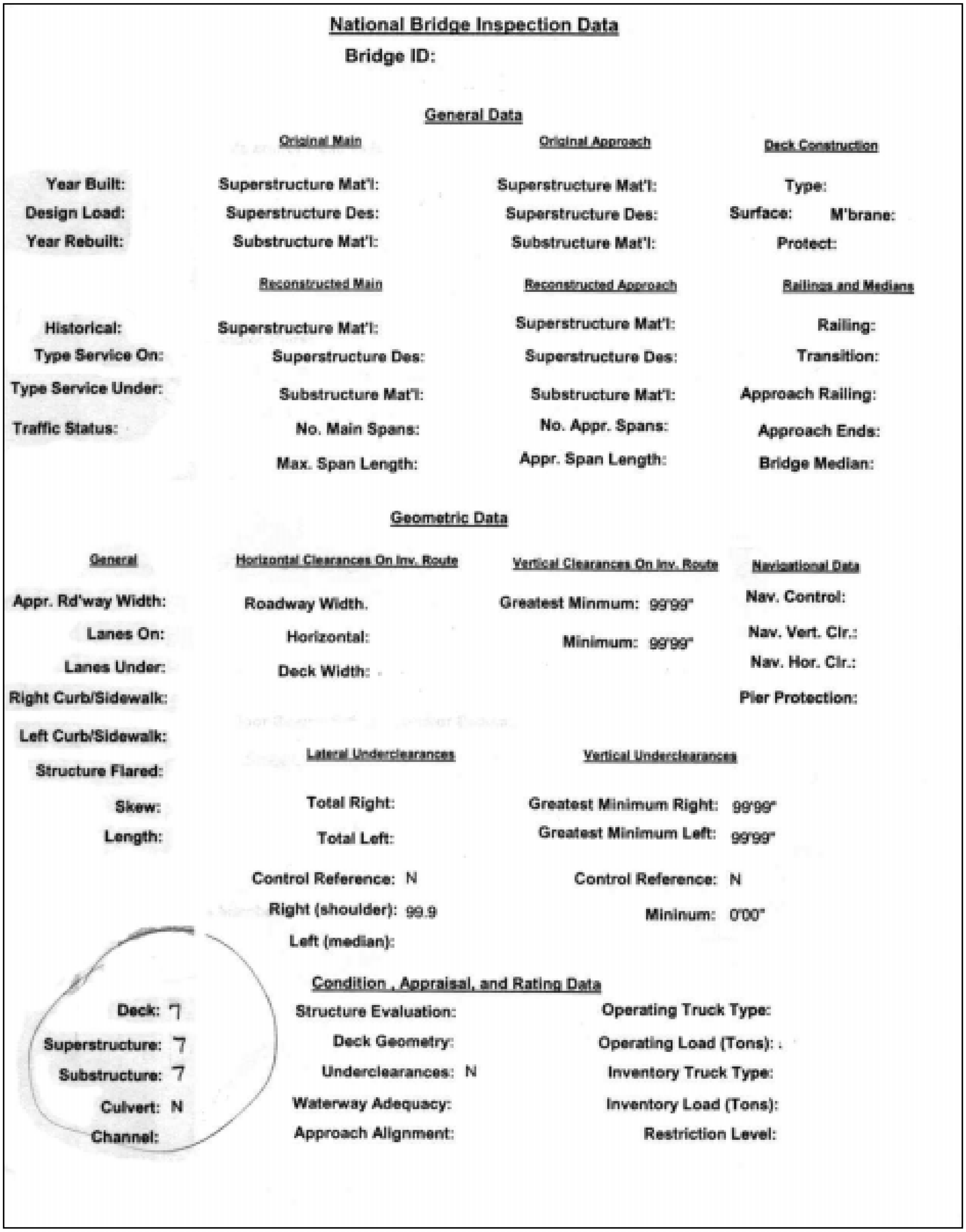
Figure 158. Sample substructure page from a field-written final report.



Bridge No. VANBUREN RD BRDGE
Bent No. 2 of 2
Date [redacted]

ELEMENT	RATING	COMMENT
CAP	G-F	LITE SCALE, 2WIRE POPOUTS ON BOTTOM
COLUMNS	G	
PLUMP	G	
FOOTINGS	NV	
BEARING	F	SLITE CORROSION, PAINT SCALE, LITE RUST

Figure 159. Sample substructure worksheet page from a field-written final report.



National Bridge Inspection Data

Bridge ID:

General Data

Original Main | Original Approach | Deck Construction

Year Built:
Design Load:
Year Rebuilt:

Superstructure Mat'l:
Superstructure Des:
Substructure Mat'l:

Superstructure Mat'l:
Superstructure Des:
Substructure Mat'l:

Type:
Surface: M'brane:
Protect:

Reconstructed Main | Reconstructed Approach | Railings and Medians

Historical:
Type Service On:
Type Service Under:
Traffic Status:

Superstructure Mat'l:
Superstructure Des:
Substructure Mat'l:
No. Main Spans:
Max. Span Length:

Superstructure Mat'l:
Superstructure Des:
Substructure Mat'l:
No. Appr. Spans:
Appr. Span Length:

Railing:
Transition:
Approach Railing:
Approach Ends:
Bridge Median:

Geometric Data

General | Horizontal Clearances On Inv. Route | Vertical Clearances On Inv. Route | Navigational Data

Appr. Rd'way Width:
Lanes On:
Lanes Under:
Right Curb/Sidewalk:
Left Curb/Sidewalk:
Structure Flared:
Skew:
Length:

Roadway Width.
Horizontal:
Deck Width:

Greatest Minmum: 99'99"
Minimum: 99'99"

Nav. Control:
Nav. Vert. Clr.:
Nav. Hor. Clr.:
Pier Protection:

Lateral Underclearances

Total Right:
Total Left:
Control Reference: N
Right (shoulder): 99.9
Left (median):

Vertical Underclearances

Greatest Minimum Right: 99'99"
Greatest Minimum Left: 99'99"
Control Reference: N
Mininum: 0'00"

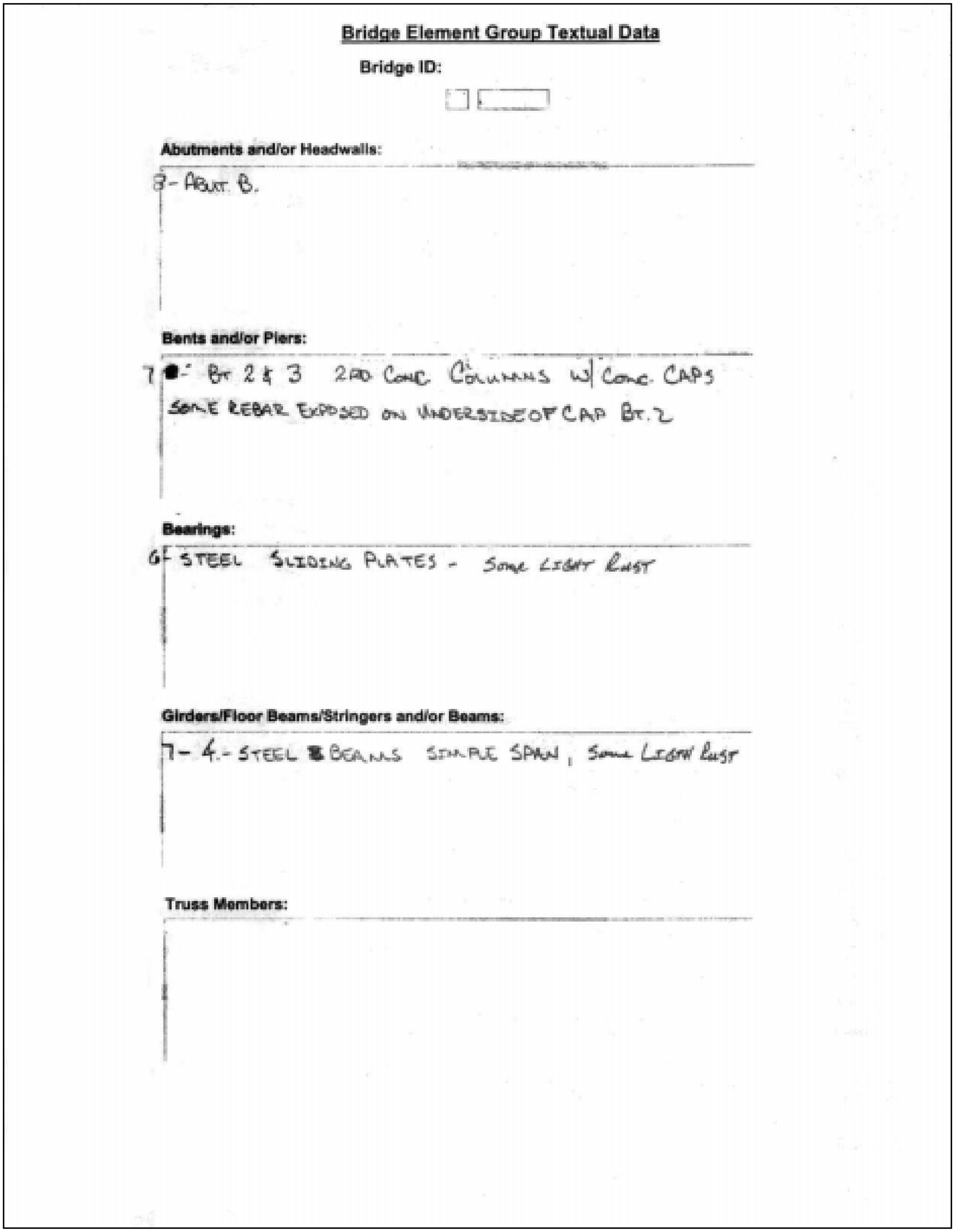
Condition , Appraisal, and Rating Data

Deck: 7
Superstructure: 7
Substructure: 7
Culvert: N
Channel:

Structure Evaluation:
Deck Geometry:
Underclearances: N
Waterway Adequacy:
Approach Alignment:

Operating Truck Type:
Operating Load (Tons):
Inventory Truck Type:
Inventory Load (Tons):
Restriction Level:

Figure 160. Sample Condition Rating page from a field-written intermediate report.



Bridge Element Group Textual Data

Bridge ID:

Abutments and/or Headwalls:

8 - ABUT. B.

Bents and/or Piers:

7 - BT 2 & 3 2 RD CONC. COLUMNS W/ CONC. CAPS

SOME REBAR EXPOSED ON UNDERSIDE OF CAP BT. 2

Bearings:

6 - STEEL SLIDING PLATES - SOME LIGHT RUST

Girders/Floor Beams/Stringers and/or Beams:

7 - 4. - STEEL BEAMS SIMPLE SPAN, SOME LIGHT RUST

Truss Members:

Figure 161. Sample notes page from a field-written intermediate report.

[redacted]

PAGE 1 OF 3

STRUCTURES INSPECTION FIELD REPORT
ROUTINE INSPECTION

2-DIST	B.I.N.	BR. DEPT. NO.

CITY/TOWN	8-STRUCTURE NO.	11-KILO. POINT	41-STATUS	90-ROUTINE INSP DATE
			OPEN-A	[redacted]

07-FACILITY CARRIED	MEMORIAL NAME/LOCAL NAME	27-YR BUILT	106-YR REBUILT	YR REHAB'D (NON 106)
VAN BUREN RD		1960	0000	

06-FEATURES INTERSECTED	26-FUNCTIONAL CLASS.	DISTRICT BRIDGE INSPECTION ENGINEER
QUANTICO CREEEK		

43-STRUCTURE TYPE	22-OWNER	21-MAINTAINER	TEAM LEADER:
STEEL STRINGER/MULTI-BEAM			[redacted]

107-DECK TYPE	WEATHER	TEMP. (air)	TEAM MEMBERS
CONCRETE CAST-IN-PLACE	SUNNY	24 C	[redacted]

ITEM 58 — DECK: 6

DECK		DEF
1. Wearing surface	N	
2. Deck Condition	6	M/P
3. Stay in place forms	N	
4. Curbs	7	
5. Median	N	
6. Sidewalks	N	
7. Parapets	N	
8. Railing	7	M/P
9. Anti Missile Fence	N	
10. Drainage System	7	
11. Lighting Standards	N	
12. Utilities	N	
13. Deck Joints	6	M/P
14.		
15.		
16.		

CURB REVEAL (in millimeters): N/E 230; S/W 230

APPROACHES		DEF
a. Appr. pavement condition	N	
b. Appr. Roadway Settlement	N	
c. Appr. Sidewalk Settlement	N	

OVERHEAD SIGNS (Attached to bridge) (Y/N): N

		DEF
a. Condition of Welds	N	
b. Condition of Bolts	N	
c. Condition of Signs	N	

ITEM 59 — SUPERSTRUCTURE: 7

SUPERSTRUCTURE		DEF
1. Stringers	N	
2. Floorbeams	N	
3. Floor System Bracing	N	
4. Girders or Beams	7	
5. Trusses - General	N	
a. Upper Chords	N	
b. Lower Chords	N	
c. Web Members	N	
d. Lateral Bracings	N	
e. Sway Bracings	N	
f. Portals	N	
g. End Posts	N	
6. Pin & Hangers	N	
7. Conn Pl't's, Gussets & Angles	7	
8. Cover Plates	7	
9. Bearing Devices	7	
10. Diaphragms/Cross Frames	7	
11. Rivets & Bolts	7	
12. Welds	7	
13. Member Alignment	8	
14. Paint/ Coating	6	M/P
15.		
Year Painted:	X	

COLLISION DAMAGE: Please explain: None (X) Minor ( ) Moderate ( ) Severe ( )

LOAD DEFLECTION: Please explain: None ( ) Minor (X) Moderate ( ) Severe ( )

LOAD VIBRATION: Please explain: None ( ) Minor (X) Moderate ( ) Severe ( )

Any Fracture Critical Member : (Y/N) N

Any Cracks : (Y/N) N

ITEM 60 — SUBSTRUCTURE: 7

SUBSTRUCTURE	Dive Rpt.	This Rpt.		DEF
1. Abutments			7	
a. Pedestals	N	7		
b. Bridge Seats	N	7		
c. Backwalls	N	7		M/P
d. Breastwalls	N	7		M/P
e. Wingwalls	N	8		
f. Slope Paving/Rip-Rap	N	8		
g. Pointing	N	N		
h. Footings	N	H		
i. Piles	N	N		
j. Scour	N	8		
k. Settlement	N	8		
l.				
m.				
2. Piers or Bents			7	
a. Pedestals	N	7		
b. Caps	N	7		M/P
c. Columns	N	7		M/P
d. Stems/Webs/Pierwalls	N	N		
e. Pointing	N	N		
f. Footing	N	H		
g. Piles	N	N		
h. Scour	N	7		
i. Settlement	N	8		
j.				
k.				
3. Pile Bents			N	
a. Pile Caps	N	N		
b. Piles	N	N		
c. Diagonal Bracing	N	N		
d. Horizontal Bracing	N	N		
e. Fasteners	N	N		

UNDERMINING (Y/N) If YES please explain: N

COLLISION DAMAGE: None (X) Minor ( ) Moderate ( ) Severe ( )

I-60 (Dive Report): N   I-60 (This Report): 7

93b-U/W (DIVE) INSP DATE: N 00

X=UNKNOWN N=NOT APPLICABLE H=HIDDEN/INACCESSIBLE R=REMOVED

[redacted]

Figure 162. Sample Condition Rating page from a computer-generated final report.

PAGE 3 OF 3

CITY/TOWN	B.I.N.	BR. DEPT. NO.	8-STRUCTURE NO.	INSPECTION DATE
				[redacted]

REMARKS, SKETCHES & PHOTOS

DECK

58-2- The top side of the deck has hairline transverse cracking at the center of roadway with numerous hollow areas throughout. In span #2 there is random hairline map cracking.

58-8- The west rail south end has two nuts not seated properly at the base plate. At post #3 there is one anchor nut missing. The east rail south end has one bolt sheared off at the base plate. There are numerous heavily rusted anchor nuts at both railings.

58-13- At the south abutment the preformed filler is missing a small section in the northbound roadway. The filler is missing completely at pier #1. At pier #2 there are two areas where the filler is missing at the western third of the roadway.

SUPERSTRUCTURE

59-14- There is minor to moderate rust throughout the paint at pier #1 and pier #2 bearings. There is very minor rusting of the bottom flanges of the stringers and bottom of interior diaphragms in span #1. In span #2 there is less rusting at similar locations.

NOTE: There are four 1/4" drill holes in the web of beam #31 at pier #2.

SUBSTRUCTURE

60-1c- The south backwall has two hairline vertical cracks.

60-1d- The south breastwall has two hairline vertical cracks.

60-2b- There is minor scaling at the rounded edge at the west end of pier #1. Pier #2 cap south face has a 4.5 foot long hairline horizontal crack at the top between beams #32 and #33.

60-2c- There is minor abrasion at the bottom two feet above the mudline at the upstream column at pier #1. At pier #2 the downstream column has minor scaling directly below the north face of the cap.

Figure 163. Sample notes page from a computer-generated final report.

excerpts from larger reports, none of which are presented in their entirety. In addition, note that the shortest report fit on 1 page, while the longest was 29 pages. Despite the drastic length differences, the same basic information was contained in most of the reports.

5.4.3.2.3. NBI vs. Element-Level Assessments

There were three different styles used in the reports to describe the condition of the bridge. The first style was an NBI-oriented format. This style presents the Condition Ratings in the NBI line-item style. This style may include element-level assessments, but only as supplementary information. Excerpts from an NBI-oriented format are shown in figures 157 and 163. The second primary style used the Pontis program or another element-level format, as shown in figure 164. This format typically will include the NBIS ratings, but the element-level ratings are incorporated into the report as primary information. The NBIS ratings may, or may not, be calculated from the element-level information. The third inspection style was a pure notation format, where conditions were noted in longhand. An example of the pure notation format is shown in figure 161. Thirteen of the reports have been categorized as NBI-style, nine as element-level style, and three as notation style. Some of the reports share aspects of both categories, especially the computer printouts generated after the inspection. In general, if the element-level assessments were an integral part of the report, it was considered to be element-level style, and if the element-level assessments were included as supplemental worksheets, it was considered to be NBI style. Just over half of the NBI-style reports (7 of the 13 reports) were supplemented with element-level data. Two of the three notation-style formats included other sample information that made it obvious that the notes would normally be entered into bridge inventory software packages.

Nineteen of the reports had a section that dealt with maintenance recommendations, with 18 of these providing some recommendations in that section. None of the remaining five reports contained any comments regarding maintenance recommendations. Figures 165 and 166 illustrate examples of maintenance recommendation sections. Table 222 summarizes the items listed for maintenance actions by the various inspection reports. As shown in table 222, the most common repair recommendation was to clean and seal the joints, followed by cleaning [redacted] **BRIDGE INSPECTION REPORT** Agency [redacted]

Page 1 of 2

[redacted]

Bridge No.	000/TASK3			Structure Type	SS
Bridge Name	VAN BUREN ROAD	Route		Intersecting	QUANTICO CREEK
Structure ID	000TASK3	MilePost 0		Location	

Inspection Date [redacted]
Inspection Hours 002.0

Inspector's Signature [redacted] Indent# D2000 Co-Inspector's Signature [redacted]

	Structural Adqcy (501)	7	Drains (509)	0	Bridge Rails (536)	Y	Repair Flag (550)
	Deck Geometry (502)	7	Curbs (521)	0	Transition (536)		Card Check Flag (551)
	Underclearance (503)	9	Sidewalks (522)	0	Guardrails (536)		Photos Flag (552)
5	Operating Level (504)	7	Paint (524)	0	Terminals (536)	S	Seasonal Code (553)
8	Alignment Adqcy (505)	8	Chan/Protection (529)	0	Number Utilities (525)	Y	Soundings Flag (554)
8	Waterway Adqcy(506)	1	Pier/Abut/Protect (531)		Revise Rating (540)		Measure Clearance (555)
6	DeckOverall (507)	6	Scour (532)	0 12	Inspection Frequency(539)	Y	Monitor Structure (556)
6	Superstructure (513)	6	Aproach/Rdwy (533)				
7	Substructure (526)	9	Retaining Walls (534)				
9	Culvert (530)	9	Pier Protection (535)	L 50 7 8	Deck Scaling(512)		Sufficiency Rating

Elem	Element Description	Total	Units	Env	State1	State2	State3	State4	State5
12	Concrete Deck	3672	SF	3	3672	0	0	0	0
90	Steel Rolled Girder-Painted	724	LF	3	724	0	0	0	0
205	Concrete Col/Pile Extension	4	EA	3	4	0	0	0	0
215	Concrete Abutment	80	LF	3	80	0	0	0	0
220	Conc Submerged Pile Cap/Footing	2	EA	3	2	0	0	0	0
234	Concrete Pier Cap	51	LF	3	51	0	0	0	0
311	Moveable Bearing (Roller,Sliding)	16	EA	3	0	16	0	0	0
313	Fixed Bearing	16	EA	3	0	16	0	0	0
331	Concrete Bridge Railing	368	LF	3	368	0	0	0	0
361	Scour	1	EA	3	1	0	0	0	0
404	Compression Seal / Concrete Header	84	LF	3	37	20	27	0	0

0 Routine Inspection on Test Bridge - Van Buren Road Bridge - Task #3
The orientation is from south to north.

12 CONCRETE DECK:
Worn to aggregate in wheel lines. Scattered transverse cracks. A few pop-outs and mudball voids. Chain dragged the southbound lane - 5%-20% surface delaminated. Light scale throughout. Minor "D" cracks forming at joints.

Longitudinal and transverse hairline cracks in soffit.

90 STEEL PAINTED BEAMS:
There are four lines of steel beams laterally braced at 1/4 points. The intermediate diaphragm supports are welded to the webs of beams, many appear cracked - rusty cracked paint along the vertical welds, could not clean to verify. The beams have bottom cover plates and cracks appear to have started at south ends of beams 1C and 2B and north end of 1D.

205 CONCRETE COLUMNS:
2 concrete columns at each pier. Pier 3 has light water abrasion and numerous popouts at the waterline. Scattered hairline cracks.

215 CONCRETE ABUTMENTS:
No defects observed.

311 MOVABLE BEARINGS:
Movable bearings at the north end of each beam. Some pack rust forming between support plate and bearing, surface rust throughout.

313 FIXED BEARINGS:
Fixed bearings at south end of each beam. Some pack rust forming between support plate and bearing, surface rust throughout.

331 CONCRETE BRIDGE RAILING:
Concrete parapet with type 1R aluminum top. Light scale throughout concrete. Broken anchor bolts and loose nuts in spots on aluminum top.

361 SCOUR:
Soundings taken today. No observed change since as-built.

Figure 164. Sample element-level report format.

ELEMENT		TQ	CS 1	CS 2	CS 3	CS 4	CS 5
001	DISTRICT ACTION REQUESTED	9					

Screamer ○ F.Y.I. ○ District ◉ Inaccessible? ○

1] REMOVE ALL VEGETATION FROM SOUTHERN WINGS & SIDES OF STRUCTURE. 2] CLEAN OUT ALL DRAIN HOLES & INSTALL FIBERGLASS SHIELDS TO DRAIN WATER AWAY FROM STEEL. 3] RESEAL ALL JOINTS A.S.A.P.. PIER 1 OPEN 1 1/4", PIER 2 & S. ABUT. OPEN 3/4". 4] PAINT ID #s ON END BLOCKS, BRIDGE # 6114 IS PAINTED NEAR THE N.E. END. 5] INSTALL GUARDRAILS AT ALL 4 CORNERS & ATTACH THEM TO THE ENDBLOCKS. 6] TIGHTEN OR REPLACE ANY LOOSE & OR MISSING ANCHOR BOLTS FOR HANDRAILS AT THE SOUTH ENDS & GRIND SMOOTH THE 4th VERTICAL POST FROM THE S.E. CORNER WHICH HAS A SMALL CHIP AT THE TOP WITH SHARP EDGES EXPOSED & IS A PEDESTRIAN HAZARD. 7] STRIP THE ROADWAY AS REQUIRED. 8] RESEAL THE TOP OF THE SOUTH SLOPE @ THE BREASTWALL JOINT. 9] REPLACE ALL MISSING REFLECTORS ON PARAPETS.

Figure 165. First example of maintenance recommendation section.

WORK RECOMMENDATIONS

Perfrom an in-depth investigation of the cover plate welds.

Item#	Rec. Date	Work By	Work Id.	Prog. Method	Cost
1	[redacted]	Other	41234X99265X		

Clean joints and replace seals with an approved Type "A" joint seal compound.

Item#	Rec. Date	Work By	Work Id.	Prog. Method	Cost
2	[redacted]	Bridge Crew	41234X99265X	H3013	$3,000

Clean debris from around the bearing area.

Item#	Rec. Date	Work By	Work Id.	Prog. Method	Cost
3	[redacted]	Bridge Crew	41234X99265X	H2152	$1,000

Extract five 4" diameter cores from five random locations on the deck, and send to [redacted] for petrographic analysis. In addition chip back a small portion of unsound concrete and inspect the condition of the reinforcing steel.

Item#	Rec. Date	Work By	Work Id.	Prog. Method	Cost
4	[redacted]	Bridge Crew	41234X99265X	H0122	$4,000

Figure 166. Second example of maintenance recommendation section.

and painting the bearings. Of note from the table, more teams recommended that an overlay program be initiated (three) than indicated that a deck survey be performed (two) or that the delaminations should be repaired (two). Also, note that the third most frequent response (seven teams) was that there were no recommendations at all or that maintenance was not required. In fact, one of these teams indicated that their State does not allow the inspectors to make repair recommendations; those decisions are left to a separate maintenance unit.

Table 222. Task I – Repair recommendations.

Recommendation	Number of Teams
Seal Joints	14
Clean & Paint Bearings	8
Tighten Handrail Connections	6
Cut Vegetation	5
Perform In-Depth Inspection of Welds	5
Clean Drains/Improve Drainage	4
Determine Chloride Content	3
Install Guardrails	3
Install Overlay	3
Repair Delaminations	2
Perform Deck Survey	2
Clean and Paint Beams	2
Miscellaneous Concrete Repair	2
Monitor Welds	2
Install Reflectors/Other Signage	2
Determine Core Strength	1
Clean Debris Off Substructure	1
Monitor Erosion	1
Seal Concrete Cracks	1
No Recommendations or Maintenance Not Required	7

5.4.3.2.4.   Photographic Documentation

Twelve teams used pictures to provide photographic documentation of their findings, and of the 12, 8 provided a log of photographs taken. Another two teams provided a log of photographs that they would have taken had they had a camera with them. Therefore, a total of 14 teams provided photographic documentation of their inspection. Twelve basic categories were used to describe the photographs. Credit was only given on a category basis; multiple pictures within a particular category were only counted once (e.g., if there were both east and west elevation photographs, the elevation category was credited once, not twice). Table 223 summarizes the frequency of pictures taken by the various teams. Figures 167 through 178 illustrate examples of these categories. The three “overall” pictures listed in table 223 were taken the most frequently, while close-up photographic documentation of each of the specific elements listed in table 223 was provided by half or fewer of the inspection teams.

Table 223. Task I – Photographic documentation.

Photograph Category	Frequency
Overall Approach	79%
Overall Elevation	64%
Overall Below-Deck Superstructure and Substructure	50%
Girder	50%
Joint	50%
Railing	43%
Bearing	36%
Curb	29%
Pier Cap	21%
Abutment	14%
Deck	14%
Stream Profile	14%

5.4.3.2.5. Equipment Use

Some other important information was also tracked in the various reports. Team usage of access equipment to perform this task has been documented elsewhere. Seven of the reports also included information about the access equipment required to perform this inspection or future inspections.

5.4.3.3. CONDITION RATINGS COMPARISONS

Twenty-four of the 25 teams provided Condition Ratings of the primary elements of this bridge. Table 224 provides a summary of the statistical information associated with these ratings, while figure 179 shows the actual frequency distribution of the Condition Ratings. Table 224 also provides the NDEVC reference rating for each of the primary elements.

As shown in table 224, the average deck rating is 5.8, compared to a reference value of 7. The superstructure average rating is 6.8, compared to a reference of 7; and the substructure average rating is 6.7, compared to a reference of 8. Results of detailed delamination surveys are typically not available when generating deck Condition Ratings, especially when there are no

Figure 167. Overall approach example photograph.

Figure 168. Overall elevation example photograph.

Figure 169. Overall below-deck superstructure and substructure example photograph.

Figure 170. Girder close-up example photograph.

Figure 171. Joint close-up example photograph.

Figure 172. Railing close-up example photograph.

Figure 173. Bearing close-up example photograph.

Figure 174. Curb close-up example photograph.

Figure 175. Pier cap close-up example photograph.

Figure 176. Abutment close-up example photograph.

Figure 177. Deck close-up example photograph.

Figure 178. Stream profile example photograph.

visible indications of delaminations. Therefore, a detailed delamination survey performed by the NDEVC was not considered when assigning the deck reference Condition Rating.

A series of t-tests were performed to determine whether the sample averages were different from the reference values at a 10 percent significance level. Only the average of the superstructure ratings passed this test, being statistically not different from the reference.

Table 224. NBIS Condition Ratings for Task I.

Condition Rating	Primary Element		
	Deck	Superstructure	Substructure
Reference	7	7	8
Average	5.8	6.8	6.7
Standard Deviation	0.92	0.64	0.62
COV	0.16	0.09	0.09
Minimum	4	6	6
Maximum	7	9	8
Mode	5	7	7
N	24	24	24

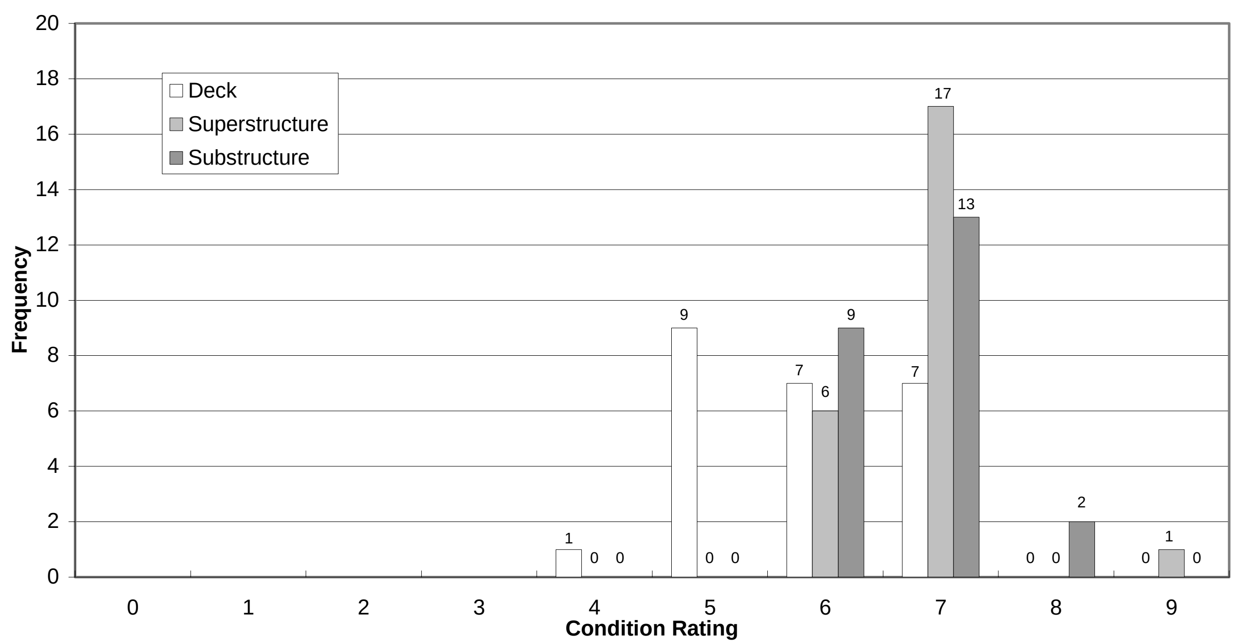


Figure 179. Condition Rating frequency distribution.

5.4.3.3.1. Distribution of Experimental Population

Table 225 summarizes the distribution of the Condition Ratings about the reference, mode, and average values. As shown in table 225, although 96 percent of the inspectors were within one rating point of the reference for the superstructure, fewer than two-thirds of the inspectors were within one rating point of the reference for the deck and substructure. Note that the distribution comparison for the average value only includes two rating values (i.e., with an average of 5.8, the deck average comparisons include ratings between 4.8 and 6.8; therefore, only ratings of 5 and 6 are included). Also shown in the table, 71 of the 72 element ratings fell within two points of the reference value. The one rating outside of this interval was three points from the reference value. Similarly, 71 of the 72 element ratings were within two points of the sample averages; again, the one outlier fell within three points of its sample average. All of the element ratings fell within two points of the sample modes.

Table 225. Distribution of sample Condition Ratings.

Element	Reference	Average	Mode	Percentage of Sample Within					
				± 1	± 2	± 1	± 2	± 1	± 2
				of					
				Reference		Average		Mode	
Deck	7	5.8	5	58	96	67	100	71	100
Superstructure	7	6.8	7	96	100	96	96	96	100
Substructure	8	6.7	7	63	100	92	100	100	100

Since the State-dependent tasks only produced one set of Condition Ratings, reporting DFR by element is irrelevant. However, the deck, superstructure, and substructure ratings can be combined using the DFR concept described in the Routine Inspection section. The overall average DFR is -0.88 (standard deviation of 0.89), with a minimum of -3 and a maximum of 2. When using this concept to describe the data, the distribution is as shown in table 219. Note that the distribution is bimodal. If the mode is considered to be -1, 97 percent of the ratings are within one rating point. If the mode is considered to be 0, 72 percent of the ratings are within one rating point. Seventy of the 72 ratings (97 percent) are within one point of either mode value.

Table 226. Distribution of sample DFRs.

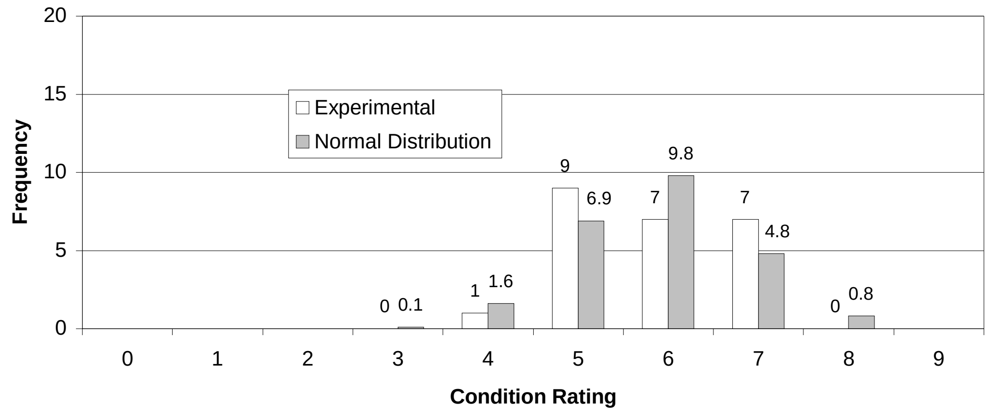
Element	Average DFR	Mode DFR	Percentage of Sample Within					
			± 1	± 2	± 1	± 2	± 1	± 2
			of					
			Zero DFR		Average DFR		Mode DFR	
All Elements	-0.89	-1, 0	72	99	72	97	97, 72*	99

* Distribution is bimodal. If -1 is considered the mode, 97 percent are within one rating point. If 0 is considered the mode, 72 percent is within one rating point.

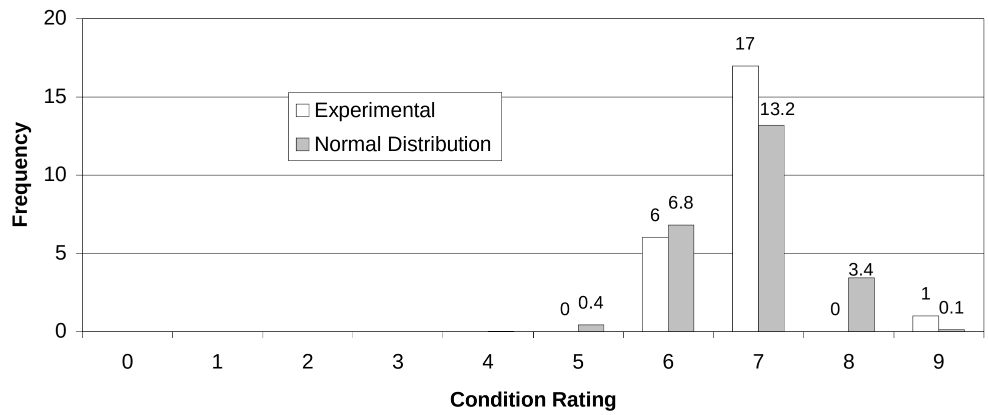
5.4.3.3.2. Analytical Modeling

Comparing the ratings against the normal distribution allows a determination of whether the sample followed a normal distribution. Figure 180 shows the frequency histograms for the deck, superstructure, and substructure for Task I. Also shown in figure 180 is the normal distribution based on the average, size, and standard deviation of the sample. The appropriateness of the distribution was then verified by applying the χ^2 test for goodness-of-fit. At the 5 percent significance level, the goodness-of-fit test was satisfied by the Condition Rating distributions for the deck and the substructure. The test was not satisfied for the superstructure.

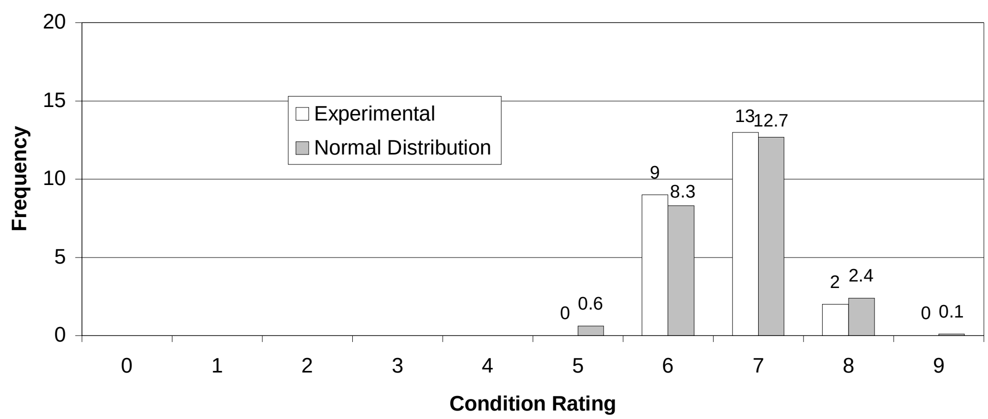
To examine the overall distribution of the State-dependent Condition Ratings, the DFR histogram is presented as figure 181. This figure combines the DFR distributions for the deck, superstructure, and substructure. Again, the expected normal distribution for the overall average DFR is also presented. When the χ^2 test for goodness-of-fit is applied, it passes the test at the 5 percent significance level and can be considered normally distributed. Assuming the normal distribution, it would be predicted for Task I that 68 percent of the population of bridge inspectors would produce Condition Ratings with an overall DFR between -1.8 and 0. Similarly, 95 percent of the population would have an overall DFR between -2.6 and 0.9, and 99 percent of the population would have an overall DFR between -3.2 and 1.4.



a. Deck



b. Superstructure



c. Substructure

Figure 180. Task I experimental and theoretical Condition Rating distribution.

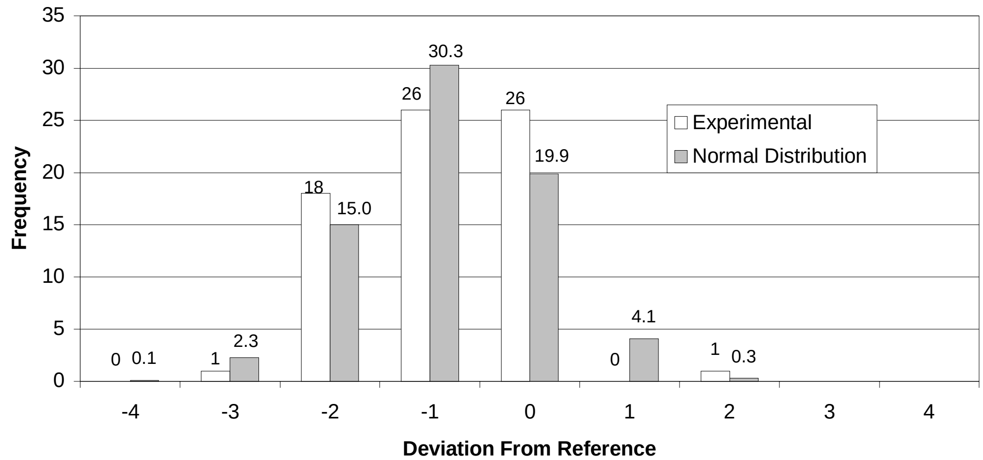


Figure 181. Experimental and theoretical DFR distribution – All element types.

5.4.3.3.3. Variability of Condition Ratings by State and Region

Similar to the comparisons performed in the Routine Inspection section, it was desirable to see whether there were any differences in the way each State rated bridges. A qualitative analysis of the Condition Ratings assigned by the 24 teams that performed Task I indicated that there was no consistent, overall trend. It was found that of the 24 ratings provided, 10 teams were higher than the sample averages for all 3 primary elements. Conversely, only three teams were lower than the sample averages for all three primary elements. The team from State 3, which had a statistical difference between their Routine Inspection ratings (Tasks A, B, C, D, E, and G) and those from the other teams, was found in Task I to have the highest overall ratings. This team was the only team to provide primary element ratings more than two points higher than average, and they also had another primary element rating more than one point higher than average.

Of the 10 teams that provided ratings higher than average for all 3 primary elements, 5 were found to be from northern States. Additional analyses were performed that compared the ratings assigned by teams from a region with teams from other regions. The regional definitions were based on the 10 FHWA regions. It was found that there was a statistical difference in the higher superstructure and substructure ratings assigned from the northern region previously mentioned. In addition, a statistical difference was noticed in the lower deck ratings assigned by an eastern region. None of the other regions had statistical differences between their ratings and those assigned by the other teams. Regional weather conditions may not be the only reason for these differences. Among the many other possible reasons for these differences, some might include the material types frequently used, administrative policies, and interactions between neighboring States.

5.4.3.3.4. Assembled Team vs. Existing Team Condition Ratings

A comparison was made between the Condition Ratings assigned by the assembled teams and those assigned by the existing teams. Table 227 summarizes some of the basic statistical information for these two groups. As shown in table 227, there is very little difference between the average Condition Ratings of the assembled teams and those of the existing teams. At a 5 percent significance level, the t-test indicates that there is no statistical difference between these two groups.

Table 227. Condition Rating comparisons between assembled teams and existing teams.

	Assembled Team			Existing Team		
	Deck	Superstructure	Substructure	Deck	Superstructure	Substructure
Reference	7	7	8	7	7	8
Mean	5.9	6.7	6.8	5.9	7.0	6.7
Mode	6	7	7	5	7	7
Standard	0.79	0.49	0.62	0.94	0.77	0.65
Minimum	5	6	6	5	6	6
Maximum	7	7	8	7	9	8
N	12	12	12	11	11	11

5.4.3.3.5. Division of Labor

The Division of Labor category was examined to see if there was a difference among the Condition Ratings assigned by the groups. Specifically, comparisons were made between each of the groups (Worked Together, Inspector and Note-Taker, Independent Inspectors, and Unclassified) and the combination of the other teams that were not members of that particular group. One team that was classified into a Division of Labor category did not submit ratings, and this team has been omitted from this analysis. Table 228 summarizes the results from the

Table 228. Division of Labor.

Group	Element	Average	Standard Deviation	Pass t-Test at 5% Significance?
Overall	Deck	5.8	0.92	—
	Superstructure	6.8	0.64	—
	Substructure	6.7	0.62	—
Worked Together	Deck	6.1	0.90	No
	Superstructure	6.9	0.38	No
	Substructure	6.9	0.69	No
Inspector and Note-Taker	Deck	5.8	0.96	No
	Superstructure	6.5	0.58	No
	Substructure	6.3	0.50	No
Independent Inspectors	Deck	5.8	0.79	No
	Superstructure	6.9	0.88	No
	Substructure	6.8	0.63	No
Unclassified	Deck	5.3	1.53	No
	Superstructure	7.0	0.00	No
	Substructure	6.7	0.58	No

different groups. None of the groups passed the t-test, indicating that there was no statistical difference among the Condition Ratings assigned by the groups.

5.4.3.3.6. Relationship

Similar to the Division of Labor category, the Relationship category was also used to combine similar teams into groups. This analysis determined whether there was a statistical difference between the ratings assigned by one team and those assigned by the other teams. Results from these analyses are presented in table 229. Only one group had a statistical difference for the ratings assigned to one of the elements. This group was the Leader/Helper group assigning ratings for the superstructure. None of the other groups or elements passed the t-test.

5.4.3.3.7. Level of Preparation

The Level of Preparation category was also used to determine whether the different levels of preparation affected the Condition Ratings assigned. Two different analyses were performed: one based on the preparation apparent from the materials submitted, and a second based on the

Table 229. Relationship.

Group	Element	Average	Standard Deviation	Pass t-Test at 5% Significance?
Overall	Deck	5.8	0.92	—
	Superstructure	6.8	0.64	—
	Substructure	6.7	0.62	—
Equals	Deck	5.8	0.75	No
	Superstructure	6.7	0.47	No
	Substructure	6.7	0.65	No
Leader / Inspector	Deck	5.3	0.95	No
	Superstructure	6.7	0.49	No
	Substructure	6.4	0.53	No
Leader / Helper	Deck	6.3	0.96	No
	Superstructure	7.5	1.00	Yes
	Substructure	7.3	0.50	No
Unclassified	Deck	7.0	0.00	No
	Superstructure	6.5	0.71	No
	Substructure	6.5	0.71	No

reported amount of time spent preparing for this inspection. The classification categories are: Preparation Before Arrival, No Preparation Apparent, Indeterminate Preparation, and Less Than 2 H Preparation. Note that Preparation Before Arrival, No Preparation Apparent, and Indeterminate Preparation are mutually exclusive categories. This analysis determined whether there was a statistical difference between the ratings assigned by one group and the balance of the other groups. The results from the analysis based on the materials submitted are presented in table 230, while results based on the Reported Preparation Time are presented in table 231. Only two groups, Indeterminate Preparation and Less Than 2 H Preparation, had a statistical difference for any of the ratings assigned. Both groups had average Condition Ratings that were lower than the corresponding balance of other groups for deck elements.

5.4.3.3.8. Report Presentation

The Inspection Report Presentation category was also used to determine whether there was a correlation between the different report formats used and the Condition Ratings assigned. The

Table 230. Level of Preparation (based on reports submitted).

Group	Element	Average	Standard Deviation	Pass t-Test at 5% Significance?
Overall	Deck	5.8	0.92	—
	Superstructure	6.8	0.64	—
	Substructure	6.7	0.62	—
Preparation Before Arrival	Deck	5.8	0.75	No
	Superstructure	6.7	0.52	No
	Substructure	6.8	0.41	No
No Preparation Apparent	Deck	6.2	0.94	No
	Superstructure	7.0	0.74	No
	Substructure	6.8	0.72	No
Indeterminate Preparation	Deck	5.2	0.75	Yes
	Superstructure	6.7	0.52	No
	Substructure	6.3	0.52	No

Table 231. Level of Preparation (based on reported preparation time).

Group	Element	Average	Standard Deviation	Pass t-Test at 5% Significance?
Overall	Deck	5.8	0.92	—
	Superstructure	6.8	0.64	—
	Substructure	6.7	0.62	—
Less Than 2 H Preparation	Deck	5.4	1.00	Yes
	Superstructure	7.0	0.74	No
	Substructure	6.6	0.52	No

classification categories were: Final Report (Computer-Generated), Final Report (Field-Written), and Intermediate Report (Field-Written). This analysis determined whether there was a statistical difference between the ratings assigned by one group and the balance of the other groups. Results from these analyses are presented in table 232. None of the groups had a statistical difference for the ratings assigned for any of the elements.

5.4.3.4. ELEMENT-LEVEL COMPARISONS

The element-level inspection is the other primary inspection style. Several teams submitted inspection information in this format. The element-level inspections rely upon specific definitions of elements to classify the bridge structure and describe any deterioration observed.

Table 232. Report Categories.

Group	Element	Average	Standard Deviation	Pass t-Test at 5% Significance?
Overall	Deck	5.8	0.92	—
	Superstructure	6.8	0.64	—
	Substructure	6.7	0.62	—
				—
Final Report (Computer-Generated)	Deck	5.5	0.93	No
	Superstructure	6.7	0.47	No
	Substructure	6.5	0.69	No
Final Report (Field-Written)	Deck	6.0	1.0	No
	Superstructure	7.0	0.87	No
	Substructure	6.9	0.60	No
Intermediate Report (Field-Written)	Deck	6.3	0.50	No
	Superstructure	6.8	0.50	No
	Substructure	6.8	0.50	No

One of the most common element-level inspection systems uses the Pontis bridge management system, but other systems also exist. As indicated above, 16 teams submitted element-level inspection data. Two of those teams used element nomenclature inconsistent with the Commonly Recognized (CoRe) elements, as defined in the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements*.[5] These CoRe elements are commonly used by the Pontis program and elsewhere. Therefore, only 14 of the element-level inspection data sets contained information that was comparable. A wide variety of observations can be made from the element-level data. Conclusions can be drawn regarding inspector familiarity with the system from the selection of the various element categories used to describe the structure.

Comparisons can also be made regarding the quantities and units used by the various States. Finally, comparisons can be made using the Condition States of the CoRe elements.

5.4.3.4.1. Element Use

The CoRe elements are defined in the CoRe element guide mentioned above. In general, they share three traits: (1) the elements are generally primary structural members of the same material type, (2) the elements represent members that can deteriorate in a similar manner and have specific Condition State descriptions to represent the various deterioration levels, and (3) the elements can be inventoried in a quantifiable manner.[5] CoRe elements are defined for most types of *primary superstructure elements* (girders, trusses, arches, etc.), *primary substructure elements* (abutments, columns, caps, piles, etc.), *primary deck elements* (concrete, timber, open steel, etc.), and *other primary elements* (bearings, joints, and railings).

CoRe elements can be divided into sub-elements to further track cost or performance. Sub-elements should use the same units as the parent element, and parent element data should still be obtainable from sub-element data. Replacing element no. 107, "Open Steel Girder, Painted" with two sub-elements— no. 172, "Open Steel Girder, Painted, Exterior" and no. 173, "Open Steel Girder, Painted, Interior"— is an example of the use of sub-elements. Individual sub-elements are State-defined; they are not defined in reference 5. The sub-elements may not have uniform element number assignments; therefore, a sub-element such as "Open Steel Girder, Painted, Exterior" will probably have two different numbers if used by two different States.

Further flexibility in the system can be added by using Smart Flags. Smart Flags allow the tracking of local deterioration not included within the Condition State language for that element. Examples of Smart Flags include Pack Rust, Fatigue Cracking, and Deck Cracking.

The balance of items tracked are the Non-CoRe elements. These Non-CoRe items track other members that may not be primary members, or may not be easily described in Condition State language. Examples of Non-CoRe elements are wingwalls and slope protection devices. Within this study, use of the CoRe elements on the major elements was fairly consistent, while use on elements such as joints and rails was not. Teams were provided with bridge plans in advance and were asked to prepare for this inspection as they normally would. It was expected that this would include element selection and quantity take-offs for the teams performing element-level inspections (if it would not normally be done in the field). Table 233 summarizes the use of the CoRe elements. Fourteen reports with element data followed this format.

Table 233. Use of CoRe Elements.

Element Number	Description	Usage Frequency
12	Concrete Deck – Bare	13
18	Concrete Deck – Protected w/Thin Overlay	1
107	Open Girder, Steel Painted	11
201	Column or Pile Extension – Steel Unpainted	1
205	Column or Pile Extension – Reinforced Concrete	14
215	Abutment – Reinforced Concrete	14
234	Pier Cap – Reinforced Concrete	14
301	Pourable Joint Seal	5
302	Compression Joint Seal	4
304	Open Expansion Joints	1
311	Moveable Bearing (Roller, Sliding, etc.)	13
313	Fixed Bearing	12
330	Bridge Railing – Metal, Coated	3
331	Bridge Railing – Reinforced Concrete	7
333	Bridge Railing – Other	3
334	Bridge Railing – Metal, Uncoated	3

The major deck, superstructure, and substructure elements were used consistently. As shown in table 233, all but one team used element no. 12 to describe the deck. The one team that did not choose this element inspected in the rain, and apparently thought that there was an overlay on the deck. Three teams did not use element no. 107 for the steel girders, although, in fairness, these three teams used sub-elements to track the girders either as rolled, or as exterior/interior. Major substructure elements were also uniformly recorded. One difference with these major substructure elements is that one team made notes about the steel piles, which are indicated on the plans, but are not visible. The bearings were also uniformly recorded, although one team did not comment on the moveable bearings, and two teams did not comment on the fixed bearings.

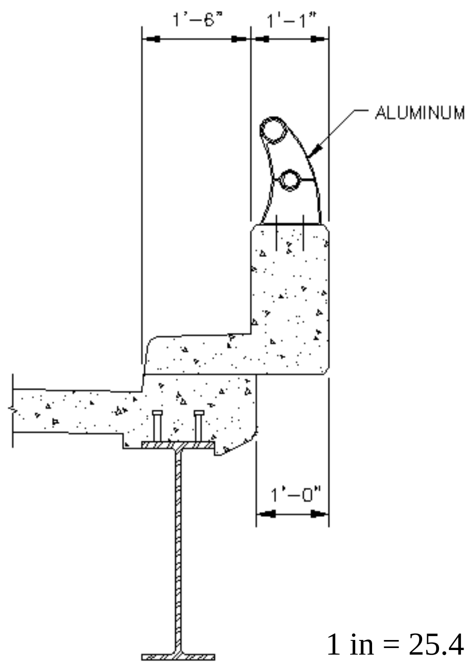
The other primary elements were recorded much less consistently. As noted above, there was the most confusion with the use of CoRe elements for the joints. Five teams thought that the joints were pourable seals, four thought that they were compression seals, and another team thought that they were open joints. This confusion is thought to have three primary causes. First, the as-built plans indicate that 25-mm preformed seals were to be installed at the time of construction. Second, significant portions of the joints are currently missing. Third, the portions that remain have significant debris on top of the joint, obscuring the view of the joint material. Since the inspectors were not allowed to disturb the debris above the joint, there was no way to visually determine joint composition. All of these items indicate that the joint confusion is not necessarily a misapplication of the CoRe elements on the part of the inspectors.

Confusion also existed with the use of the bridge railing elements. As shown in table 233, three teams used element no. 330, “Bridge Railing – Metal, Coated”; seven teams used element no. 331, “Bridge Railing, Reinforced Concrete”; three teams used element no. 333, “Bridge Railing – Other”; and three teams used element no. 334, “Bridge Railing – Metal, Uncoated.” Note that the total number of elements used exceeds the number of teams producing element-level inspection results consistent with CoRe element use. Several teams used both the reinforced concrete railing element and the uncoated metal railing element to describe the complete railing. As shown in figure 182, the rail is a combination rail, with a reinforced concrete lower section and a metal handrail above. The CoRe element guide indicates that combination rails should be recorded as no. 333, Bridge Railing – Other; if made of multiple materials, the rail is not to be split between the various types.[5] No procedural requirements with the experiment can be linked to the confusion on the appropriate railing type.

The most variation occurred with the non-CoRe elements. Five teams used five different elements to track wingwall information. Another four teams used five different elements to track slope protection.

5.4.3.4.2. Quantities and Units

The CoRe element guide also defines units of measurement associated with each element, using metric units where possible.[5] In the study, most of the reported units used matched the reference definitions. However, there were a few notable exceptions. Some of these exceptions may be due to changes in element use by the individual States. Three of the



1 in = 25.4 mm, 1 ft = 0.305 m

Figure 182. Combination rail section.

teams used metric units; the other 11 used English units. Another unit change occurred with a particular team; this team used area units to describe the girder, column, and abutment elements (instead of the typical linear feet [LF], each [EA], and LF, respectively). Teams also had many inconsistencies in the unit usage of element no. 12, “Concrete Deck – Bare.” Of the 13 teams that used this element, only 4 used the reference unit EA, while the other 9 teams used area units (either square feet [SF] or square meters [SM]). Again, this may be due to changes in the element-level system by the States. Other inconsistencies with the use of the deck element units are presented with Task J. Since non-CoRe elements are State-defined, it was expected that most teams would use different units. This situation was found to be true.

Also observed in the element-level ratings was the improper use of quantities. No restrictions on the scope of the inspection were presented in the Advance Information package sent to the inspection teams. Therefore, the inspection teams that performed a quantity take-off prior to arrival at the test bridge would have prepared quantities based on the complete bridge. However, the inspectors were told upon arrival at the bridge site that the scope of the inspection task would be limited to the southern two spans. Six of the 14 teams submitted reports that used quantities for a three-span bridge. Two possibilities exist to explain this behavior. Either those teams inspected all three spans, and therefore based their quantities on the full bridge (only one team was documented as such), or their quantities were never adjusted to the two-span amounts. An additional three teams submitted inconsistent quantities (for example, a two-span deck quantity with only one span of girder information). Only 5 of the 14 teams (36 percent) submitted quantities consistent with the inspection of the two southern spans.

5.4.3.4.3. Element-Level Ratings Comparisons

It was desirable to compare the ratings assigned by the various teams submitting element-level inspection data. The CoRe elements were selected for these comparisons, since they have common definitions for the different Condition States. Elements that are included in these comparisons are the concrete deck, steel girders, concrete columns, concrete abutments, concrete pier caps, moveable bearings, and fixed bearings. There was significant variability in the use of the joint and railing elements, so comparisons were not made with these elements. To normalize the ratings and allow for comparison, it was necessary to convert each of the quantities in the Condition States to percentages. These percentages were based on each report's stated quantity for that particular element. Table 234 summarizes the distribution of ratings assigned to each Condition State (CS). Note that "N/A" has been used to indicate that a particular element has no defined Condition States at that level. Some slight variability did exist with the CoRe elements considered. However, since these variations are minor, this variability has been overlooked. As an example, 13 of the 14 reports used deck element no. 12, "Concrete Deck – Bare," and the other report used no. 18, "Concrete Deck – Protected With Thin Overlay." In comparing the concrete deck elements, element no. 18 information was combined with element no. 12 information. The distributions reported in table 234 may be slightly misleading because many of the elements do not allow quantities to be split among different Condition States.

Table 234. Distribution of ratings for element-level inspections.

Element	CS1	CS2	CS3	CS4	CS5
Deck	20%	15%	43%	21%	0%
Steel Girders	63%	36%	1%	0%	0%
Concrete Columns	86%	14%	0%	0%	N/A
Concrete Abutments	99%	1%	0%	0%	N/A
Concrete Pier Caps	90%	6%	4%	0%	N/A
Moveable Bearings	48%	52%	0%	N/A	N/A
Fixed Bearings	57%	38%	4%	N/A	N/A

5.4.4. Task J

In Task J, the inspectors were asked to perform a deck survey of the two southernmost deck spans of the Van Buren Road Bridge. Since it was understood that only the tools in their tool bags could be used, a complete deck survey, including chloride analysis, was not possible. A delamination survey was asked of the inspectors, and that is what all inspectors understood that they were to perform. It was desirable to determine how many teams perform a delamination survey as part of their normal Routine Inspections. Other objectives included an investigation of the procedures and reporting variations of a delamination survey, and an assessment of the accuracy of that inspection. This deck shows very few visible signs of deterioration; however, it contains a significant amount of delaminated concrete. A sounding survey may be the primary technique used to detect this type of deterioration. A previous delamination survey performed by the NDEVC on the entire deck indicated that it is approximately 15 to 20 percent delaminated. This first preliminary inspection was performed approximately 1 year prior to the study and primarily concentrated on estimating the quantity of the repair area as if it were to be repaired. A more detailed survey was performed after the field tasks, primarily oriented toward determining detailed outlines of the delaminations. Given that the underside of the deck is in very good condition and that all of the inspection teams performed their sounding surveys from the top of the deck, the NDEVC also chose to perform this sounding survey from the top of the deck. Approximately 2 man-days were spent creating this detailed survey. The two surveys correlated fairly well, considering their different objectives. Both of these inspections included the north span, which has smaller-sized delaminations than the other two spans, and, therefore, lowers the overall delamination percentage. When the north span is excluded (to match the scope of the Task J inspection), the delamination percentage found by the detailed survey is approximately 19 percent. A map of the delaminations identified by the NDEVC in the southern two spans is presented in figure 183.

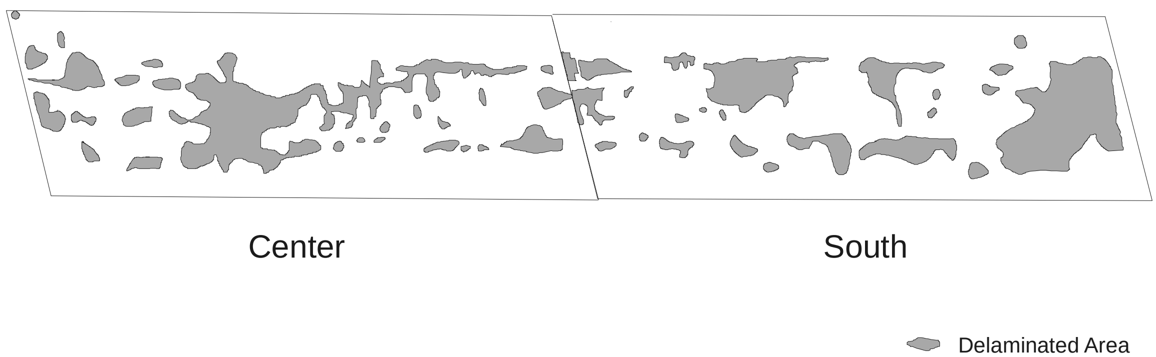


Figure 183. Delaminations detected at the Van Buren Road Bridge by the NDEVC.

A coring program was developed to confirm the delamination calls made in the detailed NDEVC survey. Ten cores were taken from the three spans, eight of which were in the two spans covered within the scope of the Task J inspection. Of the 10 core locations, 5 were located within areas that were indicated by the NDEVC as being delaminated. The results of the coring verified that the delamination calls from the detailed NDEVC survey were correct at all 10 locations.

Two limitations of the task probably had an impact on the results obtained by the inspectors. First, inspectors were not allowed to make any marks on the bridge while performing the task. Several inspectors commented to the observers during this task that they would normally have marked the outlines of the delaminations they had found directly on the concrete. These inspectors were then forced to communicate the shape of the delaminations through other means, and they felt that the limitation of not marking on the deck may have affected their results. A second limitation was discovered during the analysis of the data. The data sheets prepared for this task by the NDEVC were on unlined paper and contained a drawing of the deck to a scale of 10 mm = 0.96 m (converted from the English 1/8 in = 1 ft). During the analysis of the results, three significant variations were found. First, several delamination maps were not drawn to scale. Second, on some teams' delamination maps, some delaminations that were shaped and sized correctly, were not in the correct position. Third, some delaminations calls were positioned in series from one end of the span and contained dimensions to close the string. After the calls were plotted, the corrected closing distances were significantly different than the closing distances indicated on the maps. Attempts to correct these errors failed, due to uncertainty as to which dimension or position was correct.

5.4.4.1. PROCEDURAL VARIATIONS

Twenty-two teams performed a sounding survey to quantify the level of deterioration. The other three teams experienced rainy conditions; therefore, they did not perform the task. Nine teams initiated a sounding survey during Task I that was systematic and detailed enough for the observers to direct the inspectors to the appropriate Task J data sheets in their notebook. As mentioned above, the occasional integration of this task into Task I meant that pre- and post-task data were not collected. Firsthand observations during the task were conducted as expected, and most of these have already been presented.

One piece of observer information not yet presented is a qualitative assessment of the chaining experience of the teams. Sixteen of the teams demonstrated at least marginal experience performing a deck sounding survey. Seven teams indicated that a delamination survey would never be performed by the regular inspectors in the field, and that this task was one of the first times that they had ever performed a deck sounding survey. Five of those teams indicated that other inspection teams or other divisions would normally perform the delamination surveys. Two teams indicated that nearly all of the bridges in their State have an asphalt overlay; therefore, inspectors almost never perform delamination surveys. Finally, two teams showed their sounding inexperience in their selection and use of the available tools.

Two primary procedures were used to perform the sounding. These included using a masonry hammer to tap on the concrete surface or dragging a length of steel chain across the deck surface. Delaminations will produce discernable changes in tone using either method, and the degree of change in tone varies depending on the size and depth of the delaminations. The majority of the teams (20 out of 22) used the chain as their primary sounding technique. Of these, at least half further refined the size and shape of the delaminated areas detected by using the hammer. Only two teams, and one member of a third team, used the hammer as their primary sounding tool.

5.4.4.2. REPORTING VARIATIONS

The reporting techniques varied considerably for the delamination survey. Although some teams brought along worksheets to record delaminations, most teams used the deck plans provided by the NDEVC. Twenty teams submitted delamination maps. An additional two teams provided a delamination percentage without an accompanying map. Sketches ranged from quickly drawn, schematic representations of the deterioration with no dimensions provided, to positioned sketches with dimensions provided. Only a few teams used their resulting delamination map to provide an estimate of the percentage of delaminations. To illustrate the range of sketches submitted, figures 184 through 187 show sample delamination maps. Note that none of these sketches are drawn to scale. An example of a fully-dimensioned sketch recording delamination positions, but without a total delamination quantity, is presented as figure 184. Figure 185 shows a sketch with only partial delamination positioning, which also does not provide a total delamination quantity. Figure 186 illustrates a sketch without dimensions; however, it does include an estimate of the total delamination quantity. Figure 187 shows one of the sketches made by a team on their own notepaper.

5.4.4.2.1. Delamination Percentages

The overall average of delamination percentages found by the 22 teams performing this task is 13 percent. Further investigations into these results can be made by dividing the sample into groups. Delamination maps resulting from this task can be grouped into three different categories: (1) those that quantified the total delamination areas; (2) those that measured individual delamination areas but did not quantify the total delamination areas; and (3) those that indicated only approximate delaminated areas, without any measurements. The team delamination percentages are presented by category in table 235. Eight teams provided

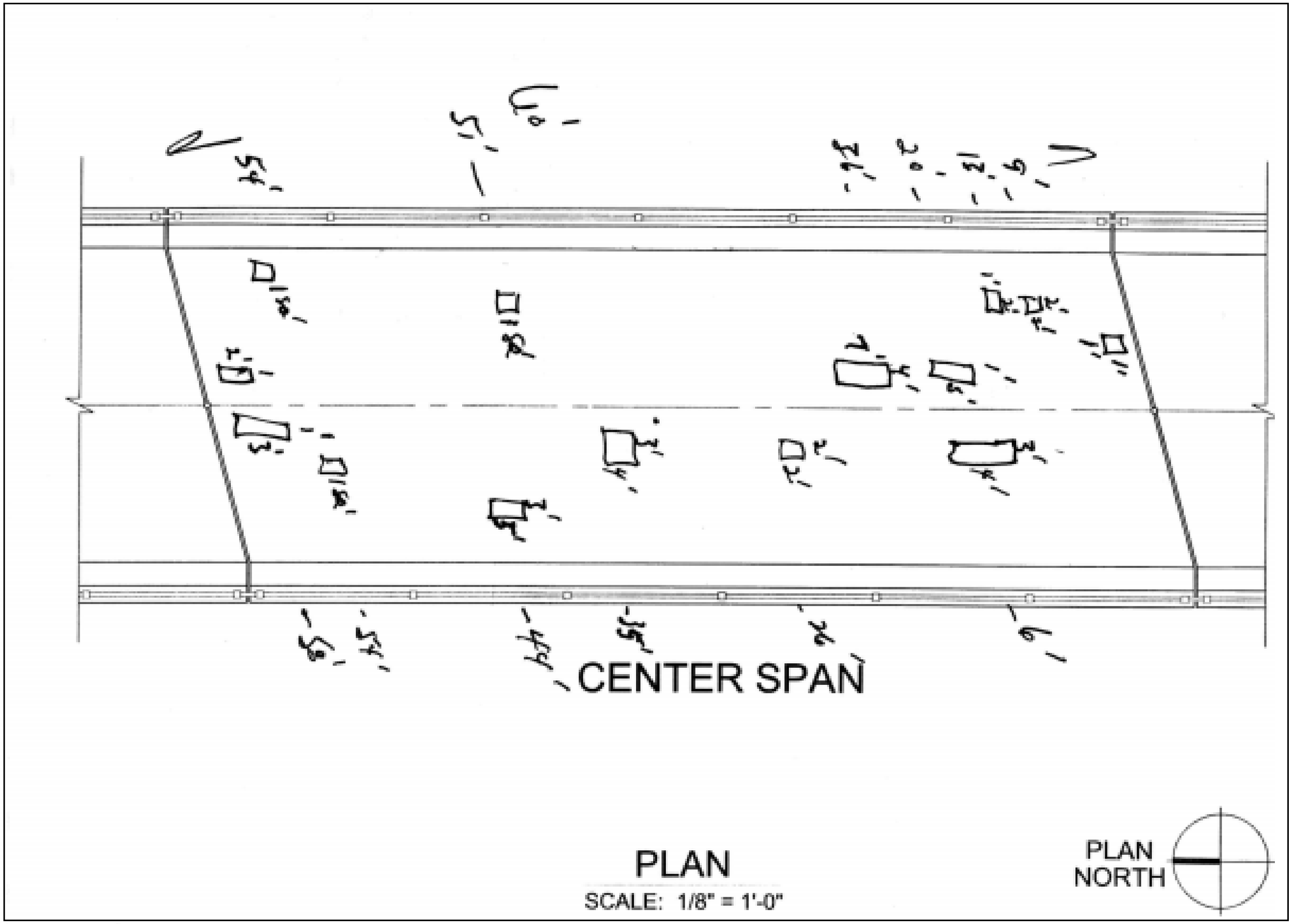


Figure 184. First sample of sketches provided by inspection teams for Task J.

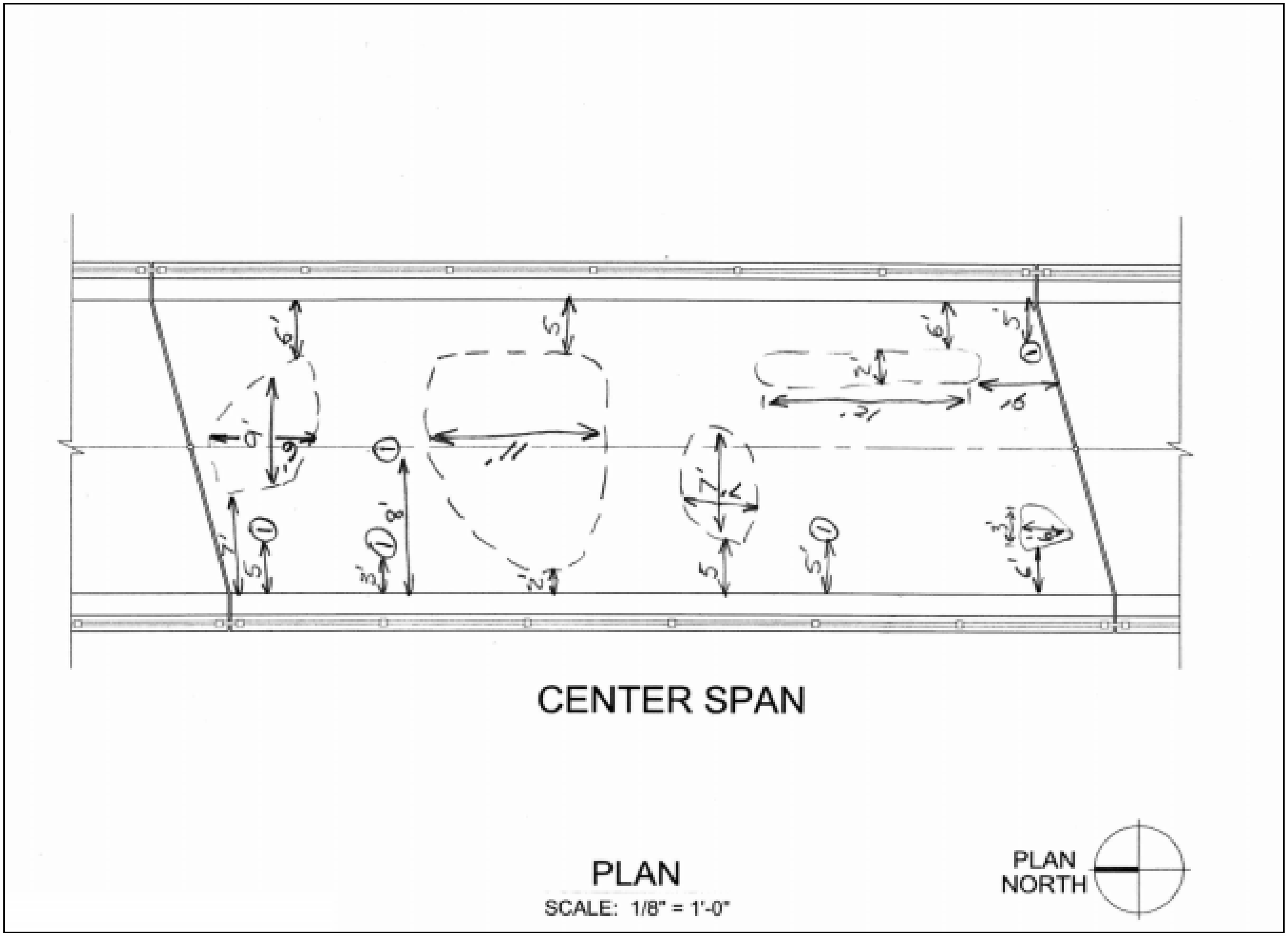


Figure 185. Second sample of sketches provided by inspection teams for Task J.

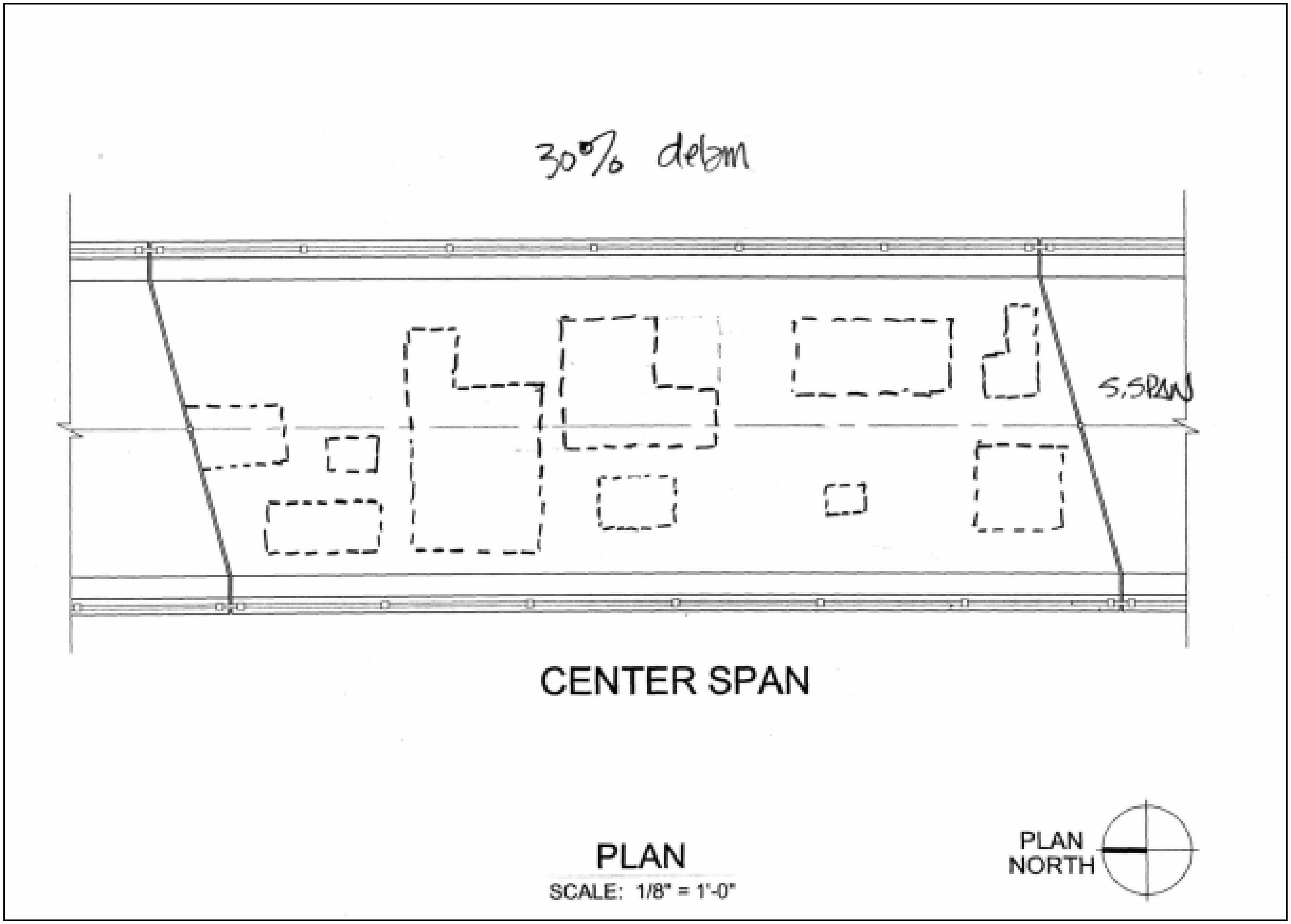


Figure 186. Third sample of sketches provided by inspection teams for Task J.

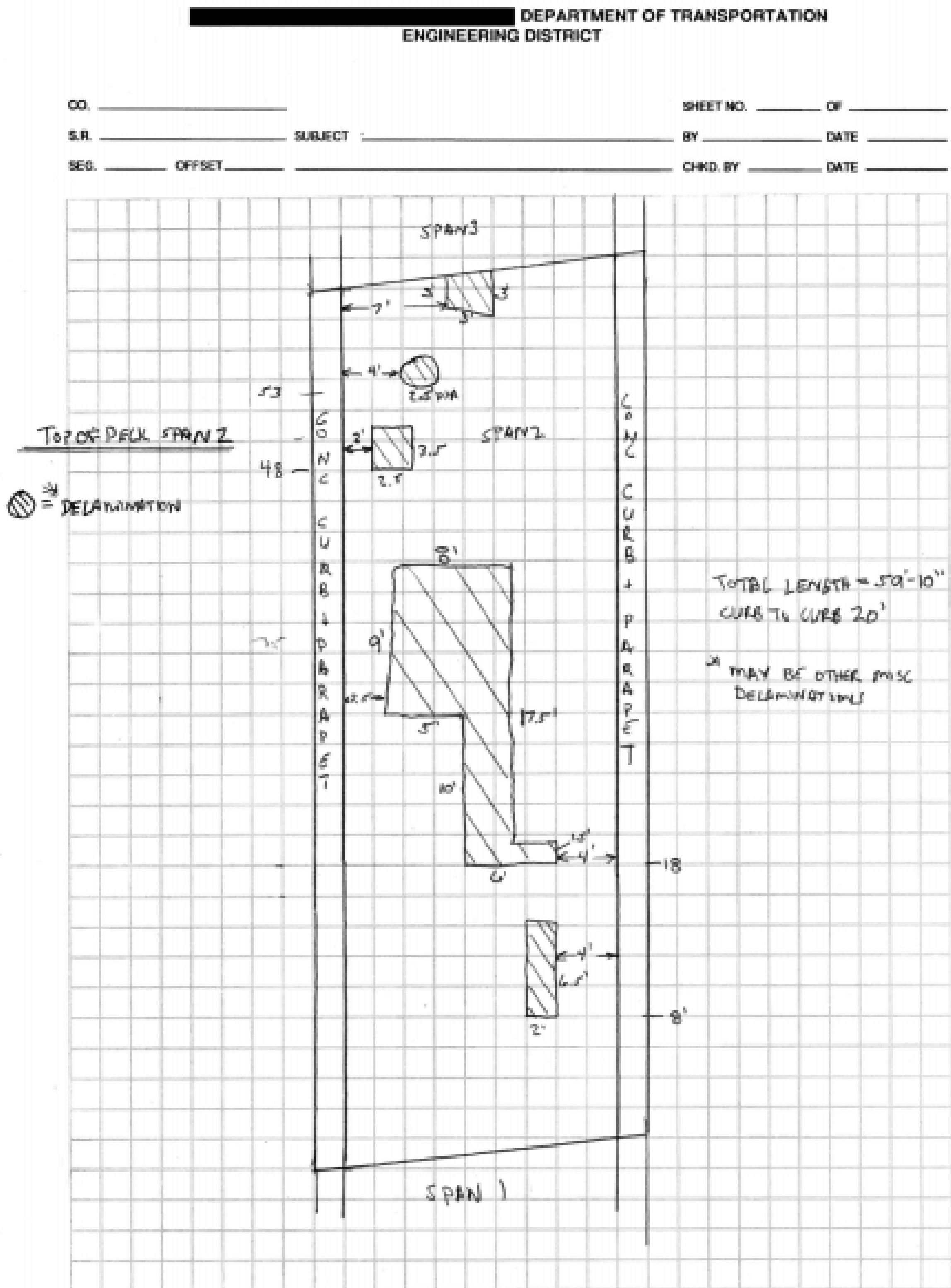


Figure 187. Fourth sample of sketches provided by inspection teams for Task J.

Table 235. Team delamination percentages.

Dimensioned and Totaled Group		Dimensioned, But Not Totaled, Group		No Dimensions Group	
Team Number	Delamination Percentage	Team Number	Delamination Percentage	Team Number	Delamination Percentage
1	2%	9	2%	20	9%
2	4%	10	5%	21	11%
3	5%	11	7%	22	35%
4	10%	12	9%		
5*	10%	13	10%		
6*	15%	14	11%		
7	16%	15	13%		
8	17%	16	17%		
		17	21%		
		18	25%		
		19	30%		
	10% average		14% average		18% average

*No map provided.

quantified delamination areas (either an estimated area of delaminated concrete or an estimated delamination percentage). Two of these eight teams provided only an estimate of the total delamination quantity; no sketches were provided. The average of these eight team estimates is 10 percent delaminated, with estimates ranging from 2 to 17 percent. An additional 11 teams provided delamination maps with dimensions, but without totals. The average delamination percentage according to this group is 14 percent, with estimates ranging from 2 to 30 percent. The remaining three teams who performed this task submitted delamination maps without dimensions. Additional work was needed to calculate delamination percentages for this group. Since no dimensions were given on the sketches of these three teams, it had to be assumed that the sketches were drawn to scale. Their sketches were digitized and the delamination percentages were determined graphically using the digital images. The average delamination percentage for these three teams is 18 percent, with team estimates ranging from 9 to 35 percent.

The results can also be compared for those inspectors displaying some experience at sounding and for those inspectors who appeared to have little or no experience. As mentioned above, 7 of the teams appeared to have little or no experience, while 16 teams appeared to have at least some experience. If the results are divided into an inexperienced group and the experienced group, the averages are 10 percent delaminated for the inexperienced group and 14 percent delaminated for the experienced group.

The NDEVC-estimated delamination percentage can be used to explore the accuracy of the reported delamination percentages. Recall that the NDEVC estimate is 19 percent. As shown in table 235, only 4 of the 22 teams produced delamination percentages for their inspections with a 15 percent error rate (i.e., between 16 percent and 22 percent) as compared to the NDEVC estimate. Furthermore, only five of the teams produced delamination percentages within 5 percentage points of the NDEVC estimate (i.e., between 14 percent and 24 percent). This 5 percentage point standard will be used for subsequent analyses.

5.4.4.3. INSPECTION FACTORS

An analysis was performed to determine whether there was a correlation between some of the inspection factors and the resulting team delamination percentages. Inspection factors that were considered include Heat Index, Light Intensity on Deck, Time of Day, and Day of Week. Initially, a linear, univariate analysis was performed to determine the degree of correlation. Since the largest correlation coefficient for these analyses was 0.19, a second-order, univariate analysis was performed on the same four variables. In the second-order analysis, the degree of correlation between Heat Index and team delamination percentage improved, with a correlation coefficient of 0.47. The maximum correlation coefficient for the other three variables was low, with a maximum of 0.29. A multivariate, second-order analysis was performed using the same four variables. The correlation coefficient for this multivariate analysis is 0.64. In parallel with previous discussions, the resulting equation is given in Equation 11, while the coefficients from this equation are shown in table 236. To ensure uniformity, the value used for the Heat Index was that obtained from Task I below the superstructure.

$$Delamination\ Percentage = y_0 + I_1 + I_2 + I_3 + I_4 \qquad (11)$$

where: $I_1 = a(F_1) + b(F_1)^2$

$I_2 = c(F_2) + d(F_2)^2$

$I_3 = e(F_3) + f(F_3)^2$

$I_4 = g(F_4) + h(F_4)^2$

with: F_1 = Day of Week

F_2 = Light Intensity on Deck

F_3 = Heat Index

F_4 = Time of Day

Table 236. Equation coefficients for predicting deck delamination percentages.

Coefficient	Value
y_0	326
a	6.14
b	-0.893
c	-3.27e-4
d	2.89e-9
e	-5.52
f	0.0976
g	-38.2
h	1.50

Figures 188 through 191 graphically represent the influence of each of the four factors investigated (Day of Week, Light Intensity, Heat Index, and Time of Day). As can be seen from these graphs, the influence of the Heat Index seems to have the most influence on the resulting delamination percentage.

5.4.4.3.1. Delamination Estimates Compared to Element-Level Data

The results of Task J can be compared with the deck results from Task I. Particularly useful in these comparisons are the Pontis data for element no. 12, Concrete Deck – Bare. A discussion has already been presented regarding the use of units (according to the CoRe element guide, not necessarily according to individual State procedures) in the element-level data. Further inconsistencies in CoRe element use are observed when each team's individual deck delamination percentage is compared with the Condition State assigned by that team to the deck element. The language in the CoRe element guide is very precise in describing the different Condition States. To summarize the Condition State language for deck elements:

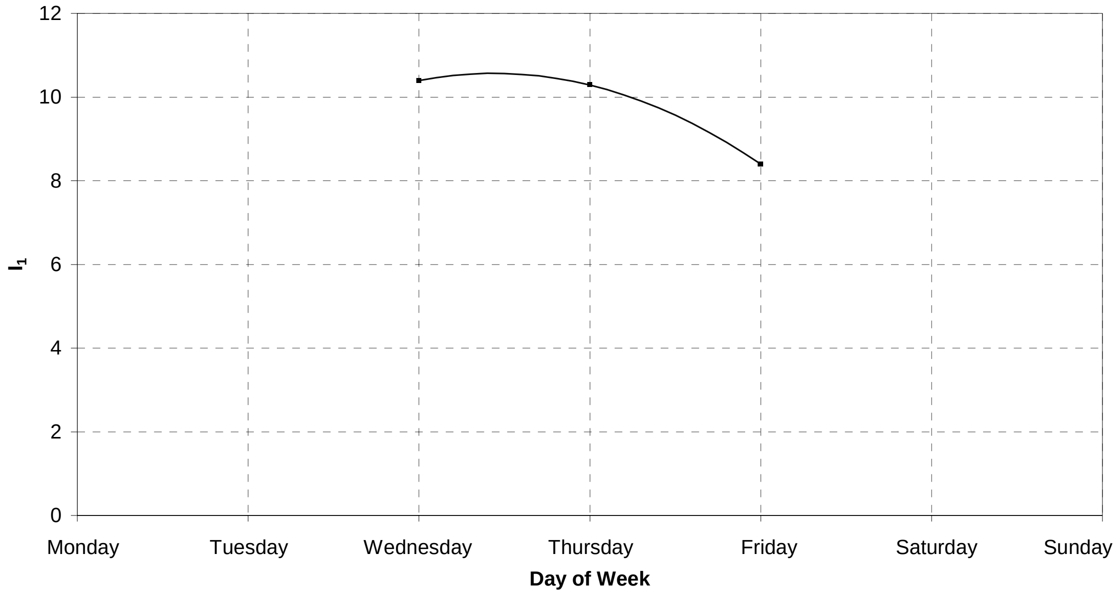


Figure 188. Influence of Day of Week on delamination percentage.

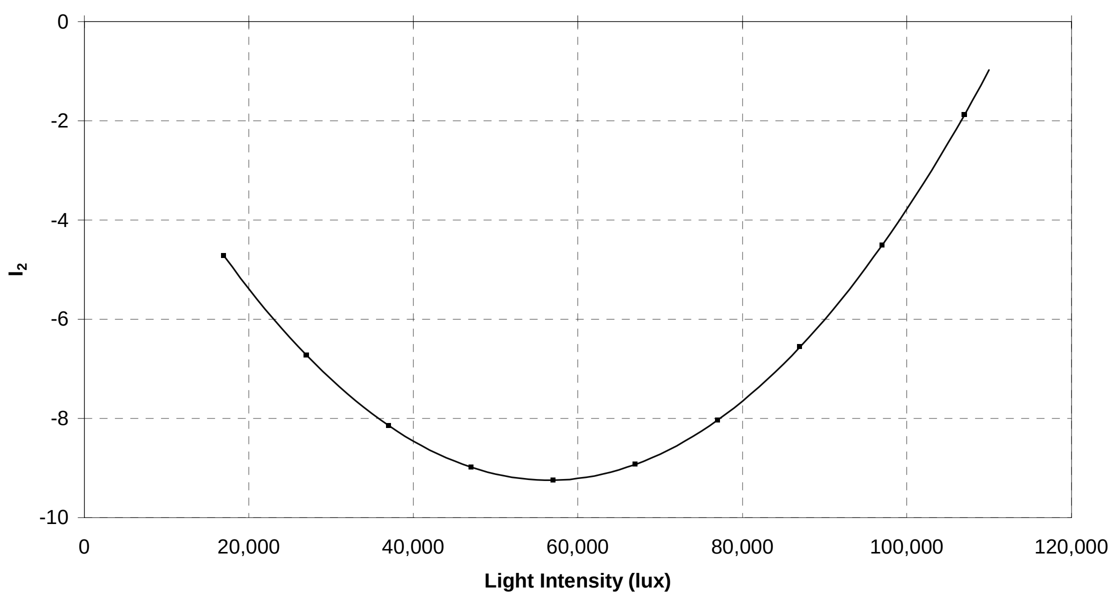


Figure 189. Influence of Light Intensity on delamination percentage.

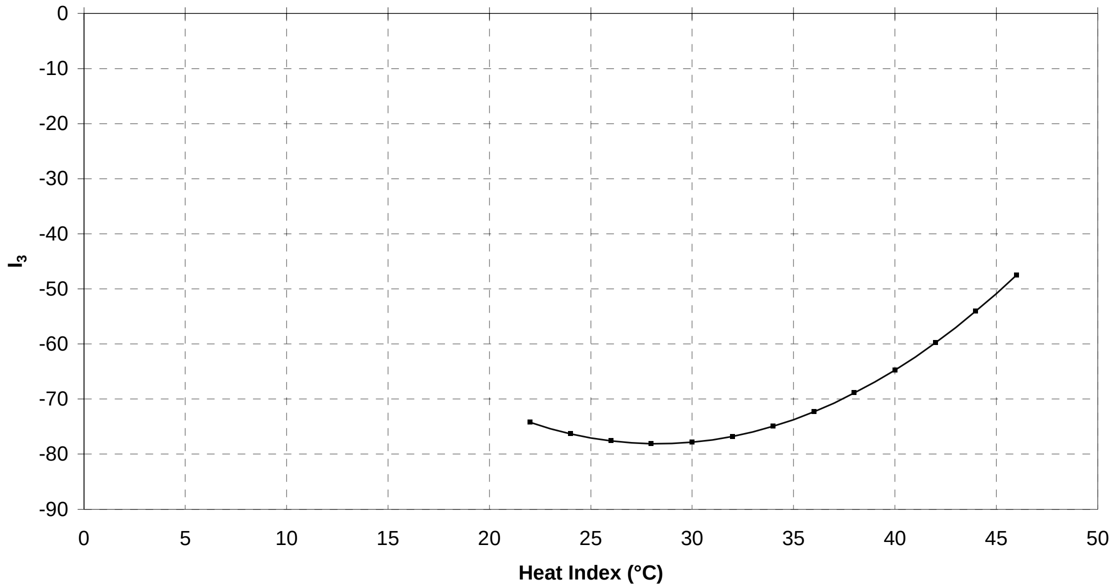


Figure 190. Influence of Heat Index on delamination percentage.

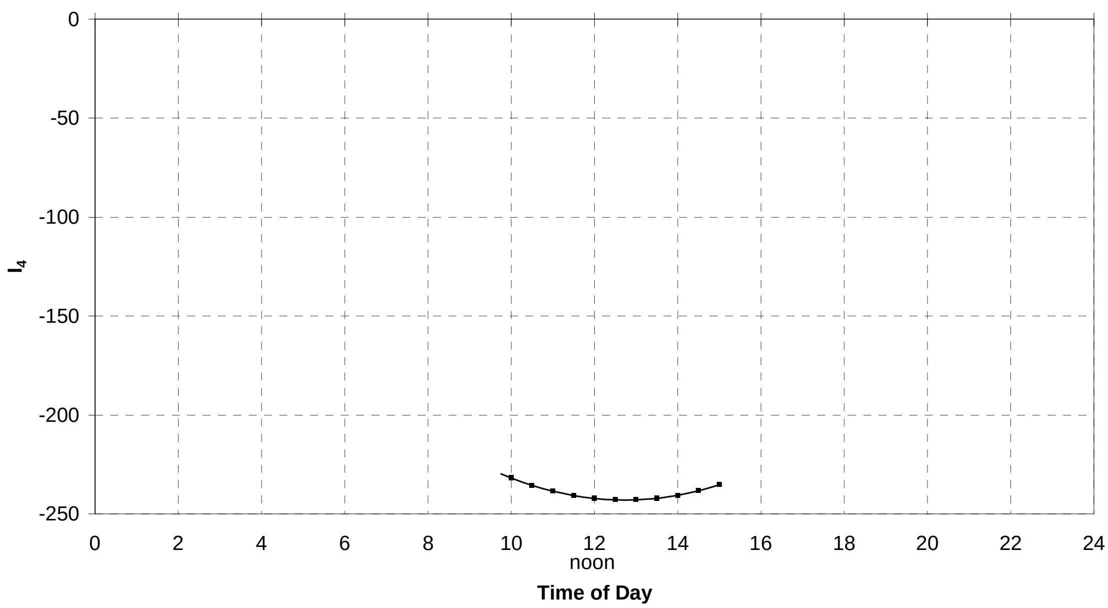


Figure 191. Influence of Time of Day on delamination percentage.

CS1 exhibits no deterioration, CS2 has less than 2 percent deterioration, CS3 has between 2 and 10 percent deterioration, CS4 has between 10 and 25 percent deterioration, and CS5 has more than 25 percent deterioration. All of the deck is to be rated in the single Condition State that is appropriate (i.e., no splitting across multiple Condition States).

Of the 13 teams that both have element-level data and have performed Task J, 3 subdivided the deck into multiple Condition States for their element-level ratings. Of the remaining 10 teams, 5 properly selected the appropriate Condition State for the level of deterioration indicated on their Task J data sheets, while 5 selected Condition States that do not match their estimated delamination percentages. It has been reported that some States may have changed the element-level definitions to allow for their specific uses, possibly changes along these lines have introduced these types of inconsistencies.

5.4.4.3.2. Comparison of Individual Delaminations

If it is assumed that the actual delamination percentage is approximately 19 percent, and if an allowance of ± 5 percentage points is permitted as reasonable error (between 14 and 24 percent delaminated), table 235 shows that only five of the teams had estimates that fell in this range. This is less than a quarter of the teams that performed the task.

Figures 192 through 211 show overlays of the team sketches superimposed upon the delamination outlines determined by the NDEVC. These figures are identified using the same team identifiers used in table 235. Recall that Teams 5 and 6 did not submit delamination maps; therefore, data from these teams are not included in figures 192 through 211. These overlays were created assuming that the maps submitted by the teams were drawn to scale. For most of the sketches, this assumption is justifiable. However, a few of the maps were drawn to an inconsistent scale, with 0.6-m by 0.6-m dimensioned areas drawn about the same size as 1.8-m by 1.8-m dimensioned areas. Attempts were made to regenerate some of these maps using the position and size information provided, but these “corrected” maps had enough other errors in positioning and sizing that they were not considered to have improved on the original sketch that was submitted. Therefore, all areas are shown without modification. In two cases, automobiles were parked on the deck, preventing complete inspection of the deck. These areas have been noted.

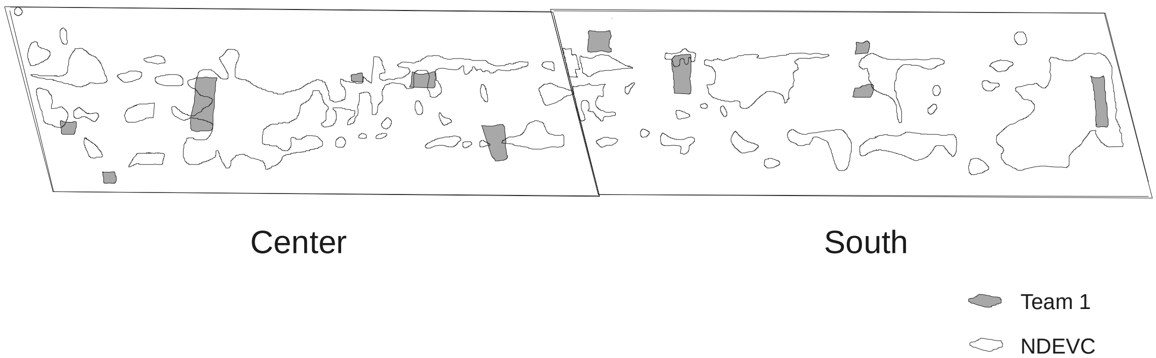


Figure 192. Delamination map from Team 1.

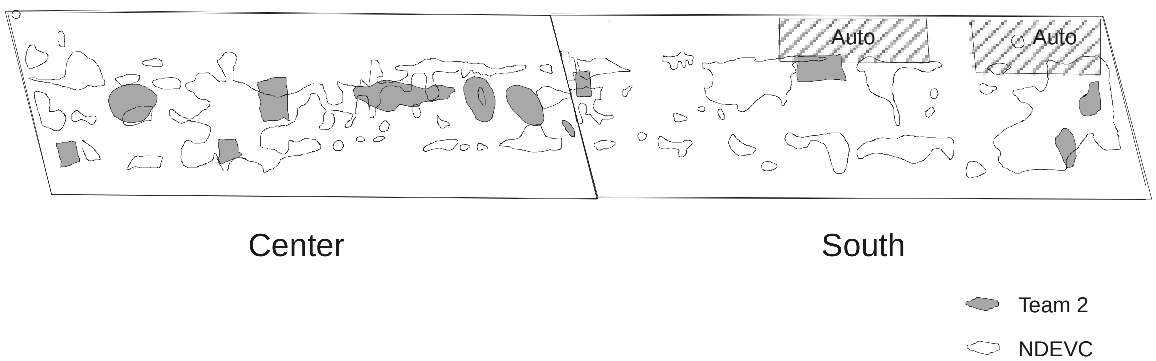


Figure 193. Delamination map from Team 2.

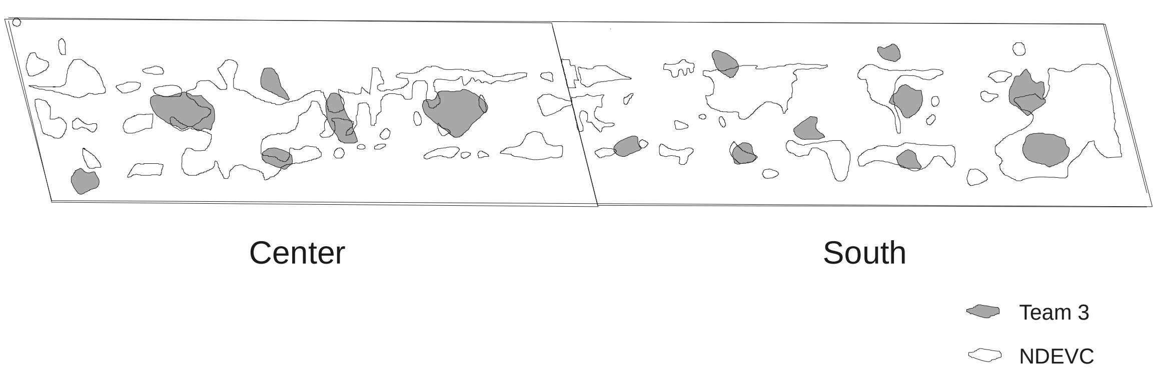


Figure 194. Delamination map from Team 3.

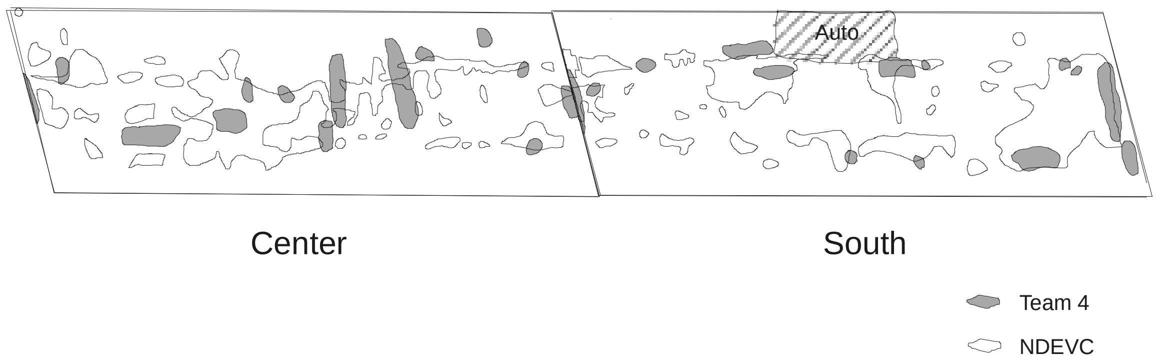


Figure 195. Delamination map from Team 4.

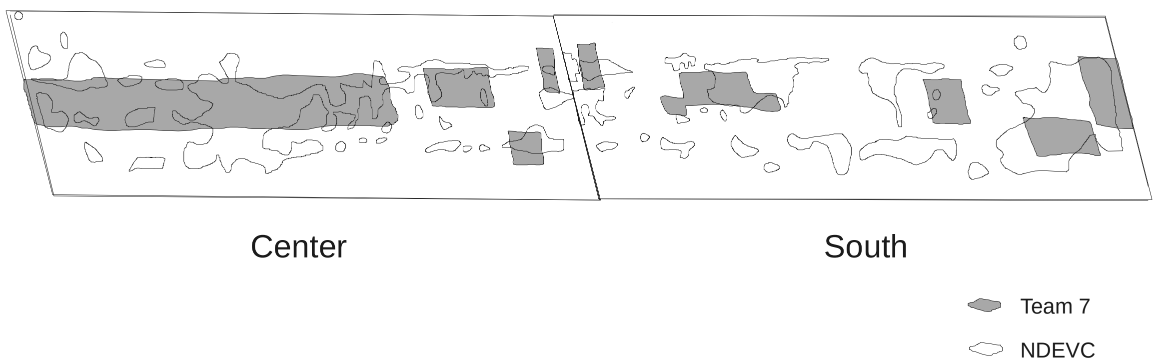


Figure 196. Delamination map from Team 7.

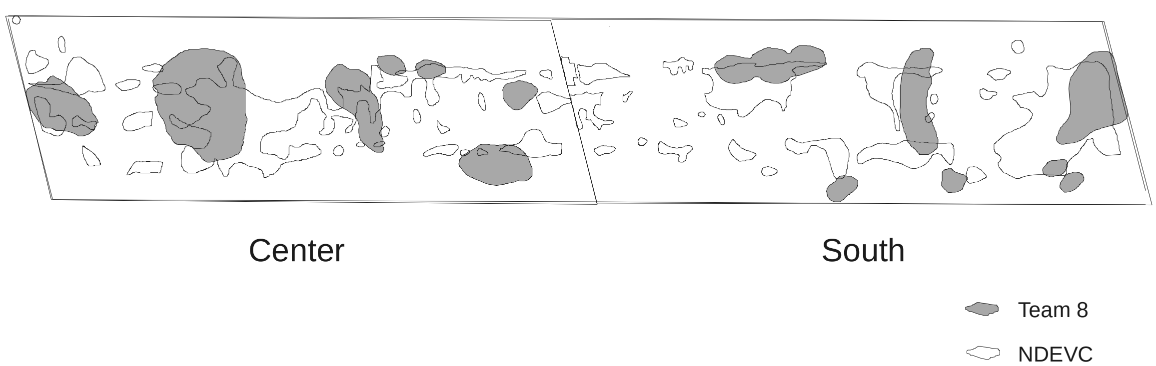


Figure 197. Delamination map from Team 8.

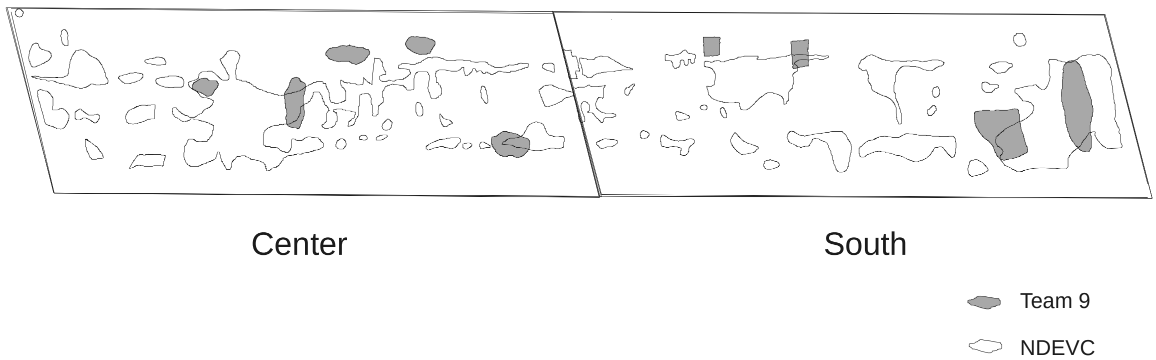


Figure 198. Delamination map from Team 9.

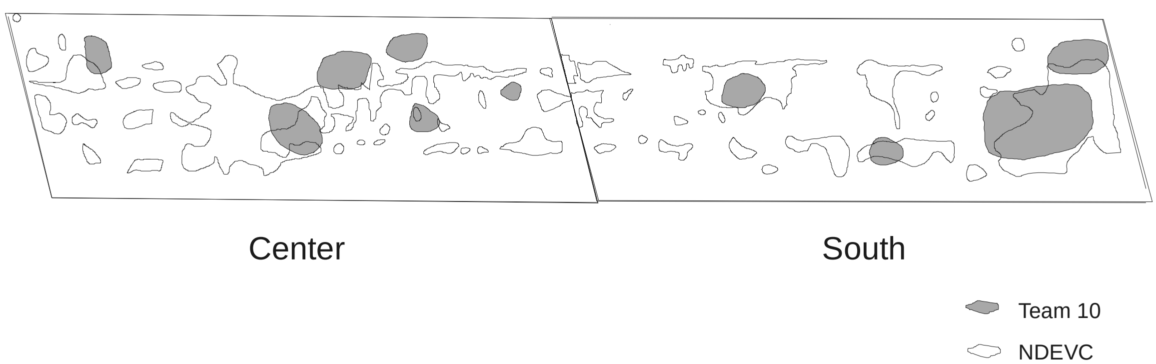


Figure 199. Delamination map from Team 10.

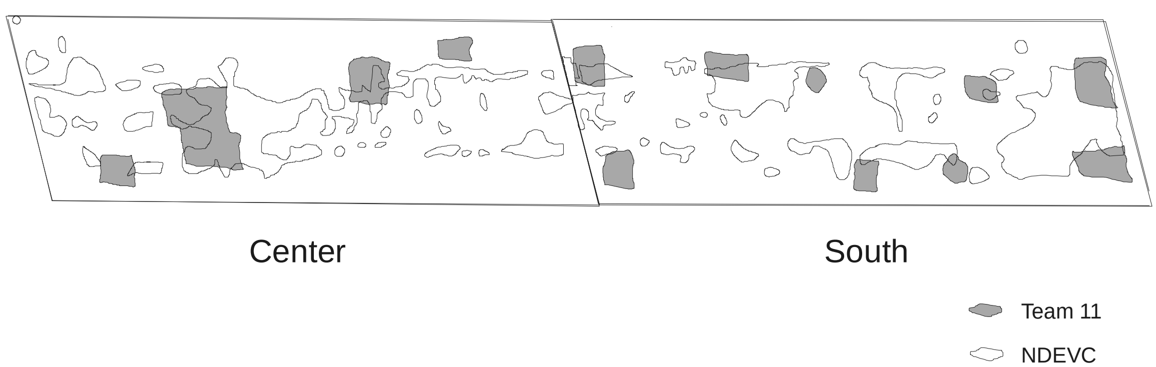


Figure 200. Delamination map from Team 11.

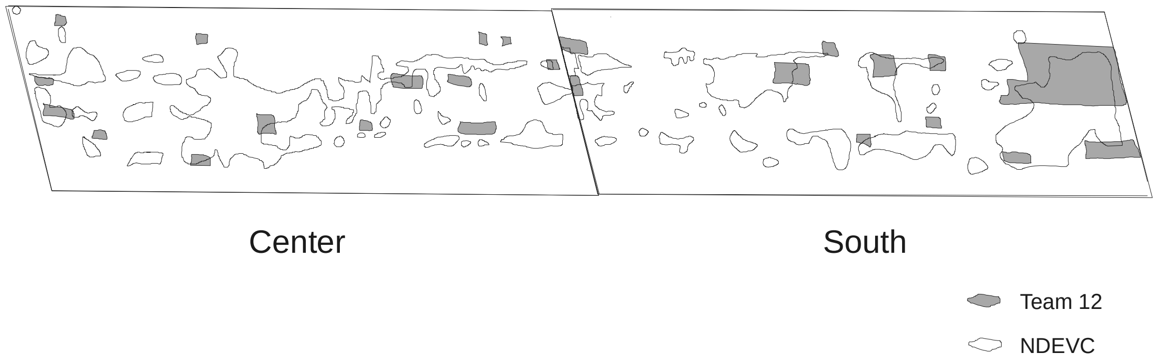


Figure 201. Delamination map from Team 12.

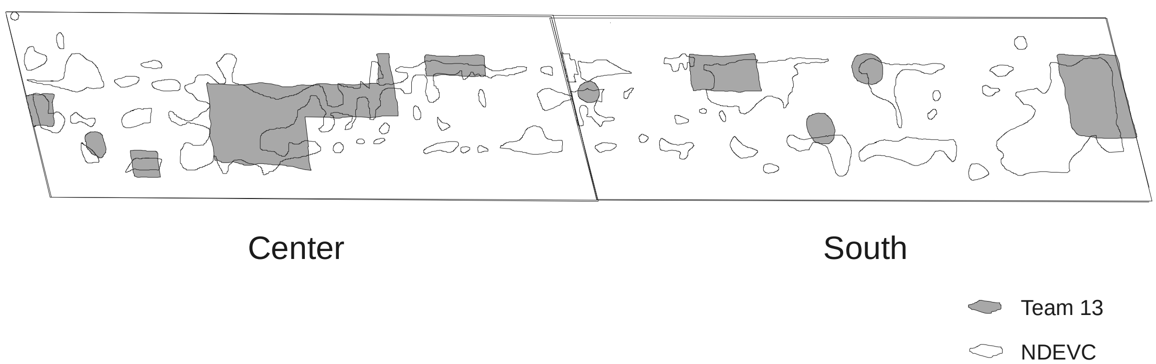


Figure 202. Delamination map from Team 13.

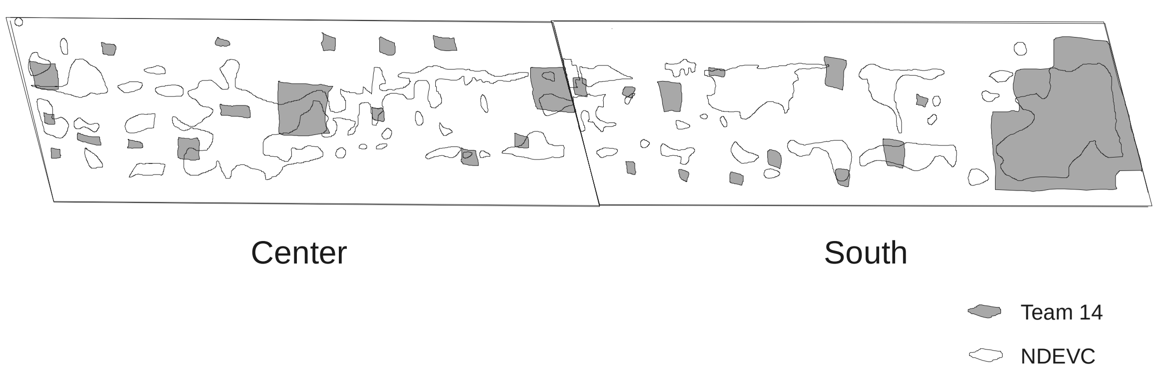


Figure 203. Delamination map from Team 14.

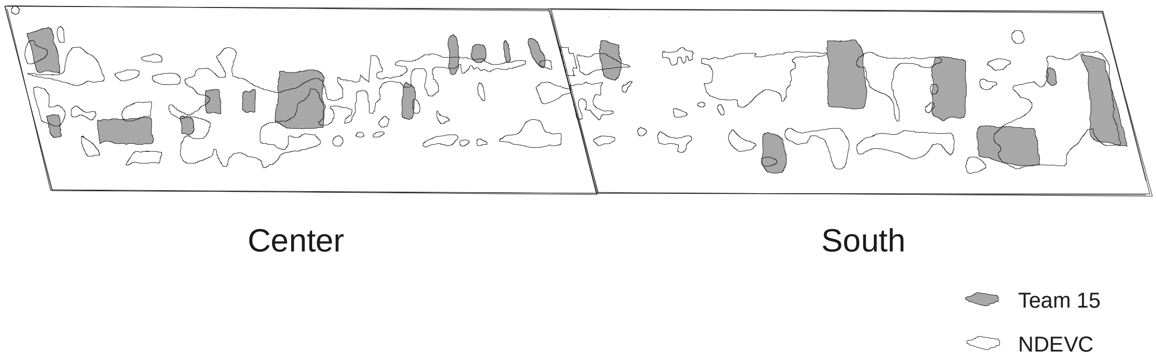


Figure 204. Delamination map from Team 15.

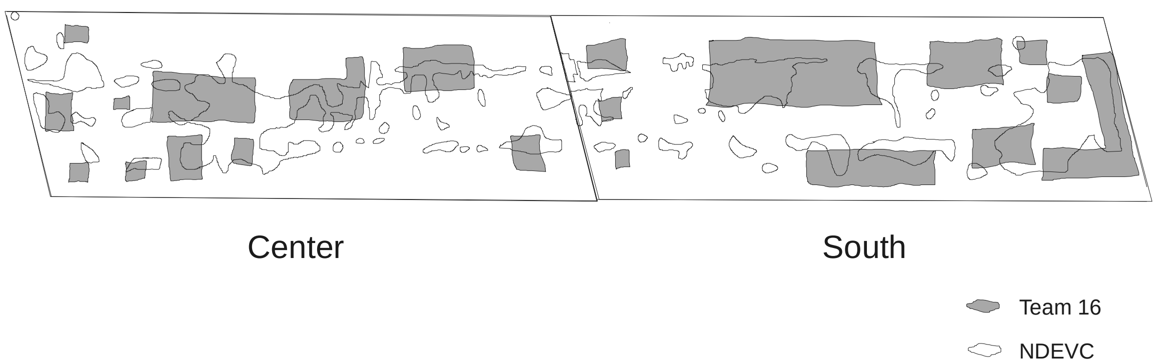


Figure 205. Delamination map from Team 16.

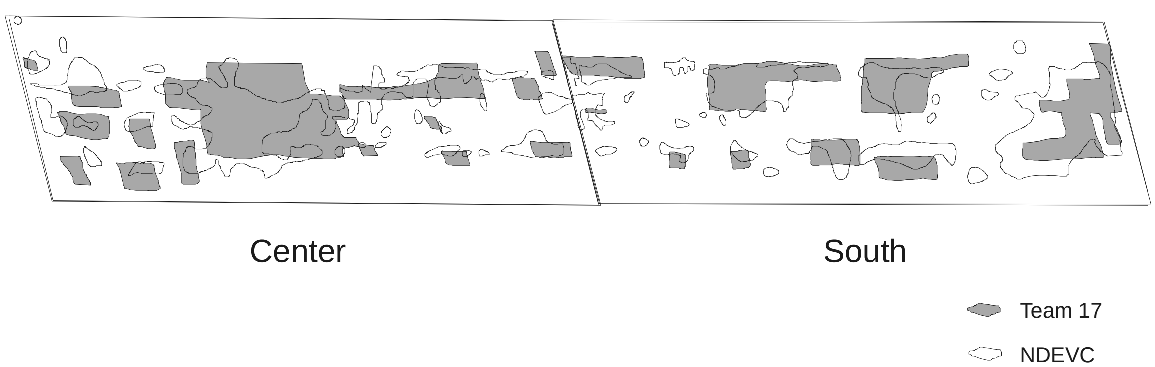


Figure 206. Delamination map from Team 17.

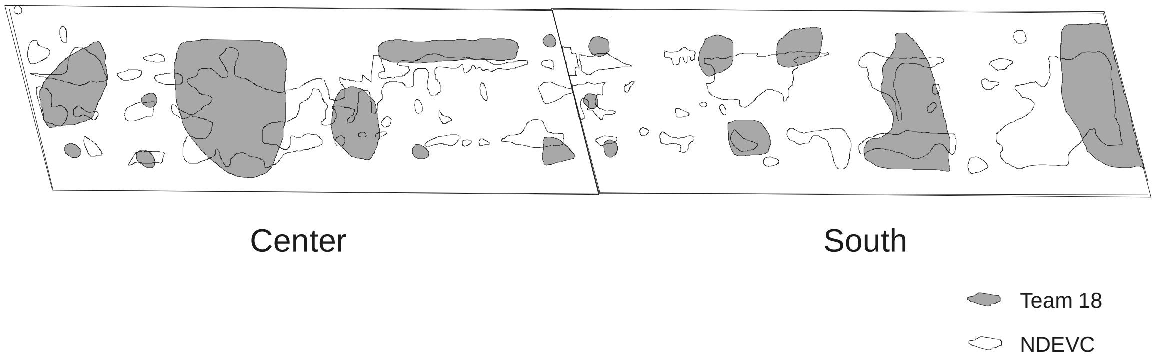


Figure 207. Delamination map from Team 18.

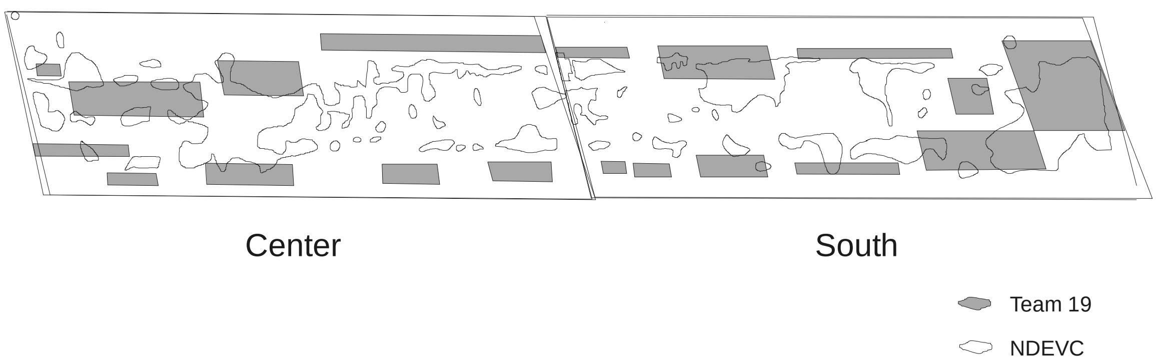


Figure 208. Delamination map from Team 19.

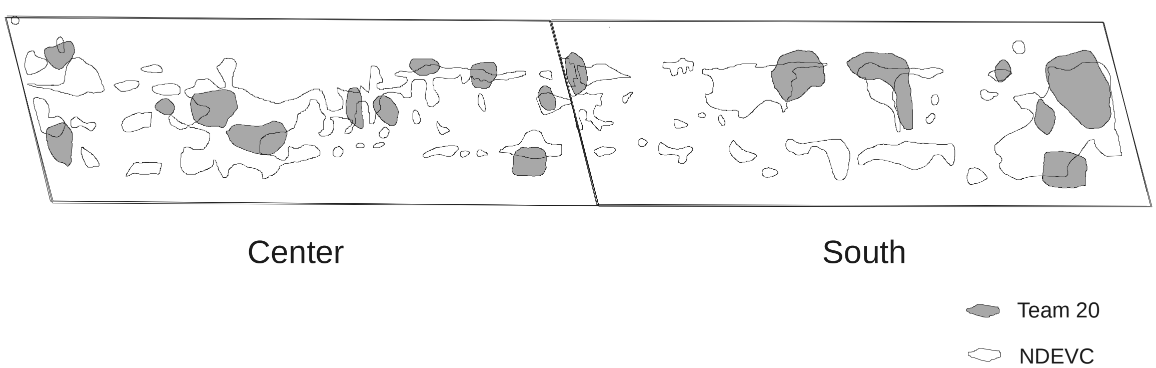


Figure 209. Delamination map from Team 20.

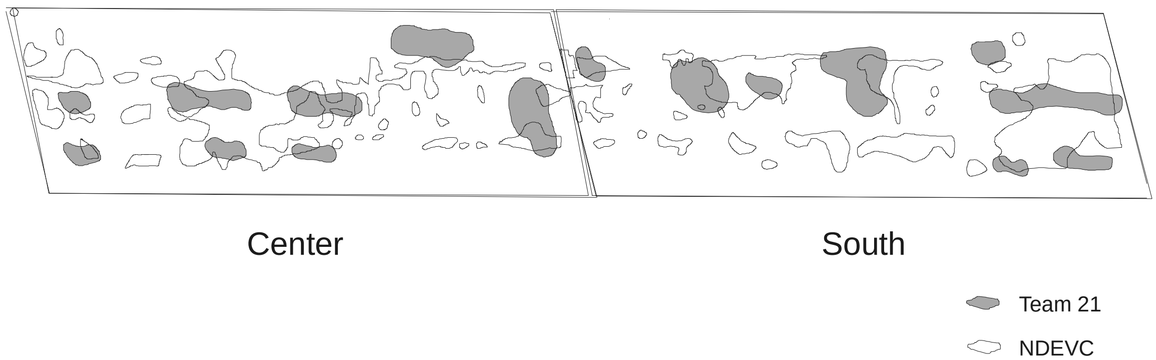


Figure 210. Delamination map from Team 21.

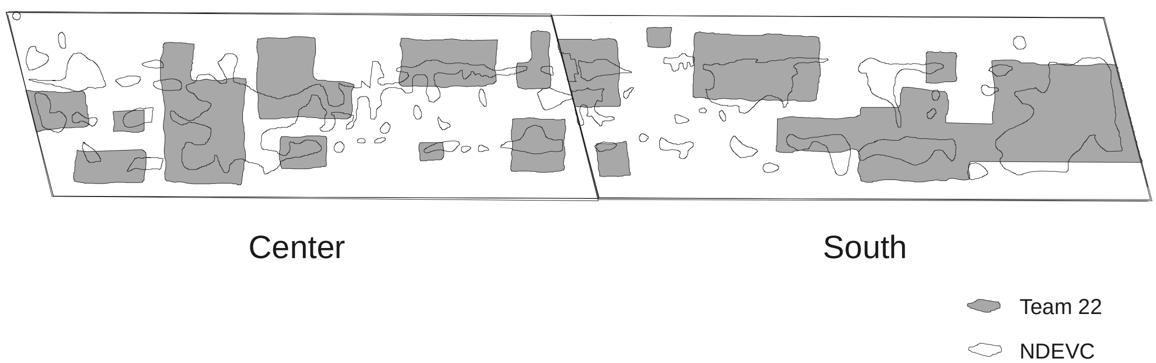


Figure 211. Delamination map from Team 22.

RECTANGULAR OUTLINES VERSUS ACTUAL OUTLINES: Looking at the delamination maps presented in figures 192 through 211, it appears that two different philosophies were used to develop these sketches. One philosophy uses rectangular areas to mark the delaminations. The other philosophy uses areas that are either generally circular or oval to mark the actual outlines of the delaminations. Table 237 summarizes the delamination percentages indicated by each of these two groups. As shown in table 237, the teams that mainly seemed to indicate actual areas had a much smaller average delamination percentage than those who indicated rectangular areas. The indication from this table is that inspector accuracy of delamination percentage estimates may actually be poorer than previously reported. Although the average delamination estimates of the teams that indicated rectangular areas are much closer to the

Table 237. Team delamination percentages – Actual areas versus rectangular areas.

Team Number	Actual Areas	Team Number	Rectangular Areas
1	2%	7	16%
2	4%	11	7%
3	5%	12	9%
4	10%	13	10%
8	17%	14	11%
9	2%	15	13%
10	5%	16	17%
18	25%	17	21%
20	9%	19	30%
21	11%	22	35%
	9% average		17% average

NDEVC average, their estimates have been inflated by adding nearby undelaminated areas to their totals.

COMMON AREAS NOT INDICATED AS DELAMINATED: Superposition of the delamination maps provided by the 20 teams can be used to illustrate areas that none of the teams indicated were delaminated. This superposition is shown in figure 212, where areas indicated to be delaminated are shown in white, and areas not indicated to be delaminated by any team are shown in either light or dark gray. Recall that no adjustments were made to the sketches as drawn, so some errors exist within this superposition, but it remains illustrative of several points. Approximately 31 percent of the deck, largely concentrated along the curbs, did not receive any delamination calls. Conversely, the union of all of the areas indicated as being delaminated is 69 percent. Recall that the average deck delamination was 13 percent, and the highest team total was 35 percent. This indicates a significant divergence of opinion as to where the delaminations are located. Figure 212 also indicates the areas identified as being delaminated by the NDEVC that were not indicated by any of the inspection teams on any of the delamination maps. These areas are shaded more heavily, and comprise about one-half of 1 percent of the deck area. As shown, these areas are typically very small and near the edges of the areas called out as delaminations. It seems reasonable to assume that a large percentage of these areas exist due to errors in recording the delaminations identified.

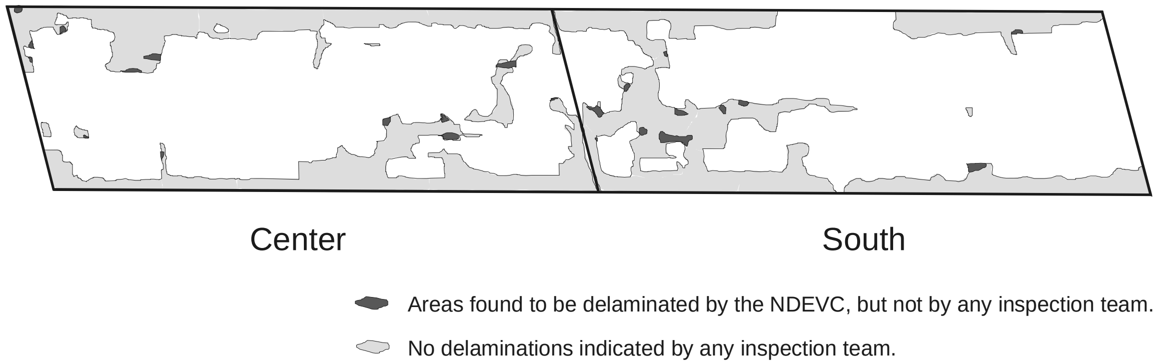


Figure 212. Areas all teams indicated were intact.

COMMON AREAS INDICATED AS DELAMINATED: Given the inspection team delamination reporting method used, it is also possible to determine common deck areas that several teams indicated were delaminated. This could be completed several different ways. First the intersection of all 20 maps was generated. However, it was observed that there were no areas that all teams indicated were delaminated; therefore, this figure is not presented.

An alternative method of presentation to illustrate commonly indicated delaminated areas was developed that uses additive fills for each team's delaminations. As the fills overlap, a darker shading results. The degree of shading indicates the frequency of delamination calls. The complete additive overlay is presented in figure 213. In parallel with figure 213, table 238 quantifies the percentage of deck area at each level of commonality (i.e., the percentage of the deck covered by areas indicated as being delaminated by exactly N teams). This table also shows the maximum amount of deck area to receive at least N delamination calls. In examining this table, it can be seen that the highest degree of commonality for any single, sizable delamination (0.2 percent of the deck area, or 0.4 m^2) was 15 teams. Figure 214 shows the delamination map representing delamination calls by at least 15 teams. This image actually indicates a maximum degree of commonality of 17 teams (this area is actually less than 32 cm^2). This area is small enough that it is probably outside the tolerance of the map and may not actually exist.

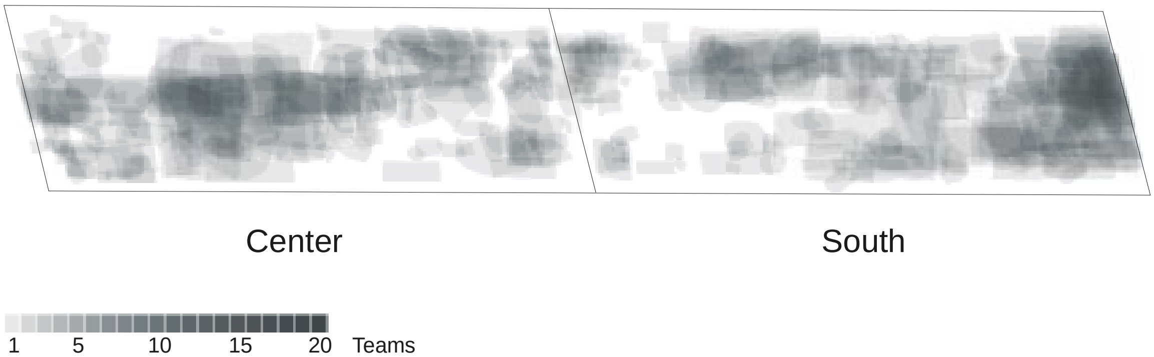


Figure 213. Transparent overlay of all delamination maps.

Table 238. Commonality percentages of deck delamination areas.

Level of Commonality	Percentage of Deck Area	Cumulative Percentage of Deck Area Delaminated
0	31.0	—
1	15.8	69.0
2	13.0	53.2
3	11.0	40.2
4	8.3	29.2
5	6.5	20.9
6	4.8	14.5
7	3.5	9.7
8	2.2	6.2
9	1.3	4.0
10	1.0	2.7
11	0.6	1.7
12	0.5	1.2
13	0.3	0.7
14	0.2	0.4
15	0.1	0.2
16	0.04	0.04
17	0.001	0.001
18	0	0
19	0	0
20	0	0

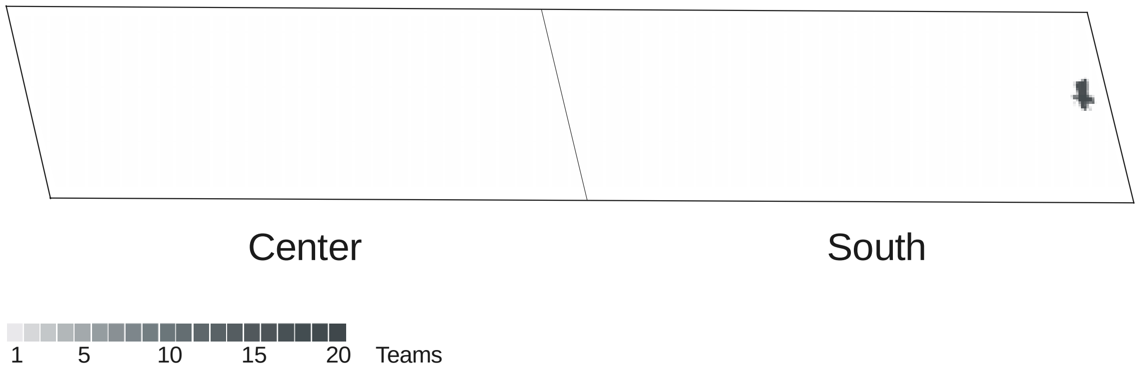


Figure 214. Areas indicated as containing delaminations by 15 or more teams.

Two other commonality levels were studied graphically. First, since the delamination maps submitted by the teams were approximate, the areas indicated as being delaminated by at least three teams were investigated. This investigation may reduce some of the errors within the maps by eliminating unique delamination calls and the first intersection level, both of which may be mislocated due to positioning errors in recording the data. As shown in figure 215, the total area with at least three delamination calls covers 40 percent of the deck area. Second, it was calculated that the amount of the deck area covered by at least five delamination calls was 21 percent. This level is closest to the 19 percent indicated by the NDEVC survey. Figure 216 compares the delamination map showing at least five delamination calls with the survey performed by the NDEVC.

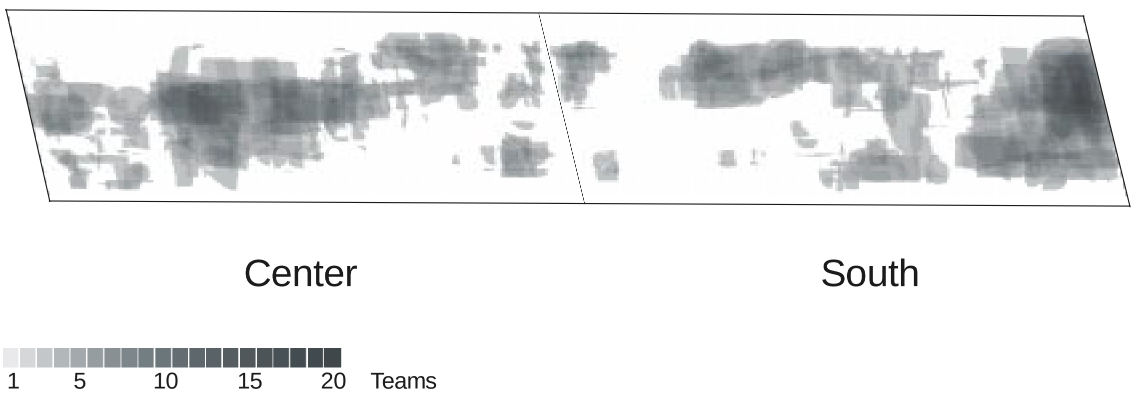


Figure 215. Areas indicated as containing delaminations by three or more teams.

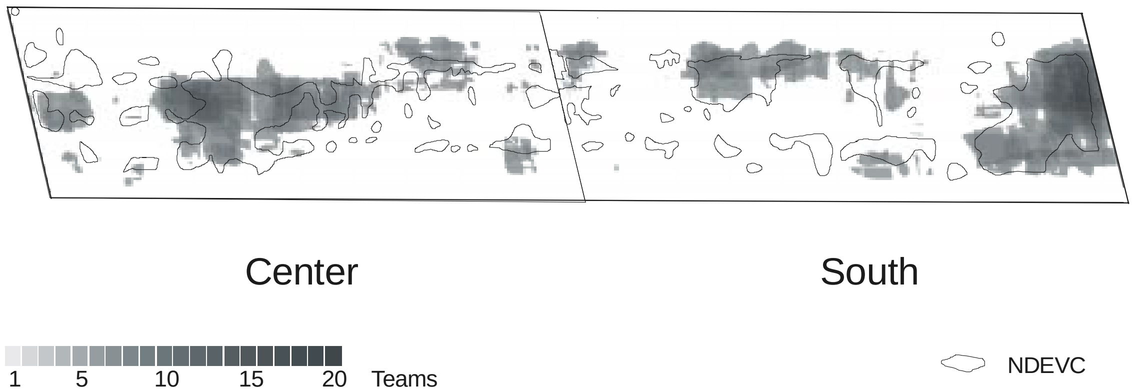


Figure 216. Areas indicated as containing delaminations by five or more teams, together with the results of the NDEVC survey.

The coring program that was mentioned previously also investigated some of the differences between team delamination calls and the NDEVC survey. Specifically, four of these disputed areas were cored; half of which were considered to be delaminated by the NDEVC. In addition, one of the disputed areas had at least five delamination calls by teams, although the NDEVC did not detect any signs of delamination. The results of the coring program determined that all four of the disputed areas were properly called by the NDEVC.

Another analysis was performed that investigated the correlation of the delamination maps between any two teams. There are 190 possible combinations of 2 different delamination maps. Figure 217 shows a histogram of the amount of intersection of the delamination areas for these combinations of two teams. The maximum amount of deck area indicated as being delaminated according to the intersection of two teams is 15.5 percent, while the most frequent amount of delamination intersection is between 1 and 2 percent.

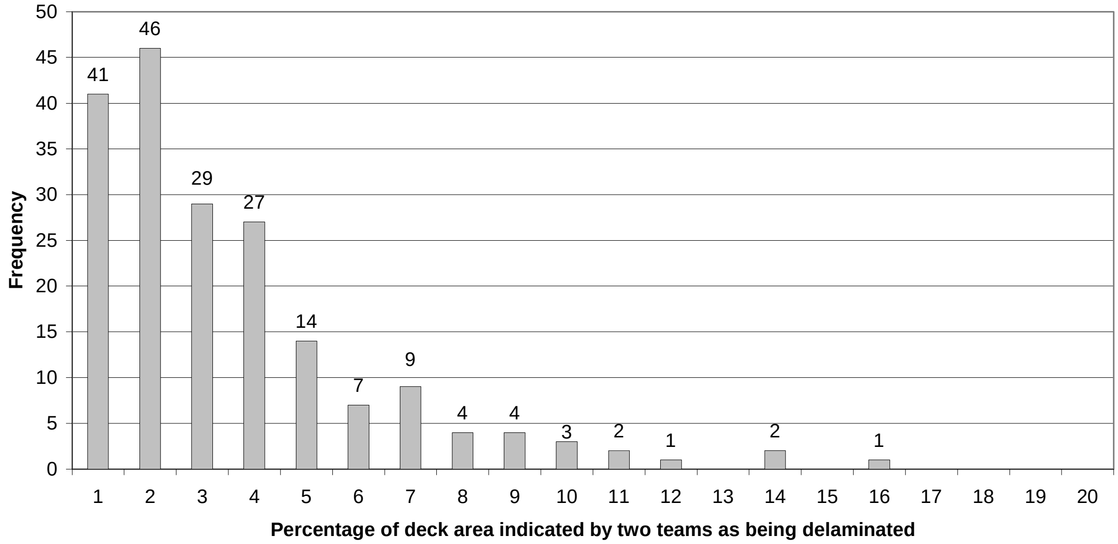


Figure 217. Histogram of amount of deck area indicated by two teams as being delaminated.

6. DISCUSSION OF FINDINGS

The following sections discuss the findings of this study. The discussion is presented in five primary sections. First, the findings from the State-of-the-Practice Survey will be discussed. The findings from the Routine Inspection tasks will follow. Next, the findings from the In-Depth Inspection tasks will be discussed. Comparisons between portions of the Routine and In-Depth Inspection findings are then presented. Finally, the findings from the State-dependent tasks will be discussed.

6.1. STATE-OF-THE-PRACTICE SURVEY

A survey was conducted to determine the state of the practice for bridge inspection. Participant groups that were targeted included State DOTs, county DOTs from Iowa, and bridge inspection contractors. Responses were received from 42 State DOTs, 72 counties, and 6 inspection contractors. Components of the survey included questions focusing on bridge inspection team composition and administrative requirements (both specifically in terms of Visual Inspection [VI]), and the general use of NDE.

Typical questions asked about the composition of inspection teams included: who performs bridge inspections, the types of inspections for which contractors are used, time and manpower budgets for a given inspection situation, PE presence during inspections and why, and experience levels for team members. Contractors were found to be used by a large percentage of States and counties, and may be used for a wide variety of inspection situations. State respondents indicated that PEs were typically not present on site for inspections. Almost 50 percent of State respondents indicated that a PE was present for less than 20 percent of their inspections. Contractors were most likely to have a PE on site during inspections.

Typical questions asked about administrative issues related to VI included: the size of the inspection units, required inspector training, procedure/policy improvements, vision testing, use of old inspection reports, the number of bridges inspected each year, and quality measures. Increased use of NDE, increased personnel, and increased equipment were frequently listed targets for additional bridge inspection resources. The Bridge Inspector’s Training Course was found to be the most frequently required training course by States, counties, and contractors for team leaders and other team members. Bridge management systems, training, and other operational areas were all topics that respondents suggested could be improved. Vision testing for inspectors was found to be almost non-existent; any vision tests (i.e., driver's license vision tests) were usually administered to satisfy other job requirements. The top QC response was review of inspection reports, and the top QA response was field re-inspection programs to spot-check inspection reports.

Typical questions asked about general NDE techniques included: the use of ASNT Level III inspectors, inspector certifications, NDE techniques currently used, NDE technique used most frequently, any discontinuation of NDE techniques for any reason, and applications for future research. A compilation of currently used NDE techniques was determined, with VI being cited most frequently. Some novel NDE techniques were also listed, such as acoustic emission, radar, and thermography. Concrete deck research and prestressed concrete superstructure research were the most frequently requested areas by State and county respondents for future NDE research.

6.2. ROUTINE INSPECTION

Aside from the State-dependent tasks, inspectors were asked to complete six Routine Inspection tasks. The following subsections discuss the findings from these tasks, focusing on inspection procedure, accuracy of inspection results, and factors influencing Condition Rating assignment.

6.2.1. Inspection Procedure

Inspection procedure includes three broad topics. First, the inspector's ability to identify structural attributes and probable structural deterioration modes was examined. This was done through a series of questions posed prior to each task that asked the inspectors to describe the bridge and to identify expected deterioration modes. The inspectors were generally able to identify the overall structure type. However, most inspectors did not indicate the existence of important structural attributes that may influence how each bridge should be inspected (e.g., skew, support conditions, etc.). In addition, most inspectors indicated that they expected to find some type of concrete and/or steel deterioration. However, there was less consensus on how the deterioration would be manifested.

The second inspection procedure topic focused on the inspector's methods for completing the inspection. In general, most inspectors visually examined each of the primary bridge components. Inspection tool use was minimal and, as a result, few detailed examinations were completed (e.g., sounding, measurement, etc.). Although typically used by less than 50 percent of the inspectors, the most common inspection tools used during the Routine Inspection tasks included a masonry hammer, flashlight, tape measure, and binoculars.

The final inspection procedure topic focused on the differences between an inspector's normal practices and those used during these performance trials. Although the inspection tasks were completed in a somewhat artificial manner (e.g., under observation, within prescribed time limits, etc.), the participating inspectors indicated that the tasks were administered and completed in a manner similar to normal Routine Inspections. Furthermore, the inspectors generally indicated that they were about as thorough as usual and that they exerted a typical amount of effort to complete the tasks.

6.2.2. Accuracy of Inspection Results

Accuracy of inspection results includes three broad topics. First is the accuracy with which Condition Ratings were assigned to the primary bridge elements. On average, there were between four and five different Condition Rating values assigned to each primary element. In addition, even if one does not know what the correct Condition Rating is, it has been shown that at least 48 percent of the individual Condition Ratings for the primary elements were assigned incorrectly, and if the NDEVC reference Condition Ratings are correct, then 58 percent of the individual ratings were assigned incorrectly. When considered as a group, at least 56 percent of the sample average Condition Ratings for the primary elements were incorrect with a 95 percent probability, and if the NDEVC reference Condition Ratings were correct, then 78 percent of the sample average ratings were incorrect with a 95 percent probability. The distribution of assigned primary element Condition Ratings was normal, and as a result, it is predicted that 95 percent of the primary element Condition Ratings for the entire bridge inspector population will vary within approximately two rating points from the average. It is also predicted that only 68 percent of the population would vary within approximately one rating point from the average. Thus, it appears that inspectors may have difficulty defining the level of deterioration in terms of the verbiage used in the Condition Rating system. The assignment of Condition Ratings to the secondary elements was completed with less consensus than for the primary elements. This is probably attributable to the fact that inspectors may not normally assign Condition Ratings to these types of elements.

The second topic within accuracy of inspection results focused on relationships between individual Condition Ratings. Overall, “better” condition primary bridge elements were rated lower than the reference Condition Ratings and “poorer” condition primary elements were rated higher than the reference Condition Ratings. In addition, the greatest dispersion in inspection results was from assessments of the substructures and “poorer” condition elements. Generally, inspectors who rated one primary element type higher than the reference also tended to do so for the other element types. A similar relationship exists between Condition Rating assignment on “poorer” and “better” condition primary elements. Finally, it appears that as the severity of the deficiencies rises, so does the difficulty in assessing the severity. This difficulty is most prevalent in the assessment of bridge decks.

The final topic within accuracy of inspection results focused on inspection documentation. Recall that during Task D, inspectors were provided with a camera with which they could photographically document their observations. The use of photographic documentation varied significantly. The most common photographs were of joint deterioration, deterioration of the parapet, an overall elevation view, and a general approach view. All other photographs were taken by less than half of the inspectors. However, providing photographic documentation did not appear to influence the assignment of the Task D Condition Ratings. Inspector documentation was also studied in terms of the specific field notes inspectors recorded during these six Routine Inspection tasks. Of the 20 investigated field notes describing moderate to severe deficiencies, most were taken by more than half of the inspectors. In general, the following inspector factors showed the strongest relationship with note-taking proficiency: Fear of Traffic, Perception of Bridge Inspection Importance to Public Safety, Quality of Relationship

With Supervisor, Estimated Additional Years as a Bridge Inspector, Comparison to Other Inspectors, General Education Level, and Formal Bridge Inspection Training. On a task-by-task basis, similar to the photographic documentation, note-taking appears to have no influence on the assignment of Condition Ratings. However, when the task results are combined, inspectors who took a greater number of total notes tended to give Condition Ratings that were higher than the reference ratings and that contained less dispersion overall. The converse was also found to be true.

6.2.3. Factors Influencing Condition Rating Assignment

Multivariate equations that model the inspector and inspection factors have been developed to predict the sample primary element Condition Rating results. The most frequently recurring inspector factors in these equations include: Reported Fear of Traffic, Near Visual Acuity, Color Vision, and Formal Bridge Inspection Training. Similarly, the most frequently recurring inspection factors include: Light Intensity, Reported Structure Maintenance Level, Reported Structure Accessibility Level, Reported Structure Complexity Level, Inspector Rushed Level, and Wind Speed. An interaction between the inspector and the inspection factors does exist, and when these factors were considered jointly, the predictability of the sample primary element Condition Rating results is improved.

There were a number of factors that one might logically think could influence Condition Rating assignment that were found to have minimal correlation. Specifically, these include such items as being a registered PE, general education level, and bridge inspection experience.

6.3. IN-DEPTH INSPECTION

Aside from the State-dependent tasks, inspectors were asked to complete two In-Depth Inspections. The following discusses the findings of these tasks, focusing on the accuracy of the inspection results and on the factors that tend to relate to the inspection results.

6.3.1. Accuracy of Inspection Results

Detailed results of the In-Depth Inspections were presented in Chapter 5. Within both Task F and Task H, deficiencies considered to warrant notation in an inspection report were selected as the expected defects that inspectors should have noted during their inspections. Table 232 presents a summary of the deficiency detection results for these items. The table includes the number of inspectors who performed the specific portion of the task necessary to have located the defect, and the number and percentage of inspectors who correctly located the defect.

There are a few clear trends evident in the information contained in Table 239. First, general coating defects in a steel superstructure will probably be noted during an In-Depth Inspection. As would be expected, it is also evident that a superstructure with a greater level of deterioration (i.e., Task F) will be more likely to be indicated as having deficiencies.

With regard to more localized, specific defects, the results show that it is unlikely that an inspector will note the types of deficiencies examined in this study. In every case, less than 8 percent of the inspectors noted either of the implanted defects in Task F or any of the weld crack indications in Task H. The results from the weld crack indications in Task H show that, for the types of indications present in this task, the overall accuracy rate for identifying these defects is 3.9 percent. Finally, with regard to the bolt defects in Task H, the results show that, in general, only approximately 25 percent of the inspectors will note this type of deficiency.

6.3.2. Factors Correlating With Inspection Results

The factors that show some correlation with the inspection results from the In-Depth Inspections were presented in Chapter 5. Within this group of factors, there are 11 specific factors that show stronger relationships to the inspection results. The following combines the results from Tasks F and H and presents a discussion of these factors and factor categories. The discussion includes factors related to inspection thoroughness, inspection time, inspector comfort during inspection, structure complexity, structure accessibility, inspector viewing of welds, flashlight use, and number of annual bridge inspections.

In general, the factors mentioned above correlate to some portion of the inspector subsets. However, correlation does not necessarily indicate causation. Since this was only a univariate analysis that compared one factor to a set of results, it may not be correct to conclude that an inspector who rates favorably on one factor scale will automatically perform a better inspection.

These results present a group of factors that show some relationship to the findings and thus may have an influence on the results.

Among the factors found to relate to the inspection results, the inspection thoroughness as measured and analyzed in Task H provided a strong relationship. These results showed that inspectors who performed a more thorough inspection were more likely to locate specific deficiencies, such as weld crack indications. The inspectors who performed thorough inspections also tended to be focused, had a high tolerance for working at heights, used the necessary tools, and inspected critical locations.

Table 239. In-Depth Inspection deficiency detection results.

	Deficiency	Inspector Sample	Number of Inspectors Identifying Deficiency	Percentage of Inspectors Identifying Deficiency
Task F	Paint System Failure	42	42	100%
	General Corrosion	42	41	98%
	Rivet Head Corrosion	42	19	45%
	Efflorescence	42	29	69%
	Implanted Tack Weld Crack	42	3	7%
	Implanted Missing Rivet Head	42	2	5%
	Impact Damage	42	7	17%
	Bearing Misalignment	42	21	50%
Task H	Paint System Failure	44	29	66%
	General Corrosion	44	24	55%
	Member Distortion	44	5	11%
	Fabrication Error	44	1	2%
	Crack Indication W1	44	1	2%
	Crack Indication W2	44	2	5%
	Crack Indication W3	44	3	7%
	Crack Indication W4	42	1	2%
	Crack Indication W5	44	2	5%
	Crack Indication W6	44	1	2%
	Crack Indication W7	42	2	5%
	Bolt Defect B1	44	14	32%
	Bolt Defect B2	42	8	19%
	Bolt Defect B3	42	9	21%

Actual Time to Complete Inspection is a factor that showed some correlation with the results. The results from both tasks show a tendency for inspectors who located defects to have spent more time on their inspection. The results also show that the inspectors who indicated that there were no defects tended to spend less time on their inspections. Furthermore, the results from Task H show that inspectors who correctly located multiple relatively minute detail defects, such as a weld crack indication or bolt defects, tended to take significantly more time to complete the task. With regard to Estimated Time to Complete Inspection, the inspectors who noted defects tended to spend more time on the inspection than they had anticipated spending, while the inspectors who noted no deficiencies spent significantly less time than they had anticipated. These results seem to indicate that the inspectors who worked more slowly found more defects. However, these results also allow for the possibility that the detection of a defect would tend to slow the inspector, forcing a longer, more thorough examination of the bridge.

There are three factors that focus on the comfort of the inspector while performing an inspection at heights. All three of these factors tended to correlate with the results from Task H. This is probably due to the task being performed from a boom lift more than 15.2 m (50 ft) above ground level. These three factors — Fear of Heights, Observed Inspector Comfort With Heights, and Observed Inspector Comfort With Lift — will all be discussed together due to their close relationship. The first tendency is for the inspectors who noted no deficiencies in Task H to also receive a relatively low rating for Comfort With Lift and Comfort With Heights, and for them to report that they had a greater than average fear of heights. Conversely, the inspectors who noted a weld crack indication or the distortion defect tended to receive greater than average ratings for Comfort With Heights and Comfort With Lift. The inspectors who noted a weld crack indication also reported that they had less fear of heights than average. Clearly, inspectors who were more comfortable working at heights were more likely to correctly locate defects, while those who were uncomfortable tended to locate no defects.

Inspector-Reported Structure Accessibility and Inspector-Reported Structure Complexity are both factors that were found to relate to certain subsets of inspectors, and thus with the detection of certain types of defects. This is probably due to two reasons. First, both factors tend to affect the way an inspection is performed, possibly causing the inspector to not gain the access that may be necessary to fully inspect certain details. Second, they also describe the inspector's overall view of the structure, providing an indication of the types of defects that are being looked for. With regard to complexity, the inspectors who noted an implanted defect in Task F and the inspectors who noted a weld crack indication in Task H rated the respective structures as more complex. The inspectors who noted a weld crack indication in Task H also rated the accessibility of that structure as being lower than average. Alternatively, the inspectors who noted the distortion defect in Task H, as compared to the average inspector, felt that the bridge was more accessible and less complex. These results seem to indicate that the inspectors who tend to find smaller defects, such as a weld crack indication, are more likely to feel that the structure is more difficult to inspect than average. Also, inspectors who locate larger defects, such as overall flange distortions, seem more likely to indicate that the structure is easier to inspect than average. Note, however, that the converse of both of these statements may also be true, with the perception of complexity and accessibility possibly causing the inspector to find certain defects.

The physical action of inspecting welds during Task H leads to two more factors that tend to relate to the inspection results from that task. The Observed Variation in Viewing Angle and the Observed Distance to Weld Inspected are both factors that clearly demonstrate that the inspectors who located certain types of defects did so because they were specifically looking for that type of defect. Inspectors who noted a weld crack indication were significantly more likely to be observed varying their viewing angle when inspecting welded connections. These inspectors were also observed to be much closer than average to the welds that they were inspecting. Alternatively, the inspectors who did not note any defects in Task H were observed to vary their viewing angle less frequently and to be much farther away from the welds that they were inspecting than the average inspector. It seems clear that some inspectors were looking for certain types of defects, while others were not.

Along similar lines, the use of a flashlight is another factor that relates to certain inspectors. Compared to the average, a higher percentage of the inspectors who located the implanted defect in Task F, the impact damage in Task F, or a weld defect in Task H tended to use a flashlight. Since it is unlikely that the act of detecting a weld crack indication would cause the inspector to use the flashlight, it seems clear that the use of the flashlight aided the inspector in the location of these defects.

Finally, the Number of Annual Bridge Inspections also tended to relate to the results from Task H. These results show that inspectors who correctly located one or multiple weld crack indications tend to inspect significantly fewer bridges per year than average. Alternatively, the inspectors who indicated that there were no deficiencies in Task H tended to inspect significantly more bridges per year than average. This may indicate that inspectors who inspect more bridges per year either become more rushed and thus perform a less thorough inspection or are less familiar with performing In-Depth Inspections and thus do not know what deficiencies to look for. Inspectors who perform fewer inspections per year than average may be more familiar with In-Depth Inspections and thus may have performed better inspections.

6.4. COMPARISON OF ROUTINE AND IN-DEPTH INSPECTION SUBSETS

Comparisons can be made between various subsets of inspectors, as defined through the results that were obtained in the Routine and In-Depth Inspection portions of this study. The following section discusses comparisons between these subsets of inspectors.

6.4.1. Routine Inspection Subset Comparison

In Chapter 5, the Routine Inspection results were analyzed in a number of different ways. From these analyses, the inspectors can be grouped into subsets based on their individual performance. The subsets are based on six general measurements: (1) overall Condition Rating accuracy, (2) superstructure Condition Rating accuracy, (3) overall Condition Rating precision, (4) superstructure Condition Rating precision, (5) photographic documentation, and (6) field inspection notes. The inspectors were grouped into “high” and “low” performance groups of these subsets based on the data in Chapter 5, thereby creating 12 subsets. Note that for these analyses, inspectors not in either the high or low performance groups were not included. The criteria used to determine which inspectors were classified into each subset are shown in table 240. This table also shows how many inspectors were in each subset. Also note that the high and low superstructure Condition Rating accuracy groups are primarily included here for completeness, as they are used in later comparisons between Routine and In-Depth Inspection inspector subsets.

Table 240. Routine Inspection subset classification.

	Performance Criteria			
	High		Low	
Inspector Subset Types	N	Criteria	N	Criteria
Accuracy (Overall)	14	$\|DFR\|<0.20$	6	$\|DFR\|>0.75$
Accuracy (Superstructure)	20	$\|DFR\|<0.20$	9	$\|DFR\|>0.75$
Precision (Overall)	14	$\sigma<0.72$	7	$\sigma>1.00$
Precision (Superstructure)	15	$\sigma<0.60$	10	$\sigma>1.00$
Photographs	11	Percentage of total > 50%	13	Percentage of total < 30%
Notes	11	Total number of notes > 16	16	Total number of notes < 14

The following analysis focuses on whether inspectors who may have been grouped into one of the Routine Inspection subsets also tended to fall into another of these subsets. Table 241 presents the results of these comparisons. The rows of this table present the inspector subsets, along with the results of the overall set of inspectors. These subsets are the inspectors who are being analyzed. The columns show the associated subsets. For example, the table shows that 50 percent of the inspectors who had high overall accuracy also had high accuracy in assessing the superstructures. This result could be compared to the overall inspector sample result, which indicates that 41 percent of the overall inspector sample had high accuracy in assessing the superstructures.

There are a number of specific subset comparisons that deserve to be mentioned. First note that 100 percent of the low overall accuracy inspectors also had low accuracy for the superstructures, as compared to 18 percent overall. Also note that 57 percent of the high overall precision inspectors also had high precision for the superstructures, as compared to 31 percent overall. Similarly, 43 percent of the inspectors with low overall precision also had low precision on the superstructures, as compared to 20 percent overall. Finally, note that none of the inspectors that took a large number of photographs also took a large number of notes, as compared to 33 percent overall. Based on these data, it appears that the inspector subsets analyzed here tend to produce certain types of inspection results. Specifically, these inspectors are generally consistent in their Condition Rating assignment accuracy and precision.

Table 241. Comparison of Routine Inspection subsets.

	High Accuracy (Overall)	Low Accuracy (Overall)	High Accuracy (Superstructure)	Low Accuracy (Superstructure)	High Precision (Overall)	Low Precision (Overall)	High Precision (Superstructure)	Low Precision (Superstructure)	Large Number of Photos Taken	Small Number of Photos Taken	Large Number of Notes Taken	Small Number of Notes Taken
Overall	29%	12%	41%	18%	29%	14%	31%	20%	22%	27%	22%	33%
High Accuracy (Overall)	100%	0%	50%	0%	29%	0%	29%	7%	21%	21%	21%	29%
Low Accuracy (Overall)	0%	100%	0%	100%	0%	50%	0%	50%	0%	33%	50%	50%
High Accuracy (Superstructure)	35%	0%	100%	0%	35%	10%	25%	15%	30%	30%	25%	40%
Low Accuracy (Superstructure)	0%	67%	0%	100%	11%	44%	11%	44%	11%	22%	33%	56%
High Precision (Overall)	29%	0%	50%	7%	100%	0%	57%	0%	21%	36%	14%	50%
Low Precision (Overall)	0%	43%	29%	57%	0%	100%	0%	43%	29%	29%	43%	29%
High Precision (Superstructure)	27%	0%	33%	7%	53%	0%	100%	0%	27%	13%	27%	33%
Low Precision (Superstructure)	10%	30%	30%	40%	0%	30%	0%	100%	30%	10%	20%	40%
Large Number of Photos Taken	27%	0%	55%	9%	27%	18%	36%	27%	100%	0%	0%	36%
Small Number of Photos Taken	23%	15%	46%	15%	38%	15%	15%	8%	0%	100%	15%	31%
Large Number of Notes Taken	27%	27%	45%	27%	18%	27%	36%	18%	0%	18%	100%	0%
Small Number of Notes Taken	25%	19%	50%	31%	44%	13%	31%	25%	25%	25%	0%	100%

6.4.2. In-Depth Inspection Subset Comparison

In Chapter 5, a number of subsets of inspectors were defined for both Task F and for Task H. This section focuses on whether inspectors, who may have been grouped into one of these In-Depth Inspection subsets, also tended to fall into another of these subsets. Ten of the 12 inspector subsets defined for Tasks F and H will be used here. The subsets of inspectors who identified multiple weld crack indications and multiple bolt defects will not be discussed.

Table 242 presents the results of these comparisons. The rows of this table present the 10 inspector subsets, along with the results from the overall set of inspectors. These subsets are the inspectors who are being analyzed to determine if they tended to fall into other subset categories. The columns show the associated subsets. These are the deficiencies (or non-deficiencies) with which the primary inspector subsets are being compared.

There are a number of specific subset comparisons that deserve to be mentioned. First, note that 50 percent of the inspectors who noted a Task F implanted defect also noted a Task H weld crack indication, as compared to only 16 percent overall. Also note that 60 percent of the inspectors who noted the Task H distortion defect also noted the Task F impact damage, as compared to 17 percent overall. Eighty percent of the inspectors who noted the Task H distortion defect also noted a Task H bolt defect, however, none of those inspectors noted a weld crack indication. Finally, note that 50 percent of the inspectors who indicated that there were no deficiencies in Task H also indicated no deficiencies in Task F, as compared to 21 percent of the inspectors overall.

These findings indicate that certain types of inspectors tend to produce certain types of inspection results. Specifically, inspectors who find small, detailed defects (such as a weld crack indication) will tend to do so regardless of the bridge. Inspectors who find gross dimensional defects (such as distortions or impact damage) will also tend to do so regardless of the bridge. Finally, those inspectors who find fewer than average defects in one bridge will probably do the same for another bridge.

Table 242. Comparison of In-Depth Inspection subsets.

			Associated Inspector Subset									
			Task F					Task H				
			Rivet Corrosion Defect	Implanted Defect	Bearing Defect	Impact Damage	No Deficiencies	Weld Crack Indication	Bolt Defect	Distortion Defect	Coating Defect	No Deficiencies
		Overall	45%	10%	50%	17%	21%	16%	39%	11%	66%	18%
Inspector Subset	Task F	Rivet Corrosion Defect	100%	16%	58%	16%	0%	21%	26%	5%	68%	0%
		Implanted Defect	75%	100%	50%	0%	0%	50%	50%	0%	50%	0%
		Bearing Defect	52%	10%	100%	5%	0%	19%	24%	5%	57%	14%
		Impact Damage	43%	0%	14%	100%	0%	14%	57%	43%	71%	0%
		No Deficiencies	0%	0%	0%	0%	100%	0%	22%	11%	33%	44%
	Task H	Weld Crack Indication	57%	29%	57%	14%	0%	100%	43%	0%	43%	0%
		Bolt Defect	29%	12%	29%	24%	12%	18%	100%	24%	65%	0%
		Distortion Defect	20%	0%	20%	60%	20%	0%	80%	100%	80%	0%
		Coating Defect	45%	7%	41%	17%	10%	10%	38%	14%	100%	0%
		No Deficiencies	0%	0%	38%	0%	50%	0%	0%	0%	0%	100%

6.4.3. Routine Inspection Performance of In-Depth Inspection Subsets

In this section, the In-Depth Inspection subsets that were discussed previously are analyzed with respect to their performance on the Routine Inspection tasks. Five general descriptors of performance will be used in this analysis: Condition Rating accuracy, DFR accuracy, DFR precision, written inspection note proficiency, and photographic documentation proficiency. These five sets of data were the subject of much of the analysis presented previously in the Routine Inspection Results section.

Table 243 summarizes the probability that inspectors from each of the In-Depth Inspection subsets gave Condition Ratings that were not different from inspectors not in the particular inspector subset. The probabilities shown in table 243 vary from 0 percent to 100 percent, indicating a wide range of potential relationships.

Table 243. In-Depth inspector subset relationship with Routine Inspection Condition Ratings.

	Deck					
Inspector Subset	Task A	Task B	Task C	Task D	Task E	Task G
Rivet Corrosion Defect	25%	31%	81%	57%	60%	54%
Implanted Defect	93%	68%	79%	27%	79%	100%
Bearing Defect	58%	16%	63%	80%	55%	54%
Impact Damage	45%	47%	22%	65%	79%	41%
No Deficiencies (Task F)	67%	47%	45%	45%	57%	45%
Weld Crack Indication	23%	41%	8%	93%	94%	36%
Bolt Defect	19%	37%	37%	84%	94%	24%
Coating Defect	99%	70%	36%	0%	90%	62%
Distortion Defect	72%	28%	5%	12%	33%	68%
No Deficiencies (Task H)	52%	24%	47%	9%	61%	17%

	Superstructure					
Inspector Subset	Task A	Task B	Task C	Task D	Task E	Task G
Rivet Corrosion Defect	14%	10%	15%	97%	83%	76%
Implanted Defect	71%	97%	37%	16%	85%	65%
Bearing Defect	5%	84%	85%	45%	89%	52%
Impact Damage	11%	13%	93%	1%	59%	1%
No Deficiencies (Task F)	20%	86%	53%	38%	69%	38%
Weld Crack Indication	73%	96%	86%	61%	41%	82%
Bolt Defect	85%	3%	25%	14%	91%	15%
Coating Defect	73%	42%	48%	34%	86%	37%
Distortion Defect	79%	97%	97%	47%	43%	15%
No Deficiencies (Task H)	89%	69%	90%	16%	85%	33%

	Substructure					
Inspector Subset	Task A	Task B	Task C	Task D	Task E	Task G
Rivet Corrosion Defect	29%	59%	9%	93%	38%	7%
Implanted Defect	83%	46%	24%	73%	71%	65%
Bearing Defect	36%	13%	89%	12%	51%	1%
Impact Damage	56%	31%	86%	3%	77%	90%
No Deficiencies (Task F)	50%	79%	47%	67%	18%	0%
Weld Crack Indication	37%	84%	31%	12%	17%	58%
Bolt Defect	11%	13%	46%	3%	85%	54%
Coating Defect	96%	67%	60%	11%	36%	94%
Distortion Defect	91%	72%	55%	55%	100%	67%
No Deficiencies (Task H)	82%	53%	83%	79%	47%	75%

Table 243 provides the following results. Note that the results pertaining to the Routine Inspection superstructure are of the most interest due to their closer relationship to the In-Depth Inspection results, which focus solely on superstructure inspections. It appears that inspectors who identified the impact damage may have generally given statistically different Condition Ratings for four of the six superstructures. Furthermore, a review of the Task A superstructure data reveals three findings. First, there was a difference between inspectors noting the rivet corrosion defect and those not noting this defect. This is expected given the fact that the Task A bridge was also a riveted structure. Second, the bearing defect subset also appears to have assigned statistically different Condition Ratings from those not noting the bearing defect. This is again expected since the Task F and Task A bridges had similar bearing types. Third, the Condition Ratings assigned by the impact damage subset differed from those inspectors who did not identify this defect. Again, the Task A bridge also had impact damage and could have contributed to the differences. On the other hand, there were no significant differences in the Condition Ratings assigned by any of the subsets for Task E (i.e., the Routine Inspection of the same bridge inspected in Task F).

Similar to the data presented in table 243, table 244 summarizes the probability that inspectors from each of the In-Depth Inspection inspector subsets gave DFRs that were not different from inspectors not in each of the inspector subsets. Two of the inspector subsets appear to have a strong correlation with the DFR data: Impact Damage and Bolt Defect. Both of these subsets had very low probabilities of not being different (2 and 3 percent, respectively) for the superstructure DFR and relatively low probability for the general DFR (i.e., all elements). As was discussed in the In-Depth Inspection Results section, the inspectors who identified the impact damage defect were inspectors who, overall, tended to identify a larger than average percentage of the general structural deficiencies. This type of inspection finding is very similar to the findings that would normally be made during a Routine Inspection, thus possibly accounting for the low probability. The identification of loose bolts, such as those identified by the bolt defect group, is relatively straightforward and is another type of defect that might be found during a Routine Inspection. In light of this, it appears logical that the inspectors identifying the bolt defect could have assigned statistically different Condition Ratings for the superstructures.

Table 244. In-Depth inspector subset relationship with Routine Inspection DFR.

Inspector Subset	Deck	Superstructure	Substructure	All Elements
Rivet Corrosion Defect	86%	15%	90%	49%
Implanted Defect	89%	65%	83%	93%
Bearing Defect	69%	26%	37%	43%
Impact Damage	18%	2%	29%	9%
No Deficiencies (Task F)	48%	78%	97%	88%
Weld Crack Indication	44%	100%	15%	41%
Bolt Defect	18%	3%	10%	7%
Coating Defect	29%	71%	91%	65%
Distortion Defect	44%	19%	88%	44%
No Deficiencies (Task H)	58%	72%	88%	85%

A review of the inspector DFR data, with respect to the precision of their assessments is given in table 245. As in the previous discussion, the inspectors identifying the impact damage again showed statistical differences in the dispersion data. The inspectors identifying the bearing defect showed differences in their dispersion for the substructure. This may indicate that the evaluation of bearings and substructures may be completed in a similar manner or may require similar skills. Also, inspectors identifying a weld crack indication had a statistically different precision in the evaluation of the decks. Inspectors identifying the coating defect tended to have a statistically different precision when all element types were combined. This is probably attributable to the fact that the coating defect was manifested in a number of different ways and required the inspector to possess a number of different inspection skills. In a similar manner, a number of different skills would be needed to evaluate all of the element types.

Table 245. In-Depth inspector subset relationship with dispersion on Routine Inspection DFR.

Inspector Subset	Deck	Superstructure	Substructure	All Elements
Rivet Corrosion Defect	82%	41%	91%	52%
Implanted Defect	45%	85%	62%	92%
Bearing Defect	24%	44%	0%	1%
Impact Damage	9%	19%	9%	15%
No Deficiencies (Task F)	71%	24%	32%	18%
Weld Crack Indication	8%	67%	97%	68%
Bolt Defect	43%	27%	38%	62%
Coating Defect	59%	86%	30%	8%
Distortion Defect	60%	29%	97%	94%
No Deficiencies (Task H)	100%	50%	97%	84%

The data in table 246 summarizes the relationship between the In-Depth Inspection subsets and their Routine Inspection notes and photographic documentation performance. The table shows that a number of subsets gave a statistically different number of inspection notes than those inspectors not in those subsets. As expected, inspectors in the rivet corrosion defect subset and the implanted defect subset took an overall larger number of notes, whereas those inspectors not noting any deficiencies during the In-Depth Inspections took a statistically smaller number of notes during the Routine Inspections. The only subset to show any differences in the photographic documentation provided was the rivet corrosion defect subset. For reasons still unclear, inspectors in this subset provided a statistically smaller number of photographs than inspectors not in this subset.

Table 246. In-Depth inspector subset relationship with Routine Inspection documentation.

	Inspector Subset	Inspection Notes	Photographic Documentation
Task F	Rivet Corrosion Defect	0%	6%
	Implanted Defect	6%	45%
	Bearing Defect	37%	72%
	Impact Damage	78%	87%
	No Deficiencies	3%	52%
Task H	Weld Crack Indication	31%	31%
	Bolt Defect	36%	60%
	Coating Defect	89%	47%
	Distortion Defect	47%	30%
	No Deficiencies	5%	56%

6.4.4. In-Depth Inspection Defect Assessment of Routine Inspection Subsets

This section examines any relationships that may be present between the Routine Inspection subsets and their ability to correctly identify In-Depth Inspection deficiencies. The same 12 Routine Inspection subsets as presented previously in this chapter are used here. The In-Depth Inspection subsets are also the same as previously discussed.

Table 247 presents the percentage of each Routine Inspection subset that falls into the In-Depth Inspection subset. The Routine Inspection subsets are presented in the rows and the In-Depth

Inspection subsets are presented in the columns. For comparison, this table provides a row that contains the percentage of the overall sample that are in each In-Depth Inspection subset.

Table 247. Comparison of Routine Inspection subsets with In-Depth Inspection results.

	Task F					Task H				
	Rivet Corrosion Defect	Implanted Defect	Bearing Defect	Impact Damage	No Deficiencies	Weld Crack Indication	Bolt Defect	Distortion Defect	Coating Defect	No Deficiencies
Overall	45%	10%	50%	17%	21%	16%	39%	11%	66%	18%
High Accuracy (Overall)	43%	14%	43%	14%	14%	14%	36%	7%	43%	29%
Low Accuracy (Overall)	50%	0%	83%	0%	0%	0%	33%	0%	83%	17%
High Accuracy (Superstructure)	35%	10%	30%	20%	30%	20%	30%	10%	45%	25%
Low Accuracy (Superstructure)	33%	0%	56%	11%	22%	0%	44%	11%	67%	22%
High Precision (Overall)	14%	7%	21%	14%	36%	7%	29%	21%	57%	21%
Low Precision (Overall)	29%	14%	86%	0%	14%	29%	29%	0%	43%	29%
High Precision (Superstructure)	40%	7%	33%	0%	27%	13%	20%	7%	53%	13%
Low Precision (Superstructure)	60%	0%	50%	20%	10%	10%	30%	10%	70%	10%
Large Number of Photos Taken	23%	8%	38%	15%	23%	0%	54%	8%	77%	23%
Small Number of Photos Taken	55%	9%	27%	9%	18%	36%	27%	9%	27%	18%
Large Number of Notes Taken	64%	18%	64%	18%	0%	18%	9%	9%	64%	18%
Small Number of Notes Taken	13%	0%	38%	13%	44%	0%	25%	6%	38%	38%

There are relatively few overall trends evident within these results. In general, there does not seem to be a strong relationship between these Routine Inspection subsets and the In-Depth Inspection subsets. However, two of the Routine Inspection attributes tend to show some slight correlation. First, table 247 shows that the inspectors that exhibited high precision, both overall and specifically with regard to the superstructure, tended to correctly identify slightly fewer of the In-Depth Inspection deficiencies. Second, there is a relatively strong correlation with the inspectors who took a small number of notes. These inspectors tended to locate significantly fewer of the In-Depth Inspection deficiencies than the overall inspector sample. This result was not unexpected given the reliance of In-Depth Inspection on handwritten, defect-specific inspector's notes.

6.5. STATE-DEPENDENT TASKS

Many of the results from the Routine and In-Depth Inspection tasks have been presented in terms of the accuracy of the inspection and the factors affecting the inspection. Since the primary goal of the State-dependent tasks was different from the goals of the Routine and In-Depth Inspection tasks, these tasks will be discussed in a different manner. The State-dependent tasks will be discussed primarily in terms of procedural and reporting differences between States, with comments about inspection accuracy as appropriate.

6.5.1. State-Dependent Routine Inspection Task

Task I, the Routine Inspection of the Van Buren Road Bridge, was performed in a similar manner by each of the inspection teams. The majority of the differences can be classified as either procedural differences or reporting differences.

6.5.1.1. PROCEDURAL DIFFERENCES

Observing differences in the procedural methods used by different States to complete this task was one of the goals of this study. Interaction between team members was one area where differences existed. About half of the teams that participated were assembled specifically for this study, while others were regular partners. It was observed that most of the assembled teams worked as equals, while most of the pre-existing teams had a clear leader in charge of the inspection. Assembled teams were also observed to fall into two of the three division of labor categories, either to work together or to work independently. No clear trend was observed for the division of labor for the pre-existing teams. The markedly different styles between the assembled teams and the pre-existing teams may imply that the assembled teams might have performed an inspection different from their regular State procedures. Regardless, neither the relationship aspect nor the division of labor aspect were found to influence the Condition Ratings assigned to the bridge.

The level of preparation prior to arrival at the bridge site was another procedural aspect that was studied. Teams were classified into one of three groups based on the preparation apparent in the work product submitted. The categories were No Preparation Observed, Some Preparation Observed, and Indeterminate Preparation. The members of the Indeterminate Preparation group all submitted computer-generated reports without any intermediate work products. Only a quarter of the teams showed evidence of preparation in the work products submitted. Although one element of one group showed a statistical difference from the teams not in that group, no clear trend was observed that showed that any of these methods of preparation affected the Condition Ratings assigned.

Finally, nine teams performed a deck delamination survey as part of their regular Routine Inspection. Another seven teams indicated that deck delamination surveys are either handled by a different organization or that all bridges in their State have an asphalt overlay. The remaining eight teams performed some sounding, but did not perform enough sounding to determine the extent of the deterioration.

6.5.1.2. REPORTING DIFFERENCES

One of the other primary aspects of the State-dependent tasks was to investigate reporting differences between the various States. Differences were observed in the presentation of the reports and in some of the element-level data that were presented; however, most of the reporting differences were minor. Some of the more significant differences are discussed below.

The reports themselves varied quite drastically in appearance and length. However, examination of the reports showed that nearly all of the same information is present in each report. Final reports were submitted that were either written in the field or generated on computer (either in the field or in the office). Also, some teams only submitted an intermediate report. These reports contained all of the data necessary for a complete report, but in a less complete form than normal. An analysis showed that there was no statistical difference in the Condition Ratings assigned by teams using different reporting styles.

Photographic documentation was another component of the submitted reports. Fourteen teams either submitted photographs or submitted a log of the photographs that would have been taken had they had a camera available. Results were similar to those obtained from Task D. Overall photographs of the elevation and of the approach (including the deck) were taken by about two-thirds of the teams. Photographs showing details were not taken as frequently, with girder and railing photographs being the most common local condition photographs taken.

More than half of the teams submitted element-level data. Most, but not all, of the teams that submitted element-level data used a format compatible with the Pontis system. Major CoRe elements were used fairly consistently and, in general, correctly. Some deviations were observed with the units used and in the manner in which some of the Condition States were apparently defined. The most common difference was the substitution of area units for the deck elements. Of greater concern was the splitting of the deck quantity over multiple Condition States. It has not been determined whether the Condition States have been redefined by those States, or whether it was a mistake on the part of the individual inspectors. The other primary elements were used with much more variation, specifically the multiple joint and railing elements that were selected. However, given the condition of the joints and the constraints imposed on the inspectors, the joint inconsistencies may not be significant. Inconsistencies in railing element selection are more difficult to explain. Although the CoRe element guide very clearly indicates that railing of multiple materials should be listed as a combination railing, many teams tracked the railing with the other elements. It is unclear whether some of the States have redefined railing elements or whether inspector error caused the inconsistencies. Sub-elements were used by some of the teams, allowing tracking of additional information. These sub-elements appeared to have been used properly. Many teams also used non-CoRe elements, and since these elements are not defined nationally, it was expected that they would vary from State to State. Finally, “smart flags” were used by several teams.

6.5.2. State-Dependent In-Depth Inspection Task

An In-Depth Inspection of the deck of the Van Buren Road Bridge was the other State-dependent task. Teams were asked to perform a delamination survey on the southern two spans.

6.5.2.1. PROCEDURAL DIFFERENCES

The various teams performed this task using basically similar methods. Almost all of the teams used the chain to survey the deck. About half of the teams used a sounding hammer to refine the shape of the areas found by the chain. Generally, one inspector chained while the other took notes, and typically, both inspectors took turns performing the sounding.

Another procedural difference observed was the philosophy of how to find the delaminations. Some teams only tried to “box in” every delamination they found with a rectangular shape, thus not attempting to identify the exact outline of the delaminations. Others spent a considerable amount of time attempting to identify the actual outline of the delaminated areas. As can be expected by these two philosophies, the delamination percentages indicated by the actual outline group tended to be much smaller than those assigned by the rectangular outline group.

6.5.2.2. ACCURACY OF THE IN-DEPTH INSPECTION

The results of this In-Depth Inspection show that only a small percentage of the inspection teams provided an accurate measurement of the level of deck deterioration. The NDEVC determined that the deck was approximately 19 percent delaminated. If an allowance of ± 5 percentage points is permitted as reasonable error (between 14 and 24 percent delaminated), only 5 of the 22 teams had estimates falling within this range. However, two limitations were discovered in the course of the administration of this inspection task that may have affected the results. To preserve the deck in the same condition for all participating inspectors, a prohibition was placed on marking the surface of the deck. This may have led to inaccuracies in the recording of delamination size and position. In addition, data sheets were provided on unlined paper, showing only a scaled drawing of the outline of the deck spans. The use of graph paper may have increased positioning accuracy.

Some of the possible reporting accuracy problems can be addressed in the analysis. Additive overlays of the delamination maps can be created and unique and low-frequency delamination calls can be filtered out. Although the overall average delamination percentage indicated by the teams was 13 percent, the amount of deck area covered by the union of all the delamination areas was 69 percent. This number can be reduced to 40 percent by filtering out areas with only one or two delamination calls, or further reduced to 21 percent by filtering out areas with four or fewer delamination calls. The areas of the deck with at least five delamination calls had relatively good correlation in quantity and location with the delamination map determined by the NDEVC. In addition, only about 0.4 m^2 of the deck had at least 15 layers of common delamination calls.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. GENERAL

The Visual Inspection (VI) method is, by far, 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 VI as it relates to bridge inspections had not been undertaken. Given these facts and the understanding that VI may have limitations that affect its reliability, the FHWA Nondestructive Evaluation Validation Center (NDEVC) initiated a comprehensive study to examine the reliability of the VI method as it is currently practiced in the United States.

The general goal of this study was to examine the reliability of VI of highway bridges. As such, the reliability was studied within the context of its normal application. This study focused on the two most commonly completed inspections: Routine and In-Depth Inspections. In order to ensure that this study would be applicable, the inspection results were studied in the forms in which they are normally manifested. Specifically, for the Routine Inspections, Condition Ratings for the deck, superstructure, and substructure, as defined in the *Bridge Inspector's Training Manual 90,* were used. The Condition Rating system requires that inspectors assign a rating from 0 to 9 that reflects the structural capacity of a bridge and describes any structural deficiencies and the degree to which they are distributed. For the In-Depth Inspections, the inspection results were evaluated based solely on the inspector's field notes. These field notes were a reflection of the specific deficiencies that were identified.

To accomplish the study goals, the investigation consisted of a literature review, a survey of bridge inspection agencies, and a series of performance trials using State department of transportation bridge inspectors. The performance trials were completed by 49 State bridge inspectors who completed 6 Routine Inspections, 2 In-Depth Inspections, and 2 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 study their relationship with the inspection results.

7.2. CONCLUSIONS

The following conclusions are based on the research presented in this report:

1. **Professional Engineers are typically not present on site for inspections.** In the results of the State-of-the-Practice Survey, 60 percent of the State respondents indicated that a Professional Engineer was on site for less than 40 percent of the inspections.
2. **Vision testing for inspectors is almost non-existent, with any employment-related vision tests (i.e., driver's license vision tests) being administered to satisfy other job requirements.** In the State-of-the-Practice Survey, only two State respondents indicated that their inspectors had their vision tested.
3. **Visual Inspection is the most frequently used nondestructive evaluation technique for concrete, steel, and timber bridges**. **In addition, some novel nondestructive evaluation techniques, such as acoustic emission, radar, and thermography, are being used by State departments of transportation.** These conclusions refer to the State-of-the-Practice Survey that asked questions regarding nondestructive evaluation technique use and those techniques that are used most frequently.
4. **State departments of transportation and Iowa county departments of transportation feel that concrete deck research and prestressed concrete superstructure research have the most pressing need for future research.** From the results of the State-of-the-Practice Survey, prestressed concrete superstructures were the top research response among the States. Concrete decks were the top research response among the Iowa counties, as well as nearly half of the State respondents.
5. **When asked, many inspectors did not indicate, and may not have identified, the presence of important structural aspects of the bridge that they were inspecting.** These would include such things as support conditions, skew, and the identification of fracture-critical members. Specifically, on average, less than 25 percent of the inspectors correctly indicated the support conditions. Also, less than 10 percent of the inspectors correctly indicated the presence of skew when it existed. Finally, less than half of the inspectors indicated that a particular fracture-critical bridge was indeed fracture-critical. Knowledge of these aspects may be essential for the full completion of an inspection.
6. **There is significant variability in the amount of time inspectors predicted that they would need to perform a bridge inspection, as well as in the time inspectors actually**

took to complete the inspection. Predicted inspection times for both Routine and In-Depth Inspections ranged from a few minutes to a number of hours. Actual inspection times ranged from a small fraction of the times allotted for the inspections up to the full times.

7. **Routine Inspections are completed with significant variability.** The variability is most prominent in the assignment of Condition Ratings, but is also present in inspection documentation. As evidence, recall that, on average, between four and five different Condition Rating values were assigned to each primary element, with a maximum of six. In addition, although, on average, the inspectors provided just over seven photographs, there were only four photographs that were taken by more than half of the inspectors. There is also significant variability in the frequency with which field notes are taken.
8. **Ninety-five percent of the primary element Condition Ratings for individual bridges will vary within two rating points of the average. Similarly, only 68 percent of these ratings will vary within one rating point.** Recall that the distribution of the sample Condition Ratings was found to be normal. This finding allows the sample results to be extrapolated to the general population of bridge inspectors. This analysis takes into account the natural variations in the sample and extends them to the population, resulting in a predicted range of Condition Rating results.
9. **Inspectors are hesitant to assign "low" or "high" Condition Ratings and, as a result, tend to be grouped toward the middle of the Condition Rating scale.** Recall that inspectors tended to rate lower than the reference Condition Rating for better condition elements and higher than the reference Condition Rating for poorer condition elements. This resulted in a significant portion of the ratings being clustered between a 5 and a 7 Condition Rating, inclusive.
10. **The National Bridge Inspection Standards Condition Rating system definitions may not be refined enough to allow for reliable Routine Inspection results. In addition, with the exception of some bridge management software, Condition Rating values are generally not assigned through the use of a rational approach.** This general conclusion is based on the inconsistencies found to exist in the Condition Rating assignment, as well as the fact that the inaccuracies were greatest over a discrete range of Condition Ratings. Furthermore, it was observed by the NDEVC staff that most

inspectors did not approach the condition assessments with a formulated, systematic approach.

11. **A number of factors appear to correlate with the Routine Inspection results.** In this study, they include factors related to Reported Fear of Traffic, Near Visual Acuity, Color Vision, Formal Bridge Inspection Training, Light Intensity, Reported Structure Maintenance Level, Reported Structure Accessibility Level, Reported Structure Complexity Level, Inspector Rushed Level, and Wind Speed.
12. **In-Depth Inspections are not likely to detect and identify the specific types of defects for which this inspection is sometimes prescribed.** For example, in Task H, more than 300 inspections were performed on details containing small, weld crack indications. Only 12 correct indication identifications resulted from these inspections. These 12 calls were made by a total of 7 inspectors, while the remaining 37 inspectors who completed the task did not make any correct calls. Also, within Task F, only 3 of the 42 inspectors who completed the task identified the implanted tack weld crack indication.
13. **A significant proportion of the In-Depth Inspections will not reveal deficiencies beyond those that could be noted during a Routine Inspection.** Detailed observations of the methods inspectors used to complete Task H show that approximately 40 percent of the inspectors performed cursory inspections of many of the critical welded connections.
14. **A number of factors appear to relate to In-Depth Inspection results.** The overall thoroughness with which inspectors completed Task H tended to have an effect on the likelihood of an inspector detecting weld crack indications. In addition, factors related to time to complete inspection, inspector comfort with access equipment and heights, structure complexity and accessibility, inspector viewing of welds, flashlight use, and number of annual bridge inspections provided some relationship to the In-Depth Inspection results.
15. **There appears to be some correlation between subsets of inspectors who note certain In-Depth Inspection deficiencies.** Specifically, inspectors who find small, detailed defects are more likely to do so regardless of the bridge. Also, inspectors who find gross dimensional defects (such as distortions or impact damage) are more likely to do so on other bridges as well. Finally, inspectors who find fewer than the average number of

defects found on one bridge are likely to do so on other bridges. All of these findings are based on comparisons between the various subsets of inspectors who provided certain findings in Tasks F and H.

16. **The detail of documentation of the findings that an inspector provides for one inspection, including notes and photographs, is likely to be similar to that provided for another inspection.** Inspectors who take relatively few notes during Routine Inspections tend to indicate the presence of fewer deficiencies during In-Depth Inspections. Also, individual inspectors tend to rely more heavily on either written or photographic documentation, but not both.
17. **Most States follow similar inspection procedures and provide the same general information in their inspection reports.** Similar levels of inspection were observed from the teams performing the State-dependent Routine and In-Depth Inspections. The presentation of the inspection reports varied considerably, but the same basic data were present within each report.
18. **Use of the element-level inspection elements was generally consistent with the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements*, with several notable exceptions.** Element-level data for the State-dependent Routine Inspection were presented by about two-thirds of the States in this study. Use of the major deck, substructure, and superstructure elements is fairly consistent, with some possible inconsistencies. Inconsistencies observed in this study included the use of units, the division of quantities, and the definitions of the Condition States. Some of these inconsistencies may be due to re-definitions of the elements by the individual States to suit their needs. Element-level data for the other primary elements are also typically provided. However, these elements may be used much less consistently. Inspectors appear to have some problems with the coding of the other primary elements.
19. **Few bridge inspection teams perform an in-depth-level delamination survey as part of their Routine Inspection.** As an example, in this study, only 39 percent of the teams performed the delamination survey of the Van Buren Road Bridge deck as part of their Routine Inspection. However, many departments of transportation may have other divisions within their States that are responsible for delamination surveys.

20. **There are inaccuracies in in-depth-level delamination survey assessments.** As an example, in this study, only 5 of the 22 teams that performed Task J provided deck delamination estimates that fell within 5 percentage points of that determined by the Nondestructive Evaluation Validation Center. Some limitations from the task itself may have contributed to this poor performance. Eliminating delaminated areas indicated by less than a quarter of the sample produced a delamination map fairly consistent with that determined by the Nondestructive Evaluation Validation Center.

7.3. RECOMMENDATIONS

The research conducted for this study and the conclusions presented above suggest a number of recommendations:

1. The accuracy and reliability of Routine Inspections may be greatly increased by revising the Condition Rating system. Additional work is needed to clearly define the source(s) of the inaccuracies.
2. The accuracy and reliability of In-Depth Inspections could be increased through increased training of inspectors in the types of defects that should be identified and the methods that would frequently allow this identification to be possible. Clearly, there is some need for an increased inspector knowledge base with regard to the types of defects that frequently occur and the methods recommended to aid in the identification of these defects. In addition, more clearly defined inspection procedures that outline systematic search criteria and methods may increase inspection accuracy.
3. The accuracy and reliability of both Routine and In-Depth Inspections could be further increased by considering the identified factors in the selection and training of inspectors. Furthermore, bridge design practices should put a greater emphasis on the ease with which the bridge could be inspected (i.e., accessibility, complexity, etc). Additional research into each of these factors is needed to establish useful guidelines.
4. More research should be performed to determine whether ensuring minimum vision standards (with corrective lenses, if necessary) through vision testing programs would benefit bridge inspection.
5. Further examination of the types and sizes of specific defects that are likely to be identified during an In-Depth Inspection is warranted. Specifically, a study of the various

types of defects that could occur in concrete superstructures, as well as the various different sizes of defects that could occur in steel superstructures, is warranted.

6. More research should be performed to determine the accuracy with which the CoRe elements are used in the field. This could determine which parts of the element use variations are attributable to State re-definitions and which parts are due to lack of proper training of the inspectors.
7. Further study of deck delamination surveys should be performed. This research should investigate both team and individual detection abilities, as well as difficulties inherent in the reporting process. In addition, this research could compare mechanical sounding delamination detection techniques to many other nondestructive evaluation techniques.

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