

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.

Inspector Subset Types	Performance Criteria			
	High		Low	
	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	σ <0.72	7	σ >1.00
Precision (Superstructure)	15	σ <0.60	10	σ >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.

Inspector Subset	Deck					
	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%

Inspector Subset	Superstructure					
	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%

Inspector Subset	Substructure					
	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 m² 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.

REFERENCES

1. *Code of Federal Regulations, National Bridge Inspection Standards – 23CFR650*. U.S. Government Printing Office via GPO Access, revised April 1, 1998, pp. 238-240.
2. Phares, B.M., G.A. Washer, and M.E. Moore. “The FHWA’s NDE Validation Center: A National Resource,” *Transportation Research Record 1680*. Transportation Research Board, Washington, DC.
3. *Manual for Condition Evaluation of Bridges, 1994*. American Association of State Highway and Transportation Officials, Washington, DC, 1994.
4. *Bridge Inspector’s Training Manual 90*. Federal Highway Administration, McLean, VA, 1995.
5. *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements*. American Association of State Highway and Transportation Officials, Washington, DC, 1997.
6. Caltrans Unpublished Data.
7. *The American Society for Nondestructive Testing, Recommended Practice No. SNT-TC-1A, 1996*. The American Society for Nondestructive Testing, Columbus, OH, 1996.
8. Rens, K.L., T.J. Wipf, F.W. Klaiber. “Review of Nondestructive Evaluation Techniques of Civil Infrastructure,” *Journal of Performance of Constructed Facilities*, Vol. 11, No. 4, November 1997, pp. 152-160.
9. Rens, K.L. and D.J. Transue. “Recent Trends in Nondestructive Inspections in State Highway Agencies,” *Journal of Performance of Constructed Facilities*, Vol. 12, No. 2, May 1998, pp. 94-96.
10. Purvis, R.L. “Inspection of Fracture-Critical Bridge Members,” *Transportation Research Record 1184*. Transportation Research Board, Washington, DC.
11. Estes, A.C. “A System Reliability Approach to the Lifetime Optimization of Inspection and Repair of Highway Bridges.” Thesis, University of Colorado, 1997.
12. Purvis, R.L. “Bridge Safety Inspection Quality Assurance,” *Transportation Research Record 1290*. Transportation Research Board, Washington, DC.
13. Purvis, R.L. and H.P. Koretzky. “Bridge Safety Inspection Quality Assurance: Pennsylvania Department of Transportation,” *Transportation Research Record 1290*. Transportation Research Board, Washington, DC.

14. Smith, C. and P.L. Walter. "Revisiting the Aging Aircraft Nondestructive Inspection Validation Center – A Resource for the FAA and Industry," *Materials Evaluation*, Vol. 53, No. 8, August 1995, pp. 900-902.
15. Spencer, F.W. *Visual Inspection Research Project Report on Benchmark Inspections*. U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 1996.
16. Endoh, S., H. Tomita, H. Asada, and T. Sotozaki. "Practical Evaluation of Crack Detection Capability for Visual Inspection in Japan," *Durability and Structural Integrity of Airframes: Proceedings of the 17th Symposium of the International Committee on Aeronautical Fatigue*, June 9-11, 1993.
17. Schoonard, J.W., J.D. Gould, and L.A. Miller. "Studies of Visual Inspection," *Ergonomics*, Vol. 16, No. 4, 1973, pp. 365-379.
18. Jamieson, G.H. "Inspection in the Telecommunications Industry: A Field Study of Age and Other Performance Variables," *Ergonomics*, Vol. 9, No. 4, 1966, pp. 297-303.
19. Spencer, F.W. and D. Schurman. *Reliability Assessment at Airline Inspection Facilities, Volume III: Results of an Eddy Current Inspection Reliability Experiment*. Department of Transportation, Federal Aviation Administration, Washington, DC, 1995.
20. Rummel, G. and G. Matzkahnin. *NDE Capabilities Data Book, 3rd Edition*. Nondestructive Testing Information Analysis Center, NTIAC-DB-97-02, 1997.
21. Megaw, E.D. "Factors Affecting Visual Inspection Accuracy," *Applied Ergonomics*, March 1979, pp. 27-32.
22. Johnston, D.M. "Search Performance as a Function of Peripheral Acuity," *Human Factors*, December 1965, pp. 527-535.
23. Erickson, R.A. "Relationship Between Visual Search Time and Peripheral Visual Acuity," *Human Factors*, April 1964, pp. 165-177.
24. Ohtani, A. "An Analysis of Eye Movements During a Visual Task," *Ergonomics*, Vol. 14, No. 1, 1971, pp. 167-174.
25. Fox, J.G. "Background Music and Industrial Efficiency – A Review," *Applied Ergonomics*, June 1971, pp. 70-73.
26. Poulton, E.C. "Arousing Stresses Increase Vigilance." *NATO Conference Series: III, Human Factors*, Vol. 3, 1977, pp. 423-459.
27. Colquhoun, W.P. *The Effect of Short Rest-Pause on Inspection Efficiency*. Medical Research Council, Applied Psychology Research Unit, Cambridge.

28. Deaton, M., J.S. Tobias, and R.T. Wilkinson. "The Effect of Sleep Deprivation on Signal Detection Parameters," *Quarterly Journal of Experimental Psychology*, Vol. 23, pp. 449-452.
29. Lintern, G. "Field Independence, Intelligence, and Target Detection," *Human Factors*, Vol. 18, No. 3, 1976, pp. 293-298.
30. Pond, D.J., D.T. Donohoo, and R.V. Harris, Jr. *An Evaluation of Human Factors Research for Ultrasonic Inservice Inspection*. Division of Engineering Technology, Office of Nuclear Regulatory Research, Washington, D.C., 1998.
31. Mitten, L.G. "Research Team Approach to an Inspection Operation," *Introduction to Operations Research – Chapter 3*.
32. Gallwey, T.J. and C.G. Drury. "Task Complexity in Visual Inspection," *Human Factors*, Vol. 28, No. 5, 1986, pp. 595-606.
33. Faulkner, T.W. and T.J. Murphy. "Lighting for Difficult Visual Tasks," *Human Factors*, Vol. 15, No. 2, 1973, pp. 149-162.
34. Mackworth, N.H. "Visual Noise Causes Tunnel Vision," *Psychonomic Science*, Vol. 3, 1965, pp. 67-68.
35. Sheehan, J.J. and C.G. Drury. "The Analysis of Industrial Inspection," *Applied Ergonomics*, June 1971, pp. 74-78.
36. Noro, K. "Analysis of Visual and Tactile Search in Industrial Inspection," *Ergonomics*, Vol. 27, No. 7, 1984, pp. 733-743.
37. Thomas, L.F. and A.E.M. Seaborne. "The Socio-Technical Context of Industrial Inspection."
38. Lion, J.S., E. Richardson, D. Weightman, and R.C. Browne. "The Influence of the Visual Arrangement on Material, and of Working Singly or in Pairs, Upon Performance at Simulated Industrial Inspection," *Ergonomics*, Vol. 18, No. 2, 1975, pp. 295-304.
39. Gallwey, T.J. "Selection Tests for Visual Inspection on a Multiple Fault Type Task," *Ergonomics*, Vol. 25, No. 11, 1982, pp. 1077-1092.
40. Tiffin, J. and H.B. Rogers. "The Selection and Training of Inspectors," *Personnel*, Vol. 18, 1941.
41. Riley, J.N., E.P. Papadakis, and S.J. Gorton, "Availability of Training in Visual Inspection for the Air Transport Industry," *Materials Evaluation*, 1996, pp. 1368-1375.

42. Chaney, F.B. and K.S. Teel. "Improving Inspector Performance Through Training and Visual Aids," *Journal of Applied Psychology*, Vol. 51, No. 4, 1967, pp. 311-315.
43. Phares, B.M. "A Design Methodology for a Low-Volume Road Bridge Alternative: Steel Beam Precast Units." Dissertation, Iowa State University, 1998.